MIDLAND TELEVISION
INC.

POWER & LIGHT BUILDING, KANSAS CITY, MISSOURI

UNIT NO. 5

INTRODUCTION TO TELEVISION

LESSON NO. 1

TELEVISION

.....another product of man's imagination.

On the inside of the front cover of a transmitter lesson, we told you that 'what man imagines, man can do'.

For years man imagined that he could send his voice through space at will, and without wires. And today radio accomplishes that very thing. Yet we give but slight thought to the marvels of this masterful scientific development, that is such a boon to commerce and entertainment.

Man also imagined that he could send pictures through the air......moving pictures. Millions of dollars were spent upon research, experimentation, and development. Progress was slow, but sure. Finally a flickering picture was transmitted and received. But man was not satisfied. He imagined that he could produce a much better picture by employing a different system.

More years were devoted to intense research. More money was spent. A new system WAS developed. And the transmission of excellent pictures became a reality. Again man backed his imagination with action and came through a winner.

In entering upon the study of television, you are taking an active part in a new era of broadcasting, whose future development can readily exceed our most vivid imagination. Man is never satisfied. He continually strives to improve, And there you have the dominant power behind the continual development of this earth of ours.

You too, should continually strive to improve yourself. Your desire for success should be so strong, that it will be an all-impelling power that will continually drive you to greater accomplishments and earning power.

Unit Five

FUNDAMENTALS

of TELEVISION

"This unit, consisting of 12 lessons, will thoroughly cover the Fundamentals of Television. The first lesson is devoted to a history of the early development of Television, bringing you up to present day practices. Next, a study of Physics, Light, Mirrors, Lenses, and Optics will be covered, based on their application to modern Television. The principle of Scanning, both mechanical and electronic will be covered thoroughly. Because of the importance of the subject, the unit will deviate from Television a little in that it will cover the fundamental theory of Photoelectric Cells, followed by a lesson on their commercial applications. Following that, we have included a complete study of the modern Cathode Ray Tube and its applications to Television Reception. All of the fundamental circuits necessary for the operation of a Cathode Ray Tube in a Television Receiver will be covered thoroughly. This covers sweep oscillators and synchronizing methods. Then tuning and radio frequency circuits will receive their just places in your training. Unit Five holds the same important position in Television as Unit One did in your study of Radio Broadcasting and Radio Reception.

"A thorough understanding of this unit is quite necessary if you are to have a complete mastery of the science of Television. In this unit you will learn the components necessary for the reception of pictures while in the following unit, the servicing of such receivers will be covered".

INTRODUCTION

to

TELEVISION

"Before you actually enter into a thorough study of the science of television, I thought that you should become familiar with the history of the developments leading to modern television.

"The information given in this lesson is designed to acquaint you with the work and struggles of these early scientists. It is not intended that you should have an actual working knowledge of these early experiments."

1. FIRST PICTURE TRANSMISSION. Within recent months, the word "television" has become quite commonplace, used to convey the idea of pictures transmitted by wire or radio. When viewed in the light of commercial possibilities, television is a mere infant, but from a standpoint of scientific research, it is, relatively, quite an old man. It seems almost incredible that the actual beginnings of television should date back almost a hundred years, when in 1847 an English teacher of electricity by the name of Frederick Bakewell operated a device known as the "copying telegraph." According to Bakewell, this equipment "transmits the handwriting of correspondents. Every letter and mark made with the pen are transferred exactly to the other instrument, however distant." This early system transmitted recognizable pictures between Brighton and London, England, a distance of about 50 miles. Thus, it is seen that the idea of television was cradled in England and one would expect to find its progress well advanced in that country. Naturally, England does seem to have led the world in the advent of commercial television programs, although from the standpoint of actual scientific achievement in the laboratories, the matter of actual leadership is somewhat debatable since the United States, Germany, Italy, France and Russia all have advanced television in their laboratories.

The ancients dreamed of a Magic Carpet of Bagdad and television seems to be the modern answer. In the case of the Magic Carpet, the individual was literally transported from point to point, but scientists have made this dream more real than the most fantastic dreams, for instead of taking you to distant points on such a carpet, these distant points are brought to you! There is paraded before your eyes for amusement and education, plays, operas, great classics of baseball and football, and other points of interest too numerous to mention. Remarkable? It is miraculous! Yet today, we have become so accustomed to the unusual and strange things, that we seldom stop to actually consider how really wonderful they are.

A long process of experimentation, through the years, has been necessary in order for us to enjoy the many modern miracles our grandfathers would have assured us were quite impossible. Strictly speaking, the word "impossible" is no longer recognized in the scientific field, but is qualified by the statement "it seems impossible in the light of present day knowledge."

Therefore, if we are to appreciate our study of the subject, Television, we must go back to its beginnings, follow it step by step through each intermediate stage of development to arrive at the present "budding" stage and then we can only conjecture as to the final perfection of the bloom itself.

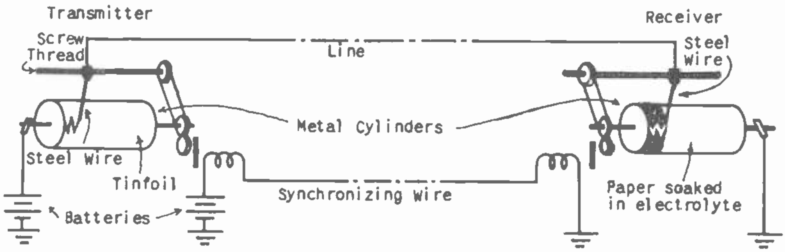


Fig.1 Bakewell's picture transmitter. Transmission of this type is now known as wirephoto or facsimile.

The ingenious method devised by Bakewell is shown in Fig. 1. The two cylinders are of metal and are six inches in diameter. The message to be transmitted was drawn on a piece of tinfoil by means of a pen which used an insulating varnish, instead of ink, then the tinfoil was wrapped on the cylinder at the transmitting end. Now, as the cylinder rotated, the small steel wire bore against this surface and was moved along by a screw thread very much similar in operation to the dictaphone needle moving across a cylindrical record. When this steel wire touched a part of the picture; that is, the insulating varnish, the line current was cut off until the wire was moved into a position where it again touched the unvarnished foil.

A similar cylinder rotated at the receiver and was kept in synchronism with the transmitting cylinder by means of a specially transmitted synchronizing signal. Now, this receiving cylinder differed from the one at the transmitter in that it was wrapped with a paper which had been soaked in a chemical solution. On this paper was also pressed a wire which was connected to the transmitter's steel wire through a line. This steel wire stained the paper under it blue whenever line current was flowing. As a result, the received picture was reproduced with a blue background on which appeared white lines which corresponded to the lines drawn with varnish on the tinfoil. This apparatus was so complete and well designed that quite excellent results were obtainable, although the transmissions were of a necessity limited to more or less simple figures which one might draw with a pen.

Thus, it is seen that the first picture transmission resulted from the coordination and use of information which was already old to science, to produce a new and useful result. This type of procedure we know as invention. It is interesting to note that most inventions in their original state are the result of individual ingenuity for finding new applications for old ideas. The terms "invention" and "discovery" are ofttimes used interchangeably because they are so closely related; discovery, however, is the finding of some new law or principle or substance which, prior to that time, was unknown. All modern electrical and mechanical apparatus are, of course, the results of both invention and discovery. Like the age-old argument "which came first, the chicken or the egg", it is difficult to answer the same question as it relates to discovery and invention. Certainly, one cannot progress far without the other. So it was with the beginnings of television when Bakewell's simple system had to wait on the discovery that the metal, selenium, changed its electrical resistance in accordance with the amount of light falling upon it. It is interesting to speculate that, if this information had been available to Bakewell, we might have been doing around 1905 the things we are just accomplishing in television today.

2. DISCOVERY OF FIRST LIGHT CELL. In the year 1873, a man named May discovered, incidentally perhaps, that the element, selenium, in addition to smelling like horseradish when he burned it, had the peculiar property of changing its electrical resistance when subjected to light rays of varying intensity. To most of us, the fact that selenium behaved in such an odd manner would probably have meant nothing at all, but with May it was different. His was the scientific mind which demanded an explanation when anything in nature acted in an unusual manner.

The discovery came about in this manner. May was working as a telegraph operator in the Atlantic cable receiving station on the west coast of Ireland when he noted his instruments acted in a peculiar manner at certain times. It so happened that in his instrument circuits, the metal, selenium, was used as a resistance much the same as we use carbon for its resistant property today. May noted that occasionally as the sun shone through a window upon the selenium that the needle on his instrument moved; this indicated that the sun must be affecting the resistance of the material. He first thought that it was the heat which produced the change, but later discovered it was the light.

May's reaction to this discovery prompted him to attempt the construction of apparatus, capable of transmitting pictures; and so three years before Alexander Graham Bell patented the telephone, and, of course, many years before radio was even dreamed of, he actually constructed equipment by which he hoped to transmit pictures. It was crude and it was such a total failure that he didn't get even a flicker out of it. Briefly, his method consisted of projecting a picture upon a selenium plate with a lens, and hoping that selenium would do the rest through its ability to convert light into electrical energy.

About this time, another scientist by the name of Carey felt that he knew the reason for May's failure. Carey had experimented considerably with light and had evolved the theory that if pictures were ever to be transmitted, it would have to be done by breaking them up into fragments--elements, he called them--and so two years later, in 1875, we find him improving upon the May device by using a plate composed of a great number of tiny selenium cells, each one of which, according to his notion, would transmit its own energy and thus send out its own part of the picture (Fig. 2). As we now know, his reasoning was more accurate than he, himself, knew, but he failed also because, having too many cells, he had no way of connecting the great number of separate circuits from the cells to what we now call the receiving set. He had, however, through his theoretical discovery that a picture must be torn into countless fragments and thus shipped piecemeal to a receiver which would put them together again, added greatly to the fundamental television knowledge. It was, as a result of this discovery, after a long line of other scientists working during a period of over thirty years and all using selenium plates with a great number of cells that achieved no results whatever, that it finally came about in 1906 two Frenchmen, Rignoux and Fournier, brought to an end the first chapter of television research by actually transmitting and reproducing a picture.

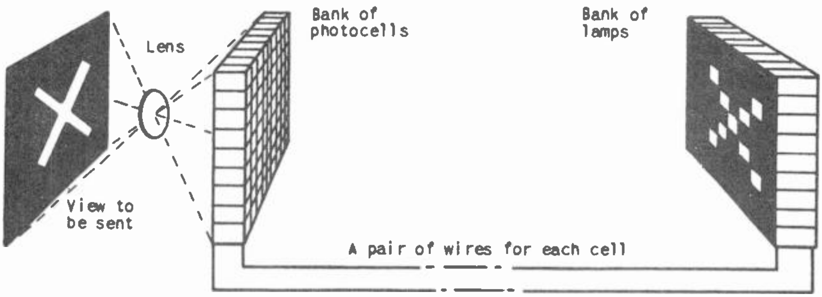


Fig.2 Carey's attempt to imitate the eye. A pair of wires was necessary for each cell.

3. FIRST APPLICATION OF SCANNING. Before describing the work of these Frenchmen, let us hear from an Englishman by the name of Shelford Bidwell, who read before the Society of Telegraph Engineers and Electricians, convened at Paris in 1881, a paper on some "...apparatus, merely of an experimental nature".

Bidwell's receiving system was exactly like Bakewell's except that it used a considerably smaller cylinder giving a picture about 2" square. Bidwell's transmitter, however, was radically different. The picture, or scene to be transmitted was projected upon a ground glass screen, as shown in Fig. 3, behind which a selenium cell moved slowly up and quickly down, gathering light from a pinhole through successive portions of the picture in turn. During each upward motion, the selenium cell moved across the image approximately $\frac{1}{64}$ inch and on the receiving cylinder a screw thread moved a platinum recording point across an equal distance at each revolution. Thus, the pictures transmitted were not artificial drawings upon tinfoil or some other substance but the projected images of actual objects.

In 1887, Hertz performed his practical experiments which led to his discovery of the photoelectric effect. The succeeding years witnessed considerable activity and progress in this line by such men as Hallwack, Elster, Geitel, and many others. (The early history of photocells is given in the lesson on photocells.) Thus far we have noted that the pictures which the early experimenters were able to transmit were, of a necessity, "stills." The mechanical apparatus used in the production of these pictures was much too slow for the transmission of motion and since the receiving end employed a chemical process in the reproduction of these transmissions, it would have been utterly impossible to have received motion pictures even if the transmitter had been capable of sending them.

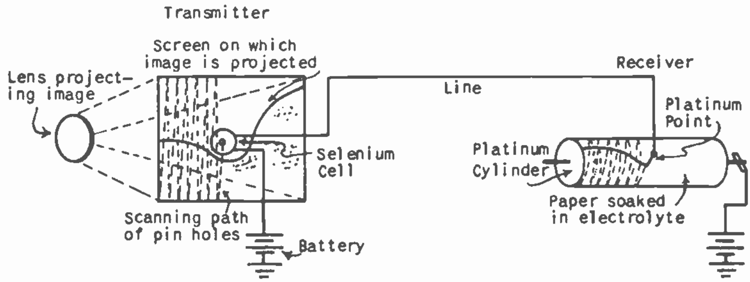


Fig.3 Bidwell's arrangement for picture transmission.

Today, this type of picture transmission is known as wirephoto or facsimile. Television, as we think of it now; that is, the art of reproducing *action pictures* at a distant point from the transmitter, had its beginning in the year 1884 with the advent of the Nipkow disc.

4. THE NIPKOW OR SCANNING DISC. Probably one of the greatest names associated with television history is that of Paul Nipkow. (At the time of this writing, Paul Nipkow is living in Berlin, Germany.) He used at the transmitter and receiver two discs, perforated with small holes along similar spiral curves, which were caused to rotate in synchronism. A complete description of this method is given in a later lesson on scanning. This mechanical disc system laid the foundation for modern television and was used in practically all television transmitters and receivers until the last few years when electrical, inertialess systems were devised to accomplish speeds unthought of in the early days and impossible with the mechanical disc. Prior to the advent of the Nipkow disc, Carey and others had proposed systems consisting of a great number of minute selenium cells, each having its own wire connection, which naturally led to a very elaborate system. The transmission of a picture of good quality required a great many pairs of separate wires. This, of course, was impractical. Nipkow's disc simplified this problem since it transmitted the picture point by point, a method now known as "scanning." While the scanning disc simplified the problem considerably, since it enabled the transmission of the picture over a single wire or a single communication channel, the television prob-

lem as a whole was far from being solved, due to a lack of some more very essential elements.

Full, practical exploitation of Nipkow's ideas had to wait on three developments in other scientific fields. In the first place, selenium cells followed light changes much too slowly for efficient television purposes. Something quite inertialess was needed and, fortunately, it appeared as the photoelectric cell of Elster and Geitel in 1890. (Hallwack observed the photoelectric effect in 1888.) Furthermore, the very weak picture current at the receiving end made intelligible reproduction exceedingly difficult. In 1907, the beginning of the end of this difficulty was started by DeForest's invention of the triode amplifier. And, finally, there was the lack of a satisfactory light arrangement at both the transmitter and receiver. In order to fully appreciate this third difficulty as it relates to the transmitter, you must understand that the picture is scanned point by point and, therefore, the photosensitive element is affected by the light from a given point only for a very short period of time. Consequently, the resulting photocell current becomes extremely microscopic with attempts to improve the picture definition, that is, the number of picture elements in a given picture. This limitation stood like a Gibraltar for many years in the path of increasing picture resolution[1] and seemed to exclude all hopes of an outdoor picture.

To further understand this light problem, it is necessary that we go more into detail to see what was actually happening at the receiver. An image, when in motion, represents a great number of points which vary in brilliance. In normal vision, an exact reproduction of this picture is projected on the retina of the eye and numerous light-sensitive nerves carry the impression to the brain. It was this information which led the early experimenters to the very natural conclusion that numerous transmitting systems would be necessary for just one image. The solution, as we have seen, was provided by the Nipkow disc which divided the image into small squares and transmitted the brilliance of each square in turn. Naturally, the squares had to be sent over in a definite order and reassembled again at the other end (receiver); this had to be done so fast that the eye received the impression of a steady picture. At the transmitter, the light from each of these tiny squares falls in its turn on a photocell which translates it into an electric current having a strength dependent upon the average illumination of the square. Now, at the receiving end, this electric current has to have a light source which is powerful enough and can follow the very fast fluctuations of light as required in television. The answer to this problem was to be practically solved in later developments.

5. CONTRIBUTING DEVELOPMENTS. In the years around and following 1880 there was an unusual amount of activity in inventions relating to television, brought about, no doubt, by the commercial

[1] Resolution: This is defined as the process of breaking a picture up into a large number of elements; the greater the number of elements for a given picture, the better the detail.

importance which electrotechnology was rapidly assuming in connection with telegraphy, telephony, railway signaling, and lighting. Because of this, everyone expected a rapid solution of the special problems of this new branch and that its practical application would be contemporaneous with that of the telephone. Television was "just around the corner." It is perhaps just as well for the art that these earlier experimenters did have this feeling concerning the arrival of television, for had they known the actual number of years which were to intervene, they would no doubt have lost much of their enthusiasm and perhaps the high standard of perfection existing in the art as we know it today would still be out in that uncertain future.

In the meantime, many other events occurred which, while removed from actual television experimentation, they nevertheless helped pave the way for modern developments. In 1891, Amstutz, an American, sent the first halftone picture over a 25 mile wire, using celluloid sheets etched in relief. In 1898, Szczepanik proposed color television, later staging a practical demonstration. In 1902, Korn sent the first photograph by wire. In 1909, Knudsen sent the first line drawing by radio (prior to this time all picture transmission had been by means of wire), using one metal plate at the spark transmitter and at the receiver a second plate covered with lamp black on which the drawing was scratched by a coherer relay.

This brings us now to the year 1906 when our two Frenchmen, Rignoux and Fournier, accomplished a history-making experiment. The exact day is not known, for perhaps the events of many days were involved in the successful completion of their experiment. To us, accustomed to the modern precision of "streamlined" laboratories, their setup would, no doubt, have appeared quite crude. The transmitting end of their experiment consisted of a checkerboard of 64 squares, each one of which was connected by two wires to a corresponding tiny shutter in a similar checkerboard set up as the receiver on the other side of the laboratory. In front of this second checkerboard stood a screen.

With a lens, they focused a prepared picture, made up of a simple pattern, upon their first checkerboard and, instantly, magically, some of the 64 shutters in the other checkerboard flew open, the light from behind them flashed through; the patterns were dimly reproduced upon the screen! For them, television had arrived!

But what good was it? Within a comparatively short time, as you and I sit in our own home and watch football games, prizefights and moving pictures, we will be able to answer that question very conclusively. But the two Frenchmen couldn't. To them, undoubtedly, the important thing was that where many of their predecessors had failed, they had at last fully demonstrated the soundness of two fundamental theories regarding television.

One can readily see, however, that the device which the Frenchmen had perfected, no matter how fully it justified or proved the scientific theories, was entirely impractical. For a picture to be any good at all, it must have detail, which means that instead of being torn into 64 fragments, it must be, as we will see later, torn into thousands of elements. Naturally, no one would want to undertake to construct a device consisting of that many individual cells having a pair of connecting wires to as many individual shutters.

Although the Nipkow disc opened up the first practical method for scanning a picture, it also provided an impetus to the various television experimenters to provide an improved method for obtaining the same results. The outgrowth of these labors were such devices as the drum scanner and many arrangements involving the use of rotating mirrors and lenses. Now, mechanical scanning methods were all right so long as the televised picture was composed of only a comparatively few lines; however, the amount of detail possible with a few lines is very limited. As we increase the number of lines composing the picture, the mechanical arrangements used in scanning the picture necessarily become involved, due principally to the mechanical power requirements. Also, the light requirements for such a system as shown in Fig. 4 was another source of trouble.

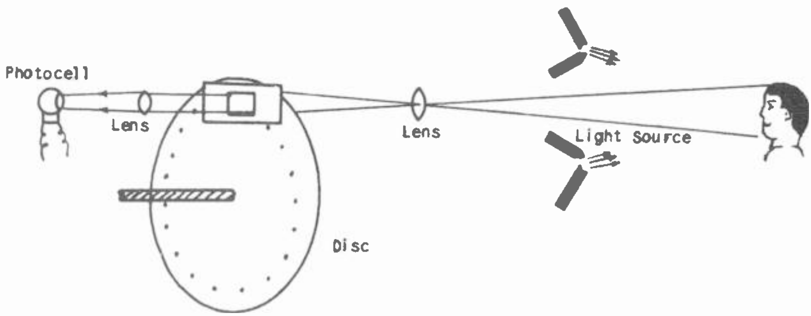


Fig.4 Nipkow Disc (direct scanning method).

Through the passage of the years, it became more and more evident to the experimenters that they must find a way to eliminate these difficulties. It was not strange then, that someone should think of using in preference to mechanically directed rays, the inertialess electron ray beam of a Braun cathode ray oscillograph tube. Here again we find a new application for an old idea, for the oscillograph tube was familiar to the Germans, Lux and Dieckmann, in 1906. In 1907, Rosing in a British patent and Campbell-Swinton independently in "Nature" had published suggested systems of television in which a cathode ray tube was employed by the television receiver. The article in Nature is of particular historical interest and is, therefore, quoted in part.

"...This part of the problem of distant electric vision can probably be solved by the employment of two beams of cathode rays (one at the transmitting and one at the receiving station) synchronously deflected by the varying field of two electromagnets placed at right angles to one another and energized by alternating currents of widely different frequencies so that the moving extremities of the two beams are caused to sweep synchronously over the whole of the required surfaces within the $\frac{1}{10}$ second necessary to take advantage of visual persistence. (Note: Today, anything slower than $\frac{1}{16}$ second is considered too slow.) Indeed, so far as the receiving apparatus is concerned, the moving cathode ray beam has only to be impinged on a sufficiently sensitive fluorescent screen and given suitable variations in its intensity to obtain the desired results." Thus we see that the cathode ray receiver so widely hailed at present as the last word in television is in principle over 30 years old.

In 1909, the Andersens proposed a scheme for transmitting images of objects in their natural colors. This idea of television in color is interesting indeed, since we have yet to see practical commercial realization of an idea which originated prior to the World War. Laboratory processes capable of transmitting color television have been demonstrated with various degrees of success and we have every reason to believe that just as in the case of the motion picture, color will one day in the not-too-distant future add additional beauty and reality to television.

When one considers the faintness of illumination produced by an optical image of a non-luminous object, such as that shown in Fig. 4, and then figure that on the average for an 80 line picture only $\frac{1}{6400}$ of the total light flux enters the photosensitive device at one instant and that the element affects the sensitive device only $\frac{1}{102,400}$ second when it is represented at all, it becomes quite evident that even with the modern photocell, the problem is almost hopeless.

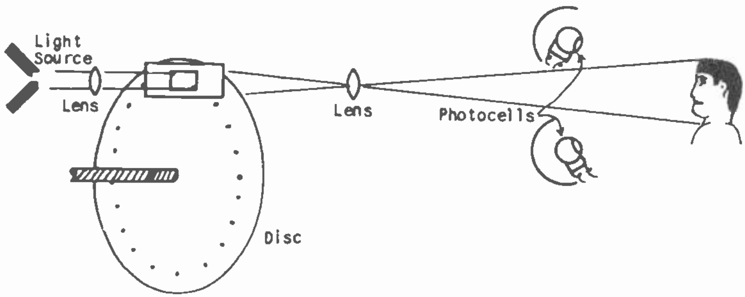


Fig.5 Nipkow Disc (indirect or "flying spot" scanning method).

As a way out of this difficulty, it was proposed by A. Ekström in 1910 to reverse the system of optics. Instead of dividing an optical image into numerous elements, he suggested scanning the object directly by a moving spot of light, better known now as the "flying spot" and receiving the light reflection from the spot by a single or group of photocells placed very close to the object. Such an arrangement is shown in Fig. 5. Two distinct advantages were gained in the use of this method; first, the spot of light may be made very intense by concentrating the radiations from a brilliant arc and, second, a large amount of light may be collected by employing either a very large photocell, or else a large reflector with a small photocell, or a group of photocells. This scheme as used in connection with the Nipkow disc made possible the first practical solution of the television problem and it was used extensively as late as 1933.

The names that have been prominent in the development of television which have been mentioned in our discussion are by no means a complete list. The names are those of persons who have been directly or indirectly responsible for some definite progress in the growth of the art. There are hundreds and thousands of workers and research men, of course, whose names will remain unknown, but whose accomplishments, nevertheless, made possible the achievements of these comparatively few men. The situation has a very excellent parallel in our television laboratory researches today where hundreds of men make possible the success and achievement generally ascribed to the individual or company heading the laboratory.

We have now reached the stage in the development of television where the thermionic valve or better known as the radio tube was first making its appearance. Without question, it has been the one greatest revolutionary agent in the history of the art pertaining to the transference of intelligency by electricity. Latour, in 1916, explained the principles underlying the operation of a triode vacuum tube and by 1920 the use of these vacuum tubes in the amplification of speech frequencies was well established. Those conversant with the needs of television will recognize that by this time (1920), no element, in the state of physical knowledge, was lacking necessary to the accomplishment of practical television and yet the whole field was more or less littered with unsolved schemes, many of which involved elements of the greatest importance today. Unfortunately, none of them seemed to have hit upon that combination so essential to success.

6. FIRST PRACTICAL TELEVISION. The period starting with the advent of the vacuum tube around 1910 is in striking contrast with the haphazard development through the 33 years prior to this time. There has been an intensive awakening of directed scientific effort inaugurated by the World War period which has continued with increasing intensity for the last 25 years. We see a change from the haphazard individual experiments to the systematic development in well equipped laboratories of systems as a whole. In this early transition period, the work of two men was preeminent. The work of C. Frances Jenkins in America and John L. Baird in England brought the early dreams of Nipkow to their first actual fruition. Much credit is due these two men for laying the first solid foundation for television progress in their respective countries. In 1923, both Baird and Jenkins succeeded in demonstrating the transmission of silhouettes, or shadow-outlines of objects. It is believed that early in 1925 Baird was able to show natural pictures in halftones.

On a cloudy Saturday in June of the same year, a distinguished group of Washingtonians assembled in the Jenkins laboratory on Connecticut Avenue to watch the flickering image of a toy windmill which was seen to revolve. The windmill itself was turning in Anacostia, five miles away and radio was bridging the visual gap.[1] In

[1] Mr. Jerry Taylor witnessed Jenkins' early work while in Washington during the summer of 1928.

January, 1926, Baird, in England, demonstrated an improved television system before members of the Royal Institution, assembled in London. They saw recognizable faces and were much impressed.

At the time of these initial successful demonstrations, Baird was working with directly coupled amplifiers in order to preserve the same brightness level in the reproduced image as well as the variation of the transmitted scene. Those who have worked with two or three stages of DC coupled amplifiers can only partially realize the difficulties which beset Baird in his attempt to use nine or ten tubes coupled in this manner. His ideas in this matter have long since been more or less superseded, thanks to the phenomenal advance in recent years of communication technique in general which, as we have already seen, was made possible by the advent of the three electrode vacuum tube. From this has sprung another important branch of knowledge not previously appreciated or even partly developed; that is, the theory and design of electrical compensating networks.

The underlying electrical theory relating to distortion correcting networks was given by the English scientist and mathematician, Oliver Heaviside, near the close of the last century in his classic work, "Electromagnetic Theory." Heaviside himself was something of a hermit which, perhaps, accounts partially for the fact that communication engineering has not even yet experienced the full benefit of his work.

Engineers were beginning to learn that the idea of perfect amplification, even given suitable tubes and other circuit components, is by no means easy to obtain; that an amplifier is not merely a box with two terminals for input and two for output with works inside capable of delivering a faithful replica on a large scale of the minute varying potential differences applied to it. In fact, the channel itself of which the amplifier forms but a part is almost as deadly an enemy as the lag of selenium cells was originally to the production of an early television image. To further complicate matters, both the frequency band of the channel and the amplifiers have far more exacting requirements when applied to television than for sound transmission due to the extreme importance in television of preserving the phases of the various components of the signal.

Thus, by 1927, a considerable part of this amplifier technique had already been developed and was the contributing factor to the success of Baird, Jenkins, and others.

In this same year, Baird demonstrated certain apparatus which he called Noctovision (the original idea was suggested by Nipkow back in 1884), using infra red rays, to the British Association meeting at Leeds. In this same year, the Bell Laboratories in New York City demonstrated television "in the grand manner." This great research organization quite naturally eclipsed the best efforts of these two pioneers. A photograph of this early equipment is shown in Fig. 6. The screen on which the picture was shown was about two feet square; the faces and speech came in over the air from a point 20 miles away and over wire circuits a distance of approximately 300 miles from Washington, D.C. This long distance line transmission of television pictures forcefully demonstrated beyond all doubt the importance of line correction.

The only practical method of converting television signals into light at that time depended upon bringing a rarefied atmosphere of neon gas to luminosity by means of the two element neon tube or light. The neon tube, the invention of Dr. D. McFarland Moore, is surprisingly fast in its action and was fully capable of handling picture signals representative of great detail. (Photocells were used at the transmitter, neon lights at the receiver.) In order to produce a 72 line picture optically enlarged from about two inches square, it was necessary to develop a special neon tube, capable of handling 200 ma., employing water-cooling to dissipate the heat. Consequently to project a picture of any size upon a screen with a neon tube seemed impractical since it must assume the proportions of a power device.

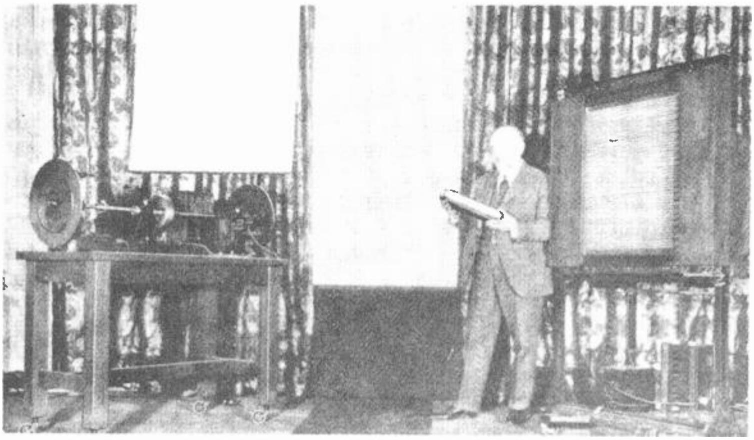


Fig.6 Early Bell Telephone Laboratory Equipment. Dr. Ives holds one of the large photoelectric cells used at the transmitter.

Later, a new type neon lamp was developed which permitted the reproduction of large scale pictures, using a limited number of lines. Although the many able men who planned and built the Bell equipment made vast improvements in existing technique, yet they discovered no new principles.

7. THE KERR CELL. At this point, let us examine the work of a Scotchman by the name of John Kerr who began his contributions to the art of television in 1875. His ideas developed the application of a principle, long known to science, to the operation of a light valve. Kerr observed that the direction of polarization by a beam of polarized light can be changed by passing it through an electrostatic field. (Faraday had previously observed a similar phenomenon in connection with intense magnetic fields as had also Nipkow in connection with schemes he had proposed for projecting television.) Kerr's electrostatic bending of polarized light was embodied in a practical light control device by Dr. August Karolus of Leipzig, Germany. The General Electric Company later obtained American rights to Dr. Karolus' invention, which Dr. Alexanderson

built into a practical television projector. Before discussing Dr. Alexanderson's light device, perhaps it would be well to acquaint the student with the nature of polarized light for it is sometimes difficult for the layman to understand the difference between polarized light and an ordinary ray. It is sufficient for our purposes to state that ordinary light consists of vibrations in many planes, while with polarized light the vibration has been reduced to a single plane. Such a beam of light can be affected by a magnetic or electrostatic field in much the same way as a beam of electrons in a vacuum can be controlled. Further detailed information on this subject will be contained in the leeson devoted to the study of the Kerr cell.

The apparatus which was built under Dr. Alexanderson's direction consisted of a light valve controlling a powerful illumination source from a radio signal. Projection was accomplished by passing an intensely powerful beam of a standard 175 amp. motion picture arc through a high frequency light valve, through a scanning disc to a transluscent screen to the eyes of the observer. The operation of the light valve is seen, therefore, to be quite similar to that of the grid of a vacuum tube by means of which a small incoming impulse controls a relative large *space current* obtained from a local battery. This light valve like the grid has no apparent inertia and can handle picture signals of any conceivable frequency.

The light of the arc passed through the Karolus projector is first drawn into parallel rays by means of a lens system. After passing through a special lens system it becomes a plane polarized ray to be projected through the light valve. The complete process is much too involved to be of interest to the student at this point. The important point to remember is that the Kerr cell did play an important part in the development of television.

8. FIRST ATTEMPT TO COMMERCIALIZE. In this same year (1927), Belin and Holweck achieved a certain measure of success in transmitting what amounted to outlines and "shadowgraph" by means of their cathode ray television system. Judging from the number of successful television demonstrations which made them a major event in the story of television, the year 1927 may be rightly termed the date of television's "coming out party."

The first public demonstration of television probably took place in a London theatre in July, 1930. At this time, living artists and motion picture film were transmitted from a studio in Long Acre and reproduced on a multi-cellular lamp screen on the stage. In this same year, M. von Ardenne in Germany began his researches on cathode ray systems for the reception of cathode ray images and, a little later, was the first to produce results comparable to those of mechanical scanning devices.

Meanwhile, let us see what has been happening in our own country, the United States. The previously mentioned experiments of Jenkins were successful enough that several companies, around 1927 and 1928, undertook the manufacture of television receivers and television receiver kits. A few scattered broadcasting stations began furnishing experimental programs. These premature commercial attempts were doomed to failure on two counts from the very start.

In the first place, it took more than a flickering 45 or 60 line picture a little larger in size than a postage stamp to hold the interest of a public already accustomed to the high perfection of similar entertainment obtainable at any motion picture house; and secondly, satisfactory program material was not available. The public admitted that as a scientific toy, this television baby was marvelous. In the same breath, they admitted their willingness to wait until "it was perfected." Thus, with a distinct lag in public interest came the closing, one by one, of the television broadcasting schedules and, likewise, the deflation of many promotional balloons.

From time to time in the succeeding years, there has appeared at various functions over the country traveling shows that were advertised as television demonstrations. Prominent in this group was an individual by the name of Sanabria whose chief claim for fame seems to have been his own ingenuity and the design of a multi-spiral disc (to reduce flicker), rather than the excellence of the demonstration. The best that could be said of these types of demonstrations was that they kept the layman satisfied with their radio sets while the research groups of various radio companies labored secretly behind locked doors on television equipment which was far more advanced than anything the public had ever been privileged to see.

During 1928 and 1929, most of the television research work in this country was confined to the television laboratories of the General Electric Company in Schenectady, New York, and the Westinghouse Manufacturing Company in Pittsburgh, Pennsylvania. The work which was carried on under the direction of Dr. Alexanderson at General Electric and V. K. Zworykin at Westinghouse laid the foundation for our present television system in this country. The formation of the RCA Victor Company (now known as the RCA Manufacturing Company) in Camden, New Jersey, in 1929, attracted men prominent in television research from both companies and made possible RCA's outstanding contribution to both research and development in the television field.

A noteworthy example of individual contribution to the television art was a special form of photoelectric cathode ray tube which was developed by P. T. Farnsworth for use in his own television transmitting system. Farnsworth originally established his company on the West Coast and then later came to take over the television activities of the Philco Radio Company in Philadelphia, whose chief interest in television was, admittedly, television receiver development. Shortly thereafter, however, Mr. Farnsworth established his own separate company in Chestnut Hill at the outskirts of Philadelphia and continued his television research work there.

9. FIRST ELECTRONIC RECEIVERS. During the years that have followed since 1930, so many interesting and important events have occurred in the process of television development both here and abroad that it would be utterly impossible to give a complete account in a short history such as this. Therefore, only those events considered as being of major importance can be recorded.

Probably the most active in television research in this country is the RCA Company, located in Camden, New Jersey. During 1931 and 1932, this company installed studio and transmitter equipment in the top of the Empire State Building in New York City for the purpose of making actual field tests. Two transmitters were used, one being for the picture and the other for the sound. Mechanical scanning equipment was used in the transmission of both motion picture film and studio pickup. At first, only 120 line pictures were produced, but later this number was increased to 180, each having a picture repetition frequency of 24 per second. These transmitters were operated in the experimental television band, located between 40 and 80 megacycles. A picture of the RCA antennas atop the Empire State Building is shown in Fig. 7.

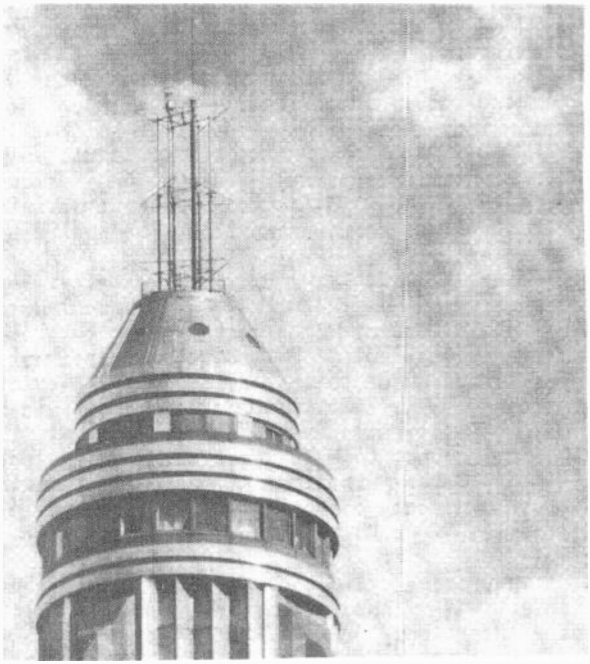


Fig. 7 Television Antenna at top of Empire State Building.

These tests inaugurated the use of higher frequencies for the transmission of television signals by radio (the band being around 6 meters). It had long been apparent that if we were to have pictures that would compare in definition and clearness to those found at a motion picture theatre, those wavelengths found in the normal broadcast band would be entirely inadequate. The frequency range lying between 40 and 80 megacycles was found to be suited for this type of transmission. In addition, it provided ample room for the increase of picture detail which was naturally expected to follow in the course of the development of the art.

While transmission was mechanical, reception was accomplished entirely by electrical means. The experimental television receiver employed a cathode ray receiving tube having a diameter of 9" and showing a greenish-colored picture. The sound was received in the same receiver cabinet by means of a separate sound receiver having its own controls.

Much interest was evidenced in New York City concerning the television activities at the top of the Empire State Building, but the only information available was that which the individual could obtain through his binoculars focused on the top of this building. Absolute secrecy was maintained throughout these early trial periods. These tests indicated, among other things, that first, with only 180 lines, the picture and subject material had to be carefully selected to have any entertainment value; this called for an increase in the number of lines; and second that the mechanical scanning arrangement used was not flexible enough for satisfactory studio or outdoor pickup.

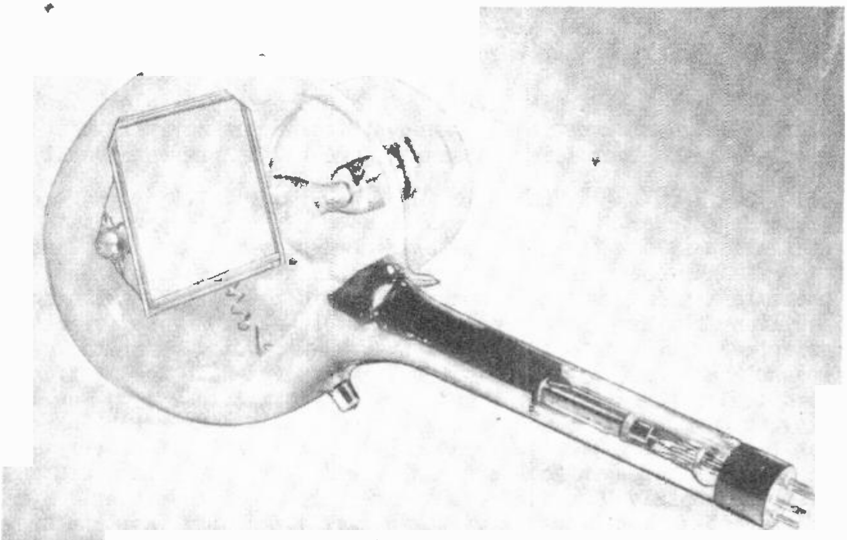


Fig.8 The "Electric Eye" called the Iconoscope by RCA.

10. FIRST ELECTRONIC TRANSMISSION. By 1933, most of these objections had been partially overcome.

The idea which Carey had attempted to demonstrate more than 50 years back when he tried to use individual cells in the transmitting device had now been developed to a point where practical demonstrations were made. The device invented to accomplish this took the form of a special television transmitting tube and became known as the "iconoscope" by the RCA Company in whose laboratories it was developed. A picture of this tube is shown in Fig. 8. Perhaps no single development since the advent of the Nipkow disc has influenced the progress of television to the extent as has this special transmitting tube. You will recall that in Carey's device, he used less than a hundred individual cells, but in this tube, the screen or mosaic upon which the picture is focused actually contains what amounts to some 300,000 individual photoelectric cells! Furthermore, this screen is scanned electrically and not mechanically, for there is not a single, mechanically-moving part in the entire system!

This tube is so truly remarkable in its conception, yet comparatively simple in its design that one cannot read about it without feeling an increased respect for the ingenuity of the human mind. For the first time, television could see the ultimate realization of its initial dream; namely, that of outdoor pickups, etc., which would make possible the transmission of sports events. (A complete description of this tube is given in a later lesson.) Perhaps one of the earliest transmissions of out-of-door scenes occurred when the RCA research engineers working with an iconoscope pickup camera in research laboratories adjacent to the Philadelphia-Camden Bridge pointed it out the window and watched bridge traffic as well as pedestrians on the street below. A novel transmission was made a little later when a partial eclipse of the sun was televised.

Naturally, with the advent of the iconoscope, television research and development took on new life and an activity that has continued with increasing intensity down to the present moment.

11. TELEVISION TESTED IN THE FIELD. During 1933 a more comprehensive television system was planned for the Empire State installation in New York City as well as the home apparatus in Camden.

The new equipment when completed in Camden made possible the transmission and reception of the television pictures consisting of 240 lines repeated 24 times per second. In order to give television an actual field workout, a relay station was located 64 miles southwest of New York City and 23 miles from Camden on the top of Arney's Mount; This relayed the Empire State transmissions from New York City to Camden. A second remote pickup station was established up the Delaware River, a mile from the Camden terminal. Receivers were located in a home in Collingswood, New Jersey, an airline distance of approximately four miles from the Camden transmitter. A map showing these locations is given in Fig. 9. A more intimate knowledge of this setup is interesting. When all equipment had been built and installations made, it was possible to originate a program at New York City in the top of the Empire State Building and then by short wave, transmit it to the antenna on Arney's Mount where it would be retransmitted on a different wavelength to the top of the building housing the research laboratories in Camden in which the control room was located. This point served as the clearing house for all programs and from here they were sent through a specially constructed 1500 foot cable to the television transmitter located in another building; here again the signal was put on the air for its final journey to the receivers located four miles away. At the second remote point (up the Delaware River) was located the outdoor pickup and from this point pictures were transmitted by radio to the control room, where, as in the case of the New York signals, they were monitored, then retransmitted for actual reception.

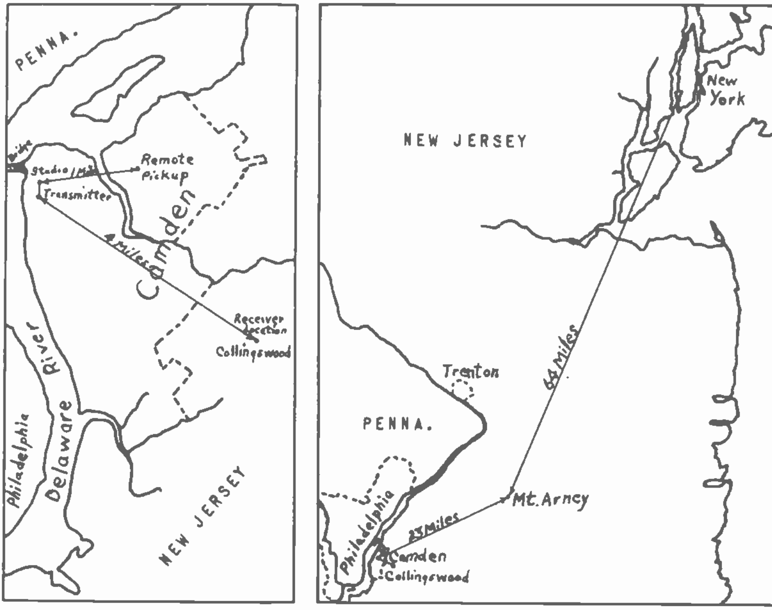


Fig.9 Map showing first television network.

Thus it is seen that with so comprehensive a plan embracing practically every phase of the television activity, television was given its first real workout.

Both picture and sound were available at the receivers. The New York pictures were composed of 120 lines, while those originating in Camden were made up of 240 lines. A typical program consisted of a motion picture transmission from New York City, followed by a short musical program from the Camden studio along with pictures of street traffic (involving a fake automobile accident) and table tennis. Wrestling matches were originated at the point up the river, and then a switchback to the projection room of the Camden studio where a final motion picture film was shown. These tests were so successful and the viewers located at the receivers in Collingswood sufficiently impressed that it is believed if the financial condition of the country had warranted it at that time, plans for the immediate commercialization of television would have been made. Instead, and fortunately perhaps, an additional period of research and development was agreed upon. The high state of development of the motion picture art automatically provided a criterion of such perfection that television pictures at this time suffered by comparison. It was quite evident that pictures must have still more detail and much less flicker than afforded by a 24 picture per second repetition frequency. Considering the rate at which picture lines were being increased and, consequently, the width of the band of frequencies required for transmission, engineers set about to find some method by which they might increase the number of apparent pictures per second without greatly increasing the required frequency spectrum.

The idea of interlacing was resorted to. (You will remember that Sanabria had made the use of this same principle with the triple spiral disc several years prior to this time.) Interlacing consists of scanning the odd lines of an entire picture first and then returning to scan the even lines in the same picture, thereby making two complete scans of a single picture. Now, since they were using a scanning rate of 24 complete pictures per second, it was decided to double this by the interlacing method and obtain 48 fields per second, while still retaining the 24 complete pictures or frames. This idea was taken from the motion picture arts, since they show 24 pictures per second, but break it up by means of a shutter to give the effect of 48 and thereby reduce the flicker. This scanning arrangement worked, but had one very distinct drawback; namely, since all of the equipment was operated from a 60 cycle line, it was necessary to carry filtering of the voltage supplies to an impractical degree of perfection if they were to have either satisfactory interlacing or hum free pictures.

12. TELEVISION EXPANDS. From this it was definitely concluded that the sensible thing to do was to increase the frame frequency to 30, thereby making the field frequency equal to 60 and synchronous with the power line frequency. Consequently, by the close of 1934, we find transmission being carried on, using 343 lines to the completed picture which was repeated 30 times per second. (This is equivalent to 60 fields of 171½ lines each.) The year of 1935 was one of changes during which both the RCA and Philco companies changed all of their transmitting and receiving equipment over to the newly accepted plan of 343 lines, 30 frames.

During this same year, these companies had a visit from the television committee which was designated by the British government to investigate and report on the status of television in the United States. These gentlemen seemed quite duly impressed. Their report to the British government was in part as follows: "We have come to the conclusion that a start could best be made with a service of high definition television by the establishment of such a service in London. It seems probable that the London area can be covered by one transmitting station, and that two systems of television can be operated from that station. On this assumption we suggest that a start be made in such a manner as to provide an extensive trial of two systems under strictly comparable conditions by installing them side by side at a station in London where they would be used alternately—and not simultaneously for a public service..... We recommend that the Baird Company be given an opportunity to supply the necessary apparatus for the operation of its system at the London station and that the Marconi-EMI[1] Company be given a similar opportunity in respect to operation of its system also at that station..... Lastly, we are quite unable to agree that there is no urgency. On the contrary, our inquiries convince us that, apart altogether from any question of scientific prestige, any delay would be most regrettable; and we feel that, if our conclusions are ac-

[1] The Marconi-EMI Company in England compares with the RCA Company in the United States. These two companies have working arrangements on television.

cepted, it is most desirable that the minimum amount of time should be lost in giving effect to our recommendations."

By July, 1936, the Radio Corporation of America had expanded its television facilities to include studios in the RCA Building at Radio City as well as the transmitter which was located in the top of the Empire State Building. All equipment had been made to conform to the idea of 343 line transmission.

At this time, the president of RCA, Mr. David Sarnoff, in his report on the status of television, made this significant statement: "This corporation is second to none in the scientific and technical development of television. We have gone much beyond the standards fixed elsewhere for experimental equipment, but this is a far cry from the expectations of such a service aroused by pure speculation on the subject. There is a long and difficult road ahead for those who would pioneer in the development and establishment of a public television service."

On July 7, RCA staged their first planned show over the newly installed New York equipment. The invited guests who viewed the performance at Radio City were licensees of the Radio Corporation of America. The program consisted of, first, a conversation between Major General J. G. Harbord, chairman of the board of RCA, and David Sarnoff, president, sitting at a desk reviewing television's progress. Then came a dance by twenty girls introduced as the Water Lily Ensemble. A film was then shown, featuring the streamlined train, Mercury. A glimpse of what is ahead in the world of fashion was given by models from Bonwit Teller. Additional films were shown and Henry Hull, actor, entertained with a monologue of his role in "Tobacco Road." Graham McNamee and Ed Wynn showed what comics may do in the future. A film of army maneuvers then ended the performance.

The greenish-hued images which the radio manufacturers viewed measured 5" × 7", reproduced by a 33-tube instrument, equipped with 14 control knobs.

Of minor importance, yet significant, was the fact that this television program inaugurated demonstrations of a completely electronic television system. Prior to this time, a motor driven disc had been used to generate the synchronizing signal.

In the latter part of 1936, two other events made television history. One was the televising of the Olympic games at Berlin, Germany. The other was the official opening of the Alexandra Palace, England's first television station at 3:00 p.m., November 2. (The first public transmission, however, from this station occurred during August.) The dedicatory remarks of some of those participating in the program are interesting, and therefore, are given in part. Lord Selsdon, chairman of the English television committee said: "From the technical point of view, I wish to say that my committee hopes to be able, after some experience of the working of the public service, definitely to recommend certain standards as to number of lines, frame frequency, and ratio of synchronizing impulse to picture." From the speech of the Postmaster General: "On behalf of my colleagues in the government, I welcome the assurance that Great Briatin is leading the world in the matter of television broadcasting, and, in inaugurating this new service, I confidently predict a great and successful future for it."

The government followed the recommendations of the television committee regarding the use of two different systems to begin with, both of which were to be housed in the Alexandra Palace. The Baird system used 240 lines, 25 pictures per second; the Marconi-EMI system used 405 lines with 25 pictures per second, interlaced scanning (giving, of course, the appearance of 50 pictures a second). For direct television, the Baird system made use of intermediate film and the image-dissector, while the Marconi-EMI Company used the iconoscope camera (called the emitron). For film transmission, the Baird Company used mechanical scanning, while Marconi-EMI used the iconoscope camera. (In February of the following year the Baird Company system was dropped, the Marconi-EMI system having proved the more successful in the test.)

Some hint as to the success and popularity of these televised programs may be gained from an editorial which appeared in a British magazine, Television and Short Wave World of December 1936. "At this early stage, it would be manifestly unfair to unduly criticize the programs transmitted from Alexandra Palace, but we are only voicing the general opinion when we say they do not come up to a standard which the degree of technical development warrants..... On many occasions there have been intervals (no program) totaling over 15 minutes in a brief hour's program. It should be appreciated that owners of television receivers are not disposed to run a matter of 20 valves (radio tubes) plus the cathode ray tube merely to hear a few gramophone records; neither are they pleased to have to sit and look at the hands of a clock.....

"Our second great grumble concerns the repetition of material that is presented. Particularly is this the case with films. Everybody has seen the film 'Television Comes to London,' so many times that the point of boredom has long been passed....."

As the student may have surmised, the British television system is under direct governmental supervision and control. This is true also of the television activities in most other foreign countries. In the United States, television like most other business owes its development to private initiative.

13. MODERN TELEVISION DEMONSTRATIONS. On August 11, the Philco Radio and Television Company of Philadelphia, Pennsylvania, gave its first television broadcast demonstration to a group of over a hundred newspaper men gathered at a point seven miles from the transmitter) Regarding this demonstration, the Philadelphia Record had this to say: "Television came out of the laboratory and into the home in perfect form yesterday in Philadelphia..... Reception compared favorably with home motion pictures..... The pictures themselves flashed on a panel atop the receiver, measuring 7¾" × 8¾". They had no faint greenish tinge, but were straight black and white." These pictures consisted of 345 lines and the program, which lasted 55 minutes featured the radio commentator, Boake Carter, in conversation with several member of the newspaper fraternity over a telephone line. In addition to this the program provided music, a boxing match and also some reels of motion pictures.

On February 11, 1937, exactly six months later to the day, this same company gave another demonstration for the press at which time a 441 line picture was used. The story of this event and the reaction of the average individual who saw it is found in an article printed in the Philadelphia Inquirer on Friday morning, February 12. The article is titled, "Television Gals Float, Boys Gloat," and a subtitle, "Pretty Models Steal the Show by Wearing and Bearing." The article goes on to say: "Shapely maidens floated through the air over Philadelphia yesterday, but not a neck was craned upward. For fifteen minutes, the coy lassies showing for the most part and for the lesser part the sheer, flimsy lingerie they modeled, glided through the ozone. Their route extended three miles over one of the busiest sections of the city--

"But, gosh, don't get all worked up; you couldn't have seen them if you had tried. That is, unless you were among the hundred guests who huddled around receiving sets in the FIRST large scale demonstration of television, 1937 style.

"And, men, it's okay."

The FIRST 441-line picture in this country and perhaps in the world was produced in the laboratories of this same company on November 21, 1936.

It should be pointed out that none of these demonstrations involved the discovery of new ideas, but rather they exhibited the improvement possibilities for existing apparatus.

In commenting upon the development of television in this country early in 1937, just after the adoption of the 441-line picture standards, David Sarnoff, president of RCA, said; "Developments here and abroad have demonstrated the fact that RCA is in the forefront of technical development in this new and promising field. Recently the authorities responsible for television in England adopted the Marconi-EMI system of television in preference to the other systems they tested. The system thus adopted and the English standard, is based on RCA invention. In our own country, the Columbia Broadcasting System has just announced its plans to enter the field of experimental, high definition television."

In reciting the more recent events in the progress of television, one must not overlook the activities of the Don Lee Broadcasting System on the West Coast. Television broadcasts were inaugurated on September 1, 1936, under the unusual condition that the sound portion of the television program was broadcast over KHJ, Los Angeles, on the regular broadcasting band, while the television portion of the program emanated from W6XAO, the television transmitting station. Later, the sound as well as the picture, was broadcast in the high frequency spectrum around six meters. During the first two years of the operation of this company's television station, it probably had to its credit more actual program time on the air than the other experimental stations of this country all combined. A picture of a portion of their equipment is shown in Fig. 10.

In May of 1937, television chalked up another red letter day when the British Broadcasting Company was able to televise the Coronation procession. Although the televising of the Coronation procession was not the first actual outside broadcast that had been

Fig.10 Mr. Lubke, Chief Engineer of W6XAO, shown with portion of the equipment at that station. He is holding late model iconoscope.

made, it was the first to employ outside equipment and it did vary materially from the transmissions which had taken place within the precinct of the Alexandra Palace.

It brought into service for the first time the British Broadcasting Company's new mobile unit. Owing to technical reasons which limited the length of the cable connecting the television cameras with the control room, previous television outside broadcasts had been confined to the grounds of the London television station at Alexandra Palace. This mobile unit consisted of three vehicles, each the size of a large motor coach. In one was the television control room, containing all the necessary equipment for the operation of three television cameras. The second contained a 1 kw.

ultra short wave vision transmitter. The third unit provided for the power supply in the event that a satisfactory connection to the power company's mains was not available. A picture of the RCA mobile unit is shown in Fig. 11.

With the advent of the all-electrical television system, one would naturally conclude that the curtain had been rung down once and for all on all mechanical devices. The facts are quite to the contrary as we shall presently see, for apparently those who sponsored mechanical systems set about with renewed determination to prove their actual superiority under certain conditions.

Fig.11 RCA-NBC Portable Television pick-up Equipment.

14. POSSIBILITIES OF CHAIN TELEVISION. Meanwhile, between Philadelphia and New York City there had been completed a special telephone cable by the Bell Telephone Laboratories of New York for the purpose of transmitting carrier channel telephony. This cable was known as the "coaxial" type and had a frequency characteristic such that it offered for the first time on a single cable the possibility of 240 different channels for a telephone conversation; that is, 240 conversations could be carried on simultaneously without interfering with each other. Although the length of this cable was something around 90 miles, yet in testing this multiple channel system, the channels were connected end to end so that the equivalent length of the circuit was 3800 miles, looping back and forth through the same cable some 45 times. Satisfactory telephone service was possible even over this arrangement.

Since this cable had a frequency characteristic that was good up to a million cycles, it was decided by the Bell Labs to give it a tryout in the transmission of a television picture. Consequently, on November 9, 1937, a demonstration was given for executives of the American Telephone and Telegraph Company and operating Bell Telephone Company. The program was originated in New York City and

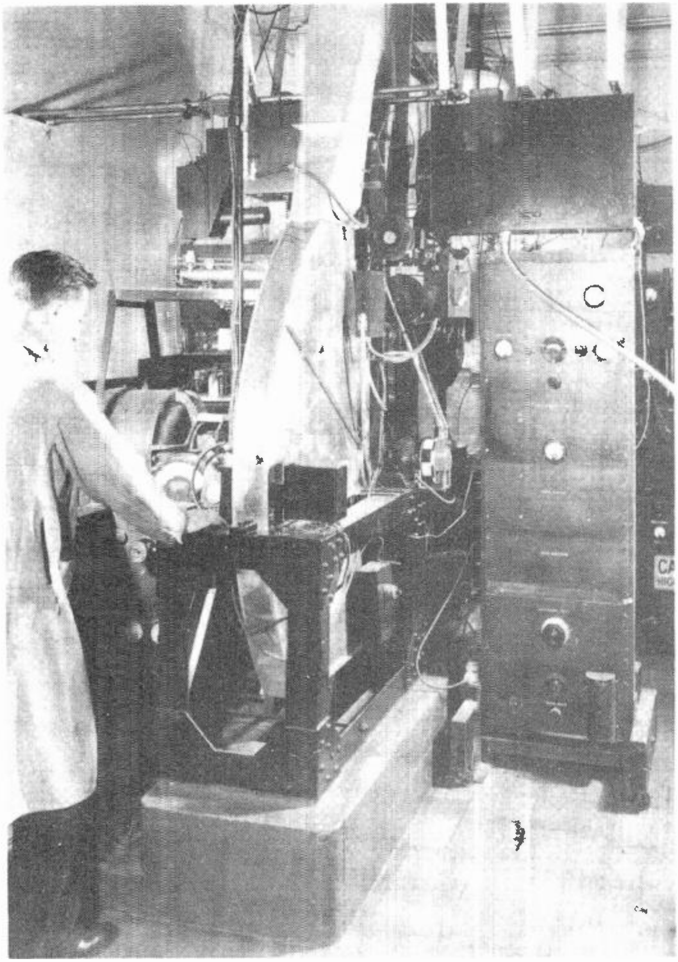
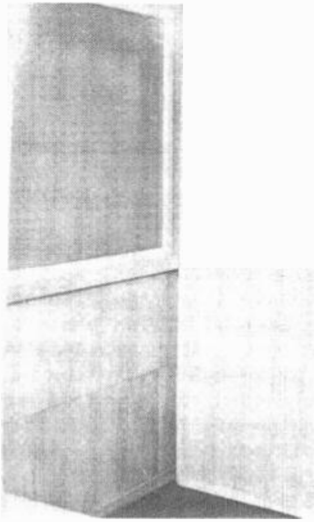


Fig.12 The Bell Telephone's Television Equipment. This was used for the cable transmission between New York and Philadelphia.

received in Philadelphia. A view of the transmitting equipment is shown in Fig. 12. Many of those who viewed the demonstration felt that the images produced, while based on the limited possibilities of 240 lines and 24 frames (without interlacing) were the equal, if not actually superior to the 441-line 30 frame interlaced images recently demonstrated in New York and Philadelphia. The receivers used were the conventional cathode ray tube type, producing a picture about 7" × 9" in size, green in color. The scanner at the transmitting end consisted of a 6' steel disc, rotated at 1440 r.p.m. and in which was set 240 high speed lenses, each located at the same radius from the center. The picture transmitted was obtained from film.

15. COLOR TELEVISION. In the winter of '37 and '38, Baird in England transmitted, for the first time by wireless, television in color. A flag, for example, could be held in front of the camera and be reproduced at the receiver in natural colors. The pictures were produced by optical mechanical methods and three light sources were employed, blue, green, and red. On February 4, a public demonstration was given by Baird at the Dominion Theatre. The reproduced pictures were 12' × 9' and were transmitted by radio from the south tower of the Crystal Palace on a wavelength of 8.3 meters. The color was said to be extremely good and, on the whole, more pleasing to the eye than some of the colored motion pictures.



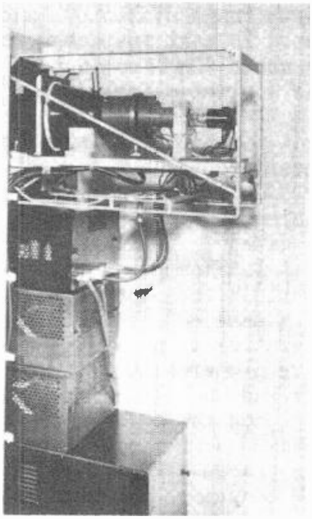


Fig.13 A German Cathode Ray Projector for Television.

16. GERMAN TELEVISION. Television has not been limited as to its field, for there is a great deal of activity and interest in both France and Germany. What is said to be the world's most powerful television station is now nearing completion in the top of the Eiffel Tower in Paris. Television developments in Germany, too, have been keeping pace, if not running a little ahead in that the German engineers have been very keen to develop the commercial side of television where applicable to telephone use. A service has been in operation for some time between Berlin and Leipzig (90 miles). This has proved so satisfactory that the service is being extended so that 30 telephone calls with vision may be made simultaneously.

In addition to this, it seems that Germany has produced one of the most outstanding television exhibits (which opened August 5, 1938,) from the standpoint of demonstrative results that has ever been given. The work and equipment of the Fernseh A.G. Company was perhaps most outstanding for they were showing a 10' × 12' picture projected from a cathode ray tube employing between 60,000 and 80,000 volts on the anode! One early German model of such equipment is shown in Fig. 13. According to one correspondent, "In my opinion, this picture is the best television ever shown in public. In all respects, size, brightness and definition, and halftones, it was practically equivalent to a cinema picture.........." The picture was composed of 441 lines and was scanned by a disc at the transmitter. Quoting the same correspondent further, "The construction of this transmitter must rank as one of the outstanding feats of precision engineering of our time." Receivers were available which used a 20" cathode ray tube and produced black and white pictures of enormous brilliance. In addition to the disc, Farnsworth image dissectors and RCA iconoscopes were also available for use. In most instances where mechanical scanning is used, it will be noted that motion picture film or lantern slides usually form the subject material.

In the light of recent mechanical demonstration, it was seen that for the transmission of film, mechanical scanners have been developed to a state of perfection surpassing the results obtained by the iconoscope camera. However, for portability and for live subject matter the camera type of transmitting tube has no equal to date.

In connection with German television development, we must not overlook the process known as intermediate film transmission. In this case, a special camera employed a loop of motion picture film operating through a special developing tank. The procedure was to take pictures much in the same manner as is done by motion picture cameras and then these films were developed and scanned; as the reel continued to pass through the equipment, the old picture was removed and replaced by a newly sensitized film, ready again for the camera. From the time the camera took the picture until it was scanned for transmission, only 12 seconds elapsed. A similar process was used at the receiving end with the exception that the received picture impulses, having been transferred into light, exposed the film which was in turn developed and then projected on the screen much the same as an ordinary motion picture.

17. OTHER HIGH QUALITY TELEVISION. In England, the Scophony Company has also produced surprising results with large-sized pictures using mechanical scanning for reception. They have a home type receiver with a screen 22" × 24" and a motion picture type with a screen 4' × 5'. They have also developed 405 line mechanical scanners for transmission.

We have seen how most of the television developments in this country have been confined to the east and west coast. However, in the early spring of 1938, Midland Television, Inc., demonstrated the first high definition, 441-line television system to be put in operation in this country west of Philadelphia. A picture of Midland's television equipment is shown in Fig. 14.

On June 7, the National Broadcasting Company made television history when it transmitted a Broadway play from New York's Radio City. The play, "Susan and God", was presented by John Golden and starred Gertrude Lawrence. The old expression, taken from Shakespeare's work, "All the world's a stage," is now taking on a new and fuller meaning.

18. RMA TELEVISION STANDARDS COMMITTEE. Behind the scenes of television development in this country, there is one group heretofore unmentioned that must at this time take the spotlight; namely, the Radio Manufacturer's Association Committee on Television. Since 1935, this committee has been active in formulating tentative standards and evaluating progress made by various companies engaged in

Fig.14 Midland Television's Control Room Equipment. The television picture shown on the monitor is a televised photograph of a movie actress.

television research. When cathode ray television began to emerge from behind locked doors in 1934, there was no agreement among the various companies on what constituted a good television picture. In fact, there were as many different ideas on television standards as there were experimenters. Now, we find the industry, the technical part of it at least, presenting a solid front on television standards and with such good effects that their recommendations have been accepted, substantially, by the Federal Communications Commission in setting up the allocations for the ultra-high frequencies, (In June, 1938, all television standard recommendations had been completed for this country.)

As we look back on what has gone before in the development of television, it seems quite probable that no present day art represents the adaptation of more diversified ideas from scientific development than does television. To even begin to understand the fundamentals of its workings, we must know something about electricity, electronics, chemistry, and optics. Consequently, you, the student, unlike Alexander the Great, need not despair for fear the day of great exploits is over. There are many new scientific worlds to conquer. As David Sarnoff so aptly said, "Once we faced the frontiers of geography; today we face the infinite frontiers of science."

EXAMINATION QUESTIONS

INSTRUCTIONS. Before starting to answer these examination questions, you should have studied the lesson material at least three times. Be sure that you understand each question--then proceed to write the best answer you can. Make all answers complete and in detail. Print your name, address, and file number on each page and be neat in your work. Your paper must be easily legible; otherwise, it will be returned ungraded. Finish this examination before starting your study of the next lesson. However, send in at least three examinations at a time.

1. By whom and when was the first television, or rather, facsimile, picture transmitted?

2. What fundamental principle of television picture transmission was embodied in Carey's experiment?

3. For what is Paul Nipkow famous?

4. What two men were prominent (one English, one American) in the first practical demonstrations of television?

5. What is the difference between wirephoto and television?

6. Name two technical difficulties which hindered television progress in its early stages.

7. What invention took television out of the laboratory into the street?

8. How does the United States differ from England and most foreign countries in the control of television?

9. Why was the broadcasting by television of the Coronation of particular significance?

10. Has electronic television entirely supplanted mechanical?

Notes

(These extra pages are provided for your use in taking special notes)

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UNIT NO. 5

PRINCIPLES OF SCANNING

LESSON NO. 2

SMOKE & DRUMS

.....the wireless of plain and jungle.

Today, smoke rising into the sky represents industry. But in the day of the settler who traveled to our great plains region in covered wagons, columns of smoke rising into the sky spelled 'danger'. American Indians used the smoke system of communication to excellent advantage. And it was not long before the settlers themselves signaled to each other in dots and dashes composed of smoke.

Progress has eliminated this picturesque method of communication from the American plains. Instead, radio waves bounce against the Heaviside layer and back to the antennas of thousands of radio receivers. But progress has yet to silence the eerie beat of signaling drums deep in the jungle country. Staccato beats, rolling beats, slow beats booming through the night, carry messages of high importance to the listening savages.....and often bring chills to jungle travelers. War, peace, sickness and disease, the coming of a Doctor, or the arrival of a trader are announced by the native drum 'operators'. They are just as important to life and commerce in the jungle, as the skilled radio technician is to life and commerce in the civilized world. While the American Indian has come to accept radio as 'just another addition to the pleasure of living', the jungle folk who have heard radio receivers talk and sing are still mystified and often times afraid.

But progress cannot be denied. Radio will penetrate the jungle just as it did the plains. And television will follow. It is ambitious men like you, who today are training, will tomorrow carry radio and television to new fields, greater accomplishments, and a better life.

Lesson Two

PRINCIPLES of SCANNING

"While this lesson is to be devoted to a study of scanning as it relates to mechanical systems, still I do not want to give the idea that we are recommending the use of mechanical scanning over that of electronic scanning. It is my sincere opinion that if a student first secures a thorough and comprehensive understanding of the older mechanical systems, he will then be able to grasp more readily the principles of the more modern electronic system.

"At the time this is being written, there are practically no mechanical scanning systems in use in the United States; all companies except one are using the electronic method. However, in England while the electronic method seems to prevail, still there are some very satisfactory pictures being reproduced using mechanical scanning equipment; therefore, we feel as though your time will not be wasted by learning the fundamental principles of this type of scanning."

1. NEED FOR SCANNING. In the lesson just completed, you studied about the many attempts made to duplicate the action of the human eye. While that would be the Utopia for television, still it appears as though a substitute is going to have to be used if successful picture transmission is to be realized. Of the equipment available today, none is capable of duplicating the action of the eye; therefore, successful television was impossible until the invention of the Nipkow scanning disc.

A more complete understanding of the problems involved in television can be had by comparing present television systems with two more familiar functions. The first of these is the ordinary photographic camera and its contemporary, the motion picture camera; while the second is the marvelous action of the human eye. While these two functions have no direct relation to television, still we feel as though the time spent in learning more about their operation will enable you to better understand the problems which you are now going to study.

2. THE CAMERA. The actual chemical analysis necessary to explain the process of taking a photographic picture is quite complicated. Therefore, in this lesson we will cover only the high spots of such an explanation, giving you enough information to understand the processes involved.

The function of an ordinary camera can be described as follows. Through the use of a lens, an image of the object to be photographed is focused sharply on a sensitized plate or film. A shutter is used so that the film can be exposed for the correct length of time. After the film has been exposed, it is carefully kept from light and then placed in a chemical solution known as a developer. After a short length of time, the silver salt in this film, at those portions corresponding to the bright portions of the image will turn dark. Less bright portions of the image will show less dark on the film, and so on; thus forming a readily recognized image. The chemical action of the developer changes the light struck portions of the silver salt on the plate or film into metallic silver which appears black.

After a certain length of time in developing, the process must be stopped or the entire film would turn black. Accordingly, the film is next immersed in a fixing bath, known as hypo. This solution dissolves the silver salt which has not already been reduced to metallic silver and this makes the image permanent. After this, the film is thoroughly washed in clear water and then dried.

The film just prepared is now called a negative. It is possible to print from this negative, positive prints in which the blacks and whites are in their proper relation. These prints are prepared on specially sensitized paper. It is also necessary to put this paper through certain chemical processes in order that the picture will remain permanent.

In considering the negative, it is called a negative because the white portions of the picture are black and the black portions of the picture are light, or white. Therefore, the image is reversed. When a positive print is made from a negative, the process is reversed and the black and white portions of the picture appear in their natural relationship.

From this discussion, you can see that an image of the picture desired is etched on the film, or plate, showing in black and white every detail of the picture to be transmitted or preserved. The entire process, however, has involved a considerable period of time.

3. THE MOTION PICTURE PROJECTOR. Motion pictures as we know them today, are made possible through a certain peculiar, physical characteristic of the eye. This phenomena of the eye is called the "persistence of vision", or the "retentivity" of the eye. It is explained as a property of the eye, having the power to continue seeing an object even after that object has moved on. In other words, when our eyes view an image and then the image is suddenly removed, our eyes have the property of momentarily retaining an impression of that image.

Therefore, motion pictures as we know them today are not really moving, but rather are taking advantage of this peculiar property

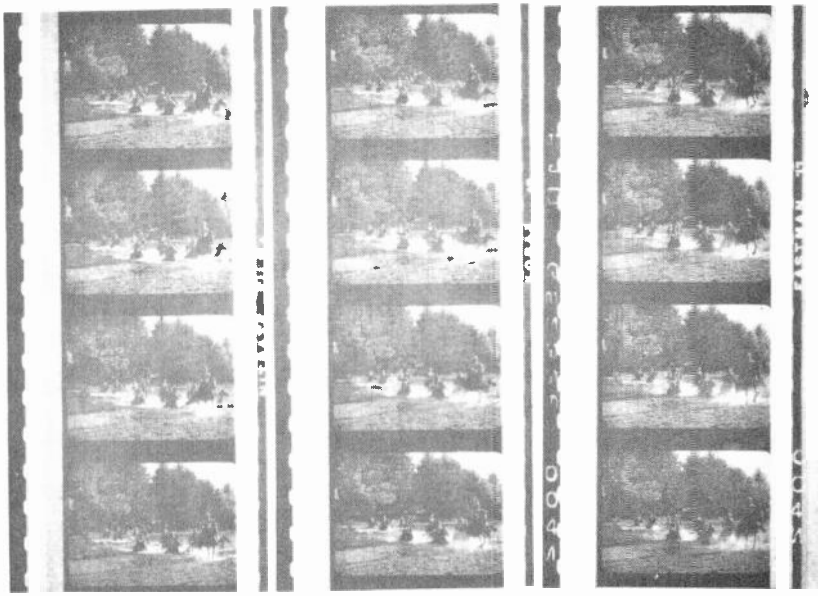


Fig.1 A photograph of a piece of movie film. By looking closely you can see the motion which has taken place as the frames progressed.

of the eye known as "persistence of vision". Through this peculiar property we are presented unusual entertainment and with the addition of sound, the illusion is perfect. A few years ago, the movies were not as good as we know them today because the engineers had not learned to take full advantage of this peculiar retentivity property of the eye.

In order to make the picture move, a number of still pictures are used, each of them having various persons in a certain action, in certain fixed positions that have a continued relation one to another. These separate and individual scenes are all attached together on a long strip of film. Such a film is shown in Fig. 1. This film is then run through a special machine known as a "motion picture projector". This projector causes these photographic views to be flashed on a screen at the rate of 24 per second. A motion picture projector is shown in Fig. 2. Through the use of a mechanism known as the "intermittent sprocket", each picture is actually stopped before a light gate for a very small fraction of a second and the image of it remains on the screen for that short time. After the eyes have viewed it, a shutter is automatically moved before the light and the picture is cut off the screen. For this small fraction of a second, the screen is actually dark, and during this short interval another picture is automatically placed before the light gate and the action repeated. As a result of the lag in the eye, the individual pictures that are projected on the screen blend into one another and the reaction on the brain is that the pictures really move.

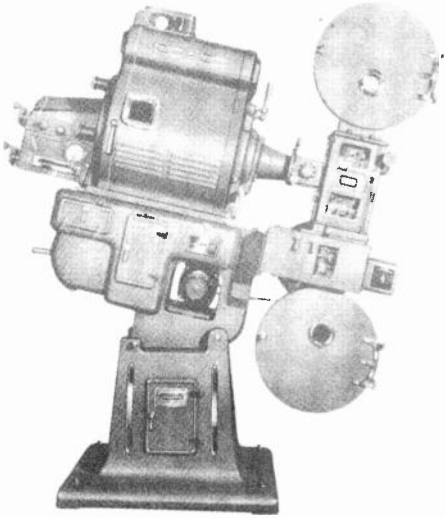


Fig.2 A modern motion picture projector.

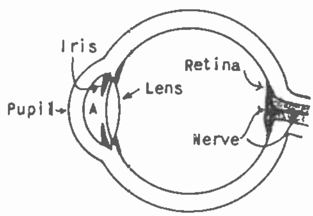
This explanation might lead one to believe that the development of the motion picture art was comparatively simple. However, this was not the case since motion picture machines did not arrive in their present perfected state but were only developed through many long years of experimentation and hard work.

The photographic views used in movies are made at the rate of 24 per second. Then they are printed in a direct progression on a ribbon of film one and three-eighths inches in width and between one thousand and two thousand feet in length. Each view is condensed into a rectangular shape approximately one inch wide and three-quarter inch high. Each individual picture is then called a "frame". To each foot of film there are sixteen of these frames. In the normal operation of a projection machine, 24 frames are flashed on the screen each second. This results in the film being run at a speed of 90 feet per minute. Standard film as used in motion picture work is 35 millimeters (mm) wide which also includes the space allowed for the sound track. Small home movie film is either 16 or 8 millimeters wide. At the present time they are starting the application of the sound track to 16 millimeter film, but so far, sound is not included on the small 8 millimeter type. (There are 26 millimeters in an inch.)

In the earlier days of the movie industry, motion picture projection machines were operated at 16 frames per second. However, the engineers found that this came too close to the allowable changes to take full advantage of the retentivity of the human eye. Therefore, the speed was changed to 24 frames per second; and while this produced considerably less flicker, still there was another improvement to be had. Today, a special shutter is used which has made possible the present day flickerless motion picture. This shutter has two blades on it. The first blade cuts off the light source and a new frame is moved in front of the light gate, then the shutter opens the light gate and permits an image to be thrown on the screen. The shutter continues to revolve and then the other blade of the shutter cuts off the light source, but during this period, the picture frame is not moved. As the shutter moves on, the same frame is again exposed, resulting in two picture exposures for each frame moved before the light gate. The result of this operation is that there are, in reality, 48 pictures flashed on the screen each second. This operation has removed all flicker from present day motion picture projection.

4. THE HUMAN EYE. In the preceding explanation, we have discovered one method used in portraying motion. Now we come to the study of the most perfect means of accomplishing the same purpose.....our eyes. In this lesson we will not go into the optical properties of the eye, but will reserve that for the following lesson in which you are studying the principles of optics. However, at this time it is advisable to present some information on the working of the eyes in order that you can better understand the problems involved in transmitting and receiving television images.

Fig.3 A diagram of the human eye, showing the location of the more important parts.



Except for a small portion at the front, the eye is nearly spherical, and in adults has a diameter of about one inch. In a sense, the eye is quite similar to a camera. It consists of a light proof chamber with a black inner coating. It has a lens and a screen; the lens throwing an image of the scene before the eyes on the screen. Referring to Fig. 3, light from an object enters through the crystalline lens and forms upon the retina at the back of the eye an inverted image. The retina corresponds to the photographic plate in a camera. It is a specialized expansion of the optic nerve through which it transmits to the brain the impression of the image which falls upon it. In the pupil of the eye is a circular aperture called the "iris". Through muscular action of the eye, the pupil becomes very small when intense light is focused on it and very large in feeble light. Thus, the iris of the eye corresponds to the stop in a camera.

The surface of the retina is found to consist of a mosaic made up of an enormous number of elements called "rods" and "cones". These rods and cones are then directly connected to the brain by a number of nerve filaments along which travel impulses that are dependent upon the intensity of the light falling on each cell. The images which we see are thus resolved[1] into a large number of elements of varying degrees of light and shade. Through the action of the brain, these varying degrees of light and shades create a sensation, permitting the brain to tell us a story of what the eyes see.

In music, the information is conveyed to us over an interval of time. Imagine if you can what an entire musical selection would sound like if it were possible to play it all at once. Even by using your wildest imagination, it would be impossible for you to name the selection after hearing it. Time is required to play the selection so that the person, or persons listening may catch its meaning. On the other hand, due to the eye being made up of an infinite number of small cells, each having a path to the brain, the eye is able to transmit a whole picture or scene to the brain at once. This picture is really not transmitted as a whole unit but as thousands of separate units and is instantly recombined by the action of the brain.

If it were possible for us to have, like the brain, thousands of connections between the television pickup equipment and the receiving apparatus, scanning would not be necessary. As it is, like reading the page of a book, or hearing a musical selection, an interval of time must elapse before the picture can be properly reproduced. This is due to the fact that we have only one channel, not thousands, over which to transmit a single picture.

As described in the preceding lesson, models along the lines of the eye were actually constructed. That is, separate pairs of wires were run between each pickup unit and each light unit. However, the feasibility of such apparatus insofar as commercial television is concerned, is readily recognized as impossible.

5. HOW SCANNING IS ACCOMPLISHED. Now since we have no apparatus which will duplicate the action of the human eye, it has been found necessary to break the picture up into small sections, transmit each section separately and then at the receiving end, put the picture back together in the same orderly procession as it was torn apart at the transmitting end. All of this must be accomplished with sufficient speed so as to take advantage of the retentivity of the eye and thus portray motion. This process is known as "scanning".

When you read a book, you do not read an entire page at once. Instead, you read each word separately. Due to constant association with words, you do not have to look at every letter of the word to understand its meaning. Usually a glance at a word as a unit is sufficient to enable us to understand its meaning. In order to understand the information contained on a page, you read the first line across the page from left to right. Then you read the second line, again starting from the left hand side, etc. After an interval of time, you have completely read, or scanned, the page.

Before continuing the study of scanning, let us stop for a

[1] Resolved. To reduce to constituent parts. To analyze.

minute and briefly review the various stages through which a person's voice passes when it is transmitted. First of all, when a person speaks into a microphone the sound waves are converted into varying electrical impulses. These varying impulses of current are then amplified many times and used to modulate the carrier wave of a transmitter. This modulated carrier wave travels through the ether to the aerial of your receiver causing corresponding currents to be induced in the antenna. This weak R.F. signal is then amplified, rectified, and amplified again until both the voltage and current of the audio frequency component is of sufficient amplitude to operate the loud speaker. These varying currents then vibrate the cone of a loud speaker causing the production of sound waves. Notice that the sound waves are immediately converted into electrical impulses and remain just that until the final operation wherein the loud speaker reconverts the electrical impulses into sound waves.

In the transmission of sound, we know that all of the sound waves combine to form an impulse which is equal to the sum of all the frequencies involved. It is known for a fact that at some minute spot on a phonograph recording, all of the frequencies generated by each instrument in a large symphony orchestra is contained and, at the proper moment of reproduction, this spot causes a harmonious emission of the complex frequencies that caused it and the resultant sound which we hear again reproduces that particular cord, or note, from all instruments. The eye takes in every frequency and impression of every source the instant it regards a particular field of view. No means yet at our disposal has enabled duplication of this feat.

In attempting to duplicate the action of the eye mechanically or electrically, the field of view must be resolved or broken down by the scanning system since this is the only means so far known to us of analyzing a field of view and yet making it possible for us to retain its detail. This scanning process must be carried on so as to secure a series of electrical impulses corresponding to the light variations in the scene to be transmitted. These light variations in turn must be picked up by photoelectric cells so that these impulses may be transmitted either by wire or radio.

A complete study of the photoelectric cell and its applications will be covered in a future lesson; however, at this point it is advisable to insert here a simple statement concerning its operation. *The photoelectric cell is a vacuum tube device capable of changing its electrical output with changes of light intensity falling on its active surface.*

Since a photoelectric cell is capable of changing its output with a change in light intensity striking its surface, it is often the opinion of newcomers in this field that a scene could be exposed to a photoelectric cell and in that way an entire image transmitted. However, impulses that actuate the photoelectric cell are due to reflected light and it is the *average* impulse that is transmitted. Therefore, any attempt to transmit the entire field of view as a single impulse would be like looking at a field of view through a ground glass window because nothing but a blur of light would be visible.

By first investigating a phenomenon with which you are a little more familiar, we will lead up to an actual method of scanning. Take, for example, a newspaper picture. By close observation, you will notice that the picture is not solid, but is made up of thousands of small dots. If you hold the picture at normal reading distance, you are not aware of the presence of the dots, instead

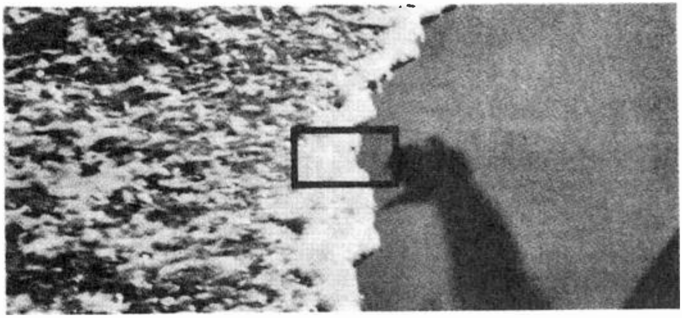


Fig.4 A photograph reproduction of a half tone picture.

you notice only the picture. You are not interested in the dots that make up the picture, so you hold it at a distance which permits you to interpolate the information these dots are conveying. It may be a person, or it may be a new kind of an airplane; whatever the subject may be, that is what you are interested in, not the dots.

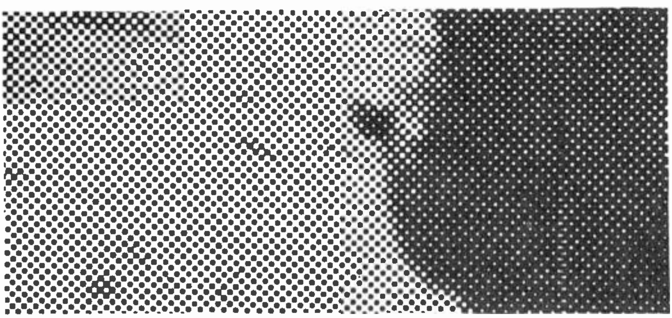


Fig.5 This figure shows an enlarged view of the part enclosed in the square in Fig. 4. Notice how the various dots make up the lights and shades of the picture.

Even better quality pictures such as those shown in magazines are not solid, but are made up of small dots. A half-tone picture is illustrated in Fig. 4. Fig. 5 is a magnified section of Fig. 4 showing how it is made up of dots. Small, widely spaced dots form white or light areas while large dots closer together form dark areas.

Newspapers use what is known as a 65-line screen. This means there are 65 dots in a line one inch long, or 4,225 dots per square inch. Most high quality magazines use a 133-line screen.

Now with all these facts in mind, let us investigate the process of scanning. Suppose we wish to transmit the picture shown in Fig. 6. If we could take that picture apart in an orderly manner, we would find it to be made up of an infinite number of dots which are

Fig. 6 A half tone photograph reproduction.

black, white, and varying shades between black and white. If these dots were passed in front of us, or so arranged that they would effect some piece of equipment capable of converting the varying shades of these dots into corresponding varying current impulses, then insofar as transmission is concerned, the remainder could be handled in much the same manner as a sound wave. At the receiver it would, of course, be necessary to have a reproducing device which would be capable of converting the variations in current into light variations. It would also be necessary that these variations of light be produced in the proper sequence so as to form an image of the original picture..

Fig. 7 shows the same picture as Fig. 6 except that the top section has been cut into strips. Notice that these strips vary in color between black and white. If you were to take one of these strips and view it with your eye through a very small opening, as you moved the strip across the opening all you would see would be a spot varying in shades between black and white.

The purpose of scanning, therefore, is to divide the picture to be transmitted into small sections in an orderly manner so that each section may be transmitted separately, thus providing an interval of time so that one channel may serve as the transmission medium.

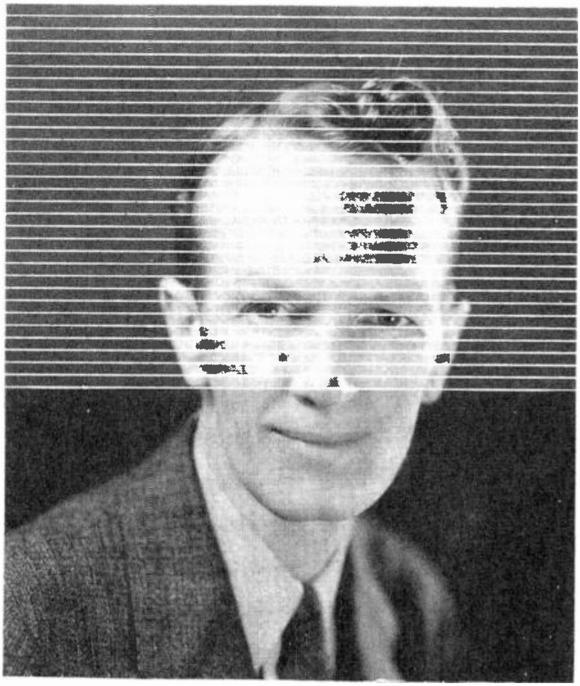


Fig.7 Showing how the photograph in Fig. 6 is broken up into scanning strips.

6. FLYING SPOT SCANNING. At this time a brief study of one method of accomplishing scanning will help the student to secure a better grasp of the entire problem of television technique. Fig. 8 shows how this television system of transmission is accomplished. The lamp shown at M is a powerful mazda lamp which produces a concentrated light, focused by the lens L on the scanning disc D. The powerful light produced by the mazda lamp shining through one of the small, round holes in the disc D, is projected on the subject being scanned through the projection lens L1. When hole 1 in the disc D is at the top, it will cause a dot of light to fall in the upper right hand corner of the scene to be transmitted. A close up view of the disc is shown in Fig. 9. As the disc revolves, the spot of light will move across the image from right to left. The mask P is used so that only one hole can be in front of the light source at a time and, therefore, only one spot of light is on the

subject at a time. This mask P is shown in both Fig. 8 and 9. As hole 1 leaves the light source mask, hole 2 will enter; but because of its placement on the disc (spiral arrangement) the top edge of hole 2 will be just at the bottom edge of hole 1. Thus, two strips of light will be covered across the image, or subject to be transmitted. As the disc continues to revolve, the entire image or subject will be completely covered with dots of light. Each dot of light will produce a line of light across the scene. The total number of dots of light per second will depend entirely upon the number of holes in the disc and the speed at which it is being revolved.

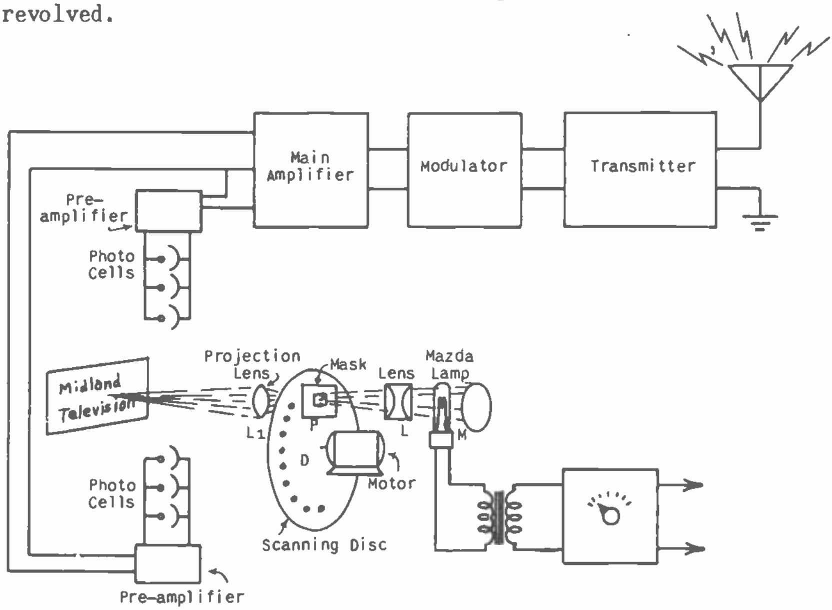


Fig.8 A schematic diagram of a complete flying spot system of scanning.

The next step in this simple system of television transmission is that as each of these dots of light fall on the subject, or scene, a certain amount of light will be reflected. This reflected light is picked up by the photocells as shown in Fig. 8. The output of these photocells is connected to a powerful amplifier so that their feeble output current will be built up sufficiently to properly modulate a radio transmitter. As these spots of light streak across the subject, they will encounter various lights and shades. In other words, the dark hair of a person would reflect very little light back to the photoelectric cells while the light skin of a person would be a good reflecting surface. A white background is practically always used behind the subject so that when a dot of light is not striking the subject, there will be a reflection from the white background. As the dots of light streak across the subject, reflecting more or less light, the output of the photoelectric cells will vary exactly in accordance with the amount of light falling on them. This variation in electrical output will cause the transmitter to be modulated just as though a sound wave were being used in the modulating system.

In this flying spot system of scanning, a means has been found for taking the scene, or subject, apart piece by piece. Through the action of the photoelectric cells, a means of recording the lights and shades of the subject has been accomplished so that its true contrast can be maintained.

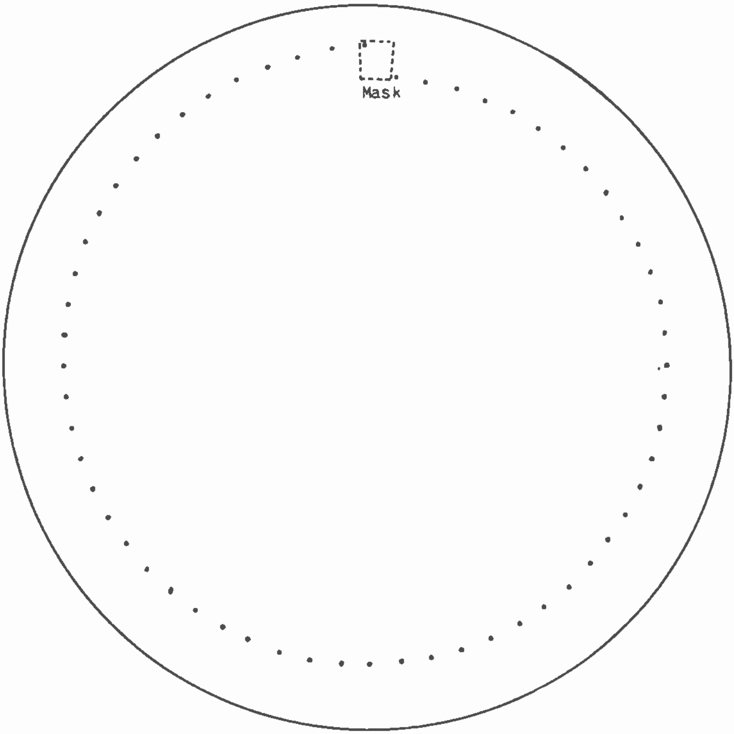


Fig.9 A diagram of a single spiral scanning disc, showing location of holes and mask.

The radio waves emitted from the transmitter are propagated into space to be picked up by the receiving antenna. The receiving antenna is connected to a special short wave receiver. This receiver contains a detector and amplifying system similar to that used in a sound receiver. In this special short wave receiver instead of putting the output of the amplifying system into a loud speaker, it is connected to a reproducing device called a "neon lamp". A composite receiving system is shown in Fig. 10. The neon lamp has the property of changing its light intensity as the amount of current flowing through it changes. The current through the lamp will change in direct relation to the modulation changes at the transmitter. Then, since the modulation of the transmitter is controlled by the output of the photoelectric cells, the output of the neon lamp will also be controlled by the output of these cells.

With the light from this lamp projected directly on a screen, there would be nothing but a large blur that would continually vary in intensity. However, by revolving another scanning disc, similar to the one used at the transmitter, in front of this lamp, and also revolving this disc at exactly the same speed as the one used at the transmitter, the picture can be reconstructed piece by piece

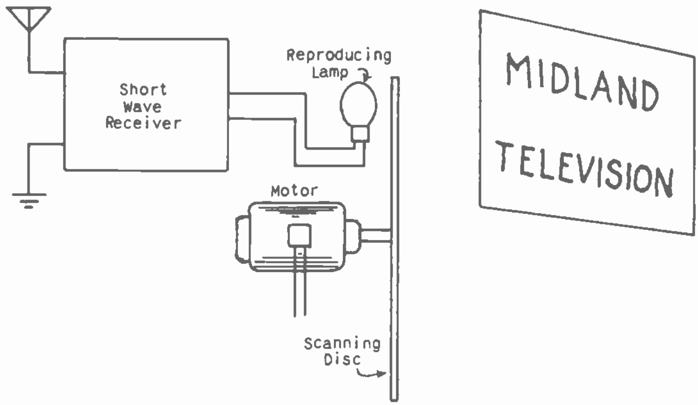


Fig.10 Composite view of a scanning disc receiving system.

exactly as it was taken apart at the transmitting station. In other words, when hole 1 of the transmitting disc is in the upper right hand corner of the scene to be transmitted; hole 1 of the receiving disc must also show a spot of light in the upper right hand corner of the receiving screen. If the particular point of the area being transmitted reflects a large amount of light to the photocells, a strong current will be sent through the transmitter, and the receiver will receive a strong impulse. This, in turn, will cause the receiving lamp to glow brightly, thus making this corresponding spot bright on the receiving screen.

As the scanning spot streaks across the image at the transmitting end, the light intensity will rise and fall, according to the lights and shades of the scene being transmitted. This, in turn, will cause the receiving lamp to rise and fall in light intensity. Therefore, the image reproduced at the receiving end will have the same lights and shades as the picture being transmitted.

Fig. 9 shows a Nipkow scanning disc. The holes in the disc are arranged in a spiral manner and are spaced uniformly around the disc. The number of lines desired in the picture to be transmitted will determine the number of holes in the disc. For example, if the picture to be transmitted is to be made up of 60 horizontal lines, there will be 60 holes in the disc. To determine the spacing required between the holes, the number of holes in the disc is divided into 360°. If there are to be 60 evenly spaced holes, then a line drawn from each hole to the center of the disc will form an angle with its adjacent hole of 360° divided by 60, or 6 degrees. This is illustrated in Fig. 11.

If, on the other hand, the picture to be transmitted was to have 240 horizontal lines, then there would be 240 evenly spaced holes, each hole forming an angle of 360° divided by 240, or 1.5 degrees with the center of the disc and the adjacent hole.

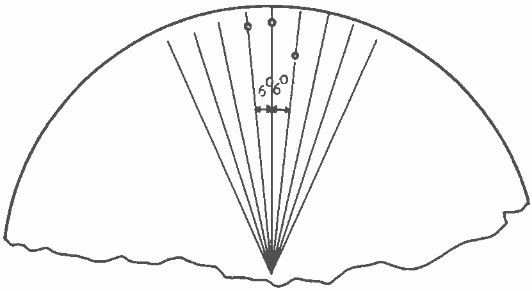


Fig.11 Diagram of a scanning disc, showing the angular separation between holes on a 60 line disc.

It takes one complete revolution of the disc to entirely cover the subject with dots of light. If full advantage is to be taken of the persistence of vision of the human eye, it is necessary that not less than 24 of these scenes be transmitted per second to create the illusion of motion. This means that the disc must revolve not less than 1440 revolutions per minute. It has been found by experimentation that less than 24 revolutions per second will produce considerable flicker. In modern television systems, 30 frames per second are being transmitted with a unique system devised to produce the same effect as though 60 frames were available. More information concerning this will be given later.

7. DIRECT PICKUP SYSTEM. In the system of scanning just discussed, it is termed "flying spot" because the light is scanned, meaning that the light is projected on the subject in narrow strips formed by the spot of light shining through the scanning disc. The next system to be considered is somewhat different, but still having the same fundamental principles. In this system the illumination is uniform and is not projected as a beam. Here the scanning disc is placed between the scene and the photoelectric cell, whereas in the system just discussed, it was between the light and the scene. A fundamental diagram of the direct pickup type of scanning is shown in Fig. 12.

Although the direct pickup system experienced very little popularity during the earlier days of television, still it was used considerably in the scanning of motion picture films. Today, all television transmission is carried on by the direct pickup method but scanning discs are not employed. The main reason for its lack of popularity as a method of studio scanning was due to the extremely small output available from the single photoelectric cell used. The amount of light necessary on the subject being scanned, to obtain sufficient output from the single photoelectric cell, was, under normal circumstances, prohibitive. With film scanning, on the other hand, a picture having a sufficient amount of light could quite easily be projected on the scanning disc.

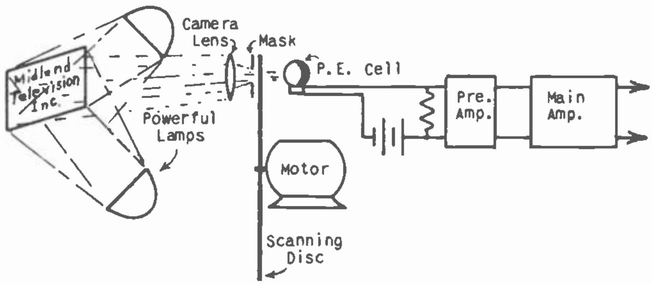


Fig.12 Schematic diagram of a direct pickup system of scanning.

In referring to Fig. 12, it will be noticed that only one photoelectric cell is being used. This is the chief cause for the small output obtainable. In this figure, you will note that a very intense light is focused on the subject being scanned. A lens is mounted on the front of the camera so that an image of the scene to be transmitted is focused on the scanning disc. This lens is easily accessible by the operator in order that he may secure a sharp focus on the image. In back of the lens is a mask which forms the edges of the picture. The scanning disc is placed directly behind this mask, then a short distance to the rear of the scanning disc is placed a photoelectric cell. The construction of the motor, the scanning disc and mask for this method of scanning is exactly the same as previously described for the other method of mechanical scanning. More information along these lines will be given a little later in this lesson.

At first thought, it might seem that with this method there would be more light and thus greater variations of light reaching the photoelectric cell than with the type of scanning previously described. This is not true, due mainly to the fact that only a small portion of the light reflected from the object being scanned reaches the photoelectric cell. In the first place, reflected light is not as strong as direct light and only one cell can be used. Secondly, the photoelectric cell is much further from the source. As you will learn in the next lesson, intensity of light varies inversely as the square of the distance. Thus, it is easy to see that the farther away a photoelectric cell is from the object being scanned, the less illumination it will receive.

In considering the first difficulty, the light has to pass through the very small holes in the scanning disc before it can reach the photoelectric cell. As a direct result of this, there will be very little difference in the amount of illumination on the photoelectric cell between a bright portion of the object being scanned and the dark portion. Naturally, then the current variations produced by the photocell will be very small in amplitude. The chief difference between the flying spot system of scanning and the direct pickup system is the fact that you now have only one photoelectric cell whereas in the flying spot system of scanning, it is possible to use several photocells, the output of which can be added together.

If it were not for the difficulties just mentioned, the direct pickup type of mechanical scanning would have had several advantages over the flying spot system of scanning, the most outstanding being that outdoor shots in bright daylight could be used as well as studio shots. It was not until the development of the "iconoscope" and the Farnsworth "image dissector" methods of scanning that enough output was available to permit this dream to come true. These systems of electronic scanning are successful because of the fact that they make use of much more of the available light.

8. MECHANICAL SCANNING CONSIDERATIONS: THE MASK. In either the direct or flying spot system of scanning, the light source is confined to a certain area on the scanning disc by means of a rectangular shield or mask. This mask has certain definite dimensions that are determined by the size of the disc and the spiral of the holes. The width of the opening in the mask is equal to the distance between two holes in the disc and the height of the mask is equal to the pitch of the spiral; that is, the difference between the radii of the outer and inner holes.

As shown in Fig. 9, when the disc is stationary, the light can shine upon the subject through only the hole that is before the opening in the mask. The width of the mask is such that just as one hole is passing out of this area, the next hole is just coming into place. Consequently, there is only one hole in the opening of the mask at any one moment. This is true no matter what the position of the disc may be. One complete revolution of the disc allows each and every hole in the spiral to pass in rotation across the mask opening. As the disc revolves, the hole travels progressively across and downward from the top of the mask until the last hole clears the bottom of the masking frame. When the first, or outermost hole is ready to begin at the top again, the action is repeated. On account of the above action, only one hole is exposed at a time with the result that successive strips are made across the subject. Thus when one complete revolution of the scanning disc has occurred, the entire subject has been completely scanned once.

There is absolutely no discontinuity of the scanning spot. That is, there is no interval between the end of one scanned strip and the beginning of the next. Each hole forms a spot instantaneously after the preceding one has passed by the mask. As a result, the subject is dissected, so to speak, into a number of parallel strips which, if placed end to end, would form a tape carrying every variation of light and shade of the subject. In reality the lines across the subject form an arc, but since they are arcs of a comparatively large circle, confined to a small area, they are, to all practical purposes, straight parallel lines.

By referring to Fig. 9 you will notice that the opening in the mask is wider at the top than at the bottom. It is necessary that the opening diverge in this manner due to the difference in circumference of the disc at the top and bottom of the picture. Just how noticeable this is will depend upon the diameter of the disc.

9. TYPES OF HOLES IN SCANNING DISCS. There are several different types of holes used in the various types of scanning discs. Each type has its particular advantages and disadvantages. Three of the more commonly used types of holes are as follows: The round, square, and radial type. A drawing of these three types is shown in Fig. 13.

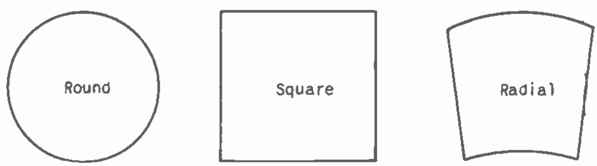


Fig.13 Diagram showing three common types of scanning disc holes.

Of these three, the most common is the round hole type. The two chief advantages of this type is its simplicity and cheapness of construction. There are also two chief disadvantages. First, the amount of light emitted is small, especially when comparing it with the square type of hole; and, secondly, the size of the holes does not conform with the frame of the picture.

The round type of hole is easiest to make, and it is the most commonly used. Accurate machinery is required in making any type of disc, but round holes require no special apparatus that cannot be found in a well equipped machine shop. Such apparatus, however, requires the finest kind of dividing index head for properly locating the holes. It can be readily seen if a hole is off from its proper position by even a fraction of an inch, it will cause some sort of distortion. Extreme care, therefore,,is necessary in locating these holes for proper operation of this part of the television system.

10. SQUARE HOLES. This type of hole cannot be drilled, but must be die-cut, or punched. The same care, however, must be used in making this type of hole as with the round hole. The chief advantage of the square hole is that it allows more light to pass through than a round hole of the same width. Let us assume, for the purpose of illustration, a round hole, one inch in diameter.

The area of the round hole is equal to πR^2. In this case, $R = \frac{1}{2}$" and our formula develops into $\pi(\frac{1}{2})^2$, or $\pi\frac{1}{4}$, or .7854 square inch, which is the area of this hole. A square hole of the same width would have an area of $1 \times 1 = 1$ square inch. Hence, the square hole has nearly 22% more area than a round hole of the same size and would be expected to pass more light. This is important since all of the light you can possibly secure through the scanning disc is needed.

11. RADIAL HOLES. Both the square and radial shaped holes are much better in respect to the first disadvantage of the round hole type; that is, both of these types will admit more light.

From the standpoint of the amount of light emitted and conforming with the frame of the picture to be transmitted, the radial hole is best. The disadvantage of the radial type of hole is the expense involved in manufacturing. Whether or not the advantages will offset the expense involved will depend mainly on the equipment used. For the remainder of the discussion on mechanical scanning discs, we are going to confine our remarks to round holes. We are following this procedure because electronic methods of scanning of a necessity employ a round spot for scanning and, inasmuch as we are primarily interested in electronic scanning, we shall confine ourselves to the use of a round scanning spot.

It might be well to remind you again that in spite of the preceding statement, a thorough understanding of mechanical methods of scanning is essential if one desires to completely understand the factors governing electronic scanning.

12. FRAME FREQUENCY. A scanning disc is so designed that with each complete revolution of the disc, the scene is scanned once. Thus, it is easy to see that the speed of the disc will determine the number of times the object will be scanned per second. For example, if the disc is turning at 900 r.p.m., the object will be scanned $900 \div 60$ (60 seconds in a minute), or 15 times per second. This is known as the "frame frequency". (The frame frequency is the number of times per second the picture area is completely scanned.)

To fix this in your mind firmly, let us take another example. If we desire to scan the object 24 times per second, it will be necessary to have a motor which will drive the disc at a speed of 24×60 or 1440 r.p.m. In other words, a disc spinning at the rate of 1440 r.p.m. would produce 24 frames per second.

13. PICTURE ELEMENTS. Since the number of parallel lines formed by the scanning spot sweeping across the field of view determines the rating of a particular scanning disc, we must next consider the number of elements produced by such an arrangement. Each line is divided into an arbitrary number of picture elements. This number of elements per line is calculated by dividing the effective diameter of the scanning aperture or hole into the arc through which the hole sweeps while scanning each line. With a square field of view, the number of picture elements is equivalent to the square of the number of lines. Therefore, a 24 line

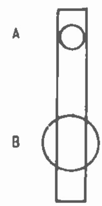
system divides the field of view into 24 × 24, or 576 picture elements; and a 45 line system divides it into 2,025 elements. In the same manner, a 100 line system would have a field of view containing 10,000 elements.

The scanning process involves one of the greatest problems in television. The field of view as seen must be scanned by the accepted method in the short time that the eye can reassemble the separate elements into complete images, if instantaneous reproduction and sustained action is to be obtained. When the number of lines is increased to satisfy acceptable detail, the number of picture elements is multiplied at a rapid rate. This, too, concerns the question of transmission, for the entire system must be able to respond to the increase of the impulses generated by the increase in picture elements. Take for example, in a 200 line system operating at 30 frames per second, 1,200,000 picture elements must be handled each second. This means 1,200,000 flashes each second on the photocell.

14. DEFINITION. Definition is the condition of distinctness or outline and precision in detail; the capability of an optical system to form distinct and sharply defined images.

Because of the wealth of detail, the extreme range of brightness and contrast found in nature, the eye tends to demand image resolution up to the limits of the eye. We have, however, become somewhat accustomed to certain compromises, due to constant association with such things as paintings, photographs and other methods of reproduction, because of the limitation of these agencies of reproduction.

Fig.14 Diagram representing scanning definition, according to size of scanning spot.



It is impossible to receive better definition than that transmitted, so the effect of the transmitter scanning system as it affects definition is extremely important. When considering the flying spot system of scanning, the dots of light created by the projected light shining through the holes in the scanning disc are enlarged by a lens system and then projected on the subject to be transmitted. The definition of the subject that is transmitted will then depend on how much of the total image area is covered by each individual scanning spot. This is best represented by a line as shown in Fig. 14. If the scanning spot is the size of A, then it will show the line, because the spot just covers the line. Or, if the scanning spot were smaller than A, the line would be transmitted. If the size of the scanning spot is that of B, then only a blur will occur where the line should be, because the spot is larger than the line and, at the time the spot crosses the line, it will be transmitting an average of that which it crosses and, in this case, the average will include more than the line itself.

Another example, shown in Fig. 15, is that of the mouth and teeth of a person. If the scanning spot is large enough, then it just covers the mouth and only a shaded space or outline will be transmitted. If the scanning spot is small so that several spots must pass over the teeth before they are completely covered, then these spots will pick up each individual tooth and, when reconstructed will appear as nearly like the original as the size of the spot permits.

Fig.15 Diagram showing detail change with changes in scanning spot size.

In a direct pickup or flying spot system of mechanical scanning, depending upon the lens system used, it is possible then in transmission to secure a change in definition when using a given sized scanning disc by increasing or decreasing the size of the field of view. When the field of view is small, the scanning spot becomes small and the definition is increased. When the field of view is large, then each scanning spot becomes larger and the definition is decreased. In a 100 line system for instance, there are 10,000 dots of light to cover the field of view. From this it can be seen that the only way to increase the definition for a given size of field of view is to divide the field into a larger number of dots and this can be done only by increasing the number of lines in the scanning system. Due to a peculiar action of the eye and the psychological effect of seeing something which does not exist, it is possible to see definition clearly which is smaller than the size of the spot.

In viewing reproductions, the observer attempts to position himself so that he is satisfied regarding information and effects he wishes to obtain. (The position of the eye for the greatest resolution is about 8 to 10 inches for the average person.) When viewing a painting, we rather unconsciously use a position where the brush strokes become unnoticeable, and where we can obtain the effect the artist wishes to convey. As explained earlier in the lesson, when looking at a newspaper picture, we hold the newspaper off at a distance. We also know what, in general, to expect from motion pictures in the theatre and home. We note further that good photographs go beyond the resolution limits of the eye and that they may even be optically enlarged.

Suppose, on the other hand, we attempted to enlarge an ordinary newspaper picture. Say we were to enlarge it five times. We would find that as we increased the size of the newspaper picture, the dots, which make up the picture, become more and more noticeable. Then in order to catch the meaning which the picture is attempting to convey, we would have to stand back farther from the picture. Upon standing back farther from the picture, the print will again approach the resolution limits of the eye, and the dots will blend together and again the picture will appear as a single unit, rather than a multiplicity of dots.

From the preceding paragraph, you can see that if the person viewing the picture is to remain standing at a given distance from the picture as we enlarge the size of the picture we have to increase the number of elements building up that picture. If we do not, the picture will appear as individual dots rather than a single unit and the detail will be lost. We also notice that there is a way to increase the permissible picture size with a given number of elements. This is for the person viewing the picture to stand back at a greater distance each time the picture is enlarged.

Fig.16 A diagram to be used in demonstrating the resolution ability of the eye.

Up to the present time, we have merely discussed general cases, giving no specific examples. In the following description, however, we will use definite values. For our first example, let us use two black parallel lines separated by a space equivalent to the width of one of the lines. This is shown in Fig. 16. Prop this lesson up on a well lighted table. Now when standing close to the figure you will notice two distinct lines; upon walking backward, away from the figure, you will notice that you come to a point where by standing still and rocking backwards, that the two lines would appear as one, but if you rock forward they would again appear as two separate lines. For the average person, this critical point is at that point where the lines are separated so that the distance between them subtends an angle to the eye of one minute.[1] At greater viewing distances, the two lines will appear as one.

Fig. 17 is a chart plotted in terms of scanning lines against viewing distances. When using the chart illustrated in Fig. 17, the following procedure should be followed: Suppose, for example, that you are standing at a distance of 4 feet from the object or screen. By referring to the chart you will notice that there should be 70 scanning lines per inch. Understand, this is scanning lines

[1] There are 60 minutes in one degree.

per inch, not total scanning lines. Taking a more practical example, suppose that we have a 240 line picture that is 12" tall. This picture would then consist of 240 ÷ 12 or 20 scanning lines per inch. Referring to the chart, we notice that it is necessary to stand at a distance of 14 feet from the screen. If the person viewing the picture were to stand closer than 14 feet, the eye would not be satisfied, since the picture structure would be pronounced, resulting in lack of detail. For greater viewing distances than 14 feet, with this number of scanning lines and this picture size, the eye will be satisfied from a standpoint of detail, but more detail is available than is required for maximum eye resolution.

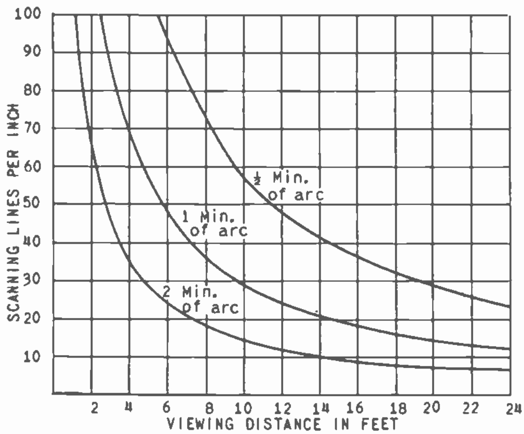


Fig.17 A graph showing the relation between viewing distance and number of scanning lines.

In other words, the person viewing the picture should stand at least 14 feet away from the screen in order that the picture have sufficient detail. If, on the other hand, the picture were reduced in size, for example, made ½ its present height and the number of elements in the picture not decreased, referring to the chart in Fig. 17, we would find that the person should stand at a distance of approximately 7 feet. This is due to the fact that we have increased the number of scanning lines per inch from 20 to 40.

In the preceding paragraphs, we have discussed the relationship between picture height and the required number of scanning lines and proper viewing distances, but we have not taken into consideration the picture size. By referring to Fig. 18 and knowing the total number of scanning lines and the desired viewing distance, we can readily calculate the picture height. This does not, however, tell us that at that viewing distance we have chosen a size of picture that will be pleasant to view. If the picture is too small, it will be unsatisfactory because too much attention will be required for viewing. If, on the other hand, the picture is too large, it will be unsatisfactory because too large a movement of eyes or head will be required for viewing. In television, because of the practical limitation in the number of possible scanning lines, we are normally confronted with too small rather than too large pictures.

In moderately large theatres, the distance from the back row of the orchestra section to the screen does not usually exceed 6 to 7 times the screen height, while the front row of seats may be as close as 2 times the screen height. Normally the choice position is approximately 4 times the screen height. In home movies (where less detail is available because of the smaller size film) the desired viewing distances cover a range from 4 to 8 times the picture height. Since, at the present time we are considering television as a medium of home entertainment, we shall use the same accepted ratio of picture height to viewing distance as for home movies; that is, from 4 to 8 times the screen height.

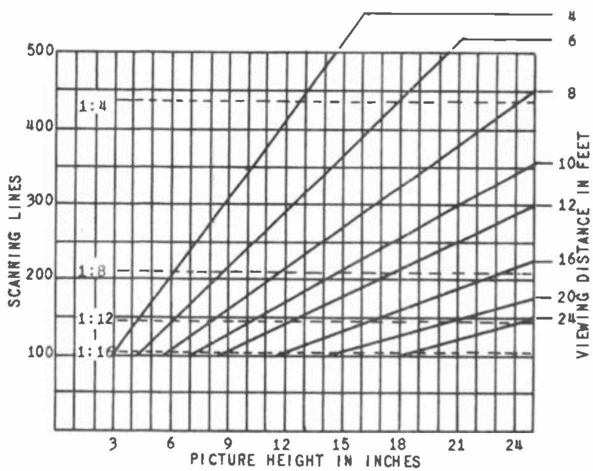


Fig.18 A graph showing several relations between picture height and number of scanning lines with changes in viewing distance.

As an example, if we were using a standard 12" cathode ray tube for the reproduction of our picture, this would give us a picture a little larger than 7" by 9". In viewing a picture of this size, the most satisfactory distance would be $7 \times 4 = 28 \div 12 = 2\frac{1}{3}$ ft. to $7 \times 8 = 56 \div 12 = 4\frac{2}{3}$ ft. In other words, the best viewing distances would be between $2\frac{1}{3}$ and $4\frac{2}{3}$ feet from the face of the tube.

Fig. 18 is a chart showing the relationship between scanning lines, picture size, viewing distance and the desired ratio of picture height to viewing distance. This chart includes all the necessary information to determine the scanning lines required if viewing distances and picture height have been decided upon. This chart may also be used to determine the picture size if a certain number of scanning lines are possible and a certain viewing distance is desired. The chart also provides a guide for the desired picture sizes for general viewing conditions. Referring to the chart in Fig. 18, notice the four dotted horizontal lines. These lines are for the purpose of showing the picture height to viewing distance ratio. When using this chart, remember that between the 1:4 and 1:8 picture height to viewing distance, the viewing conditions will be satisfactory. Below the 1:8 ratio line, viewing conditions become less satisfactory and below the 1:12 ratio line, it is generally considered unsatisfactory. Taking an example, suppose that we had a modern 441-line television picture and we wished to view this picture at a distance of four feet, the ideal height of the picture would then be 12". Notice that, at this point, for a picture of this height, we are approximately as close as we should be for satisfactory results. Using this chart in another manner, suppose we wish to view a television image at a distance of 6 feet. Starting down the 6 foot line, notice that with a 441-line picture we may have a picture height of approximately 18". Also note that the picture height to viewing distance is very satisfactory.

For the average home receiver, the following table gives comparison as to the ability of an observer to understand and follow action and story by means of television:

SCANNING LINES	PICTURE
60	Entirely Inadequate
120	Hardly Passable
180	Minimum Acceptable
240	Satisfactory
360	Excellent
480	Equivalent to Movies

Remember, this is for plays, etc. and does not refer to the ability to reproduce titles and small objects.

There is another point which should be brought out at this time; that is, motion in a picture will increase the apparent detail. There are several reasons for this, the most outstanding being that the observer's interest is now directed to the moving object or objects. The eye then does not tend to explore each small section of the picture. Under these conditions, the eye requires less detail than for a still picture. This is assuming that the detail is sufficient so that the purpose of the movement may be understood. Another reason for this peculiar condition is that objects made up of too few picture elements to recognize while stationary, may be recognizable and even realistic while in motion.

Summarizing the information contained in the preceding paragraph, we find that there are three reasons for pictures in motion having more apparent detail than still pictures. First, part of this is due to the concentration of interest around the motion. Second, experience on the part of the person, or persons, viewing the picture to associate the motion with things and the processes he understands. Third, more favorable conditions for scanning while the object is in motion.

Fig. 19 illustrates the effects of increasing the number of scanning lines in the picture. Fig. 19A illustrates an old style 90-line picture as used in 1929. Fig. 19B illustrates the improvement when the scanning lines are increased from 90 to 120. This picture was similar to the type found in experimental labs around 1931. In 1934 there was a decided improvement in elimination of visible scanning lines. The number of lines was increased from 120 to 180. Notice, however, the lack of sharpness in contrast to the picture. This is illustrated in Fig. 19C. Fig. 19D illustrates a modern 441-line picture. Notice the great improvement in the quality of the picture, both with a reduction of visible scanning lines and in detail of the picture.

Fig.19 Four photographs showing the progress in Television as the number of scanning lines were increased.

15. PICTURE RATIO.[1] By picture ratio, we mean the ratio of the width to the height of the picture being transmitted. As motion pictures use a ratio of 4:3, and inasmuch as a large portion of television broadcasting will be done with the aid of motion picture film, it is only logical to assume we should use the same ratio. As a result of this, modern electronic television has been standardized with a picture ratio of 4 to 3.

For example, if we wish to transmit a 60-line picture and have its aspect ratio the same as motion pictures, we would break the picture up into 60 × 80, or 4,800 elements. The 80 is derived from

[1] Picture ratio is often called "aspect ratio."

the fact that if the aspect ratio of the picture is 4 to 3, this means it will be four units wide and three units high, or in other words, 1⅓ times as high as it is wide. If the picture to be transmitted is 60 elements high, it will be $\frac{4}{3} \times 60$, or 80 elements wide. Let us take another example. Suppose we wish to transmit a 240-line picture with the same aspect ratio. Our picture is 240 elements high and $\frac{4}{3} \times 240$, or 320 elements wide. Therefore, each picture must be broken into 240×320, or 76,800 elements.

The Radio Manufacturers Association has recommended that this ratio be adopted as standard for the United States. The same standard is also used in England.

16. FREQUENCY REQUIREMENTS. Due to the vast improvement in picture quality with an increase in the number of scanning lines, it might at first thought seem advisable to further increase the number of lines. However, increasing the number of scanning lines results in a very serious disadvantage; that is, every time the number of scanning lines is increased, the frequency requirements of the video amplifiers are also increased.

A complete television signal will consist of all frequencies from the highest down to zero, zero being equivalent to a total dark or light spot occurring during the complete width of the subject being scanned. Such spots would form DC components or require an extremely low frequency of change. In those portions of a picture showing a variety of change, the changes in light value and, therefore, in frequency would be at a maximum. Every picture or object has an equivalent in frequency changes, depending upon its complications or completeness.

Fig.20 A chart showing how the maximum frequency can be generated by a scanning spot.

The preceding may best be illustrated by reference to the scanning pattern illustrated in Fig. 20. By referring to this figure, you will note that this scanning pattern consists of a series of alternate black and white vertical bars. The maximum possible frequency will be generated by the scanning device, provided the width of each bar is equal to the diameter of the scanning spot. This frequency may be very conveniently calculated by the following formula: $F = \frac{1}{2}A^2RN$,

Where: F is the maximum frequency in cycles,
A is the number of scanning lines,
R is the aspect ratio of the picture,
N is the frame repetition frequency.

The reason for dividing by 2 is that a complete cycle consists of one black and one white impulse. Therefore, one cycle is two impulses.

As stated previously in this lesson, normally, an aspect ratio of 4 to 3 is used, this being the same as that of motion pictures. In the following examples, we will use this aspect ratio. Now, in order to show the tremendous increase in frequency as we increase the number of scanning lines, we shall first figure out the maximum frequency generated when using an old style 120-line picture with a frame repetition frequency of 24 per second. Substituting these values in the equation, the equation now reads:

$$F = \tfrac{1}{2} \times 120^2 \times \frac{4}{3} \times 24$$

$$= \frac{14,400}{2} \times 32$$

$$= 7,200 \times 32$$

$$= 230,400 \text{ cps.}$$

From the foregoing example, it is seen that to properly amplify and transmit all the frequencies generated by a scanning device when utilizing a 120-line system with an aspect ratio of 4 to 3 and a frame repetition frequency of 24 per second, it will be necessary to amplify all frequencies between zero and 230,400 cps.[1]

Now let us double the number of scanning lines, leaving the repetition frequency and aspect ratio the same. Substituting these new values in our equation, it now reads:

$$F = \tfrac{1}{2} \times 240^2 \times \frac{4}{3} \times 24$$

$$= \frac{57,600}{2} \times 32$$

$$= 28,800 \times 32$$

$$= 921,600 \text{ cps.}$$

From these examples, it will be noted that by doubling the number of scanning lines; that is, increasing the number of lines from 120 to 240, we have increased the frequency requirements of the video amplifier from 230,400 cps. to 921,600 cps., or four times.

Inasmuch as the balance of our studies in television will deal mainly with systems employing electronic scanning, let us calculate the maximum frequency generated by these scanning devices. Electronic television utilizes 441 lines with a frame repetition frequency of 30 and a field frequency of 60. The field frequency of 60 is obtained by using interlaced scanning. More information concerning interlaced scanning will be included later in this lesson.

[1] As you will learn in a later lesson, in order to properly amplify the background, DC has to be transmitted as well as AC.

Substituting these values in this formula, it now reads:

$$F = \tfrac{1}{2} \times 441^2 \times \frac{4}{3} \times 30$$

$$= \frac{194,481}{2} \times 40$$

$$= 194,481 \times 20$$

$$= 3,889,620 \text{ cps.}$$

Understand, frequencies ranging from 0 to this frequency (approximately 3.9 megacycles) must be equally amplified just as if they were audio frequencies and made to modulate the carrier wave of the transmitting station. This is, of course, providing we intend to transmit all of the frequencies generated by the scanning device.

The reason that the words "video frequencies" are used is that a television scanning system which generates a range of frequencies from 0 to 3.9 megacycles is generating both audio and radio frequency signals. However, the word "video", meaning picture signals, includes both the audio frequency and radio frequency band generated by such a system.

From your earlier lessons, you learned that when the carrier wave of a transmitting station was modulated with an audio note, there would be two frequencies produced other than the actual carrier wave, one equal in frequency to the carrier wave, plus the frequency of the audio note; the other equal in frequency to the carrier wave minus the frequency of the audio note. These frequencies are called sideband frequencies. Now, referring to the last example just given, notice that if we are going to transmit all of the frequencies generated by the scanning system, when transmitting a modern 441-line picture, it will require a band width of 2 × 3,889,620 cycles, or 7,779,240 cycles. It is for this reason that it is deemed advisable not to increase the number of scanning lines to any greater extent than it is thought necessary to satisfy the demands of the resolution ability of the eye under average circumstances.

17. SCANNING SPEEDS. It must be kept in mind that the scanning speed does not have anything to do with the transmission of definition. As long as the scanning speed is sufficiently rapid to convey the idea of motion, the speed may be very slow. If still pictures, or diagrams only were to be transmitted, it would not be necessary to have a scanning speed of over six frames per second; but as the motion to be conveyed is increased in speed, then the scanning speed will have to be increased to take care of the resulting motion. The effect of smooth motion can be obtained only by sufficiently rapid scanning speeds.

It has been determined that not less than 15 frames per second when using interlaced scanning, and preferably not less than 30 reproductions of the field of view in the case of single spiral transmission can be used satisfactorily. The number of frames transmitted per second is one of the factors determining the amount of flicker in the reproduced image. The more frames per second, the less the flicker. Another factor involved in considering flicker is the intensity of illumination at the receiver. The greater the illumination, the greater the flicker for a given number of frames per second. This is a result of the persistence of vision of the human eye.

As the scanning speed is increased, the frequency response demand on the equipment is also very much increased without adding materially to the definition of the image, so it is quite desirable to keep the scanning speed as low as possible. However, if the scanning speed is too slow, flicker will result and the portrayal of motion cannot be accomplished.

13. MULTIPLE SPIRAL (INTERLACED) SCANNING. As the development of television advanced, the necessity of a higher quality picture became very apparent. The first pictures were very poor, both in quality and in flicker. As motion pictures and television are quite closely associated, let us turn for a minute to a brief review of the development of motion pictures. When motion pictures were in the earlier stages of their development, they, too, were of very poor quality and suffered from the effect known as flickering. As has been explained, due to the persistence of vision of the eye, if pictures are flashed rapidly enough on the screen the person viewing the picture will perceive it as a single picture rather than a series of pictures.

First, if these pictures were flashed on the screen at a very slow rate, say one a second, a person viewing the picture would be able to see each individual picture. Then if the pictures were flashed a little bit faster, he would begin to perceive them as one instead of several separate units. However, there would be a very annoying flash (or flickering) due to the slow speed at which the pictures are being projected on the screen. If, however, these pictures were flashed on the screen at a much faster rate, take for example, 24 per second, the person viewing the picture would notice very little flicker.

However, as motion pictures continued to develop, the demand for better quality pictures arose. It was found that if 48 of these pictures were flashed on the screen per second, there would be no flicker noticeable to a person viewing the picture. Even with this decision, there was a very decided disadvantage in projecting this number of pictures on the screen per second. This disadvantage was due to the fact that each picture takes a certain amount of space on the film. Thus, if twice the number of pictures were flashed on the screen per second, twice the amount of film would be used up per second, which would naturally increase the cost tremendously. This disadvantage led to the development of the present system of projecting motion pictures.

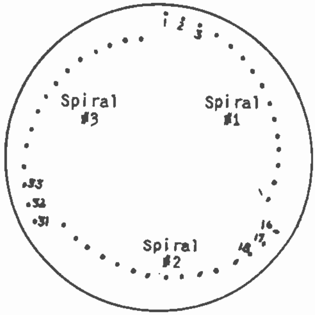
At the present time, in order to reduce flicker and still use a minimum amount of film, the pictures are run through the projecting machine at a rate of 24 per second. However, to reduce flicker, each picture is flashed on the screen twice. As a result of this operation, we have the same amount of flicker as if 48 pictures were being flashed on the screen per second.

Television engineers were confronted with a similar problem; that is, it was found necessary to increase the number of frames per second in order to decrease the flicker to a permissible amount. The first television pictures used a frame frequency of around 12 to 15 frames per second. Not only was the picture annoying due to the flicker but moving objects could not be properly reproduced. As a result, the frame speed was increased to 24 frames per second. At this speed, the flicker was not very objectionable; however, it was still noticeable.

With the coming of high definition television, it was found that no longer was such a slow frame frequency permissible. On the other hand, as you have already learned, each increase in the frame frequency brought a tremendous increase in the frequency requirements in the television video amplifiers. As it is necessary to keep this frequency as low as possible, we naturally do not want to increase the number of frames per second to any higher value than is absolutely necessary. As motion picture engineers have found the answer to their problems without increasing the speed of the film through the projector, television engineers found an answer to their problems along similar lines. The answer to this problem was found with the invention of multiple-spiral, or interlaced scanning. Electronic methods of scanning employ what is termed "interlaced scanning". The path followed by the spot is the same as that followed by two spiral, mechanical scanning discs.

The multiple spiral disc was invented by U. A. Sanabria during the period 1926-1928. On a three spiral scanning disc, the holes are evenly spaced around the disc, the same as with the common single spiral disc. However, they are arranged in three spirals, rather than one. If this disc were inserted in place of the single spiral disc in Fig. 9, its operation would be as follows. Hole 1 would scan across the top of the object. Then, hole 2 would scan across the object in the third space below hole 1. In other words, it would leave two spaces between the two lines; each the width of one spot. Next, hole 3 would scan in the third space below hole 2, leaving a space the width of two lines. This continues until the scanning disc has rotated one-third of a turn. At this time, each hole in spiral 1 would have scanned the picture frame, each leaving a space whose height was the same as twice the diameter of the scanning spot. A drawing of a three spiral disc and the manner in which it scans a frame is illustrated in Fig. 21. Now, as the disc rotates through the next one-third of its revolution, we find that hole 16 now fills in the space next to the area scanned by hole 1. Hole 17 fills in the space next to the area scanned by hole 2 and so on until this second spiral has again scanned the picture frame. With the next third of the revolution of the scanning disc, hole 31 fills in the position left between the area scanned by holes 2 and 16. Then, hole 32 fills in the area left between that scanned by holes 3 and 18. In this way, the entire picture is lighted up three times more often than in the single spiral method. This creates an optical illusion of greater light and more detail.

This has practically the same effect in reducing flicker in television pictures as is obtained in motion pictures by flashing each picture on the screen twice. Yet, notice that if the speed of the disc remains the same, we have increased neither the number of lines nor the number of frames per second. Due to this, we have eliminated the necessity of doubling the frequency requirements of the video amplifier. When interlaced scanning is used, if two interlaces are used, the field frequency will be twice the frame frequency. If three interlaces are used, the field frequency will be three times the frame frequency. The frame frequency is the number of complete pictures per second, while the field frequency is the number of times the picture is partially scanned. For example, if we were transmitting a picture of 30 frames per second, employing interlaced scanning, we would have a field frequency of 60 per second.



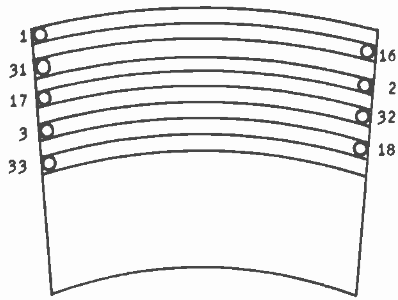


Fig.21 Two diagrams showing the construction of a three spiral disc, and the sequence in which the frame is scanned.

When mechanical scanning systems were employed, it was quite common practice to use three spirals, instead of two. This had the advantage of reducing the flicker to a marked degree, at the same time not increasing the frequency requirements of the video amplifiers. However, modern electronic television systems merely employ the equivalent of a two spiral scanning disc, called interlaced scanning. They do not attempt to interlace three times because of the complications existing with such circuits.

19. NECESSITY OF SYNCHRONIZATION. Throughout all of our discussion of mechanical television systems, we have failed to mention one very important factor which must be given consideration in any television system. In electronic television systems, the problem of synchronization has been adequately solved, but still, the study of such a subject is of sufficient importance that an entire lesson will be devoted to it. Nevertheless, in this lesson we feel as though some information should be included concerning the synchronizing problems involved with the older mechanical systems of scanning.

Synchronization is for the purpose of keeping in step (synchronizing) the scanning equipment at the transmitting and receiv-

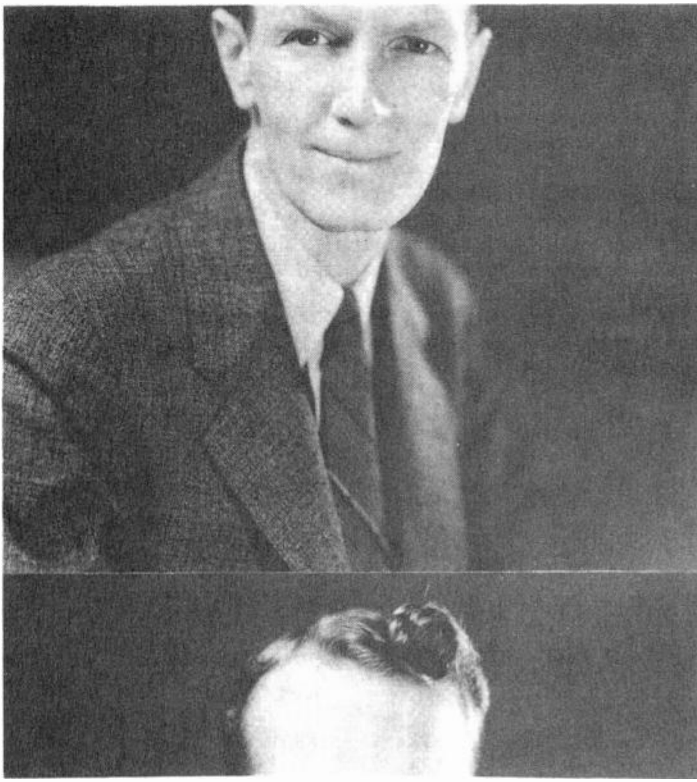


Fig.22 A photograph showing the results secured when two scanning discs are revolving at the same speed but not starting at the same time. This is known as out of frame.

ing end. In other words, for the picture to be properly reproduced, it is necessary that hole 1, or rather a spot having an equivalent position, be sweeping across the image at the receiver at the same time that hole 1 of the scanning disc is causing a spot of light to travel across the object being scanned at the transmitting station. It is also necessary that this spot start across the face of the received and transmitted images at the same time. If the above conditions do not exist, the image formed at the receiver will not be a true reproduction of the object being scanned. Fig. 22 shows a picture of a television image as it might be seen if the receiver scanning circuit were sweeping the spot across and up and down the screen at the correct rate of speed, but not starting at the proper time. Notice that while the spot is moving across at the receiving end to form line 1, the spot sweeping across the object being scanned at the transmitting station is not sweeping across the top of the object, but rather nearer the center. As a result, the top portion of the image is at the bottom, rather than at the top where it should be.

Bad as this condition is, this is not the main difficulty, as it is a matter of small consequence to reset the circuits so they will start at the proper time. The greater difficulty lies in the fact that even though the receiver may be adjusted to start at the proper time, without some synchronizing device, it is practically impossible for the two to keep in step. Thus, we will find that the picture will have a tendency to drift. Naturally, this must be prevented if reception of the picture is to be satisfactory. Here is the real need of synchronization.

In the old-style mechanical receivers employing scanning discs for reproduction of the picture, it was only necessary to set the disc so that the picture was properly framed. Then, keep the discs in step with each other; that is, be sure they spin at the same rate of speed.

The accomplishment of this synchronization, however, using motors at both the receiving and transmitting end was not always as simple as it might seem. This was due mainly to the small tolerance permitted. For example, if we were transmitting a 240-line picture at the rate of 24 frames per second, the scanning disc would be turning at a speed of 1440 rpm. Now, if the scanning disc at the receiver was turning even 1% faster, it would be turning at a rate of 1454 rpm. As a result, while the scanning disc at the transmitter was completing one frame, the scanning disc at the receiver would have completed 1.0097 frames. As there are 240 lines in each frame, we would find that while the transmitter was completing one frame, the receiver would be completing one frame plus 2.228 lines of the next frame. Naturally, this much difference in the picture would not be permissible.

From the foregoing example, you can see that one must be very careful to keep the receiving and transmitting discs revolving at the same speed once the picture has been properly framed.

In the earlier days of television transmission, there were several mechanical schemes advanced for the maintaining of synchronization between transmitting and receiving discs. None of these proved really successful and so proper synchronization was finally solved by electrical methods.

One of the simplest and most effective methods was the use of a synchronous motor. The speed of this type of motor is determined primarily by the frequency of the AC power supply. Motors used in electric clocks work on the same principle. Whenever both the receiver and transmitter obtain their power from the same supply source, this method was entirely satisfactory. However, due to variations in the frequency of the generators in different power supply systems, this system was not satisfactory if the receiver was operated on power supplied by some system other than that supplying the transmitter. This, of course, brought forth a demand for a method of synchronization which would operate independently of the line supply.

There was developed in the earlier days of television, an electrical system of synchronization involving the use of a phonic wheel. This is a particular type of synchronous motor, operated from an amplified power supply which received its original energy from a transmitted synchronizing signal from the transmitting station.

While phonic wheels did not prove very satisfactory in the earlier days of transmission, still, there has been considerable improvement in such devices and they are now being used in England where mechanical systems for receiving are still in use. Since one of the lessons in your course will be devoted to the study of the reproduction of large pictures and since large pictures are reproduced by mechanical scanning means, we will reserve a description of this type of synchronization to be included with that material.

EXAMINATION QUESTIONS

INSTRUCTIONS. Before starting to answer these examination questions, you should have studied the lesson material at least three times. Be sure that you understand each question--then proceed to write the best answer you can. Make all answers complete and in detail. Print your name, address, and file number on each page and be neat in your work. Your paper must be easily legible; otherwise, it will be returned ungraded. Finish this examination before starting your study of the next lesson. However, send in at least three examinations at a time.

1. Explain in your own words why it is necessary in Television to have a system of scanning.

2. Explain how a picture is transmitted using the flying spot method of scanning.

3. What is the difference between the direct pickup system and the flying spot system of scanning?

4. What is the chief advantage of a square hole over a round one in a scanning disc? What is the chief disadvantage?

5. If you drew a line from two adjacent scanning holes to the center of a scanning disc, what would be the angle subtended if the scanning disc were designed for 90-line transmission?

6. What is meant by line elements? What will be the number of elements per line on a 100-line picture having an aspect ratio of 4 to 3?

7. What is the maximum video frequency generated by a scanning system using 300 lines at 30 frames, interlaced, and with an aspect ratio of 4 to 3?

8. What is meant by frame and field frequency? If a scanning disc motor, driving a 3 spiral disc, runs at a speed of 1200 r.p.m., what are the frame and field frequencies?

9. What are the advantages of interlaced or multiple spiral scanning? Explain how it works.

10. Why is it necessary to have a system of synchronization?

Notes

(These extra pages are provided for your use in taking special notes)

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UNIT NO. 5

LIGHT OPTICS

LESSON NO. 3

FORTUNES

.....their foundation was 'strength'.

One of the outstanding factors in the development of our great country was, and still is, the opportunity it offers poor but ambitious men to become successful in science, industry, and business in general. History offers conclusive proof that many of our wealthiest men landed upon our shores with almost empty pockets. But even though these men started life without money, they were not poor for they had strengtn.....not brawn.....but 'strength of mind' and ambition.

Any man who is the fortunate possessor of those two vital factors is far richer than the idle spendthrift who makes no effort to replace his dwindling fortune. Just what is 'strength of mind'? *It is the power of man to direct his mind so that it will control his body.* When the going gets tough----when the body becomes tired-----or wnen discouragement arises before you.....then comes the time when your 'strength of mind' should exert it's full power and drive you on and on.

Your mind may be compared to the rudder of a ship. The rudder can either bring the ship safely to dock or may direct that same ship to rocky reefs and disaster. Your mind, Mr. Student is at the wheel that will steer your ship of life. As to where it will take you depends entirely upon yourself. If you have any reason to doubt the reality of these words, look around you a bit at the human shipwrecks that can be found in almost any city or town.....sad eyed men without homes, friends or ambition......men drifting through life with no objective.

The fact that you have progressed through your training to this point, is an excellent indication that you have *"strength of mind" and ambition.* You are directing your ship of life away from the rocky reefs and into the port of prosperity where all the good things of life await you.

Lesson Three

LIGHT
OPTICS

"Light carries the picture from the televised scene to the television camera. Light carries the received picture produced on the end of the cathode ray tube to our eyes. Light is the agency which activates the sense of sight. There can be no seeing without light.

"Therefore, the television engineer must have a good working knowledge of light. He must be familiar with the laws that light obeys. He must understand the operation of simple optical instruments, such as the camera and the projection machine".

1. COMMONLY KNOWN PROPERTIES OF LIGHT. If you ask the ordinary individual to explain his conception of light, he will tell you that he requires light in order to see things. If you should ask him to prove his statement, he would probably take you into a room in which there was no light. He would then ask you to tell him what you could see. Naturally, you would reply that you couldn't see anything. Then he would illuminate the room, either by providing a source of light in the room or by permitting outside light to enter the room. Again, he would ask you the question, "What can you see?" This time you would name the articles of furniture and other objects that were in the room. This demonstration would prove to you very conclusively that we need light in order to see.

We all know our eyes are the agencies by which the story that light tells us is conveyed to the brain. Therefore, the television engineer must have an accurate and comprehensive knowledge of light. Most of us, through our everyday observations, know many of the properties of light. Light travels in straight lines. We know this, because we cannot see behind objects. We cannot see over the horizon. When at the seashore or on board ship, the upper part of an approaching ship is visible first, as the light rays travel in straight lines and do not follow the earth's curvature. The shadows formed by sunlight, incandescent lamps, and other forms of illumination have sharp, distinct boundaries. There is an abrupt change from full illumination to no illumination. This can be true only under the condition that light travels in a straight line. The reader, from his own observations, can give many additional proofs of the fact that light travels in a straight line.

We have already stated that we must have light present in order to see things and when there is no illumination, we cannot see them. It is evident then that most objects in themselves do not produce light. We say then we see them by *reflected* light. We say that the light rays[1] flow from the source of light to the object and are reflected from the object to our eyes. The fact that we are able now to see the object means that there has been some change made to the light rays from the source of illumination. We shall a little later study the laws covering reflection and learn what happens to light during reflection from objects.

There are two types of reflection, direct and diffused. Reflection from a mirror is an example of direct reflection. The mirror changes the paths of the rays of light in such a way that we are able to see in the mirror ourselves and many other objects depending on our position with respect to the mirror. The mirror has not changed the nature of light, but only the direction of its path. The mirror is invisible. The reflection of light from surfaces that makes them visible is termed "diffused reflection". Many smooth surfaces such as windows, quiet rivers, and polished metal produce direct reflection.

Although light rays travel in straight lines, we already know that their path can be changed through reflection. There is another way in which the path of a light ray may be changed; that is, by the phenomenon knows as *refraction*. By refraction we mean the bending of a light ray as it passes from one substance into another of different density. For example, a stick partially submerged in water appears bent at the point where the stick enters the water. (See Fig. 1.) This apparent bending of the stick is due to the fact

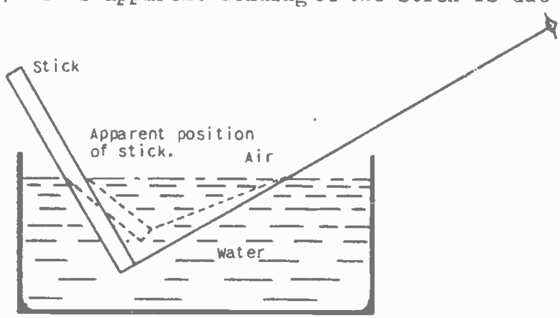


Fig. 1 Refraction of light by water.

that the light rays reflected from the stick in the water are bent upon leaving the surface of the water while the rays from the stick above the water reach the eye direct. Another example of refraction is the flattened appearance of the sun and moon when near the horizon. The reason for this phenomenon is that the density of the air changes as the distance from the surface of the earth increases. The light is bent as it passes through the changing density of the

[1] "Ray" is the term applied to a small pencil of light.

air. The twinkling of stars is caused by refraction of starlight in the air. The air density is constantly changing and therefore the path of the light is changing continually, thus creating the effect of twinkling. Later we shall study the process of refraction, and the laws controlling refraction.

Another property we associate with light is that of color. We know that when white light shines upon an object, the object does not appear white, but some other color, while in the dark, objects do not have any color. They then exhibit the properties of color only when illuminated by light. Therefore, the color must be due to the light or to some effect that the illuminated object has upon the light.

When we illuminate a room with colored light, the effect is very striking. Many objects which were visible when the illumination consisted of white light are now no longer visible. Many other objects which had a distinct color now appear black. The illuminated objects take on the color of the source of illumination.

The motion picture industry, commercial photography, and amateur photography are all dependent upon a very distinctive property of light. The word "photography" means "light writing". Some substances when exposed to light, are changed chemically. Such substances are called "photo-sensitive". In a simple camera, an image of the object being photographed is projected upon a photo-sensitive surface or film for a short interval. The light causes a change in the photo-sensitive surface. The magnitude of the change depends upon the magnitude or intensity of the light incident upon that area. In processes known as developing and fixing, the light changes are converted into an actual picture.

Light is also known as a form of energy; energy is the ability to do work. The energy in coal, petroleum, waterfalls, and winds all originally came from the energy in sunlight.

Light has another very interesting property; that is, its ability to pass through different substances. Light passes through some substances easily; others with considerable difficulty, and again, it will not pass through some at all. The terms used to define such substances are: transparent, translucent, and opaque. Transparent substances are those through which light will pass very easily and through which we are able to see objects on the other side. Window glass is an example. Translucent substances will transmit light readily, but we cannot see objects on the other side. Frosted glass is such an example. Opaque substances are those which will neither pass light, nor can be seen through. You can readily list many opaque substances.

The foregoing is a brief summary of the facts and properties concerning light with which most of us are acquainted. In the following section, we will discuss the laws governing these different properties of light and how to make use of them in building equipment for television. The television engineer will be called upon to handle optical equipment such as television cameras, projectors, and receivers. He will also be called upon to build the necessary equipment for transmission and reception. The quality of the transmitted picture at the transmitter and also at the receiver depends upon the care taken in the design of the lens systems and the way the lens systems are used.

2. NATURE OF LIGHT. Before discussing the laws affecting light, we must know something about the nature of light. In other words, we must know what light is. Back in Sir Isaac Newton's day, it was believed that light was a stream of very fine particles. It was believed that incandescent bodies and other generators of light ejected these particles in all directions. The reflection of light can be explained quite satisfactorily by this particle, or corpuscular theory of the nature of light. The law of reflection, which we will study, holds true for a stream of particles. A stream of light particles can be reflected from a surface as a stream of water can be deflected by a wall. The linearity of light motion would also be true by the corpuscular theory, but when we consider refraction and other light phenomena, such as interference or polarization, the corpuscular theory of light falls down. From experiments, we also know that any part of a light wave travels at the same speed as any other part. With an actual stream of particles, this would not necessarily be true. Some particles could travel faster than other particles. Therefore, the corpuscular theory of light is not altogether a satisfactory one.

Today, scientists accept the theory that light radiation is a form of wave motion; in fact, light is the same type of wave motion as the radio wave, an electromagnetic wave. Light frequencies are very, very much higher than radio frequencies. We define a light wave just as we do a radio wave as a transverse wave; that is, a wave in which the vibration of the medium is at right angles to the direction of propagation of the wave. In the case of light, as in radio, we call ether the medium. We can represent a light wave just as we do a radio wave, by means of an ordinary sine curve. We stated that the corpuscular theory fell down in that it did not explain such phenomena as refraction, interference and polarization. However, the wave theory of light does account for these phenomena completely. The discussion of refraction in terms of the corpuscular theory and the wave theory is beyond the scope of this lesson. Polarization we shall describe in detail in a later lesson.

Interference is a phenomenon with which you are already acquainted. In the case of radio waves, it is called "fading". You will recall that fading occurs when two radio waves reach a certain place 180° out of phase. In that case, the two waves cancel each other and there is no voltage at that point. If the two waves arrive at a given point in phase, then the signal strength is twice the value of one wave or is equal to the sum of the peak values of the two waves. In the case of fading, one wave traveled to the listening point direct from the radiating antenna; the other wave reached the listening point by reflection from the outer atmosphere. This process of fading in the case of light, we call interference. When two light waves arrive at a point 180° out of phase, they cancel and we have darkness. Fig. 2 shows in the case of radio the process of fading and in the case of light the process of interference. The interference, or fading in light waves is not usually noticeable to the average observer without special equipment. In your high school physics course, your instructor may have demonstrated to you the Newton Ring experiment. This experiment is the illustration of the interference of light. The fact that every part of a light wave travels at the same speed as every other part is to be expected when considering the wave theory. We know that all parts of the radiation pattern of a broadcast station travels at

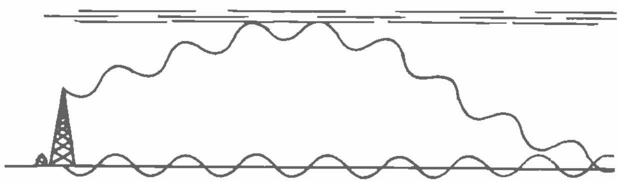


Fig. 2 Interference of two waves.

the same speed as every other part. In fact, the speed that light travels is the same as that at which radio waves travel; namely, 186,000 miles per second. From now on, in our discussion of light, we will think of light as a wave motion. Light, then, has frequency or wavelength. We can use the sine curve as the representation of a light wave. We can also speak of the phase of light waves. The equation frequency times wavelength is equal to velocity which was learned for radio waves is also true for light waves.

The wave theory of light has been modified somewhat by modern physicists. The theory as it stands does not account for, or explain, the energy relationship between electrons and light. In the study of photo-electricity, we will take this point up. The name applied to the present conception of light is called the "Quantum theory". The Quantum theory requires a slight modification of the wave theory of light, but as far as we are concerned in our study of light and television, we shall consider the wave theory as an accurate and true representation of the nature of light. From now on, we shall consider light, as are radio waves, an electromagnetic wave motion. The frequency of light waves is very, very much higher than that of radio waves. Therefore, the wavelength will be very much shorter.

3. VISIBLE SPECTRUM. It has already been stated that light forms a part of the electromagnetic spectrum of which radio waves also constitute a part. The range of frequencies which we call light or the range of frequencies to which our eyes are sensitive, we call the visible spectrum. Fig. 3 is a representation of the entire electromagnetic wave spectrum. It may be easily seen that the frequencies of radio and light take up but a small section of the entire range of frequencies covered by the electromagnetic form of waves. The visible spectrum covers a range of from 375,000,000,000,000 cycles to 750,000,000,000,000 cycles. Thus we see the visible

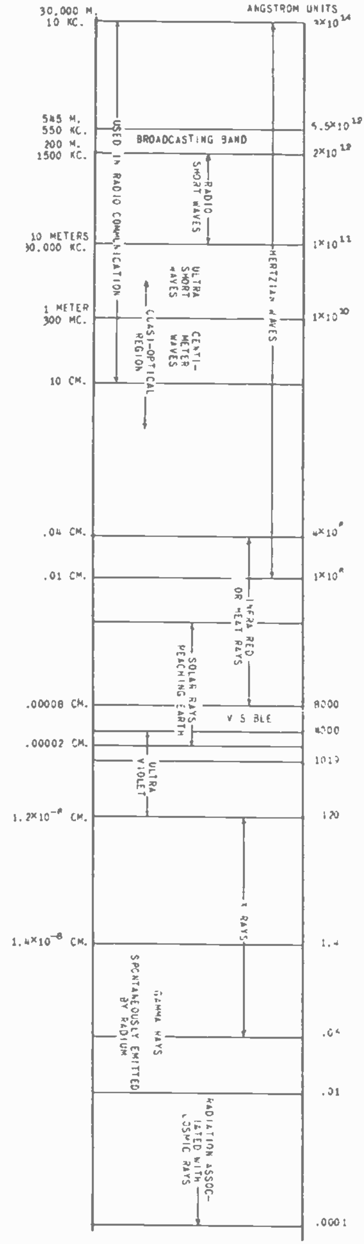


Fig.3 Electromagnetic wave spectrum.

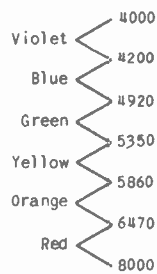
spectrum occupies only one octave[1] in the electromagnetic spectrum. If we make use of the relationship that the velocity of light is equal to the frequency times wavelength, we can calculate the wavelength of the limits of the visible spectrum. From this calculation, we will use as the velocity of light 30,000,000,000 centimeters per second. This is the approximate equivalent of 186,000 miles per second. The shortest wavelength then to which the eye is sensitive is .00004 centimeter and the longest wavelength is .00008 centimeter. You see then, that the frequencies of the visible spectrum are very much higher than those in the radio spectrum while, correspondingly, the wavelengths are very much shorter. In radio, we measure our wavelength in meters and in tens and hundreds of meters; with light, we measure our wavelength in very small fractions of a centimeter. For convenience, we use another unit to measure the wavelength of light. It is called the *angstrom*. One angstrom is equivalent to .00000001 of a centimeter; that is, one centimeter contains 100,000,000 angstrom units. Then, .00004 centimeter is equivalent to 4,000 angstrom units and .00008 centimeter is equal to 8,000 angstrom units. Thus we say the visible spectrum covers a wavelength range of from 4,000 to 8,000 angstrom units. For longer wavelengths or lower frequencies, another unit called the millimicron is used. One millimicron is equal to 10 angstrom units. Another unit which is sometimes used for wavelength measurements is the micron. One micron is equal to .0001 centimeter. Thus, a wavelength of 4,000 angstrom units corresponds to 400 millimi-

[1] An octave is a range of frequencies in which the highest is twice the lowest.

crons or .4 micron. When discussing light, or the visible spectrum, we shall use the angstrom as the unit of measurement of the wavelength rather than using frequency in cycles per second. The frequency magnitudes are large and difficult to handle. The part of the electromagnetic spectrum which we call light or the visible spectrum ranges from 4,000 angstroms to 8,000 angstroms.

In what way is the eye able to distinguish one frequency from another? The eye interprets the different frequencies of the visible spectrum as differences in color. Similarly, in sound, the ear distinguishes differences in frequency as different pitches. The color that the eye associates with light that has a wavelength of 8,000 angstrom units is red. The color that the eye associates with light having a wavelength of 4,000 angstrom units is violet. As the wavelength lengthens from 4,000 angstrom units to 8,000 angstrom units, the eye sees the following colors: violet, blue, green, yellow, orange, and red. There is no sharp change from one color to the next; it is a gradual change or merging. This is true because the visible spectrum covers a continuous range of frequencies between the two limits. Fig. 4 shows the colors and their corresponding wavelengths for the boundaries of the band.

Fig. 4 Wavelengths of colors of the visible spectrum



You are probably wondering where white occurs or what wavelength white has in the visible spectrum. There is no such thing as white in terms of wavelength or frequency. White is the sensation the eye receives when all the colors of the spectrum are merged together.

To prove this, it is necessary to separate white light into all the frequencies covered by the visible spectrum. To do this, we will pass a ray of white light through a glass prism. A prism will change the path of the light rays, but changes some frequencies more than others.. The amount of bending is proportional to the frequency or inversely proportional to wavelength. The shortest wavelength or the violet end of the spectrum is bent the most. Fig. 5 shows what happens to a beam of white light when it is passed through a glass prism. Thus, we can see that white light does not exist, but can be considered as being made up of all the frequencies or wavelengths occurring in the visible spectrum. This process of separating white light into its component frequencies is called *dispersion*. A rainbow is a case of dispersion produced by nature.

A rainbow occurs when the sun is shining during rainfall. The little drops of water in the rain act as prisms and disperse the sunlight into all its component frequencies or wavelengths.

Likewise, in the visible spectrum, there is no wavelength to which is attached the name "black". The eye receives the sensation of black when there is no light being reflected to it from the object. Therefore, black and white, as true colors, do not exist. Black means that no color is being received by the eye, while white means that all colors in the visible spectrum are being sent to the eye.

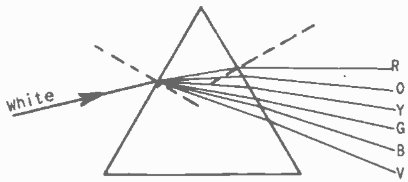


Fig.5 Dispersion of white light by a prism.

4. COLOR. Now we are ready to state why objects appear to have a color when exposed to white light. We call an object "red" when it reflects red light to our eyes and absorbs all the other colors in the spectrum. Similarly, we call an object "green" when it absorbs all colors in the spectrum except green and reflects the green back to our eyes. Therefore, the color of an object is the color of the light which it reflects. The color of transparent or translucent substances is the color of the light they will transmit. Thus, a piece of red glass will let red light pass through it, but absorbs all other colors. Thus, the color that the eye associates with an object is the color that the object will reflect or transmit to the eye. We have been discussing the color of objects when illuminated by white light. White light, remember, contains all of the frequencies present in the visible spectrum. Suppose we shine a red light on the colored comic section of a newspaper. As stated before, the color of an object is the color of the light which it will reflect, all other colors being absorbed. The white section of the paper will reflect all of the colors. The red parts of the pictures and the white would reflect the red light equally well and we would be unable to distinguish the red section from the white. All other colored sections of the picture such as the blue, green, etc., will absorb the red light and appear black. If we now illuminate the paper with green light, all parts of the picture which were green will disappear. The red and all the other colors will show up as black.

The color of transparent objects is the color of the light that they transmit. If we view a green object through a red glass, the object appears black because the red glass is unable to transmit green light. If we view a colored picture on a white background through a piece of green glass, all of the green parts of the picture will disappear by merging with the white background. All of the other colors in the picture appear black. The effectiveness of stage illumiuation depends upon these properties of color.

We have stated before that the sensation of white is the effect produced when all of the colors of the visible spectrum are present. However, it is not necessary to have all of the colors of the spectrum to produce a white sensation. For example, if we have blue and yellow light mixed together, we get the sensation of white. Such colors are called "complementary colors"; that is, any pair of colors which produce the sensation of white are called complementary colors. During the discussion of complementary colors, we are speaking of mixing colored light. If we mix blue and yellow paint together, the result is green, not white. Yellow paint absorbs all of the colors at the violet end of the spectrum and reflects yellow, some red and some green. Blue paint being at the opposite end of the spectrum, absorbs all the red and all the yellow, but reflects a little green. The only color reflected by the combination is green. Therefore, a mixture of blue and yellow pigment gives the effect of green. It is quite important to carefully distinguish between the mixing of colored lights and the mixing of pigments. The color of a mixture of pigments is the color that they all reflect in common. The eye receives one color from a mixture of pigments, but it receives all the colors present in the mixture of colored lights.

Some of the mechanisms used in television are sensitive to a much wider range of frequencies than is the human eye. As stated before, the human eye is sensitive to wavelengths ranging from 4,000 angstrom to 8,000 angstrom. We apply the name *ultra-violet* to the wavelengths beyond the violet end of the spectrum. We apply the name *infra-red* to those wavelengths that are beyond the red end of the spectrum. We usually apply the name ultra-violet to that range of frequencies with wavelengths from 4,000 angstroms down to 200 angstroms. The infra-red covers the range of wavelengths from 8,000 angstroms (.00008 centimeter) to those wavelengths approximately .03 centimeter. Wavelengths shorter than the ultra-violet rays are called X-rays, Gamma rays, and cosmic rays in the order of decreasing wavelength. We consider wavelengths greater than those in the infra-red region as heat waves and then comes the ultra-ultra short radio waves. We are particularly interested in the infra-red and ultra-violet regions of the electromagnetic wave spectrum, because many of our light sensitive devices, which are sensitive to wavelengths in the visible spectrum, are also sensitive to wavelengths in these two sections at either end of the visible spectrum.

5. PRODUCTION OF LIGHT. We are familiar with the ways in which radio waves are produced. The simplest radio wave generator consists of an oscillator coupled to an antenna. The oscillating antenna current sets up electromagnetic waves in the surrounding ether. These electromagnetic waves consist of but one frequency. The exact process involved in the generation of electromagnetic waves in the visible region of the electromagnetic wave spectrum is not well known. Therefore, we shall not attempt to explain how light waves are generated.

There are four ways in which light is produced: incancescence, luminescence, fluorescence, and phosphorescence. By incandescence we mean the light radiated by very hot solids and liquids. This light usually contains all of the frequencies covered by the visible spectrum. The filament in an incandescent lamp is an example of a solid generating light by incandescence. Liquid iron also radiates light by incandescence and the light radiated covers the entire visible spectrum. On the other hand, incandescent gases radiate one or more very narrow bands of frequencies over the visible spectrum range. Incandescent gases radiate a single color, while incandescent solids or liquids radiate white light.

Luminescence is the generation of light by a gas when it is excited by an electric spark, such as a neon sign or a mercury vapor lamp. Again, the light produced consists of one small band of frequencies or several very narrow bands of frequencies distributed throughout the visible spectrum. There is not a continuous spectrum radiated.

We apply fluorescence to the generation of light by substances when they are exposed to streams of electrons or to short wavelengths such as the ultra-violet or X-rays. For example, when certain kinds of glass are exposed to ultra-violet light, they will give off a green light. The radiated light ceases just as soon as the ultra-violet, X-rays, or electron beam is removed. Many solids, liquids, and gases can be made to generate light by fluorescence. The cathode ray tube screen depends upon fluorescence for the production of light. The end of the cathode ray tube is coated with a substance which will fluoresce and generate light when exposed to a beam of electrons.

Light generation by phosphorescence is similar to that produced by fluorescence except that phosphorescence continues after the exciting beam is removed. Phosphorescence and fluorescence usually occur together. Some phosphorescent materials radiate light for just a fraction of a second after the X-rays, ultra-violet rays, or electron beam is removed, while others will generate it for many hours after the exciting agency is removed. In the case of the kinescope, the television cathode ray picture tube, the screen material does not generate much light by phosphorescence; that is, its phosphorescent period is extremely short. Otherwise, the received picture of rapidly moving objects will be very much blurred.

Modern physicists are beginning to understand the production of light by these four methods much more clearly than they formerly did. However, it is beyond the scope of this lesson and we will not go into any of the modern theories of the generation of light.

6. LIGHT INTENSITY MEASUREMENT. In our discussion of light, we have said nothing of the units for measuring the quantity of light or the intensity of light. However, we are familiar with the means of measuring the intensity of electromagnetic waves. We speak of it as so many "microvolts per meter", or "volts per meter", depending upon the proper unit needed. We also speak of the number of watts that is transmitted by the radiating system. Similarly, in light we want units for indicating the magnitude of the light generated and also the amount of illumination received at any point from that source.

First, we wish to know about the law of the intensity of illumination; that is, how the amount of illumination on a given surface varies as that surface is moved from the light source. Let us consider Fig. 6. Let F represent the source of light such as an incandescent lamp or candle flame. We know that the light will leave F in straight lines in all directions. Let us surround F with a sphere that has a radius of 1 foot, with F at the exact center of the sphere. Let us cut a hole (A B C D) one inch square. The

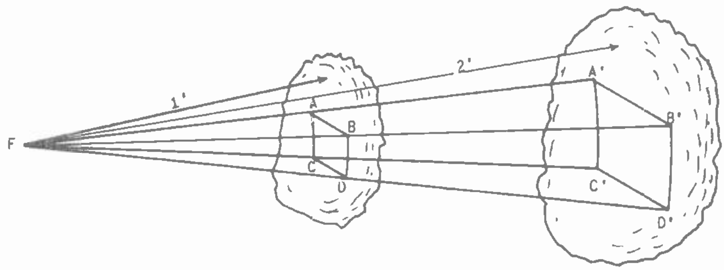


Fig.6 Inverse square law of intensity of illumination.

area of the hole is one square inch. Let us surround the first sphere by a second sphere with a radius of 2 feet, concentric to the first shpere. Since the light rays from F are diverging, those which pass through the hole in the first sphere will cover a much larger area (A'B'C'D') on the surface of the second sphere. Since the light area illuminated on the second sphere is larger than the hole through which the light passes on the first sphere, the intensity of illumination on the second sphere must be less than the intensity of illumination on the first sphere. Let us draw lines from the source of light to the edges of the hole (A B C D) on the first sphere and continue them in straight lines to the second sphere. The figure (A'B'C'D') outlined by these lines on the outside sphere will also be a square, but we see that it is a square whose sides are just twice the length of the sides of the one inch square hole we cut in the first sphere. Each side of the second square is 2 inches long and its area is 4 square inches. We said the area of the first hole was 1 square inch. That means that the amount of light passing through one square inch of the first sphere has to cover 4 square inches of the second sphere; and the intensity of illumination on the second sphere will be one-fourth as great as the intensity of illumination on the first sphere. We can see that as far as the second sphere is concerned, the distance has doubled, but the illumination has been reduced to one-quarter. From this, we see that the intensity of illumination then varies inversely as the distance. To be more exact, we should say the intensity of illumination varies inversely as the square of the distance; that is, when we double the distance, the light intensity is reduced to one-quarter. Similarly, if we triple the distance, the light intensity is reduced to one-ninth.

We shall now list some of the units used in measuring the luminous intensity of light sources and the amount of illumination. We usually rate the intensity of the source in terms of candle power. The original standard used was a sperm candle that burned at the rate of 8 grams per hour. Such a candle was defined as generating a luminous intensity of 1 candle power. Such a standard, however, is undependable because it is difficult to make candles exactly alike and, therefore, develop the same amount of light each time. Today, candle power is defined in terms of a pentane lamp developed by Vernon Harcourt which, when constructed under the specified conditions, will produce a light source of 10 candle power. Another light which is sometimes used as a standard uses amyl acetate for fuel. This light, when built according to specifications, produces a light source of .9 candle power.

However, for routine measurements of light source intensities, we use incandescent lamps that are calibrated in terms of these standard lamps. The light generated by an incandescent lamp depends upon the amount of current flowing through its filament. Incandescent lamps make a good standard because we can always pass the same amount of current through the lamp. Because of the shape of the filament in an incandescent lamp, the amount of light radiated in various directions will vary; so when using an incandescent lamp as a standard, we must always be careful that we are using the same side of the filament as our source of light.

We define the intensity of illumination on a surface in terms of foot-candles. The intensity of illumination falling on a screen one foot distant from a one candle power source is a foot-candle. Then, according to our law concerning intensity and distance; the intensity of illumination will be .25 foot-candle at a distance of 2 feet.

The quantity of light shining on a surface is measured in terms of lumens. A lumen is the quantity of light received in one second by a surface with an area of one square foot when the intensity of illumination is one foot-candle.

To find the intensity of illumination in foot candles upon a given surface, we divide the intensity of the source in candle power by the square of the distance from the source to the screen in feet. This will give us the intensity of illumination on the surface in foot-candles. For example, a screen four feet away from a 20 candle power light will receive an illumination of an intensity equal to $20 \div 4^2$ or 1.25 foot-candles.

To find the amount of light in lumens reaching a given area, we must multiply the area of the illuminated surface in square feet by the intensity of the illumination on that surface in foot-candles. In the example just given, let us calculate the number of lumens received on four square feet of the surface of the screen. According to our rule, the number of lumens is equal to the area in square feet times the intensity in candle power. The intensity of illumination is 1.25 foot-candles. The quantity of light received then would be equal to 4×1.25 or 5 lumens.

Let us consider another example. Let us calculate the amount of illumination received by a piece of paper one inch square and placed at a distance of 10 feet from a 5 candle power source. The intensity of illumination at the paper is equal to the intensity of the source divided by the square root of the distance from the source to the paper. In this case, the intensity of the illumination will be equal to $\frac{5}{100}$ or .05 foot-candles. Since a lumen is defined in terms of square feet, it will be necessary to convert our square inch to a fraction of a square foot. One square inch equals $\frac{1}{144}$ square foot. Expressed as a decimal, 1 square inch is .007 square foot. When multiplying the intensity in foot-candles by the area in square feet, we will have $.05 \times .007$ or .00035 lumen.

Let us consider another type of problem. Suppose in the television studio, there is a certain scene requiring an intensity of illumination of 100 foot-candles. The light source available is rated at 10,000 candle power. How far away should we place the light source from the object to be televised in order that the object be illuminated with an intensity equal to 100 foot-candles. According to the rule, the intensity in foot-candles is equal to the intensity of the source in candle power divided by the square of the distance from the object to the source. In this case, our distance is the unknown quantity. Solving our equation for this distance, we will have:

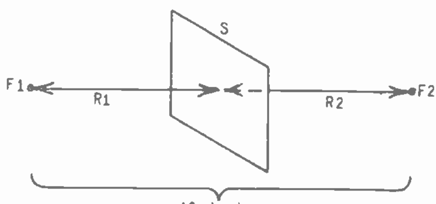
$$\text{Distance}^2 = \frac{\text{Intensity in candle power}}{\text{Intensity of illumination in foot candles}} \qquad (1)$$

$$D^2 = \frac{10,000}{100}$$

$$D^2 = 100$$

Then, taking the square root of 100, we will have 10. Therefore, the light source must be placed 10 feet away from the object to be televised in order for the intensity of illumination on the object to be equal to 100 foot-candles. The studio technician must be able to make many similar calculations.

Fig.7 A simple photometer.



7. PHOTOMETRY. It is often necessary to measure the intensity of a source of light in candle power. The instrument used to do this is called a photometer. Fig. 7 illustrates a simple photometer. Let us consider F_1 as a known source of light and F_2 as an unknown source of light. They are placed at a distance of 10 inches from each other. S is a screen between the two sources F_1 and F_2, per-

pendicular to the line joining them. We move the screen back and forth until we find the point between the two sources F_1 and F_2 where, to the eye, the illumination of both sides of the screen appears to be the same. Let us call the distance from F_1 to the screen R_1 and the distance from F_2 to the screen R_2. Let us call the intensity of the source F_1, I candlepower, and the intensity of the source F_2, or the unknown candlepower X. We can calculate the intensity of illumination on both sides of the screen, remembering that the intensity of illumination is equal to the intensity of the source divided by the square of the distance from the source to the surface. The intensity of illumination on the F_1 side of the screen is equal to $I \div R_1^2$ and the illumination on the other side of the screen is equal to $X \div R_2^2$. We adjusted the position of the screen so that these two illuminations were equal, then:

$$\frac{I}{R_1^2} = \frac{X}{R_2^2} \tag{2}$$

and, $$IR_2^2 = XR_1^2$$

and, $$XR_1^2 = IR_2^2$$

and, $$\frac{X}{I} = \frac{R_2^2}{R_1^2}$$

Solving this equation for X, we have:

$$X = I \times \frac{R_2^2}{R_1^2}$$

In other words, we can say that the intensity of the unknown is to the intensity of the known as the square of the unknown distance from the screen is to the square of the known distance to the screen.

Let us consider an example involving the use of a photometer. We have a standard of 10 candle power. The distance between the standard and the unknown is equal to 10 inches. When there is equal illumination on both sides of the screen, the screen is two inches away from the standard. What is the candle power of the unknown? Our rule states that the candle power of the unknown is equal to the candle power of the standard multiplied by the square of the unknown distance to the screen and divided by the square of the known distance or standard distance from the screen. In this case, the unknown will be equal to:

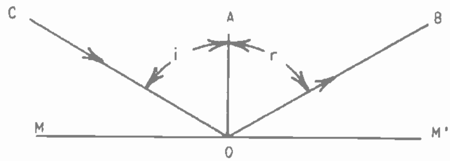
$$(10 \times 8^2) \div 2^2 \text{ or } \frac{10 \times \overset{16}{\cancel{64}}}{\cancel{4}} = 160 \text{ candle power}$$

Commercial photometers take many forms, but they are all based on the same principle; that for equal illumination, the intensities of the two light sources will vary directly as the square of the distance from the illuminated area.

8. STUDY OF REFLECTION. We shall now make a more detailed study of the subject of reflection. As previously stated, there are two types of reflection, direct and diffused. Direct reflection occurs when a beam of light falls on a smooth surface and is reflected in one direction. Diffused reflection occurs when a beam of light falls on a surface and is reflected or scattered in many directions. Diffused reflection is the type that is most common. Direct reflection is limited to mirrors and other extremely smooth surfaces.

There is a law which reflection obeys. We shall illustrate this law of reflection by means of Fig. 8. MM' is a mirror. At point O is erected a perpendicular AO. This perpendicular is merely for convenience. The ray of light CO touches the mirror at point O, so we say that the ray of light CO is incident to the mirror at

Fig. 8 Law of reflection.



point O. Upon reflection the ray follows the path OB, so we say then that OB is the reflected ray. We will call the angle between the incident ray and the perpendicular, i, and the angle of the reflected ray and the perpendicular, r. The law of reflection states that the angle of incidence is equal to the angle of reflection. This law holds true for all types of reflection, whether regular or diffused.

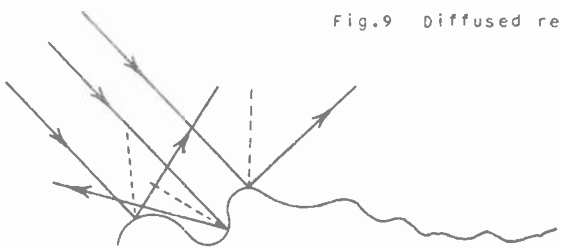


Fig. 9 Diffused reflection.

We have already stated that diffused reflection occurs with rough surfaces. In Fig. 9 we show a beam of light consisting of parallel rays incident upon a rough surface. At the point of incidence between each ray and the surface, we draw a line perpendicular to the surface at that point. The path taken by the reflected ray at that point will be such that the angle of reflection will be equal to the angle of incidence. Although the reflected rays of our beam are scattered in all directions, the law of reflection holds true; that is, the angle of incidence equals the angle of reflection. We shall make use of this law of reflection many times.

9. PLANE MIRROR. Optical devices that depend upon the law of reflection for their operation are called mirrors. We will consider the case of a plane mirror first; that is, a mirror whose surface is flat. An ordinary looking glass is an example. Let us consider mirror M and the object O in Fig. 10. Let us trace the path of two rays of light from point O to the points T_1 and T_2 on the mirror. At points T_1 and T_2, erect perpendiculars to the surface of the mirror. The ray I_1 to the point T_1 will be reflected so that the angle of reflection is equal to the angle of incidence. We will

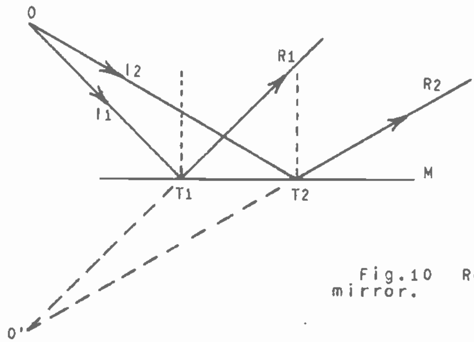


Fig.10 Reflection by a plane mirror.

call the reflected ray R_1. Likewise, the ray I_2 to the point T_2 is reflected as R_2 and the angle of reflection and the angle of incidence will again be equal. The rays R_1 and R_2 are diverging, but to an observer, they appear to come from behind the mirror at point O'. The observer sees an image of O at O'. We can run many more lines from O to the mirror and upon their reflection they appear to come from point O'. It is evident from the figure that the image O' is just as far behind the mirror as the object O is in front of the mirror. The student can readily prove this by geometry. Another rule that holds true for a plane mirror is that its image is just the same size as the object.

The image produced by a plane mirror (or in this particular case O') is called a virtual image. To have a real image produced, all of the rays of light from a point on the object after reflection must come together at another point. If this were true, we could produce on a screen an image of O, but in the case of a plane mirror, the rays after reflection are diverging and never do come together again, so there cannot be a real image of O. What we see is a virtual image and it appears to be behind the mirror at the point from which the rays appear to come. It is important that the student should be able to distinguish between real and virtual images. Again, we define a real image as one which can be formed upon a screen. A virtual image is one which can be seen but does not actually exist. The location of the virtual image is always behind the mirror. We will have a real image if, as we said before, the rays from a given point on the object after reflection come together again at a point. Their intersection will constitute the image of the point of their origination.

10. CONCAVE MIRROR. We will now take up the case of a concave mirror. A concave mirror is formed by cutting out a circular section of a sphere and using the inside surface as the mirror. The point where the center of the sphere occurs we call the center of curvature, (Fig. 11). Let us draw a line through C perpendicular to the mirror at N. This line we will call the principal axis. Let a ray of light S parallel to the principal axis fall upon the mirror at point P. From the geometry of the sphere, the perpendicular PC

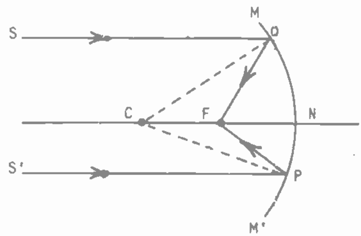


Fig. 11 Principal focus of a concave mirror.

will pass through the center of the curvature C. From P the ray is reflected so that the angle of reflection is equal to the angle of incidence. The reflected ray crosses the principal axis at point F. If we follow the path of any other ray parallel to the principal axis, we find that after reflection it also will pass through point F. All parallel rays of light incident upon the surface of the mirror, after reflection, pass through point F, or we can say that F is the image of some object extremely distant from the mirror, such as the sun. Point F we call the principal focus. We define the principal focus as the point where all rays parallel to the principal axis of a concave mirror pass through after reflection; or we say, come to a focus.

If we use a small section of the sphere as the reflecting surface, which is all we can use to get a sharp image; point F occurs midway between N and C. The distance NF we call the focal length of the mirror and it is equal to one-half the radius of curvature; we designate it by f. If we place a source of light at point F, all of the rays reflected from the surface of the mirror form a parallel beam. A concave mirror is used as the reflector in automobile headlights and searchlights. The source of light is at the focal point of the concave mirror and all the light reaching the mirror's surface is reflected to form a parallel beam.

It is possible to have real and virtual images with a concave mirror. We shall take up the case of real images first. In Fig. 12 we have a mirror MM', the principal axis CN, the center of curvature C, and the focal point F. OO' represents the object. In order to locate the image of a point on the object, we will have to follow the paths of at least two rays from that point on the object. First, let us take a ray from the point O going to the mirror parallel to the principal axis. After reflection that ray will pass through the principal focus F. Let us take a ray from O through the principal focus F to the surface of the mirror. After reflection, that ray will be reflected parallel to the principal axis. Let us follow the path of a third ray from O perpendicular to the surface of the mirror. After reflection, this will be reflected back along itself and through the center of curvature C. These three reflected rays intersect at point I; therefore, I is the image of point O. Draw an arrow to I from the principal axis. This arrow is an image of the arrow at OO'. In this case we use three rays to locate our image. Two are sufficient; however, the two rays

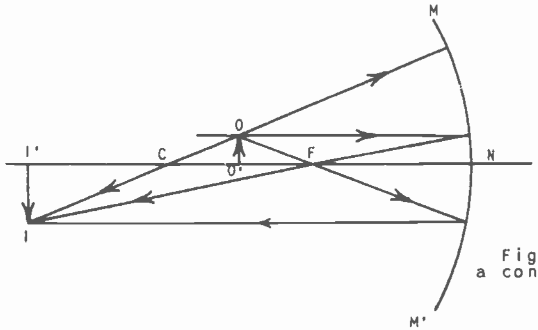


Fig.12 Real image for a concave mirror.

must originate from the same point on the object. From this figure we can see that our image is inverted and is much larger than the object. Now, if we reverse the positions of the object and image; that is, let I' represent the object and O' will be the image. The image is smaller than the object and is inverted. In such a case where the object and image positions are interchangeable, we call the two points conjugate foci.

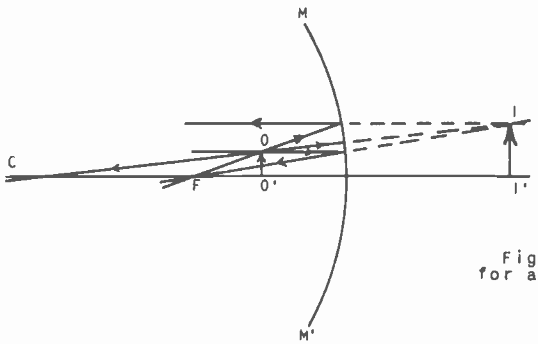


Fig.13 Virtual image for a concave mirror.

Now let us take the case of a virtual image for a concave mirror. The object will be between the focal point F and the mirror MM'. In Fig. 13 the object OO' is in between F and the mirror. Let us now follow the same process as before. Draw three rays from the object to the surface of the mirror and draw their paths after reflection. Let us take one ray from point O parallel to the principal axis. After reflection that ray will pass through the principal focus F. Let us take another ray through F to the mirror and after reflection that ray will be parallel to the principal axis. Let us take another ray from O perpendicular to the surface of the mirror. After reflection that ray will be reflected back along itself through point C. You notice that these three rays are diverging or spreading apart. They seem to come from a point behind the mirror. Extend the reflected rays behind the mirror until they intersect. Since these three rays appear to an observer to come from point I, we will say then that II' is a virtual image of OO'. Since II' is behind the mirror, we are unable to show it on a screen. The observer will see the virtual image as his eye lenses converge the rays and form a real image on the retina. The image is erect and larger.

Let us summarize the characteristics of the image for different object locations. When the object is in between the center of curvature and the principal focus, the image is outside the center of curvature away from the mirror; it is real, inverted, and larger than the object. When the object is outside the center of curvature away from the mirror, the image is in between the center of curvature and the principal focus. It is real, smaller, and inverted. When the object is in between the principal focus and the surface of the mirror, the image formed is virtual. It is behind the mirror, is erect, and is larger than the object.

11. SIZE AND POSITION OF IMAGE FOR MIRRORS. There is a very simple relationship between the size of the object and image and in their distances from the mirror. In the first construction we made (Fig. 12), let us call the distance O'N of the object from the mirror, P; and the distance of the image I'N from the mirror, Q. The law states that the size of the object is to the size of the image as the object distance from the mirror is to the image distance from the mirror. In other words, the sizes of the image and object are directly proportional to their distances from the mirror.

For example, let O'N or P in Fig. 12 be 15 inches, and I'N or Q be 20 inches. If the object height is 5 inches, what is the image height? The law states that:

$$\frac{\text{Image size}}{\text{Object size}} = \frac{\text{Image distance}}{\text{Object distance}} \tag{3}$$

Substituting the known quantities in this equation:

$$\frac{\text{Image size}}{5} = \frac{20}{15}$$

Therefore, the image size equals:

$$\frac{5 \times \overset{4}{\cancel{20}}}{\underset{3}{\cancel{15}}} = \frac{20}{3} = 6\tfrac{2}{3} \text{ inches}$$

There is another law for concave mirrors which is important. It is the law which gives a relationship between the image distance, the object distance, and the radius of curvature. This law states that:

$$\frac{1}{P} + \frac{1}{Q} = \frac{2}{R} \tag{4}$$

Where: P is the distance of the object from the mirror;
Q is the distance of the image from the mirror;
R is the radius of curvature of the mirror.

For example, let us take a mirror with a radius of curvature of 30 inches. That means the focal length will be 15 inches. Then, if we have an object distance of 20 inches; what is the image distance? In our formula, we will substitute 20 for P and 30 for R. Solving for $1 \div Q$, we have:

$$\frac{1}{Q} = \frac{2}{30} - \frac{1}{20}$$

$$= \frac{1}{60}$$

Solving for Q, we have:

$$Q = 60$$

The image distance is 60 inches.

Now, let us calculate the size of the image. We will let the object have a height of 2 inches. We have already stated that the sizes of the object and image are directly proportional to their distances from the surface of the mirror. Substituting in the proper formula (3), we find that the image size is 6 inches. Let us apply the formula for the relationship between image and object distance and the radius of curvature to the case where we had a virtual image. Since the image is behind the mirror, the image distance will be represented by a negative number. Let's take the same mirror as in the previous example, but in this case our object is at a distance of 5 inches from the mirror. Then, we will have:

$$\frac{1}{5} + \frac{1}{Q} = \frac{2}{30}$$

$$\frac{1}{Q} = \frac{2}{30} - \frac{1}{5} = \frac{1}{15} - \frac{1}{5} = \frac{1}{15} - \frac{3}{15}$$

$$= -\frac{2}{15}$$

$$Q = -7\tfrac{1}{2}$$

The answer is negative and shows that the image is behind the mirror and is virtual.

12. CONVEX MIRROR. Now let us consider the convex mirror; that is, using the section of the outside surface of the sphere as

our reflector. The center of the sphere we will again designate as the center of curvature. The principal axis is drawn through the center of curvature perpendicular to the mirror. If we let a beam of rays parallel to the principal axis be incident upon the mirror, we will find after reflection that they appear to come from a point behind the mirror, Fig. 14. This point we shall call

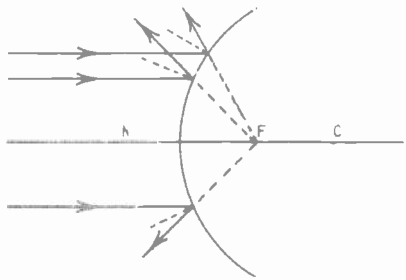


Fig.14 Principal focus of a convex mirror.

the principal focus. Again, the principal focus as in the case of a concave mirror is half way between the center of curvature and the surface of the mirror. Since light waves reflected from a convex mirror will always be diverging, we shall under no conditions have a real image formed. All images will be virtual. Let us take an example. In Fig. 15, OO' is our object. If we follow a ray of

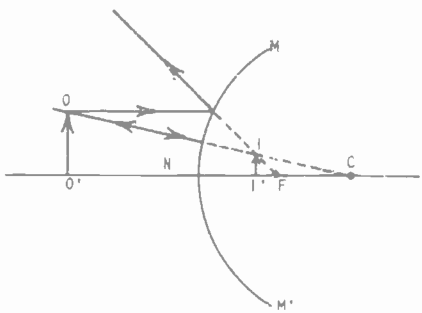


Fig.15 Virtual image for a convex mirror.

light from O to the mirror parallel to the principal axis, after reflection from the surface of the mirror, the reflected ray will appear to come from the principal focus F. Let us take another ray from O perpendicular to the surface of the mirror. After reflection, the ray will be reflected back along itself to O. The two reflected rays are diverging; therefore they will not form a real image. If we trace the rays back behind the mirror to the point that they appear to come from, you will find they intersect and at the point of intersection will be located a virtual image of the object. You will notice that this image will be erect and much smaller than the object. The law for the location of image and object holds true for the convex mirror as well as the concave, but since the center of curvature is behind the mirror in this case, we use a negative number for the value of radius of curvature and focal distance. Likewise, since the image is virtual, the image distance will also be negative. The student can think of an example and work it out for the case of a convex mirror.

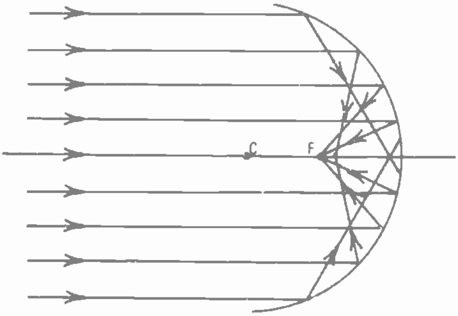


Fig. 16 Spherical aberration in a concave mirror.

13. SPHERICAL ABERRATION. In discussing concave and convex mirrors, we always use a small section of the sphere as our mirror. If we use a large section of the sphere as our mirror, our image is blurred, while if we use a very small section, the image is quite sharp. This blurring is due to what is called "spherical aberration." Fig. 16 illustrates what is meant by spherical aberration. We defined the principal focus of a concave mirror as the point through which all light parallel to the principal axis passes after

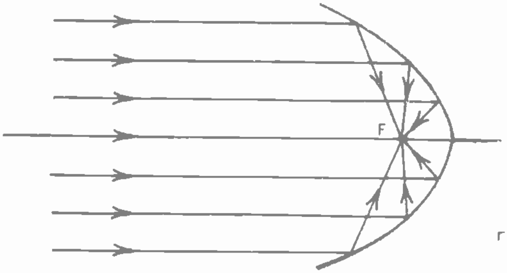


Fig. 17 Parabolic mirror.

reflection. Spherical aberration occurs when the light, after reflection, especially the rays reaching the outside of the mirror, do not pass through the principal focus but do pass through a series of points nearer the surface of the mirror. This lack of a sharp, distinct focus causes the image to be blurred. To correct this, we usually use a parabolic surface such as shown in Fig. 17. An automobile headlight reflector is an example of a parabolic surface. For a parabolic surface, all rays of light parallel to the principal axis, after reflection, pass through the focal point. All rays of light originating at the focal point after reflection from the mirror form a beam parallel to the principal axis.

14. REFRACTION. We shall now go into a more detailed study of the subject of refraction. As previously stated, refraction is the bending of light rays when they pass from one medium into another. Bending always takes place at the boundary between the two mediums. When light passes from air to water, for example, the light ray is bent toward the perpendicular erected at the point of contact between the water and air. (Fig. 18.) When it moves from water into air, it is bent away from the perpendicular at the point of contact between the two mediums. We summarize this by saying that when light passes from one medium into a denser medium, it is bent toward the perpendicular at point of entry; and when it passes

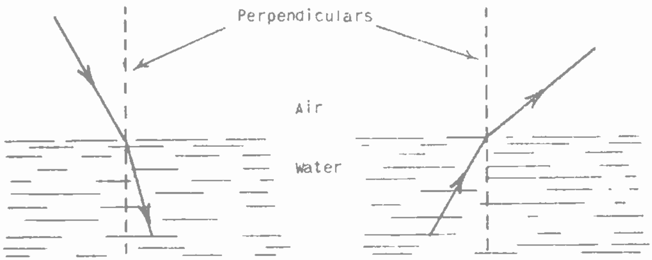


Fig.18 Refraction by water.

from one medium to one of lesser density, it is bent away from the perpendicular at point of entry to the second medium. The reason for the bending is the difference in velocity of the light in the two mediums; the more dense the medium, the slower is the velocity of light. We can give an example to illustrate why the bending occurs. Let us consider a column of soldiers walking on a concrete pavement or a very smooth parade ground. Let us think of the parade ground as being bordered by a freshly plowed field. As the column of soldiers approach the boundary between the parade ground and plowed field obliquely, part of the column will leave the parade ground before the rest as illustrated in Fig. 19. Just as soon as the first man in the front line of the column reaches the plowed ground, he is slowed up as the walking is more difficult and, as each man enters the plowed region, he is slowed up likewise. This slowing up in speed causes the direction of the column to be shifted toward a perpendicular to the boundary and if the column continues exerting the same amount of energy in walking, its speed will be slowed up and the direction of the column will be bent or deflected. Now let us take the case of the column of soldiers returning from the plowed field to the smooth, level parade ground. Again, let them approach the boundary obliquely. When the first man in the first row reached the parade ground, he walks much faster and as each man in the first line approaches the parade ground, his speed will increase because of the easier walking. In this way the first man reaching the parade ground will cover a greater distance than the last man to reach it in a given interval of time. Thus, the direction in which the column of soldiers is moving is deflected. This time the deflection will be away from the perpendicular to the point of entry at the boundary line. If the column approaches the boundary perpendicularly, all in the front row will increase speed together, and the direction will be unchanged. In a like manner, a ray of light is deflected or bent at the point of entry from one medium into another; (provided the light ray is not perpendicular to the boundary), since the velocity in the denser medium will be slower than that in the less dense medium and the amount of bending will be proportional to the change in density between the two mediums.

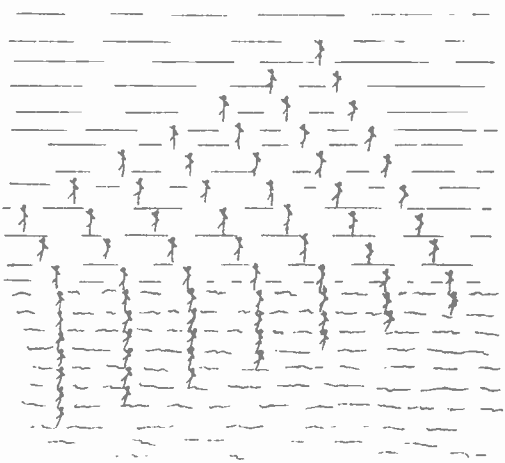


Fig. 19 Illustrating cause of refraction.

The measure of the magnitude of bending we label with the term "index of refraction". The index of refraction is defined as the ratio of the velocities of light in the two mediums; and in calculating the value of the index of refraction, the speed of light in any medium is referred to its speed in vacuum. Also, the shorter wavelengths of the visible spectrum are bent more than the longer wavelengths; that is, the shorter wavelengths are slowed up more when passing from one medium into a denser medium than are the longer wavelengths. Therefore, the index of refraction varies with the wavelength; is greatest for the short wavelengths and least for the long wavelengths.

This information will enable us to explain why a glass prism is able to separate white light into its component frequencies. In Fig. 5, we have a glass prism with perpendiculars erected to two of its surfaces. A ray of light is incident on one surface and when it enters in the glass prism it is bent toward the perpendicular, violet being bent most and red being bent the least. The light beam is separated into its component colors. When these components reach the other surface of the prism and enter into a less dense medium, the air, they are bent away from the perpendicular. In this case, the violet will be bent away the most and the red least, thus further separating the components of the white light. If we place a screen in the path of the light leaving the prism, the colors of the spectrum will be revealed. The name we gave to this process, you will recall is dispersion.

15. **LENSES.** An optical device which makes use of the refractional properties of light when passing from one medium to another is the lens. You are already familiar with some of the common forms of lenses such as eyeglasses and the reading glass. We have two general types of lenses, convex and concave. The convex lens is called a converging lens, because it brings light rays that pass through it together. The other type of lens is called a diverging lens, because it causes parallel light rays that pass through it to diverge or go apart. The reason that lenses have these properties is because

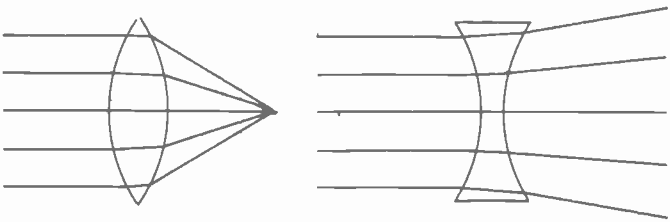


Fig.20 Converging and diverging lenses.

of the different speeds of light in glass and in air. If we take a cross section of a convex lens, we can think of it as two prisms with their bases together. We have already shown that light when passing through a prism is bent and since the two prisms have their bases together, the light passing through the edges will be bent toward each other, while the light through the center, where the surfaces are practically parallel, will not be changed.

Fig. 20 illustrates the action of light in going through a diverging and a converging lens. In the case of the diverging lens, the two prisms have their apexes together, and as the light going

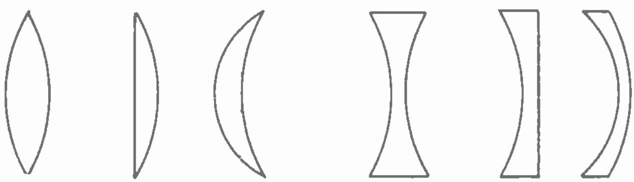


Fig.21 Types of lenses.

through a prism is always bent to the thick side, the light passing through the lens is bent toward the edges. A lens will be a converging lens if it is thicker in the center than the edges, and a diverging lens if it is thinner in the center than at the edges.

All lenses may be classified under six general headings as illustrated in Fig. 21. The name depends upon the type of surfaces the lens has. Naming them in order from left to right, we have a double-convex, plano-convex, concavo-convex, double-concave, plano-concave, and convexo-concave.

In studying lenses, we shall have to give them certain properties. We shall call the line passing through the center of the lens perpendicular to its surfaces, the principal axis. All lenses have a principal focus. In the case of a converging lens, the principal focus is that point at which a parallel beam of light after passing through the lens comes to a focus. In the case of a diverging lens, a parallel beam of light after passing through the lens, diverges, but appears to diverge from a point. That point is called the focal point. For a simple double-convex lens, the focal points are at the centers of curvature. If we place a point source of light at the focal point of a converging lens, the rays after leaving the lens will form a parallel beam. Searchlights use this property of a convex lens to form a parallel beam of light. If we consider the center of the lens, we notice that the two surfaces of the lens are practically parallel at that point. Therefore, a ray of light going through the center of a lens is passing through a region of constant thickness and will not be deviated. Since the center of the lens has this property, we call it the optical center of the lens. If the lens is very thick at the center, the optical center is not a well defined point, but for thin lenses, the optical center is essentially a point.

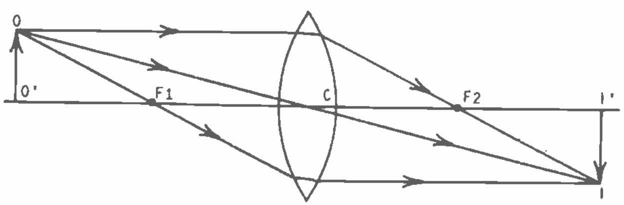


Fig.22 Real image for convex lens.

16. **CONVEX LENS.** We shall locate the images graphically for lenses just as we did in the case of mirrors. Let us first consider a convex lens as in Fig. 22. Draw in the principal axis F_1CF_2 and the principal foci F_1 and F_2. We will have a principal focus on each side of the lens, because a parallel beam of light passing through either side will converge on the other. In this case, let us locate our object outside of the principal focus on one side of the lens. We will follow the same process as we did before. We require at least two rays of light in order to locate the image. In this case, we will use three. First, let us take a ray of light from point O on our object and let it pass parallel to the principal axis. After passing through the lens, according to our definition, it is bent and passes through the principal focus at F_2. Now let us take another ray from O through the optical center of the lens. According to our definition of the optical center, this ray will pass through the lens without any change in direction. Now, let us take a third ray, this time from O through the focus F_1 to the lens. According to definition, after passing through the

lens, this ray will be parallel to the principal axis. These three rays all intersect at point I. Thus II' is the image of OO'. The image is real and inverted. In this particular case, the image is about the same size as the object, but from observation of this figure, we can see that as the object is moved away from the lens, the image will approach the lens and, as it approaches, will become smaller. As the object moves toward the lens, the image will recede from the lens and will become larger. When the object reaches the focal point, the image will be at an extremely distant point from the lens. Likewise, if the object is extremely far from the lens, the image will be at the focal point on the other side of the lens.

Let us consider the case when the object is between the focal point and the lens. Fig. 23 shows the type of image we have. Follow the same process of construction of the image. First, let us take a ray of light from O parallel to the principal axis. After bending by the lens, this ray will pass through F2 or the principal

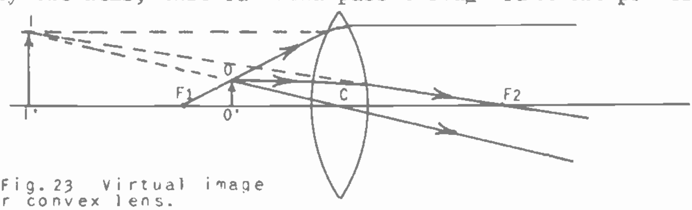


Fig. 23 Virtual image for convex lens.

focus. Let us take a ray from O through the optical center of the lens. After passing through the lens, this ray will continue without any change in its path. Let us take a ray from O to the lens as though it came from F1. This ray, after passing through the lens will be bent parallel to the principal axis. You will notice that these three rays are all diverging. Therefore, we can never have a real image formed, but to the observer on the right side of the lens, the rays will appear to come from some point behind the lens. Continue the rays back until they intersect and the point of intersection I will be a virtual image of O. We indicate the apparent path of these light rays by dotted lines. In this case, the virtual image is erect. It is larger than the object. From Fig. 23 we can see that as the object approaches the focal point, the size of the image will become larger, and, when the object reaches the focal point, the virtual image will disappear and we will have a real image formed on the other side of the lens at an extremely far distant point.

We will summarize the properties of the image for various positions of the object in relation to the lens. If the object is between the focal point and the lens, we will have a virtual image which is enlarged, on the same side of the lens as is the object, and is erect. When the object is outside of the focal point, we will have a real image on the other side of the lens, and its size will depend upon the position of the object with respect to the focal point. The image is inverted. When the object is at the focal point, the image will have its maximum size, but as the object recedes from the focal point, the image becomes smaller until it has its minimum size and is at the focal point while the object is at an infinite distance. We can use a convex lens for magnifying when the object is between the focal point and the lens, and we have a virtual image. A virtual image, as you will remember, is one we cannot cast on a screen, but as the eye constitutes a small optical system, the virtual image of the reading glass acts as an object for our eye. In this case, since the object will be outside the focal point of the eye, a real image will be formed on the retina of the eye. A little later, we will go into the discussion of optical instruments and the construction of the eye. This point will then become clear. Most people have, at one time, experimented with a reading glass and became acquainted with the fact that the images of distant objects are always inverted and that they can be cast on a screen while the images of objects very close to the lens are enlarged and magnified, are erect and cannot be cast on a screen. Perhaps you are not familiar with this fact. When a reading glass is used as a burning glass, we have a case where the object is extremely distant, the image appearing at the focal point. In this case, it is the image of the sun at the focal point of the lens.

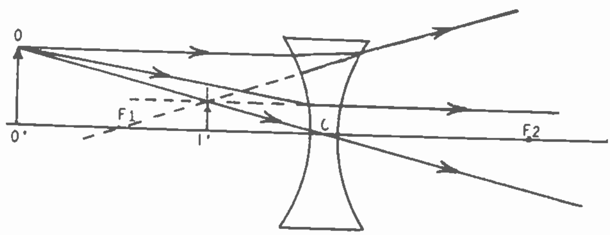


Fig.24 Virtual image for concave lens.

17. CONCAVE LENS. Now let us consider the case of a concave lens; that is, a lens which is thinner at the center than at the edges. The lens diverges the light rays that pass through it. In Fig. 24 we have a diverging or concave lens, principal axis F_1F_2, two focal points, F_1 and F_2, and the optical center C. Remember, in the case of a concave lens, we defined the focal point as the point from which parallel rays of light appear to diverge after passing through the lens. Since we can pass a parallel beam through the lens in either direction, we will have two such points. For a simple double-concave lens, the focal points are all near the centers of curvature. Since a concave lens causes light rays to diverge, we know that we are going to have a virtual image because diverging light can never intersect or come together.

First, let us take the case of an object outside of the focal point. We will follow the same process as before. First, let us take a ray from point O parallel to the principal axis. After passing through the lens, it will appear to diverge from F_1. Let us take another ray from O through the optical center of the lens. This ray will continue with its path unchanged. Take another ray from O in the direction of F_2. This ray, after passing through the lens will be bent parallel to the principal axis by definition for the focal point F_2. You will notice that these three rays of light are diverging; that is, they will never come together. Let us continue them to the left by dotted lines. We find they intersect at I. Therefore, I will be a virtual image of O. In this case, the virtual image is erect and is smaller than the object. We can see from the figure that as the object recedes from the lens, the image will get larger. The maximum size of the image will be equal to the size of the object when the object is right next to the lens. In general, then, the characteristics of the image for a concave lens are that it is virtual, erect and, smaller than the object.

18. SIZE AND POSITION OF IMAGE FOR LENSES. We will next take up the laws of lenses. You will recall that in the case of the mirror, there is a relationship existing between the size of the object and image and their distances from the mirror. The sizes of the object and image are directly proportional to their distances from the mirror. The same law holds true for a lens; that is, the size of the object is to the size of the image as the object distance is to the image distance. Like the mirror, there is a law relating the distances of the object and image from the lens with some physical characteristic of the lens. You will recall in the case of the mirror, we are able to have an equation relating the object and image distance to the radius of curvature of the mirror. In the case of the lens, the law takes the form of:

$$\frac{1}{P} + \frac{1}{Q} = \frac{1}{f} \tag{5}$$

Where: P is the object distance,
Q is the image distance,
f is the focal length of the lens.

By means of these two laws, we are able to describe the size and position of the image when we know the size and distance of the object and the focal length of the lens.

Let us work out an example. Consider a lens that has a focal length of 30 inches, the object is 40 inches from the lens. Where will the image be? In this case, P = 40, f = 30, so our equation will take the form.

$$\frac{1}{40} + \frac{1}{Q} = \frac{1}{30}$$

Solving for $\frac{1}{Q}$, we have:

$$\frac{1}{Q} = \frac{1}{30} - \frac{1}{40}$$

Since the least common denominator is 120, we will have:

$$\frac{1}{Q} = \frac{4}{120} - \frac{3}{120} = \frac{1}{120}$$

Solving for Q,

$$Q = 120 \text{ inches.}$$

The image will be 120 inches from the lens. Now, let us consider the image as having a size of 1 inch. What will be the size of the object? The sizes of the image and object are directly proportional to their distances from the lens. We have then:

$$\frac{120}{40} = \frac{1}{X}$$

Solving this equation, then, we will have:

$$120X = 40$$

$$X = \frac{40}{120}$$

$$= \frac{1}{3}$$

The size of the object, then, would be $\frac{1}{3}$ inch. In this particular example, we located the object outside of the focal point. Now, let us consider the case when the object is inside the principal focus or focal point. Using the name lens with a focal length of 30 inches, let us have the object a distance of 20 inches from the lens. We will have:

$$\frac{1}{20} + \frac{1}{Q} = \frac{1}{30}$$

$$\frac{1}{Q} = \frac{1}{30} - \frac{1}{20}$$

The least common denominator is 60, so we will have:

$$\frac{1}{Q} = \frac{2}{60} - \frac{3}{60}$$

Or, we can say:

$$\frac{1}{Q} = -\frac{1}{60}$$

Solving the equation for Q, we will have:

$$Q = -60$$

When we have a real image, it is on the opposite side of the lens from the object Now, in this case, since the image distance comes out negative, we know we will have a virtual image and the image will be on the same side of the lens as the object. Now, let us calculate the size of the image if the object is one inch high. Keep in mind that the object size is to the image size as the object distance is to the image distance. We will have:

$$\frac{1}{X} = \frac{20}{60}$$

Solving the equation, we will have:

$$20X = 60$$

$$X = 3 \text{ inches}$$

In this case, we will have a magnification of 3; that is, the image is three times the size of the object. Whenever we make use of a virtual image, whether it be with a concave mirror or converging lens, we must be sure to always consider our image distance as a negative number.

We make use of the same formula for the diverging lens, but since the light rays after passing through a diverging lens spread out instead of coming together, we will not have a positive number to represent the focal length of that lens, but the distance from the lens to the apparent focus or the distance from the lens to the point at which the light rays appear to diverge we will call the focal length of the lens, and, in this case, since the light rays are diverging and not converging, we will give it a negative value. Also, since the image is always virtual, our image distance will always be negative.

Let us take an example. We will consider a diverging or concave lens that has a focal length of 30 inches. In this case, we will let the object distance equal 40 inches. Let us locate the image. We said in the case of a concave lens, that f, or the focal length will be negative. We will have:

$$\frac{1}{40} + \frac{1}{Q} = -\frac{1}{30}$$

$$\frac{1}{Q} = -\frac{1}{30} - \frac{1}{40}$$

The common denominator is 120. Therefore,

$$\frac{1}{Q} = -\frac{40}{120} - \frac{30}{120}$$

$$\frac{1}{Q} = -\frac{70}{120}$$

$$-70Q = 120$$

Solving for Q: $\quad Q = -\frac{120}{70} = -\frac{12}{7}$ inches

The law giving the relationship between image and object size and their distances from the lens holds true for a concave lens. In the previous example, let the object size be two inches. What is the image size. The law states that the object size is to the image size as the object distance is to the image distance. Substituting the known values in this proportion:

$$\frac{2}{X} = \frac{40}{\frac{12}{7}}$$

$$40X = \frac{24}{7}$$

$$X = \frac{\overset{6}{\cancel{24}}}{7\times\underset{10}{\cancel{40}}}$$

$$= \frac{6}{70} \text{ inches, image size.}$$

The negative sign indicates that the image is virtual and erect.

19. SPHERICAL ABERRATION. In a simple lens, the light going through near the edges has a different focal point than the light going through the center, as shown in Fig. 25. The light going

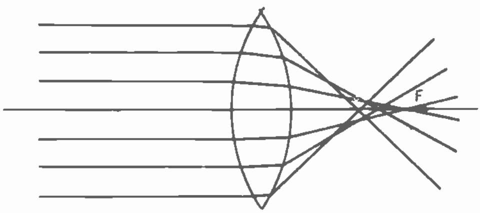


Fig. 25 Spherical aberration with a lens.

through the outside comes to a focus sooner than the light through the center. You will recall that a large concave spherical mirror produced a blurred image in a similar way. This defect of a lens and a mirror is called spherical aberration.

In the case of simple lenses, the trouble is reduced by using just the center of the lens; that is, by using a mask before the lens with a small opening concentric with the center of the lens. In this way, the image formed is sharply focused. We say that the lens has been stopped down. You may be acquainted with the term through using your kodak.

20. CHROMATIC ABERRATION. Another difficulty with the simple lens is known as chromatic aberration. You recall that when white light passed through a prism, it is separated into its component colors. In the original discussion of a lens, we described it as being made up of prisms. You remember that when light passed through a prism, the violet was bent more than the red. Similarly, when a

beam of light passes through a lens, it will be dispersed slightly; that is, the violet will be brought to a focus sooner than the red, while the other colors of the spectrum will be brought to a focus in between the violet focus and the red focus in the order of their wavelength. The method of correcting this is based on the fact that different kinds of glass disperse light differently; that is, the value of the index of refraction for the range from red to violet varies more for some glasses than it does for others while the average value of the index of refraction may be the same. The variation from the red end to the violet end will be less in one glass than it is for another, as illustrated in Fig. 26. C is a prism which

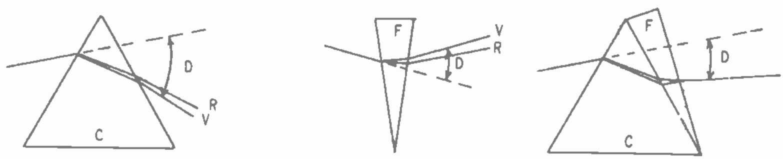


Fig.26 Chromatic aberration and its correction.

will change the total path of the light by a certain amount and will disperse the light as indicated by the limits V and R. We have another prism of a different kind of glass F. Notice in this case the total deviation of the light ray is very little while the amount of dispersion or the separation of the component colors is just the same as with the previous prism. The prism called C is made of crown glass. This is a sodium glass. Prism F is made of flint glass which is a lead glass. By combining these two prisms so that one will counteract the dispersion of the other, we will have no dispersion, but will have bending of the light rays. By a similar method, we can correct lenses for chromatic aberration; that is, we will combine a convex lens with a concave lens, one of crown glass and the other of flint glass. The crown glass lens will have a very short focal length, while the concave or flint glass lens

Fig.27 Astigmatism.

will have a very long focal length. The dispersion of one will be neutralized by the dispersion of the other, but the combination will still have convergence, or will be a concave lens. It is necessary then, in the construction of optical instruments, to correct lenses for chromatic aberration. The corrected lens is called an achromatic lens; that is, it focuses all of the colors of the spectrum at the same point. We are familiar with cheap opera glasses. When using them, you will notice that all objects viewed by them are outlined in the colors of the spectrum. This is due to the fact that these lenses are not corrected for chromatic aberration.

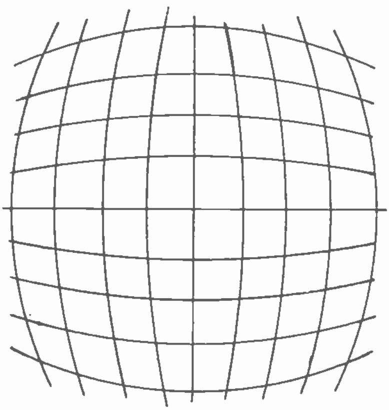


Fig.28 Distortion produced when the stop is in front of lens.

21. ASTIGMATISM. Another type of distortion that occurs in lenses used in cameras is called astigmatism. Astigmatism occurs when the light rays pass obliquely through a lens. The vertical lines in an object are brought to a focus at a different place than

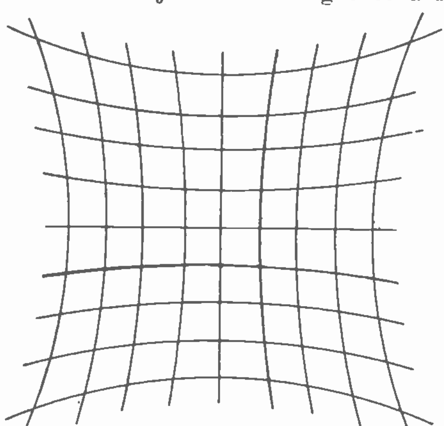


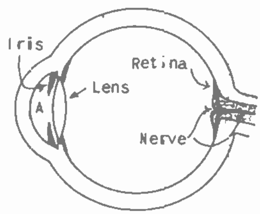
Fig.29 Distortion produced when stop is in back of the lens.

are the horizontal. Fig. 27 is an illustration of astigmatism. The object is a piece of wire netting. The vertical lines are focused at A and the horizontal at B. Astigmatism can be corrected by proper lens combinations.

Astigmatism also occurs when lenses are barrel shaped, that is, the curvature is greater in one direction across the lens than it is in the other. The lens of the eye often has this type of lens distortion. It can be corrected by using additional lenses so shaped that the combination forms a true spherical lens.

There are two other types of distortion that occur in camera lenses. These are known as *barrel-shaped* distortion and *pin-cushion shaped* distortion. Figs. 28 and 29 illustrate these forms of distortion where the object is a mesh. In barrel-shaped distortion, the center of the image is magnified more than the outside. In pin-cushion shaped distortion, the reverse is true. These kinds of distortion can be controlled by the proper placement of the stop. If the stop is placed outside the lens, barrel-shaped distortion occurs; if it is inside the lens (between lens and film) the other occurs. By placing the stop close to the lens, these forms of distortion are reduced. When a combination of lenses are used, distortion can be prevented by placing the stop inside the combination.

Fig.30 The eye.



22. THE EYE. Perhaps the optical instrument most of us are interested in is the human eye. In Fig. 30 is a diagram of the human eye. We see that the eye consists of a container and a lens system with an opening, or iris, to the lens system. At the back of the eye, opposite the lens, is a sensitive layer called the retina. The lens and interior of the eye are filled with a transparent fluid. Light given out by an object outside the eye passes through the opening A and is focused by the lens on the retina. A nerve network connects the retina to the brain and the brain interprets the image that is formed on the retina. The eye opening, or iris, corresponds to the stop used with an ordinary lens to control the amount of light entering the eye. In the study of lenses, you will recall that as the object distance changed in respect to the lens, the image distance also changed. In the case of the eye, since the distance from the lens to the retina is fixed, we will need some other means of making arrangements for correcting for the variations in object distance. If you will recall the formula for the relationship between object distance and image distance;

$$\frac{1}{P} + \frac{1}{Q} = \frac{1}{f}$$

Where: P is object distance,
Q is image distance,
f is focal length.

In the ordinary lens system, f is a constant, but P and Q vary. In the case of the eye, Q is a constant because the distance between the lens and the retina cannot change. Therefore, in order to change the focus, we must vary f when P varies. In the case of the eye, this is done by changing the curvature of the lens. There are little muscles that pull or push on the outside of the eye lens. In this way, it is made to have a longer or shorter focal length so that the image distance may always be made equal to the distance from the lens to the retina of the eye.

For many people, the muscles controlling the eye lens are unable to adjust the focal length of the lens for the best vision over a wide range of object distances. Some people are able to see distant objects very well, but cannot see objects that are close to

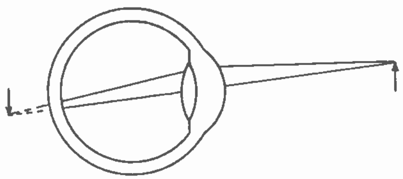


Fig.31 Far-sighted eye.

them. Such people are said to be far sighted. Other individuals can see objects distinctly when they are close to their eyes, but cannot see anything at a distance. These people, we say are near sighted. If you will recall the law for the location of the object and image with respect to the lens, you will remember that as the object approaches the lens, the image will recede from it. In the case of a person's eye, we mean then, that in order to keep the image at the same relation to the eye lens, the focal length of the lens in the eye must become less; that means it must have a greater curvature. A far sighted person, then, is one whose eye muscles are unable to increase the curvature of his eye lenses, or to decrease the focal length, and the image occurs behind the eye retina instead of on the eye retina. (Fig. 31) The means of cor-

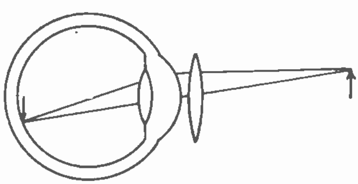
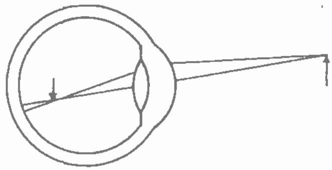


Fig.32 Far-sighted eye corrected by convex lens.

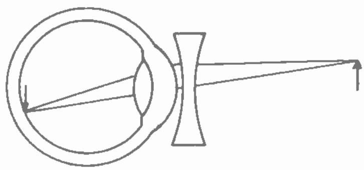
recting this, then, is to use some means which will shorten the effective focal length of the eye lens. This can be done by adding an external convex lens which is a converging lens. (Fig. 32) So, people who are far sighted have converging lenses, or convex lenses in their spectacles. Far sightedness is a characteristic of old people, The muscles in their eyes no longer have the strength to bring the eye lens to the proper shape for close vision. A near sighted person is one who is able to see objects close up. The law for the relation of image and object distance for a lens, states that as the object recedes from the lens, the image will approach the lens. In this particular case, the muscles of the eye are unable to relax sufficiently to increase the focal length for the image to remain on the retina, but instead, the image is formed inside of the eye before the retina. (Fig. 33) In order to correct this difficulty, we have to have some means of lengthening the focal length of the lens of the eye. This can be done by using an external concave or

Fig. 33 Near-sighted eye.



diverging lens. Therefore short sighted people usually have diverging lenses in their spectacles. (Fig. 34) Short sightedness is usually a characteristic of young people whose eye muscles are stronger than they need be. The eye sometimes has astigmatism. In this case, the lack of focus of both the vertical and horizontal lines in the same plane is due to the shape of the lens. It has more curvature in the vertical direction than in the horizontal direction, or vice versa. The means of correcting this is to use a lens that also varies in its curvature in both the horizontal and vertical directions so that the combination of the two will produce a lens which focuses on the same plane for both horizontal and vertical lines. Such a lens is called a cylindrical lens.

Fig. 34 Near-sightedness corrected by concave lens.



In optical instruments, simple lenses are never used. A lens system usually has to be corrected for spherical aberration and for chromatic aberration. In the study of optical instruments, we will always consider a lens combination as a simple lens. In the case of two lenses in contact, the focal length of the combination F is given by the equation:

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

Where: F_1 and F_2 are the focal lengths of the lenses in contact. F_1 and F_2 may be positive or negative, depending upon whether it is a converging or diverging lens. Any combination of lenses, when the lenses are very close together and the focal lengths are long in comparison to the distance between the lenses, can be considered as a simple lens with one focal length. In a case where the lenses are far apart, we can locate the image for one lens and use that image as the object for the other lens, thereby finding the image for the combination.

23. OPTICAL INSTRUMENTS. The two optical instruments with which we will come in contact as television engineers, will be the camera and the projection lantern. Fig. 35 illustrates a simple

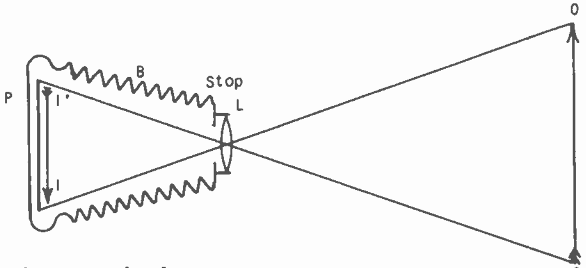


Fig.35 Simple camera.

camera. It consists of a lens L and a sensitized plate P. The lens is a converging lens and produces a real image of the object upon the plate P. The lens illustrated here is a simple lens, but in good cameras, it is a combination of lenses correcting for both spherical and achromatic aberration and astigmatism. To focus the camera, we can vary the distance between the lens L and the plate P. The distance between the lens L and plate P is enclosed by

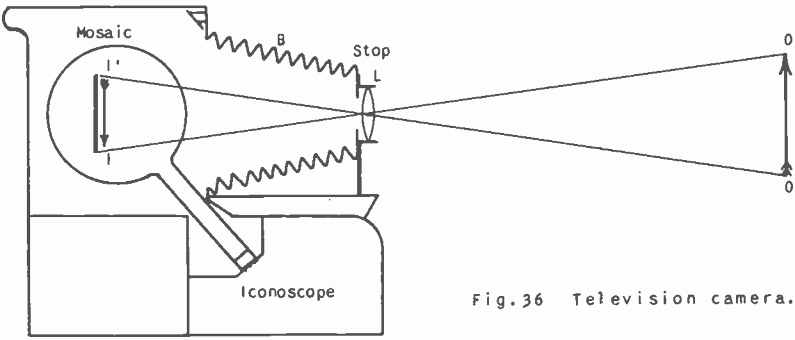


Fig.36 Television camera.

the bellows B. This is to keep out external light other than the light going through the lens from falling on the plate P. To focus the camera we can replace the plate P with a ground glass plate. Then the bellows is adjusted to get a clear image of the object on the ground glass. The ground glass is replaced by sensitized film and exposed the proper length of time to secure a good picture.

The television camera (Fig. 36) is like a simple camera except the sensitized plate is the mosaic of the iconoscope. Therefore, it is necessary to know something about the action of a camera in order to be an efficient television engineer.

The projection machine is another optical instrument of interest to the television engineer. Fig. 37 shows the fundamental oper-

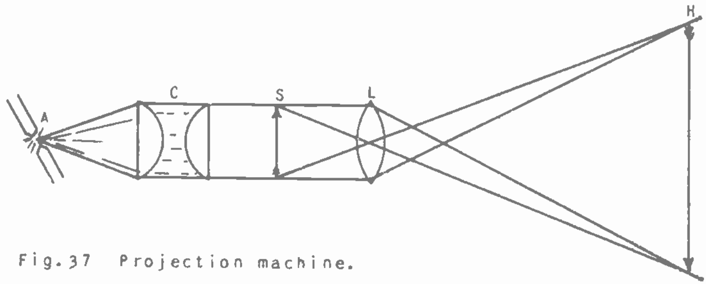


Fig. 37 Projection machine.

ation of a projection machine. A is an arc. C is a condensing lens. It is used to direct as much light as possible through the slide S. S is near the principal focus of L. An enlarged image of O is produced on the screen at H.

EXAMINATION QUESTIONS

INSTRUCTIONS. Before starting to answer these examination questions, you should have studied the lesson material at least three times. Be sure that you understand each question--then proceed to write the best answer you can. Make all answers complete and in detail. Print your name, address, and file number on each page and be neat in your work. Your paper must be easily legible; otherwise, it will be returned ungraded. Finish this examination before starting your study of the next lesson. However, send in at least three examinations at a time.

1. What is a transparent substance? Opaque substance? Translucent substance?

2. What is light and how is it produced? Describe each method briefly.

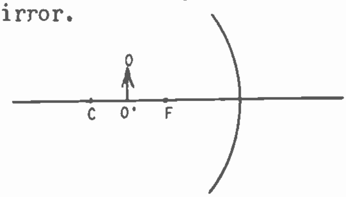
3. How does the intensity of illumination vary with distance?

4. What is the unit for measuring the intensity of a light source? What is the unit for measuring the intensity of illumination? What is the intensity of illumination at a distance of 5 feet from a 100 candlepower light?

5. What is the difference between diffused and direct reflection? Give an example of each. What is the law of reflection?

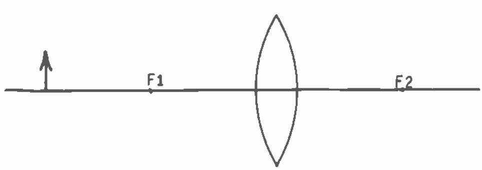
6. Distinguish between real and virtual images.

7. Draw a concave mirror. Mark and name the radius of curvature, focal point, and principal axis. Find by construction the image for the following concave mirror.



8. If in the above mirror R is equal to 20 inches and OO' is 1 inch, find the image distance Q and the image size II'.

9. Find by construction the image for the following lens.



10. Explain the cause of near-sightedness and how it can be corrected. Explain the cause of far-sightedness and how it can be corrected.

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UNIT NO. 5

PHOTOELECTRIC CELLS

LESSON NO. 4

A FELLOW WHO HAS

.....WHAT IT TAKES.

This is a true story of a fellow whom every one of us here at Midland admires, simply because he has proved that 'he has what it takes'. The name is fictitious, but the young man and his experiences are very real. We hope that they will be an incentive to you.

Dave Barnes, late of Mexico and other points south, was making a living doing radio service work in his father's radio shop. However, he realized that his knowledge of radio was very limited and that his earning power would be limited accordingly. So taking the 'bull by the horns' he burned his bridges behind him, came to Midland, and invested 'his all' for training.

Dave was a sincere, energetic student. He worked hard.. ..but he progressed. Then came the great day when his dreams were fulfilled. Midland sent him to a good job.....the kind of work he liked, and a future. During the time that he lived in Mexico, Dave contracted a disease that again struck him just as he seemed on the verge of success. An operation followed, and recovery was slow. Then Midland sent him to another job that required a physical examination. Dave could not pass. His operation had not completely healed.

Discouraged, but far from whipped, he came to our office to see if we could help him with his problem. Another job followed, but it was not the kind of work that Dave longed for, and the pay was on an hourly basis, with work uncertain. But he kept a smile on his face, and determination in his heart.

In a comparatively short period of time, we found radio employment for Dave in a mountainous section of the United States. True, it was a temporary job, but it lasted long enough to return Dave to radiant health. Again he came to our office, tanned, happy and healthy. He was convinced that he had won....and he had. Midland again put him on the job, doing the kind of work that he loved. Dave and his faith in his ability to win in spite of serious obstacles.....HAD WON.

Whenever obstacles confront you---fight all the harder, and you too will win.

Lesson Four

PHOTOELECTRIC CELLS

"Without the photoelectric cell there would be no television. Therefore I am sure that you will place the proper emphasis on your study of the material in this lesson.

"Besides the importance of the photoelectric cell in television it has many practical commercial applications. It is my belief that your training in the electronic arts would not be complete without a thorough understanding of the photoelectric cell and its applications."

1. HISTORY. The discovery of the photoelectric effect is credited to that extraordinary genius, Heinrich Hertz. That he may justly be called a genius is indisputable, in fact, the entire Radio and Television industries owe their very existence to the keen insight with which this scientist performed his tasks. Surely the photoelectric effect, could very easily have been undiscovered for many years. The changes brought about by the photoelectric phenomenon are very minute, and would have been passed over by a less observing intellect. Although the photoelectric phenomena involve almost inappreciable changes, we must not conclude that the discovery was unimportant. This lesson and the one that follows will reveal the many important uses to which this effect is applied.

In the year 1887, Hertz was performing his classical experiments on the effect of electrical discharges in one oscillatory circuit upon another similar circuit not directly connected. His apparatus consisted of an induction coil, a battery, an interrupter, a second induction coil, and a device for measuring the lengths of the sparks produced. The battery was connected to the first coil through the interrupter which opened and closed the circuit at a fairly rapid rate. A spark gap was provided across this coil, and vigorous sparking occurred when the apparatus was in operation. This action caused a voltage to be developed in the second coil which was also provided with a spark gap and a device for measuring the length of the spark produced. He discovered that the length of the secondary spark depended upon whether the first spark was visible from the position of the second coil. The sparks at the second coil were rather feeble and to observe them better, Hertz built a small box around this coil to exclude external light. This caused the length of the secondary spark to decrease. This could not be due to electrostatic or electromagnetic shielding, because the box was made of a non-conducting material. Therefore, he removed the various sides of the box separately, and discovered that only the side which obstructed the view to the primary spark made any difference in the length of the secondary spark. Seemingly, it is this small attention to details which is the determining factor between genius and mediocrity.

Hertz concluded that the ultra-violet radiation from the first spark was able to make the passage of the second spark easier. This discovery set other scientists to work in this field, and one of them, Wilhelm Hallwachs, made a rather interesting discovery. He took a polished zinc sphere, and insulated it completely. To the sphere, he connected a very sensitive electroscope. (An electroscope is a device to indicate very small amounts of charge.) Then, he charged the sphere negatively, and each time that the sphere was illuminated from the light of an arc, the electroscope showed that the sphere had lost its charge. This experiment could be repeated an indefinite number of times, although, if the sphere was charged positively, the light of the arc had no effect on it. Hallswach concluded that under the influence of ultra-violet light, negative electricity leaves a body and follows the electrostatic lines of force. This phenomenon is known as the Hallswach effect.

Other experimenters in the field were Elster and Geitel. They made remarkable advances in photoelectricity. They discovered that the alkali metals were photoelectric, and they conceived the idea of enclosing the photoelectric substance in an evacuated envelope. Their's was probably the first practical photoelectric cell.

As we shall learn later in this lesson, light has the ability of changing the electrical resistance of certain metals, notably selenium. This photo-conductive effect was known before the first experiments in photo-emission were made. Credit for this discovery is usually given to a telegraph operator named May, who in 1873 was using some rods of selenium as resistors in the Atlantic cable receiving station where he was working. He noticed that the resistance of the selenium depended upon whether light was falling on it or not. His discovery led to the development of the selenium bridge discussed in a later section of this lesson.

2. FUNDAMENTAL PHOTOELECTRIC PHENOMENA. Earlier in your studies you were taught that there were three methods by which electron emission could occur. These are thermionic emission, secondary emission, and photoelectric emission. The first of these has been considered at great length in the study of vacuum tubes used for amplification and rectification. The second is representative of what occurs in the dynatron oscillator circuit and which also takes place as an unwanted phenomenon in the operation of many tubes used for amplification. We are now ready to inquire into the third phenomenon which is the basic principle of many photocells. Through long years of intensive research it has been determined that electrons are released from the surface of many materials when radiant

energy is allowed to fall upon them. Usually, we think of a photocell as being sensitive only to light. Visible light, however, is confined to a relatively narrow band of frequencies in the electromagnetic spectrum and, since most photocells are influenced by frequencies lying both above and below the band known as visible light, it is more correct to state that photoelectric phenomena take place as the result of radiant energy.

In general, there are several types of light-sensitive devices. The first type to be considered is the photo-emissive variety, wherein the application of radiant energy causes the emission of electrons from a surface coated with a material which is affected by radiant energy of a certain band of frequencies. This type is represented by the common photoelectric cell which has the same basic principle as the iconoscope used in television. This lesson will deal with the construction and principle of operation of photoelectric devices, since a thorough understanding of their principles is absolutely essential before the subject of television may be approached. Further, it should be understood that in addition to their use in television, photoelectric devices play an important part in the industrial life of today. Every few days bring forth new uses to which the marvelous cells may be put. The list of operations which these cells accomplish is seemingly without end.

A complete discourse on the subject of photoelectricity would be very extensive and would necessitate the use of mathematics far beyond the scope of this lesson. Thus, instead of attempting to give the complete theory of photoelectric cells, we shall try to confine this discussion to more or less practical information with enough theory added to make this information understandable.

Visible light, as well as radiations outside of the visible spectrum, contains a definite amount of energy. In centuries past it was assumed that light consisted of small particles shot outward in straight lines from the luminous source. This was known as the corpuscular theory of light and the fact that light does travel in straight lines seemed to support this hypothesis. In later years it was proved by scientists working in this particular field that light is a wave motion, the same as ordinary radio waves, and that it differed from radio waves only in frequency or wavelength. This theory ties in more closely with some of the observed phenomena of light and has been quite satisfactory until recently. It is usual, however, to consider that with wave motion, energy is liberated continuously from the luminous source. It has been found that the idea of the continuous liberation of energy is not consistent with many phenomena closely associated with photoelectricity. Instead, many experiments have indicated that the energy radiated from a luminous source and that received by a photoelectric substance is not continuous but rather consists of "bundles" of energy. Each bundle of energy is known as a "quantum," the plural of which is "quanta." The actual energy represented by a quantum is extremely small, but varies with the frequency of the radiant energy. As a quantum of energy reacts with an electron of the photo-sensitive material, the electron receives the entire quantum which is now represented by the kinetic energy of the electron. The kinetic energy of any body depends upon the mass of that body and its velocity and, since all electrons have the same mass, each electron which has reacted with a quantum of radiant energy from a definite luminous source will have imparted to it a definite velocity.

The actual velocity with which a given electron leaves the surface of the photo-sensitive substance will depend upon how much opposition that electron has encountered in escaping. Naturally, there are forces present which tend to hold the electron to the surface. These are the forces which the nuclei of the various atoms have for their planetary electrons and, in order for an electron to escape, it must have sufficient energy (represented by its velocity) to overcome these attractive forces. Of course, surface electrons will experience less opposition than will those in the interior, but for any particular material there will be a minimum velocity which the electron must possess in order for it to be liberated. The energy of an electron leaving the surface will be the quantum of energy which it received, less the energy expended in overcoming the forces of attraction tending to hold it to the surface. As stated before, every electron will not expend the same amount of energy in escaping, but the minimum amount which must be used is called the work function of that particular material.

The amount of energy represented by a quantum increases directly with the frequency of the radiant energy being received. Thus, as the wavelength of the radiation is reduced, each electron will receive more energy and the velocity with which any given electron escapes the surface of the material would be correspondingly increased. From the foregoing there can now be formulated two general laws:

1. *The number of electrons released per unit time at a photoelectric surface is directly proportional to the intensity of the light falling on that surface.*

2. *The maximum energy of electrons released at a photoelectric surface is independent of the intensity of the light, but is directly proportional to the frequency of the light.*

The validity of the first law is obvious, since a larger intensity of illumination would indicate that there are more quanta present to react with the electrons, and consequently more would be released. The second law follows from the fact that as the frequency is raised each quantum represents a larger bundle of energy and thus the average velocity of the escaping electrons would be greater. Of course, the maximum energy would be possessed by those electrons near the surface which are liberated with comparative ease.

A decrease in the frequency of the radiant energy reaching the photoelectric material causes the quanta so radiated to contain less energy. Unless the quanta contain a certain minimum amount of energy, even those electrons near the surface of the material will not receive enough energy to allow them to overcome the retarding forces which tend to prevent their liberation. Thus, there is a minimum frequency which the radiant source may have to cause the emission of electrons from a given photoelectric material. This minimum frequency is called the "threshold frequency" of the particular material involved and its reality has been proved by experiment.

The work function, as stated before, is the amount of work which the electron must do in order to leave the photoelectric material. It is, of course, the least work function which is of the most interest, since this number represents the least amount of work which the electrons escaping with the most energy must do in order to be liberated. Since the work function represents a definite amount of energy it must be expressed in some energy unit. The most common unit used for extremely small amounts of energy is the electron-volt. This unit represents the amount of energy that would be acquired by one electron in falling through a potential difference of one volt. The usual method of determining the least work function of a photoelectric material is by illuminating the surface with monochromatic light (that is, light of just one frequency) and measuring the smallest reverse voltage which must be applied to prevent electrons of maximum energy from reaching a second electrode. The following table shows the least work functions for several photoelectric elements.

	VOLTS		VOLTS
Lithium	2.36	Caesium	1.36
Sodium	1.82	Calcium	2.40
Potassium	1.55	Strontium	2.00
Rubidium	1.45	Barium	1.70

It is seen that caesium has the least work function of any of the materials listed in the table and thus it would be the most suitable for use in photoelectric cells since it requires less energy to release electrons from this material than from any other. Only those elements listed in this table have small enough work functions to allow their use in practical cells, although nearly any element is slightly photoelectric. When the work function of a material is high, it not only requires a comparatively large amount of energy to cause the liberation of the electrons, but the threshold frequency is very high (above that of visible light) so that such a cell could not be used with many light sources.

3. THE PHOTOELECTRIC CELL. In order to make use of the photoelectric phenomenon, the photo-emissive substance must be enclosed within an evacuated cell. Such a cell has two electrodes; one, the electrode from which the photoelectric emission takes place, and usually called the cathode, and two, the electrode which collects the emitted electrons, normally known as the anode. In order to cause the anode to attract the photo-electrons which have been emitted from the cathode, the anode is made positive with respect to the anode just as in an ordinary thermionic tube. In Fig. 1, there is illustrated a photocell, a resistance load, and an anode battery. The symbol shown in this circuit is the one commonly used to represent a photocell. As light strikes the photo-sensitive cathode, electrons are emitted, which are then attracted by the

positive anode and flow through the load resistance, the battery and back to the cathode. The voltage developed across the load resistance and the current flowing through it are directly proportional to the quantity of light falling upon the cathode. If this quantity of light is changing at some predetermined rate, the voltage built up across the load resistor will change at the same rate, and after amplification, may be used for various purposes.

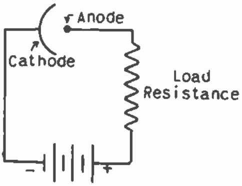


Fig. 1 A simple photocell circuit.

The output current from the cathode is extremely small; seldom over a few microamperes. So far as the efficiency of energy transfer is concerned, the photocell is notoriously inefficient. Of the total energy represented by the light falling on the cathode, only a very small fraction is actually available for producing a current flow. Much of the energy is lost due to the reflection of light from the cathode surface and much is converted into heat. Many of the quanta which react with the electrons do not impart to them sufficient energy to cause their liberation. Just how efficient any given photocell is depends upon the material of which its cathode is made in addition to other factors which determine the efficiency in a complex manner.

In many photocells, there will be some cathode current even when there is no anode battery in the circuit. Some of the photoelectrons are emitted with sufficient velocity to carry them to the anode even when the anode offers no attraction to them. The application of a small anode voltage will naturally increase the current flow since the anode will now attract electrons which were not emitted with velocities which would direct them to the anode. Increasing the anode voltage causes a further increase in current flow; the electrostatic field created between the anode and cathode becomes more intense, thereby accelerating those electrons which had been emitted with comparatively low velocities, and causing them to reach the anode. A continued increase in the anode voltage finally results in saturation. A point is reached at which all the electrons emitted are now being collected by the anode and a further increase in anode voltage would not produce an increase in the current flow. This saturation voltage for a given quantity of light falling on the cathode is dependent on several factors, among which are the accumulation of space charges on the walls of the cell, the size of the collecting anode, and the presence of residual gases within the cell. A negative charge accumulation on the clear glass walls of the cells would tend to retard the release of other electrons from the cathode. A small anode would probably cause a congestion of negative charges as the electrons approached it, and the presence of these charges would tend to neutralize the electrostatic field between the anode and cathode which is causing the electron collection by the anode.

Naturally, the current which does flow in the circuit containing the photocell will depend on the quantity of light received by the cathode. This will be determined by the luminous intensity of the light source, its distance from the cathode, and the area of the cathode. As you will remember, the luminous intensity of a light source is measured in candlepower, whereas the intensity of illumination is expressed in the unit "foot-candle." A surface placed one foot from a luminous source with an intensity of one candlepower is illuminated to the extent of one foot-candle. Now, the total quantity of light falling on this surface measured in lumens is equal to the product of the intensity of illumination in

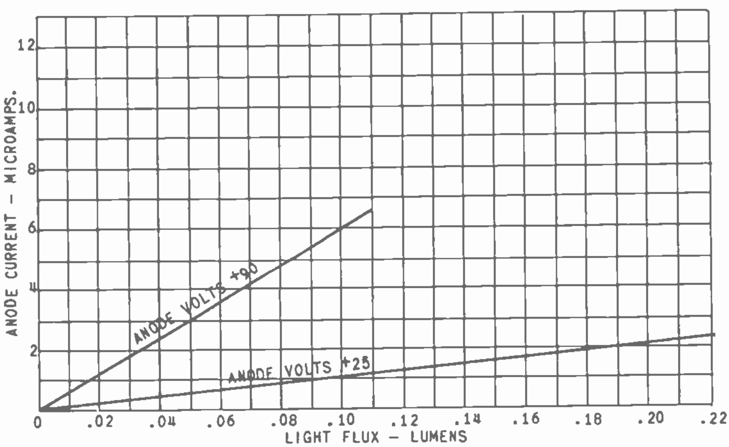


Fig.2 Relation between light flux and photocell output of a vacuum cell.

foot-candles and the area of the surface in square feet. For example, assume that a photoelectric cell has a cathode area of two square inches, which is approximately .0139 square foot. This cell is placed 2 feet from a light source with a luminous intensity of 20 candlepower. The intensity of illumination on the cathode surface is:

$$\frac{20}{2^2} = \frac{20}{4} = 5 \text{ foot-candles}$$

The quantity of light falling on the cathode is:

$$5 \times .0139 = .0695 \text{ lumen}$$

Now, as stated in the first general law, the number of electrons emitted by the cathode is directly dependent upon the quantity of light falling on the cathode so that the graph showing the relationship between the light flux and the cathode current should be a straight line. That this is true is illustrated in Fig. 2. The horizontal scale of this grpah is graduated in fractions of a lumen, whereas the vertical scale is graduated in microamperes. Two lines are shown on this graph; one is for an anode voltage of 25 volts and the other is for 90 volts. Notice that in either case the current is directly proportional to the light flux; that is, equal changes in light flux produce equal changes in cathode current.

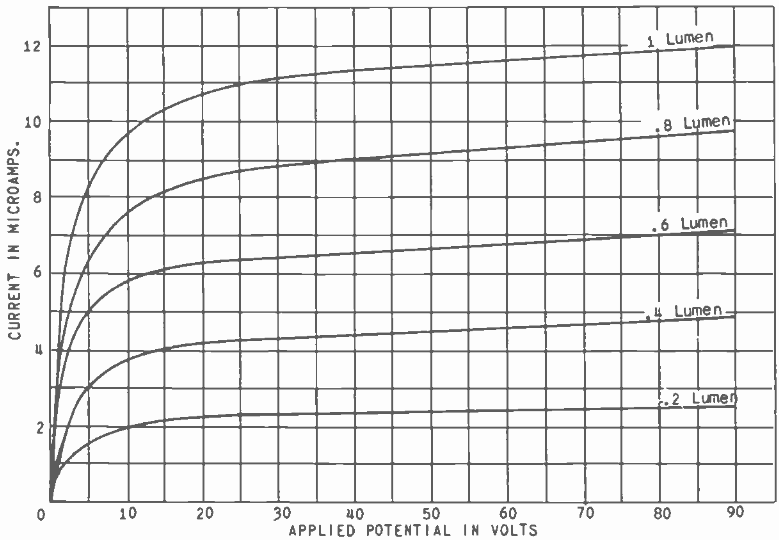


Fig.3 Relation between anode voltage and output of a vacuum cell.

A set of curves showing the relationship between the anode voltage and the current for different values of light flux is given in Fig. 3. It may be seen that the cathode current is not directly proportional to the anode voltage. When the anode voltage is very low, a small increase in this voltage will cause a comparatively large increase in the current flow, whereas after the anode voltage reaches a certain value, the curves flatten out, indicating that saturation has occurred. At this time, the anode is collecting practically all of the electrons which the given amount of light flux is producing.

In order to compare different photocells, a sensitivity rating is given to each. This sensitivity is expressed as so many microamperes per lumen. This gives the amount of cathode current that will flow when the cell is receiving one lumen of light flux. Of course, the anode voltage must also be given since increasing it will make the sensitivity greater. It is usual, however, to state the sensitivity assuming that the anode voltage is sufficient to produce saturation. The high-vacuum photocells which we have been considering will have average sensitivities of approximately 20 µA per lumen. Later in this lesson, we shall discuss gas-filled cells whose sensitivities are considerably greater.

4. COLOR RESPONSE OF PHOTOCELLS. It has been determined by experiment that a photocell is not equally sensitive to radiant energy of different wavelengths. That this should be true is indicated by the second general law given previously. This law states that the maximum energy of the emitted electrons is directly dependent on the frequency of the energy being received. Thus, light of lower wavelengths should produce a greater output from a cell than light having a high wavelength. That this is true, in part at least, will be demonstrated later. In the preceding lesson, it was learned that the visible spectrum extends from approximately 4,000 Angstroms to 8,000 Angstroms. Although it is true that the eye is sensitive to all wavelengths within this range, it is not equally sensitive to all of them. The normal visual sensitivity curve is given in Fig. 4. It is seen that the sensitivity at 4,000 Angstroms is rather

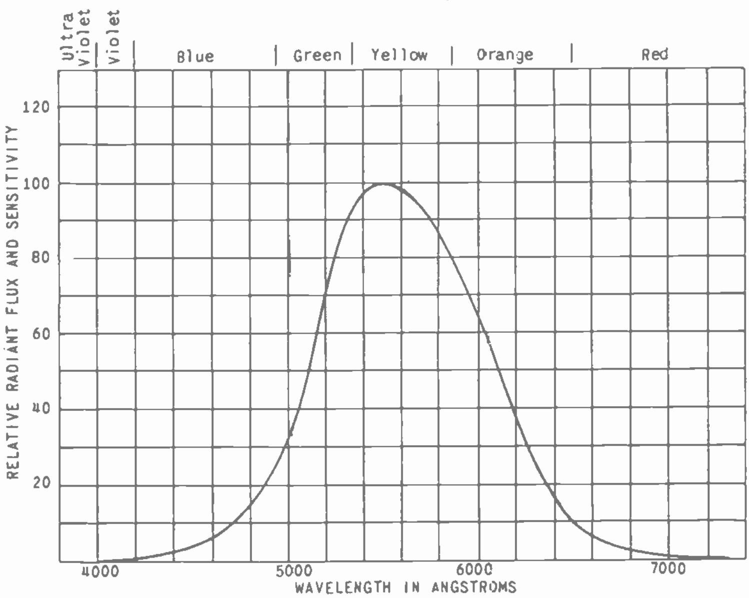


Fig. 4 The visual sensitivity curve.

low, and that the sensitivity rises, reaching a peak at 5,500 Angstroms, after which it decreases, becoming zero just under 8,000 Angstroms. The color perceived by the eye when it is receiving radiant energy of a wavelength of 5,500 Angstroms, is a brilliant yellow. Thus, if a yellow light and a red light of equal radiant energies were compared by the eye, the yellow would appear to be the brighter.

According to the theory established by the second general law, the photoelectric current should continue to increase as the radiant

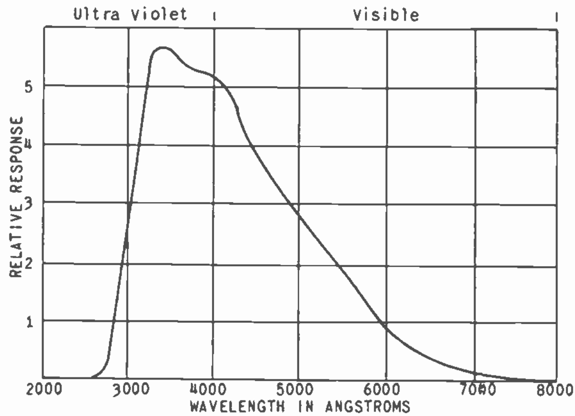


Fig. 5 Color response of a caesium-magnesium cell.

energy being received becomes shorter in wavelength. Actually, however, this does not occur; instead the response increases as the wavelength is reduced, reaches a peak, after which the response decreases. For example, consider Fig. 5, which illustrates the color sensitivity curve of a caesium-magnesium photocell. The response rises as the radiant energy decreases from 3,000 Angstroms to approximately 3,300 Angstroms. At this point it reaches a peak, and energy of lower wavelengths produce a lowered output. This is probably due to some resonant condition within the atom of the photo-sensitive substance, which causes energy of a particular wavelength to create a greater response than either a higher or lower wavelength could cause. There is also one other factor which reduces the output of a photocell as the energy becomes lower than some given value. This is the transmission characteristic of the envelope. The envelope surrounding the tube is a transparent material usually some grade of glass, and glass does not transmit radiant energy of all wavelengths equally well. There is a gradual reduction in the transmission capability of glass as the wavelength is reduced. Thus, ordinary glass will transmit wavelengths down to about 3,000 Angstroms, and even though the cell might respond to wavelengths below this value, the glass envelope does not permit their passage to the photo-sensitive surface. Fig. 6 illustrates the color sensitivities of caesium-oxide photocells using glass of various grades; it is noticed that quartz must be used for the envelope, if it is desired that the cell respond to very low wavelengths corresponding to the ultra-violet.

Since the photoelectric effect is a surface phenomenon, the emission is not determined solely by the chemical composition of the cathode. The residual gas which is left in the cell forms a layer on the photo-sensitive surface and thus changes the output as well as the color sensitivity. Cells of the same general type made by different manufacturers may have totally different color sensitivities. This fact is illustrated by the curves of Fig. 7.

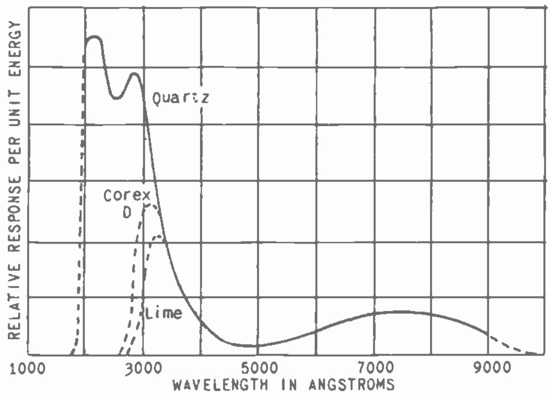


Fig.6 Color response of a caesium-oxide cell with different types of envelopes.

Furthermore, it has been determined that the output and color sensitivity are greatly affected by the thickness of the photo-sensitive film. The subject of films will be discussed later in this lesson.

Just what the color sensitivity of a photocell should be depends upon how it is to be used. In some special applications, it may be desirable that the cell respond to very short wavelengths. In such a case, it should be sensitive to the ultra-violet, and have an envelope of quartz. If the cell is to be used for color matching, it should have the same wavelength-output response as the average human eye. This is sometimes accomplished by enclosing the cell in what is known as a visual filter. This filter has a frequency-transmission curve which is nearly identical with the normal visual sensitivity curve. In the majority of applications, however, the photocell is illuminated with an ordinary incandescent lamp, and should, therefore, be most sensitive to the wavelengths which

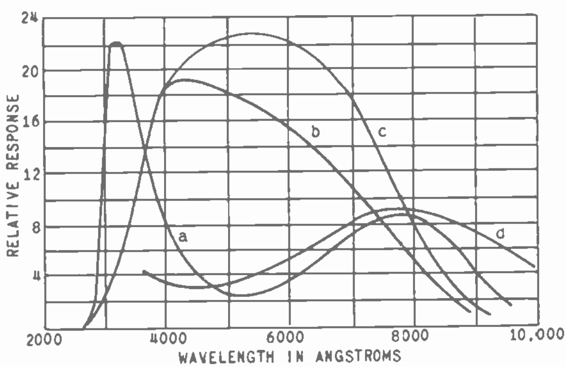


Fig.7 Color responses of different types of caesium-oxide cells.

the lamp radiates. The filament of a tungsten lamp appears reddish-yellow to the eye, indicating that most of the energy radiated is of long wavelength; in fact, there is very little energy radiated at the shorter wavelengths. The curve shown in Fig. 8 gives the relative output of the tungsten lamp at various wavelengths, and it is seen that the peak energy is radiated at a frequency which is in the infra-red, just outside of the visible spectrum. A photocell with a color sensitivity curve approaching the radiation curve of heated tungsten would give maximum response when illuminated with an ordinary Mazda lamp. This property is made use of in photocells employed with certain types of burglar alarms. The light source is covered with an infra-red filter, which eliminates practically all of the visible radiation without appreciably affecting the longer wavelengths. Thus, the beam actuating the photocell is invisible and is not easily avoided by an intruder.

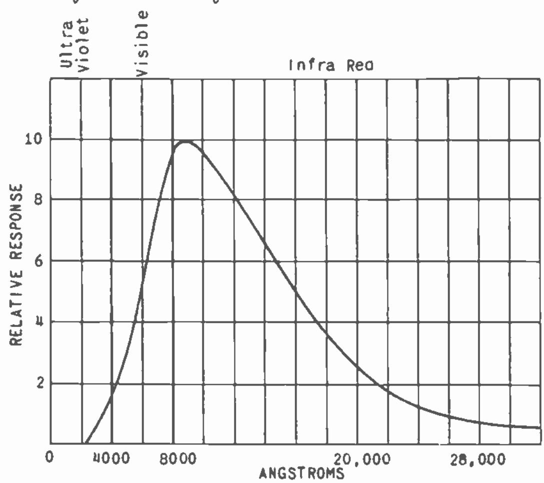


Fig.8 Showing the wavelengths of the energy radiated from a tungsten lamp.

5. PHOTOCELL CONSTRUCTION. The earliest observations of the photo-emissive effect were made from elements or compounds in bulk; that is, the actual cathode area was simply the bounding surface of a volume of given material. Most of the photo-sensitive materials, however, are substances which are not mechanically strong enough to be self supporting and so later developments led to photoelectric films, in which the sensitive material was coated on a cathode foundation composed of a material whose strength was sufficient. Later it was learned that the thickness of this film has a most important bearing on the output of the cell. In one instance, a potassium cell happened to be connected backwards in a circuit; that is, the positive terminal was connected to the cathode and the negative to the anode. Normally, it would be thought that the cell could not pass current with this connection, but, curiously enough, it was discovered that even though the anode was much smaller in area than

the cathode, the cell yielded a larger backward current than it did when connected properly. This occurrence led to exhaustive research and it was discovered that the normal anode was covered with a very thin film of potassium which had settled there after distillation from the cathode at normal room temperature. Thus, there was not as much emission from the normal cathode upon which a rather thick film of potassium had been deposited as from the normal anode with its extremely thin film.

Research with photoelectric films increased, and it was learned that maximum sensitivity resulted when the film of photoelectric material was deposited with a thickness of one atom. All attempts to explain this have centered around the phenomenon of contact potentials. When studying thermocouples, we learned that a contact potential results at the junction of two dissimilar metals. Thus, if the base metal on which the film is deposited is properly chosen, the contact potential between the two will aid in the liberation of

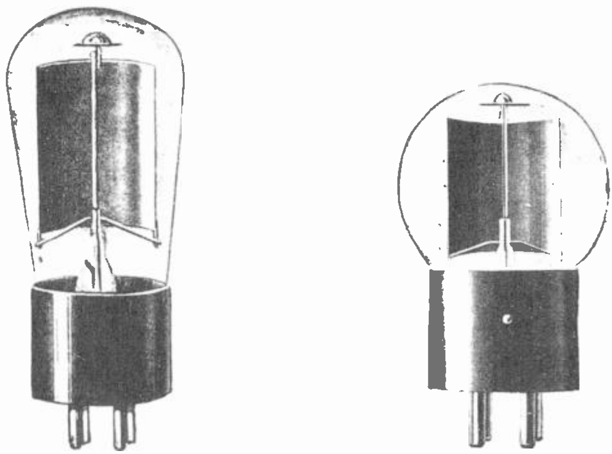


Fig.9 Two types of photo-emissive cells.

electrons from the photo-emissive surface. If the film is rather thick, the surface electrons will be too far removed from this contact potential to receive aid from this source, but if the film is only one atom thick, the surface electrons will be given an added push by the contact potential, with the result that the least work function of the photoelectric material is lowered.

Since the added advantage of using thin films was discovered, much work has been done in this field and modern photocells have multi - layer cathodes in which very thin films of different substances are deposited on a base material. Of particular interest is one cell which has high sensitivity to light radiated from a tungsten lamp. The cathode of this cell consists of a substratum of silver on which are deposited in order, oxygen, caesium, silver, caesium. The highest sensitivity of any cell announced to date consists of a cathode formed by allowing a monomolecular film of caesium to deposit on a mixture of oxides which comprise a rather thick layer. A vacuum cell of this type may have a sensitivity as high as 65 μA per lumen.

In the most modern type of photocell, the cathode is semi-cylindrical, and is supported in the middle of the envelope by wires which are sealed into the glass stem. The anode consists of a straight vertical wire or rod extending the full length of the cathode and it is similarly supported. The anode occupies a position corresponding to the center of curvature of the cathode. Naturally, the greater the surface area of the cathode, the larger will be its output current, but manufacturing difficulties make it impractical to use a cathode much larger than two or three square inches. Two such cells are illustrated in Fig. 9.

Another type of photocell uses a cathode which has been deposited on the inner surface of the envelope itself. Of course, a small opening of clear glass must be left to admit light. The glass is first silvered and then the photo-sensitive material is deposited; the small window is obtained by heating a portion of the glass to cause the evaporation of the material from that part. This type of cell ordinarily employs a cathode in the shape of an open circle, as illustrated by the photograph in Fig. 10.

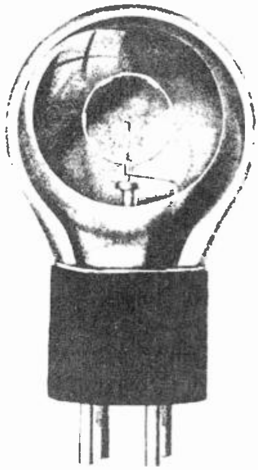


Fig.10 A photocell with the anode in the form of a ring.

Since the photocell currents are at best extremely small, it is necessary that the leakage resistance between the electrodes be large so that the leakage current will not obscure the current obtained by photoelectric effect. Leakage paths between the electrodes are ordinarily produced by allowing some of the sensitive material to condense on the glass stem at the point where the lead wires protrude. A simple expedient in eliminating this difficulty is to have the terminals at opposite ends of the cell so that the path between the lead wires will be as long as possible. The better photocells have leakage resistances of thousands of megohms, and the leakage current is negligible.

At present most photocells have cathodes made of caesium and magnesium, or else caesium and caesium oxide, while potassium cells find a limited application. For general work, the caesium-oxide cell has supplanted the other types, due to its greater red sensitivity. In its most sensitive form, the cathode consists of a monomolecular film of caesium deposited on a substratum of caesium oxide which in turn has been built up on a silver surface. The cathode base metal may be either solid silver or silver-plated copper. It is bent into the form of a semi-cylinder with a coaxial wire serving as the anode. A disc of nickel with a special pocket containing a small pellet is welded to the top of the anode. The pellet is composed of caesium compounds. The electrodes, together with their mounting assembly are sealed into a glass bulb, and the cell is then exhausted and baked to remove absorbed gas. After it cools, a small quantity of oxygen is admitted to the tube which is still on the exhaust pump to convert a part of the silver into silver oxide. The application of a fairly high voltage between the anode and cathode causes a glow discharge and the oxygen unites with the silver. The process of oxidation is observed by watching the color of the silver, which changes to a bright green. A high-frequency coil is used to heat the pellet, which explodes, depositing the caesium on the surface of the cathode. The temperature of the tube is lowered to about 200° C, and the excess caesium vapor is absorbed by a special paint which has previously been applied to the back of the cathode and the lead-in wires. As the baking continues, the cathode becomes dark gray, and at the point where the edges of the cathode begin to turn light in color, the baking is discontinued and the cell is sealed off.

6. GAS-FILLED CELLS. The cells which we have been discussing are of the high-vacuum type; that is, they have been exhausted to such an extent that the residual gas plays no part in determining the current flow. For many purposes cells of this type are advantageous. Since the electrons have negligible mass, high - vacuum cells will respond to light fluctuations of very high frequency with excellent fidelity. Such a characteristic is necessary for sound motion pictures and television applications. The foregoing property is summed up in the statement that the dynamic response of a vacuum cell does not vary with the frequency of modulation of the incident light. The static sensitivity of a cell is the current that flows as a result of 1 lumen illumination. Likewise, the dynamic sensitivity is the change produced in the current flow by a small change in the received light. The dynamic sensitivity tells how well the cell will respond to light changes and is analogous to the constant, transconductance as used with amplifier tubes.

The vacuum cell has one outstanding disadvantage; its output is extremely low. To increase this output, the gas photocell was devised. So far as physical construction is concerned, the gas cell is identical with the vacuum cell, the only difference being that at the time of manufacture a small quantity of some inert gas is introduced into the cell which will influence the current flow. The output of the gas cell is several times greater than that of a vacuum cell due to the so-called gas amplification which results.

The process is one of ionization, whereby the electron stream is increased by additional electrons dislodged from the inert gas molecules by the primary electrons.

There are always a few free electrons in any volume of gas and if a potential is applied across the electrodes between which the volume of gas is present, these electrons will accelerate toward the anode. As the electron accelerates, its velocity increases, indicating that it is gaining kinetic energy. If the voltage is great enough and the electron has a long enough unobstructed path to allow it to gain sufficient energy, it will dislodge an external electron from one of the gas molecules with which it may collide. Both electrons will continue to accelerate toward the anode and both may in turn free other electrons from gas molecules. Thus, the total number of electrons reaching the anode is much greater than could be accounted for by the primary photo-electron emission. The gas molecules which have lost an electron are now positively charged ions and will, since their mass is large, accelerate slowly toward the cathode. The intensity of the ionization will increase until the rate of liberation of electrons from gas molecules is equal to the rate of recombination of the positive ions with electrons which may be gained from the electron stream or directly from the cathode itself. At this point a state of equilibrium is established, and the intensity of the ionization remains constant.

Just how intense the ionization will be and, for that matter, whether ionization will take place or not, depends upon several factors. These are: the applied potential, the number of atoms of gas per unit volume (determined by the pressure of the gas), and the nature of the gas itself. For an electron to cause the liberation of another electron from a gas molecule, it is necessary that the primary electron possess a certain minimum amount of kinetic energy. This minimum energy depends upon the nature of the gas molecules, some gases requiring that more energy be expended than others. Instead of expressing this minimum energy in common energy units, it is customary to state the potential through which an electron must fall to acquire this amount of energy. This potential is known as the ionizing potential of that particular atom; it is the same for all molecules of a given gas. The following table records the ionizing potential for a number of gases.

	VOLTS		VOLTS
Hydrogen	13.3	Krypton	13.3
Helium	25.6	Xenon	11.5
Neon	21.5	Nitrogen	16.9
Argon	15.1	Oxygen	15.5

There are a number of points which dictate which gas should be used. First, the gas should be inert so that it will not attack chemically the rather delicate photo-sensitive surface of the cathode. Second, it should be a gas of a reasonably low ionizing potential. Third, it should be a gas which exists in abundance so that its cost will not be exorbitant. After all of these factors have been taken into account, it is found that argon is the best suited. There are other gases having a lower ionization potential than argon, but they are either chemically active, or so rare that their expense would make their use prohibitive.

Before the subject of ionization can be fully understood, it is necessary that we investigate what is meant by the mean free path. In any gas at a definite temperature and pressure, there are a certain number of collisions per second between the atoms themselves, and the atoms and free electrons. As the pressure of the gas is reduced by partial exhaustion, the number of atoms per cubic centimeter becomes less, and fewer collisions result per unit time. This means that the average length of the path traveled by an electron before it collides will be longer. A continued reduction of the pressure will lengthen the average path traveled between collisions until this path is greater than the distance between the electrodes. This average distance traveled by an electron between collisions is known as its mean free path. Due to the fact that the electron is much smaller in size than the molecules, the mean free path of an electron is greater than that for a molecule.

When a potential difference is present between two electrodes, a free electron will accelerate toward the anode. Just how far it travels before a collision, will depend upon the length of the mean free path which in turn is determined by the pressure of the gas. If, in traveling through its mean free path, an electron falls through a difference of potential equal to the ionizing potential of the gas, it will gain sufficient energy to produce ionization. Furthermore, the difference in voltage through which it falls will depend on the voltage applied between the electrodes. This brings us to the subject of voltage gradient.

The voltage gradient is defined as the voltage per unit distance between the electrodes, and is usually measured as so many volts per centimeter. For example, if the distance between the electrodes is two centimeters and the applied voltage is 100 volts, the voltage gradient is 50 volts per centimeter. (This assumes that the voltage gradient is uniform throughout the field, and will not be strictly true when a source of emission is present.) It may be proved that ionization will take place when the product of the mean free path in centimeters and the voltage gradient in volts per centimeter is equal to the ionizing potential. For example, let us take a gas filled tube in which the gas is argon. The pressure has, let us say, been reduced to the point where the mean free path of an electron is .24 centimeter. This means, that on the average, an electron will travel .24 centimeter before colliding with a gas molecule. The ionizing potential of argon is about 15 volts, and if ionization is to take place, the electron must fall through 15 volts in traveling this .24 centimeter. Thus, a voltage of 15 volts must exist across each .24 centimeter in the distance between the electrodes. This amounts to 15÷.24 or about 60 volts per centimeter. If the electrodes are spaced two centimeters apart, the total voltage applied between them must be 120 volts for ionization to occur.

The foregoing theory must be modified somewhat to be strictly correct. It is, of course, obvious that some electrons will have longer paths between collisions than the mean free path, and ionization will actually begin at lower gradients than the preceding theory would indicate. Further, except in the case of two parallel, flat, metal plates, the voltage gradient will not be uniform. With a semi-cylindrical cathode and a co-axial anode, the electrostatic field will be much stronger near the anode than near the cathode, indicating that the voltage gradient will be larger near the anode. Thus, the voltage gradient will depend on the size and shape of the electrodes.

It should be realized that the same reasoning will explain the operation of a vacuum photocell. The action of the vacuum cell is not due to the fact that the air is entirely exhausted. In fact, even in the best vacuum obtainable there are several billion gas molecules per cubic centimeter. Rather, in the vacuum tube the mean free path of the electrons is so long that most electrons will travel from the cathode to the anode without encountering any gas molecules. In an average high-vacuum photocell, the mean free path for high speed electrons is about 400 meters. Further, it should be evident that for a given electrode spacing, and a particular gas, there is an optimum pressure for which ionization will occur with the least amount of voltage between the electrodes. When the pressure is too high, the mean free path is short, and the voltage gradient would have to be very large to cause ionization. Also, when the pressure is too low, the mean free path is very long, and the chances of an electron colliding with a gas molecule are remote.

In the gas-filled photocell, the primary source of free electrons are those emitted from the light-sensitive cathode. However, if the ionization becomes sufficiently intense, the ions will strike the cathode with a force great enough to liberate electrons from the cathode. This, in part, explains the greater amplification that can be obtained with a gas photocell. The gas amplification of the cell is the ratio of the total ionization current to the electronic current, and if the cell is to be stable, the ratio should not be greater than 10. If the applied voltages are too great, the number of electrons released at the cathode by the positive ions will be sufficient to maintain the ionization even after the photoelectrons are stopped by removal of the light source. In this condition a glow discharge is present across the cell and severe damage usually results to the cathode.

Since the greatest amount of gas amplification is obtained just below the glow discharge point, the anode voltage is quite critical in gas photocells. The voltage which will initiate a glow discharge depends on the illumination, and cells using high anode voltages must be protected very carefully from intense illumination. The anode voltage, cell current relationship for different amounts of light is illustrated in Fig. 11. Notice that with large amounts of light, the current rises very rapidly as the voltage is increased. A set of curves illustrating the relationship between the current and the amount of light received is shown in Fig. 12. For very low voltages the action of the cell is practically the same as that of the vacuum type. With higher voltages, however, the relationship between the flux and the current is no longer linear, and it is therefore evident that the gas photocell is not suitable for applications such as photometric measurements.

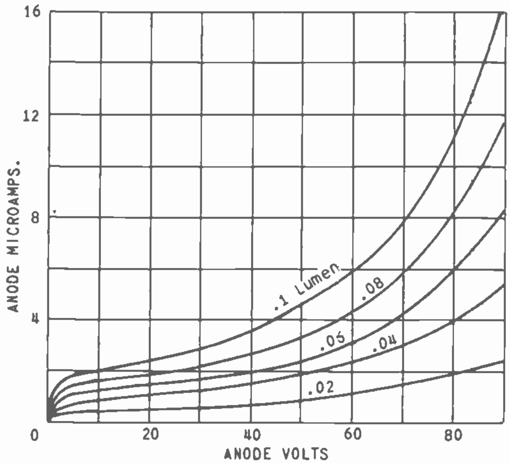


Fig.11 Relation between the anode voltage and the output of a gas cell.

You must remember that if a photocell is allowed to reach the glow discharge state, the cathode will be ruined almost immediately, due to ion bombardment. As an example of how such a condition could occur, let us consider the following circumstances. If a cell were being operated with an anode voltage of 90 volts and received a light intensity of .4 lumen, the anode current would be approximately 25 microamperes (see Fig. 12). This is near saturation for this type of cell. Now if the light striking the cell were suddenly increased from .4 to .8 lumen, a serious glow discharge would be started and the cell ruined.

The gas cell has one more disadvantage in that its dynamic sensitivity decreases as the modulation frequency of the light source becomes higher. Remember that the dynamic sensitivity tells how much the cell current will change for a small change in light

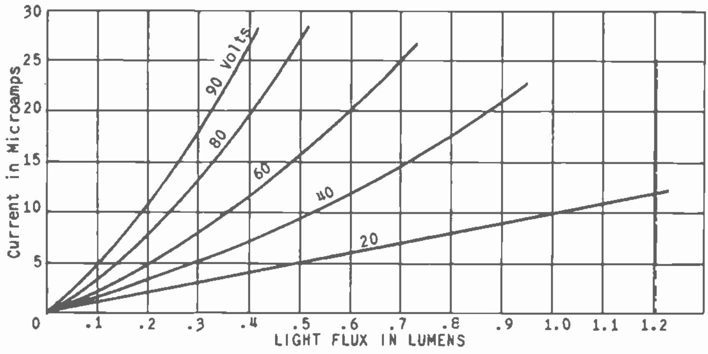


Fig.12 Relation between the light flux and the output of a gas cell.

flux. A decreased sensitivity at the higher light modulation frequencies indicates that the cell will have a smaller output for high frequencies than low ones. Such a cell could not be used for high-definition television, since its response to the high frequencies would be greatly attenuated. This fact is brought out by the curves in Fig. 13. They show the ratio of response of a gas cell to that of a vacuum cell for different anode voltages and for various light modulation frequencies. With 90 volts on the cell, the response to a steady light flux (one of zero frequency) is nearly twenty times that of a vacuum cell. As the frequency of the light flux is increased to 10,000 cycles, the ratio decreases to less

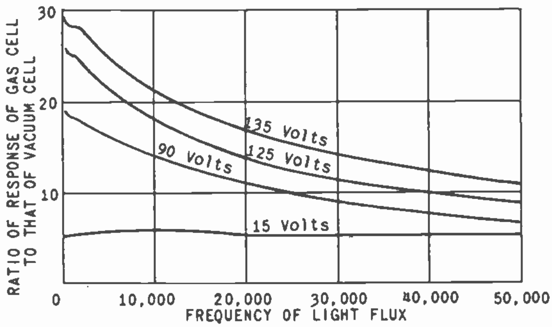


Fig.13 A comparison of the outputs of a vacuum cell and a gas cell at different modulation frequencies.

than 15. The higher the anode voltage, the greater is the percentage drop as the frequency is raised. With a low anode voltage, such as 15 volts, the curve is nearly flat, indicating that the response of the gas cell approaches that of the vacuum type, and that the response is nearly equal for all frequencies of light flux.

This dropping off of the output at high frequencies is due to the fact that the positive ions travel toward the cathode at a comparatively slow rate. When the light flux is diminished, there is a finite interval during which these ions are still traveling

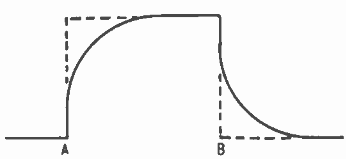
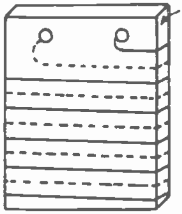


Fig.14 Illustrating the time lag of a gas cell.

toward the cathode. As they strike the cathode, they release secondary electrons which add to the electron stream. Thus, there is a definite de-ionization time, and a very small fraction of a second is required for the ions to recombine to form neutral atoms, and thus diminish the cell current. It is evident that the greater the rate of change of the light flux, the smaller will be the changes in cell current, since the intensity of the ionization cannot change instantaneously. Thus, the dynamic sensitivity of the cell becomes smaller for higher frequencies. Fig. 14 illustrates the effect of applying a rectangular light pulsation to a gas cell. At point A, the light is turned on, and continues to illuminate the cell during the time represented by the distance AB; it is then turned off. The cell current does not immediately rise to its final value with the turning on of the light, nor does it immediately fall to zero when the light is extinguished.

7. PHOTO-CONDUCTIVE CELLS. We are now ready to discuss another type of light-sensitive device. It is the so-called photo-conductive cell. Unlike the cells previously discussed, the application of light does not cause an emission of electrons, but does change the conductance of the cell. The material most widely used for this purpose is the metallic element selenium. Selenium has the peculiar property of changing its electrical resistance as its illumination is varied. Other materials which show this photo-conductive property are certain sulphides of antimony, bismuth, molybdenum, silver and lead; complex sulphides of various combinations of these elements, and the compound thallium oxysulphide. Of all these materials only selenium and thallium oxysulphide are free from certain characteristics which would render them unsuitable for practical use.

Fig.15 Showing how the grid of a photo-conductive cell is made.



Selenium exists in several different forms, of which only one, the grey crystalline type, shows any marked degree of photo-conductivity. The resistance variation with respect to illumination is such that an increase in the amount of light falling on a piece of selenium causes its resistance to be reduced. Even with a large amount of illumination, the resistance of a selenium cell is very high, usually several megohms. In order to make use of this property of selenium, a so-called selenium bridge is designed. One method of making this bridge is to wind two fine wires around a small glass plate as shown by the drawing of Fig. 15. Each wire goes to a terminal, and there is no direct connection between the two wires. Selenium is now spread over this flat plate, and is heated causing it to soften and adhere to the glass and wires. The excess material is scraped off and the plate is then annealed, a process which changes the selenium into the grey crystalline form. Such a cell is used in the circuit shown in Fig. 16. The selenium completes the electrical path between the two fine wires on the glass plate, and the total resistance of the circuit changes as the amount of illumination is varied.

Even though the selenium connects the two wires together for a considerable portion of their length, the dark resistance of this cell is several megohms. Although the photo-conductive effect can take place in the open air, exposing the cell to the air causes a deterioration of the selenium due to chemical change. For this reason, it is customary to enclose the cell in a glass tube which is evacuated and subsequently filled with some inert gas such as helium or argon. The presence of the argon tends to carry the heat generated away from the cell by convection and thus allows the cell to dissipate more power.

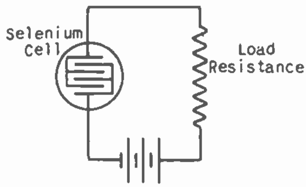


Fig.16 A simple circuit using a selenium bridge.

It is probable that the effect of light is to release electrons within the selenium, thus giving more free electrons to produce the current flow. As these electrons travel through the substance some of them will unite with positive ions, and sooner or later a point of equilibrium is reached when the rate of release of electrons is equal to their rate of recombination. When the light is removed, the rate of recombination exceeds the rate of release, the number of free electrons present is decreased and the resistance of the cell becomes larger.

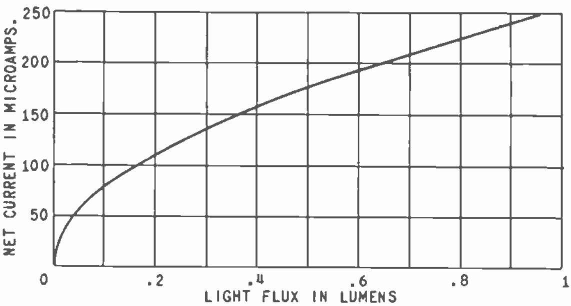


Fig.17 Relation between light flux and output of a selenium bridge.

The current passed by the cell is not in direct proportion to the illumination, but follows a law illustrated by the curve in Fig. 17. It has been proved that the current flow is almost proportional to the square root of the intensity of the light. Thus, four times as much light should give approximately twice as much current flow. One other peculiarity is that the sensitivity of the selenium to light is directly proportional to the applied voltage, a fact that indicates that the maximum voltage which the

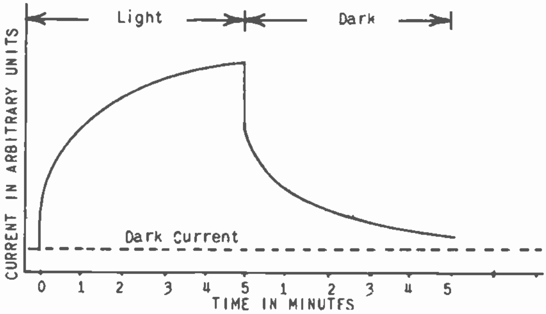


Fig.18 Illustrating the time lag of a selenium bridge.

cell can stand should be applied. This voltage is limited to the amount of power which the cell can safely dissipate.

Selenium is quite sluggish in its action toward light, and the amount of current which a given illumination can produce will depend on the intensity of the illumination and the time that it is maintained. This fact is illustrated by the curve of Fig. 18. A cell is illuminated for 5 minutes and then darkened for an equal period of time. It is seen that at the end of the first 5 minute period, the current is still rising slightly, and 5 minutes after the illumination is extinguished, the cell current is still higher than the normal dark current. This indicates that the dynamic

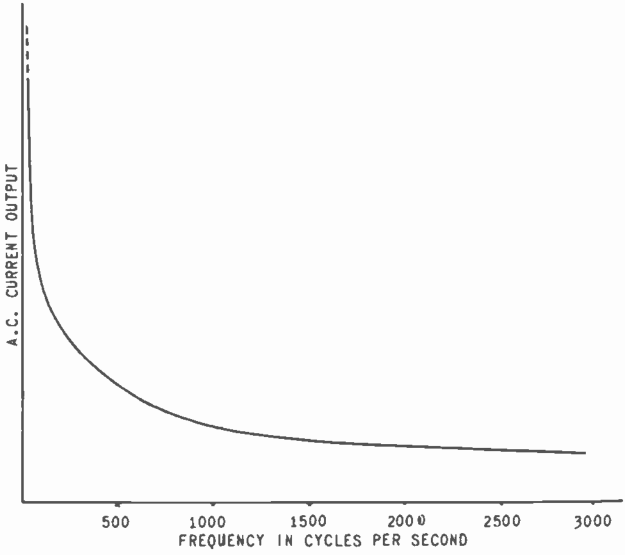


Fig.19 Relation between the frequency of the modulated light flux and the AC output of a photo-conductive cell.

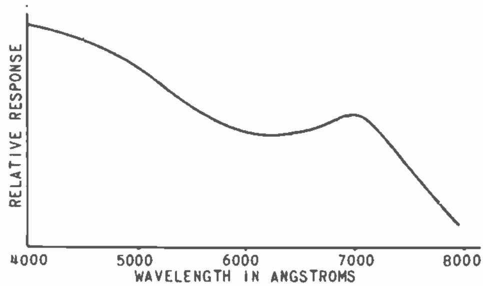


Fig.20 The color response curve of a selenium bridge.

sensitivity of the cell will decrease rapidly with an increase in the frequency of the modulated light flux. The relationship between the dynamic sensitivity and frequency is illustrated in Fig. 19. Thus, the selenium cell is not well adapted to applications requiring a modulated light flux, but is quite suitable for simple "off-on" control. Nearly all selenium cells have the same color response; a typical response curve is shown in Fig. 20.

One other type of photo-conductive cell is one which uses thallium oxysulphide as its active material. In preparing the sensitive material, very pure thallous sulphide is dried in an electric oven at about 80° C in the presence of air. The sulphide oxidizes to a dark, steel grey, and is then powdered and dusted onto a hot disk of quartz upon which it melts. The excess material is removed and a conducting grid of lead is sprayed on top of the sulphide to form the electrodes. The disk is then mounted in a glass tube, which is evacuated and finally filled with helium at about two-thirds atmospheric pressure. This cell is particularly sensitive to infra-red and possesses little inertia as compared to selenium. It is known as the Thalofide cell, and has a color response as illustrated in Fig. 21.

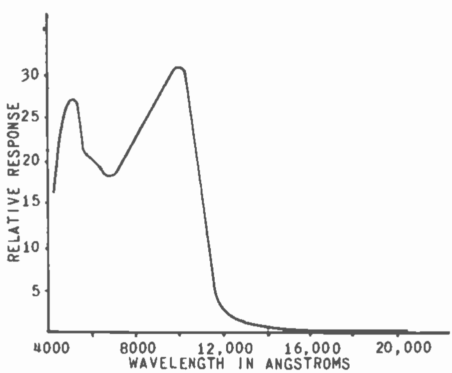


Fig.21 Color response of a Thalofide cell.

Of commercial selenium cells, perhaps the most widely known is the Radiovisor Bridge, originally developed in England, and now adapted by the Burgess Battery Company to American practice, The electrodes consist of two interlocking combs of gold fused into the surface of a glass plate. Selenium is spread over the plate to a thickness of 2.5×10^{-3} centimeter, and after annealing the plate is mounted in a tube filled with an inert gas. The tube may be operated at any voltage between 10 and 500 volts so long as the dissipation is limited to .1 watt. With 100 volts the dark resistance is between 1 and 10 megohms, and with an illumination of 10 foot-candles, the ratio of dark to light resistance is about 4 to 1. Another type of photo-conductive cell is the so-called X-cell manufactured by the Pacific Research Laboratories. It is a low-resistance cell and is designed to operate with a potential between 3 and 18 volts. The area of the selenium plate is $\frac{1}{4}$ square inch and is deposited on a very fine, ruled grid. The dark resistance of the cell is about 50,000 ohms, and with .1 lumen and a voltage of 9 volts, the dark-light ratio is 3. A photo-conductive cell is illustrated in Fig. 22.

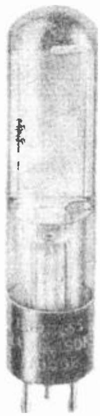


Fig.22 A photo-conductive cell.

8. PHOTO-VOLTAIC CELLS. A photo-voltaic cell is one in which light causes a voltage to be generated when it strikes the sensitive element. In this respect it is somewhat similar to a thermocouple. As is well known, when the junction of two dissimilar metals is heated, the contact voltage generated at that point is increased above the voltage existing at the cold junction, and the net voltage present causes a current to circulate around the circuit. Thus, it may be said that the thermocouple is sensitive to infra-red or heat rays. The photo-voltaic cell is, in addition, sensitive to energy of the visible spectrum.

This phenomenon is usually known as the Bequerel effect, since it was Bequerel, a French scientist who first noticed it. In 1839 he discovered that when light was allowed to fall on one of two electrodes immersed in an electrolyte, an electromotive force was developed which disappeared when this electrode was darkened. Much later, another scientist, T. W. Case, built a practical cell which consisted of two copper electrodes coated with a thin layer of cuprous oxide, which were immersed in a solution of copper formate. With full sunlight, he obtained a voltage of .11 volt, however, the output current quickly dropped to zero because the action of the sunlight changed the cuprous oxide to cupric oxide. By reversing the position of the electrodes, the output current was again present. As a result, he devised a means of rotating the electrodes for alternate exposure, thereby causing the cell to have an alternating output.

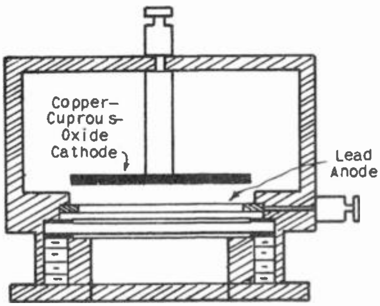


Fig. 23 Diagram of a Rayfoto cell.

The first photo-voltaic cell to be practical enough for commercial use was the Rayfoto cell. It consisted of a cathode of copper on which was a sensitive surface of cuprous oxide. The anode was lead, and the electrolyte a solution of lead nitrate. A cross-sectional view of this cell is shown in Fig. 23. It is said to have a sensitivity of 150 µA per lumen. The voltaic cell requires no external voltage source, a point which is a decided advantage. The characteristics of this cell are shown by the curves in Fig. 24. The curve labeled E illustrates how the generated voltage varies with the amount of illumination. The internal resistance of the cell is not constant, but decreases with illumination as indicated by the curve labeled R. The ratio of the generated voltage to the internal resistance is the amount of current that will flow if the cell is short-circuited. The variation of this ratio is shown by the curve marked E/R, from which it is evident that the current is directly proportional to the flux.

With an external resistance connected in the circuit, the current will not be directly proportional to the flux, because the value of the external resistance does not change as the illumination varies. The curves of Fig. 25 indicate the relation between the output current and the illumination for various values of load resistance. Notice that the lower the value of load resistance, the more nearly linear this relation will be. The cell has a maximum response at 4600 Angstroms.

There are several other types of electrolytic photo-voltaic cells which differ but slightly in principle from the one previously described. A later modification of the photo-voltaic cell is the dry type, one in which no electrolyte is used. One of the

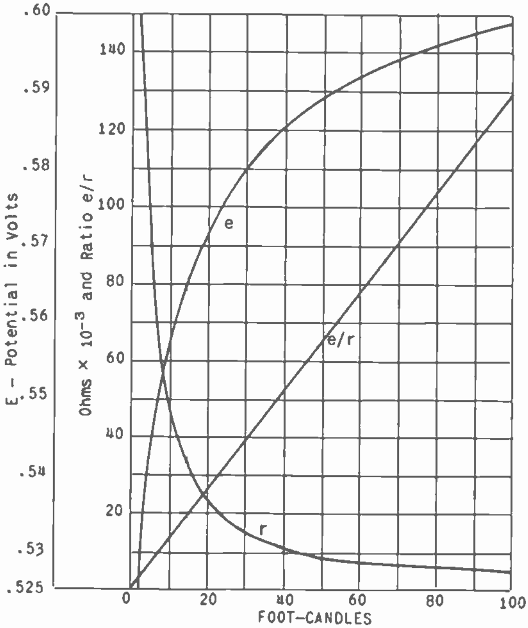


Fig.24 Illustrating the relation between the output voltage, the resistance and the current as plotted against the intensity of illumination of a photo-voltaic cell.

first of these was the "Sperrschicht" cell developed in Germany. A very thin layer of red copper oxide is formed on the outer surface of a plate of mother copper by heat treatment in the presence of oxygen. On this surface there is then sputtered a grid of copper or gold. A cross sectional view of the various layers, much magnified, is shown in Fig. 26. It is well known that a copper-copper-oxide combination can be used for rectifying purposes. The resistance in one direction is much greater than that in the opposite direction. It has been determined that this unipolar characteristic is localized not in the oxide itself but at the point of separation of the oxide and the copper, a layer which is known as the barrier plane, or in German, Sperrschicht. It would seem that the source of electrons is at this barrier plane, and when light strikes the oxide surface, it penetrates to the barrier plane, where it releases electrons which cross the plane and enter the mother copper.

These barrier plane cells are sometimes known as sandwich cells, and they seem to offer a means of converting solar energy directly into electrical energy. This conversion has long been the dream of every scientist. One square yard of copper-oxide sandwich can develop several watts of power, and on this basis a square mile of such cells could deliver about 350,000 kilowatts when illuminated by full sunlight. Practical use of such a process is still in the future, but some day it may be an established reality.

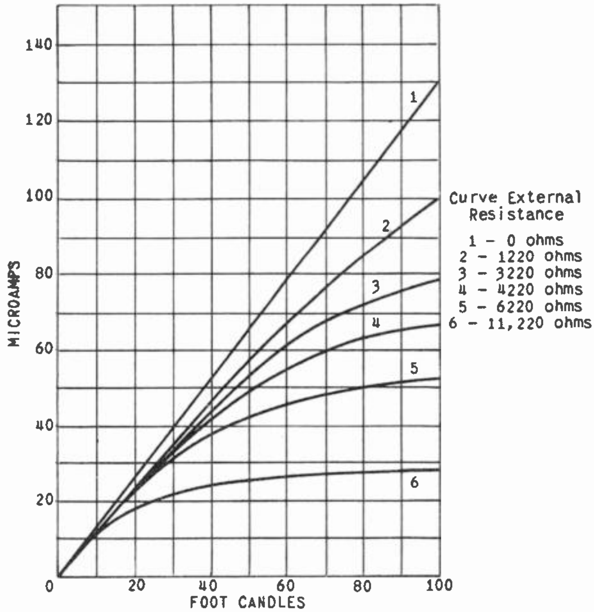


Fig. 25 Illustrating the effect of using different sizes of load resistances for a photo-voltaic cell.

The first dry photo-voltaic cell to be commercialized in this country is the Weston Photronic cell developed by the Weston Electrical Instrument Corporation. Unlike the previous cells described, it does not use copper oxide, but consists of an iron disk which is coated with iron selenide. Covering the iron selenide is a very thin transluscent film of silver. The barrier plane exists between the iron and the iron selenide. The sensitivity of the cell is about 145 microamperes per lumen. It is not damaged by strong illumination even when short-circuited, and having reached a state of equilibrium under a given illumination, it remains constant indefinitely. A photograph of this cell appears in Fig. 27.

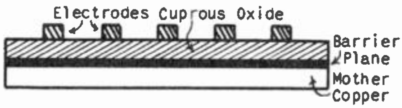


Fig. 26 Diagram of the construction of a barrier-plane cell.

The frequency response of the Photronic cell and, in fact, all photo-voltaic cells is much poorer than the vacuum-type, photoemissive cell. Calling the response at 60 cycles 100%, that at 120 cycles will be about 58%, at 240 cycles about 30%, and at 1000 cycles about 6.4%. Thus, the photo-voltaic cell is not adapted to talking pictures or television. For simple off-on circuits, however, it is ideal, since its output is so high that it can operate sensitive relays directly without additional amplification. The set of curves shown in Fig. 28 illustrate the color response of this cell. One curve is for the response without any filter, and the other two show the visual response curve, and how closely the

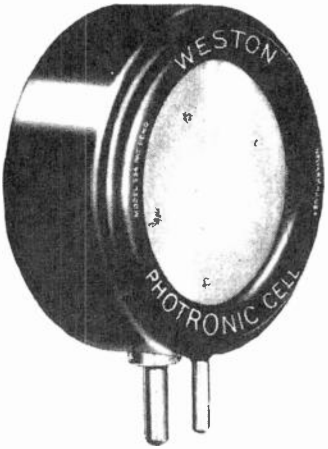


Fig. 27 A Weston Photronic cell.

output of the cell approaches it when the cell is supplied with a special viscor filter. This filter is necessary when the cell is used to make intensity of illumination measurements. Several such instruments are available from the Weston Company. They consist

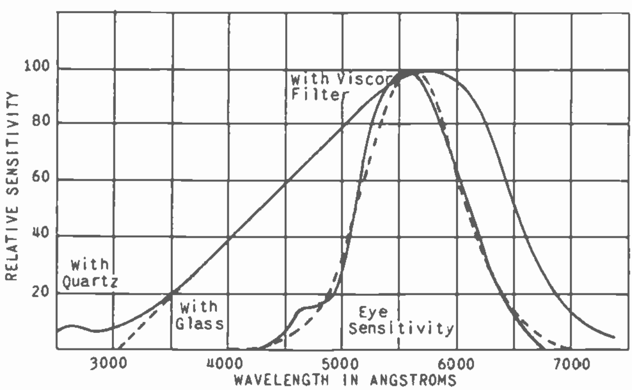


Fig. 28 the color response of a Weston Photronic cell.

of a Photronic cell and a sensitive microammeter calibrated directly in foot-candles. The same principle is used in many exposure meters for photographers; in which case the meter indicates what size stop should be used on the camera for different shutter speeds.

9. USING AN AMPLIFIER TUBE AS A PHOTO-SENSITIVE DEVICE. The grids of many ordinary amplifier tubes are light-sensitive. This is especially true of tubes using oxide coated filaments. The coating on the filaments is ordinarily a mixture of barium and strontium oxides both of which are somewhat photo-emissive. During manufacture,

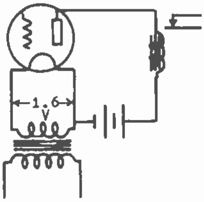


Fig. 29 A circuit for using an ordinary amplifier tube as a light-sensitive device.

a very thin layer of these oxides is deposited on the surface of the grid wires and it is from the grid that the photo-emission takes place. The circuit employed to use this characteristic is the one shown in Fig. 29. The grid is left floating; that is, it is not connected to anything. To insure that the amount of leakage between the grid and the other elements is minimum, it is better to cut off the grid prong of the tube. Whenever a grid is left free in this manner, it collects electrons, and the electrons having no place to go, form a negative charge on the grid which, for a type

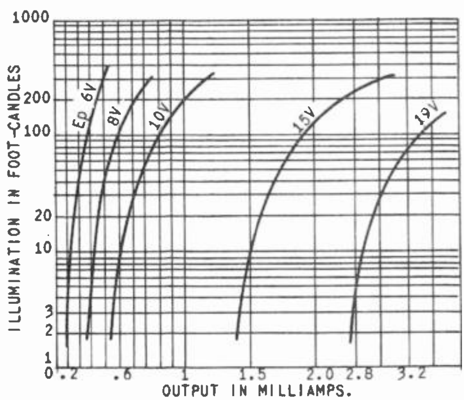


Fig. 30 Illustrating the effect of changing the light intensity on the grid of an amplifier tube.

45 tube, usually makes the grid about 1 volt negative, depending on the plate potential. Now, if a light source is allowed to illuminate the grid, the grid will lose some electrons due to photo-emission. Thus, the grid becomes less negative, and the plate current increases. The apparent action of the light is to cause the grid to lose electrons faster than it can attract them, until

a new point of equilibrium is reached. The plate voltage is ordinarily adjusted to about cut-off with 1 volt negative grid bias, and the application of the light causes the plate current to begin to flow. The filament voltage for use on a type 45 tube should be about 1.6 volts. It is desirable that the filament glow very little, if at all, as its light would affect the emission characteristic of the grid. A set of curves illustrating the action of a type 45 tube acting as a light-sensitive device is shown in Fig. 30. The output response varies directly as the logarithm of the intensity of illumination. A tube used in this manner is very satisfactory as long as it is not required to respond to small changes in light intensity. The circuit is rather sensitive to hand capacity effects, and the tube should be shielded, allowing an open space in the top of the shield for the light to enter.

EXAMINATION QUESTIONS

INSTRUCTIONS. Before starting to answer these examination questions, you should have studied the lesson material at least three times. Be sure that you understand each question--then proceed to write the best answer you can. Make all answers complete and in detail. Print your name, address, and file number on each page and be neat in your work. Your paper must be easily legible; otherwise, it will be returned ungraded. Finish this examination before starting your study of the next lesson. However, send in at least three examinations at a time.

1. What is meant by the work function of a photo-sensitive material?

2. What is the threshold frequency of a photo-sensitive substance?

3. Why are photocells which are sensitive to infra-red desirable in most applications?

4. Why must photocells to be used with ultra-violet be enclosed in an envelope of quartz?

5. What is the advantage of the gas-filled photocell and why does it have this advantage?

6. What precautions must be observed in the operation of gas photocells?

7. What are the disadvantages of the photo-conductive cell?

8. Name an advantage and a disadvantage of the photo-voltaic cell.

9. What outstanding advantages are possessed by the vacuum photo-emissive cell which none of the other types have?

10. Describe the operation of an amplifier tube as a photo-sensitive device.

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UNIT NO. 5

PHOTOCELL APPLICATIONS

LESSON NO. 5

IMPOSSIBLE

.....but it actually works.

Said the grizzled old timer----'Electric eye? They aint no sech thing. Eyes that aint in human heads aint worth a hoot. It's impossible.'

Then one night an enterprising merchant in 'Old Timer's' home town had some special work done on one of his show windows. What it was, nobody but the men who did the work, and the merchant, knew.

On the night following the work in the merchant's window, 'Old Timer' decided to walk around the town square for a breath of fresh air. Approaching the merchant's window, he noticed that it was dark, and remarked----'Well I'll be dog-goned if that ol' skinflint aint turned out the lights. Can't see a thing in his windows.'

Walking up to the window to peer into the store, 'Old Timer' was amazed when the show window lights flashed on. He moved from the window and they went out. When he returned to peer into the store, on went the lights. Looking quickly in all directions, he ambled off, shaking his head and wondering----'Durn it, was I seein' things?'

'Old Timer' was not 'seeing things.' He was merely witnessing one of the many uses of the 'electric eye' or photoelectric cell. Later, when bandits attempted to rob the local bank, and the alarm was sounded by an 'electric eye', he was finally convinced that eyes are not limited to human heads.

When you have completed the study of this lesson, which deals with the uses of the 'electric eye' you too will be amazed. Small but mighty, this tiny, insignificant appearing little bulb plays an important part in American industry. It has opened another door of rich opportunity to the Midland trained man.

Lesson Five

PHOTOCELL APPLICATIONS

"This lesson will be devoted to the study of the commercial applications of photocells. Although these applications have no direct relation to television, still your training would not be complete without this knowledge.

"I am sure you will find this lesson interesting and since the employment possibilities in this field are quite good, you should devote enough time to the study of this lesson to properly qualify you to carry on this type of work."

1. COMPARISON OF THE TYPES OF LIGHT-SENSITIVE TUBES. Of all the types of photosensitive tubes, the emissive type reached its highest state of development first, and now enjoys the greatest popularity. In most photocell applications, the change in the cell's output current is caused to actuate some type of relay. Relays can be made very sensitive, but there are none sensitive enough to operate directly from the very weak output of the emissive type of cell. All relays are rated according to the amount of power which must be sent into their coils to cause them to pull up their armatures. There is a very definite amount of magnetomotive force which must be developed in the coil of a relay before it will operate. This force is determined by the product of the current and the number of turns. If a fairly large change in current can be produced, the coil need not have very many turns, whereas a relay to be operated on a weak current change must have a large number of turns. In either case, the same amount of power is required to cause the relay to operate. This power will be the current change through the coil times the voltage change across the coil.

The photo-emissive cell is characterized by a high internal resistance, a comparatively high terminal voltage, but capable of delivering only a weak current to an external load. The current change through a load may be only a few microamperes, whereas the voltage change across the load may be several volts. That such a device does not lend itself to direct operation of electromagnetic relays is evident from the fact that most relays require a much larger current change although at a low voltage. On the other hand, the output of a photo-emissive cell may be very easily amplified. Since the output voltage of the cell may change several volts with only a moderate change in light flux, this change in voltage may be applied to the grid circuit of a vacuum tube, and the change in grid voltage created will cause the plate current of the tube to change several milliamperes, more than enough to operate a sensitive relay. Thus, the amplifier may be looked upon as a device which matches the high internal impedance of the photocell to the comparatively low impedance of the relay, and in addition provides the necessary power to actuate the relay which at present is not obtainable from the photo-emissive cell.

Work is already being done on certain types of relays employing the piezo-electric principle. For example, a piece of Rochelle salt crystal is deformed when subjected to a small voltage, and this change in shape may be used to open and close contacts. Such a relay requires practically no current change, and the 10 or more volts obtainable from a photocell are sufficient to cause the necessary deformation.

The photo-conductive cell (selenium bridge) has a somewhat lower internal resistance than the photo-emissive type, and may be used to operate some electromagnetic relays directly without any amplification. The disadvantage of this cell, however, is its time lag.

Cells of the photo-voltaic type have comparatively low internal resistances, ordinarily of 500 ohms, more or less. To deliver maximum power to their load, they must, of course, be operated into a load impedance of approximately the same impedance. Their output currents are measured in milliamperes instead of microamperes, and since their output power can be more efficiently transferred to a relay than that of an emissive type cell, they are usually operated directly into relays. The output voltage of a photo-voltaic cell is usually only a few millivolts, and since these cells do have such a low internal impedance, their output voltage connot be amplified successfully. If, however, the cell is illuminated with modulated or interrupted light, the output voltage may be amplified, since a transformer may then be used to match the output of the cell to the grid circuit of an amplifier tube. In most industrial applications, the beam of light is not modulated, and the photo-voltaic cell is operated directly into a sensitive relay whose contacts close the circuit of a power relay able to handle the power which is to be controlled.

The decision of what type of light-sensitive device to use for a particular application rests with the amount of light changes available. If the light changes are large, such as an eclipse of daylight or of concentrated light from an incandescent lamp, the photo-voltaic cell will operate very satisfactorily. On the other hand, when the light changes are rather small, it is better to use a photo-emissive cell and then amplify its output voltage before applying these changes to a relay. Since the internal impedance of the photo-voltaic cell is comparatively small, it does not need to be physically close to its relay, and may be located wherever convenient. This is an advantage not possessed by the photo-emissive cell, whose impedance is so high that the leads connecting it to its amplifier tube must be relatively short.

2. AMPLIFIERS FOR PHOTOCELLS. The output currents from photocells of the emissive type are exceedingly small. For example, only about 10 to 20 microamperes are obtainable when even the better cells are placed 10 inches from a 60-watt tungsten lamp. Before this small output is able to do useful work, it must be amplified. A typical amplifier circuit is illustrated in Fig. 1. The grid leak of the amplifier tube functions as the load circuit of the photocell. Since the cell has a very high internal resistance, it is necessary that its load resistor be of a large value so that a maximum voltage change will be created across this resistor, values from 1 to 10 megohms are common.

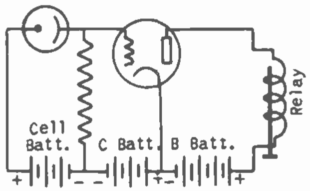


Fig.1 A photocell amplifier. The relay is energized when the cell is illuminated.

Considering the action of the amplifier circuit, we shall assume that the cell is in darkness. Thus, there will be no cell current flowing and no current will flow through the grid leak. The grid voltage on the tube will be the voltage of the C battery, and this voltage will be great enough to cause the plate current of the tube to be too low (near cut-off) to operate the relay connected in the plate circuit. Now when the cell is illuminated, a photoelectric current will flow from the cathode of the cell to the anode, through the anode battery, and up through the grid leak to the cathode. This current will develop a voltage drop across the grid leak which opposes the voltage of the C battery and the grid of the tube will become less negative. The plate current of the amplifier tube will increase and the relay will be energized.

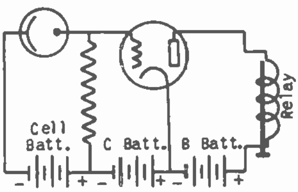


Fig.2 A reverse amplifier. The relay is energized when the cell is in darkness.

By reversing the photocell and the anode battery, the circuit shown in Fig. 2 is obtained. In this case, the voltage of the C battery would be so adjusted that with the cell in darkness, the plate current of the amplifier tube would be sufficient to operate the plate relay. Then, when the cell is illuminated, the voltage drop created across the grid leak by the photoelectric current would add to the voltage of the C battery, the plate current would be reduced and the relay would be de-energized.

It is not necessary to provide a separate battery for supplying voltage to the photocell, since the B battery used for plate voltage on the amplifier tube can very easily serve both purposes. If batteries are used as power supply, the circuit shown in Fig. 3 would be suitable. Battery power is not economical nor is it reliable, and for this reason most circuits of this kind employ AC power. In many of the simpler circuits in which only off-on control is needed, it is not necessary to rectify the AC line voltage since both the photocell and the amplifier tubes are rectifiers

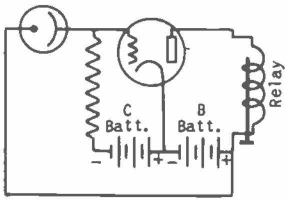


Fig.3 Illustrating how the B battery may serve as the anode voltage for the cell.

in that they will pass current only in one direction. A circuit of this type is illustrated in Fig. 4. One end of the secondary of the power transformer connects to the plate of the amplifier tube and the other end to its grid; the tap connects to the filament or cathode. The photocell is connected directly between the grid and plate of the amplifier tube. During the alternation that point B is positive with respect to point A, the plate of the amplifier tube is positive with respect to its filament and the grid is negative. Furthermore, the anode of the photocell is positive with respect to its cathode.

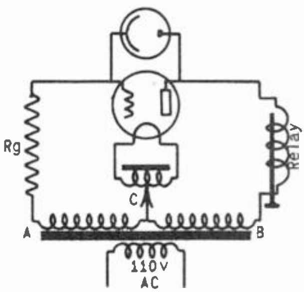
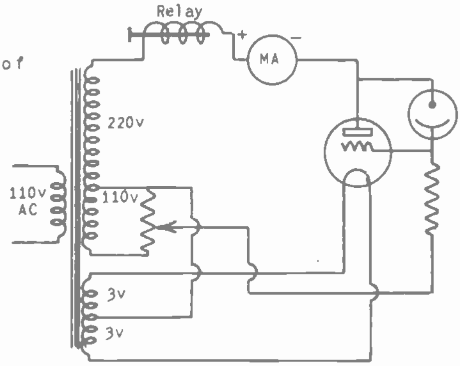


Fig.4 A simple AC-operated amplifier.

If the output of the cell is low at this time, due to the fact that its light beam is obstructed, the negative voltage present between the points A and C will provide sufficient bias on the amplifier tube to prevent plate current flow, and the relay will not be energized. If, however, light is shining on the photocell during this alternation, the photocell current will flow from cathode to anode through the relay, through the winding of the transformer from B to A, and through the grid leak Rg to the cathode of the cell. This current will create a voltage drop across Rg which bucks against the negative voltage from A to C and the voltage on the grid of the tube will become enough less negative to allow plate current to flow and energize the relay.

During the next alternation, point B will be negative with respect to point A, the plate will be negative with respect to the cathode, whereas the grid will be positive. Also, the voltage across the photocell will be reversed, and neither cell current nor plate current can flow. However, since the grid is positive, there will be some grid current flow, and this current in flowing through the grid leak will provide a voltage drop which bucks against the voltage from A to C and prevents the grid current from becoming excessive. Naturally, the relay must be slow acting so that it will not release during the intervals between the pulses. A commercial, AC-operated photocell amplifier is illustrated in Fig. 5. It is practically the same as the previous circuit, except that a potentiometer is provided for adjusting the grid voltage.

Fig.5 A commercial type of photocell amplifier.



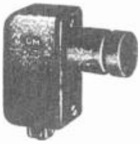
3. RELAYS FOR PHOTOCELL CIRCUITS. Most relays for photoelectric cell equipment must be very sensitive. The majority of photocell applications fall into the group in which obstructing a beam of light causes a relay to open or close one or more contacts. Since the output of the emissive type cell is so very low, at least one stage of amplification is necessary between the photocell and its relay. To cause a relay to close its contacts requires that a definite amount of magnetomotive force be established in the core on which the coil is wound. The actual amount necessary will depend on the weight of the armature and the contacts. The magnetomotive force, in turn, is dependent on the amount of current flowing through the coil and the number of turns of wire wound on the coil. By winding many thousands of turns of wire on the coil, the current required to operate the relay is correspondingly reduced; however, the fact that a large number of turns are required will cause the resistance of the relay coil to be rather large. Thus, the same amount of power will be needed to make the relay function, no matter how many or how few turns are used on the coil.

The sensitivity of a relay will be determined by the amount of power required to cause it to close its contacts and this information is given by the manufacturer. For example, a manufacturer may make a series of relays which require 15 milliwatts for operation. Each relay in this series will have a different coil resistance, and each will require a different operating current. One relay might have a coil resistance of 500 ohms, and would, therefore, need between five and six milliamperes through its coil to make it function. Another relay in the same series might have a resistance of 2,250 ohms; it would require between two and three milliamperes for operation. In each case 15 milliwatts of power must be dissipated in the coil of the relay. It should be understood that the relay manufacturer does not deliberately construct a coil to have so many ohms of resistance. Instead, the shape of the coil and the wire size are so chosen that there will be a maximum pull on the armature with the current available and so that the relay will not have to dissipate appreciable power. Even though the wire used for the coils is copper, so many turns are used, and the wire is necessarily of such small size, that some coils have resistances as high as 10,000 ohms.

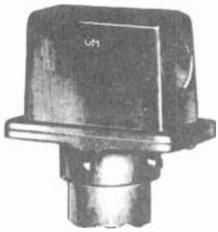
The only way by which a relay may be made more sensitive (that is, require less power for operation) is by constructing the moving parts so that they will be lighter in weight. This necessitates that the contacts themselves be smaller, and so the contacts will not be able to carry much current. If the contacts are not sufficiently sturdy to carry the necessary current to the controlled device, the sensitive relay may merely close the circuit to a power relay which in turn closes the circuit to the controlled device. It is thus evident that a series of relays really constitute an amplification system. A small change of a few milliamperes in the sensitive relay may eventually make or break a circuit carrying many amperes.

Nearly all relays require a higher current for pulling up than they do for dropping out. This is necessary, for if the drop-out current were equal to the pull-up current, then firm contact between the contact points would not be made unless the current through the coil was somewhat above the pull-up value. When a relay pulls up, it reduces the size of the air gap in the magnetic circuit, so that

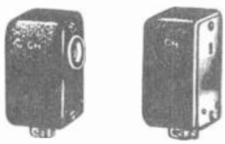
Fig.6 A Weston foot-candle meter.



(A) A light source for use with photo-cells. A narrow beam is projected by means of a lens system.



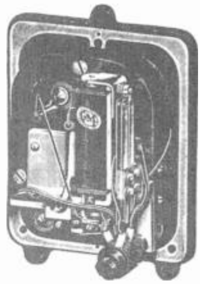
(B) A weatherproof housing for a light source which may be used outdoors.



(C)&(D) Two photo-tube housings, one having only a narrow slit for the admittance of light.

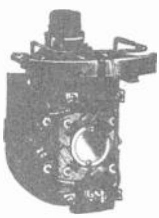
(E) A power type relay which is operated by a sensitive photo relay. The contacts will carry 10 amperes at 110v AC.

(F) A sensitive relay for use in the plate circuit of a photocell amplifier. It operates on as little as 3 ma.



(G) A galvanometer type of relay which operates when the energizing current is a fraction of a milliampere.

(H) A Weston Sensitrol relay for use with Weston Photronic cells. Two micro-amperes will energize it.



(I) An extremely sensitive, laboratory type of relay. Two-tenths of a micro-ampere will close its contacts.

with the magnetic circuit more efficient, the relay will remain closed until the current falls somewhat below the pull-up value. Naturally, the relay will drop out if the current through the coil is reduced to zero, but this may necessitate a rather large light change. An ideal type would be one which pulls up on little current and drops out on a small decrease in this current.

Very sensitive relays will operate on as little as 15 microamperes. They have resistances of approximately 1,000 ohms and the contacts will carry 200 milliamperes at 6 volts. Most relays of this type operate on the meter-movement principle; that is, they are really very sensitive microammeters equipped with contact points.

4. APPLICATIONS OF BARRIER CELLS. Since the barrier cell such as the Weston Photronic can operate a relay directly without the need of an amplifier, most of the principles involved in its application are mechanical rather than electrical. One simple, but extremely important application is the use of a barrier cell and a sensitive microammeter as a foot-candle meter. Such an instrument is illustrated in Fig. 6. The scale of the meter is calibrated in foot-candles, and three ranges are provided. The cell must be equipped with a Viscor filter so that it will have approximately the same color response as the human eye. The ranges provided are 0-60; 0-120; and 0-600 foot-candles. If more intense illumination is to be measured, a multiplier may be used. This multiplier consists of a partial shield which covers the face of the cell so that only a small area is illuminated. With this multiplier in use, all readings of the meter are multiplied by ten. Such an instrument has wide usability in determining whether the illumination in a particular location is adequate.

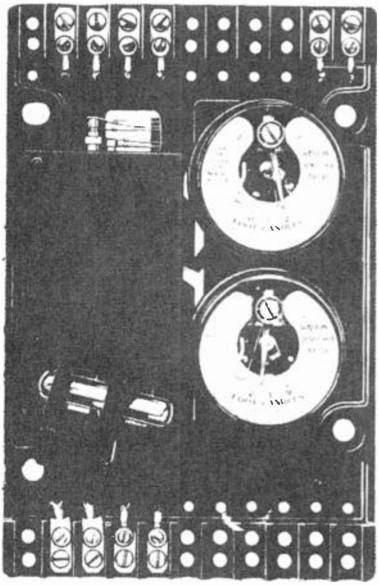


Fig.7 A Weston Illumination Control.

Of similar principle is the Weston Illumination Control. This is a device which automatically turns on the lights in a room when the daylight illumination falls below a prescribed value and then turns them off when the daylight illumination again rises. Although its uses are numberless, it is particularly suitable for schoolrooms. Ordinarily the daylight illumination fades so gradually that a person is not aware of the fact that the illumination is no longer adequate for proper work without eyestrain, and he continues to work until the light has nearly faded before supplying artificial illumination. When the illumination is automatically controlled, eyesight is safeguarded and better work results.

The Weston Illumination Control consists of a light collector containing the Weston Photronic cell and a relay cabinet in which the control equipment is located. The components are illustrated in Fig. 7. The relay cabinet contains two Sensitrol relays of the meter-movement type which operate from the output of the cell. In addition there is a small Telechron motor which drives a bakelite cam which in turn tilts a mercury tube, thereby opening or closing the controlled lighting circuit. A schematic diagram of the equipment ready to turn on the lights when the natural illumination fails is shown in Fig. 8. As the illumination fades, the output of the cell becomes less and less, and the contacts in the turn-on relay are so arranged that when the illumination falls below a given value, these contacts will close. Note that the circuit to the coil of the turn-on relay is completed through the center and upper blades of a three-blade relay switch. When the contacts of the turn-on relay close, a circuit is completed from terminal 3, the grounded side of the 110-volt line, through the contacts of the turn-on relay, to the field of the Telechron motor, and back to terminal 4, the live side of the 110-volt line. The motor now rotates the bakelite cam in a clockwise direction at a speed of one revolution per

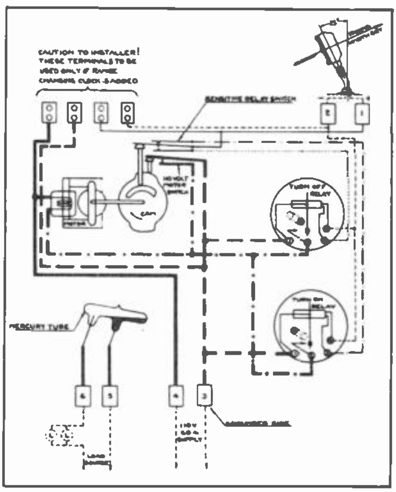


Fig. 8 Circuit of the Weston Illumination Control ready to turn on the lights.

minute. The various lobes and tracks on the cam perform the following functions:

1. The lobe on the edge of the cam allows the small plunger to fall to its normal position, thereby closing the contacts of the 110-volt motor switch whose contacts are in parallel with the contacts of the turn-on relay. This allows the motor to continue to run after the contacts of the turn-on relay are opened.

2. A track on the back of the cam, (not shown in Fig. 8) moves a lever which operates a reset mechanism within the turn-on relay to open and reset the contacts of this relay. The resetting pin then remains in such a position that the relay pointer cannot engage the stationary contact during the remainder of this cycle.

3. A track on the front face of the cam allows the large plunger to drop to its normal position, changing the photocell circuit from the turn-on to the turn-off relay.

4. A track on the back of the cam allows the reset lever of the turn-off relay to return to its normal position; but the contacts of this relay remain open because the cell is not supplying enough current. It is, however, ready to operate whenever the natural illumination rises to the proper value.

5. A track on the back of the cam moves the mercury tube lever to the right, tilting the mercury tube so that the mercury contacts close and turn on the lights.

6. The lobe on the edge of the cam raises the small plunger, opening the 110-volt motor contacts. The motor stops, and the control panel is now ready for the next cycle.

At this time, the mechanism is now set as shown in Fig. 9, and

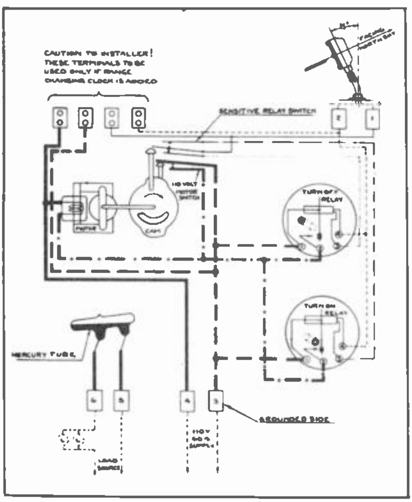


Fig. 9 The illumination control circuit in the turn-off position.

will turn off the lights whenever the daylight illumination rises. Several models are available; some are suitable for turning on lights in a room, others control street light illumination, and still others turn on advertising signs when darkness falls.

Many industrial operations are made easier through the use of photocells. Such operations as automatic counting and weighing are but two actions which a photocell can do quicker and more accurately than may be done by hand. A photo relay made by the Weston Electrical Instruments Corporation is illustrated in Fig. 10. The relay

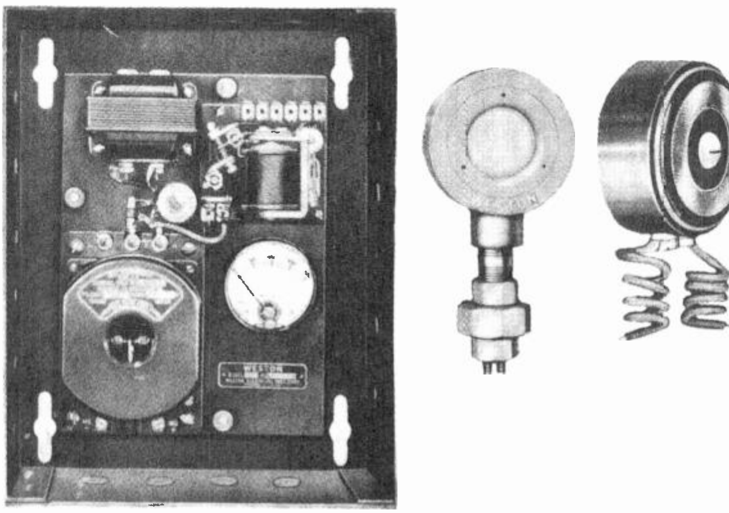


Fig.10 (A) A Weston photocell relay. (B) An outdoor photocell mounting. (C) An indoor photocell mounting.

cabinet itself contains a sensitive relay, transformer, rectifier, a power relay, and a microammeter. The sensitive relay operates from the output of a Weston Photronic cell, and its contacts, in turn, control the winding of the power relay whose contacts are able to handle a power of 500 watts at 120v AC. The energy for operating the power relay is derived from the transformer and rectifier which deliver 6 volts DC from the 110-volt AC source. The microammeter is included so that the intensity of the light beam may be more easily adjusted. Various applications are illustrated in Fig. 11. At A is shown a scheme for counting objects moving on an endless belt. The output of the relay cabinet connects to a magnetically operated tally register whose unit wheel moves forward each time that the light beam is interrupted. At B is shown a method of automatically controlling the level of a liquid in a tank. When the level of the liquid rises to a certain point, the light source is obscured and the photocell operates (through the relay cabinet) a shut-off valve to shut off the source supplying the tank. At C, there is illustrated an automatic weighing device for filling containers. When the weight of the container and its contents reach a predetermined value, the beam of the scale rises to the point where it obstructs the light source. The photocell then operates a shut-off valve to stop the flow of the material with which the container is being filled.

A novel scheme for an automatic door-opener is illustrated in Fig. 12. This set-up uses three exciting lamps and three photocells. When the doors are closed, cell 3 is short-circuited by switch 5. All three cells are connected in series and, when either light beam is obstructed, the output current of the cells falls to a low enough value to operate the relay and open the doors. When the doors are open, cell 3 is no longer short-circuited and is now illuminated from the diagonal beam. With the doors open, however, obstructing

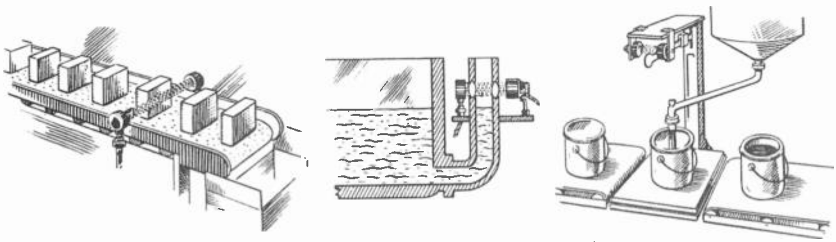


Fig.11 (A) Using a cell to count objects. (B) An automatic shut-off for filling a tank. (C) An automatic weighing device.

any one of the three light beams will reduce the output of the cells so that the doors will remain open. The purpose of the diagonal beam is to prevent the doors from closing in case a person is standing in the doorway. When the passageway is clear, the doors will begin to close and, at the time that the diagonal beam is cut off by the closing of the doors, the switch 5 will short out cell 3 and the output of the other two cells will be sufficient to keep the doors closed.

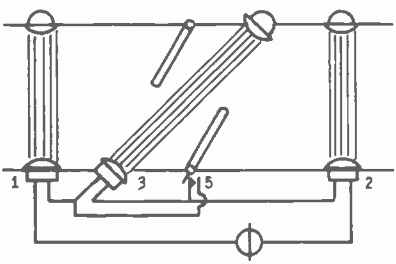


Fig.12 A door-opening photo-cell circuit.

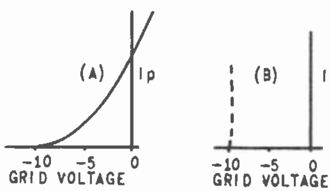
5. GASEOUS TRIODES. It has preveously been demonstrated that a much greater output is obtainable from gas-filled photocells than from those of the vacuum type. Furthermore, it is well known that a gas-filled rectifier, such as the mercury-vapor tube is far more efficient than the high-vaccum, thermionic type. This knowledge has led to the development of three electrode tubes containing gas.

The phenomenon of ionization occurs in these tubes and very large outputs are obtainable. Due to the greater number of electrons in a gaseous tube, the plate current may be measured in amperes as compared to milliamperes for a similar tube of the high-vacuum type. In addition, these currents flow through a gaseous tube with a voltage drop of only 10 to 20 volts.

Naturally, a gas-filled, three-element tube is not suitable for ordinary amplification, but such a tube may be used in conjunction with a photo-emissive cell as a means of producing a large amount of DC amplification. One application of a gas-filled triode which is fairly well known as its use for producing the sawtooth waveform required for sweep circuits in oscilloscopes. The type 885 is a typical example. In appearance, the 885 is very similar to an ordinary type 56 tube. It has, however, a small quantity of argon gas contained within its envelope which makes its characteristics widely different from those of the type 56.

Tubes designed to pass comparatively large currents are the so-called grid-controlled rectifiers. These are marketed under various trade names, such as Thyratron (General Electric), and grid-glow tube (Westinghouse). They are mercury-vapor rectifiers, but in addition to the ordinary cathode and plate they have a third element in the form of a grid. If the grid is made sufficiently negative, no current will pass through the rectifier. As the negative voltage on the grid is reduced, a point is reached where ionization can take place and plate current does flow. After this point is reached, the plate current is independent of the grid voltage and, making the grid either positive or negative, has no effect on the amount of current that flows through the tube; in fact, the only way that the plate current may be stopped, once it has been started, is to interrupt the plate voltage itself.

Fig. 13 (A) The grid voltage, plate current characteristic of a conventional, high-vacuum, amplifier tube. (B) The grid voltage, plate current characteristic of a gas-filled triode.



In Fig. 13 there are shown the grid-voltage, plate-current characteristics of two tubes. The one at A is an ordinary high-vacuum type whereas that at B is for a tube containing gas. In the high vacuum type, the plate current is proportional to the grid voltage. In the gaseous type, the plate current is independent of the grid voltage after the discharge has been initiated.

In practice, the tube is not biased close to the trigger point, for slight changes in characteristics with age or between different tubes might cause the tube to fire, or plate current to start flowing at the wrong time. Instead, the tube is usually biased some distance from the critical value of grid voltage and then to start the tube conducting, a voltage considerably greater than the critical trigger voltage is applied. This pulse which initiates the discharge could very easily be the output voltage of a photocell. By connecting a relay in the plate circuit of the grid-controlled rectifier, a small amount of light change falling on the cathode of the photocell could cause the tube to fire and a large amount of power could be controlled by the plate-circuit relay.

Cathodes of much greater efficiency may be used in gaseous tubes than are possible with high-vacuum tubes. In cathodes used for high-vacuum tubes, very little can be done to increase the efficiency except to make the proper choice of emitting surfaces or substances. A negative space charge surrounds the cathode and this space charge hinders seriously the escaping of electrons from the cathode. An entirely different situation, however, exists with gaseous tubes. Due to the ionization process, the space charge is almost completely cancelled by the positive ions which are created. Thus, electrons may escape with much greater ease and the efficiency is, therefore, increased.

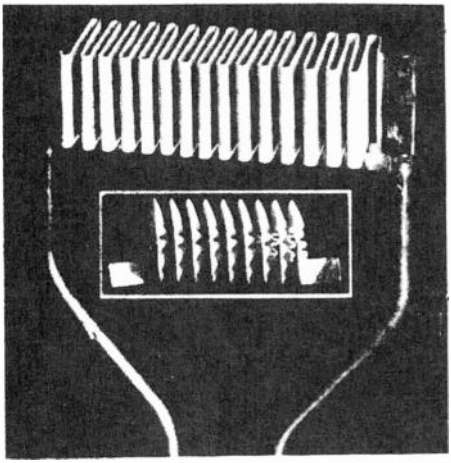


Fig.14 A cathode of a thyratron.

Cathodes in gaseous tubes may be made still more efficient by surrounding them with heat reflecting shields. The effect of a reflecting shield surrounding the cathode is to reduce heat radiation from the cathode, thereby raising its temperature and efficiency for a given amount of cathode-heating power. One type of cathode for a grid-controlled rectifier is illustrated in Fig. 14. By winding it back and forth as shown, a very large amount of emitting surface may be contained within a small space. This cathode has an emitting surface of 22.5 square inches, heats in two minutes, requires 200 watts and has an emission capacity of 65 amperes.

In order that the grid may regain control after the discharge has begun, it is usual practice to furnish an alternating voltage for the anode. Assuming that the grid voltage is less than the critical value, the tube will pass current during the alternations that the anode is positive with respect to the cathode. During the alternations that the anode is negative, no current flows and the discharge must be started once each cycle. This provides an interval during which the grid may regain control by increasing the negative grid voltage to the point where the tube is unable to fire when its anode becomes positive.

A very definite time is required for ionization to occur before the full anode current builds up. This interval is usually very small and is of the order of a few microseconds, but varies with the temperature, gas pressure, anode voltage, etc. The time required for de-ionization is much longer, for after the anode or ionization voltage is removed from the tube, the ions and electrons do not immediately disappear. The grid cannot regain control until all of the ions and electrons have diffused to the walls of the tube or recombined in the space between cathode and plate. For this reason, after the anode potential is removed, a certain time must elapse before the anode is again made positive if the grid is to regain its power to control the starting of the discharge. When the anode voltage supply for a grid-controlled rectifier is a 60-cycle alternating voltage, the de-ionization time is of little importance, but at higher frequencies, the time required for the grid to regain control of the plate current becomes a limiting factor. Thus, grid-controlled rectifiers may not be operated at frequencies much higher than 5,000 cycles.

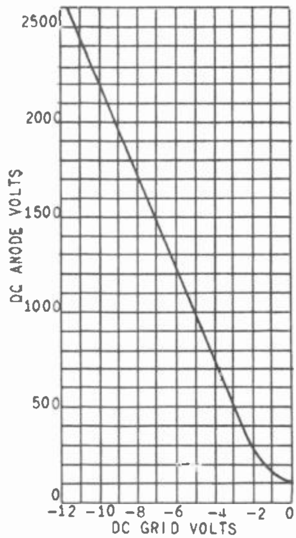


Fig.15 The characteristic of a typical gas triode.

As has been stated before, after the discharge has begun, the grid loses all control of the plate current and, no matter how negative the grid may be made, the plate current continues unaffected until the anode voltage has been removed. This is sometimes explained by stating that as the ionization process builds up, a sheath of positive ions surrounds the grid and thus shields it from what is going on in the tube. Thus, it may be seen that the grid in a gas tube is a one-way sort of control. It may prevent the flow of current, but once the tube has fired, it cannot stop the flow of current. Once conduction occurs, the grid might as well not be inside of the envelope so far as its effect upon the plate current is concerned.

The characteristics of a gaseous triode are usually shown by a graph such as the one illustrated in Fig. 15. Note this is a peculiar type of graph in that the grid voltage is plotted against the plate or anode voltage. The curve in this figure gives the value in plate voltage and grid voltage at which current will start to flow. For example, when the anode voltage is 1,000 volts, plate current will flow if the grid is less than 5 volts negative. With an anode voltage of 2500 volts, the tube will fire whenever the grid voltage is made less than -11 volts. For any value of plate voltage, there is some value of grid voltage which will prevent firing. The actual amount of plate current that does flow after conduction has started will depend almost entirely upon the load into which the tube is worked.

It is now time that we turned our attention to the various methods by which the anode current may be controlled. In the two-element rectifier, anode current will flow whenever the anode is positive with respect to the cathode. In the case of the gaseous triode, another variable controlling factor enters; namely, the voltage of the grid. Naturally, current to the anode can flow only when the anode is positive. However, unless the grid has the proper voltage, no current will flow, even if the anode is positive.

In general, there are two methods of controlling the flow of current in such tubes. These are the amplitude method and phase method. In the amplitude method, the voltage applied to the grid is changed until the discharge starts, or with a fixed grid voltage the anode voltage is increased until current begins to flow. In the phase method, alternating voltages are applied to both grid and plate electrodes. If the voltage applied to the grid is in phase with that applied to the anode, current will flow through the tube half of the time or during the interval when the anode is positive. On the other hand, if the grid and plate voltages are 180° out of phase, the grid will be negative at the time the anode is positive and conduction does not occur. By varying the phase between these two voltages, the tube may be made to pass current for larger or smaller fractions of the cycle and thus the average current passed by the tube will be varied.

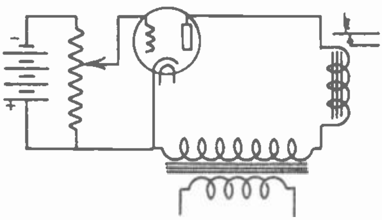


Fig.16 An amplitude method of controlling the anode current of a thyratron.

Fig. 16 illustrates a circuit using the amplitude method for controlling the plate current. Since the grid is always negative, it is not possible to cut the flow of current to less than one-quarter of a cycle. If the tube is not fired during the first half of the positive alternation, there will be no plate current flow during any part of the cycle. Thus, there are three possible values for the anode current; first, no current, produced by the adjustment of the grid voltage too low to start the anode current at the peak value of anode voltage; second, current flowing during the entire half cycle, or, third, current flowing for some period between the complete half cycle and one-half this time. So long as the grid and anode voltages are in phase, this limitation will exist and it will not be possible to cause current to flow for less than one-quarter cycle.

By adjusting the position of the potentiometer, the average current passed by the tube per cycle may be changed. Note that it is necessary for an alternating voltage to be applied to the anode; if a DC voltage were used, the discharge, having once started, would continue indefinitely. With AC on the anode, however, the discharge must be initiated once each cycle and just how high the anode voltage must rise before the discharge occurs depends upon the setting of the grid potentiometer.

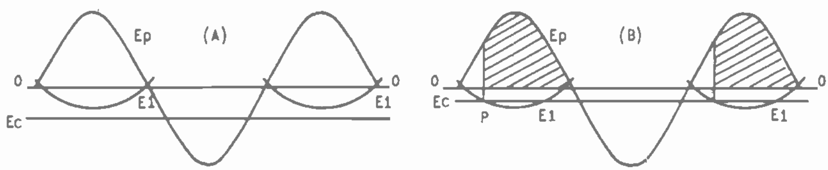


Fig. 17 (A) Illustrating the conditions existing when the grid is too far negative to allow the tube to fire. (B) Showing how a lowered grid bias will allow the tube to fire. Anode current flows during the shaded part of the cycle.

The curves shown in Fig. 17 illustrate how the amplitude method of control operates. At A it is assumed that the negative grid voltage is more than sufficient to prevent the discharge. Ep is the alternating voltage applied to the plate, and Ec is the negative grid bias. The curve marked E_1 is the critical grid voltage which would just allow the discharge to occur. Notice that its value varies throughout the cycle as the plate voltage changes. When the plate voltage is at its peak, the critical grid voltage is increased, however, in the example, the negative grid voltage is at all times greater than the critical firing voltage.

At B in the figure, it is assumed that the grid bias voltage is reduced, and at point P, the plate voltage has risen to the point at which the critical grid voltage is equal to the bias voltage. Thus the tube begins to conduct, and continues to pass current during the remainder of this alternation when its plate is positive.

It is possible to control the amount of anode current passing through the gaseous triode even when a DC voltage is applied to the plate of the tube. This is accomplished by the arrangement illustrated in Fig. 18. With the switch open, assume that the tube is conducting. If the applied voltage is, for example, 250 volts, approximately 15 volts will be dropped across the tube and the remaining 235 volts will be impressed across resistor R_2. Thus condenser C will charge to a potential of 235 volts with the left plate negative and the right plate positive. Upon closing the switch, the right plate of the condenser will be reduced to zero voltage, and since the condenser is now effectively connected across the tube,

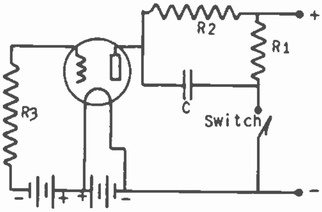


Fig.18 A method which may be used to control the flow of current when a DC voltage is applied to the anode.

the voltage applied to it is only 15 volts. Thus, the condenser discharges and, in so doing, the anode of the tube is made negative with respect to its cathode. If the time of de-ionization is less then the time required to recharge the condenser through R_2, the grid will be able to regain control and the anode current will not restart.

It is possible to construct a circuit of this type which will stop automatically by placing a glow tube across or in place of the switch. As soon as the potential of the condenser equals the breakdown potential of the glow tube, the latter becomes conductive and the potential across its terminals drops to very nearly extinction value. Thus, the potential of the anode with respect to the filament is suddenly lowered by an amount approximately equal to the difference between the breakdown and extinction potentials of the glow tube. For this reason, the condenser discharges until the potential across its terminals equals the extinction voltage of the

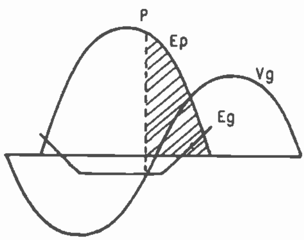


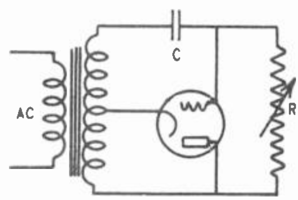
Fig.19 Illustrating how the phase method of current control works.

glow tube and then again starts charging. If the discharge is slow enough to allow the rectifier time to de-ionize before the anode again becomes 15 volts positive, the grid will be able to regain control. If the grid is more positive than the critical control value, the only effect of the glow discharge is to cause a periodic interruption of the load current.

When alternating voltages are applied to both grid and plate circuits, a better method of controlling the average anode current is by varying the phase between the grid and anode voltages. The principle of this method is illustrated in Fig. 19. Ep is the anode potential which is assumed to be a sine wave. Eg is the grid bias, positive above and negative below the line that will just allow the tube to fire at a corresponding value of Ep. Vg is a sine wave of grid voltage which is applied to the grid circuit. In this particular case, the alternating plate voltage Ep and the alternating grid voltage Vg are somewhat out of phase. At the earliest point in the cycle at which Vg crosses Eg (point P in the figure), the tube will fire. Thus, in this case, anode current will flow during that part of the cycle which is shaded.

By varying the phase relationship of the alternating grid voltage with respect to the alternating plate voltage, the tube may be made to fire at an earlier or later point in the cycle, thereby changing the average amount of anode current. When the grid voltage is directly in phase with the alternating anode voltage, current will flow throughout the complete half cycle that the anode is positive.

Fig.20 A circuit for obtaining phase control.



There are a number of ways to obtain the phase shift between the anode and grid voltages. Fig. 20 illustrates a typical circuit for obtaining the necessary phase shift. The filament, grid, and plate alternating voltages are all obtained from a transformer. Since the grid is connected to the opposite end of the transformer winding to that of the plate, the plate or anode has an opposite polarity with respect to the filament. Thus, when the anode is positive, the grid is negative. The voltages across the condenser and resistor are 90° apart. However, the sum of these two voltages, taking into account their phase difference is equal to the voltage developed across the entire transformer secondary. If the resistance is made very large, the phase difference between the grid and anode is great with a consequent decrease in the time per cycle that anode current flows. On the other hand, if the resistance were cut out entirely, then both the grid and anode would be connected to the same end of the transformer winding and the voltages applied to it would be in phase, making the tube draw current throughout the positive half cycle. Therefore, by varying the value of resistance R, the phase difference between the grid and anode voltages may be changed from in phase to nearly 180° out of phase. This will change the time that anode current flows from a very small fraction of one alternation to one-half cycle.

The value of the resistor may be changed manually as in illumination control or it may be affected by the varying resistance of a photocell under different intensities of illumination. The use of a photocell for various phase relationships is illustrated by the diagram of Fig. 21. In this case, the varying control is made possible by the varying rate at which the condenser is charged through the photocell. Thus, the actual resistance of the cell itself varies continuously and uniformly as the illumination is changed.

The grid controlled rectifier is, without a doubt, one of the most useful tools available to the electronic industry. It should be realized that these tubes are electrical contactors which close instantly, in which the current to a load can not only be turned on and off, but whose average value in any interval of time can be varied from zero to a maximum value and, furthermore, the troubles experienced with a mechanical relay, such as sparking contacts, sticking, heating, etc., are not present in the grid-controlled rectifier.

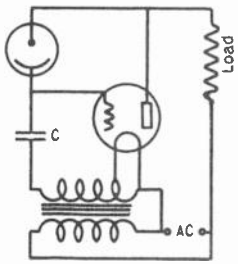


Fig. 21 Using the output of a photocell for changing the phase of the grid and anode voltages.

A combination of a photocell and a thyratron tube will perform many industrial jobs faster and with a greater accuracy than is possible manually. Grid-controlled rectifiers may be used for changing alternating voltage into direct voltage or they may be used as inverter tubes for converting direct voltage into alternating voltage. These two uses, themselves, are of great importance. As is well known, electrical power is transmitted as alternating current, since it may be stepped up by transformers and transmitted at a high voltage and a low current, with a consequent reduction in power loss along the line. Corona effects and poor power factor, however, do cause considerable loss even in alternating voltage transmission lines, two losses which would not occur if it were possible to transmit the power at a high DC voltage and a low current. At the present time, much research work is being done, using DC for power transmission. The AC voltage output of an alternator is stepped up to the high voltage necessary for transmission. It is then rectified by grid-controlled rectifiers, transmitted as a DC voltage and then, at the receiving end, it is converted into alternating voltage again by another set of grid-controlled rectifiers, after which it may be stepped down to voltages which are safe for industrial use.

One other very important use of the grid-controlled rectifier is the control of lighting for stage, theater, show windows, signs, floodlighting building exteriors, and for the interior decoration of assembly halls, etc. Before the use of grid-controlled rectifiers in illumination control, the only possible way of dimming theater lights was by use of control rheostats. To change the illumination of an incandescent lamp from maximum to minimum brilliancy, the voltage variation must be from maximum to 20% of maximum. In case the lamps are directly visible, an even greater variation may be necessary. In some cases, the minimum voltage may be as low as 8% of the maximum. When the intensity of the lamp is controlled by resistance, much power is wasted in the control rheostat. As an example, if the load current is reduced to 20%, 96% of the total power taken is being wasted in the rheostat. Thus, the rheostat acts as a losser, all the power being consumed in the lamps at full brilliance and none of the power going into the resistances. At lowered intensities, some of the power goes into the resistance and the remainder into the lamp.

In small installations, the lamps may be illuminated by allowing the rectified current from one or more grid-controlled rectifiers to pass through the filaments of the lamps. The average current passed by the grid-controlled rectifiers will, of course, depend upon the phase relationship between the grid and anode voltages. This phase relationship may be changed with negligible loss of power and, since the grid-controlled rectifiers are themselves very efficient, the actual power wasted is comparatively small even when the incandescent lamps are burning at low brilliancy. In larger installations, grid-controlled rectifiers are used in conjunction with saturable reactors. A large choke coil or reactor is connected in series with the lamps. The lamps and reactor are then connected across the AC line. The output of the grid-controlled rectifier passes through another winding on this same reactor. When the gaseous tube is non-conducting, no current flows through this auxiliary winding and the high inductive reactance of this choke coil prevents much current from flowing through the incandescent lamps. Thus, the lamps burn with very low brilliancy or not at all. Now, by changing the phase of the alternating voltage applied to the thyratron, the tube is caused to conduct and the DC current flowing through the auxiliary winding of the reactor saturates its core. With the core saturated, the inductance of the reactor falls to a very low value and, consequently, its inductive reactance is so low that the choke coil offers very little opposition to the alternating current flowing through the lamps. The lamps, therefore, burn with full brilliancy. By adjusting the fraction of the cycle during which the thyratron conducts, the average current flowing through the auxiliary windings is changed and the amount of saturation and inductance of the choke coil is varied. By this means the illumination intensity of the lamps are controlled from full brilliance to nearly darkness. If it is desired that the dimming of the lamps be automatic, such as in the floodlighting of the exteriors of buildings, the phase shifting network of the thyratron may be varied by a small motor. The power saved by this method in comparison to using rheostats will pay for the additional installation cost of the thyratron and saturable reactor in a very short time. Fig. 22 illustrates a circuit which could be used for illumination control.

6. APPLICATION OF PHOTO-EMISSIVE CELLS. Although it is impossible to list all of the applications to which photocells may be put, we shall, in the following section, describe some of the more interesting applications. For example, consider Fig. 23. This figure consists of a photocell and two amplifier tubes. It is used as a time delay circuit. When light shines on the photocell, tube

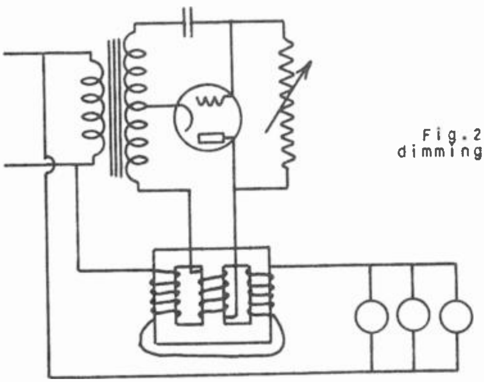


Fig.22 Using a thyratron for dimming lights.

A has a large negative grid bias which prevents the flow of plate current. Thus the contacts of relay R_1 are open. In the grid circuit of tube B, there is connected a grid leak Rg and a grid condenser Cg. When this condenser becomes fully charged, the bias on tube B is quite large and the plate current flowing through this tube is not sufficient to operate relay R_2. Thus, the contacts of relay R_2 are opened. These contacts connect to the circuit which is to be

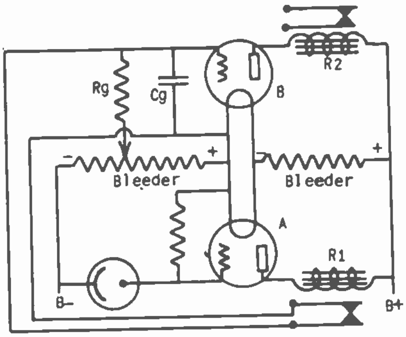


Fig.23 A time delay circuit.

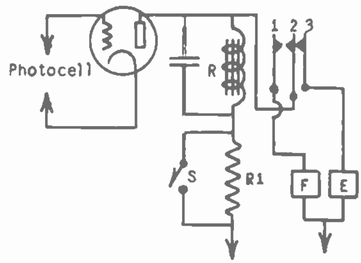
controlled. An interruption of the light beam will cause the output of the photocell to drop and the negative bias on tube A will be removed. Thus, plate current will flow through tube A, operating relay R_1. The closure of the contacts in this relay will short out the condenser Cg in the grid circuit of tube B. Shorting this condenser, however, removes the grid bias from tube B, causing plate current to flow through this tube and thereby operating relay R_2.

When the contacts of R_2 close, they in turn operate a power relay, not shown, which removes power from the controlled circuit.

When the light beam is again established, the plate current of tube A stops flowing, relay R_1 releases its contacts and the condenser Cg begins to charge. Just how long a time interval will be required for condenser Cg to charge depends upon the time constant of the grid circuit of tube B. When this definite time interval has elapsed, tube B will again be biased so negatively that relay R_2 will release its contacts and through the power relay will again apply power to the control circuit. Although this arrangement is slightly more complicated than an ordinary time delay relay, it has the advantage that there is a minimum of moving parts and thus the circuit has an almost unlimited life.

One of the simplest applications of photocells is that of counting. Objects upon a moving conveyor belt interrupt a light beam, shining onto a photocell and, for each interruption, the photocell, through an amplifier which may be either an ordinary triode or a thyratron, operates an electromagnetically controlled counting relay. This system has a number of advantages over an ordinary counter which works upon mechanical contacting principles. The objects in question may be of irregular shape and size, or perhaps very light in weight. Thus, the mechanical contacts might be too light to secure positive action of the counting relay. Although the photocell system will probably be somewhat more expensive, very often it is the only system that will serve the purpose.

Fig. 24 A photocell counting and inspection circuit.



Many times it is desirable to count large and small objects at the same time. In this case, two photocells may be used, one mounted at a higher level than the other. When a small object passes, it will interrupt only the lower light beam and one counting relay will operate. Large objects, on the other hand, will interrupt both light beams and, with the proper relay equipment may be made to operate a second counting relay. By the same principle, large objects may be separated from small ones. In this case, the photocell system becomes a counting device, an arrangement by which a record of the efficiency of an operator or system may be made by counting separately the filled and empty containers on a conveyor belt as illustrated in Fig. 24. Every time that a pocket or bin of the belt is before the cell, switch S is closed mechanically. If the bin is empty, the light beam is not interrupted and contacts 2 and 3 of the relay remain closed, causing counter E to record the fact. However, if the bin is filled, the light beam is interrupted, relay R is energized and contacts 1 and 2 are closed. This causes the counting relay F to operate. The value of the resistance of R_1 is large enough so that the current through the tube will not be able to operate the relay unless the switch S is closed. With this arrangement not only is there a total output count made, but inefficiency or inexperience is also revealed.

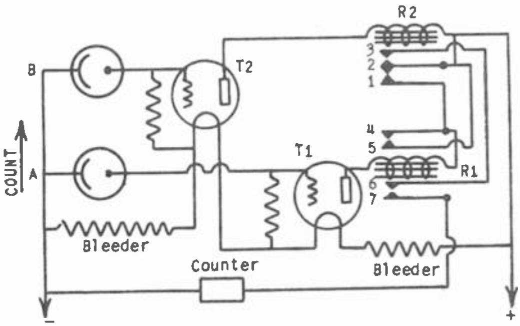


Fig. 25 A circuit which counts objects moving in one direction but not in the other. The photocells receive their positive anode voltage from the voltage drop across the bleeder resistors.

An interesting circuit for counting objects is illustrated in Fig. 25. This circuit has the peculiarity in that it counts objects moving only in one direction. An object moving in a direction from B to A will not operate the counter, whereas an object moving in the direction from A to B will cause the counter to record the fact. The two cells together with the light beams which are focused upon them are placed closely enough together so that a passing object will obstruct first one light beam, then both of them and then only the second light beam. Let us consider what takes place when an object moves in the direction from A to B. Before either light beam is interrupted, both photocells have maximum output and both amplifier tubes have such a high negative grid bias that there is no plate current flow through either. Thus the contacts 4 and 5, and 6 and 7 of relay R_1 are open whereas contacts 1 and 2 are closed. As the object to be counted passes in the direction from A to B, it first interrupts the light beam falling upon cell A. The output of this cell drops to zero and the negative bias is removed from tube T_1. Thus, plate current flows through tube T_1, through the winding of relay R_1, through contacts 1 and 2 of relay R_2 to B+. The current flowing through relay R_2 energizes it and closes contacts 4 and 5, and 6 and 7. The closing of contacts 4 and 5 makes this relay independent of contacts 1 and 2 of relay R_2. The object now passes on and obscures both light beams. The high negative bias is removed from tube T_2 and plate current now flows through this tube through the winding of relay R_2 to B+. This current energizes relay R_2, causing it to close contacts 2 and 3 and open contacts 1 and 2. A circuit is now completed from B- through the counting relay, through contacts 6 and 7, through contacts 2 and 3, to B+. Thus the counting relay operates and records the passing of the object. As the object moves on, light again falls on photocell A, the plate current of tube T_1 drops to zero and relay R_1 is de-energized. Likewise, as the object passes beyond the light beam falling upon cell B, the plate current of tube T_2 falls to zero, relay R_2 is de-energized and the circuit returns to its normal state.

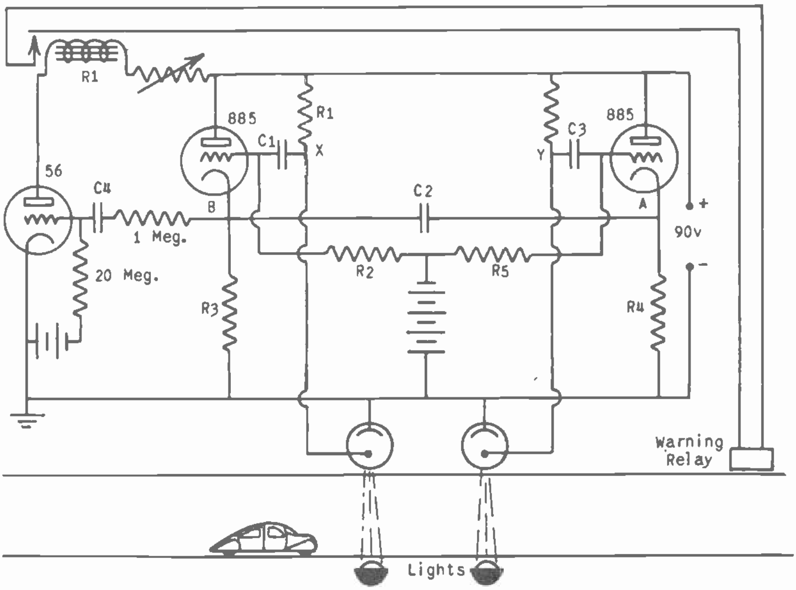


Fig.26 A photocell speed trap circuit.

Now, let us see what occurs when an object moves in the opposite direction. The light beam energizing photocell B is interrupted first. This allows current to flow through tube T_2 and relay R_2 is energized, closing contacts 2 and 3 and opening contacts 1 and 2. The object passes onward and obscures both light beams, thus releasing the negative bias on tube T_1. Plate current, however, does not flow through tube T_1 since no completed path is provided. This is due to the fact that contacts 1 and 2 of relay R_2 are open at this time. As the object moves onward, photocell B is again illuminated and its plate current drops, releasing relay R_2. Now, while photocell A is still obscured, plate current can flow through tube T_1, through the windings of relay R_2, through contacts 1 and 2 of relay R_1 to B+. This causes relay R_2 to be energized and contacts 4, 5, 6, and 7 are closed. The counter, however, does not operate, for when relay R_2 was de-energized, contacts 2 and 3 were opened and the circuit through the counting relay is not complete. As the object passes onward, both of the photocells are again illuminated and the circuit returns to its normal condition.

An interesting application of photocells used in conjunction with gas triodes is illustrated in the circuit shown in Fig. 26. This is a photoelectric automobile speed trap. The photocells and the lamps illuminating them are placed closely enough together so that a vehicle will obstruct first one beam, then both beams and, finally, just the second beam. In the normal state, the gas triode A is conductive whereas B is not. The normal plate current to the type 56 tube is not great enough to cause relay R to close its contacts, although this current is greater than the release value of relay R. We shall assume for the present that the contacts of relay R are open. As a vehicle moving from left to right obstructs the first light beam, the output of the first photocell is sharply decreased. This causes the voltage drop which has been created by the cell current across resistance R_1 to drop practically to zero and point X becomes more positive. As a result, condenser C_1 charges to a higher potential. The charging current for C_1 flows from the right plate of this condenser through resistance R_1, through the 90 volt DC source, through the bias battery and through resistance R_2 to the left plate of this same condenser. In flowing through R_2, this current created a voltage drop which bucks against the bias voltage. The grid voltage of the gas triode B becomes less negative and tube B begins to pass current.

Before tube B was conducting, there was no voltage drop across resistance R_3 connected in its cathode circuit. Now, with plate current flowing, there is a voltage across this resistance which tends to make the cathode of tube B somewhat positive with respect to ground. Before tube B was conducting, condenser C_2 was charged to the voltage existing across resistor R_4, with the left plate negative and the right plate positive. Since the left plate of condenser C_2 is now somewhat positive with respect to ground, this condenser must discharge. The discharge current of C_2 flows from the left plate of this condenser through resistance R_3 and R_4, to the right plate. In flowing through R_4, it creates a voltage drop across this resistor which makes the cathode of tube A considerably positive. In fact, the cathode of this tube becomes more positive than its plate and conduction stops. When a vehicle obstructs the second light beam, the output of the second photocell drops and the positive voltage created at point Y, causes condenser C_3 to charge. The charging current of this condenser flows through resistance R_5 and creates a voltage drop which bucks against the bias battery, allowing the grid of tube A to become less negative. This causes tube A to conduct and the voltage drop created across resistor R_4 in the cathode circuit is transferred through condenser C_2 to resistor R_3 in the cathode circuit of tube B. This action causes the cathode of tube B to become highly positive and this tube stops conducting. It is thus seen that tube B conducts only during the time that it takes the vehicle to go the distance between the two phototubes.

When tube B starts to conduct, its cathode jumps to a high positive potential and this voltage drop across resistor R_3 is transferred through condenser C_4 to the grid of the type 56 tube. This results from the charging of condenser C_4. The charging current flows from the right plate of this condenser through the 1 megohm resistor, through resistor R_3, through the bias battery and the 20 megohm grid leak to the left plate of C_4. In flowing through the 20 megohm grid leak, this charging current creates a voltage drop which bucks against the bias voltage and allows the plate current of the type 56 tube to increase sufficiently to close the contacts of relay R_1. The warning relay does not immediately close, because it is of the slow acting type. The normal plate current of the type 56 tube is just slightly less than the value required to operate the relay. The time constant of the condenser C_4 and the resistors through which it is charged is fairly great, and this condenser continues to charge while tube B is conducting. The actual voltage to which this condenser charges depends upon the length of time that tube B conducts, or upon how long it takes the vehicle to pass between the two light beams. After the second light beam is obstructed, tube B stops conducting as explained previously, and there is then, no voltage drop across resistor R_3. When this occurs, condenser C_4 begins to discharge. The discharge current flows from the left plate of this condenser down through the 20 megohm grid leak and the bias battery, up through resistor R_3 through the 1 megohm resistor, to the right plate of the same condenser. The discharge current creates a voltage drop across the 20 megohm grid leak which adds to the voltage of the bias battery and tends to make the grid of the type 56 tube more negative. Naturally, the plate current of the type 56 tube decreases, and if the vehicle which has obstructed the two light beams has been traveling at a normal rate of speed, tube B will conduct for a long enough period so that condenser C_4 will become almost fully charged. Then, when it is discharging, it will set up sufficient voltage drop across the 20 megohm grid leak to reduce the plate current of the type 56 tube to the point where relay R_1 will release. The alarm is not sounded, because the circuit to the warning relay is opened before this relay has time to operate.

Now, let us suppose that an automobile passes the light beam at an excessive rate of speed. Tube B conducts for a very short interval and condenser C_4 does not have time to charge to a very high voltage. Thus, when the car has passed, the discharge current of condenser C_4 will not be very great, the plate current of the type 56 tube will be reduced only slightly and the contacts of relay R_1 will not be released. This being the case, the contacts of the warning relay will close and an alarm will be sounded.

Once the warning relay has closed, it will remain closed for any number of fast cars and will be shut off only by a car traveling at a normal rate of speed.

With but slight changes in the installation, this circuit may be used in many different applications. The diagram illustrated is designed for a single line of traffic. For two lines of traffic traveling in the same direction, such as on four lane highways, bridges, vehicular tunnels, etc., a vertical beam of light can be used for each lane. The light source and phototube may be mounted in a hood overhead in conjunction with a mirror buried in the lower end of a vertical pipe sunk in the road. With this arrangement, trouble due to sunlight and other stray light is avoided. If desired, the relays may be replaced by DC milliammeters, calibrated in miles per hour and an accurate measurement of the instantaneous speed of racing vehicles may be made.

The next circuit that is to be described is one for the automatic timing of races. This circuit is illustrated in Fig. 27. It includes a photocell, an amplifier tube, a microphone, an electrically driven timing clock and associated relays. The operation of the circuit is as follows. The microphone is so placed that it will pick up the sound of the starter's gun. When the gun is fired, a

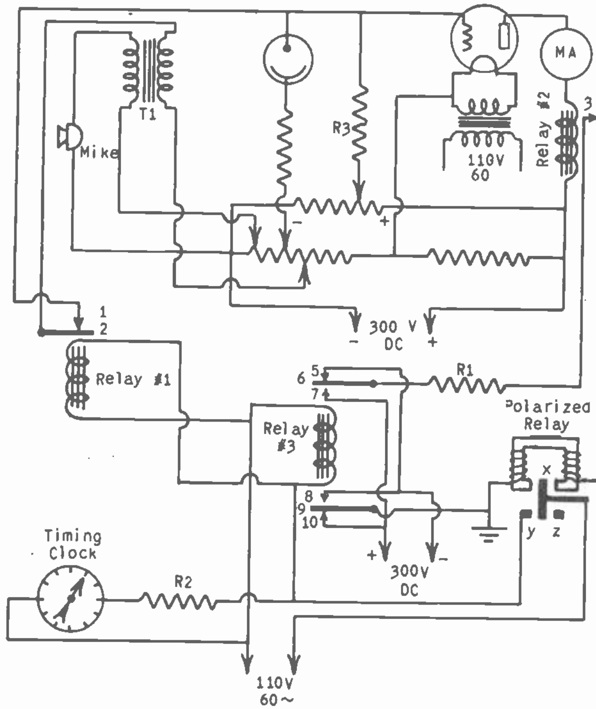


Fig. 27 A circuit for timing races.

pulse of current is delivered by the microphone to the primary of T_1. This induces a voltage across the secondary of this transformer. The top end of the secondary of this transformer is connected to contacts 1 and 2 of relay 1 to the grid of the amplifier tube. The bottom of this winding is connected to a point on the voltage divider. The voltage pulse which is created across the secondary of this transformer momentarily increases the plate current of the amplifier tube and this pulse of plate current, in passing through the winding of relay 2, closes contacts 3 and 4. Switch 1 must be in a closed position at this time. The momentary closing of contacts 3 and 4 completes a circuit through the winding of a polarized relay. Current flows from the negative terminal of the 300 volt DC source, through contacts 5 and 6 of relay 3, through the resistance R_1, through contacts 3 and 4 of relay 2, through the switch, through the winding of the polarized relay, through contacts 9 and 10 of relay 3, and back to the positive side of the voltage source.

When current flows through the winding of the polarized relay in this direction, it causes the plunger arm X to move over and make contact with point Y. Even after the original pulse created by the microphone has passed and the plate current of the amplifier circuit returns to normal, opening contacts 3 and 4, plunger X will still make contact with Y since there is no spring connected to this plunger and it remains in the position to which it has been attracted. When this plunger makes contact with point Y, a circuit is now completed from one side of the 110v line through these contacts through resistance R_2 and through the electrically driven timing clock, back to the other side of the line. Since the time lag of the circuit is very small, the timing clock is started practically simultaneously with the firing of the starter's gun.

With the closing of contacts X and Y, two other important happenings occur. A circuit is now completed through the winding of relay 1. This relay is energized and opens contacts 1 and 2, thereby disconnecting the secondary of the microphone transformer from the grid circuit of the amplifier tube. Thus, any sounds which might be picked up by the microphone will not affect the operation of the circuit. In addition, the circuit is now complete through the winding of relay 3. This relay is energized and it closes contacts 6 and 7, and 8 and 9; at the same time opening contacts 5 and 6, and 9 and 10. This is a polarity reversing relay and with the closing of these contacts, the circuit is now arranged so that current will flow through the polarizing relay in the opposite direction when this circuit is again complete. As soon as the race is started, switch 1 is opened and is left open until the runners begin their last lap.

After the last lap has begun, switch 1 is closed and the first runner passing the finishing line will interrupt the light beam to the photocell. This will reduce the output of the photocell and lower the negative voltage developed across resistance R_3. The plate current of the amplifier tube will increase, causing relay 2 to be energized and closing contacts 3 and 4. As switch 1 has already been closed, the circuit through the polarized relay is now complete. Current will flow from the negative terminal of the 300-volt source, through contacts 8 and 9, which are now closed, through the winding of the polarized relay, switch 1, contacts 3 and 4, resistance R_1, through contacts 6 and 7, and back to the positive side of this voltage source. The polarity reversing relay 3 is energized, and the current flows through the windings of this relay in the opposite direction. This being true, plunger X is attracted to the right toward point Z. Contacts X and Y are broken and the 110v circuit is interrupted, the timing clock stopped, relays 1 and 3 are de-energized and the circuit returns to normal.

Timing a race automatically by this method is far more accurate as it eliminates the reaction time of an individual. It has been shown by psychologists that reaction time will vary from .175 to .225 second. This means that when a race is timed by an observer with a stop watch, a short interval will elapse after a race has started before the observer places a stop watch into action. Furthermore, as the observer sees the runner approach the finishing tape, it is human nature for him to anticipate the moment that the tape will be reached and, consequently, there is another source of error at the end of the race. With the automatic timing circuit as just described, races may be timed accurately to within .01 second.

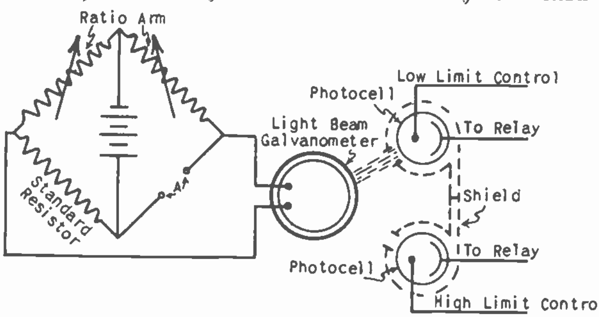


Fig. 28 Schematic diagram of a resistor sorting device, employing photocells and relay.

Another photocell application as applied to the radio manufacturing industry, is shown in Fig. 28. This circuit is for the automatic sorting of resistors. The only difference between this circuit and the standard bridge circuit is that the battery and the galvanometer have been reversed. Therefore, the sensitivity is increased at high resistance values without damaging the ratio arms, since higher voltages can be applied to the bridge. The indicating device used consists of a light beam type of galvanometer. Deflection of the light beam is dependent on the degree of variation of the resistor being tested from the standard resistance of the bridge.

If the bridge is balanced, no voltage will be applied to the galvanometer, and the beam of light from the galvanometer will be directed straight outward. An unbalance in the bridge circuit will cause a voltage to be applied to the galvanometer, and the light beam will be deflected either to the left or right, depending upon the unbalance.

Two photocells are spaced a short distance apart corresponding to the deflection of the galvanometer at the low and high resistance limits allowed by the manufacturer. The resistors are placed on a conveyor which transports them to the contact points at A on the bridge. If the resistor does not correspond within a certain percentage to the standard resistance, the light from the light beam galvanometer will fall on one of the photocells due to the fact that the bridge will be unbalanced. The photocell that the light falls on will depend on whether the resistor is above or below the standard value. These photocells operate an amplifier and associated relay and rejection mechanism which eliminate the faulty resistor.

A circuit which measures the turbidity or total light transmission of any liquid is illustrated in Fig. 29. It consists of two photocells used as two arms of a Wheatstone Bridge. The other two arms are fixed resistors. A DC voltage is applied to two diagonally opposite points of the bridge in such a manner that the anodes of the two cells will be positive. By referring to the diagram, it may be seen that the photocells are connected in series so far as the voltage source is concerned.

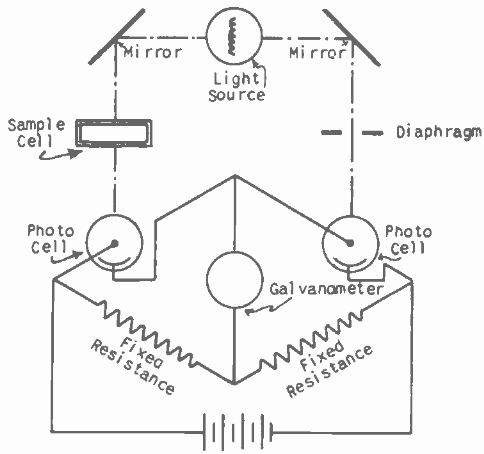


Fig. 29 Photocell device for measuring the turbidity of liquids.

The resistance of a cell depends directly upon the amount of light falling upon it, and the bridge is adjusted until a balance is obtained when the same amount of light illuminates each cell. To use the instrument, a light source is arranged so that light rays will be reflected by two mirrors placed at 45° angles, upon the photocells. One beam of light passes through a diaphragm onto one cell, and the other beam passes through a container holding the liquid whose turbidity is to be determined. Due to the fact that the liquid is not perfectly clear, the light beam passing through it will be partially obscured. Thus, the cell receiving this beam will have a lowered output, and its resistance will increase. This action will unbalance the bridge and produce a deflection of the galvanometer. The meter may be calibrated directly in units to measure the percent of light which the liquid transmits.

One use of the instrument is to measure the turbidity of drinking water in the water supply system of a city. Another important use of the device is in making blood tests. Its technical name is "scopometer."

EXAMINATION QUESTIONS

INSTRUCTIONS. Before starting to answer these examination questions, you should have studied the lesson material at least three times. Be sure that you understand each question--then proceed to write the best answer you can. Make all answers complete and in detail. Print your name, address, and file number on each page and be neat in your work. Your paper must be easily legible; otherwise, it will be returned ungraded. Finish this examination before starting your study of the next lesson. However, send in at least three examinations at a time.

1. Explain the difference between a photo - emissive and a photo-voltaic cell, with reference to commercial applications.

2. Explain the difference in operation between the two circuits shown in Figs. 1 and 2.

3. What characteristics must a relay have to be suitable for photocell applications?

4. What is meant by pull-up and release values for a relay?

5. How is it possible for a photocell and amplifier to work directly from an alternating voltage source?

6. What is the chief advantage and disadvantage of a barrier cell?

7. Explain in your own language how a gas filled triode works. What is its chief advantage?

8. What is the difference between amplitude and phase control of a gaseous triode?

9. Why is it most convenient to use an AC voltage on the plate of a gaseous triode?

10. Upon what principle does the Weston foot - candle meter work? Why is it necessary to use a viscor filter?

The text of this lesson was compiled and edited by the following members of the staff:

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UNIT NO. 5

CATHODE RAY TUBES

LESSON NO. 6

SCIENCE

........and man's mind.

During the years of the nineteenth century that have passed, marvelous scientific and mechanical accomplishments have been made. Our mode of living has continually undergone radical changes and business methods in general have been revolutionized. Naturally, these changes have, at times, created problems of a serious nature.

For example, with the advent of the automobile, large factories devoted to the building of horse-drawn vehicles were forced to turn to other products or go out of business. Factories building talking machines suffered the same fate when radio was introduced. But the problems did not stop at the source of production..the factory. They were multiplied thousands of times in the homes of men who were employed in those factories. Their trade had become obsolete. Some of these men quickly trained themselves for employment in the newly created industries. Those who failed to adjust themselves to the new conditions were, in most instances, forced to common labor.

The moral of this little story is this. *Man's mind must keep pace with scientific and mechanical development.*

In your case Mr. Student, it means that you must keep informed on the developments within the radio and related industries. You must read publications devoted to radio. Then, when you discover new developments that may have a direct bearing on your future success, you must secure all information possible about that development.

And that is where Midland service comes in. We will at all times be glad to send you such information when it is at our disposal. We want you to attain and RETAIN success, because we take a very real and sincere interest in you and your problems.

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Lesson Six

CATHODE RAY TUBES

"Without cathode rays and cathode ray tubes, modern television as we know it would be impossible.

"In this lesson you will be introduced to the fundamental principles of these tubes. Study them carefully, because this is the foundation of much material that is to follow".

1. CATHODE RAYS. Fig. 1 represents a highly evacuated glass tube. In it are sealed two electrodes. When a high DC potential is applied to these two electrodes, several interesting phenomena are produced. The negative terminal of the tube is called the cathode; the positive terminal, the anode. As soon as the DC potential is applied, the glass walls in the vicinity of the anode glow with a yellow light. The term applied to this kind of glow is fluorescence. If the simple wire anode in Fig. 1 is replaced by a large thin metal cross as in Fig. 2, the shadow of the cross is produced on the end of the tube opposite the cathode. When the position of this anode is changed, the position of the shadow changes with it. This fact proves that the yellow glow of fluorescence is due to some radiation from the cathode. The term we are going to apply to this radiation from the cathode is "cathode rays". Most substances fluoresce when exposed to cathode rays, some very brilliantly. If the position of the anode in Fig. 2 is changed, the position of its shadow also changes so that the shadow, anode, and cathode are always in line. This proves that the cathode rays travel in straight lines. If a thin, narrow screen with a narrow slit is placed in front of the cathode, the cathode rays going through the slit will form a very narrow beam. The path of this beam of cathode rays can be shown by placing lengthwise in the tube a screen coated with fluorescent material[1] and inclined slightly to the path of the beam. Such a tube is illustrated in Fig. 3. If a horseshoe magnet is placed near the tube so that the axis of the tube is at right angles to the magnetic field, the cathode rays are deflected at right

[1] Fluorescent materials generate light when bombarded by electrons.

angles to both the direction in which they are going and the magnetic field.[1] If the magnetic field is reversed, the deflection of the cathode ray beam is reversed. If the cathode ray tube in Fig. 3 is modified by inserting two parallel plane plates as in Fig. 4, another striking phenomenon of cathode rays can be seen. When a DC potential is applied across the two parallel plates, the beam of cathode rays is deflected toward the positive plate. If

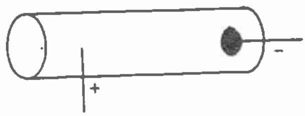


Fig. 1 A tube for generating cathode rays.

a concave cathode is used, such as is illustrated in Fig. 5, the cathode rays can be focused, or brought to a point. The location of this focus indicates that the cathode rays leave the surface of the cathode perpendicularly. If a thin sheet of metal is placed in the beam of cathode rays at the focal point, the impact of the concentrated cathode rays on the metal is sufficient to heat it to incandescence and occasionally to the melting temperature. This indicates that cathode rays have considerable energy; in fact, the

Fig. 2 Showing how cathode rays travel in straight lines.

cathode rays have sufficient energy to pass through sheets of aluminum foil and other metals. Experimenters have found that the maximum speed of cathode rays range from $\frac{1}{10}$ to $\frac{1}{2}$ that of light. The speed of light is 186,000 miles per second. The speed depends upon the magnitude of the DC potential applied between the anode and cathode of the tube. Summarizing the properties of cathode rays, we can say that cathode rays produce fluorescence, travel in straight lines, are deflected by electric and magnetic fields, can be focused, have considerable energy, and travel at high speeds.

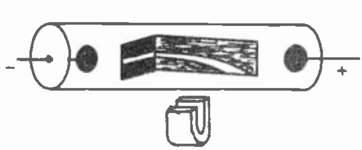


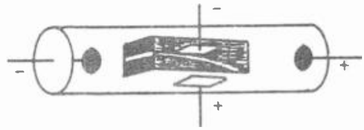
Fig. 3 Showing how cathode rays are deflected by a magnetic field.

What are cathode rays? Since cathode rays travel through space, they must either be a wave motion of some kind or a stream of very fine particles. We have just listed the properties of cathode rays. The fact that cathode rays are deflected by electric and magnetic fields proves they are not a form of wave motion. In general, wave motions are unaffected by electric and magnetic fields. The fact that cathode rays are deflected by electric and magnetic

[1] Sec. 12, Lesson 8, Unit 3.

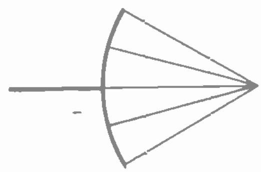
fields shows that they carry an electric charge. It was stated previously that when a beam of cathode rays is passed between two plates which have a difference in potential, the cathode ray beam is bent in the direction of the positive plate. Knowing that unlike charges attract and like charges repel, it is evident that the cathode rays are charged negatively. The direction of the deflection in the case of the magnetic field also indicates that the cathode rays are charged negatively. In other words, a beam of cathode rays has the same properties as an electric current passing through a wire as far as electric and magnetic fields are concerned. The

Fig. 4 Showing how cathode rays are deflected by an electrostatic field.



charge on the particles of a cathode ray beam have been measured and are the same as that of an electron. Also, the mass of the particles has been found to be the same as the mass of an electron. Therefore, cathode rays consist of streams of high speed electrons. If you will recall, the mass of an electron is $\frac{1}{1805}$ of the mass of a hydrogen atom (hydrogen being the lightest of the elements). This means that cathode rays are practically massless. Under the properties of cathode rays, we stated that cathode rays had a very high energy content. The energy of a moving particle, or kinetic energy, depends upon its mass and velocity. In fact, the energy of

Fig. 5 Showing how cathode rays can be focused by a concave cathode.



a moving particle is directly proportional to its mass and directly proportional to the square of its velocity. Therefore, the energy possessed by cathode rays are due to the extremely high velocity of the particles, as the mass of the particles is extremely minute. Then, anything which will increase the velocity of the cathode rays will also increase their energy.

Of what value are cathode rays to the electrical engineer and television engineer? Since cathode rays are essentially massless, can be deflected by electric and magnetic fields, and will produce fluorescence of certain types of materials; they can be used for making electrical measurements. The cathode ray beam has an advantage over the D'Arsonval movement and other mechanical type electric indicators. The cathode ray, being massless, is instantly responsive to any changes in the applied electric or magnetic field, while the mechanical movement, having mass, requires a little time to respond to the applied magnetic or electric field. Because cathode rays produce fluorescence, the magnitude of their deflection can be indicated by the change in the location of the fluorescence. Since the cathode ray beam is without inertia, it is responsive to frequencies ranging from zero to several megacycles. Also, little or no energy is required from the applied electric and magnetic fields to deflect the beam. This means that no energy is taken from the circuit under test, or in other words, a cathode ray indicating device is one of extremely high impedance.

2. SIMPLE CATHODE RAY TUBE. The device making use of the properties of the cathode ray for making electrical measurements and observations is called a cathode ray tube. The simplest cathode ray tube consists of a cathode, a screen to produce a narrow pencil of rays, an anode, and a fluorescent screen to show the deflection of the cathode ray beam. Fig. 6 is an illustration of a simple cathode ray tube; C is the cathode, F is the fluorescent

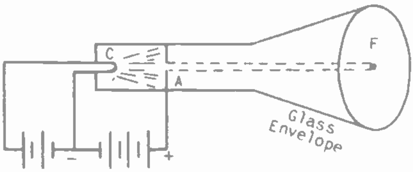


Fig.6 Simple cathode ray tube. C is the cathode, A the anode, and F the fluorescent scrren.

screen at the end of the tube on the inside surface. The screen is translucent and the fluorescence is viewed by looking at the end of the tube. A, the anode, having a small hole in the center, serves the double purpose of giving the electrons speed and forming a narrow cathode ray beam. In this case, we use a "hot" cathode, instead of the "cold" cathode used in the examples previously described. With a hot cathode, the electron emission is much more copious and the electrons are emitted by the cathode by much lower anode voltages. The tube operates as follows: The electrons are emitted by the cathode C. Anode A, having a high positive poten-

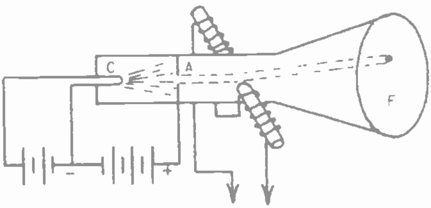
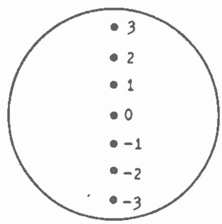


Fig.7 Cathode ray tube using magnetic deflection.

tial with respect to the cathode attracts the electrons. Since the anode does have a high positive potential with respect to the cathode, it accelerates the electrons in the direction of the anode, Most of the electrons will strike the anode. A few that are in line with the hole in the center will go through. Those passing through this hole constitutes the cathode ray or electron beam. The beam of rays will strike the fluorescent screen F at the end of the tube and cause it to fluoresce at the point of impact.

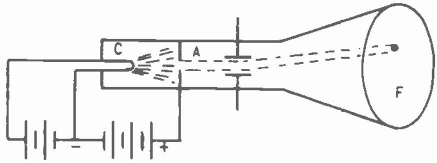
There is no method provided in Fig. 6 for deflecting the cathode rays. We can use magnetic deflection by placing an electromagnet outside of the tube as shown in Fig. 7. Since the magnetic field produced by an electromagnet depends upon the magnitude of the flow of current through the coil, Fig. 7 could be used for measuring direct current and its direction of flow. A simple cathode ray tube ammeter must first be calibrated. We first note the position of the cathode ray beam with no current flowing through the electromagnet. The position of the beam will be indicated by a spot of fluorescence on the end of the tube. We will call this point zero current. We then pass a current of 1 ampere through the coil. The beam will be deflected a certain amount. The new position of the beam will be labeled 1 ampere. Similarly, we will pass 2 amperes and then 3 amperes through the coil, and mark the two new points accordingly. If we reverse the flow of current through the electromagnet, the beam will be deflected in the opposite direction. We can call this the negative direction and locate currents of -1, -2, and -3 amperes respectively. Fig. 8, then, will represent the

Fig. 8 Calibration of cathode ray tube ammeter.



calibration of our simple cathode ray tube ammeter. We can also use our cathode ray tube ammeter for measuring AC current. If we pass an AC current through the electromagnet, the beam will be deflected in both the positive and negative regions. In this case the maximum deflection of the cathode ray beam will indicate the maximum or peak value of the current. To get the effective or R.M.S. value, you will have to multiply the peak value by .707. If the frequency of

Fig. 9 Cathode ray tube using electrostatic deflection.



the current under measurement is very slow, for instance, less than 15 c.p.s., the eye is able to follow the movement of the fluorescent spot as it moves up and down on the end of the tube. If the frequency is higher than the eye is able to follow, such as 60 cycles, the rapidly moving spot will trace a straight line on the end of the tube. The terminals of the line will be the maximum positive value and the maximum negative value that the current has.

In Fig. 9, we have a simple cathode ray tube using electrostatic deflection. This tube can be used as a voltmeter. Again, it will be necessary to calibrate our simple voltmeter. As in the previous case, we first note the position of the fluorescent spot when there is no difference in potential across the two plates. Then apply DC potentials of 1, 2, and 3 volts across the plates and mark the positions of the deflection of the beam; and we will have a calibration similar to that in Fig. 8. Similarly, if we applied an AC voltage to the plates, the beam would be deflected in both directions at a high rate of speed and would produce a continuous line from the maximum positive peak value to the minimum negative peak value of the AC voltage.

3. DEFLECTION SENSITIVITY. The factors which control the deflection sensitivity of the cathode ray tube are the speed of the moving electrons, and the intensity of the applied magnetic or electrostatic field, and the extent of the fields. The intensity of the electrostatic field is directly proportional to the difference in potential between the plates and inversely proportional to the distance between the plates. The intensity of the magnetic field is directly proportional to the inductance of the coils, and the current through the coils, cross sectional area of core, and inversely proportional to the distance between the poles. The deflection of the cathode ray tube beam is directly proportional to the magnitude of the applied electrostatic or magnetic fields, and is inversely proportional to the square of the velocity of the electrons in the beam. The velocity of the electrons in the cathode ray beam vary directly as the square root of the second anode voltage. Therefore the sensitivity of the cathode ray tube is directly proportional to the applied deflecting field and inversely proportional to the anode voltage. The actual bending or deflecting of the beam takes place only when the beam is under the influence of the electrostatic or the magnetic field; that is, when the beam is passing between plates in the case of electrostatic deflection, or between the pole pieces in the case of electromagnetic deflection. The path of the beam is unidirectional before entering the deflecting field and is again unidirectional after leaving the deflecting field. In the case of the electrostatic field, the beam is bent in the direction of the positive side of the applied field. In the case of the electromagnetic field, the beam is bent at right angles to both the applied field and the direction in which the beam is moving. In the case of electrostatic deflection, the sensitivity is rated in terms of the number of millimeters of deflection per volt impressed across the deflecting plates. Whenever a statement of sensitivity is made, the anode voltage must also be given, because the sensitivity depends upon the anode voltage. The higher the anode voltage, the less sensitivity, because the electrons are under the influence of the deflecting field for a shorter period of time. For magnetic deflection, the sensitivity is rated in millimeters per ampere turn when the dimensions of the coil are given. Otherwise, there is no rating given. By ampere turns, we mean the product of the number of turns of wire in the coil and the current flowing through it. The strength of the magnetic field is direct-

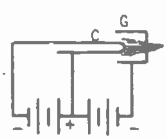
ly proportional to the number of turns on the coil, and directly proportional to the current flowing through the coil. Similarly, as with electrostatic deflection, the sensitivity depends upon the anode voltage.

Since the brilliancy of the fluorescence depends upon the energy or speed of the electrons which in turn depends upon the anode voltage, there must be a compromise between sensitivity and the brilliance of the pattern.

4. ACTION OF ELECTRONS AT THE FLUORESCENT SCREEN. Only a part of the energy of the electrons in the cathode rays is transformed into light by the fluorescent screen, Part is changed into heat and raises the temperature of the glass envelope. The remainder is spent in knocking out secondary electrons from the screen. The secondary electrons have very low velocities and are collected by the anode. The screen acquires a potential that is just enough negative to the anode so that the anode collects secondary electrons from the screen at exactly the same rate that the primary electrons arrive at the screen. Then, if a meter is placed in the anode lead, it will measure the magnitude of the secondary emission from the screen, or its equal, the beam current.

In modern, high voltage cathode ray tubes, the energy of the electrons in the beam is sufficient to puncture the glass or destroy the fluorescent screen if the beam is permitted to bombard one spot for a few seconds. The beam must always be kept in motion by the deflecting fields when the high anode voltage is on. The brilliance of the spot should be the minimum necessary for making observations.

Fig.10 Showing how the Wehnelt cylinder or grid converges the electrons emitted by the cathode.



5. THE GRID. Modern cathode ray tubes are much more complicated in structure than the one we have described. The drawback to the simple tube described was the fact that very few of the electrons emitted from the cathode actually reached the fluorescent screen. This is due to the fact that the electrons were diverging from the cathode because of the repulsion between them. If we could concentrate more of these electrons into a beam, we would have greater and more brilliant fluorescence of the screen. The first additional electrode added to the simple cathode ray tube was designed to force more of the electrons emitted by the cathode into the electron or cathode ray beam. This additional electrode is called the Wehnelt cylinder and is illustrated in Fig. 10. This cylinder is made negative with respect to cathode and it forces the electrons emitted from the cathode to converge and go through the small opening in the end of the cylinder. In this way, a larger percentage of the electrons emitted by the cathode go toward the screen. The Wehnelt cylinder has the additional advantage of con-

trolling the number of electrons that go from the cathode to the screen. By making the cylinder sufficiently negative, it will cut off the electron beam completely, thus it acts like the grid in an ordinary thermionic tube. The more common term for Wehnelt cylinder is grid.

Since the electron beam is made up of negative electrons and like charges repel each other, the beam spreads out as it moves toward the screen. One way of controlling the size of the beam would be to pass it through a series of apertures arranged along the axis of the tube. In this way, all of the electrons diverging from the beam would be eliminated; but by the time the beam reached the screen, there would be very few electrons left in it. There is a need, then, to focus the electrons coming from the cathode into a small spot at the screen; that is, there must be some sort of a lens system in between the Wehnelt cylinder or grid, and the fluorescent screen. Since the electrons, after leaving the grid, are diverging, the lens system required to focus them on the screen is a convex or converging lens.

There are three methods of focusing electrons into a spot. They are, gas focusing, magnetic focusing, and electrostatic focusing. The most common is electrostatic focusing. Magnetic focusing is used in some television systems, mainly those developed by Farnsworth. We shall describe gas focusing and magnetic focusing briefly.

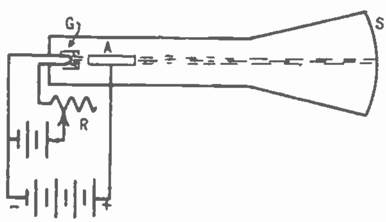
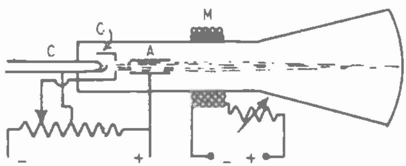


Fig.11 Cathode ray tube containing a small quantity of gas to focus the cathode rays. F is the filament, G the grid, operated at cathode potential, A the anode.

6. GAS FOCUSING. The gas focus tube is shown in Fig. 11. It has a cathode C, heater H, grid G, and anode A. The deflecting plates or deflecting coils have been left out for simplicity. The tube contains a small amount of some inert gas such as argon. The electrons emitted from the cathode are forced into a beam by the grid G and are accelerated to the screen S by the anode A. As the pencil of electrons passes through the tube, it has a tendency to spread out because of the repulsion between the electrons. This divergence is prevented by the gas. The high speed electrons ionize the argon gas in the vicinity of the pencil. The positive ions, being very much heavier than the electrons, stay where they are formed and form a positively charged tube around the electron pencil. It is only in the center of the pencil that the electrons are able to reach the screen. There collisions between the electrons and gas molecules and the positive ions are most frequent and the ions as they are formed are forced out of the center of the beam by collisions with oncoming electrons. Electrons that

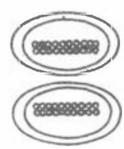
have a tendency to stray from the beam collide with the positive ion tube and are forced back into the pencil. Thus the electrons reaching the screen produce a small spot. Under the influence of deflecting fields, the positive ion tube will follow the electron beam and thus maintain focus. The quality of the focus depends upon the magnitude of ionization which in turn depends upon the number and velocity of the electrons. The velocity is controlled by the anode voltage and the number can be controlled by the cathode emission. In a gas tube oscilloscope, the anode voltage is kept constant and focus adjustments are made by varying the heater current by means of rheostat (R in Fig. 11).

Fig.12 Cathode ray tube with magnetic focusing coil. C is the cathode, G the grid, A the anode, M the focusing coil, and F the fluorescent screen.



Gas focus tubes are unsatisfactory because of limited deflection frequency response and short life. The maximum deflection frequency is controlled by the time it takes the ionization to build up around the beam as its position changes. If there isn't time for the positive ion tube to be formed, the focus is destroyed. The pressure and purity of the gas changes during tube life and therefore the quality of the focus varies during tube life. There is a tendency for the cathode to be destroyed by positive ion bombardment. A big advantage of the gas tube is that it will produce an excellent focus for anode voltages ranging from 300 to 500 volts. Therefore, it can be used with weak deflecting fields, or, in other words, it has a high sensitivity.

Fig.13 Magnetic field around focusing coil.



7. MAGNETIC FOCUSING. The magnetic focused tube is shown in Fig. 12. In structure, it is similar to the gas tube. However, the tube is highly evacuated. Around the neck of the tube just beyond the anode is the magnetic focusing coil M. This coil consists of many turns in several layers. The axis of the coil coincides with that of the tube. Focus is controlled by varying the current through the coil. The field strength required varies between 200 and 300 ampere turns.

You recall that the path of an electron through a magnetic field is deflected in a direction that is at right angles to both the direction of the magnetic field and the direction of motion of the electron. Electrons moving parallel with a magnetic field are not deflected. Fig. 13 shows the magnetic field around the focusing coil. Electrons moving along the axis of the tube will pass through the field with their direction unchanged. Electrons diverging from the beam will cross the magnetic field and will be deflected in a direction perpendicular to both the field and the direction of the electron. The electron is thus given direction that is tangent to a circle whose plane is perpendicular to the axis of the tube. As long as the electron remains in the magnetic field, it is deflected perpendicularly to its instantaneous direction and that of the field. In other words, the electron will follow a spiral path around the axis of the tube as it moves toward the screen. At some point on the axis of the tube, this spiraling electron will cross the path of the undeviated electrons that started out parallel to the axis of the tube. The electrons leaving the

Fig.14 Path of an electron in focusing coil when viewed along axis of coil.

anode are diverging from the same spot and form a cone whose apex is outside the grid. (Fig. 15.) These electrons all have the same velocity as they are accelerated by the same anode voltage. Therefore, the magnitude of their deflection toward the axis of the coil or tube will vary directly with the angle that they cross the field. In other words, the electrons diverging most from the beam will have the greatest deflection back toward the center of the beam. Because all the electrons travel with the same velocity, their paths will intersect the axis of the tube at the same point. Thus, a

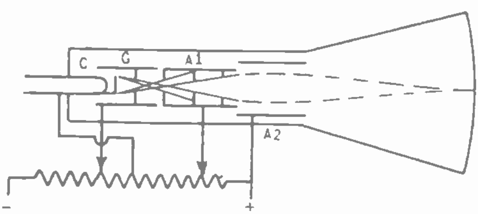


Fig.15 Electrode structure of a cathode ray tube using electrostatic focusing. C is the cathode, G the grid, A1 the 1st anode, and A2 the 2nd anode.

focus of the apex of the cone of divergence will be formed on the axis of the tube. The location of this focal point depends on the strength of the magnetic field and the velocity of the electrons. The magnitude of the focusing magnetic field is adjusted so that the focus occurs at the fluorescent screen. This is done by varying the magnitude of the direct current through the coil. Fig. 12 shows how the electrons travel to a focus at the screen. Fig. 14 shows the path of an electron when the observer looks along the axis of the tube.

8. ELECTROSTATIC FOCUSING. In Fig. 15, we have an electrostatic focused tube. Cylinders A1 and A2 constitute the electron lens. Cylinder A1 is at a high positive potential with respect to the grid G and cathode C. This serves to give the electrons a high velocity. In the cylinder are three aperture discs and the holes in the disc increase in diameter from the cathode end of the cylinder. This confines the divergence of the electrons to a certain limit. As electrons have a tendency to diverge more than the openings will allow, they are collected by the cylinder A1, or the first anode. A2 (or second anode) is another cylinder which is at a considerably higher voltage than A1 and this cylinder (A2) causes the electrons to converge again and form a focus at the fluorescent screen. The equivalent optical system is shown in Fig. 16. Cylinder A2, or the

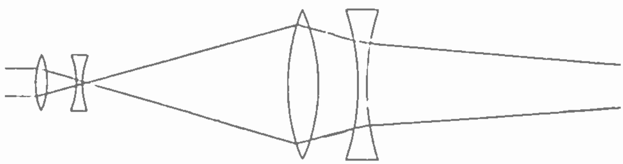


Fig.16 Optical equivalent of the electrostatic lens.

second anode, being of higher potential than cylinder A1, or the first anode, will give the electrons additional acceleration. Fig. 17 is the same as Fig. 15, except that equal potential lines have been put in. By equal potential lines, we mean the lines that pass through all the points in an electrostatic field where the potential is the same. As stated before, the grid is negative with respect to the cathode; the anode A1 is positive with respect to the grid; and A2 is positive with respect to A1. Then, between the cathode and grid, we have one electrostatic field set up; between the grid and A1 we have another electrostatic field; and between A1 and A2 we have a third electrostatic field. You will notice in Fig. 17 that the equal potential lines are curved like the surfaces of a convex lens. Therefore, a converging lens for electrons consists of equal potential surfaces that have the identical shape of the equivalent optical lens.

There is one very important difference between an electrostatic lens and an optical lens. In the optical case, there is distinct boundary between the lens and the rest of the region through which the light is passing. In other words, there is an abrupt change in the index of refraction of the region through which the light is passing. For an electrostatic lens, the index of refraction changes gradually as the electron passes through the field between the regions of different potential such as A1 and A2 of Fig. 17. Therefore, the exact optical equivalent of an electrostatic lens is not as simple as Fig. 16 suggests.

The focal length of this lens can be controlled by varying the difference in potential between two electrodes such as A1 and A2. The potential of the first anode A1 and that of the second anode

A2 are measured with respect to the cathode. When the spot is focused correctly the first anode potential will be from one-third to one-fifth of the second anode potential. This ratio depends upon the design of the electron gun. The equal potential surfaces between A1 and A2 represent higher and higher positive potentials from

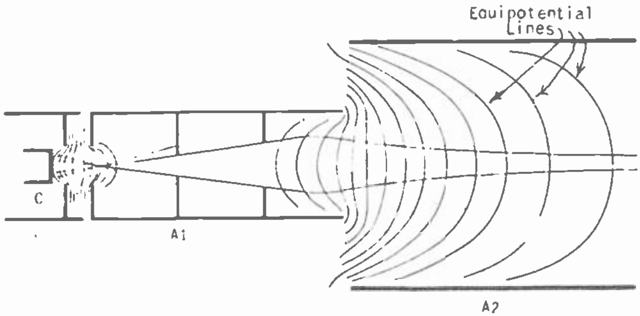


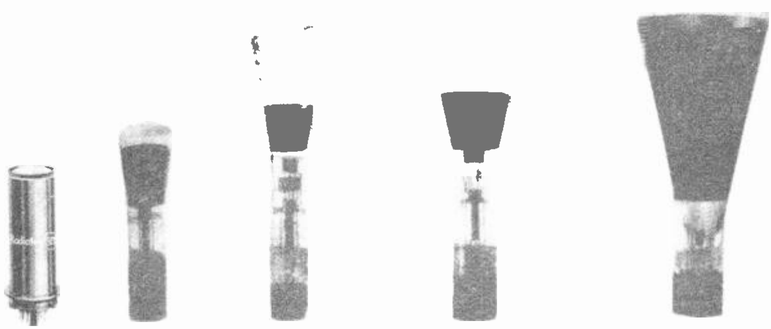
Fig.17 Electrostatic lens with equipotential lines.

left to right. Whenever an electron passes obliquely through a series of equal potential surfaces of increasing potential, it is given a component of velocity normal to each surface as it passes through. The equal potential surfaces set up by the cathode, grid and A1 form one converging lens, which causes the electrons emitted by the cathode to converge or have a crossover just in front of A1. This crossover or intersection of the electron paths is the object for the lens system formed by A1 and A2. This second converging lens produces an image of the object or the crossover on the fluorescent screen. The series of apertures in A1 force the electrons to pass through the center of the electrostatic lens. This is to reduce distortion. It is similar to spherical aberration of an optical lens; that is, electrons going through the outer regions of the electrostatic lens are brought to a focus at a different point than those going through the center. Another name given to this electron lens system is the "electron gun".

9. MODERN CATHODE RAY TUBES. Most modern cathode ray tubes used in oscilloscopes have electrostatic focusing. Those which use electrostatic deflection of the beam have two pairs of deflecting plates built in the tube next to the electron gun. The direction of the deflection produced by one pair is perpendicular to that produced by the other. The reason for this construction will be explained later. Tubes used with magnetic deflection contain an electron gun only. The deflecting coils are mounted outside of the tube. Some tubes contain one pair of deflecting plates and depend upon magnetic deflection for the perpendicular direction.

Commercial tubes are made with a screen diameter from one to nine inches. All of them except those with one inch screens have glass envelopes. The one inch tube (RCA 913) has a metal shell. The fluorescent screen is on the back of a glass window mounted in the end of the tube. Fig. 18 shows several modern commercial tubes.

10. POWER SUPPLIES FOR CATHODE RAY TUBES. The voltages required to operate cathode ray tubes, even the smaller ones, are much higher than those ordinarily encountered in radio work. The RCA 906, which has a 3" screen, has a second anode voltage of 1,000 to 1,200 volts. Power supplies to furnish the high voltages for cathode ray tubes must be well designed and well insulated. A 3" cathode ray tube requires a heater supply of 2.5v, capable of supplying 2.5 amperes. The high voltage source must supply a voltage of 1,000 to 1,200 volts, at a very small current drain, 1 or 2 ma. at the most. In the smaller cathode ray tubes using electrostatic deflection, one of each pair of plates is tied to the second anode. This simplifies the construction of the tube, but it requires that the second anode be operated at ground potential. This means that the cathode must be 1,000 to 1,200 volts negative with respect to ground. Another reason for having one of each pair of deflecting plates tied to ground is that extraneous electric fields will not

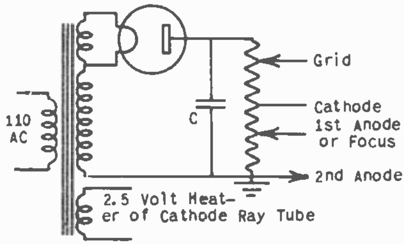


(A) (B) (C) (D) (E)

Fig.18 Various types of cathode ray tubes. (A) Type 913, 1 inch screen, using double electrostatic deflection; (B) Type 902, 2 inch screen, using double electrostatic deflection; (C) Type 34-XH, 3 inch screen, using double electrostatic deflection; (D) Type 54-XH, 5 inch screen, using double electrostatic deflection; (E) Type 94-8-H, 9 inch screen, using double electrostatic deflection.

affect the electron beam to the extent they would be if the deflecting plates were way above ground. Fig. 19 is the diagram of a power supply for an ordinary 3" cathode ray tube. Since the high voltage current requirements are very slight, very little filtering is required. One condenser is sufficient; it has a capacity of .5 to 1 microfarad. The bleeder across the output furnishes the necessary focusing voltage, or first anode voltage, and the bias voltage, or the grid voltage. The cathode ray tube is always operated so that the control grid is never positive. The voltage on the grid of the tube controls the intensity of the spot; the voltage on the second anode or focusing voltage controls the size of the spot; therefore, these controls are variable. Since the current requirements are very small, condenser C will cause the output voltage to approximate the peak voltage supplied to the rectifier.

Fig.19 High voltage power supply for cathode ray tube.



There are two rectifier tubes available today to satisfy the requirements for a cathode ray high voltage power supply. They are the 879 and the 878. The characteristics of the 878 are: filament voltage, 2.5v; filament current, 5 amperes; maximum AC plate voltage R.M.S., 7100 volts; maximum inverse peak voltage, 20,000 volts; DC output current, 5 ma., maximum. The characteristics of the 879 are: filament voltage, 2.5v; filament current 1.75 amperes; maximum AC plate voltage R.M.S., 2650 volts; inverse peak voltage, 7500 volts; DC output current, 7.5 ma. The transformers that are used with the cathode ray tube power supplies must be insulated to withstand the high output voltage. Notice in Fig. 19 that the filament winding for the rectifier is tied to one end of the high voltage secondary, while the other end is grounded. The entire secondary voltage is impressed between the filament winding and ground. Therefore, the filament winding must be well insulated from the core and the rest of the transformer. Likewise, the heater supply for the cathode ray tube is operated way below ground. It also must be well insulated from the core and the rest of the transformer. (The cathode is tied to one side of the heater internally in all cathode ray tubes).

When voltages in the order of 2,000 and 3,000 are required for the larger tubes, it is often more economical to use voltage doubling rather than use a higher voltage rectifier. Fig. 20 illustrates the voltage doubling circuit. Two rectifiers are used, each with a separate filament winding, well insulated from the rest of the transformer. One side of the high voltage winding is tied to the junction of condensers C1 and C2. The other side of the high voltage winding is connected to the filament of one rectifier and the plate of the other. The plate of T1 is tied to C1 and the filament of T2 is tied to condenser C2. When the A end of the high voltage winding is positive, the plate of rectifier T2 is positive with respect to its filament and therefore condenser C2 will become charged. When B becomes positive, rectifier T1 becomes conductive, because its plate will be positive in respect to its filament and condenser C1 will become charged. The only way that each condenser can discharge is through the bleeder or external circuit.

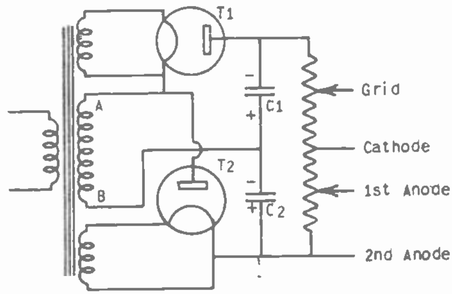


Fig. 20 High voltage power supply using voltage doubling circuit.

The two condensers are connected in series and when they discharge, their two voltages will add together. The two condensers were charged separately on alternate half cycles and when they discharge, they discharge together in series, so the output voltage is twice that obtained by one rectifier and one condenser. In order to obtain an appreciable output voltage from this system, the condensers must be very large. Voltage doubling is only suitable for very low current drain requirements. For a cathode ray tube, values of 2 mfd. for C1 and C2 are sufficient.

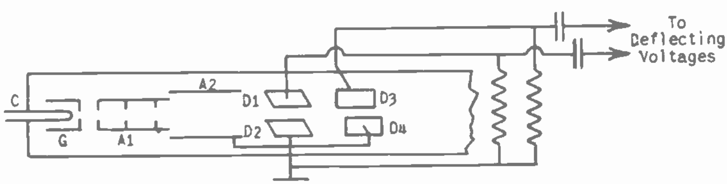


Fig. 21 Modern cathode ray tube. D1 and D2 form one pair of deflecting plates, while D3 and D4 form another pair, perpendicular to the first pair.

11. COUPLING CIRCUITS FOR DEFLECTING PLATES. IN FIG. 21 we have illustrated a modern cathode ray tube, using double electrostatic deflection. One of each pair of plates is tied to the second anode. The deflecting voltages are applied across each pair of plates. The voltage used for deflecting the beam is usually fed between one plate and ground and is coupled to the free plate by means of a condenser. This means that the free plate of each pair would have no definite DC potential. The potential of the free plates would be some negative voltage determined by the number of stray electrons they collect from the beam and the number of the secondary electrons they collect from the screen. This would have a tendency to cause a permanent deflection of the beam and would

also make the deflection erratic as this potential varied. In order that the free plate can be at ground potential, they are usually connected to ground through a resistor. Since this resistor would constitute a load on the deflecting voltage source, it is made as large as possible. If it is made too large, the flow of electrons through it would give the free plate a definite potential which would cause permanent deflection of the beam. Values of .5 to 2 or 3 megohms are usually suitable. If the resistor is too large, the beam will be deflected when the intensity and the focus controls are varied, especially the intensity control. This controls the number of electrons in the beam, and therefore controls the number of electrons the free deflecting plates are likely to collect. Then, in order to make the deflection of the beam independent of the focus and intensity control and yet make the input impedance of the oscilloscope high, there must be a compromise in the value of the resistors used for tying the free deflecting plates to ground.

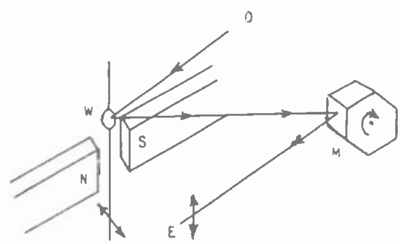
In many cathode ray tubes, the axis of the electron gun is not coincident with the axis of the tube. When there are no deflecting voltages applied to the tube, the spot is off center. In commercial cathode ray oscilloscopes, a means is provided to feed voltage through the resistors connecting the plates together so that a fixed DC potential can be applied across each pair of plates in the correct direction to pull the spot to the center of the screen. These controls are called "spot shifts" or "centering controls". Often a pattern can be observed better if it is shifted up or down on the screen. This can be easily done with the vertical spot shift. In Fig. 27, one method of spot shifting is shown.

In some of the larger cathode ray tubes, there are two pairs of electrostatic deflecting plates and all four plates have separate leads. In this case, each pair of plates is tied together by a resistor and the center tap of the resistor is grounded. When we discuss cathode ray tubes for use in television receivers, we will find out why it is preferable to have all deflecting plate leads brought out separately rather than have one of each pair tied to the second anode.

12, THE OSCILLOSCOPE. We have discussed the use of a cathode ray tube as a voltmeter or an ammeter. In these cases, it was an advantage to use the cathode ray tube as it required no power to operate it. An electron beam is made up of electrons which are practically massless and very little energy is required to deflect the beam either from an electrostatic or magnetic field. Another advantage of cathode ray tubes is the high input impedance. The DC component of the impedance or the power consuming part is limited by the size of resistors that have to be connected across the deflecting plates. The reactive component of the impedance is the capacitance between the plates for electrostatic deflection and this is usually of a very small order (3 to 4 mmfd.). Therefore, the cathode ray tube can be used as an accurate indicator of magnitudes for frequencies from a very few cycles to several million cycles. It is only when the time of one cycle is of the same duration as the time the electron is in the deflecting field that the cathode ray tube falls down as a waveform or voltage indicating device.

The most useful measuring instrument to the engineer or physicist is the oscilloscope. The oscilloscope is an instrument for viewing waveforms and transients.[1] By means of an oscilloscope, the actual waveforms of either the current or voltage in a circuit may be viewed and photographed. The early oscilloscopes were mechanical, consisting of a wire suspended in a permanent magnetic field. A small mirror was attached to a wire and, when the current under the test passed through the wire, the wire vibrated in the magnetic field according to the waveform of the current. The light reflected from the mirror was made to trace out the changes or vibrations of the wire. The mechanical oscilloscope has its disadvantages; it is dependable only at medium and very low frequencies, and it requires considerable energy to operate it. Being a mechanical system, there is a lag behind the applied voltage or current under test and the movement of the wire. It also has a natural period of vibration and therefore can't be used in the neighborhood of that frequency. Also, because it is a mechanical system, its frequency response is limited, and it is not suitable for frequencies over 500 or 600 cycles.

Fig.22 Schematic of a mechanical oscilloscope.



An oscilloscope is a device for telling what is happening in an electric circuit with time. Fig. 22 is a diagram of the elements of the ordinary mechanical type of oscilloscope. The wire carrying the mirror is between the pole pieces of the magnet and vibrates in the direction shown. Light from source O is directed upon the mirror W. After reflection, the beam goes to the mirror M; after reflection from M it goes to the observer at E. When the mirror M is stationary, the observer at E will see a horizontal bright line on the mirror M. The mirror M consists of six plane mirrors mounted on the sides of a hexagon. This is rotated in the direction shown. Consider the case when the mirror at W is still and the mirror M is rotated. The light, after being reflected from M to the observer at E, would form a bright vertical line as indicated by the arrow. As the mirror M rotates, the ray of light from the mirror at W will strike one of the surfaces near the top and will be reflected downward. As the mirror rotates in the direction indi-

[1] A transient is a voltage or current change that occurs once and is not repeated. Transients are produced when a circuit is opened or closed. The television signal consists of transients as the changes in voltage produced by scanning the picture are not periodic but depend on the change in shade between the picture elements.

cated, the reflected ray will move upward until the incident light ray just strikes the bottom of that surface. Then that surface will move out of the range and the reflected ray of light will be shot down again as the new surface comes in place. As the mirror rotates at a constant rate of speed, the ray of light reflected from it at point E will move upward, suddenly return to the starting point and move up again. It will describe a series of vertical motions that are linear with time; that is, the distance covered per second is constant. When the current is passing through S,

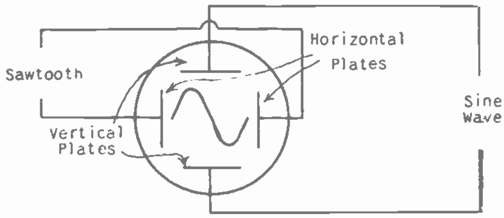


Fig.23 Showing the formation of a sine wave on the end of a cathode ray tube.

the mirror W will vibrate in the direction indicated and add another motion to the light beam at right angles to the motion caused by the rotating mirror M. The observer at E will be able to see how the wire W vibrates with time or will get an actual picture of the current as it varies according to time. That is a brief description of a mechanical oscilloscope which, as stated before, has a limited usefulness. Another name for the mechanical oscilloscope is "string oscilloscope".

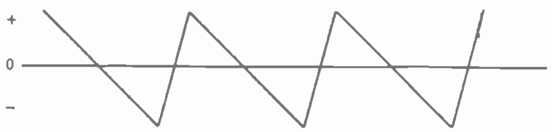
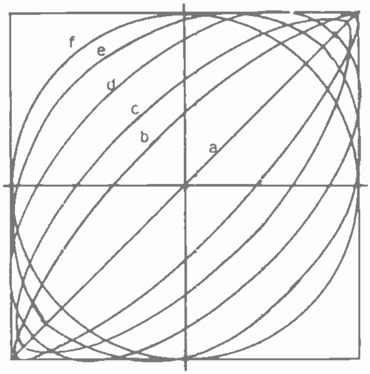


Fig.24 Showing a sawtooth voltage wave.

We stated in a previous paragraph that modern cathode ray tubes have four pairs of deflecting plates, one pair at right angles to the other pair. Fig. 23 represents the front view of a cathode ray tube, showing the four sets of plates. Across the vertical pair of plates we apply a sine wave, or the voltage whose waveform we wish to examine. If there is no voltage across the horizontal plates the electron beam, or cathode ray beam will merely trace a vertical line on the front of the tube. The total deflection will be twice the peak value of the applied signal. To see what the waveform is like, we want to examine the instantaneous values of the AC as the time varies. This can be done by deflecting the beam horizontally. For each horizontal position, the vertical magnitude will be different. If we pull the beam across at a constant rate with respect to time; that is, the deflection per unit time will be the same, then the instantaneous values of the sine wave will be evident. We will see an actual picture of the sine wave provided the horizontal deflection is synchronized with the vertical. The horizontal sweep will have to start off at the left hand side and move over at a constant rate of speed to the right hand side and then fly back suddenly to the left and repeat the cycle. This horizontal waveform is called a "sawtooth" and is illustrated in Fig. 24. A little later we shall describe the construction and operation of a simple sawtooth oscillator.

Another excellent use of the oscilloscope is to check the phase difference between two sinusoidal waves. If we impress upon the two pairs of plates two sine waves of equal amplitude and phase, the potential differences across the two sets of plates will increase in phase and the deflecting force applied to the beam is the same for both pairs of plates. Therefore, the beam will describe a straight line that is inclined at an angle of 45 degrees to the horizontal. If the amplitude of one of the waves is changed, the line will be straight, but the angle to the horizontal will depend upon the relative amplitudes. Likewise, if the two waves are 180° out of phase, a straight line will be produced. In this case, the angle of the line will be 90° to its position when the two waves were in phase. For phase differences other than zero, or 180°, the figure described will be an ellipse. If the phase is varied, the ratio of the two diameters will vary from that for a straight line to that for a circle. With a phase difference of 90°, a circle will be the figure formed on the end of the tube. Fig. 25 shows the pattern for several phase differences ranging from 0° to 90°. If the

Fig. 25 Patterns produced on cathode ray tube by voltages with phase differences of: (a) 0°, (b) 180°, (c) 30°, (d) 45°, (e) 60°, (f) 90°.



two sinusoidals differ slightly in frequency, the pattern described will go through all stages from a straight line to a circle and back to a straight line, as the two sine waves go through the various phase differences 0°, 90°, 180°, etc., until they are in phase again. When the two frequencies are different, but one is a multiple or sub-multiple of the other, many interesting patterns are described on the end of the tube. These patterns are known as Lissajous' figures. Fig. 26 shows several examples of Lissajous' figures and the ratio of the frequencies producing them.

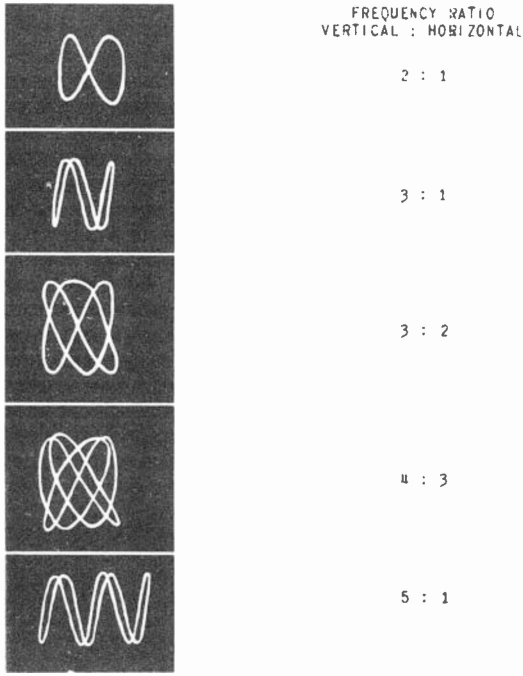


Fig. 26 Lissajous' figures.

In all the discussion of applying different types of voltages to the pairs of deflecting plates of a cathode ray tube, we spoke as though the voltages in all cases were applied directly to the plates. Usually, the magnitudes of the voltages are too small to produce appreciable deflection of the cathode ray beam. Under these conditions, the voltages have to be amplified and the output of the amplifier applied to the plates. There is a separate amplifier for each pair of plates. It is necessary that these amplifiers have a

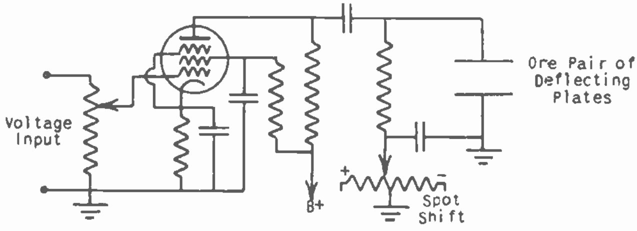
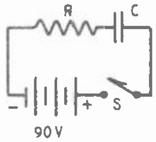


Fig. 27 Schematic showing an amplifier coupled to one pair of deflecting plates.

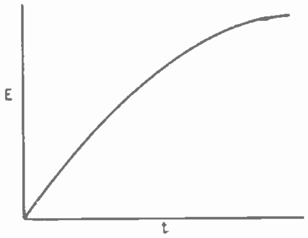
flat frequency response over the range that you expect to use the oscilloscope. The ordinary radio serviceman's oscilloscope has a frequency range flat to approximately 10,000 or 15,000 cycles. The cathode ray oscilloscope used for television testing must have amplifiers flat to 2,000,000 or 3,000,000 cycles. The oscilloscope used at Midland Television for television testing has amplifiers that are flat from 20 to 2,000,000 cycles. A serviceman's oscilloscope with amplifiers flat to 15,000 or 20,000 cycles can be used on higher frequencies provided the voltage of the high frequency is of sufficient magnitude to deflect the beam when it is applied directly to the plates of the oscilloscope. Fig. 27 shows how an amplifier is coupled to one pair of deflecting plates.

Fig. 28 Charging a condenser through a resistance.



13. THE SAWTOOTH WAVE GENERATOR. We shall now describe the method of constructing a simple sawtooth oscillator. In Fig. 28, condenser C is connected in series with the resistance R, the 90 volt battery B, and a switch S. When the switch is open, there is no charge on condenser C and the voltage across condenser C is zero. As soon as the switch is closed, the current flows from the battery through the resistor R into the condenser C. The condenser C charges until its voltage reaches 90. Fig. 29 represents the voltage across

Fig. 29 Charging curve of a condenser.



the condenser at any time t after the switch has been closed until the condenser is fully charged. We note from the curve that at the beginning of the charging cycle the voltage across the condenser builds up linearly; that is, the voltage across the condenser is directly proportional to the time. However, after the condenser has become partly charged, the rate of charging falls off because the condenser has a back voltage which reduces the flow of current into it. Let us modify Fig. 28 by substituting for the switch S, a single pole double throw switch so that in one position of the switch, the condenser is charged through R and in another position of the switch, the condenser is discharged (Fig. 30). We now have the basic elements of a system for generating a sawtooth waveform.

First connect the condenser to the battery. When the voltage across the condenser reaches a chosen value such as 5 volts, throw the switch in shorting position long enough for the condenser to discharge. The condenser will discharge instantaneously as there is zero resistance in the discharge circuit. If the charging and discharging are continued, the voltage developed across the condenser will be a sawtooth with a peak to peak value of 5 volts. (See Fig. 31.)

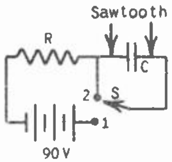


Fig.30 Simple sawtooth voltage generator.

We can get a sawtooth waveform by charging the condenser slowly and discharging it rapidly. We charge the condenser until its voltage is just a small fraction of the applied voltage. In this way, the charging current is constant, or linear with the time. The sawtooth will be linear provided the voltage to which the condenser is charged is 5% or less of the applied voltage. The reason the curve is not linear during the entire charging cycle of the

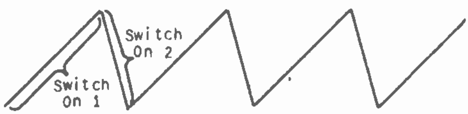


Fig.31 waveform of sawtooth voltage produced by generator shown in Fig.30.

condenser is that as the condenser charges, it has a voltage which opposes the voltage of the charging battery, so the net voltage to charge the condenser is gradually reduced as the condenser charges. Therefore, the flow of current into the condenser is reduced as the condenser charges. If the charging current can be maintained at a constant rate, we can use much more of the charging cycle of the condenser for our sawtooth waveform. If we replace resistor R by

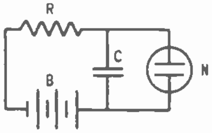
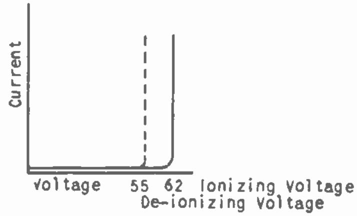


Fig.32 Neon lamp sawtooth wave oscillator.

some sort of a constant current device; that is, a mechanism which will let current flow through it at one rate only and not permit it to vary, we can use the entire charging cycle of the condenser, because it will be linear all the way.

14, NEON LAMP OSCILLATOR. If the hand switch in Fig. 30 is replaced by an automatic switch, the circuit could be used as a sawtooth wave generator. Fig. 32 is automatic in operation. N is an ordinary 2 watt neon lamp. A neon lamp consists of two electrodes in neon gas at a fairly low pressure. If we plot a current vs. voltage curve for the neon lamp, we will have the curve shown in Fig. 33. We note from the curve that as the voltage starts from zero, the current is zero. It continues to remain zero until the voltage reaches the ionizing potential. Then the tube resistance drops to practically zero and the flow of current through it is limited only by the resistance in the external circuit. If the voltage across the tube is now reduced below the value for current flow, the current continues to flow until the voltage reaches a point several volts lower. Then the tube resistance instantly rises to an infinite value again as the gas de-ionizes.

Fig.33 Current vs. voltage characteristic of neon lamp.



Let us consider the operation of the neon lamp in Fig. 32. If the voltage across the condenser is zero, the neon lamp is a non-conductor. The condenser will gradually charge. When the voltage across the condenser reaches the ionizing voltage of the neon lamp, the neon lamp resistance will become zero and the condenser will discharge through it. When the neon lamp ionizes, the voltage across it is approximately 62 volts. The neon lamp resistance becomes infinite when the voltage across it drops to about 55 volts. Therefore, the condenser is discharged from 62 volts to 55 volts as at 55 volts the neon lamp becomes deionized. The condenser charges again until it reaches a voltage of 62 and the cycle is repeated. The voltage across the condenser will have a sawtooth component whose magnitude is 7 volts from peak to peak. The frequency of the sawtooth waveform generated can be controlled by varying the capacity of C or varying the resistor R. When R is made smaller, the condenser can charge faster; therefore, the frequency of the sawtooth will be higher. If C is made smaller, it can charge faster and the frequency will be higher.

Oscillators whose output waveform depend on the charge and discharge of a condenser are called "relaxation oscillators". The neon lamp type of oscillator has several disadvantages. The frequency range is very limited; it is difficult to get a sawtooth with frequencies above 700 or 800 cycles from such a system; the output is very small; there is no control over the voltage at which the neon lamp becomes conducting; and it is not easy to synchronize the output of a neon lamp relaxation oscillator with a given frequency. In order to introduce enough of the synchronizing frequency to synchronize, the output of the neon lamp type of oscillator is distorted.

15. GAS TRIODE OSCILLATOR. A more suitable tube to use in the relaxation type of oscillator or sawtooth oscillator is the thyratron or gas triode. The construction of the gas triode is similar to an ordinary triode, except that gas is present at a very low pressure. If we plot the plate-current plate-voltage curve of a gas triode, the curve is similar to that of Fig. 33, except in the case of a gas triode, the ionizing voltage is not a fixed value, but depends entirely on the negative grid voltage. The plate voltage required for ionization or current flow is directly proportional to the negative grid voltage. If the plate voltage is raised beyond the ionizing point, the tube ionizes and the flow of plate current is limited only by resistance in the external circuit.

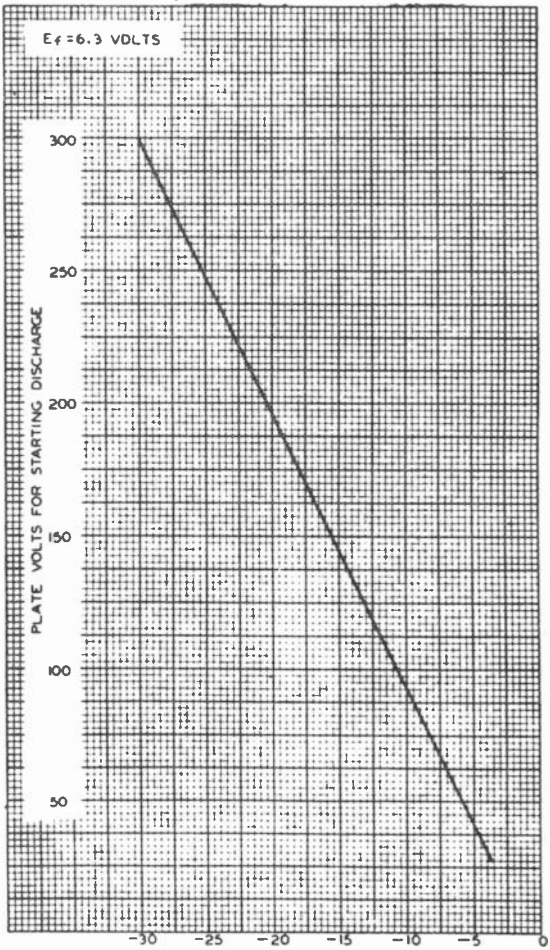


Fig.34 Ionizing voltage vs. grid voltage characteristic for gas triode (885).

As soon as the plate current flow begins, the grid loses all control of the plate current. Plate current continues to flow until the plate voltage is reduced below the 16 volts, the value necessary to maintain ionization. As soon as the tube becomes ionized, the internal plate resistance becomes very low and the drop across the tube will be around 16 volts. Fig. 34 shows the relation between grid voltage and the plate voltage required before ionization will take place. It is a linear relationship, and as the grid voltage increases negatively, the plate voltage must increase in a positive direction before the ionizing value is reached.

Fig.35 Sawtooth oscillator using gas triode.

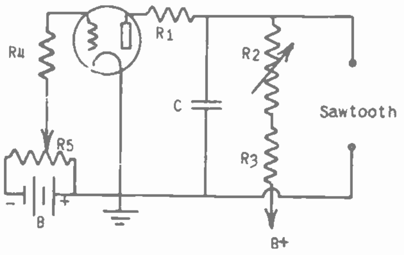


Fig. 35 shows the gas triode type sawtooth oscillator. Condenser C is charged from the B+ supply through resistors R2 and R3. When the voltage across condenser C reaches the ionizing voltage of the gas triode, the tube immediately ionizes and the condenser discharges through the tube. As soon as the voltage across the condenser drops below 16 volts, the value that is necessary to maintain ionization, the tube immediately becomes deionized. Resistor R1 is to prevent the discharge current of the condenser through the tube from exceeding the maximum safe value. As stated before, the current through the tube is limited only by the external resistance. By means of R5, the negative bias on the grid of the tube can be adjusted to give the required value of plate voltage for ionization. As mentioned before, the positive plate voltage required for ionization is inversely proportional to the negative grid voltage. Therefore, the amplitude of the sweep will be inversely proportional to the negative grid bias. The purpose of R4 is to keep the grid current that flows during discharge time under the safe maximum value. Thus, by means of the bias control, we can control the amplitude of the sawtooth generated. Another advantage of being able to control the ionizing value of the plate voltage is that we can select the section of the charging curve of the condenser that will give a linear sawtooth. The charging curve is the one given in Fig. 29. By means of the proper setting of bias control, we can use as much of that curve as is straight or will give a linear sawtooth. The frequency of the sawtooth produced will vary inversely with the applied grid bias, inversely with the size of the condenser C, and inversely with resistor R2. The reason we use a fixed resistor R3 is to be sure that during the discharge period, the tube cannot pull enough current from the B+ supply to keep the voltage drop across it above the ionization values.

In calculating C and R2 for any given frequency, we want to pick out such values that, during the charging period of the condenser, we are always on the straight portion of the charging curve. The frequency range of the gas triode type sawtooth oscillator varies from a fraction of a cycle per second to several thousand cycles per second. The limit to the maximum frequency is the time required for the gas in the tube to de-ionize. If the tube has not completely de-ionized by the time the condenser has discharged, the sawtooth waveform is distorted. By keeping the amplitude of the generated sawtooth small, a very satisfactory linear sawtooth can be produced at the higher frequencies. The maximum frequency is about 20,000 cycles.

16. CONSTANT CURRENT GAS TRIODE OSCILLATOR. In a previous paragraph, we stated that if the condenser can be charged at a constant rate; that is, by means of a constant current, we can use the entire charging curve for our sawtooth. This means that if the plate supply voltage, or charging voltage, is 300 volts, it is possible to charge the condenser up to 300 volts before discharging it, and obtain a linear sawtooth. Thus, a sawtooth with an amplitude of 300 volts is produced. A sawtooth with an amplitude of 300 volts is sufficient to deflect almost any cathode ray tube beam. In your study of the R.F. pentode, such as 6C6, 77, 6J7, or a 57, you learned the plate current was dependent on the grid and the screen voltages and was independent of the plate voltage; that is, the plate voltage could be varied over very wide limits, and there would be no change in the plate current. So, as far as plate-current plate-voltage relation is concerned, the R.F. pentode is a constant current device. If we use the plate resistance of an R.F. pentode as a charging resistance for a condenser, we will have the condenser charged by means of a constant current; that is, provided the screen and grid voltages on the tube remain constant during the charging period.

Fig. 36 shows an R.F. pentode used with a gas triode to produce a linear sawtooth of high amplitude. In Fig. 36, T1 is a constant current pentode and T2 is a gas triode. C is the condenser that is charged and discharged to generate the sawtooth, and the plate resistance of T1 is the constant current charging resistance. You will notice that in this circuit, the positive side of the power supply is grounded. There are two reasons for this. One is that we want one side of the sawtooth connected to ground, as one of each pair of deflecting plates in the cathode ray tube are grounded. If the two tubes are interchanged; that is, T1 and T2, then the cathode of T2 would be at ground and one side of the sawtooth would be connected to ground; but there is an objection to placing the tubes in this position. As stated before, T1 is a charging resistance. The reason we use T1 as the charging resistance is that the current flowing through it is constant and independent of the plate voltage. In order to keep this current constant and independent of the plate voltage, it is necessary that the screen voltage when measured with respect to the cathode be constant. With the circuit given in Fig. 36, we can readily do this, because the voltage drop across R4 is constant and is applied to the bottom of the cathode bias resistor and screen. The bias of T1 is varied by changing the resistance R5. If R5 is varied, it varies the plate resistance of T1 and thereby varies the plate current of T1 or the charging current of the condenser C. The frequency of the sawtooth will be proportional to the charging current. A wider range of frequencies can be obtained by using several different condensers at C. In order to control the bias on T2, it is necessary to use a battery between cathode and grid, as the cathode potential of T2 is constantly changing with respect to ground.

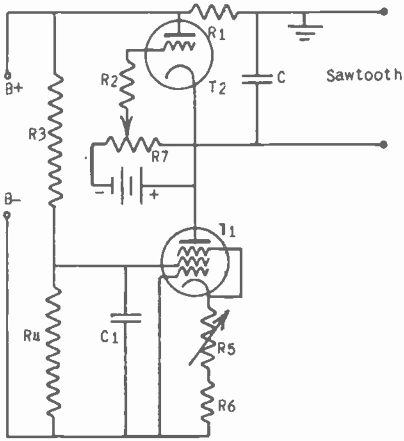


Fig. 36 Sawtooth oscillator using a constant current pentode as the charging resistance.

The amplitude of the sawtooth generated by this type of oscillator is sufficient to deflect the beam of the cathode ray tube without additional amplification. However, in most oscilloscopes, the first method of using the gas triode described is used. The small amplitude of the sawtooth generator is amplified by means of a vacuum tube amplifier to a magnitude sufficient to deflect the beam of the tube. The main reason for doing it this way is that the vacuum tube amplifier can be used to amplify some external frequency that is to be applied to the horizontal plates.

17. SYNCHRONIZATION OF SAWTOOTH. Another advantage of using the gas triode for the generation of the sawtooth waveform is that it can be synchronized to operate on the same frequency or a submultiple of the frequency applied to the vertical plates. If we are examining a 1,000 cycle wave and want to see one single wave of that 1,000 cycle, it is necessary that our sweep or horizontal frequency also be 1,000 cycles. If the spot is to retrace its path each time, the vertical deflecting frequency and the horizontal deflecting frequency must be in step at the start of each cycle. In order to see three complete cycles of our 1,000 cycle frequency, the sweep or horizontal frequency will have to be exactly one-third of the 1,000 cycles. After the completion of three cycles, the spot should jump back to the left-hand side of the tube and commence trac-

ing over the same three cycles again. As stated before, the grid bias on the gas triode controls the value of plate potential at which the tube will ionize. We can initiate a discharge by suddenly dropping the grid voltage to a value which will cause ionization to occur for the plate voltage applied at that instant. Fig. 37 shows a method of introducing the synchronizing voltage into the gas discharge tube or gas triode. R3 is a potentiometer to control the magnitude of the signal impressed on the grid of the gas triode. Fig. 38 illustrates how the sawtooth oscillator is kept in step with the synchronizing frequency. With no signal from the synchronizing

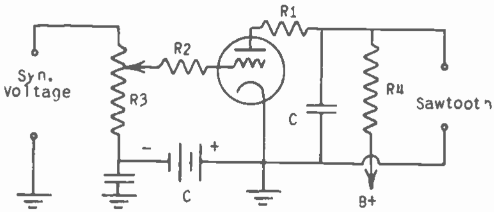


Fig. 37 Method of synchronizing a gas triode sawtooth oscillator.

voltage being impressed on the grid of the gas triode, the frequency of the sawtooth is set to the approximate value of the synchronizing voltage or slightly lower; preferably lower. Fixed bias on the grid of the gas triode is maintained by the battery C in Fig. 37. If the voltage across the condenser C has almost reached the value for ionization determined by the fixed grid bias on the tube; then by dropping the grid bias slightly, the gas triode may be made to ionize and discharge the condenser slightly earlier. If a small amplitude

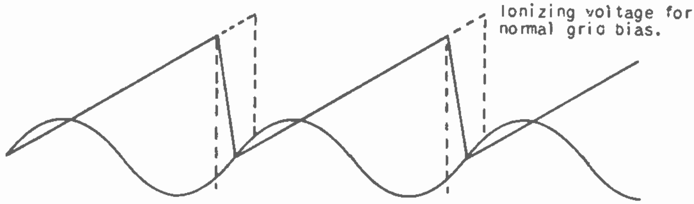


Fig. 38 Showing how the synchronizing voltage causes an early discharge by reducing the grid bias of the gas triode sawtooth oscillator.

of the synchronizing voltage is fed into the grid of the gas triode, the negative voltage on the grid is reduced slightly by the positive swing of the synchronizing voltage. If this occurs just before the condenser has reached its peak charge, it will discharge slightly earlier than normal. Thus the condenser can be made to discharge in step with the positive swing of the synchronizing voltage. Then the charging cycle (which sweeps the spot from left to right) will start on exactly the same part of the cycle of the synchronizing voltage for every cycle. This is shown in Fig. 38.

Similarly, you can synchronize the sawtooth oscillator at frequencies that are one-half, one-third, one-fourth, etc., of the sine wave being impressed on the grid of the tube; that is, the discharge will be started by every second, third, or fourth cycle of the grid voltage. From one to several cycles can be made to stand still on the end of the cathode ray tube. Care must be taken not to feed too much synchronizing voltage to the grid of the gas triode because large signals cause distortion in the waveform of the sawtooth. For large input amplitudes, the gas triode acts similar to an ordinary triode; that is, it acts as an ordinary amplifier. For a large synchronizing voltage, the output sawtooth will have a sine wave impressed on it. So instead of having a perfect sawtooth, it will be a sawtooth that has ripples on the charging portion of the cycle.

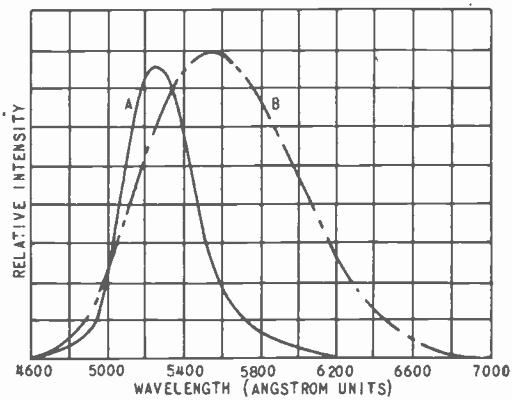


Fig. 39 Comparison of color sensitivity of eye to colors produced by ordinary cathode ray tube screens. (A) Intensity vs. wavelength emitted by screen. (B) Sensitivity of eye vs. wavelength.

18. THE FLUORESCENT SCREEN. In our discussion of cathode ray tubes, we have said very little concerning the fluorescent screen. There are several characteristics that the material used in this fluorescent screen must have. The material used should fluoresce brilliantly for the electron velocity produced in ordinary cathode ray tubes; that is, velocities due to accelerating voltages from 400 to 6,000 volts. Another property of the material is that the intensity of illumination must be directly proportional to the number of electrons in the beam. This factor is more important in a cathode ray tube used for television than it is for one used in an ordinary oscilloscope. The light emitted from the material must be due to fluorescence, rather than phosphorescence. You recall that fluorescence is the light generated from a substance when under the influence of the exciting radiation; that is, we mean the light emitted from a material when it is under the bombardment of cathode rays. Phosphorescence is the light generated after the energizing radiation has been removed. Usually phosphorescence lasts for several seconds or even hours after the radiation has been removed. We could not have light generated by phosphorescence on the screen of a cathode ray tube because the pattern produced a short time ago

would still appear along with the new pattern if we are viewing a signal whose waveform is constantly changing. The color of the fluorescence must be suited to the purpose for which the tube is being used. For ordinary photographic work, fluorescence in the ultra-violet or toward the blue end of the spectrum is preferable. For visual observation, green fluorescence is preferable because the human eye is most sensitive to green. Fig. 39 compares the color sensitivity of the eye to the wavelength of the green fluorescence produced by most cathode ray tubes. In television pictures, however, the preferable color is black and white. Most people associate black and white with motion pictures, and therefore, expect to see television pictures of the same color. Another characteristic in fluorescent material is its life. It should last a long period of time; that is, it should retain its fluorescent qualities as long as the cathode retains its electron emission. Also, it should be resistant to burning caused by high electron concentration.

Preparation of the fluorescent screen of the cathode ray tube is quite complicated. Some materials used will fluoresce naturally; that is, they don't require any special preparation in order to be used on the fluorescent screen. Other substances in their natural state will not fluoresce; they require the addition of an activator. The amount of activator required varies from one part in a thousand to one part in one hundred thousand of the fluorescent material. The name often applied to fluorescent material is phosphor, the name applied to the activator is phosphorogen. Some materials must be in a crystalline state before they will fluoresce. Fluorescence of other materials depend upon the way in which they have been prepared and the kind of activator used. Also, the fluorescent material, after it is prepared, must be able to withstand the temperatures required in evacuating a cathode ray tube. (A vacuum tube is heated to a high temperature in order to get rid of all the gas in the elements and glass.)

We are listing some of the substances which will produce fluorescence, their color, and a brief description.

1. Synthetic willemite—Is prepared zinc silicate; fluoresces green.
2. Calcium tungstate—Fluoresces blue-white; and is rich in rays affecting photographic plates.
3. Cadmium tungstate—Color is pale blue; and at lower intensities, appears black and white. Objectionable because it requires extremely high voltages to get any brilliancy.
4. Zinc phosphate—Produces red fluorescence.
5. Mixtures of zinc sulphide and zinc cadmium sulphide—Any color obtainable by using proper activator and proper mixture of the two substances. Gives maximum light for a given current density.

As was said previously, any color can be obtained by using zinc sulphide and zinc cadmium sulphide with a proper activator. In order to get black and white, the color most acceptable to the television viewer, it is necessary to select a combination which under the influence of the cathode ray beam will yield the primary colors of the visible spectrum. These are blue, green, and red in the proper proportion to give white. The intensity of illumination for all three colors must have the same relation to the intensity of the electron beam. That is, if the electron beam intensity is halved, the intensity of all three colors radiated should be halved. Otherwise, the color of pattern would change with different intensities of the electron beam.

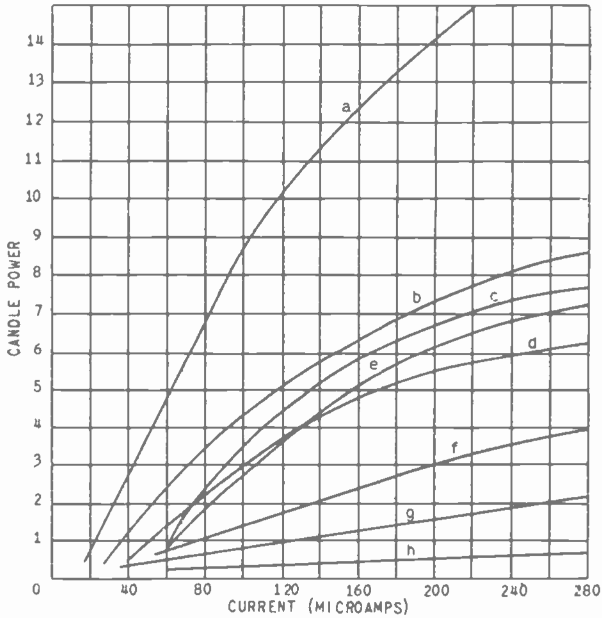


Fig. 40 Curves showing relationship between intensity in candle power of the emitted light and the intensity of electron beam in microamperes, when the following substances are used on the fluorescent screen: (a) Zinc sulphide and zinc cadmium sulphide; (b) Zinc sulphide; (c) Zinc sulphide; (d) Zinc-cadmium sulphide; (e) Zinc-cadmium sulphide; (f) Willemite; (g) Cadmium tungstate; (h) Zinc phosphate.

Black and white screens on cathode ray tubes are troubled by what is known as "black spot" formation. After the tube has been in use, a black spot forms in the center of the screen and increases in size as the tube ages. This black spot is caused by lack of sensitivity of the fluorescent material in that region. It is caused by the changes in the fluorescent material due to bombardment by negative ions that are given off by the cathode. The negative ions, being so much heavier than the electrons, are deflected very little by the deflecting fields.

Fig. 40 shows a curve illustrating the relationship between the intensity in candle power of the emitted light and the intensity of the electron beam in microamperes. Several different substances are given and several preparations of one single substance, zinc sulphide. Note the intensity of illumination varies widely for different electron concentration; however, their relationship is linear. Curve marked A has the greatest change in intensity for a given change in electron density. The relationship is linear for currents from 20 microamperes to currents of around 110 microamperes. This is an important thing to remember and will be more important when we study cathode ray tubes used for television.

The preparation of material for fluorescent screens is important. The actual method of depositing of the fluorescent material on the end of the tube to form the screen is also very important. Since the electron beam impinges on the screen opposite from the side on which the pattern is viewed, the screen must not be too thick. However, it should be thick enough that all the available energy of the cathode ray beam can be converted into light.

The best method of depositing the fluorescent material on the end of a cathode ray tube is to form a suspension of the fluorescent material in some liquid. By suspension, we mean the material is in an extremely finely divided state, distributed homogeneously throughout the liquid. This liquid is poured in the cathode ray tube blank and the blank is allowed to stand with the face down. In time, the finely divided fluorescent material will be deposited on the bottom of the blank or on the end of the tube. If the solution is properly prepared, the material will deposit out in a fine, even layer, the thickness of the layer being controlled by pouring in the proper amount of solution. After the solution has been allowed to settle for several hours, the tube is tilted and the liquid poured out gradually. It usually takes 30 to 40 minutes to completely remove all the liquid. No binder is required to hold the fluorescent material to the glass. Due to the fine state of division of the particles, the adhesive force between them and the glass is sufficient to keep them in place.

Other methods of forming fluorescent screens are used. One is to spray the material on the end of the tube. Another is to "dust" the fluorescent material on the end of the tube. The screens produced in this way, although satisfactory and economical, lack the tenacity and uniformity of the screens formed by allowing the material to settle from a liquid suspension.

902

HIGH-VACUUM CATHODE-RAY TUBE

LOW-VOLTAGE ELECTROSTATIC-DEFLECTION TYPE

WITH 2" MEDIUM-PERSISTENCE SCREEN FOR OSCILLOGRAPHIC USE

Heater	Coated Unipotential Cathode	
Voltage	6.3	a-c or d-c volts
Current	0.6	amp.
Fluorescent Screen:		
Material		Phosphor No. 1
Pattern Color		Greenish
Direct Interelectrode Capacitances:		
Control Electrode to all other Electrodes		8.0 max. μμf
Deflecting Plate D_1 to Deflecting Plate D_2		3.0 max. μμf
Deflecting Plate D_3 to Deflecting Plate D_4		2.8 max. μμf
For plate identification, see following page.		
Overall Length		7-7/16" ± 3/16"
Maximum Diameter		2-1/16"
Bulb		J-16
Base		Medium Shell Octal 8-Pin

MAXIMUM RATINGS and TYPICAL OPERATING CONDITIONS

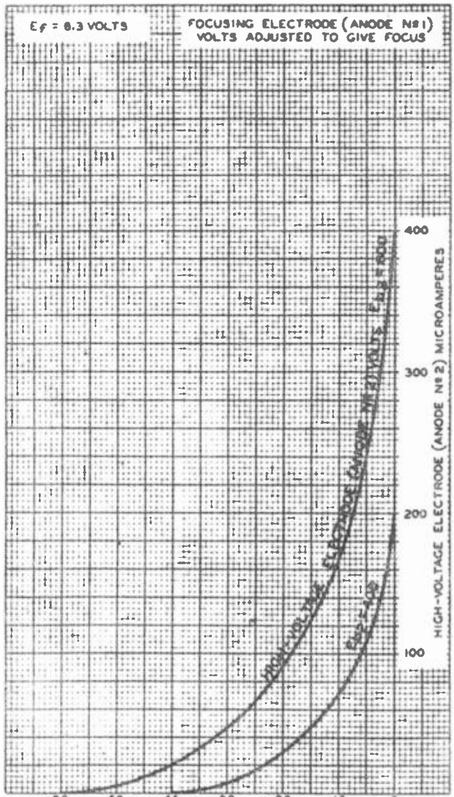
High-Voltage Electrode (Anode No. 2) Voltage	600 max.	volts
Focusing Electrode (Anode No. 1) Voltage	175 max.	volts
Control Electrode (Grid) Voltage	Never positive	
Grid Voltage for Current Cut-off *	-80 approx.	volts
Peak Voltage between Anode No. 2 and any deflecting plate	350 max.	volts
Fluorescent-Screen Input Power/sq cm	5 max.	mw

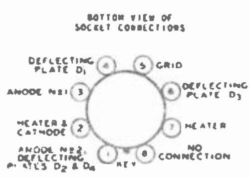
Typical Operation:			
Heater Voltage	6.3	6.3	volts
Anode #2 Voltage	400	600	volts
Anode #1 Voltage	100	150	approx. volts
Grid Voltage	Adjusted to give suitable luminous spot		
Deflection Sensitivity:			
Plates D_1 & D_2	0.28	0.19	mm/volt d.c.
Plates D_3 & D_4	0.33	0.22	mm/volt d.c.

* with maximum voltage on Anode #1.

902

AVERAGE CHARACTERISTICS





906

HIGH-VACUUM CATHODE-RAY TUBE

ELECTROSTATIC-DEFLECTION TYPE WITH 3" MEDIUM-PERSISTENCE SCREEN FOR OSCILLOGRAPHIC USE

Heater	Coated Unipotential Cathode	
Voltage	2.5	a-c or d-c Volts
Current	2.1	amp.
Fluorescent Screen:		
Material		Phosphor No.1
Pattern Color		Greenish
Direct Interelectrode Capacitances:		
Control Electrode to all other Electrodes	10 max.	μμf
Deflecting Plate D_1 to Deflecting Plate D_2	4 max.	μμf
Deflecting Plate D_3 to Deflecting Plate D_4	3 max.	μμf

For plate identification, see second following page.

Overall Length	11-1/2" ± 3/8"
Maximum Diameter	3-1/16"
Bulb	J-24
Base	Medium 7-Pin

MAXIMUM RATINGS and TYPICAL OPERATING CONDITIONS

High-Voltage Electrode (Anode #2) Voltage	1500 max.	volts
Focusing Electrode (Anode #1) Voltage	525 max.	volts
Control Electrode (Grid) Voltage	Never positive	
Grid Voltage for Current Cut-off *	-70 approx.	volts
Peak Voltage between Anode #2 and any deflecting plate	600 max.	volts
Fluorescent-Screen Input Power/sq cm	10 max.	mw

Typical Operation:

Heater Voltage	2.5	2.5	2.5	2.5	2.5	2.5	volts
Anode #2 Voltage	400	600	800	1000	1200	1500	volts
Anode #1 Voltage	128	170	230	285	345	475	volts &
Grid Voltage	Adjusted to give suitable luminous spot						
Deflection Sensitivity:							
Plates D_1 & D_2	0.81	0.55	0.41	0.33	0.27	0.22	mm/volt ●
Plates D_3 & D_4	0.87	0.59	0.44	0.35	0.29	0.23	mm/volt ●

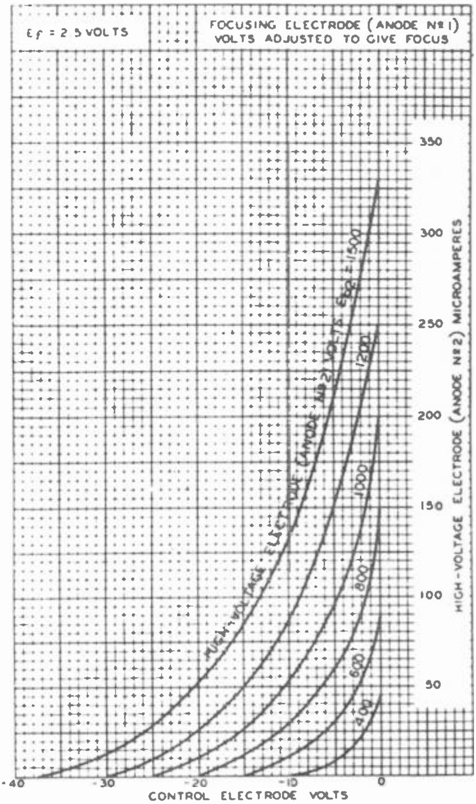
& Approx. ● D-C volt.

* With maximum voltage on Anode #1.

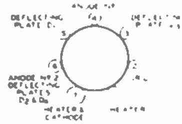
←Indicates a change.

906

AVERAGE CHARACTERISTICS



TOP VIEW OF SOCKET CONNECTIONS



RCA RADIOTRON DIVISION

913

HIGH-VACUUM CATHODE-RAY TUBE

LOW-VOLTAGE ELECTROSTATIC-DEFLECTION TYPE
WITH 1" MEDIUM-PERSISTENCE SCREEN FOR OSCILLOGRAPHIC USE

Heater	Coated Unipotential Cathode	
Voltage	6.3	a-c or d-c volts
Current	0.6	amp.
Fluorescent Screen:		
Material		Phosphor No.1
Pattern Color		Greenish
Direct Interelectrode Capacitances:		
Control Electrode to all other Electrodes	10.5 max.	μμf
Deflecting Plate D_1 to Deflecting Plate D_2	3.6 max.	μμf
Deflecting Plate D_3 to Deflecting Plate D_4	4.3 max.	μμf

For plate identification, see next page.

Maximum Overall Length	4-3/4"
Maximum Diameter	1-23/32"
Bulb	Metal Shell, MT-10 ←
Base	Octal 8-Pin

MAXIMUM RATINGS and TYPICAL OPERATING CONDITIONS

High-Voltage Electrode (Anode No.2) Voltage		500 max.	volts
Focusing Electrode (Anode No.1) Voltage		125 max.	volts
Control Electrode (Grid) Voltage		Never positive	
Grid Voltage for Current Cut-off *		-90 approx.	volts
Peak Voltage between Anode No.2 and any deflecting plate		250 max.	volts
Fluorescent-Screen Input Power/sq cm		5 max.	mw
Typical Operation:			
Heater Voltage	6.3	6.3	volts
Anode #2 Voltage	250	500	volts
Anode #1 Voltage	50	100	approx. volts
Grid Voltage	Adjusted to give suitable luminous spot		
Deflection Sensitivity:			
Plates D_1 & D_2	0.15	0.07	mm/volt d.c.
Plates D_3 & D_4	0.21	0.10	mm/volt d.c.

* With maximum voltage applied to Anode No.1.

← Indicates a change

913

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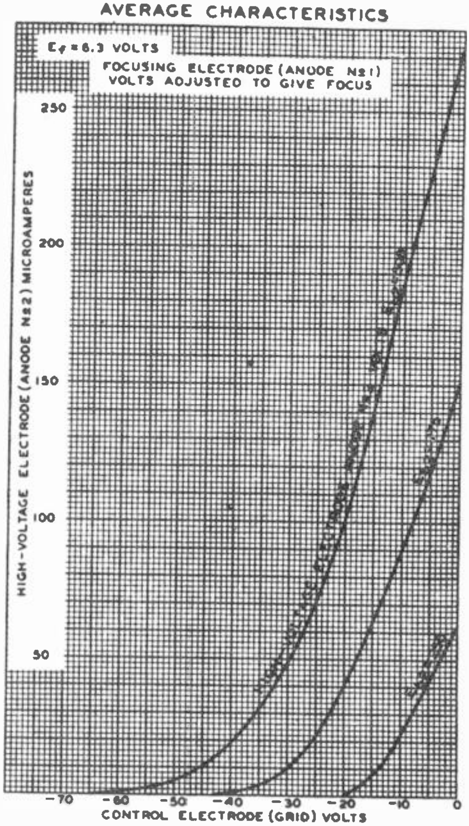
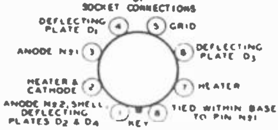


BOTTOM VIEW OF SOCKET CONNECTIONS



RCA RADIOTRON DIVISION
RCA MANUFACTURING COMPANY INC.

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MIDLAND TELEVISION INC.

POWER & LIGHT BUILDING, KANSAS CITY, MISSOURI

UNIT NO. 5

TELEVISION CATHODE RAY TUBES

LESSON NO. 7

SECONDS, HOURS, YEARS,

.....Time Marches On!

The clock on the mantle in the living room ticks steadily away. Now it is only six P.M. The clock continues to tick away tiny seconds, and almost before we realize it, another hour has passed. Then the alarm rings in the morning and a new day begins.

Days become weeks, weeks become months and then around rolls another year. And with the ticking away of those little seconds, we become steadily older. Twenty one years of age----twenty five----thirty years of age----and then forty and forty five. Time is relentless; it has no favorites. Brown hair turns to grey and then to snowy white. Old age has arrived.

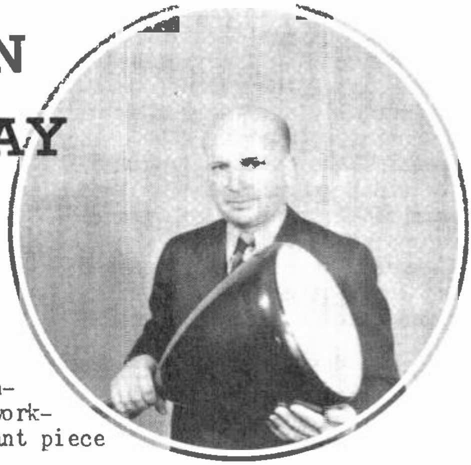
You are probably a long way from old age. But those seconds are ticking away. Individually, they seem of little consequence. But when 86,400 seconds have been ticked out by the clock, another day has passed. And out of each day you should invest as many of those spare seconds as you possibly can. Invest them in your training, so that they can return dollars to you in the future.

The lesson that you are about to study pertains to the Cathode Ray Tube, a marvelous piece of equipment that shoots electrons so rapidly that the fastest machine gun ever invented seems slow in comparison. Just as the second is tiny, the electron is so minute as to challenge our imagination. But every electron has its job to do. Just how important that job is, you will discover on the following pages.

One electron can accomplish nothing. Millions of electrons accomplish wonders. If you were to invest one second in training, the result would be zero. But when you invest thousands of seconds in study, you go far toward insuring your success.

Lesson Seven

TELEVISION CATHODE RAY TUBES



"Since the cathode ray tube is the heart of every electronic television receiving system, it is highly essential that you have a thorough working knowledge of this important piece of equipment.

"This lesson is not designed to teach you how to build such tubes, but rather to show you the difference in construction between these and the common types of cathode ray tubes. In addition, the study of some of the associated circuits is covered with the idea of teaching you how to secure the best in results from such equipment."

1. ELECTRONIC TELEVISION. Modern electronic television uses the cathode ray tube as the picture reproducing agent. In the modern television receiver, the picture appears on the end of the cathode ray tube. This tube is electrically identical to the cathode ray tubes we studied in the previous lesson. However, there are some additional refinements in design so that the maximum in detail may be produced.

We shall review briefly the process of televising and reproducing a picture. In order to transmit a picture electrically, it is necessary to resolve the picture into a large number of elementary areas of varying density. Each area is converted into electrical impulses whose magnitude is directly proportional to the light intensity of that area. Each of these impulses must be transmitted separately. At the receiver, each electrical impulse is converted back into the corresponding area of light intensity in the proper sequence so that the original picture is reproduced.

The term we apply to this resolution of a picture into separate elements is called scanning. In Lesson 2, the process of scanning was explained in detail in terms of a mechanical scanning system. In the flying spot system of scanning, a spot of light covered the subject to be televised in a series of horizontal lines. Each line is displaced from the previous line by a distance equal to the height of the scanning spot. The variations in intensity of the light reflected from the scanned subject are converted by means of a photocell into electrical impulses. At the receiver the process is reversed, the picture signal, consisting of electrical impulses of different magnitudes is reconverted into a picture.

The cathode ray tube can be used as a television reproducer. The variations in light intensity can be obtained by varying the intensity of the electron beam and this in turn will vary the intensity of the fluorescence produced at the screen. Scanning or synthesizing the picture can be obtained by deflecting the beam both horizontally and vertically in step with the flying spot at the transmitter; that is, the cathode ray beam may be made to scan horizontal lines on the front of the tube, displaced from each other by the width of a line. By using sawtooth deflecting voltages, the beam can be made to go from left to right horizontally across the screen at a slow rate of speed and from right to left at a high rate of speed. Similarly, it can be made to go from top to bottom slowly and from bottom to top rapidly. Thus, the entire screen of the tube is scanned as one would read a printed page.

2. SPECIAL REQUIREMENTS OF TELEVISION CATHODE RAY TUBES. The design requirements for the electron gun in a television cathode ray tube are much more rigid than those required for an electron gun in an ordinary oscilloscope cathode ray tube. In the oscilloscope cathode ray tube, the grid merely serves the purpose of controlling the intensity of the pattern. In the television cathode ray tube, the grid must modulate the cathode ray beam so that its intensity variations form a replica of the picture signal. Therefore, the grid design is much more strict for television cathode ray tubes.

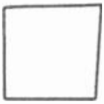
Also, the focus must be the same over the entire face of the cathode ray tube screen; that is, the spot must be in good focus at any point on the screen. In many cathode ray tubes used for oscilloscopes, the focus is good in the center of the tube, but when the spot is deflected near the edges, the focus is poor and the spot becomes enlarged. This results in a loss of detail and contrast as far as the television picture is concerned. One cause for this variation in focus is that the sections of the electron gun are not properly aligned.

Another important factor is that the center of curvature of the face of the tube and the point of application of the deflecting fields should be the same. This is necessary in order that paths followed by the electrons from the cathode to the screen should be the same for any location of the spot on the screen. This is impossible to obtain in practice.

In the smaller cathode ray tubes for oscilloscope use, one of each pair of deflecting plates is tied to the second anode, which is operated at ground potential. This means that when a deflecting voltage is applied to either pair of plates, the average voltage of that pair of plates will not be zero, but will vary above and below ground. When the free plate is positive, the average voltage will be above ground. When the free plate becomes negative on the next half cycle, the average voltage will be below ground. This means that the average value of the electrostatic field around the second anode will change above and below ground with changes in the applied deflecting voltage. The amount of change will be proportional to the magnitude of the peak value of the applied deflecting voltage. Since the voltage on the second anode is one of the factors controlling the quality of focus of the spot on the fluorescent screen, the focus will vary as the beam is deflected away from the center of the screen.

Another bad result from having one of each pair of plates tied to the second anode is the variation in deflection sensitivity with the application of the deflecting voltage. When the average voltage of the deflecting plates is above ground, the additional voltage will cause an increase in the speed of the electrons. When the average deflecting voltage is below ground, this negative voltage will cause the electrons to be retarded slightly. You will recall the magnitude of deflection of the electron beam varies inversely with its velocity. Therefore, there will be a variation in deflection sensitivity as the average voltage of the deflection plate varies below and above ground. The deflection sensitivity will be higher if the average voltage is below ground and lower when the average voltage is above ground. We normally expect to have a square, solid pattern formed on the front of the cathode ray tube when we apply voltages of equal amplitude, but differing in frequency, to the deflecting plates of the cathode ray tube. (That is, the frequency of the voltage applied to one pair of plates is many times that applied to the other.) However, the pattern formed is not a square, but is distorted, as shown in Fig. 1. Therefore, the best television cathode ray tubes which use electrostatic deflection have all four of their deflecting plates free; that is, there is no connection from any of them to the second anode.

Fig.1 Distorted scanning pattern.



Another special requirement of the cathode ray tube for television is that the deflection sensitivity must be independent of the voltage applied to the grid. In other words, the grid must control only the number of electrons constituting the beam and must not change their velocity in any way. Grid changes in the positive direction should increase the number of electrons in the beam and grid changes in the negative direction should decrease the number of electrons in the beam. If the grid accelerated the electrons as well as increased their number when changing in the positive direction, the deflection sensitivity would be reduced and the bright spots of the picture would be pulled together while the darker parts would be expanded.

Variations in electron velocity with variations in grid voltage will cause defocusing. Therefore, in television cathode ray tubes the functions of the grid and the accelerating or focusing anode must be separated. This is done by the insertion of an additional electrode, called the screen grid, into the electron gun. The screen grid is placed in between the grid and the first anode. It consists of a perforated disc and is operated at a potential of 200 or 300 volts positive with respect to the cathode in larger tubes. Fig. 2 shows an electron gun in which the screen grid has been added. The screen grid also makes the intensity of the electron beam independent of variations in the first anode voltage. If you will recall, the first anode has a series of aperture discs in order to confine the divergence of the electrons coming from the crossover in front of the grid. The number of electrons collected by these discs will depend upon the intensity of the cathode ray beam. When these electrons are flowing through the voltage divider to the positive side of the power supply, they will change the voltage drop across that section of the divider and the first anode voltage will vary with variations in the beam intensity. By means of the screen grid, the first anode voltage variations are prevented from changing the intensity of the electron beam.

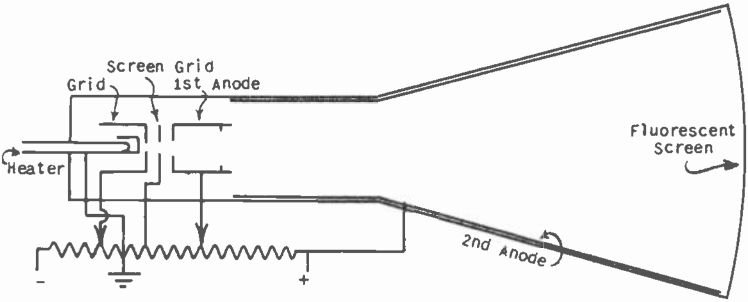
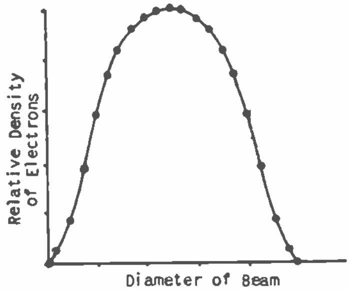


Fig.2 Electron gun structure of a television cathode ray tube.

In many cathode ray tubes, the second anode consists of a coating of some conducting material on the inside of the glass envelope extending from the end of the first anode to the fluorescent screen. This type of anode is illustrated in Fig. 2. The reason that the second anode or inner coating is extended right up to the fluorescent screen is to collect all the secondary electrons emitted from the screen. If the inner side of the tube nearest the fluorescent screen were not coated with this conducting material, there would be a tendency for the secondary electrons to accumulate on the glass insulation and thus set up negative fields which would have a tendency to destroy the focus. However, with the coating, all the secondary electrons are safely conducted to ground through the power supply.

This inner coating also serves another important purpose in an electrostatic deflection tube. You will recall that in our discussion of oscilloscope type cathode ray tubes, we stated that the deflecting plates were connected together by high resistances and that one of each pair of plates was connected to ground. One of the reasons for connecting them to ground by such resistances is to provide a path for any secondary electrons picked up by the free deflecting plates to go to ground. The number of secondary electrons collected by the free deflecting plates depends upon their positive voltage with respect to the second anode or ground. As stated before, an important requirement of a cathode ray tube used for television is that the deflecting plates have separate leads. We also stated in the previous lesson that under this condition, the two plates of each pair were tied together by a large resistance and the center tap of that resistance was grounded. When a deflecting voltage is applied to a pair of plates, the voltages of the plates will have a phase difference of 180° and the average voltage will be zero. That means the positive plate will collect all of the secondary electrons, while the negative plate will collect few or none. Then as far as the generator supplying the deflecting voltages is concerned, the positive plate will produce a greater load on the deflecting source than will the negative plate. This means the deflection wave form will be distorted. Thus it is important that no secondary electrons be collected by the deflecting plates because of the waveform distortion caused by the unequal collection of secondary electrons by one of the deflecting plates of a pair. The inner coating of the cathode ray tube will prevent any secondaries from being collected by the deflecting plates; that is, the inner coating will collect all of the secondary electrons before they have a chance to get as far back in the tube as where the deflecting plates are located.

Fig.3 Distribution of electrons in cathode ray beam.



3. SPOT SIZE. The spot produced on the screen of the cathode ray tube must be circular in shape. If the spot is elongated in the horizontal direction, there will be a loss in detail as the spot will be covering more than one picture element at a time. If the spot is elongated in the vertical direction, there will be an overlapping of scanning lines and a loss in detail. The spot shape and size depends entirely upon the construction and assembly of the electron gun. The actual size of the spot, of course, depends upon how fast the spot is moving. This is due to the fact that the distribution of the electron beam is not completely homogeneous, but has a distribution as shown in Fig. 3. When the spot is moving slowly, fluorescence caused by all the electrons in the beam is noticeable. When the spot is moving rapidly, only the fluorescence produced by the electrons in the center of the beam is noticeable, because their density is much greater. Therefore, the width of a line depends upon the number of lines in the picture; that is, the

picture reproduced on the end of the tube with 441 lines will have narrower lines than one reproduced with 220 lines. However, it is necessary that the spot size be fixed so that there is no overlapping, regardless of the number of lines on the front of the tube; that is, there is a limit to the maximum size of the spot produced by fluorescence for any deflecting velocities. The spot size is determined by the construction of the electron gun. The spot size also varies inversely with the second anode voltage. Therefore, picture detail is maximum when the second anode voltage is maximum.

In the discussion in the previous lesson concerning the formation and nature of the fluorescent screen of cathode ray tubes, we also stated the light produced was due to both fluorescence and phosphorescence. We stated that fluorescence was the light generated during the time the electron beam was actually in contact with the fluorescent area and that phosphorescence was the light generated for some time after the beam had left the light emitting area. It is necessary in a television picture to have quite a little of the light radiated by the screen to be generated by phosphorescence.

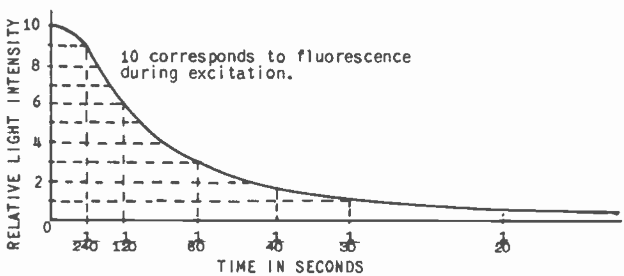


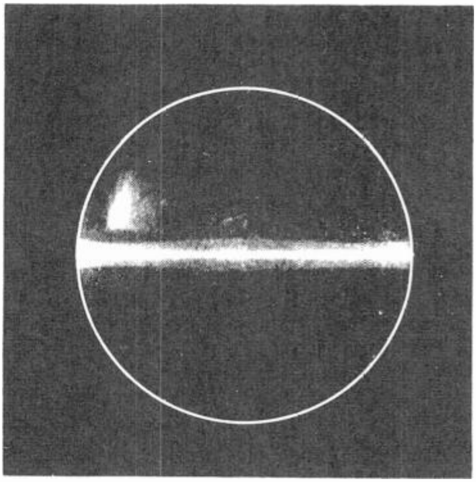
Fig.4 Decay curve of a fluorescent material.

The picture formed on the end of the cathode ray tube is produced a spot at a time as the electron beam moves in a series of horizontal lines from the upper left-hand corner to the lower right-hand corner. This process is repeated at the rate of 30 times a second for straight scanning, or 60 times per second for interlaced scanning. We depend upon the persistence of vision to integrate all the positions of the spot during each frame into a complete picture. The effective brightness of the picture would be increased if light were emitted by any part of the screen for a considerably longer time than the period that the electron beam is incident upon that part of the screen. Thus we would like to have light generated by phosphorescence during most of the interval between passages of the beam over a certain area on the screen. In this way the flicker effect is very much reduced. Fig. 4 shows a decay curve for the screen material used on some tubes after the exciting agency has been removed. It represents the time and duration of the phosphorescence. We see that the light generated by phosphorescence becomes negligible after 1/20 of a second. If the phosphorescence is too long, that is, light is being generated from the previous passage of the beam when the beam again arrives at that point, the picture will be blurred if the subject has moved during the frame interval.

4. PICTURE CONTRAST. We are able to see detail through differences in color or through differences in brightness. Since the television picture contains but one color, we must depend on differences in brightness or contrast to distinguish detail. Therefore, it is important that the television cathode ray tube be designed to produce maximum contrast.

Fig.5A Effect of screen curvature on contrast.

Fig.5B Photograph of halation around a line.



One important factor controlling the contrast of the reproduced picture is the character of the fluorescent screen. Willemite screens which produce green fluorescence, have excellent contrast. This is partly due to the eye's greater sensitivity to green. However, green pictures are unsatisfactory. Most of the television cathode ray tubes produced in this country have willemite screens which produce yellow fluorescence or zinc sulphide screens which fluoresce blue or white. The contrast of the yellow picture is not as great as that of the green. However, the yellow seems to be more pleasing to the observer than the green.

There is also a reduction in contrast of the reproduced picture because of the curved surface of the screen. Fig. 5A shows a cross section of the screen of a cathode ray tube. Point *a* represents a dark part of the picture while *b* and *c* represent bright parts of the picture. Light radiated from *b* and *c* fall on *a* and cause *a* to be illuminated. Thus, there is a reduction in the contrast between *a* and the bright parts *b* and *c*. The amount of light reaching *a* from the rest of the picture will increase as the curvature of screen is increased. It is necessary to have some curvature in the screen in order to maintain good focus over the entire surface. Also, a curved surface is much stronger than a flat one and is better able to withstand the air pressure on the outside of the tube. The force exerted by the atmosphere on the screen of a nine-inch tube is approximately one-half ton.

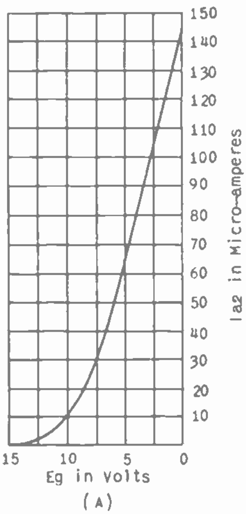
There is also a loss in contrast which is caused by an effect known as halation. Halation shows up as a ring or halo around all the brightly illuminated parts of the picture. This halation is caused by light being reflected back and forth between the two surfaces of the glass and illuminating parts of the screen at a distance from where the light was generated. This is shown in Fig. 5B.

Light reaching the screen through reflection from other parts of the tube will cause a reduction in contrast. The inner coating which forms the second anode is the principal offender.

Stray electrons striking the screen and producing fluorescence will cause a reduction in contrast. The usual sources of these stray electrons are the cold emission from the electron gun and secondary emission from the electron gun and the screen. In a well designed tube there is no secondary emission from the gun. The secondaries from the screen usually lack sufficient velocity to cause fluorescence.

5. MODULATION CHARACTERISTICS. In order that the variations of light intensity on the front of the tube be a true representation of the contrast in the original picture, it is necessary that the intensity of light generated be directly proportional to the amplitude of the signal applied to the grid of the tube. This means that two things must be true. First, the intensity of the electron beam must vary directly with the amplitude of the signal applied to the grid. Secondly, the intensity of the fluorescence produced must be directly proportional to the number of electrons constituting the electron beam. The first condition is difficult to attain in practice. Fig. 6(A) shows the second anode, or beam current versus grid-voltage curve of a modern television receiver tube. Fig. 6(B) gives the relation between the intensity in candlepower of the radiated light and the grid voltage. Examining Fig. 6(A) we see that the second anode current change is linear for grid voltages between 0 and -7.5 volts, but has considerable curvature between cutoff and -7.5 volts. Since second anode current cutoff occurs with zero light intensity or black, the operating range of the grid will be from cutoff to 0 grid volts. This means that for low light levels the contrast will be reduced for this tube as a change in grid voltage from -15 to -10 will produce less change in the light intensity than a change from -10 to -5. Likewise, the change from -10 to -5 will produce less variation than the change from -5 to 0.

The selection of a proper operating point on the grid-voltage, second anode current curve for a television cathode ray tube is not such a simple matter as selecting the proper operating point for an output tube in a sound receiver. If we let the curve in Fig. 6(A) represent the grid voltage plate current curve of an output tube and if the tube is operated as a Class A amplifier, we would select as the operating point a bias of -4.5 volts. We select this point so we can make use of the maximum portion of the straight part of the curve in the negative bias section. The grid is swung equally above and below this point. This operating point is satisfactory for all sound levels to the maximum undistorted power output capabilities of the tube.



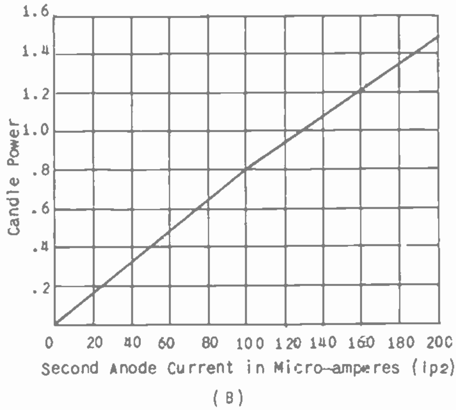


Fig.6 (A) Beam current versus grid voltage curve. (B) Intensity of illumination versus second anode current.

For the television cathode ray tube reproducer, a somewhat different situation exists. The operating point we select on the grid - voltage, second anode current curve determines the average level of each picture; that is, the average light level. However, the average light level of the scene to be televised does not remain constant, but changes with different scenes and the motion of objects before the camera. Therefore, it is necessary to vary the operating point on the grid-voltage, second anode current characteristic as the average light level of the picture varies. In lesson 2, it was stated that the television signal contained all frequencies from zero to the maximum determined by the number of picture elements. The very slow variations, or DC component, carries the average light level. Therefore, it is necessary to use the DC component of the signal as part of the bias for the television cathode ray tube. The fixed bias for the tube is set at cutoff or black.

Let us consider the three squares in Fig. 7. Square *a* consists of alternate black and white bars of the same width. Square *b* consists of alternate black and white bars, but the white bars are twice as wide as the black. Square *c* consists of black and white bars, but the white bars are three times as wide as the black. All three squares are equally illuminated. Under each square is

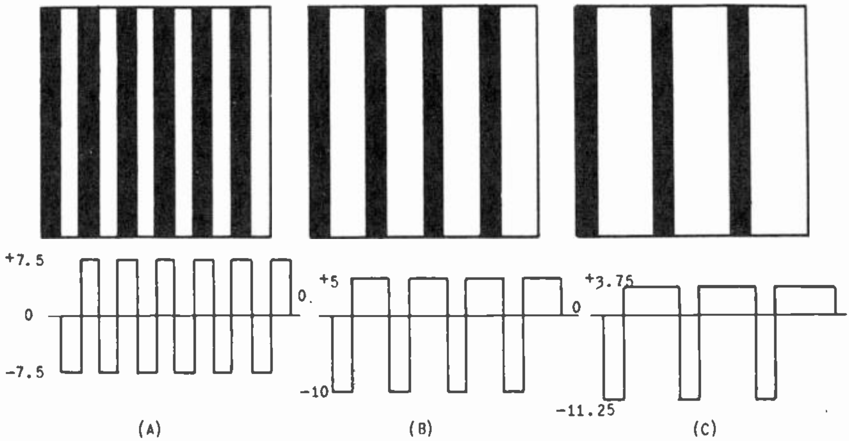


Fig.7 Three types of patterns and the corresponding signals generated by scanning one line of each.

shown the corresponding AC wave form with a peak to peak value of 15 volts. Remember, in a pure AC wave there is just as much enclosed area below the axis as above.

Let us consider the curve in Fig. 8 as an ideal curve; that is, the grid-voltage second anode current relation is linear. We will assume that a grid voltage of -15 corresponds to black and a grid voltage of 0 corresponds to white. What must the bias be in order to reproduce each square with the proper contrast between black and white? Square *a* consists of equal numbers of black and white bars. The positive part of the corresponding AC wave form has the same amplitude as the negative. Therefore, the operating point on the grid-voltage second anode current curve should be mid-

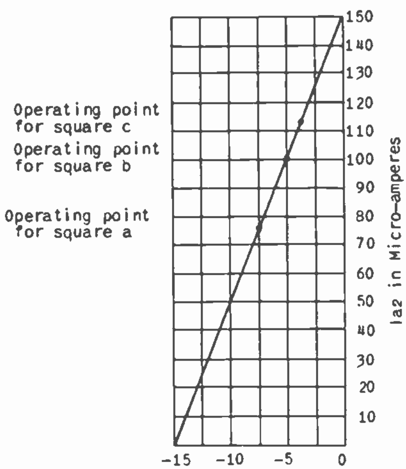


Fig.8 An ideal beam current, versus grid voltage curve.

way between -15 and 0 or -7.5 volts, if the white part of the cycle is to swing the grid to 0 volts. Square *b* has white bars twice as wide as the black. The positive part of the corresponding AC wave form has an amplitude which is one-half as great as the amplitude of the black part. Therefore, the operating point should be two-thirds of the way between -15 and 0 or -5 volts if the white part of the cycle is to swing the grid to 0 volts. Square *c* has white bars three times as wide as the black. The positive part of the corresponding AC wave form has an amplitude that is one-fourth as great as the amplitude of the negative part. Therefore, the operating point should be three quarters of the way between -15 and 0 or -3.75 volts if the white part of the cycle is to swing the grid to 0 volts. We see that in each case the position of the operating point between -15 and 0 is proportional to the average value of the light reflected from each square.

In order to apply this DC component to the grid of the television cathode ray tube, the preceding amplifiers must be direct coupled and direct coupled to the grid of the tube. Amplifier and coupling circuits will be explained in a later lesson.

If AC coupling or condenser coupling is used to the grid of the picture tube or television cathode ray receiving tube, some means must be provided to vary the operating point of the tube as the average light value changes. This can be accomplished by using a rectifier across the grid leak preceding each stage of the amplifier as well as the grid of the cathode ray tube. How this operates will be explained in detail in a later lesson.

6. MODERN TELEVISION CATHODE RAY TUBES. Fig. 9 is a picture of two RCA television cathode ray tubes called kinescopes.[1] One is a 9" tube and the other is a 5" tube. Both use magnetic deflection. The 9" tube has a maximum second anode voltage of 7,000

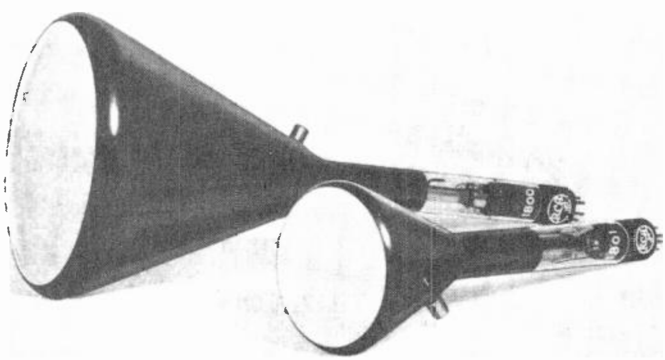


Fig.9 Nine and five inch RCA television cathode ray tubes.

[1] Kinescope. This is a trade name used by RCA to designate their cathode ray receiving tubes designed for television.

volts. The 5" tube has a maximum second anode voltage of 3,000. Both tubes have a pale yellow type fluorescent screen. Fig. 10 is a picture of a modern television cathode ray tube that uses double electrostatic deflection. The terminals to the deflecting plates are brought out at the middle of the tube about halfway between the base and the screen. The maximum second anode voltage for this

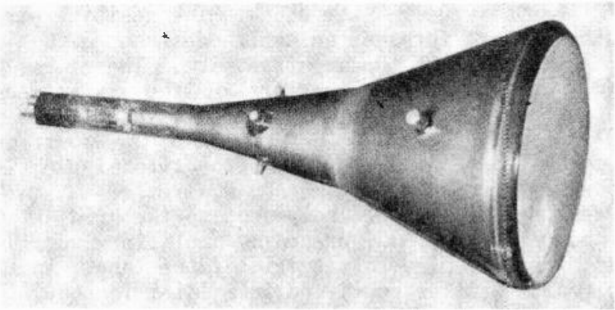


Fig.10 Nine inch television cathode ray tube using double electrostatic deflection.

tube is 7,000 volts. The screen fluoresces with a pale green light. Fig. 11 is a picture of an English cathode ray tube for television reception. This tube uses double electrostatic deflection and has a maximum second anode voltage of 5,000. The screen fluoresces white. The screen diameter is approximately 12". There is also available from RCA a 12" tube similar to their 9" kinescope.

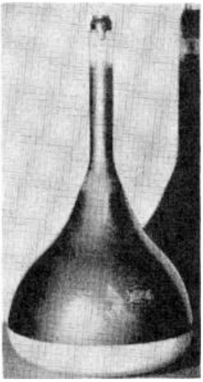


Fig.11 Twelve inch English television cathode ray tube, using double electrostatic deflection.

7. POWER SUPPLIES FOR TELEVISION CATHODE RAY TUBES. The design requirements of the high voltage power supplies used for television cathode ray tubes are much more rigid than those used for oscilloscope type cathode ray tubes. The power supply must have good regulation and the ripple voltage must be low. If there is any ripple in the high voltage supply and if the fixed grid bias is obtained from the same supply, the ripple voltage will appear

on the grid of the television cathode ray tube and cause the light intensity radiated by the tube to vary with the ripple frequency. This will produce bright and dark bands across the picture. The number of these bands will depend on the AC frequency and the frequency of the vertical deflection of the cathode ray beam.

If both the vertical and AC frequency are 60 there will be one dark band across the picture. Ripple present in the second anode supply will cause the deflection sensitivity to vary in unison with the AC power frequency. This produces variations in the line spacing and in line length from top to bottom of the picture. The effects of ripple in the high voltage power supply will be discussed in more detail in the lessons on servicing television receivers.

In the television cathode ray tube, the picture signal is impressed on the grid of the tube. These variations in grid voltage cause the first and second anode currents to vary in unison. If the power supply regulation is not satisfactory, the voltages applied to the elements of the cathode ray tube will change in step with the grid voltage. This will result in changes in the deflection sensitivity and the size of the spot. Both of these factors will result in a loss of detail in the picture. Therefore, it is extremely important that the high voltage power supply for television cathode ray tubes have good regulation.

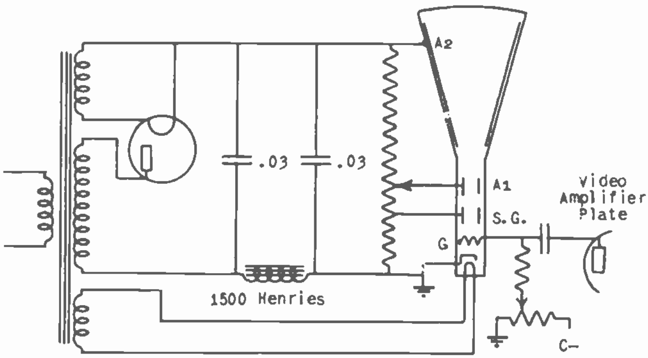


Fig.12 Power supply for television cathode ray tube.

Power supplies like those described in the previous lesson for oscilloscope cathode ray tubes can be used if the single condenser in the filter is made large enough. A capacity of 2 microfarads will produce satisfactory filtering and regulation. However, a condenser of that capacity and of the required voltage rating for the larger television cathode ray tubes is expensive. Also, the energy stored in a 2 microfarad condenser when it is charged to 6,000 volts is sufficient to cause death if an individual accidentally comes in contact with the high voltage supply. Therefore, when using condensers of this size at high voltages, automatic safety switches must be incorporated in the power supply.

Fig. 12 is a diagram of a power supply that is suitable for television cathode ray tubes. A regular condenser input low pass filter is used. The bleeder current is about the same order of magnitude as the load current so that variations of the first and second anode currents will not change the voltages applied to the elements of the tube. Fig. 13 shows a diagram of a high voltage power supply using a low pass condenser resistance filter. Resistance can be used as a component of the filter as the voltage drop with the low current value required by the cathode ray tube is negligible.

The two power supplies in Figs. 12 and 13 have the negative sides grounded because they were designed for tubes using magnetic deflection. The plus side of the high voltage power supply is grounded when it is employed with a tube using electrostatic deflection. In tubes using electrostatic deflection, the average potential of the deflecting plates must be the same as the second anode. If an electrostatic tube were operated with the second anode at a high positive voltage with respect to ground, the condensers coupling the deflecting plates to the deflecting amplifiers would have the entire second anode voltage across them. High voltage condensers are very expensive. However, since the grid is operated way below ground when the positive side is grounded, it must be coupled to the video amplifier by a high voltage condenser.

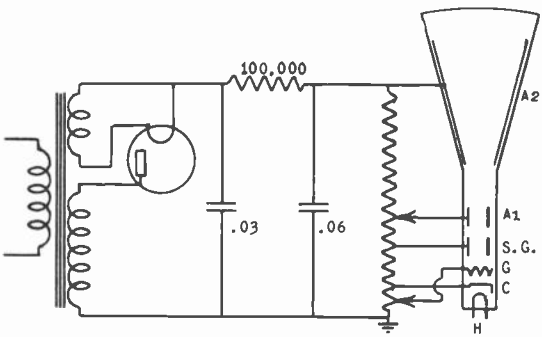


Fig. 13 Power supply for television cathode ray tube.

When chokes are used in the filter they are always placed in the ground side in order to eliminate insulation difficulties. When resistors are used they can be placed in the high voltage side as it is a simple problem to insulate a resistor from ground.

In Fig. 12 the cathode of the cathode ray tube is operated at ground potential. Therefore, the grid bias must be obtained from another source. This is an advantage as the bias supply can be as well filtered as needed to keep ripple voltage out of the grid circuit. In Fig. 13 the bias is obtained from the high voltage supply. When electrostatic tubes are used the bias must be obtained from the high voltage supply as a separate bias supply would have to be operated way below ground. All the components of the supply would have to be insulated to withstand the high voltage used on the cathode ray tube.

8. SCANNING CIRCUIT REQUIREMENTS. The design requirements for the scanning circuits used with a television cathode ray tube are much nore rigid than those for oscilloscope cathode ray tubes. Electrostatic fields, magnetic fields, and a combination of the two are used to deflect the beam in a television cathode ray tube. In England and on the continent, electrostatic deflection is most commonly used, while in this country, magnetic deflection is most common. When a combination of the two is used, electrostatic deflection is used for horizontal scanning and magnetic deflection is used for the vertical deflection of the beam.

Two scanning circuits are required, one for the vertical deflection of the beam and the other for the horizontal deflection. Both scanning fields have a sawtooth waveform. The fields are applied so that the spot is moved from left to right during the slow part of the cycle of the horizontal and from top to bottom during the slow part of the cycle of the vertical. The beam is deflected horizontally at the line frequency rate and vertically at the frame, or field frequency rate. You will recall that the frame frequency indicates the number of complete pictures transmitted per second. The field frequency is the number of times the pattern is scanned if interlaced scanning is used.

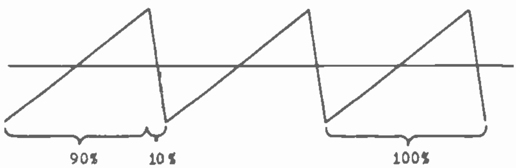


Fig.14 Sawtooth in which return time takes 10% of cycle.

Television stations in the United States use 441-line definition with an interlaced ratio of two to one. The number of pictures transmitter per second is 30 and, since the interlaced ratio is two, the number of times the pattern is scanned is 60 per second. Therefore, the vertical deflecting frequency will be 60 cps. The horizontal, or line frequency, is equal to the number of frames transmitted per second times the number of lines per frame. The horizontal deflection frequency is 13,230 cps. which is 30 times 441. The deflecting field waveform is such that the return time constitutes about 10% or less of a cycle. Fig. 14 is the diagram of a sawtooth in which the return time constitutes about 10% of the cycle. It is during the return time that the synchronizing impulses act to keep the sawtooth oscillator in step with the transmitter.

Deflecting circuits, whether they be magnetic, electrostatic, or a combination of both, should have the following characteristics:

1. Use minimum power to give the required deflection amplitude.
2. Cause no defocusing of the spot as it is deflected from one part to another in the pattern.
3. The pattern free of distortion.
4. Generate a waveform that has a high enough ratio of scanning to return time.

5. The sawtooth oscillators have little drift when running free; that is, without synchronization.
6. Linear scanning sawtooth.
7. Satisfactory oscillator synchronization.

Most of these are self-explanatory. However, the 3rd, 4th, and 5th need a little more explanation. Pattern distortion occurs in two ways; one, by non-uniform rate of spot travel in either the vertical, horizontal, or both directions: and two, the pattern shape is not rectangular.

As stated in a previous paragraph the proper ratio of scanning time to return time is (9:1) nine to one. One of the important factors effecting this ratio is the frequency response of the system. The frequency range required to handle a sawtooth increases as the ratio of scanning time to return time increases. For a ratio of (9:1) nine to one, the frequency response of the deflecting circuit should be flat to the tenth harmonic of the sawtooth frequency.

The frequencies of the oscillators should not drift to a point where the synchronizing impulses in the picture signal can not pull them into step. Best synchronization is usually obtained when the sawtooth oscillator operates at a frequency just slightly below the synchronizing frequency. If the oscillator drifts over a wide range either above or below the required frequency, synchronizing becomes unsatisfactory.

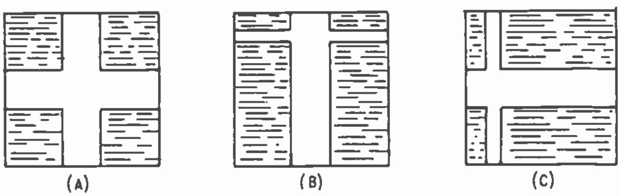


Fig.15 Distortion caused by lack of linearity in deflecting fields.

Linearity in the sweep is far more important in the deflecting circuits for television cathode ray tubes than it is in oscilloscope work. Lack of linearity here will not only distort the shape and size of the picture pattern, but also the objects in the picture. Fig. 15 shows the distortion produced by lack of linearity in the sweep or the deflecting circuits of a television cathode ray tube. A is a cross in its correct proportion. B shows the cross with the vertical deflecting field lacking linearity, and C shows the reproduced cross with the horizontal deflecting field lacking linearity. When the deflecting field is not linear, the picture is crowded on the slow part of the cycle and spread out on the fast part of the cycle.

9. SAWTOOTH OSCILLATORS. The gas discharge tube type sawtooth oscillator was described very fully in the last lesson. This type of oscillator, while very satisfactory for cathode ray tube oscilloscopes, is not equally satisfactory for television use. In our study of the gas discharge tube sawtooth oscillator, we found that

the frequency of the sawtooth is very susceptible to changes in plate voltage and grid bias. Also, the ionizing voltage of a gas depends on its pressure, and the pressure depends upon the temperature of the gas. Therefore, the ionizing potential of the gas in the discharge tube is going to vary as the temperature varies. This variation in the ionizing potential will also cause a change in the frequency of the sawtooth. The amount of grid voltage required to

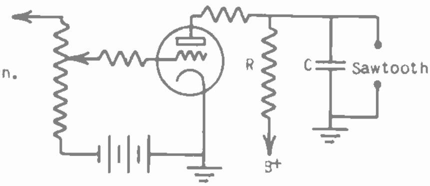
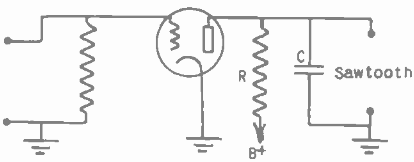


Fig.16 Gas triode sawtooth oscillator.

initiate a discharge will vary with changes in temperature and plate voltage. Since the gas discharge tube is synchronized by introducing the synchronizing voltage into its grid, the accuracy of the synchronization will vary with changes in temperature, plate voltage, and grid voltage. Interlacing requires accurate synchronization of the sweep oscillator with the synchronizing impulses. It is sometimes difficult to secure good interlacing if gas discharge type sawtooth oscillators are used. Therefore, most television receivers in the United States will not be likely to use gas discharge sawtooth oscillators for the vertical and horizontal deflection of the cathode ray beam.

In Fig. 16, we have a diagram of a gas griode type sawtooth oscillator. A complete description of its operation is given in Lesson 6. Condenser C is charged through the resistance R. When the voltage across the condenser reaches the ionizing potential of

Fig.17 Thermionic triode discharge tube.



the tube, the condenser is discharged through the tube. When the voltage across the condenser becomes lower than the value necessary to maintain ionization, the tube de-ionizes and the condenser starts to charge again. Thus, the cycle is repeated. The purpose of the gas triode is to discharge the condenser at proper intervals. There is a need then, to find some other kind of device which will discharge the condenser at the proper interval that does not have the drawbacks of the gas triode.

An ordinary thermionic tube can be used as a discharge tube if it is possible to reduce its plate resistance to a low enough value to discharge the condenser at a fast enough rate. Fig. 17 shows an ordinary thermionic triode discharge circuit. This triode can be a 56 or 76 or any of the similar type triodes. This circuit will produce sawtooth oscillations if the plate resistance is very high during the charging cycle of a condenser, and if the plate resistance can be reduced sufficiently to discharge the condenser during the discharge cycle or return time. If the tube is biased to cutoff, the condition for charging the condenser is satisfied. However, to discharge the condenser, it will be necessary to impress

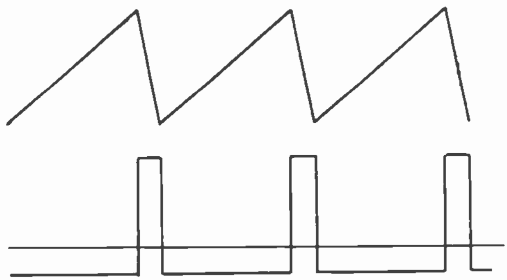


Fig.18 (A) Sawtooth. (B) Required grid voltage wave shape to generate sawtooth.

on the grid of the tube, sharp positive pulses at proper intervals. Fig. 18A shows the type of sawtooth required. Fig. 18B shows the necessary waveform which must be applied to the grid in order to discharge the condenser at the proper intervals and to bias the tube to cutoff during the charging cycle. (They are drawn to show correct phase relationship.)

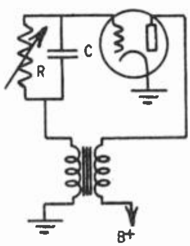


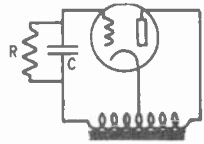
Fig.19 Blocking tube oscillator

There have been several types of oscillators devised which will produce the waveform required to discharge the condenser in Fig. 17. There are only two, however, that are commonly used. One is the blocking tube oscillator which is common in this country and the other is a multi-vibrator oscillator which is common in England. However, it is possible that many American sets will use the English type of multi-vibrator. Therefore, we will wish to know something of its operation.

10. BLOCKING TUBE OSCILLATORS. Fig. 19 is a diagram of a blocking tube oscillator; Fig. 20 shows the equivalent circuit. We see that it is an ordinary Hartley oscillator in which the plate and grid coils are very closely coupled. You will recall that in the Hartley oscillator, the phase relations between the grid and plate voltages are such that any change in the grid voltage, after

amplification, is impressed upon the grid again in the same phase. For the values of C and R ordinarily used, the output waveform is continuous, and more or less sinusoidal. If R and C are made very large, the output becomes intermittent. During the positive swing of the grid, at the start of oscillation, the negative voltage built up across the condenser C, due to the flow of grid current, will gain sufficient magnitude to bias the tube to cutoff and oscillations

Fig.20 Equivalent circuit of blocking tube oscillator.



will stop. The only way for the condenser to discharge is through the resistance R. The tube will remain at cutoff until the voltage across the condenser C drops to a value that will permit plate current to flow again. Then, the cycle will be repeated. When the negative voltage developed across C cuts off the plate current, the voltage induced back in the grid circuit will have the same polarity. For a moment, the grid will be made far more negative than the voltage developed across the condenser C. The frequency of the oscillator will vary inversely with the time of discharge of C. Increasing either R or C will decrease the frequency. If you put

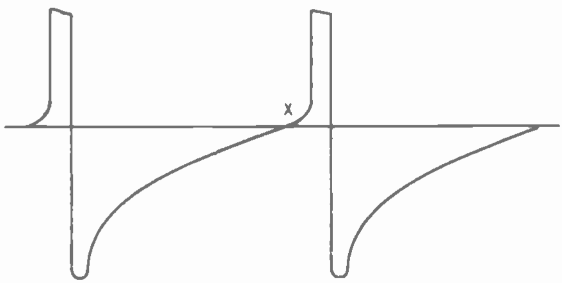


Fig.21 Waveform produced between grid and cathode of blocking tube oscillator.

an oscilloscope from grid to cathode of the tube in Fig. 19 or Fig. 20, the waveform in Fig. 21 is produced. In Fig. 22, A shows the waveform between grid and cathode; B and C show the waveforms developed across the condenser C and the grid coil respectively. A is the sum of B and C. The actual operation of the grid blocking oscillator is considerably more complicated than the simple explanation given here. However, for our purpose, this will suffice.

The waveform generated between grid and cathode of the blocking tube oscillator is similar to that shown in Fig. 18B. It has a short sharp positive pulse and a long negative pulse. Therefore, it can be used to operate a thermionic discharge type sawtooth oscillator.

Fig. 23 is a diagram of a blocking tube type sawtooth wave generator. The two tubes can be separate triodes, such as 56's or

76's, or the two sections of a double triode, such as the 6N7. The 6N7 is usually used, as it works very satisfactorily in this type of a circuit. You will note that the two grids are tied together. This means that the waveform developed between grid and cathode of the blocking tube oscillator will be applied between grid and cathode of the discharge tube, or tube 2. During the positive pulse on the grid of the blocking tube oscillator, or tube 1, the plate resistance of tube 2 will be reduced to a low value and condenser C1 will discharge through tube 2. During the negative cycle of the voltage on the grid of the blocking tube oscillator tube 1, the grid on

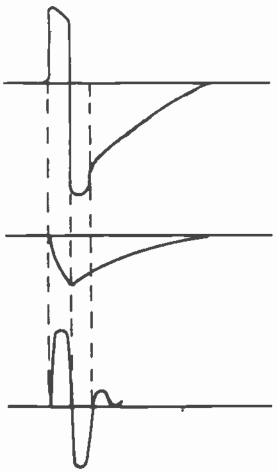


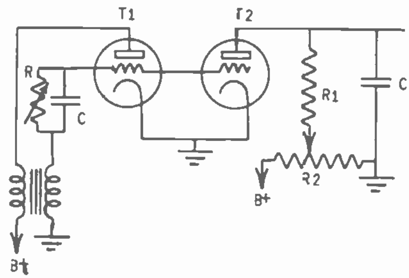
Fig.22 (A) Waveform between grid and cathode. (B) Waveform across C. (C) Waveform across grid coil.

tube 2 will be biased way beyond cutoff and the condenser C1 will charge through the resistor R1. Thus, a sawtooth voltage will be developed across condenser C1. By means of the potentiometer R2, the magnitude of the charging supply voltage is varied and, therefore, the amplitude of charge developed across C1 can be varied. Thus, R2 can be used to control the amplitude of the sawtooth.

As stated in the last lesson on the discussion of the gas discharge type tube oscillator, the linearity of the sawtooth produced depends upon how much of the condenser charging curve that was used. This will hold true for the type of sawtooth produced by an ordinary thermionic discharge tube driven by a blocking tube oscillator. However, in this type of sawtooth oscillator, the frequency of the sawtooth is not determined by the magnitudes of R and C in the discharge circuit (such as R1 and C1 in Fig. 23) but is determined only by the frequency of the blocking tube oscillator. However, we wish to select an R1C1 combination so that the voltage across C1 will, at the maximum, reach a value of about 5% to 10% of the available voltage for charging the condenser C1. Under this condition, the scanning part of the sawtooth cycle will be linear.

Since the frequency of the blocking tube oscillator is controlled by the RC combination in its grid, it is necessary that the time constant for that circuit be right for the desired frequency. The time constant for an RC circuit is dependent upon both the value of R and the value of C. The time *constant* in seconds of an RC circuit is equal to the product of the resistance in ohms and the capacity in farads. We define the *time constant* of an RC combination for a charging condenser as the time required for the voltage across the condenser to reach 67% of the voltage of the charging source. For a discharging condenser, it is the time required for the charge or voltage to drop to 33% of the initial value. The time *constant* is independent of the magnitude of the applied voltage or initial charge on the condenser.

Fig.23 Blocking tube oscillator type sawtooth generator.



Therefore, the desired time constant of the RC circuit in the grid of the blocking tube oscillator is determined by the required frequency of the sawtooth that is generated in the plate circuit of the discharge tube.. The blocking tube oscillator which generates the vertical sawtooth has a frequency of 60 cycles. Therefore, the RC product in the grid will have to equal approximately $\frac{1}{60}$ second. A condenser with a capacity of .5 mfd. and a resistor of 33,000 ohms will give a time constant of .0165 second (.000005 × 33000 = .0165) which is approximately $\frac{1}{60}$ second.

The return period of the sawtooth wave is the time that the condenser C1 (Fig. 23) is being discharged. The time of discharge is controlled by the width of the positive pulse applied to the grid of the discharge tube. The width of the positive impulse generated by the blocking tube oscillator is controlled by the time it takes the condenser C in the grid circuit to charge through the input resistance of the tube oscillator and resistance of the grid coil. The rate of charge will be determined by how rapidly the grid voltage rises, which, in turn, is dependent upon the inductance of the coils. Therefore, the width of the positive pulse will be proportional to the capacity C and inversely to the inductance of the coils in the oscillation transformer. The horizontal blocking tube oscillator will have lower values of C and L than the vertical. This will be explained in greater detail in a future lesson.

The blocking tube oscillator can be synchronized by introducing a positive impulse into the grid circuit. Fig. 21 shows the waveform produced between grid and cathode of the oscillator. If the oscillator is running slightly slower than the frequency of the synchronizing impulses the oscillator can be brought into step by starting the positive swing of the grid through impressing on the grid a positive impulse at the time x shown in Fig. 21. A more detailed discussion of synchronization will appear in a later lesson. Fig. 35 shows one method of introducing synchronizing impulses.

11. THE MULTI-VIBRATOR SAWTOOTH OSCILLATOR. Another circuit used to generate sawtooth waveforms is the multi-vibrator. Fig. 24 is a diagram of one type of multi-vibrator used in television receivers. We see from the diagram that the multi-vibrator is a two-stage resistance-coupled amplifier with the output coupled to the input. Each stage of a resistance-coupled amplifier reverses the phase by 180 degrees. Therefore, the voltage in the output of a two-stage amplifier will have the same phase as the original voltage fed into the grid of the amplifier. Since the output is coupled to the input and the phase of the output and input voltages are the same, regeneration will take place, and a sustained oscillation will be produced.

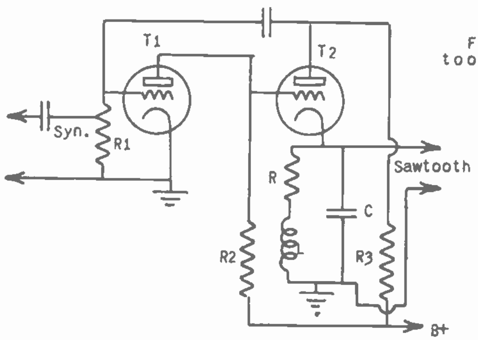


Fig.24 Multi-vibrator sawtooth generator.

In Fig. 24, oscillation is started by the initial transient produced by applying the plate voltage. We will assume that this initial transient occurs across the resistor R3 and in such a direction that the grid of T1 is swung slightly negative. This transient will, after amplification by T1, swing the grid of T2 in the positive direction. After amplification by T2 this voltage will be impressed again on the grid of T1 as a negative voltage but of a magnitude much greater than the original transient. As this regeneration continues the plate current of T1 is reduced and the plate current of T2 is increased. The condenser C in the cathode circuit of T2 will be charged by the plate current of T2 through the plate resistance of T2 and R3. As this condenser charges the cathode of T2 will become positive with respect to ground, or the grid will become negative with respect to the cathode. In a very short interval after the regeneration has commenced, the voltage developed across C will reduce the rate of increase of the positive voltage on the grid of T2 caused by the regeneration. This will cause a reduction in the plate current of T2, which after amplification by T1, will further reduce the rate of increase of the posi-

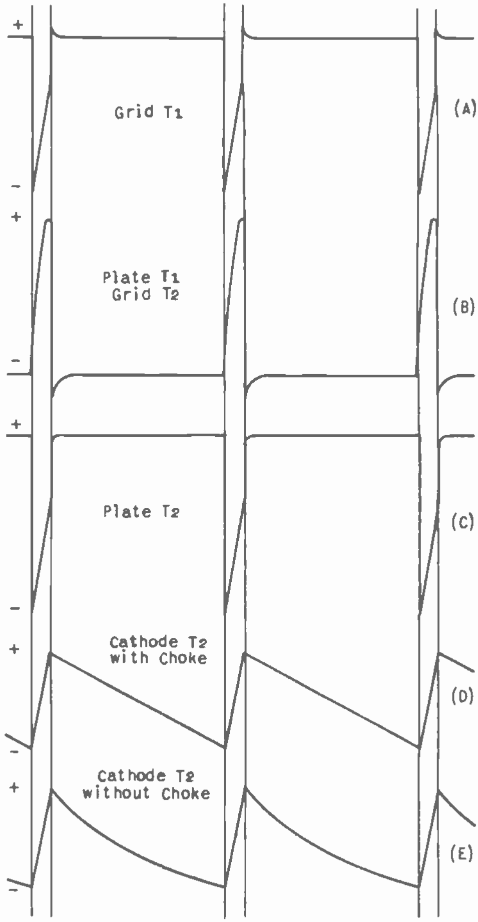


Fig.25 Waveforms produced by multi-vibrator: (A) Between grid and ground of T1. (B) Between plate and ground of T1, or grid and ground of T2. (C) Between plate and ground of T2. (D) Between cathode and ground of T2. (E) Between cathode and ground of T2, with L shorted out of the circuit.

tive voltage on the grid of T2. This cycle will be continued until the plate current of T2 is reduced to zero. The plate current of T2 will remain zero until the negative bias produced by the voltage of C is reduced sufficiently to permit plate current flow. When C has discharged through R and L, the charging cycle will be resumed. (The charging of the condenser takes place in a very short interval.) Fig. 25 shows the waveforms produced in the different parts of the circuit. The plate current pulse of T2 is very sharp.

The sawtooth is generated between the cathode of T2 and ground. In this circuit the condenser is charged at a high rate of speed and discharged at a slow rate of speed. The spot on the cathode ray tube screen will scan during the discharge of the condenser and will fly back during the charging period. This is the reverse of previous systems described.

The purpose of the choke L is to make the discharge cycle of the condenser linear. Without the choke, the condenser discharges most rapidly at the beginning of the discharge cycle. As the condenser discharges through L, the back voltage developed across L will be proportional to the rate of discharge or the rate of current flow. The actual voltage causing a current flow through the C, L, and R circuit will be the difference between the voltage across the condenser and the back voltage of the inductance. If the magnitude of L is sufficient, the current will flow from the condenser at a constant rate, and the discharge of the condenser will be linear.

The multi-vibrator can be synchronized by introducing the synchronizing impulses into the grid of T1 (Fig. 24). The waveform on the grid of T1 (Fig. 25A) consists of a series of sharp negative impulses. The negative impulses occur during the return time of the cathode ray beam. If the multi-vibrator is running slightly slower than the required frequency, it can be brought into step by introducing into the grid circuit negative impulses of the proper frequency. These negative impulses will start the negative swing on the grid of T1 and initiate a new cycle.

12. ELECTROSTATIC DEFLECTION. In the past few paragraphs we have studied the construction and operation of three types of sawtooth wave generators. Of these, the gas discharge tube type is the least suitable for high quality picture reproduction. However, many of the cheaper television sets on the market today use gas discharge tube type deflection circuits. Therefore, we must know something about them and their operation. The multi-vibrator type and the blocking tube oscillator type are suitable for producing pictures of high definition.

We shall first describe the use of these sawtooth oscillators with television cathode ray tubes employing electrostatic deflection. In the early part of the lesson we mentioned the fact that tubes using electrostatic deflection for television reproduction should have connections brought out from all four deflection plates. We stated also that the deflection voltage applied to these plates must be balanced with respect to ground. All the sawtooth oscillators described have an output that is not balanced against ground. We must, therefore, insert between the sawtooth oscillator and deflecting plates of the cathode ray tube an amplifier whose output voltage is balanced against ground.

Such an amplifier is known as a push-pull amplifier. In order to drive the push-pull stage from a single ended stage or a stage unbalanced to ground, a means of phase inversion must be inserted. You will recall that the voltages applied to the two grids of a push-pull stage are 180° out of phase. In audio circuits, we often use a transformer to accomplish phase inversion. The secondary center tap is grounded and the voltages developed at the two ends of the secondary are 180° out of phase. Economical design of a transformer that will pass a sawtooth wave without distortion has yet to be accomplished. Therefore, we use some other means of phase inversion. You are undoubtedly familiar with circuits used for phase inversion in audio resistance-coupled amplifiers. The same method can be used for television deflecting circuits. Fig. 26 shows one method of phase inversion. T1 and T2 constitute the push-pull driving stage for one pair of electrostatic plates. The load resistances of T1 and T2 are the same. The voltage applied to each plate of the two pairs is balanced against ground; that is, their sum is zero. T2 supplies the out of phase component. If the AC plate voltages of T1 and T2 are 180° out of phase, the grid voltage of T2 will have the same phase as the plate voltage of T1. We can see from the diagram that the grid of T2 is connected to point P on the load resistor of T1. We select point P on the load resistor of T1 so that (Ra + Rb) ÷ Rb is equal to the gain of T2 or T1. If this condition is met, the AC voltage from the plate of T1 to ground and from the plate of T2 to ground will have the opposite phase and the same magnitude; and the deflecting plates of the cathode ray tube will be fed with a voltage balanced against ground.

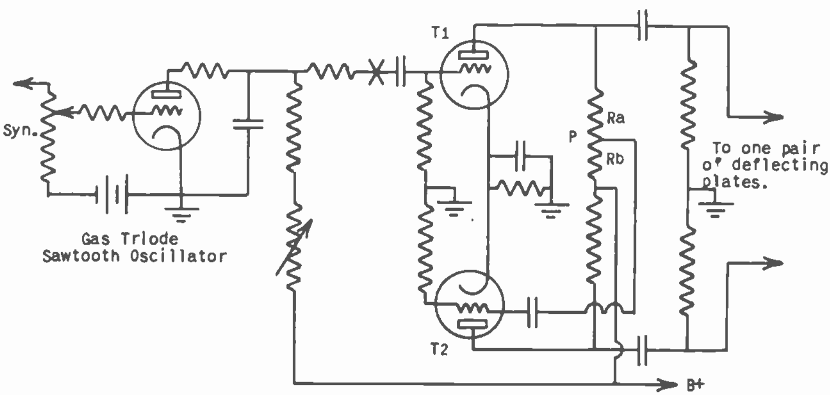


Fig.26 Push-pull stage using phase inversion to couple a sawtooth oscillator to one pair of deflecting plates.

The same circuit can be used with either the multi-vibrator or the blocking tube type oscillator. The output of either oscillator can be connected to the phase inverter stage at point X in Fig. 26.

Sometimes the axis of the electron gun does not coincide with the axis of the cathode ray tube and the pattern is not centered on the front of the tube. Also the earth's magnetic field can displace the pattern from the center of the tube. Therefore, some means must be provided to apply a DC voltage across each pair of deflecting plates in the proper direction to center the pattern. In order to prevent defocusing, this DC voltage must be balanced against ground. Suppose that a difference of potential of ten volts must be applied across the vertical plates of a television cathode ray tube in order to center the pattern vertically. Then one plate will have to be made five volts positive; and the other, five volts negative with respect to ground. Fig. 27 shows one method of suplying a balanced centering voltage. The two potentiometers, R1 and R2 are ganged. The two potentiometers are connected to a DC voltage source which has the center grounded or balanced against ground. When the arms of the potentiometers are in the center, the deflecting plates are at ground potential. When the arms of the potentiometers are moved to the right of the center, the upper plate becomes negative with respect to ground while the lower plate becomes positive with respect to ground by the same amount. Moving the potentiometer arms to the left of center reverses the polarity of the voltages applied to the plates.

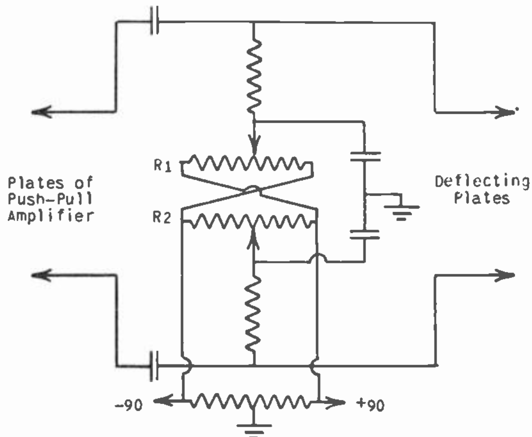
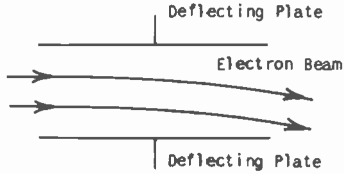


Fig.27 Circuit for centering pattern on television cathode ray tube.

Electrostatic deflection is not convenient to use with large cathode ray tubes if they are operated with a high second anode voltage. You will recall that in the last lesson we learned that the deflection sensitivity varied inversely as the second anode voltage for a tube using electrostatic deflection. For example, one of the 9" cathode ray receiving tubes on the market today has a deflection sensitivity of .1 millimeter per volt for one pair of plates when the second anode voltage is 5,000 and .2 millimeter per volt when the second anode voltage is 2500. If we wish to completely fill the tube screen with a picture, it will be necessary to deflect the beam 4.5 inches from its center position. The voltage required to deflect the beam 4.5 inches when the second anode voltage is 5,000 will be given by $4.5 \times 25 \div .1$, where 25 is the number of millimeters in an inch and .1 is the deflection sensitivity in millimeters per volt. The value of this expression is 1125; that is, it requires a difference in potential of 1125 volts between the deflection plates to deflect the beam 4.5 inches. If the phase of the voltage applied to the deflecting plates is reversed, the beam will be deflected 4.5 inches in the other direction and, therefore, the beam will be deflected completely across the tube for a peak to peak voltage of 1125. Since we use a push-pull circuit to deflect the beam, each tube of the output stage will have to supply one-half of the 1125 volts, or 562.5 volts. A plate swing of that magnitude is difficult to obtain without using high plate voltage transmitter type tubes. These are not economical to purchase and operate. Therefore, in many receivers using large electrostatic deflection type tubes, the second anode voltage is much lower than the rated voltage of the tube. Naturally, with the reduced second anode voltage, the brilliancy and detail of the picture suffers.

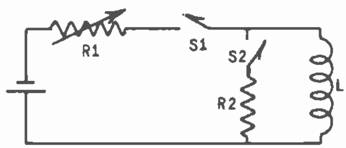
Fig.28 De-focusing caused when electron beam passes between deflecting plates.



The other pair of deflecting plates in the same 9" tube has a deflecting sensitivity of .13 millimeters per volt for a second anode voltage of 5000. This was the pair of deflection plates nearest the electron gun.[1] Even with this increased sensitivity, a peak to peak voltage of 865 is required. The student should check this calculation. The output voltage per tube in the output stage would be about 433 volts which is still exceedingly difficult to obtain with tubes ordinarily available.

The scanning pattern produced by electrostatic deflection usually suffers from a little defocusing in the corners. This is true even when the deflecting field is balanced against ground. Whenever the electron beam is deflected by an electrostatic field, the beam will be nearer one of the pair of deflecting plates. (See Fig. 28) The beam has a considerable cross section when it passes between the deflecting plates. The electrons on the upper part of the beam are slowed up slightly while those on the under side of the beam

Fig.29 Current rise and decay in an inductance.



are speeded up slightly. This causes defocusing of the spot. However as the electron beam leaves the field of the deflecting plates, the faster lower electrons are deflected slightly more than the slower upper electrons. Thus part of the defocusing is corrected. A complete explanation of these effects is beyond the scope of this lesson.

13. MAGNETIC DEFLECTION. Magnetic deflection at this stage of the art is believed to be preferable to electrostatic deflection for high quality picture reproduction. For that reason we shall spend considerable time in the study of the circuits involved.

[1] The pair of plates nearest the gun will have greater deflection sensitivity because the screen is further away. The magnitude of the deflection for a given deflecting field increases as the distance between the plates and screen increase.

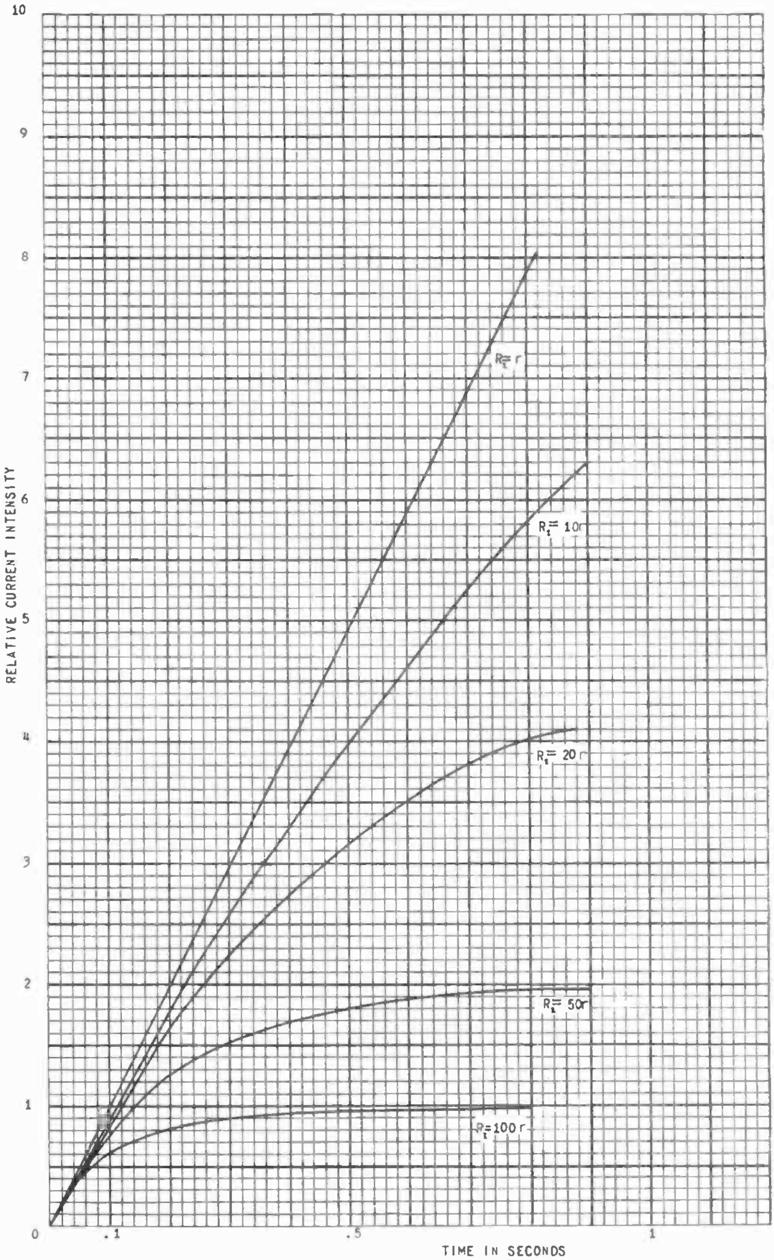


Fig.30 Rate and linearity of current increase through an inductance as the series resistance is varied. (r) represents the minimum value of R_1.

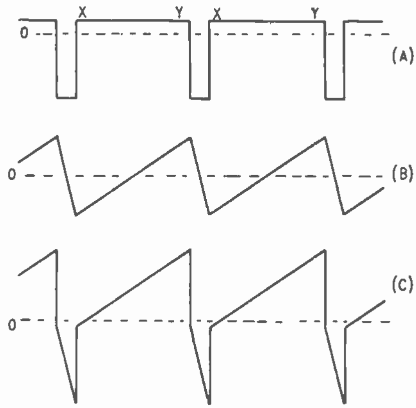


Fig.31 Waveforms required to force a current sawtooth through: (A) Inductance, (B) resistance, and (C) inductance and resistance in series.

It is of utmost importance that the cathode ray beam move at a uniform rate of speed in the horizontal direction when it forms the time axis for an oscilloscope and in both the horizontal and vertical direction when it draws the picture pattern for a television receiver. When the beam is operating in this manner, it is said to have "linear deflection." Since it is the magnetic field produced by the deflecting coils that actually produces the motion of the electron beam, the intensity of this magnetic field must also change at a constant rate.

Then, what is it that produces this magnetic field? The answer, of course, is the current in the coils. Therefore, the linearity of the beam deflection depends upon the waveform of the current in the deflecting coils and this, in turn, depends upon the waveform of the voltage across the coils. And here is a very important consideration. The waveform of the current required to

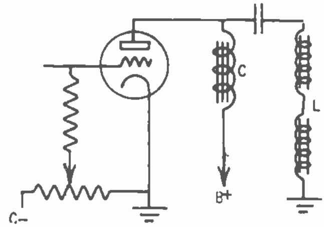


Fig.32 Deflecting yoke, choke-coupled to vacuum tube.

change the intensity of the magnetic field at a constant rate has always the same general shape, but the voltage necessary to produce this current waveform does change, depending upon the constants of the circuit. For example, any coil of wire has inductance, but it also has resistance and it is this ratio of resistance to inductance that determines the correct voltage waveform necessary to produce linear deflection.

Fig. 29 shows an inductance connected in series with a 100v battery, a variable resistance R_1, and a switch S_1. When S_1 is closed the current will gradually rise to a maximum value, determined by the battery voltage divided by R_1 ($E \div R_1$). Now the rate at which the current in this circuit increases, depends upon the magnitude of the series resistance. This relationship is best shown by Fig. 30; here the current increase with time (seconds) is given for several values of the resistance R_1. Suppose we arbitrarily assign a value to r equal to 1,000 ohms. Now in the case where the value of R_1 equals 50,000 ohms, we note that in about .1 second the current has a relative intensity of approximately three-quarters. When the value of R_1 is something like 10,000 ohms, it will require something

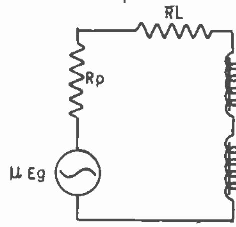


Fig. 33 Equivalent circuit of Fig. 32.

like .5 second to reach a corresponding point on the straighter portion of the curve, but it will have a relative current intensity of 4. From this it is seen that both the duration and magnitude of the *straight portion of the charging current curve varies inversely with the resistance.* In view of this fact, it follows that the increase of current through an inductance can be made more nearly linear by decreasing the circuit resistance. If the circuit resistance could be reduced to zero, the current through the inductance could be considered as motivated by a voltage source whose output is constant.

The time constant of an inductive circuit is defined as the time required for the current to reach 67% of its maximum value. This time will be independent of the applied voltage, but will vary directly with inductance and inversely with the series resistance. This time constant is generally indicated by the ratio L/R, where L is the inductance in henries and R is the resistance in ohms. Under these conditions, the time will be given in seconds.

The magnetic field that is built up about a coil through which a current is passing represents stored-up energy. We have already seen how this magnetic field is proportional to current flowing through the coil and it therefore follows that this field will collapse when the current source is removed. If in Fig. 29, switch S_2 is closed and S_1 is opened, the changing magnetic field causes a flow of current through R_2. The time required for the current to drop to 67% of the initial value is also defined as the time constant for a decaying current, or $L \div R_2$. Since the time required by the magnetic field to collapse is inversely proportional to R, if $R = 0$, it will require an infinitely long time for the field or current to reach zero. If on the other hand R_2 is infinitely large, which is the same as an open circuit, the magnetic field and current will decrease to zero instantaneously.[1] (The voltage developed

[1] A coil of wire will produce a magnetic field when there is current flowing through the coil; the more current, the greater the field or vice versa. Since a resistance in series with the coil reduces the current, it will in turn reduce the field. Therefore, the greater the series resistance, the quicker will the magnetic field collapse. This is another way of stating the formula for the time constant of an inductive circuit, which is equal to L/R.

across the inductance by this rapid change in the current will reach a very high value.)

Now the current waveform and the voltage waveform are the same across a resistor as shown in Fig. 31B. Because of its resemblance, this type of waveform is known as a "sawtooth." This is the current waveform necessary to produce linear deflection of a cathode ray beam.

If it were possible to have a coil with no resistance, it would require a voltage waveform like that shown in Fig. 31A to force a sawtooth of current like that at B through the coil; it therefore follows, since the coil is composed of both inductance and resistance, that the voltage waveform necessary for a sawtooth of current is really some combination of A and B, such as shown at C, the exact ratio of one to the other depending upon the ratio of resistance to inductance (time constant) in the coil.

Fig. 32 shows the output circuit of a system for magnetic deflection, L being the deflecting coils. If the DC plate supply for the tube were allowed to flow through the deflecting coils, we should have the AC deflecting field superimposed on that of the DC field and this DC field would cause a fixed displacement of the pattern on the face of the tube; that is, the pattern would be off-center. Consequently, condenser coupling is necessary and choke C is used to provide maximum coupling with the least amount of voltage drop due to resistance. While resistance could be used for coupling purposes, it would require a much higher supply voltage to deliver the

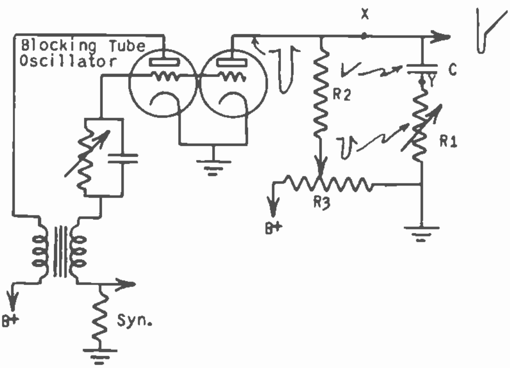


Fig.34 Circuit to produce waveform shown in Fig.31C.

same amount of voltage as the choke coupling at the tube plate. Fig. 33 is the equivalent circuit of Fig. 32, showing both the resistance and inductance in this circuit. Here the plate resistance of the tube is represented by Rp and the load resistance by R_L (R_L is the resistance of the wire in the deflecting coils L). Consequently, the waveform shown in Fig. 31C when applied to the grid of this output tube will cause the required sawtooth waveform to flow in the deflecting coils.

Let us go further into the action of this compound wave. To begin with, since there is resistance in this inductive circuit, the voltage across the inductance drops as the current through the inductance increases (because of the voltage drop across the resistance). Now, the sawtooth component of this compound waveform (that portion shown at 31B) will overcome the voltage drop due to resistance in series with the inductance, and the constant voltage part (XY, Fig. 31A) can then force a sawtooth of current through the inductance. The sharp negative pulse (YX, Fig. 31A) will drive the grid of the output tube to cut-off at the end of each scanning part of the cycle; thus increasing the plate resistance (Rp, Fig. 33) to a very large value, thereby providing the necessary high resistance for the rapid collapse of the magnetic field. This collapse returns the beam very rapidly to its initial position, ready for the next scanning cycle; this period is known as the return time of the beam, or the flyback. We have already seen how this rapid current change will produce a high positive voltage on the plate of the tube and, therefore, this negative pulse must have sufficient magnitude to maintain cut-off of the output tube during this return time of the beam. Now, since the magnitude of the high back voltage is dependent upon (1) the amount of current flowing in the coil, (2) the inductance of the coils, and (3) the length of time required for the return period, they determine the amount of negative impulse voltage required.

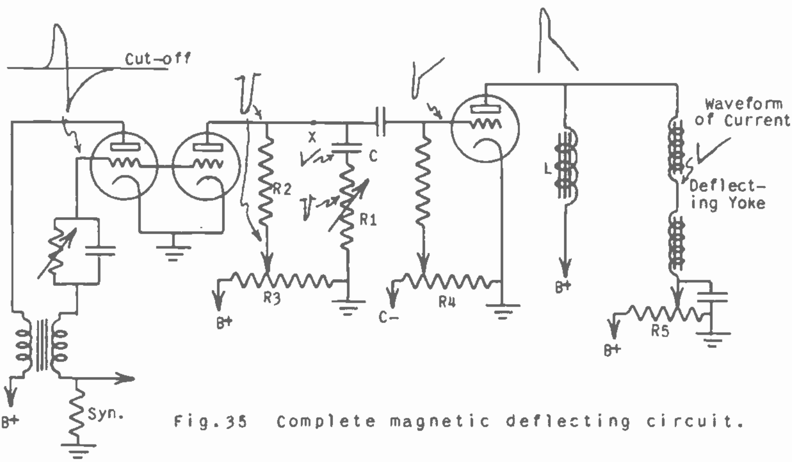


Fig.35 Complete magnetic deflecting circuit.

One method for inserting this negative impulse and also controlling its amplitude is shown in Fig. 34. The diagram is that of a regular blocking tube oscillator and discharge circuit. Now, if a switch be located at X in the plate of the discharge tube, so that we can open the circuit and view on an oscilloscope only the waveform appearing across resistor R_2, we shall find it resembling that of the impulse shown in the figure. Now, R_2 may be of such a value as .5 megohm or greater, while R_1 normally is a 25,000 or 50,000 ohm rheostat. If we connect the oscilloscope at point Y and look at the voltage appearing across R_1, we will find it to be identical to that appearing across R_2 excepting, much reduced in amplitude. (The switch at X must be closed.) Now, if resistance R_1 is decreased to zero, the voltage waveform appearing across condenser C is a sawtooth. In normal operation, these two waveforms add together to produce the required compound wave. Since there is no switch at X, then the actual waveform developed in the circuit is that shown on the grid of the output tube, the amount of the negative impulse component being controlled by the value of R_1. This rheostat is called the "peaking control." The rheostat R_3 controls the amplitude of the output of the entire circuit.

Fig. 35 is a diagram of a complete magnetic deflecting circuit showing the voltage waveforms at the various points in the circuit. The bias on the output tube is made variable in order that the operating point on the tube's characteristic may be checked for the best sawtooth of current through the deflecting yoke. A more detailed discussion of correct bias for the output tube will be given in a later lesson.

The purpose of R_6 is to pass a small amount of DC through the deflecting coils in either direction so that the picture can be centered on the end of the tube. The voltage at the plate side of the coils will be less than the power supply voltage by an amount equal to the drop across the resistance of the choke L. The voltage at the bottom of the coils can be made higher or lower than the voltage at the top by means of the potentiometer R_5. Thus, a current of desired magnitude can be sent through the deflecting coils in the direction necessary to center the picture.

The design of deflecting circuits for the vertical and horizontal movements of the beam are different. For a system showing a 441-line picture, the vertical deflecting frequency (that is, the field frequency) is 60 c.p.s. and the horizontal deflecting frequency (that is, the line frequency) is 13,230 c.p.s. The differences in circuit design of the two will be discussed in a later lesson.

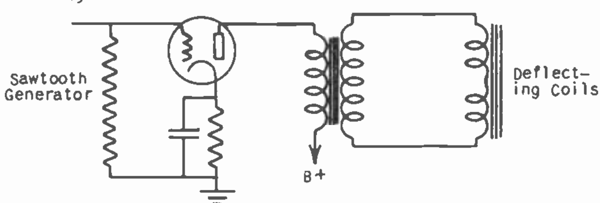


Fig.36 Tube, transformer-coupled to deflecting yoke.

It was stated in a previous paragraph that a linear current rise would be produced in an inductance if the resistance in series with the coil could be reduced to zero, or very nearly to zero. Since the time constant for such a circuit is L÷R, if R is extremely small, approaching zero, then the time constant becomes very large. Under these conditions, a sawtooth waveform of current can be forced thru an inductive circuit. Some systems depend upon this fact in order to produce a sawtooth of current in the deflecting coils. The schematic diagram for such a system is shown in Fig. 36 where the deflecting coils are coupled to the output tube by means of a step-down transformer. Both the deflecting coils and the secondary of the transformer have comparatively few turns of wire and, therefore, the resistance is low so that the load presented to the output tube has a very large ratio of inductance to resistance; in other words, a very large time constant.

Fig. 37 shows the multi - vibrator sawtooth generator coupled to the vertical deflecting yoke by means of transformer coupling. The output of the multi-vibrator is a sawtooth of fair linearity when the choke in the discharge circuit is left out. (Fig. 25E) An additional stage of amplification is required as the output of the multi-vibrator is considerable lower than that of the blocking tube oscillator and gas triode type sawtooth oscillators. The bias of the amplifiers is made variable so that the curvature of the lower part of the grid voltage, plate current characteristic can be used to neutralize part of the curvature in the sawtooth produced by the multi-vibrator. The high frequency filter in the grid circuit of the output tube is to further increase the linearity of the sawtooth. This is CR in Fig. 37.

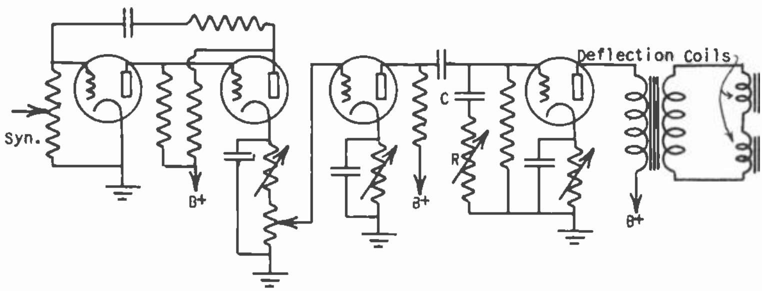


Fig. 37 Complete deflecting circuit driven by multi-vibrator.

We stated in the early part of this lesson that an amplifier had to have a frequency response flat for a frequency range from the fundamental through the tenth harmonic of the sawtooth frequency if the ratio of scan to return time is 9 to 1. In other words, a sawtooth consists of all the harmonic frequencies of the fundamental through the tenth harmonic combined with the fundamental with proper amplitude and phase. The sawtooth produced by the multi-vibrator when the choke in the discharge circuit is omitted has more than the required amplitudes of the harmonic frequencies to produce a good sawtooth. The filter in the grid of the output tube is adjusted so that enough of the high frequency components are by-passed so that the resulting waveform is a good sawtooth. The filter also compensates for poor low frequency response of the amplifier. This filter is unnecessary with the circuit for the horizontal or line frequency deflection.

It is not convenient to use the multi-vibrator with deflecting yokes containing considerable resistance, since there is no simple method of adding the impulse component to the sawtooth as in the other sawtooth generator.

14. KIPP OSCILLATOR SAWTOOTH GENERATOR. Another type of oscillator that is used to magnetically deflect the beam of a cathode ray tube is the Kipp oscillator. Fig. 38 shows a diagram of the Kipp oscillator. The circuit requires only one tube instead of the three required by the blocking tube oscillator circuit (two are actually used, since a double triode is used for the oscillator tube and discharge tube).

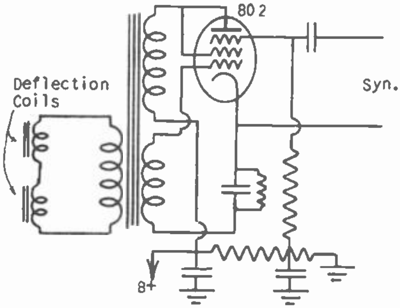


Fig.38 Kipp oscillator sawtooth generator.

Fig. 39 shows a simplified circuit of the Kipp oscillator. It is an over coupled oscillator; that is, the voltage induced in the grid circuit is far greater than that necessary to maintain sustained oscillations. The time constant of the plate circuit, Lp÷(RL + Rp) is very large. RL is the resistance of Lp, and Rp is the plate resistance of the tube. At the beginning of oscillation the grid bias will be zero and the plate current will rise at a rate determined by the time constant of the plate circuit. Since this time constant is very large the plate current rise will be linear. This linear plate current rise will induce a constant positive voltage on the

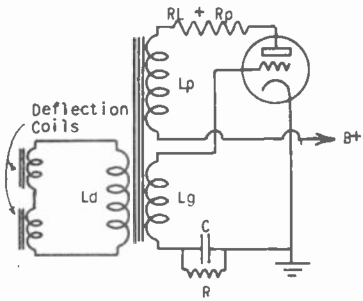


Fig.39 Simplified circuit of Fig. 38.

grid of the tube. This will lower the value of Rp and will increase the time constant of the plate circuit and, therefore, the linearity of the plate current rise. The positive grid voltage will cause a flow of grid current which will charge the condenser C. The voltage developed across C will apply a negative voltage on the grid. The grid current will not be constant but will increase at a rate determined by the time constant of the grid circuit Lg÷Rg where Rg is the input resistance of the tube. When the plate current reaches its maximum value which is determined by the plate supply voltage, plate resistance, and the resistance of the inductance, it stops increasing and, therefore, the positive voltage induced into the grid circuit drops to zero. The negative voltage applied to the grid due to the charge on C will immediately reduce the flow of plate current. The reduction in plate current will induce into the grid circuit an additional negative voltage which will cause a further reduction in plate current. This will continue until the plate current is reduced to zero. The plate current will remain at zero until C discharges through R. Then the cycle will commence again. The reduction of the plate current to zero occurs at a very rapid rate because the negative voltage applied to the grid of the tube increases the plate resistance Rp. This causes a big reduction in the time constant of the plate circuit. The plate current is zero for an extremely short time. The factor controlling the interval that the plate current is zero is the time constant of the CR circuit in the grid circuit of the tube. This is made very small.

The plate current of the oscillator has a sawtooth form. This causes a sawtooth of current to flow through the deflecting coils coupled to the winding Ld. The scan part of the cycle occurs during the slow linear plate current rise and the fly back occurs during the rapid plate current fall. The frequency of the sawtooth depends practically entirely upon the design of the oscillation transformer. The frequency can be controlled to a small extent by varying the time constant of the CR circuit since this controls the time that the plate current is zero.

Synchronizing is introduced into the tube by means of a separate grid. (Fig. 38) For satisfactory operation, this grid must have very little influence on the plate current. One of the available tubes that will operate efficiently in this circuit is the 802. The screen is connected to the plate and the synchronizing impulses are impressed on the suppressor grid. The suppressor is operated at a small positive voltage. The polarity of the synchronizing impulses is positive since a positive pulse will initiate the plate current rise at the start of the cycle. For positive synchronization, the oscillator must be slightly slower than the frequency of the synchronizing impulses.

The Kipp oscillator is never used for the frame or vertical frequency because the required transformer is too bulky.

EXAMINATION QUESTIONS

INSTRUCTIONS. Before starting to answer these examination questions, you should have studied the lesson material at least three times. Be sure that you understand each question--then proceed to write the best answer you can. Make all answers complete and in detail. Print your name, address, and file number on each page and be neat in your work. Your paper must be easily legible; otherwise, it will be returned ungraded. Finish this examination before starting your study of the next lesson. However, send in at least three examinations at a time.

1. How can a cathode ray tube be used to reproduce a television picture?

2. Give five requirements that a cathode ray tube suitable for television picture reproduction must have. Explain each briefly.

3. Give four things which cause a reduction in contrast of the picture. Explain each briefly.

4. Why is it necessary for the bias on the grid of a television cathode ray tube to vary during the reproduction of a picture?

5. What is the difference between the high voltage power supply used with a cathode ray tube designed for magnetic deflection and that used for a tube designed for electrostatic deflection? Explain each briefly.

6. What are the characteristics that a deflecting circuit should have?

7. What is the function of the blocking tube oscillator section in Fig. 23?

8. Explain briefly the operation of the multi-vibrator.

9. Why must the deflecting plates of a television cathode ray tube be fed through a push-pull output stage on the sawtooth oscillator?

10. What is the grid voltage waveform required to produce a sawtooth of current in the plate circuit of a tube when the load contains resistance and inductance?

Apparent Line Width: The apparent line width (the visible or recorded width of the moving spot) can be different from the apparent spot size of the stationary spot because screen luminescence is dependent upon the duration of excitation.

Apparent Spot Size: When the spot size is measured visually or from a photographic record, the resultant spot size is not necessarily the true spot size; therefore, the terms "apparent spot size" or "apparent spot diameter" should be used in such cases.

Beam Current: The current in the electron beam at the screen, usually measured in microamperes.

Beam Voltage: The instantaneous voltage of the electron beam at any point; usually referred to as the voltage of the beam at the point of deflection, where the beam voltage is substantially the same as the second anode voltage.

Candle Power-Distribution Characteristic: This characteristic shows how the candle power of a luminescent screen varies when the screen is viewed at different angles. When plotted it is invariably represented by a polar curve illustrating the luminous intensity of a cathode ray tube in a plane of the tube axis and with the screen at the origin.

Deflection Sensitivity (Electrostatic): The ratio of the distance which the electron beam moves across the screen to the change in potential difference between the deflection plates; this is usually expressed in millimeters per volt. The sensitivity varies inversely with the beam voltage at the point of deflection.

Deflection Sensitivity (Magnetic): The ratio of the distance which the electron beam moves across the screen to the change in the flux density producing the motion. The sensitivity may be expressed in millimeters per gauss, but due to the difficulty in the determination of flux density, it is often more practical to express the sensitivity in millimeters per ampere-turn, or simply in millimeters per ampere. It varies inversely as the square root of the beam voltage at the point of deflection.

Defocused: A term used to describe a spot which is not optimum with respect to shape and size.

Efficiency, Gun-current: The ratio of the beam current which leaves the cathode. This ratio, multiplied by 100, gives the gun-current efficiency in per cent.

Efficiency, Screen Actinic: The measure of the ability of a viewing screen to convert the electrical energy of the electron beam to radiation which affects a certain photographic surface. This term should be expressed in microwatts per watt, but is often expressed for ease of measurement in terms of actinic power per watt relative to a screen of well known characteristics.

Efficiency, Screen Luminous: The measure of the ability of a viewing screen to produce visible radiation from the electrical energy of the electron beam. The efficiency should be measured in lumens per watt. For convenience of measurement, however, it is usually expressed in candle power per watt, because candle power is a measure of the luminous flux per unit solid angle in a given direction and can be converted to lumens where the candle power-distribution characteristic of the screen is known. It is the usual practice to measure candle power in the direction normal to the screen.

Efficiency, Screen Radiant: The measure of the ability of a viewing screen to produce luminescence from the electrical energy of the electron beam. The efficiency should be expressed in microwatts per watt, but due to the difficulty of making absolute measurements is more often expressed in radiant energy per watt relative to some screen of well-known characteristics.

Fluorescence: The luminescence emitted by a phosphor during excitation. As applied to a cathode ray tube, this term refers to the radiation emitted by the viewing screen during the period of beam excitation.

Line Width: The true width of the moving spot measured at right angles to its direction of motion.

Luminescence: The term describing all forms of visible and heat - visible radiation which depart widely from the black - body radiation law. It can be divided according to the means of excitation into many classes, such as: candoluminescence--the luminescence of incandescent solids: photoluminescence--the luminescence created by exposure to radiation; chemi-luminescence--the luminescence created by chemical reactions; electro - luminescence--the luminescence given off by ionized gas; bio - luminescence--the luminescence emitted by living organisms; tribo - luminescence--the luminescence created by the disruption of crystals; crystallo-luminescence--the luminescence excited by emissions from radio-active materials; galvano - luminescence--the luminescence phenomena observed at electrodes during some electrolysis; cathode-luminescence--the luminescence produced by the impact of electrons, etc. In cathode ray tubes, cathode-luminescence is principally involved; therefore, the luminescence of the screen is that radiation which is produced by the impact of the electron beam.

Luminescent Spot: The spot formed on the screen of a cathode-ray tube at the impact point of the focused electron beam.

Pattern Distortion: When the electron beam is moved by changing fields, a pattern is formed on the screen; the waveform of the spot movement will be identical with the resultant waveforms of the electrical phenomena producing these fields unless there is pattern distortion present. This distortion takes many forms, such as: amplitude, frequency, phase, brightness, persistence, spot size, etc.

Persistence Characteristic: The relation showing brilliance of light emitted by a cathode ray tube screen as a function of time after excitation. This characteristic is generally shown in a curve where relative brilliance as the ordinate is plotted on a logarithmic scale against time on a linear scale. "Relative brilliance" is used to denote luminous intensity per unit area evaluated in arbitrary units.

Phosphor: The solid material in the screen which produces luminescence when excited by the electron beam.

Phosphorescence: The luminescence emitted after excitation. As applied to a cathode ray tube, this term refers to the radiation which persists after the electron beam excitation has ceased.

Spectral Characteristic: The relation between the radiant energy per element of wavelength and each wavelength of the spectrum. It is generally shown in a curve plotted with relative radiant energy against wavelength in angstroms, microns, or millimicrons. "Relative radiant energy" is expressed in arbitrary units of radiant energy.

Spectral Characteristic, Actinic: The relation between the energy per element of wavelength which affects a certain photographic surface, and each wavelength of the spectrum. This is generally shown in a curve plotted with relative actinic energy against wavelength in angstroms, microns, or millimicrons. "Relative actinic energy" is obtained by multiplying the relative radiant energy values (taken from the screen's spectral characteristic) for each wavelength by the relative sensitivity of a given photographic surface at that wavelength.

Spectral Characteristic, Visual: The relation between the luminous energy per element of wavelength and each wavelength of the spectrum. It is generally shown in a curve plotted with relative luminous energy against wavelength in angstroms, microns, or millimicrons. "Relative luminous energy" is obtained by multiplying the relative radiant energy values (taken from the screen's spectral characteristic) for each wavelength by the relative response of the eye at that wavelength.

Spot Diameter: The term used to express the true size of a round spot.

Spot Distortion: A term used to describe the condition of a spot which is not optimum with regard to shape.

Spot Size: The true dimension or dimensions of the spot. Spot size may be measured under various conditions, and is commonly designated by such names as "spot diameter" or "line width." When the spot is stationary its size can be measured in any direction, but is usually determined by its dimensions along the longest and shortest axes.

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UNIT NO. 5

TELEVISION R. F. CIRCUIT DESIGN

LESSON NO. 8

CONCENTRATED ENERGY

.....obstacles and problems fade before it.

Sunshine is essential to the life of man and animal alike. Without it, we would fade away and die. It warms our bodies and makes plant life possible. It draws moisture from the earth into the air so that rain may fall over our land. How fortunate we are to be blessed with the sun.

But what a different story we have when the rays of the sun are concentrated. A magnifying glass concentrates several inches of sunshine into a tiny point of light. When this tiny spot of light falls on our hand, it burns ...it will set buildings and dry fields on fire. By using a larger glass, the point of light becomes so hot that it will burn its way through steel.

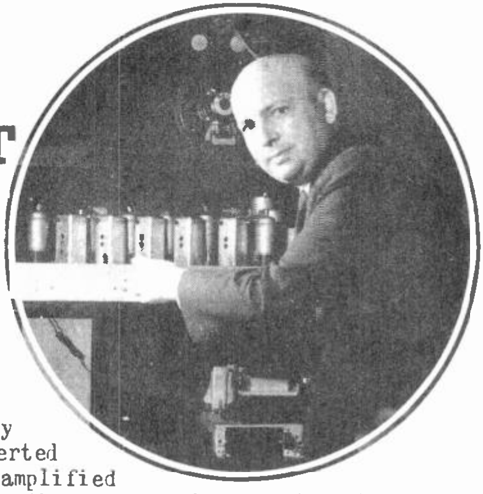
Your energy may in many ways be compared to the rays of the sun. If you spread this energy over many different interests and activities, you may have a good time, but you will merely warm the surface. Nothing worth-while will be achieved.

But....when you concentrate your energy and focus it on ONE OBJECTIVE, its flaming force will burn through all obstacles and problems that may confront you.

You are now applying your energies to the fascinating study of television. You hope to reap the rich rewards that this amazing scientific development has placed before you. Therefore, to reach your goal you must concentrate your energies on one single point....television. If you will do this, your progress will be rapid and you will come through, a winner.

Lesson Eight

TELEVISION R.F. CIRCUIT DESIGN



"Modern television receivers present some unusual problems. In this lesson you will take up the study of how the signal picked up by the antenna is amplified, converted to an intermediate frequency, amplified again, and then detected. Also the process of separating the sound signal from the video signal is covered thoroughly.

"I hope that you will attach the proper significance to this lesson so that you will give it enough time to master its contents."

1. TELEVISION RECEIVER REQUIREMENTS. In previous lessons, you have studied many of the fundamentals of television. We now come to a point where we are ready to utilize this information in the study of television receivers.

Before going into this, however, it might be well to learn first some of the many problems involved, and thereby be prepared to understand and appreciate the subject as a whole. There are two fundamental facts upon which the whole possibility of television depends. These are: first, with our present knowledge, it is not practicable to transmit the picture as a whole; second, as in the case of motion pictures, television also depends upon the well-known "persistence of vision" effect.

The fact that we cannot transmit a television picture as a whole as done in the broadcasting of sound is the source of many television problems. You have already studied scanning, but it is such an important process that, by way of review, we are going to repeat the reason why this operation is so necessary. Briefly, the problem of transmitting a picture is actually three dimensional; that is, it must have length, breadth, and depth, or in place of depth we call it "intensity." Now, a single radio channel is capable of transmitting only two dimensional intelligence; that is, the intensity of the signal and the duration of this signal. Then, in order to transmit the conception of an area, it is necessary to reduce the picture to a succession of single dimensional signals. Hence, we explore or scan the picture area element by element and line by line in some very logical order in such a brief interval of time as not to be detectable by the human eye. *It is this rapid repetition that makes necessary the extremely high frequencies involved in television.* In previous lessons, you have seen how this factor affects the width of the band of frequencies required to transmit a television picture. Other important factors will be brought out when we study video circuits in a later lesson.

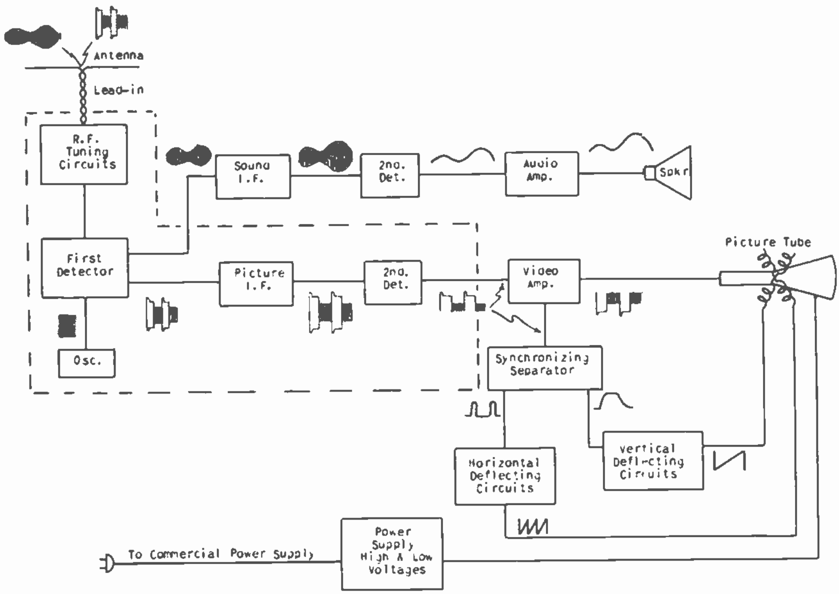


Fig. 1 Block diagram of a television receiver, showing waveforms.

A television receiver differs somewhat from a common radio receiver in that it is actually two receivers combined; first, the sound receiver and, second, the video (picture) receiver itself. While it is entirely possible to have a receiver containing the necessary equipment to receive the picture signal only, or a separate receiver that would accept the television sound signal only, yet neither is complete without the other. Hereafter, any general reference made to the television receiver will include both sight and sound. (A typical television receiver is shown in the block diagram in Fig. 1.)

This brings us immediately to the fact that the television receiver in its entirety has many problems not encountered in regular sound receivers used in normal broadcast reception. In the first place, two signals, instead of one must be received simultaneously. In order to simplify the operation of the receiver, it is highly desirable that no more than one control be used in tuning both sound and picture. Since we are accustomed to tuning in sound stations on our radio sets, it is desirable that a similar procedure be followed in tuning a television set. For example, tune the set to the sound carrier of the station you wish to hear and, once the sound is tuned correctly, the desired picture will appear on the screen simultaneously. In order to accomplish this simplified tuning, certain provisions and allocations must be made in the selection of the R.F. carriers (sight and sound) and their relative positions in the transmission band. This we shall look into presently.

Since the high video frequencies involved in the transmission of a high definition picture have made it necessary to set aside the television band in a range of frequencies above 30 megacycles, we will be in a region practically free of natural static. However, man-made interference, such as caused by sparking brushes in electrical machinery or the spark plugs of an airplane or automobile, etc., can be a source of annoyance. Unfortunately, the use of wide frequency bands causes the receiver to be more susceptible to this type of interference than are our more selective receivers used for radio broadcast reception. This fact points to the necessity of having a strong signal reach the antenna of the receiver. Therefore, it follows that the circuits of a television receiver may be somewhat less sensitive than those used in ordinary broadcast reception.

With the foregoing facts in mind, let us investigate some of the general performance characteristic requirements, insofar as the R.F. portion of the receiver is concerned. First, with average R.F. signal, the sensitivity of the receiver should be such that it is possible to reach the level where noise and interference become annoying when the receiver volume control is turned to maximum. Second, the receiver selectivity should be as great as would be consistent with economic practice; that is, satisfactory selectivity should be obtained with the least number of tuned circuits possible.

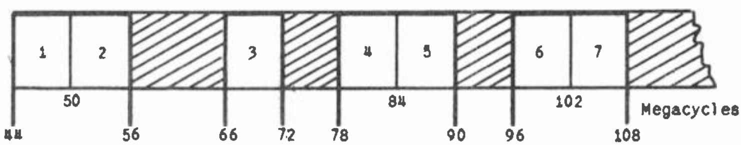


Fig. 2 Television channel allocations.

Third, tuning and I.F. circuits must pass the extremely wide picture frequency band and at the same time deliver sufficient signal for satisfactory detector action. Fourth, since the frequency band is available, the sound circuits should pass a band sufficiently wide that the R.F. section will in no way limit the final reproduction of really high fidelity sound.

2. BAND WIDTH REQUIREMENTS. In this lesson we shall consider only that portion of typical television receivers between the antenna input and the second detector output.

One of the first things to investigate is the total band of frequencies which a receiver will be required to tune if it is to receive the signals of different stations in the television band. In Fig. 2 are shown the television channels located in the frequency spectrum lying between 44 and 108 megacycles. Additional television bands have been set aside between 108 and 300 megacycles which will, no doubt, form the basis for future development. It will be noted that the band between 44 and 108 is not continuous for television service. Insofar as the manufacturer of receivers is concerned, it is highly desirable to have this a single continuous television band, but the Federal Communications Commission has decreed that, since the amateurs are already occupying the band immediately above 56 megacycles, they be allowed to retain that particular band. Also, the government has reserved a portion of the frequency spectrum immediately above the amateur band as well as two additional bands, one from 72 to 78, and the other from 90 to 96 megacycles for their own use. On the present basis of a 6 megacycle channel for television and voice reception, seven channels below the 108 megacycle band are made available for television work.

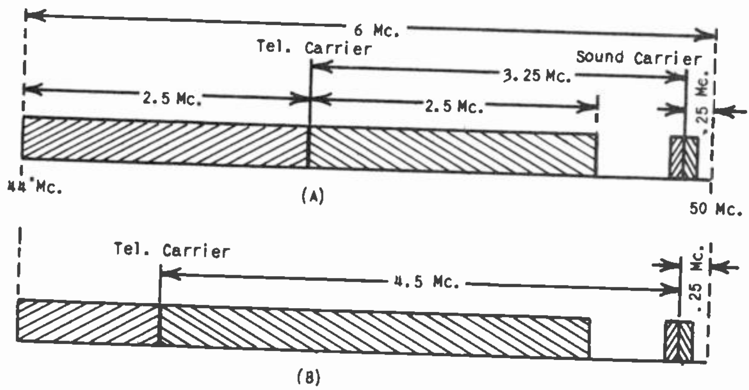


Fig.3 Details of a single television channel.

In Fig. 3A is shown a more detailed description of a single television band. In this spectrum of 6 megacycles, it is seen that the transmitted television signal itself will occupy a span of 5 megacycles; that is, 2.5 megacycles on each side of the television picture carrier. It will be noted that the sound carrier is approximately 3.25 megacycles above the picture carrier. This leaves a .75 megacycle guard band between the maximum frequency of the upper television sideband and the sound carrier. The .25 megacycle spread on the upper side of the sound carrier provides ample room for the upper sound sideband plus .15 megacycle (or better) separation from the adjoining channel. The amount of this separation will depend, of course, upon the ultimate choice of frequencies desirable for high fidelity sound reception. While, with a few exceptions, our present sound broadcasting stations may not utilize more than a 5,000 cycle sideband, it is conceivable that, with the band width

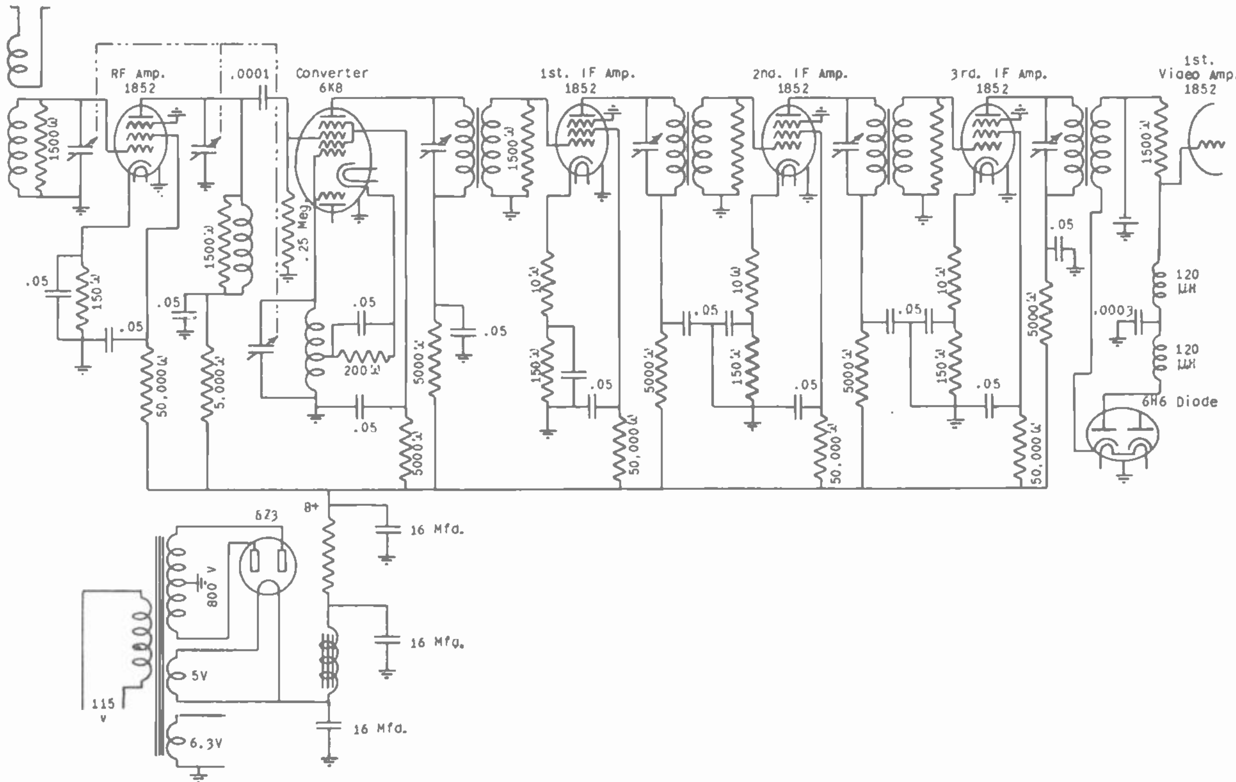


Fig. 4 Circuit diagram of an inexpensive picture receiver from antenna through second detector (no sound).

made available in television work, this frequency limit may be extended somewhat.

3. RECEIVER CIRCUITS. Since the complete signal to the television receiver consists of the picture carrier with its sidebands and the sound carrier with its sidebands, it is entirely possible to design a very simple picture receiver for the reception of the picture signals only. Likewise, a separate receiver could be built to receive the sound. The circuit for such a picture receiver alone is shown in Fig. 4 and includes the wiring diagram up through the second detector. This is more or less a conventional superheterodyne circuit. In this particular case, the superheterodyne circuit is used because it represents current commercial practice and is capable of greater stability than a tuned R.F. circuit of equal gain. Although the superheterodyne gives rise to tracking problems and requires the designing of wide band I.F. transformers for the video channel, yet these problems are no worse than the tendency of tuned R.F. stages to oscillate and the complications resulting from ganged tuning condensers for the large number of R.F. stages that would be required.

The tuning range covered by this receiver is approximately 45 to 108 megacycles. The intermediate frequency is 13 megacycles and the transformer secondaries are heavily loaded by a 1500 ohm resistance. Although this results in a lowering of the stage gain, yet the loading is necessary if we are to have a sufficiently wide bandpass for the television signal.

Of course, the television picture will be of little use without the accompanying sound and with this particular type of circuit, it would be necessary to have a separate sound receiver which would tune to the sound carrier.

Present standards require that each of the seven television channels be divided exactly as that shown in Fig. 3A. Obviously, such an arrangement has a distinct advantage from the standpoint of satisfactory reception and simplicity of receiver construction. In the first place, since the sound and television signals are adjacent in the frequency spectrum, they should have practically identical properties and characteristics; that is, both carriers would be affected very much in the same manner during the process of transmission between the transmitter antenna and the receiver antenna. Another thing, since in each channel there is a fixed separation between the two carriers, that is, the picture and the sound (the sound always occupying the higher frequency region), it becomes possible to simplify tuning as previously suggested so that a single control will tune in both sound and picture simultaneously. One method for accomplishing this result is interesting and comparatively simple. Figs. 5 and 6 show the block diagram as well as parts of the circuit diagram of a receiver whose R.F. circuits accept both the picture and sound carriers. This particular receiver is designed to cover the three lowest television channels. While the design is based on double sideband transmissions with a 2.5 megacycle picture sideband, this circuit could be readjusted for single sideband transmission so as to receive a much wider band of video signals without any constructional changes. In this type of receiver, the single R.F. stage and converter accepts both carriers at the same time and converts them to two intermediate frequencies having the same separation as the original broadcast carriers; that is, 3.25 megacycles.

There are some factors which enter into the choice of the correct heterodyne oscillator frequency which should be considered at this time. If the oscillator is worked at a frequency which is higher than either that of the picture or sound carrier, the sound I.F. will be lower than that of the picture. This naturally follows, since the difference between the sound carrier and the oscillator frequency is less than the difference between the oscillator frequency and that of the picture carrier. In the plate circuit of the detector, then, the picture I.F. frequency will be 3.25 megacycles higher than the sound frequency. Now, as an example, suppose the oscillator is adjusted to a frequency 13 megacycles above

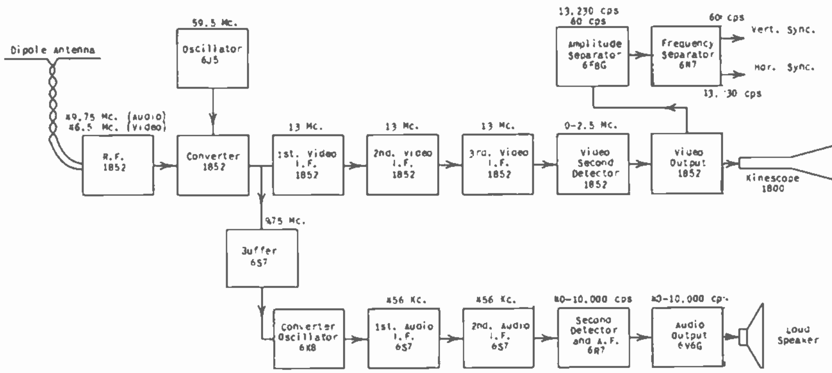


Fig.5 Detailed block diagram of a complete television receiver, using two converter tubes.

the video carrier and, if the video carrier be 2.5 megacycles above the lower side of a television channel, such as the 44-50 megacycle channel, this would place the video carrier at 44 + 2.5 or 46.5 megacycles. Then, the oscillator frequency would be 46.5 + 13 or 59.5 megacycles. As we have seen, the audio carrier is 3.25 megacycles above the video carrier, causing it to fall at 49.75 megacycles in this particular channel. If then, the oscillator frequency of 59.5 is heterodyned with the sound carrier frequency of 49.75 megacycles, we shall have 9.75 megacycles for the audio I.F. The choice of this oscillator frequency was not purely accidental, but rather the result of careful consideration. If we choose a high I.F. for the picture, a more favorable image frequency response ratio will result. However, a point will be reached, as we go up in I.F. frequencies, where it will be difficult to make our circuit sufficiently selective for the sound signals. Then, there are practical considerations, such as the construction of the I.F. transformers and circuit regeneration. Another factor to be considered in the choice of the I.F. band is the possibility of interference from other radio services; for example, there are two amateur bands, one at about 7 megacycles and another at 14 megacycles. Experience has taught that if we choose a picture intermediate frequency of 13 megacycles with the sound intermediate frequency 3.25 megacycles below, satisfactory results may be obtained.

Experience has also indicated it is possible to eliminate most of one of the television sidebands without greatly impairing the detail of the received picture. This will affect manufacturing economies by making it possible to obtain sufficient gain with fewer stages of amplification; at the same time, it will provide for future increases in picture definition since higher sideband frequencies may be used. (See Fig. 3B.) Naturally, the sideband having the position next to the sound carrier would be the one utilized since the tuning circuits are to accept both the picture and sound carriers. Under these conditions, then, the band of frequencies to be passed by the picture intermediate amplifier would extend from the 13 megacycle limit, down 2.5 megacycles to 10.5.

In the circuit shown in Fig. 6, the picture signal from the antenna enters first an R.F. stage employing a high mutual type tube. Such a stage is capable of a gain of about 4 or 5 at 50 megacycles with heavily loaded tuned circuits. This stage feeds a similar tube employed as a first detector where the signal is mixed with the oscillations from a separate triode oscillator. Both the video and sound intermediate frequencies appear, therefore, in the plate circuit of this mixer tube; but from this point, the video and picture signals traverse different paths. The video is passed through three stages of I.F. amplification, employing high mutual tubes and especially constructed coupling networks designed to completely eliminate all sound frequencies. A further discussion of the separation method will be given presently in the discussion of a third type of television circuit. The output of the third video I.F. amplifier is fed to a 6H6 diode detector. The sound is taken through a buffer stage consisting of a special rejector circuit and a 6K7 or 6S7 type tube. The purpose of this rejector circuit ($L_7C_1C_2$), of course, is to eliminate the picture signal from the sound. Actually, this circuit is a combination of a parallel and series tuned circuit. L_7 and C_1 are tuned to reject the video I.F. band, while L_7 and C_2 are resonated at 9.75 megacycles to accept the audio I.F. Hence, the voltage which appears across C_2 contains only the audio I.F. The input to the buffer stage is fed from this point. Now, the output of this buffer stage might be fed to several stages of I.F. amplification whose transformers have been especially designed for satisfactory operation at the I.F. of 9.75 megacycles; but in this particular circuit, a separate converter will be used in order to bring the sound I.F. within the operating range of standard audio receiver parts. The 6K8 type of converter tube gives very stable performance at 9.75 megacycles. This second converter changes the 9.75 megacycle audio I.F. to .456 megacycle or 456 kilocycles. The output of this converter is then fed to two I.F. stages and a type 6K7 double diode triode for detection, AVC, and first audio.

As shown in the diagram, tuning to the three different tele-

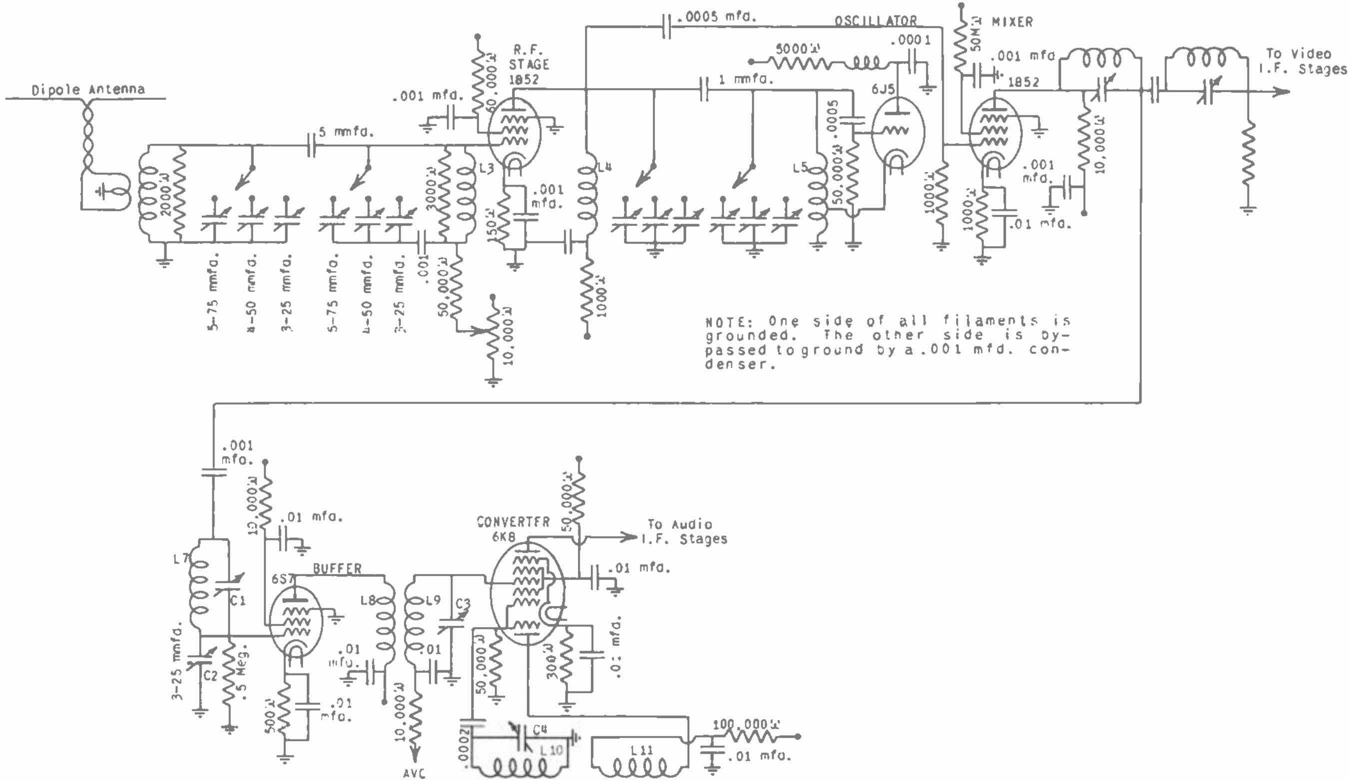


Fig.6 Television receiver input circuits. (Illustrating method of switch tuning; also sound and picture separation.

vision bands is accomplished by means of *switches*, rather than the more conventional type employing variable gang condensers. The four tuned circuits that are employed are located as follows: two between the antenna and R.F. amplifier grid, one in the R.F. amplifier plate circuit and one in the oscillator. Since this receiver is to cover three television bands, each circuit must be tuned by three condensers individually adjusted for the particular band it is to cover. Two double pole, triple throw rotary switches are used to effect the switching from one band to another.

The Garod Model 100 television receiver, mounted in a console together with an all-wave sound receiver.

It has been seen how well the superheterodyne type of receiver adapts itself to the needs of the television receiver. While other methods may be employed, this seems to be the most straightforward manner for obtaining simplified tuning. Since the picture and sound carrier bear a constant relation to each other in each of the picture channels, we have seen how it is possible to design an R.F. system sufficiently broad to accept both carriers as one and then, following a single oscillator and heterodyne detector, separate the two signals so that each is fed into its own I.F. amplifier.

In Fig. 7 is shown the R.F. and I.F. sections of an RCA combination sight and sound receiver. This particular receiver is designed to cover a tuning range of from 44 to 90 megacycles. In this receiver, a bandpass tuning circuit is used to couple the antenna to the mixer, or first detector tube. No R.F. stage is employed

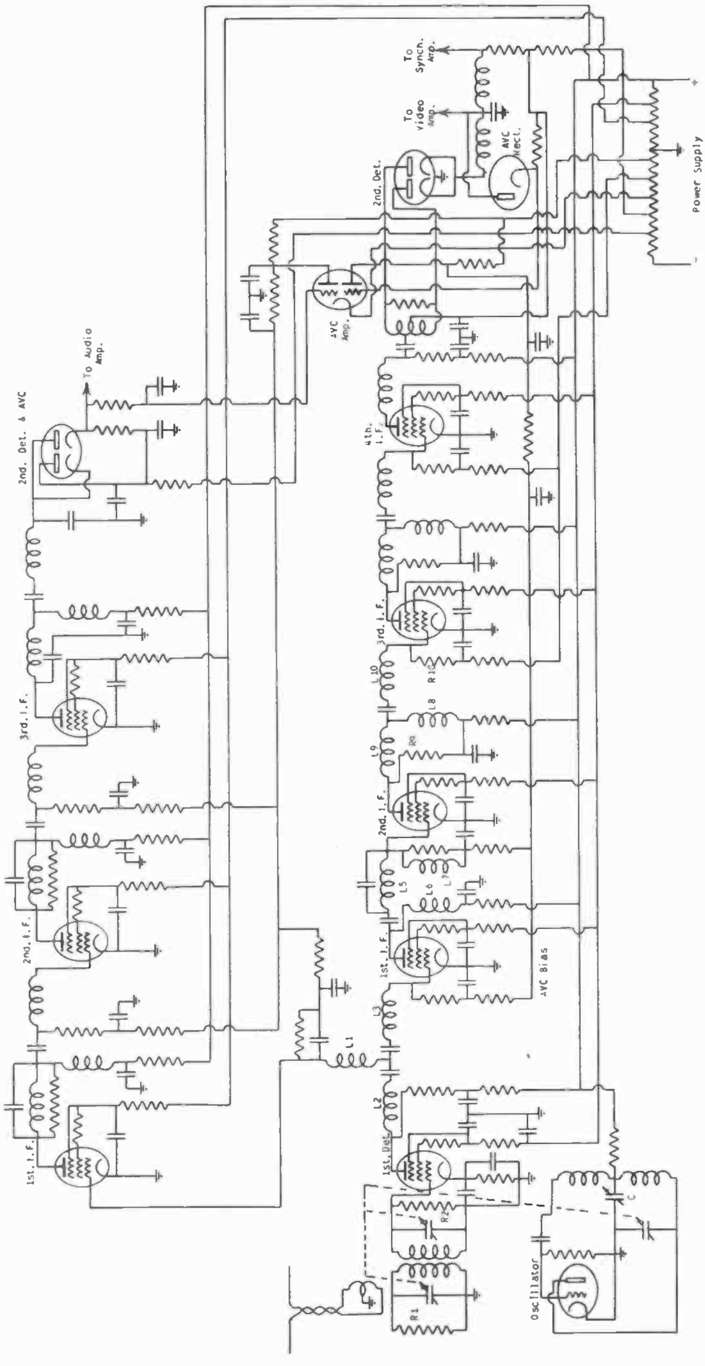


Fig. 7 RCA Television Receiver (experimental). (Also see Fig. 25).

ahead of the first detector. Such stages are usually employed to prevent image reception. Inasmuch as there will probably never be more than three television stations in any one locality, the manufacturers of this receiver did not feel that such a stage would be necessary. Adjacent channel selectivity has been secured through special design of the I.F. transformers used. Besides the use of special I.F. transformers, additional selectivity has been obtained through the design of the R.F. section.

The video intermediate frequency used in this receiver is 13 megacycles, while the sound intermediate frequency is 9.75 megacycles. A special separator circuit is used in the output of the first detector or mixer stage and a complete description of its operation will be given later on in this text. In this receiver, the sound I.F. frequency of 9.75 megacycles is maintained up to the second detector instead of using a second converter stage as described in the previous combination television receiver.

5. WIDE BANDPASS CIRCUITS: Before considering individual component circuits, we should first take up the discussion of how a tuned circuit is arranged so as to pass the wide band of frequencies necessary for television reception.

The frequency band to be passed by the tuned circuits in a television receiver is a much larger percentage of the carrier frequency than is the case for broadcast receivers. In a high-fidelity broadcast receiver, the band passed by all tuned circuits, both R.F. and I.F., has a width of 20 kc. In the R.F. section, for a frequency of 1100 kc. (the approximate center of the broadcast band), the 20 kc. band is about $\frac{1}{55}$ of the carrier frequency. For an I.F. frequency of 456 kc., the 20 kc. band is about $\frac{1}{23}$ of the intermediate frequency. In a television receiver, the bandwidth that must be passed by the tuned R.F. circuit is 6 megacycles with

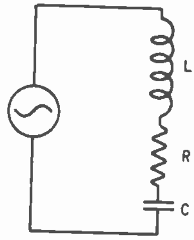


Fig.8 A series tuned circuit.

a 5 megacycle bandwidth in the I.F. stages (assuming that the R.F. section is to include both the picture and sound). However, as previously stated, good pictures can be produced when only one sideband and the carrier are passed by the receiver. Therefore, we can reduce the bandwidth that must be passed by the tuned circuits to 2.5 megacycles. For the R.F. section this constitutes about $\frac{1}{18}$ of the 46 megacycle carrier. For an I.F. of 13 megacycles, the 2.5 megacycle band constitutes about $\frac{1}{5}$ of the I.F. frequency. Thus it is seen that the tuned circuits in television receivers must pass a frequency band that is very much larger in proportion to the carrier and intermediate frequencies than is the case for a high fidelity broadcast receiver.

Let us review briefly the nature of tuned circuits, both series and parallel. *In the series tuned circuit of Fig. 8, the impedance is minimum at resonance* (the inductive and capacitive reactances are equal and opposite), and is equal to the resistance in the circuit. Below resonance, the capacitive reactance is greater, and above resonance, the inductive reactance is greater. The current through the circuit is equal to the applied voltage divided by the resistance at resonance. However, the voltages developed across the inductive and capacitive branches of the circuit are equal to the current multiplied by the inductive reactance and capacitive reactance respectively. Since in a well-designed tuned circuit the resistance is very low in comparison to the reactance present, the voltages developed across the inductive and capacitive branches are

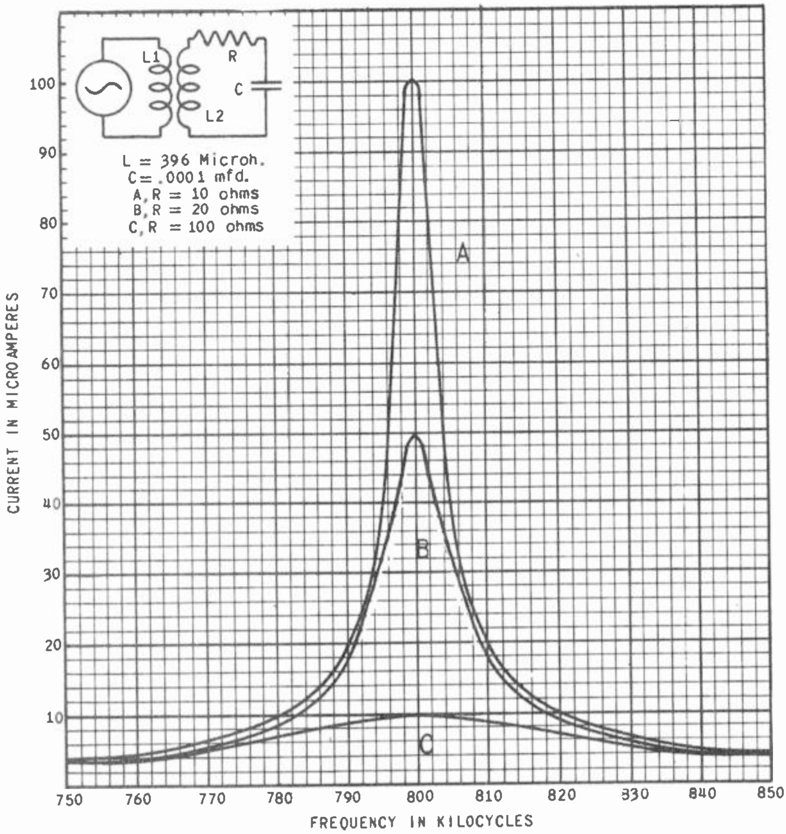


Fig. 9 Selectivity curves.

very much larger than the applied voltage. The ratio of either of these voltages to the applied voltage is termed the "gain of the tuned circuit" (Lesson 22, Unit 1). Since these voltages are proportional to the current, which is inversely proportional to the resistance, the gain of the tuned circuit is inversely proportional to the resistance. Curve A in Fig. 9 shows the magnitude of the current through a series tuned circuit when the frequency of the applied voltage is varied above and below resonance. We call such curves "selectivity curves." B and C are selectivity curves for the same circuit when the resistance is multiplied by 2 and 10 respectively. With the resulting decrease in current, the gain will be reduced. Also, as the resistance is increased, the ratio of the current for frequencies off resonance to the current at resonance does not decrease so rapidly as for lower values of series resistance. We say the curves B and C show less selectivity than A; that is, they are unable to reject frequencies higher and lower than the resonant frequency. Such circuits will, therefore, pass a wider band of frequencies than will the circuit represented by curve A.

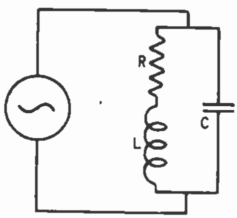


Fig. 10 A parallel tuned circuit.

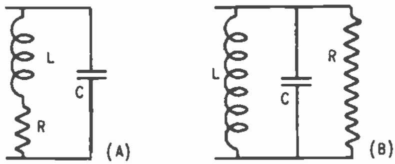
In the parallel tuned circuit shown in Fig. 10, the impedance is maximum at resonance; therefore, the current is at a minimum. This is the reverse of a series tuned circuit. The reactance of the circuit is inductive for frequencies below resonance and is capacitive for frequencies above resonance. This, again, is the reverse of series circuit conditions. If the voltage across a parallel tuned circuit is plotted against frequency, a set of curves similar to Fig. 9 are obtained. The selectivity is greatest or the voltage is maximum when the resistance in the tuned circuit is at a minimum. (See equation, Lesson 22, Unit 1.)

The bandwidth passed by tuned circuits with different resonant frequencies, but with the same LC ratio and resistance, is directly proportional to the resonant frequency. If for a given tuned circuit the inductance and capacity are both halved, the resonant frequency is doubled ($F = 1 \div 2\pi\sqrt{LC}$), and the impedance of the circuit remains unchanged. Therefore, the curves in Fig. 9 can represent the resonant curves for a tuned circuit containing 198 microhenries and .00005 mfd. if the frequencies are doubled. Then for each value of resistance, the frequency band passed will be doubled. Therefore, ordinary tuned circuits operating on 46 megacycles and 13 megacycles will pass a frequency band 42 times and 28 times as wide as those operating on 1100 kc. and 456 kc. However, these wider bands are not sufficient for good television reception.

You are well acquainted with the fact that when tuned circuits are used in several stages of amplification, the selectivity is increased. In other words, the bandwidth is reduced as it passes through each succeeding stage of amplification.

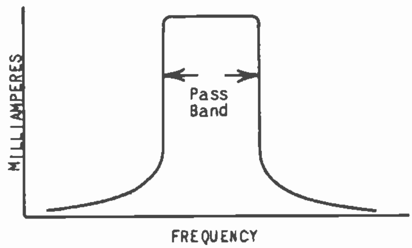
In the cheaper broadcast receivers, the bandwidth passed is from 6 to 10 kc. (including both sidebands). A receiver passing a 10 kc. band is considered good from the standpoint of fidelity. Because of the 10 kc. spacing in the broadcast band, there must be a compromise between fidelity and selectivity. Some of the better broadcast receivers are equipped with fidelity controls which change the bandwidth passed by the tuned circuits. For local reception where selectivity is not important, these controls can be set for a bandwidth of from 10 to 20 kc.

Fig. 11 Suggested methods for obtaining wide band pass. (A) series resistance; (B) parallel resistance.



Since television reception demands that a wide band of frequencies be passed, we are interested in learning how this is accomplished. One method is to add resistance to the tuned circuit as suggested by the results shown in the resonance curves in Fig. 9. This resistance can be connected in series or parallel with the tuned circuit as shown in Fig. 11. For the series connection, the resistance is many times smaller than that required by the parallel connection to produce the same change on the resonance curve. The reason for this is that all the circulating current passes through the resistance.

Fig. 12 Ideal band pass curve.



Adding resistance to a tuned circuit is not the most satisfactory method of increasing the bandwidth. The greatest objection to the use of resistance for widening the frequency response of a tuned circuit is that the boundaries of the band passed are not sharp nor the response uniform over the band passed. (See curves B and C, Fig. 9.) Thus, there is a very pronounced reduction in selectivity. The ideal bandpass curve should have the form shown in Fig. 12. Another objection to the use of resistance is that it reduces the circuit gain. This method of increasing the bandwidth cannot be used on the broadcast band where stations are separated by 10 kc. and where the signal intensities are such that the receiver has to select one out of a dozen or more signals. Also, the reduced gain per stage would increase the cost of the receiver.

The method used in the I.F. amplifiers of broadcast receivers to increase the bandwidth is to close-couple the tuned circuits in the I.F. transformer. Fig. 13 shows an ordinary I.F. transformer

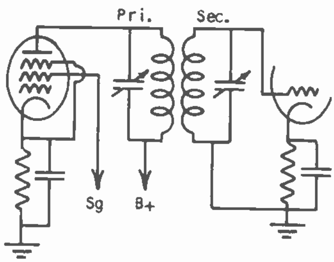


Fig. 13 Ordinary transformer I.F. coupling (sound).

coupling the two tubes. Fig. 14 shows the frequency response curve for such a transformer as the coupling is increased. We see that as the coupling is increased, the frequency band passed by the transformer is increased and also that the single peak separates into two peaks. This separation becomes more pronounced as the coupling is increased. Curve B of Fig. 14 shows a very satisfactory bandpass for a high fidelity broadcast receiver. (The bandwidth is 20 kc.) It has been stated that the 20 kc. bandwidth constituted 1/23 of the I.F. frequency of 456 kc. for broadcast receivers and that the 2.5 megacycle bandwidth constituted about 1/5 of the 13 megacycle

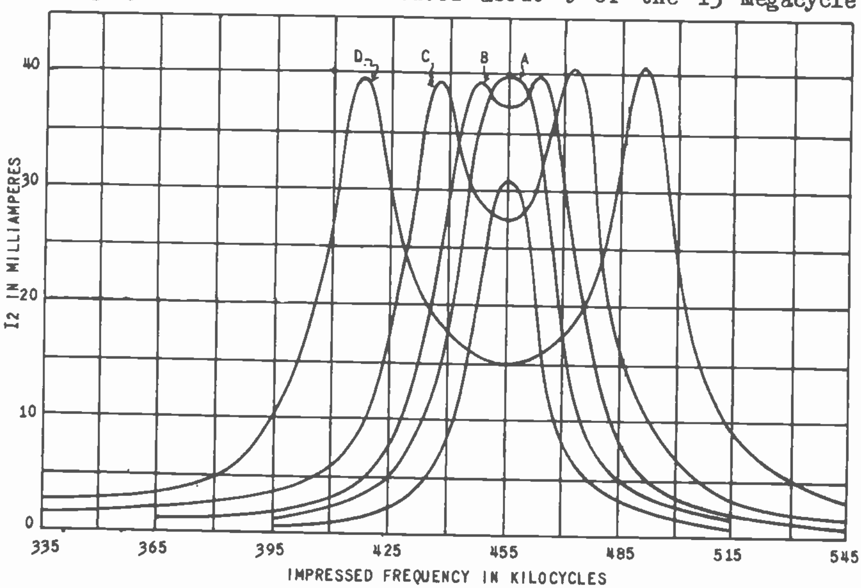
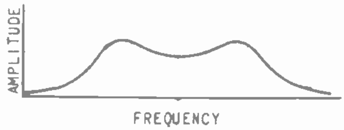


Fig. 14 Selectivity curves showing the effect of close coupling primary to secondary of I.F. transformer.

I.F. frequency for a television receiver. To obtain a bandwidth that is $\frac{1}{5}$ of the I.F. frequency will require very much closer coupling than for a bandwidth of $\frac{1}{23}$. Curve D in Fig. 14 represents, approximately, a pass band of 90 kc., which is about $\frac{1}{5}$ of the 456 kc. I.F. frequency. This curve is entirely unsatisfactory because the response is not uniform over the pass band. We would have identically the same kind of curve for a 13 megacycle I.F. transformer coupled closely enough to pass a 2.5 megacycle band. With

Fig. 15 Response curve of close-coupled tuned circuits loaded with resistance.



close-coupled I.F. transformers, the reaction of one circuit on the other makes tuning of the two sections a difficult process. The frequency response over the pass band can be made uniform by loading the tuned circuits with resistance. Fig. 15 shows the response curve of close-coupled tuned circuits when loaded with resistance. The selectivity and gain of resistance loaded close-coupled tuned circuits is superior to that of a simple tuned circuit loaded with resistance.

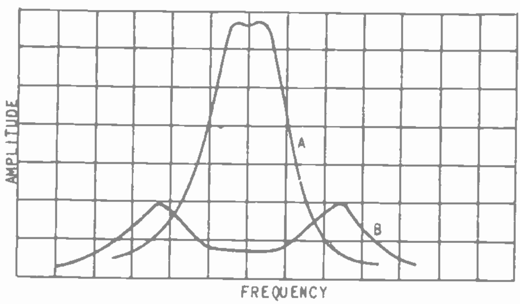


Fig. 16 I.F. response curves; (A) Primary and secondary, each tuned to I.F. frequency; (B) Effect obtained by detuning both primary and secondary of (A).

One method formerly used to obtain a bandpass effect in sound receivers is to tune the primary of the I.F. transformer to 5 to 10 kc. on one side of the I.F. frequency, and the secondary to 5 to 10 kc. on the other side of the I.F. frequency. Fig. 16 shows the frequency response of such an I.F. stage when both sides are tuned to the I.F. frequency (A) and the bandpass effect obtained by detuning on both sides of the I.F. frequency (B). When Fig. 16 is compared to Fig. 14, we see that detuning is inferior to close coupling for obtaining a bandpass effect since the gain is reduced when the primary and secondary are detuned.

The objection to the close-coupled bandpass circuit just described is the interaction of the two circuits when tuning adjustments are made. When two tuned circuits are inductively coupled, the coupling takes place through the mutual inductance of the two coils. The coupling impedance forms a part of the reactive element of each of the tuned circuits. When tuning adjustments are made on one circuit, the impedance transferred to the other through the coupling is sufficient to change the tuning of the other.

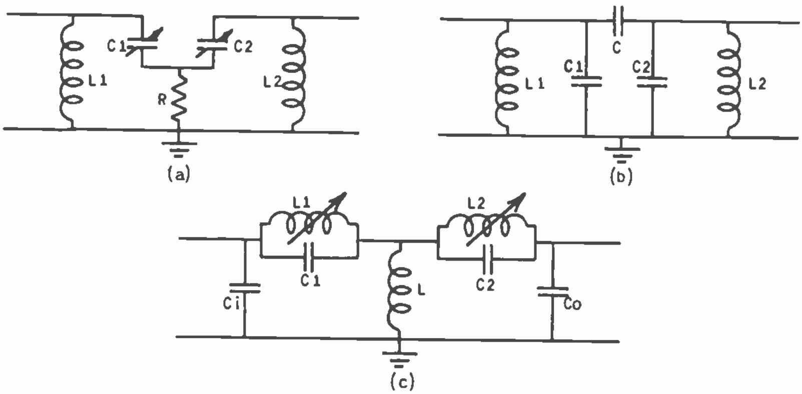


Fig. 17 Types of coupling impedances; (a) resistance, (b) capacitance, (c) inductance.

However, tuned circuits can be coupled so that the coupling impedance does not form a part of the reactive element of the tuned circuits. Fig. 17 shows three types of such coupled circuits. In a, the coupling impedance is the resistance R which is common to the tuned circuits L_1C_1 and L_2C_2. In b, the coupling impedance is the condenser C which connects the high voltage sides of the tuned circuits L_1C_1 and L_2C_2. In c, the coupling impedance is the inductance L which couples the tuned circuits L_1C_1 and L_2C_2. The condensers C_i and C_o are required to make the primary and secondary complete circuits. The frequency response of these circuits can be represented by the curves in Fig. 14. Increasing the magnitude of the coupling impedance widens the bandpass and causes the single peak to separate into two peaks; the response can be made fairly uniform over the pass band by loading the tuned circuits with resistance.

6. R.F. STAGES. It is common practice in the design of sound receivers to include one stage or more of R.F. amplification ahead of the mixer stage to reduce image frequency interference and increase the signal-to-noise ratio. Each circuit ahead of the mixer is important in affecting the signal-to-noise ratio since after this stage practically nothing can be done to improve this ratio that will not of itself cause a loss in picture detail. However, with the wide band and high carrier frequency required in television, such a stage is impractical when built around the average low transconductance tube. Fortunately, there are now tubes on the market having transconductances ranging from 5,000 to 9,000 micromhos. Otherwise, an effective stage of R.F. amplification would not be obtainable. Fig. 7 shows one method of tuning the input circuit of

a television receiver which does not employ an R.F. stage ahead of the mixer. For practical and efficient design, such a circuit should have not only the highest possible gain consistent with the necessary wide bandpass, but should also be sufficiently selective to prevent unwanted signals from reaching the mixer stage. This type of coupled circuit meets these requirements very satisfactorily in that it will pass a greater bandwidth with more selectivity against unwanted signals than would a single tuned circuit, loaded with resistance. At this stage of the art, no definite practice has been established as to the manner of tuning this bandpass circuit. Either a variable gang condenser, or a group of fixed condensers may be used. With only seven bands to cover, it would seem entirely practical to use fixed condensers and tune merely by switching. If, however, the variable type gang is used, it is desirable to limit the tuning range to as narrow a band as possible. This becomes necessary because as we increase the size of the tuning condenser, the circuit impedance is lowered, due to the smaller L/C ratio. This condition results in low overall gain. At present, it seems quite likely that the first four or five channels assigned to television may prove adequate while investigators are learning more about the problems involved in transmission and reception at the higher frequencies. In Fig. 18 are shown selectivity curves for a typical receiver input circuit (Fig. 7), covering the first five television channels.

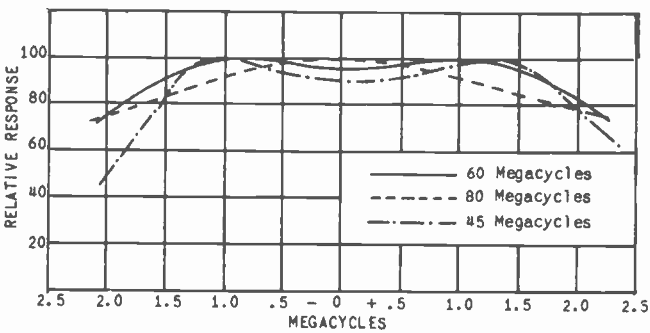


Fig. 18 Selectivity curves for the input circuit shown in Fig. 7.

Here it will be seen that if the sound carrier is made to occur at one side of this response curve with the picture carrier at the other side, the one picture sideband and both sound sidebands will be passed uniformly. The bandwidth uniformity is surprisingly good for such a wide range. Regular broadcast tuners cover a range from .5 to 1.75 megacycles, while this television receiver tunes from 44 – 90 megacycles, better than 25 times the range! However, the two peaks in the 45 megacycle curve are quite prominent, due to over-coupling at this low frequency. Without the resistances R_1 and R_2 (Fig. 7), these double peaks would become quite objectionable.

The R.F. section in Fig. 4 employs a simple tuned circuit, loaded with resistance, between the antenna and the R.F. amplifier. Since a television receiver is required to select only one of two or three stations, selectivity is not as important a problem as it is in the broadcast band. Therefore, resistance loading as a method of increasing bandwidth in the R.F. section is fairly satisfactory. The circuit coupling the R.F. amplifier to the mixer also consists of a simple tuned circuit loaded with resistance.

The R.F. section of the receiver in Fig. 6 employs a coupling network like that in Fig. 17b between the antenna and the R.F. amplifier. The two tuned circuits are loaded with resistance to give a uniform frequency response over the pass band. The circuit coupling the R.F. amplifier and mixer is a simple tuned circuit loaded with resistance. The load resistance also serves as the grid leak for the mixer.

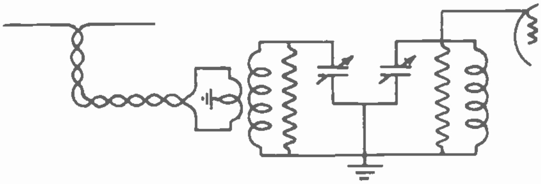


Fig. 19 R.F. section of Fig. 7 (re-drawn for comparison with Fig. 17a).

The R.F. section of the receiver in Fig. 7 does not have an R.F. amplifier. The antenna is coupled to the mixer through a bandpass circuit. This bandpass circuit is of the form shown in Fig. 17a. The R.F. section of the receiver is redrawn in Fig. 19 to show that the coupling network is of the form shown in Fig. 17a. There is no actual resistance inserted in the ground side of the ganged condenser to supply the coupling between the two tuned circuits. Due to skin resistance, the impedance of the condenser's rotor and ground connection is sufficient to couple the two circuits together at the high frequency used.

Thus far in the discussion of R.F. circuits, no mention has been made of the antenna, a factor which necessarily must be included in any discussion of input circuit design. Since the subject of television antennas is taken up in a later lesson, the only matter of concern at this time is the recognition of the fact that different types of antenna and lead-in (transmission line) connections will be used in various television set installations; also that a single antenna will be required to receive several bands, all of which may require that some provision be made for varying the set input impedance. For best reception (minimum line reflections) it is necessary for the primary of the antenna transformer which terminates the line to present a fairly uniform impedance (over several television bands) to the line. This suggests tuning the primary for each station channel. While tuning or switching is considerably simplified if an untuned fixed primary is used, yet experimenters have found that a double-tuned antenna transformer such as shown in Fig. 20 will, under similar conditions, give approximately double the gain.

If inductance tuning is used, as indicated in Fig. 20, and all circuit constants are fixed except the transformer windings, constant gain and constant bandwidth (expressed in frequency and not in a percentage of resonant frequency) may be maintained.

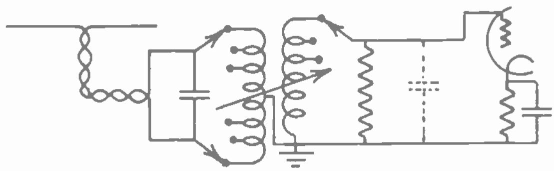


Fig. 20 Double-tuned antenna transformer.

7. OSCILLATOR AND MIXER CIRCUITS. The satisfactory operation of the local oscillator tube and circuit depends largely upon the following three factors:

First: The ratio of the tube's mutual conductance to the sum of its grid and plate circuit capacities. [Gm ÷ (Cg + Cp)]. Below is shown a tabulation of the characteristics of a few types of tubes most commonly used for this purpose.

TUBE	Gm	Cg	Cp	Gm ÷ (Cg + Cp)
6K8 (Osc. Sec.)	2400	6.0	3.2	261
6J8 (Osc. Sec.)	1600	11.7	5.5	93
955	2000	1.0	0.6	1250
6J5	2600	3.4	3.6	372
6C5	2000	4.0	13.0	118

From this table it is seen that the 955 is outstanding (however, it is seldom used because of cost) and that the 6J5 is superior to the other types in meeting this first requirement.

Second: The power output of the tube at the ultra high frequencies (UHF). The 6J5 can excite an 1852 mixer grid with at least three volts up to 120 megacycles and is, therefore, quite satisfactory.

Third: Stability of the oscillator tube and circuit with respect to power supply fluctuations.

The main cause of drift is the change in the inductance and capacity of the tuned circuit due to thermal expansion. The thermal drift in regular superheterodyne sound receivers has been extremely annoying in the past because it affected the tuning of the receiver to the extent that the signal would seem to fade out in a short time after the set had been put in operation. This same condition existed in the superheterodyne television receiver to an even greater degree since the frequencies are so much greater than those in a sound receiver. (This drift is generally proportional to the cube of the frequency.) It has been found possible to materially reduce this drift by the use of ceramics (clay materials) instead of synthetic resin in such parts as the tube sockets, coil forms, and the tuning condenser insulation. A reduction in the use of mounting blocks, by making direct connection between component parts and the use of extremely short leads is a further aid in this direction. There are condensers on the market today that are temperature compensated; that is, they are constructed so that thermal expansion changes their capacity in such a direction as to neutralize the change in the inductance due to heat.

Another cause of frequency drift may be attributed to changes in the voltages applied to the tube. Since the plate resistance of the tube is a part of the circuit load (and this changes with voltage variations), changes in this resistance will affect frequency stability. Hence, it is important to maintain the plate supply as nearly constant as possible.

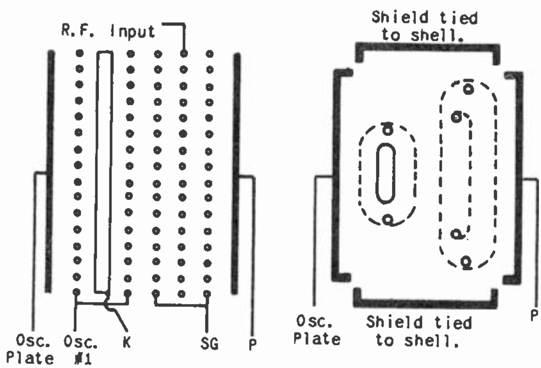


Fig. 21 Cross-section views of the 6K8 pentagrid converter tube.

If we examine the diagrams of the three receivers shown in Figs. 4, 6, and 7, we see that the oscillator and mixer can be a single tube as in Fig. 4 or separate tubes as in Figs. 6 and 7. The early forms of the pentagrid converter tube were unsatisfactory at ultra-high frequencies because of low oscillator efficiency. Furthermore, the oscillator frequency changed with variations in the AVC voltage applied to the signal grid of the pentagrid converter. The 6K8 which is a recent modification of the pentagrid converter, overcomes these two major difficulties. Fig. 21 is a cross section of the 6K8. Here the oscillator and mixer sections are on opposite sides of the cathode with the oscillator grid encircling the cathode and serving the double purpose of oscillator grid and injector grid for the mixer section. With this type of construction, the oscillator can be designed for maximum efficiency. Since the signal grid section is separate from the mixer section, changes in voltage applied to this grid will not change the oscillator current, and therefore will not affect its frequency. The shields suppress secondary emission as in a conventional beam power tube.

In the circuit shown in Fig. 4, the 6K8 is used as a combined oscillator and mixer with the screen of the mixer section used also as the plate of the oscillator. In this circuit the separation of the oscillator from the mixer section is not as complete as the design of the tube will permit.

In Fig. 25, a Hartley oscillator is used. Also, separate tubes are used as oscillator and mixer. The oscillator output is fed into the grid of the mixer tube through a 1 mmfd. condenser.

In the tuned plate type of oscillator shown in Fig. 7, separate tubes are used as oscillator and mixer. This oscillator is freer from frequency drift, particularly at high frequencies than the types of oscillators employing tuned grid circuits. The output of the oscillator is inductively coupled to the mixer tube.

The condenser C (Fig. 7) performs two functions; namely: it provides a means of adjusting the circuit so that the oscillator frequency will track properly with the R.F. circuit and it also serves to increase the feedback coupling at the low frequency end of the range. This makes possible the maintenance of fairly uniform oscillation strength from the low to the high end of the band. The action of the circuit is more evident if you note that one side of this condenser is connected to ground. As the frequency increases across this condenser, the impedance of the circuit is reduced or, conversely, as the frequency is reduced, the input of the circuit is, naturally increased.

In the event no R.F. amplification is employed ahead of the converter or mixer stage, satisfactory set performance will be determined largely by the design of the mixer circuit (the input and output), the materials used in construction and the type of tube employed. The impedance of the mixer tuned circuit is very low (for reasons already discussed) when compared with that in regular sound radio use and will, therefore, produce very little hiss (thermal agitation) in the receiver. Consequently, most of the hiss (thermal agitation voltage is proportional to the resistance component of a circuit) will be a result of the shot effect in the plate circuit of the mixer. (The shot effect results from irregularity in tube plate current flow. Since the flow of electrons between the cathode and plate of a tube may not be considered as a continuous fluid, but rather as a series of particles resembling hailstones striking the metal plate, it is understandable how this action could cause slight irregularities in the plate current which would result in noises in the amplifier. The space charge in a tube serves to cushion this effect to the extent that it is practically eliminated when complete temperature saturation exists. This points out the necessity for maintaining correct filament voltage so that the cathode temperature will be high at all times.) Since this type of interference is a factor which depends upon the plate current, and the stage gain is a function of the transconductance of the type of tube used, the mixer stage should have a high ratio of transconductance to plate current if we are to obtain a high ratio of signal-to-hiss.

(Hiss is objectionable in a picture receiver just as in a sound receiver, or even more so, since the eye is more exacting than the ear.) Single tubes combining the function of the oscillator and mixer are not satisfactory, as a rule, at these high frequencies, because of high plate current and low transconductance. Furthermore, they do not always oscillate when you wish. By the use of separate tubes to perform these two functions, it is possible to pick a sharp cutoff type for the mixer and, by use of self bias, prevent grid current[1] and reduce the oscillator excitation to a point where it is less critical.

Also, the ordinary carbon resistor should not be used, but preferably only those types showing a very low noise test; this applies not only in the mixer circuit, but in all of the circuits ahead of the second detector. Naturally, the mechanical considerations are that these resistors be as small as possible, consistent with current requirements, in order to keep circuit capacities at a minimum.

When R.F. amplification is used ahead of the mixer and is supplying a good signal-to-noise ratio at the grid of the mixer, the problem then becomes one of employing a tube with high conversion conductance[2] (Sc) and low input and output capacities. Obviously, then, the *Figure of Merit* for the converter or mixer tube becomes Sc ÷ (Ci + Co).

The following table lists the characteristics of several tubes together with their calculated Figure of Merit. The 1852 is seen to be far superior to all the other tubes listed.

TUBE	Sc	Ci	Co	Sc ÷ Ci + Co
6K8	350	6.6	3.5	34.6
6K7	676	7.0	12.0	35.6
6A8	500	12.5	12.5	20.0
6L7	350	8.5	12.5	16.7
956	738	2.7	3.5	119.0
1231	1830	8.5	6.5	122.0
1852	3300	11.0	5.0	206.0
ACTH1	870	8.8	11.5	42.7

It becomes apparent now why most of the better television sets (at this stage of the art) are employing separate tubes to perform the functions of mixer and oscillator: there is no single tube available combining the merits of the 1852 as a mixer and the 6J5 as an oscillator.

8. I.F. AMPLIFIERS. The I.F. transformers used in the receiver shown in Fig. 4 are of the conventional type; that is, the two circuits are inductively coupled and the coupling impedance (mutual in-

1 At extremely high frequencies, the impedance of the signal grid circuit to the oscillator frequency is quite high and the magnitude of the voltage becomes high enough to override a fixed bias and cause grid current.

2 Conversion conductance is expressed in micromhos and its use in calculating converter or mixer stage gain is analogous to the use of mutual conductance with R.F. amplifier pentodes. These values are supplied by the tube manufacturer.

ductance of the coils) is common to both of the tuned circuits. The circuits are close-coupled to obtain the required band width of 2.5 megacycles. The secondary is loaded with resistance to give a uniform bandpass. Since it is difficult to tune both primary and secondary, because of the interaction of the two circuits, only the primary is tuned. This factor causes a reduction in the selectivity of the transformer.

Another system used for coupling the I.F. stages in the picture section is shown in Fig. 7. The variable inductances (L8, L9, L10) make use of a small magnetite tuning core. Both primary (L9) and secondary (L10) are loaded by shunt resistors (R9 and R10). Each of these coils (L8, L9, L10) is wound on a small separate coil form and all three units mounted together between a non-metallic top and bottom plate. The bottom plate provides a mounting for each of the magnetite tuning cores. The entire unit is placed inside a shield can which in some instances may be fastened to the bottom of the tube socket in order to reduce the length of connecting wires. This type of tuning makes for ease of adjustment as well as for circuit stability. In addition to this, it offers the possibility of eliminating trimmer condensers, thereby providing a higher LC ratio in the circuit; this in turn makes possible higher gain for a given band width. (This I.F. coupling unit is of the type shown in Fig. 17C.) The major problem in this case is, of course, to pass a band width sufficiently great and, at the same time, provide satisfactory attenuation to the 9.75 megacycle sound intermediate frequency. Here again, design becomes a problem, since the imposed conditions result in low gain per stage, particularly if a regular type radio receiving tube is used. The use of such a tube as the 1853, however, should make it possible to limit the number of I.F. stages to three and still obtain sufficient selectivity and gain for satisfactory second detector output.

A coupling circuit of still another type of I.F. stage is shown in Fig. 22a. Coupling is accomplished through the parallel tuned circuit L2C2 and the capacity C1. This system of coupling is representative of that shown in Fig. 17b. The parallel tuned circuit L2C2 is adjusted to resonance at the sound I.F. and, therefore, acts as a trap to prevent passage of this band. Here again the tuning is accomplished by means of a magnetite plug. It is interesting to note (Fig. 22B) that when such a circuit is correctly adjusted, there is a rapid falling off of the response curve as the frequency of the sound intermediate (9.75 Mc.) is approached. After the first two I.F. stages, it is generally possible to eliminate this trap circuit and thereby simplify circuit design and cost.

Let us now consider some of the features of sound I.F. amplifier design. Having decided upon a pass band of 100 kc. for the sound, we must make it sharp enough so that it will have a very definite cutoff and yet, at the same time, it must be broad enough to prevent serious detuning, due to normal oscillator frequency drift. It is obvious, therefore, that in television receivers there should be no sideband losses, due to discrimination against the higher frequencies by sharply tuned circuits. Consequently, the fidelity of the sound should be a matter of circuit design following the second

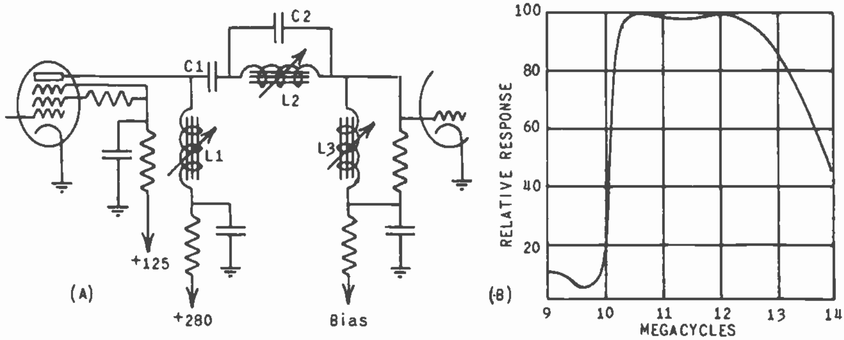


Fig. 22 (A) A coupling circuit designed to reject sound I.F. (B) Response curve for such a circuit as (A).

detector. Since the band width required by the sound is much narrower than that of the picture, more gain per stage is possible in the intermediates and, consequently, a fewer number will be required. Both primary and secondary (Fig. 23, taken from Fig. 7) are tuned by means of magnetite plugs. The I.F. coupling units are of the type shown in Fig. 17C. Coupling is accomplished by a common impedance L1 in the plate supply lead and may be varied by changing the

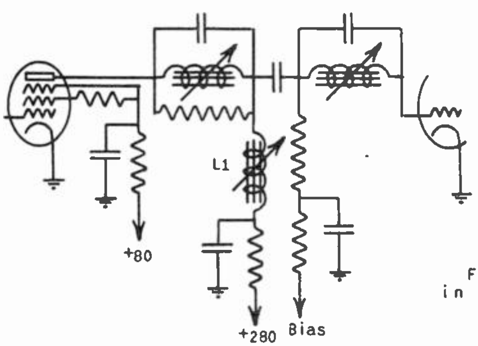


Fig. 23 A sound I.F. stage in a television receiver.

position of its magnetite plug. One advantage claimed for this type of transformer is that its primary and secondary tuning is practically independent; this makes for ease of adjustment, since tuning does not affect the coupling. Of course, it is highly desirable that the tubes used in each stage will have a high transconductance and remote grid cutoff (such as the 1853).

The wiring diagram for a television receiver such as described is shown in Fig. 7. It will be noted that no circuits are shown beyond the second detector in the case of either sound or picture. Since you have already studied A.F. amplifiers, there can be little gained in a repetition of that discussion. As already suggested, there, no doubt, will be one difference in the television audio amplifier from that found in a regular radio set; namely, it will cover a wider range of frequencies and make possible the attainment of higher fidelity than is possible in our present broadcasting channels.

The lesson which follows will continue the discussion of the television receiver; that is, from the second detector on, and circuits for that purpose will be shown.

The student should remember that the television art has not yet reached a point where a great deal of circuit information is available and, for that reason, it has been necessary to more or less confine ourselves to some fundamental circuits. However, the student should be thoroughly acquainted with the stringent requirements imposed upon a television receiver and some of the methods by which these may be met so that it will be a fairly easy matter to understand and follow the various circuit differences which are bound to be encountered in any new and rapidly developing art such as television.

9. SEPARATOR CIRCUITS. Since separator circuits are basically a special form of the I.F. transformer, they have been taken up in this study after I.F. transformers rather than in their order of appearance in the circuit.

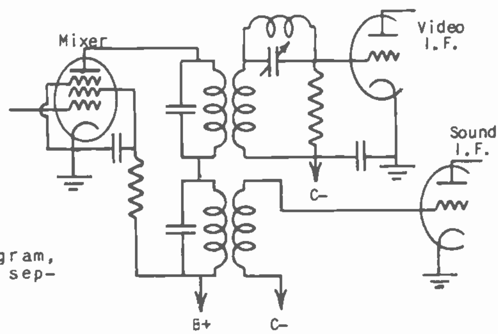


Fig. 24 Schematic diagram, suggesting one method of separating video.

Since a common R.F. and oscillator section are used in combination receivers for sight and sound, some means of separating the video and sound I.F. frequencies must be provided. Two separate mixer tubes might be used, that is, one for sound and one for picture, by connecting their grids together and feeding each plate to a separate I.F. transformer, However, such an arrangement serves to increase receiver costs and, by the additional capacity and loading, decrease its performance. It seems preferable, therefore, to use one mixer tube and provide special circuits in its plate to separate the signals intended for the I.F. sound circuit from those intended for the I.F. picture circuits.

One circuit that readily suggests itself is shown in Fig. 24. The primaries of two I.F. transformers are connected in series; one is tuned to the sound I.F. and the other is tuned to the picture I.F. The secondary of the picture I.F. transformer is loaded with resistance to give it the required bandpass. This transformer is also over-coupled for the same reason. Since the frequency response of this transformer is very broad, a trap tuned to the sound I.F. must be placed in the grid of the first picture I.F. amplifier. The selectivity of the sound I.F. transformer is sufficient to keep the picture I.F. out of the sound I.F. amplifier.

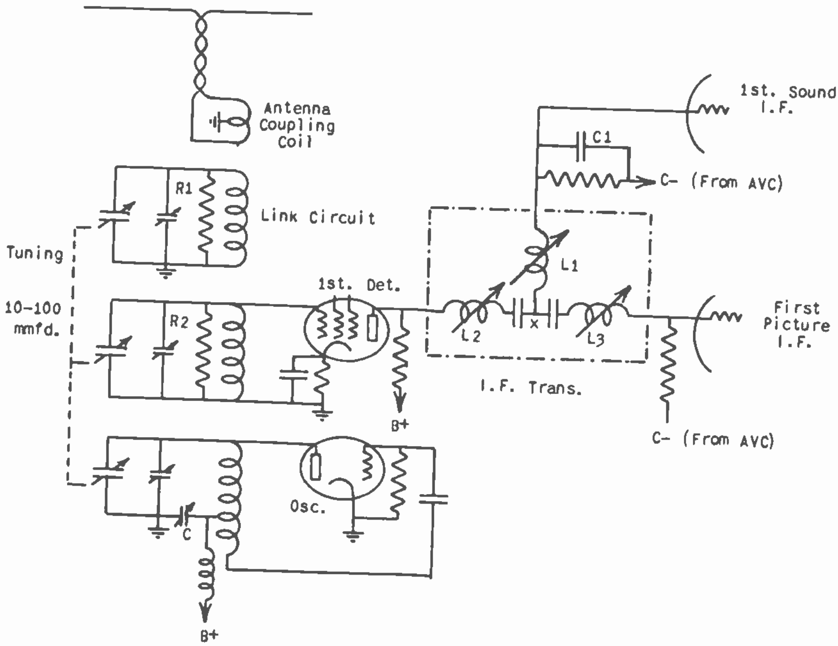


Fig. 25 A coupling circuit, designed to separate sound and picture.

One drawback to this method of separating the sound and picture I.F. frequencies is the capacitive coupling existing between the windings of the transformers. This makes complete separation of the two rather difficult.

The coupling circuit shown in Fig. 25 (Fig. 25 is a part of Fig. 7) provides a very satisfactory method of separating the sound and picture I.F. frequencies.

The coupling impedance L1 and C1 is series resonant to the sound I.F. frequency. Thus, it provides a low impedance path for the sound I.F. to ground. The voltage developed across the condenser C1 is fed into the sound I.F. amplifier. This L1C1 combination will offer a high impedance to the picture I.F. frequency and effective separation of the two will occur.

The circuit given in Fig. 26 shows another method used to separate the picture and sound I.F. frequencies. The parallel circuit L2C2 is tuned to the sound I.F. frequency. The L3C3 combination is tuned to the picture I.F. frequency. The two parallel tuned circuits L2C2 and L3C3 are connected in series insofar as the output of the mixer is concerned. The input to the sound I.F. amplifier is connected to the mixer side of the L2C2 combination. The L3C3 combination offers high impedance to the picture I.F. and low impedance to the sound I.F. The L2C2 combination will offer low impedance to the picture I.F. and high impedance to the sound I.F. Therefore, the sound I.F. voltage across L2C2 will be very much higher than that across L3C3. Also, the picture I.F. voltage across L3C3 will be very much higher than that across L2C2. The input to the picture I.F. amplifier will contain very little of the sound I.F. However, the input to the sound I.F. will contain both the picture and sound I.F. frequencies. Since the sound I.F. amplifier is very selective insofar as the picture I.F. is concerned, the picture frequency will not be passed by the sound I.F. circuits. The wide bandpass picture I.F. amplifier will not reject the sound I.F. frequency unless some sort of a trap circuit is provided (L2C2). Thus the two frequencies are effectively separated.

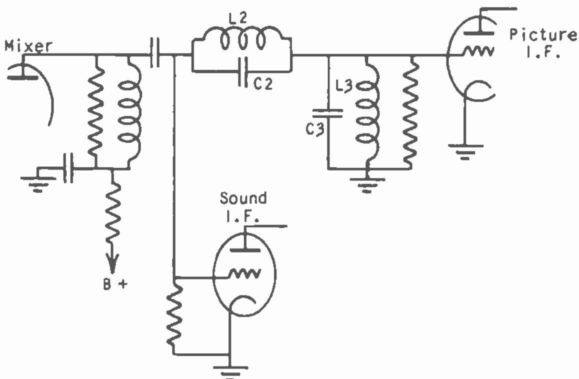


Fig. 26 Series-parallel tuned circuits for separation of sound and picture.

Another method of separating the picture and sound I.F. is shown in Fig. 6. It is very similar to that shown in Fig. 25 except for the coupling impedance L7C1C2. L7C1C2 is a combination series and parallel tuned circuit. L7C1 is a parallel tuned circuit and is resonant to the picture I.F. frequency. You recall that the picture I.F. frequency is 13 megacycles and the sound I.F. frequency is 9.75 megacycles. Remember, also that a parallel tuned circuit has inductive reactance for frequencies below resonance. Therefore, if L7C1 is tuned to 13 megacycles it can be considered as an inductance insofar as the 9.75 sound I.F. frequency is concerned. Then, by proper adjustment of C2, the combination can be made series resonant to the sound I.F. frequency. The voltage developed across C2 is fed into the sound I.F. amplifier. The tuned trap L7C1 prevents the picture I.F. frequency from reaching the sound I.F. amplifier.

10. THE SECOND DETECTOR. The problems associated with the detection of a video signal are of considerable magnitude and different in several respects from those found in ordinary broadcast sound detection. In the first place, the low ratio of I.F. carrier frequency to the video modulation band causes the suppression of the I.F. frequency after detection to become a design problem. For example, in the case of sound broadcasting, the ratio of I.F. carrier frequency to the sound band is of the order of 90 to 1 while in television this ratio may be decreased to as low as 3 to 1! In the second place, single sideband reception (present indications are that this method will become standard) involves the detection of a signal whose structure may or may not be symmetrical with respect to the carrier. In the case of low video modulation frequencies, the signal may become symmetrical, having the carrier and both sidebands. (This is possible because sideband suppression is not complete.) However, at high video modulation frequencies, the signal applied to the detector is not symmetrical, but has the general formation of a carrier plus a single sideband. Hence, in the detection of video modulation, the signal is considered as consisting of both types of structure simultaneously.

From previous lessons on radio, the student should recall that although the process of detection has non-linearity as a common basis, yet the various types of detectors may be listed under *two* general headings: plate circuit detection, and diode detection. "Grid leak detection," for example, is basically a diode detector with a plate circuit serving as an amplifier.

Since all amplifier tubes have a certain degree of non-linearity in their plate-grid characteristics, they may be used, under proper conditions of bias and plate voltage, to detect a modulated signal. The detection of a video modulated signal under these conditions assumes that normally the stage would have satisfactory response if operated as a video amplifier. Plate circuit detection, however, results in plate currents in which the I.F. carrier frequency predominates, becoming a filter problem for the reason discussed above.

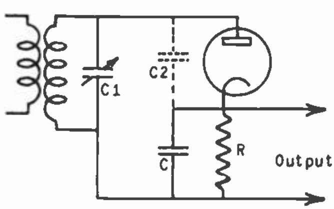


Fig. 27 A simple diode detector circuit.

Since the diode detector is used aomost universally in television receivers, it is important that we spend considerable time on this type. Diode detection has already been discussed in a previous lesson, but its application to television is of such importance as to warrant additional study. It will be recalled that the diode detector takes advantage of the fact that current flows through a diode only when the plate is positive, and makes use of a circuit arrangement such as illustrated in Fig. 27, where the resistance-condenser combination RC represents the load across which the rectified output voltage is developed. Any input voltage which is sufficiently positive to cause the plate to become more positive than the cathode will cause a pulse of plate current to flow; at all other voltages, it is non-conductive. *The internal resistance of the diode tube during conduction should be low compared to the load resistance R, and constant for efficient, distortionless detection.* The process of detection consists, simply, in charging condenser C through the resistance of the diode during a part of each positive R.F. cycle and then permitting it to discharge through resistor R during the remainder of the R.F. cycle. This seems simple enough, but there are some very important considerations as to the values of R and C which, in turn, depend upon the frequencies involved.

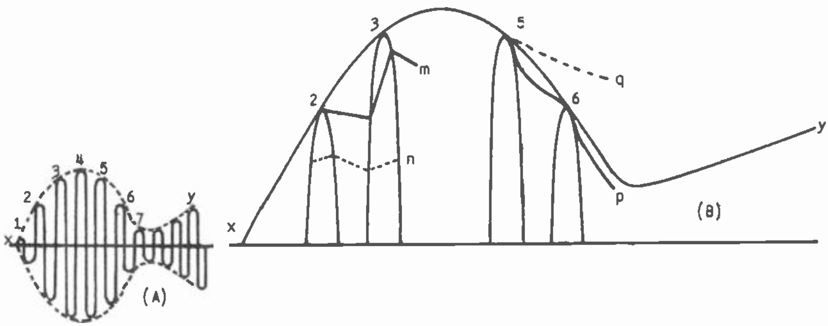


Fig. 28 (A) Portion of a symmetrically modulated carrier. (B) Enlarged view of the modulation envelope of (A).

In Fig. 28A is shown a portion of a symmetrically modulated carrier wave. The waveform desired after detection is represented by the envelope XY, which appears in Fig. 28B as the solid curve (much enlarged to make possible the explanation which follows). On the rising side of this modulation envelope are shown two of the component R.F. waves, 2 and 3 (components of the carrier frequency). The curve M shows the voltage across the diode load condenser C which rises on each R.F. peak and falls between peaks according to the circuit time constant RC. It is seen, therefore, that the resultant condenser voltage is a modulation wave with an R.F. serration (shown in part by line M) which later is either filtered out or not passed by amplifiers following the detector. If the diode resistance during the conducting periods of the R.F. cycle is too high, condenser C is not sufficiently charged on R.F. peaks, but follows the dotted curve N, which shows a reduced and distorted modulation frequency output (should be similar to curve XY). This requirement of low diode resistance during detection is satisfied by available diodes used in connection with regular broadcast reception.

Now, on the falling side of the modulation envelope, two other

R.F. component peaks are shown at points 5 and 6. If the diode load condenser C discharges through the load resistor R fast enough, the condenser voltage keeps within the modulation envelope as shown by the curve P. But, if R is too large, C does not discharge as fast as the modulation envelope falls and its voltage goes outside as shown by the curve Q. Naturally, failure to follow the modulation envelope results in both attenuation and distortion of the modulation voltages for all modulation frequencies above the point at which this failure to follow (due to the circuit time constant) starts to occur. Trouble of this sort can be avoided by proportioning the resistance-condenser combination so that the rate of decay of voltage can follow the highest modulation frequency of importance. To achieve this, it is necessary to satisfy the condition:

$$\frac{X}{R} \geqslant \frac{m}{\sqrt{1 - m^2}} \quad \text{*(See footnote)} \qquad (1)$$

Where X = reactance of condenser C at the modulation frequency in question (1 ÷ 6.28FC), and m = degree of modulation. For 100% modulation, that is, m = 1, it becomes impossible for the output voltage to follow the modulation envelope troughs of the modulation cycle. (If m = 1, the denominator of the expression becomes 0.) If the reactance of the condenser at the highest desired frequency is two or three times the resistance of R, it is possible for the output voltage to follow the modulation envelope up to modulation percentages of from 90% to 95%. Even in the case of 100% modulation, the distortion will be relatively small.

In an efficient linear diode detector circuit, the effective input resistance is equal to approximately one-half the diode load resistance.

It is well to keep in mind that the diode plus its load circuit (the impedance of the load) constitutes a load in parallel with the diode input circuit. It is easy to understand how increasing the diode resistor R could result in additional gain from the I.F. amplifier feeding the diode. In addition to this, any increase in the value of R serves to increase the diode efficiency while at the same time requiring a decrease in the value of C in order to maintain high frequency fidelity. The extent of the effect which the circuit capacity C_2 has in bypassing R.F. voltage to the diode output circuit is determined by the factor $C_2 \div (C + C_1)$.

From this it is seen that if we have to decrease the value of C on account of increasing R, the effects of C_2 become more pronounced. (Normally, it is desirable for the capacity of C to be 5 to 10 times that of C_2.) It has been found that a value of R equal to 500,000 ohms and C equal to 250 mmfd. gives a good practical compromise for the diode load when used with standard tubes and conventional circuits employed in regular sound broadcast reception. Here, however, as previously pointed out is a very important distinction, namely: the frequencies involved in television are so much greater than those met in regular broadcast practice that in order to obtain satisfactory diode detector operation, careful circuit design is important

*The symbol ⩾ means equal to, or greater than.

and many compromises are often necessary.

To be more specific, let us work out an example on the supposition that our diode circuit has an input capacity (plate to cathode) plus additional stray wiring capacity of, say, 10 mmfd. (C_2) and that the top modulation frequency is 2.5 megacycles. In regular broadcast receivers, the secondary of the I.F. transformer is usually tuned by a condenser such as C_1; however, in television receivers, the capacities C and C_2 constitute the only tuning required for the secondary. If we assume that C has the desirable capacity of five times C_2 or 50 mmfd., the reactance of C for the given high frequency will equal approximately 1275 ohms. This gives us the value of X which may be substituted in formula (1) (assume the depth of modulation m to be 80%), in order to solve for R. Equating the right to the left-hand member, we have:

$$\frac{1,275}{R} = \frac{.8}{\sqrt{1 - (.8)}} \text{ or } 1.33$$

$$1.33R = 1275$$

$$R = 955 \text{ ohms (approximately)}$$

In view of what has been said regarding linear detection (that is, the load resistance should be high in comparison to the diode resistance) and maximum output, it is quite evident that a diode detector having a load resistance of 955 ohms would be very unsatisfactory. One method of attack, of course, would be to reduce either C_2 by more efficient circuit design or to arbitrarily decrease the value of C, or perhaps do both. Another factor contributing to a solution is that the increased amplitude of the R.F. signal delivered to the television detector decreases the probability of distortion. (Usually in regular broadcast reception the R.F. signal is less.) If a peak signal of from 5 to 10 volts or more is impressed on the diode, it is possible to use a load resistor of from 1,500 to 5,000 ohms without incurring noticeable picture distortion (usual values ranging from 1500 to 3,000 ohms). Since the tube distortion occurs due to curvature of the diode characteristic near zero, the rectification of small signals, particularly of 2 volts or less, will result in damaging distortion which may reach values of 25% or more.

Actually we may consider this type of distortion as affecting only the picture contrast. Fortunately, experience thus far has indicated that a moderate degree of video detection distortion is much less annoying than would be a similar degree of audio distortion. If such were not the case, the detection of a video signal might indeed present much greater difficulties since there are the two types of modulation envelope, symmetrical and asymmetrical (nonsymmetrical); the symmetrical type requires *linear* detection to avoid distortion while the asymmetrical requires *square law* to avoid distortion. While on the subject of distortion, it should be pointed out that phase distortion originating in the detector circuit is of comparatively little concern.

The student is cautioned not to make something difficult out of the diode detector. It may be simpler to look upon it as merely a half or full wave rectifier, depending upon the construction of the tube. The circuit behavior is fundamentally the same. As a comparison, suppose that we have a power transformer capable of supplying 800 volts and that we connect it to a half wave rectifier tube. In this case, the output will be approximately 800 volts; but if the transformer is connected for full wave rectification, the output becomes approximately half, or 400 volts. In the first case, greater output voltage is obtained at the expense of increased filtering; in the second case, with full wave rectification, although reduced output results, yet at the same time (assuming power from a 60 cycle source), our fundamental frequency has been changed from 60 to 120, thereby reducing the amount of filtering required for any given percentage of ripple voltage. This is one of the chief reasons for using full wave instead of half wave diode detection. Such a circuit is shown in Fig. 29 (from a commercial English television set).

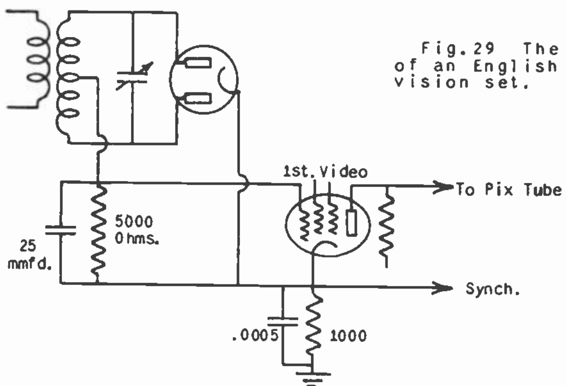


Fig. 29 The detector circuit of an English commercial television set.

In the detection of a sound signal, it makes no difference to the listener whether the output of the second detector has a positive or a negative direction. A good practical example of the importance of detector output polarity is found in an English television receiver which has been imported to the United States. In England, *positive modulation*[1] is used in the transmission of the television signal, while in the United States, *negative modulation* is the accepted standard. Attempts to receive American pictures on an English receiver without any modifications would result in a negative picture; that is, the black parts of the picture would be white, and the white, black. The same would be true if we took an American receiver to England. In the case of an English receiver in this country, we could either remove a stage of video following the second detector, or else add an additional stage in order to obtain the correct picture polarity at the grid of the picture tube. There is yet another way out, and this brings us to the reversibility of the diode.

[1] The picture carrier is said to have negative modulation when the peak of the synchronizing signal requires maximum carrier power and white in the picture occurs at minimum carrier power. Positive modulation is just the reverse: white is represented by maximum carrier power and the peak of the synchronizing signal by mimimum carrier power.

Here again we have the very useful analogy found in rectified power supplies (full wave); if a positive voltage is desired, we ground the center tap of the secondary of the power transformer and keep the cathode above ground; that is, the positive voltage is fed to the filter section. But, if we wish to change this into a negative power pack, we ground the cathode and feed the filter sections from the transformer center tap. Hence, to alter our British receiver to give the correct picture polarity for U.S. reception, we need to place our load in the cathode and ground the center tap.

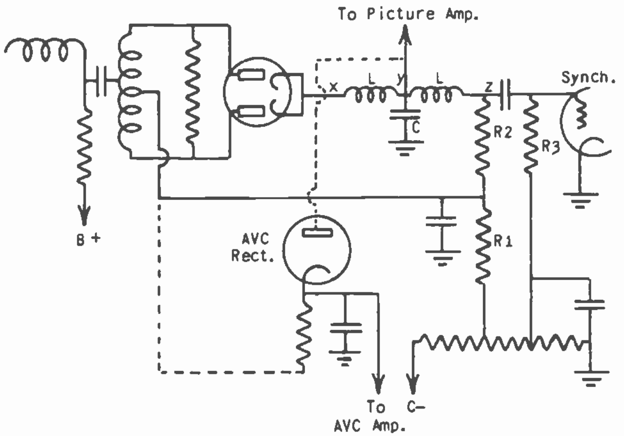


Fig.30 A detector circuit, employing two-section filter for load; dotted lines indicate possible AVC connections.

A typical detector circuit as suggested by the RCA laboratories is found in Fig. 30. In this instance, it will be noted, although of somewhat different nature, the load is in the cathode, instead of the center tap. This type of diode loading is an improvement over that shown in Fig. 29 and constitutes, in effect, a two section filter designed to cutoff at some point above the highest video frequency to be passed (around 4 mc). This arrangement provides two points from which the demodulated signal may be obtained; that is, one for the synchronizing, which means the synchronizing separating circuit, and the other, the regular picture channel itself. This is advantageous in that the loading due to these two circuits is distributed in the filter so that the frequency response is not materially affected. This is particularly significant when it is realized that the proper capacity to ground needed at the midsection of such a filter is twice as great as the capacity at either end. Since these capacities in most instances are composed largely of tube and circuit capacities, it becomes desirable to arrange the loading of this circuit so that the value of C becomes twice that of Ci or Co. For example, the input to the first video amplifier tube and the AVC tube might both be connected at point Y; the synchronizing grid would then be connected at the end of the filter (point Z), shown in Fig. 30. This arrangement would depend somewhat upon the input capacity of the various tubes. A load circuit of this type offers the additional advantage that besides improving the frequency response, it also acts as a filter to eliminate the I.F. frequency voltage from the video amplifier.

10. AUTOMATIC GAIN CONTROL. We are already acquainted with the advantages of AVC in sound receivers; however, they are even more necessary to the satisfactory operation of a good television receiver. An AVC that is operating satisfactorily will maintain a constant signal level at the second detector, even though there be wide variation of the input signal. Although the transmitter signal may not vary to any great extent within its accepted service area as a result of fading, there is, at times however, considerable variation in the signal at the receiver. This may be due to a swinging receiving antenna or transmission line or the movement of conductors or objects within the immediate field of the antenna. Later, in our study of synchronizing separator circuits, we shall learn the importance of having a constant signal level. The dotted lines in Fig. 30 indicate how one might add AVC to this circuit.

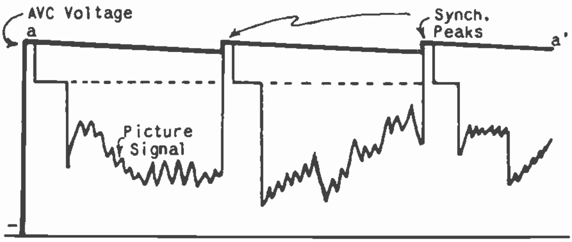


Fig.31 Picture AVC rectifier action. Line aa' indicates output voltage level of AVC rectifier. (See Fig. 7 for complete circuit connections.

In sound broadcast receivers, the AVC voltage is obtained, ordinarily, from the filtered DC drop across the diode resistor. This voltage is directly proportional to the *average* carrier amplitude at the diode. Now, in the case of a television signal, when the DC component of the picture is transmitted, the average carrier does not remain constant for changing scenes, because it is a function of the relative amount of black and white in each scene. Under extreme conditions, the carrier level for a television picture might vary approximately 5 to 1 and, consequently, an AVC operated from the average carrier of the detector would not be satisfactory. However, for negative transmission, which includes the DC component, the *peak* value of the carrier remains constant; by that we mean the peaks of the syychronizing pulses always rise to the same amplitude. Consequently, they form a satisfactory reference for AVC operation. (These impulses are transmitted at the end of each line and at the end of each field.) The AVC rectifier is connected across the output of the diode detector. The action from this point is very much similar to the diode detector as already explained; that is, the current which is drawn during the time of the synchronizing impulse peaks charges the capacitor in the AVC diode cathode circuit to a

DC potential equal to the peak of the television signal. The time constant of this circuit does not allow appreciable discharge between line synchronizing impulses. Consequently, the DC voltage is proportional to the *peak* value of the I.F. signal at the second detector. The level of this AVC voltage is represented by aa' in Fig. 31. This signal is amplified by an additional stage (DC coupled), having sufficient AVC delay, and then impressed on the grid returns of the first two picture I.F. amplifier tubes to give I.F. gain control. The AVC amplifier tube may be a double triode, one-half of which is used for the picture AVC and the other half for the sound.

It is obvious that this type of AVC circuit is suitable only for negative transmission which is the adopted U.S. standard. (The problem of suitable AVC action was a factor in the choice of the negative transmission standard instead of the positive as used in England). Positive transmission requires a much more complicated circuit arrangement.

EXAMINATION QUESTIONS

INSTRUCTIONS. Before starting to answer these examination questions, you should have studied the lesson material at least three times. Be sure that you understand each question--then proceed to write the best answer you can. Make all answers complete and in detail. Print your name, address, and file number on each page and be neat in your work. Your paper must be easily legible; otherwise, it will be returned ungraded. Finish this examination before starting your study of the next lesson. However, send in at least three examinations at a time.

1. Why does the production of a television picture require frequencies so much higher than those needed for sound?

2. Of what does the complete television signal consist, and how does this affect the circuit design of a television receiver?

3. Why are separate tubes often used as oscillator and mixer?

4. What are the principal difficulties involved in the design of a television I.F. transformer?

5. Name two requirements for satisfactory operation of the local oscillator circuit in a television receiver.

6. Draw a circuit diagram of one method by which the video and sound I.F. frequencies may be separated. Explain.

7. Draw a diagram of a simple full-wave diode detector circuit.

8. How does the diode detector load effect the amplification of the preceding stage?

9. What picture quality is affected by diode detector distortion?

10. In television, which forms the picture AVC reference point: (1) average carrier, or (2) peak carrier amplitude?

Notes

(These extra pages are provided for your use in taking special notes)

Notes

(These extra pages are provided for your use in taking special notes)

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UNIT NO. 5

TELEVISION VIDEO CIRCUIT DESIGN

LESSON NO. 9

CHEERS APLENTY

.....will be yours when you succeed.

Regardless of the game played....football, basketball, or baseball, the resounding cheers of the home fans inspire the players to superhuman efforts. Many a team with its back to the wall has come through, a winner, simply because of a cheer or a band.

But how different is the life of the patient scientist who labors year after year seeking to perfect a new idea. Forced to overcome obstacle after obstacle, scientists work in the seclusion of their laboratories. During the development stages of a new idea, they get no cheers...no bands inspire them. Yet they stick grimly to their task and often emerge with discoveries that create employment for thousands. And when this happens, cheers arise by the thousands. Success brings an abundance of cheers....for the man who is successful.

Television is a product of the laboratory. Its perfection was made possible by the untiring efforts of men who stuck to their guns in the darkest days of Television when perfection seemed beyond the realm of human accomplishment. If these men had quit, there would be no Television....no opportunities for you. But they DID stick, and you DO have a multitude of golden opportunities whose magnitude can only be determined by time.

You have what it takes to succeed....faith in the future, ambition and backbone. We know that you are going to fully equip yourself for the rich era of Television by thoroughly mastering the fine training that we have made it possible for you to secure. When your success is achieved through this training, you too, will have cheers aplenty from those who admire, and perhaps envy your success.

Lesson Nine

TELEVISION VIDEO CIRCUIT DESIGN

"In the preceding lesson, you studied about that part of a television receiver between the antenna and the second detector. In this lesson you will study video circuits. This is that portion of a television receiver which transfers the signal from the second detector to the picture tube.

"It is impossible to say that one set of circuits is more important than another; therefore, I hope that you will attach as much importance to this lesson as you did the preceding one."

1. THE VIDEO SIGNAL. In this lesson we shall deal with those circuits pertinent in transferring a satisfactory video (picture) signal from the second detector to the grid of the cathode ray picture tube. The student should bear in mind that although we have a detected signal, it is quite different in characteristics from the detected sound signal in which the frequencies may vary from 50 to 7,500 cycles. The detected video signals may have a frequency range of from 0 to better than 3,000,000 cycles. Therefore, specially and carefully constructed circuits are required in order to reproduce a picture containing a maximum amount of the originally transmitted picture information. Since picture quality is judged by the amount of detail we are able to see under widely varying conditions of contrast, it is important that we investigate the requirements placed upon both circuit and tubes of a video amplifier.

In the first place, we shall have to decide how many stages are required and, in order to reach this decision, we must know some of the determining factors. Now, it is possible to obtain a higher gain per stage from the video amplifier than is possible from the radio frequency or intermediate frequency amplifier. It might seem at first that the more V.F.[1] stages the better; however, in practice the difficulties encountered in the use of several stages actually make it preferable to use as few as possible. If several stages of video amplification are used, the gain normally would be so high that only a very small input would be required from the diode to

1 Video frequency.

fully load the picture tube. It will be recalled that the diode detector gives a very distorted output at small signal inputs due to the curve in the tube's characteristic. In order to understand how this distortion may affect the picture, refer to Fig. 1, which represents the waveform of a line of picture signal. The small impulse represented by the amplitude ab is known as the "horizontal synchronizing." This signal keeps the receiver "in step" with the transmitter; that is, it causes each line of scanning on the cathode ray picture tube to *end* at exactly the same time as does each line

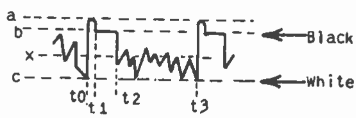


Fig. 1 Voltage waveform of a line of video signal.

in the original cathode ray camera tube located at the point of picture origin. This amplitude ab is generally of the order of 20% to 30% of the total picture signal amplitude, depending upon the standards of different countries. In the United States, the standard at present states that the synchronizing amplitude shall be not less than 20%, while in England they specify 30%. (At the conclusion of this lesson will be found a complete list of the U.S. standards as recommended by the R.M.A. Television Standards Committee and also a comparison with those used in England.) Now, for example, assume a picture signal having 30% of its amplitude given over to synchronizing (the English system) and also assume that the total amplitude has been made small in order to accommodate two or three stages of video amplification following the second detector; it will be seen that if this portion (synchronizing) of the carrier falls in the region of detector distortion, it may become so small that it is difficult to make satisfactory use of the synchronizing signal. Since American practice employs negative[1] modulation (English is positive), this type of detector distortion would affect the picture rather than the synchronizing. This picture signal is represented by the curve between t_2 and t_3 (Fig. 1). The square topped impulse represented by the amplitude cb during the time t_0-t_2 is called the "blanking-out" signal (abbreviated B.O.). It derives its name from the fact that its amplitude and time duration are sufficient to bias off the cathode ray beam of the picture tube during the time of the horizontal line return (a much wider B.O. signal being used to blank out the vertical) and thereby blank out the return line trace.

If a single stage of video amplification is used, there are two important considerations; namely, the polarity of the signal applied to the grid of this stage and the point in the circuit at which we wish to connect the synchronizing separation circuits. (This is necessary in order to correctly deliver the horizontal and vertical synchronizing signals to their respective oscillators in the sweep

1 In negative modulation, the peak of the synchronizing signal represents maximum carrier power and white in the picture occurs at minimum carrier power. Positive modulation is just the reverse.

circuits.) Inasmuch as synchronizing and sweep circuits form the subject matter for an entire lesson, this discussion will be confined to those circuits directly related to the picture.

2. PICTURE POLARITY. Let us then examine the requirements for correct picture polarity. *By polarity, we mean the relative positions of black and white as they appear in the video signal.* Now, since it is understood that this video signal is actually composed of three distinct types of signals, each having its own particular function, any reference made to the video signal in this discussion of circuits relates to the general form as shown in Fig. 1. Here the polarity is such that the picture signal is negative with respect to the synchronizing. As previously noted, the part of the signal at ab is the synchronizing; that occurring during the time between t_0-t_2 is the blanking out and the balance of the signal occurring between the time t_2-t_3 is the actual picture signal itself. For reasons which will become apparent later, the top of the blanking-out signal as represented by the level b has been established as the picture's black reference point. The part of the signal above b, that is, the synchronizing, is in the region known as "blacker than black." Any picture signal occurring below b, that is, in the direction c, is in the light region. If we assume that c represents the level of maximum brilliancy or white, then gray should fall at some position halfway between b and c, such as x, since gray is midway between black and white; hence, the region between b and c represents the shades of gray in a black and white picture.

Now, in order for the cathode ray tube to appear black, the grid of the tube must be biased to cut-off. Hence, we establish the fact that at the grid of the cathode ray picture tube, black level must be negative with respect to white, or just the reverse of the polarity shown in Fig. 1. Now if there is to be only one stage of amplification between the grid of the picture tube and the output of the diode detector, the picture signal on the grid of this stage must necessarily be opposite to that required at the grid of the picture tube; that is, black must be positive with respect to white (Fig. 1). The desired polarity for correct picture reproduction is obtained from the diode detector by making the proper load circuit connection. The method by which correct video signal polarity may be obtained from the output of the detector is illustrated by Fig. 2a. If the receiver is to detect a signal having negative modulation (the U.S. transmission standard) and the diode load RC is placed in the cathode circuit, the output taken from point y will have the polarity of that shown in Fig. 1 (picture negative with respect to synchronizing). Had positive modulation been used in the picture transmission (English standard), the detector output at y would have had the picture polarity shown by Fig. 2b--picture signal positive with respect to synchronizing. As previously stated, this same polarity (Fig. 2b) must exist when the signal reaches the grid of the cathode ray picture tube. To satisfy this condition there must be an *even* number of amplifier stages (two, four, etc.), between the output of the detector and the input to the picture tube.

But for the first case having negative modulation, there must be an *odd* number of video stages (one, three, etc.). Suppose, for example, that one stage does not give sufficient amplification and that three stages are wasteful, so that it is desirable to use two stages. We cannot change the type of modulation used at the transmitter, but it is quite simple to change the polarity of the detector output. This is done by changing the ground from point x to y and the output from y to x. Under this condition, the statements regarding even and odd numbered stages of video amplification are also reversed.

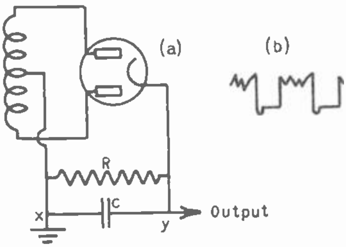


Fig. 2 Load circuit of a second detector, showing output polarity when received signal has positive modulation.

3. VIDEO AMPLIFIER REQUIREMENTS. Regarding the frequency requirements of the amplifier stage which we are to consider, the student should bear in mind this important fact: perfect picture reproduction (441 lines) depends upon the faithful transmission of all frequencies in the range of from 0 to well over 3 megacycles; this upper limit, however, may be reduced somewhat without greatly impairing the picture quality. Poor picture fidelity may be the result of any one or all of three general types of distortion, namely, *frequency distortion, amplitude distortion,* and *phase distortion.* If the low frequency amplification does not extend below 30 cycles per second (the picture frame frequency), a small portion of the picture information will be missing, namely, the picture background. Since it may not be too evident why it is necessary to actually transmit DC, let us go further into this discussion. Take the case of picture making with an ordinary camera photographing a scene in bright sunlight; the finished picture, if it is a true reproduction, will have an overall appearance of brightness which tells us immediately something of the conditions under which it was taken. Likewise if the photograph is made from a dull interior, this aspect will appear in the finished picture. Now in order to have a televised scene appear in the true state of illumination, the overall brightness of the television picture must vary according to the subject and the conditions under which it appeared. A scene having a fixed overall illumination would therefore require a DC amplifier. In view of these considerations, it is evident that *the alternating current conveys the variation in the individual parts of the picture, but a direct current is required to convey an idea of the average illumination of the scene.*

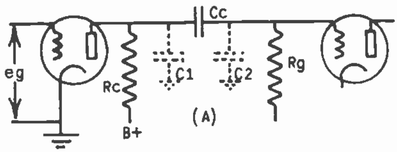
From the foregoing it would appear that we cannot use ordinary AC-coupled amplifiers if we are to receive correct picture background information. Fortunately, experience has shown that the lowest frequency of importance for the reproduction of a good quality picture, apart from the DC component, is the frame frequency; that is, 30 cycles. An amplifier that will accomplish this will be developed as the lesson progresses.

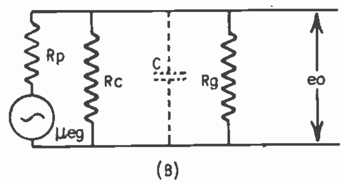
The causes and effects of the various types of distortion as mentioned will be dealt with more in detail when we come to the study of control room amplifiers. It will serve our purpose at this point if we understand that phase distortion at low frequencies will cause a very disturbing displacement of the actual picture components, that frequency distortion at the high end of the band effects the picture detail, and that amplitude distortion results chiefly in contrast differences. This type of distortion (amplitude) may occur in either the region of the highlights or the shadows, depending upon the diode connection and the operation of succeeding amplifier stages. *When we speak of the amount of contrast that is possible in a picture, we mean the number of shades that can be distinguished in the range between white and black;* this is largely dependent upon the *low frequency response* of the video amplifier. *The sharpness of contrast, however, indicates to what degree the dividing line between two shades is clearly defined and is simply another expression for picture detail.* In this case, however, it is the *high frequencies* that are of particular importance.

Assuming that we have gained a fair knowledge of some of the requirements for a satisfactory video amplifier, we may proceed to the actual circuit design of the amplifier itself.

4. VIDEO AMPLIFIER DESIGN -- HIGH FREQUENCY CONSIDERATIONS. The first consideration, of course, is the type of tubes to be used in the amplifier. The choice will be influenced by the amount of signal delivered by the second detector and the amount required by the picture tube itself. If this information is available, the selection of the amplifier tube will then hinge upon the amount of amplification possible at the necessarily wide frequency band, and this in turn may depend upon design practices followed in circuit construction. A typical stage of resistance-capacity coupled amplification is shown in Fig. 3A. So far as the high frequencies are concerned, this circuit may be resolved into that shown in Fig. 3B in which the input voltage e_g now acts as the voltage $Mu \times e_g$ in the plate circuit in series with the internal resistance of the tube, R_p. (Mu is the amplification factor of the tube.) The coupling condenser C_c is omitted, because at the higher frequencies its reactance is negligible. The capacities C_1 and C_2 (in Fig. 3A) represent, respectively, the output capacity of the first tube and the input capacity of the second plus the stray capacity resulting from wiring and placement of component circuit parts. Since R_c and R_g are in parallel, they may be replaced by a single resistor (R_{cg} in Fig. 3C) whose value is determined by the familiar parallel resistor formula. For the same reason, C_1 and C_2 may also be replaced by a single capacity (equal to $C_1 + C_2$), so that the final circuit may be reduced to that shown in Fig. 3C. Here it is seen that the voltage, $Mu \times e_g$ is impressed across the series combination R_p and

R_{cg}, and the output voltage e_o is taken from across R_{cg}. As we study this circuit, it will be noted that the larger the resistor R_{cg}, the greater will be the value of the output voltage e_o, due, of course, to the fact that R_p and R_{cg} form a voltage divider so that the voltage at the point X will be directly proportional to the size of the resistor R_{cg}.





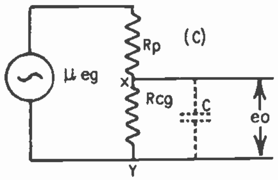


Fig.3 A resistance-capacity coupled amplifier and equivalent circuits (at high frequencies).

It should be noted that the value of the capacity C is of little consequence at the lower frequencies, but as the frequency of the input voltage is increased, the value of C becomes increasingly important; its reactance becomes less and less so that when the frequency of the incoming voltage is sufficiently high, the capacity C will act as an effective short circuit across this output voltage. Suppose, for example, that the frequency of the voltage impressed across XY is 3 megacycles, R_{cg} = 3,000 ohms, and the capacity of C = 50 mmf. Under these conditions, the reactance of C equals approximately 1050 ohms. It is quite evident that such a condition would be very effective in bypassing the higher frequencies to ground. As in the case of any filter circuit, if the value of the resistor R_{cg} is increased, due to an increase in R_c (Fig. 3A), the filtering action of the capacity C will become more effective. Since the gain of the stage is equal to $e_o \div e_g$, it is evident that the gain will decrease as the frequency is increased and that there must be a definite relationship between the values of R_c and the capacity C (Fig. 3B) if we are to obtain satisfactory high frequency output from this circuit.

Two possible methods of overcoming this loss at the high frequencies are suggested: first, by a reduction in the value of C and, second, by a device placed in series with R_c (3B) whose impedance will increase with frequency at such a rate as to compensate for the decrease in the reactance of C. Since C is composed of tube capacities plus the stray capacities due to wiring, it would be well to see what could be done in the matter of reducing these capacities. As a starting point, suppose we attempt to use as the video amplifier tube, a 6J5 amplifier triode, whose average characteristics are listed in the tube manual to be as follows: amplification factor, 20; plate resistance, 7700; Gm, 2600; grid to plate capacity, 3.4 mmf.; grid to cathode capacity, 3.4 mmf.; plate to cathode capacity, 3.6 mmf. Now, the tube's capacities affecting the amplifier circuit are not merely the sum of these interelectrode capacities, but rather a more complicated total arrived at by the following formula:

$$\text{Total capacity } C = C_{g-c} + C_{p-c} + C_{g-p}\ (1+A) \qquad (1)$$

Where: C = total shunt capacity in mmf.

C_{g-c} = capacity from grid to cathode of the output tube; that is, the next stage.

C_{p-c} = plate-cathode capacity of the stage under consideration.

C_{g-p} = grid to plate capacity of the output tube.

A = actual amplification of the stage, or $\frac{MuR_b}{r_p+R_b}$

Where: R_b = load resistance and r_p = tube plate resistance. (This value of A is satisfactory for our purposes, but, strictly speaking, it is true only when there is no reactance in the plate circuit of the tube.)

From the foregoing, it is seen, therefore, that we must take into consideration not only the actual tube in this video stage, but also the tube input capacity of the stage that is to follow.

Calculations of actual examples are helpful to a better understanding, so let us assume two stages of amplification employing 6J5 triode tubes. Assuming a gain of 7 (maximum for tube = 20) in the second stage, due to the use of a 3,000 ohm plate resistance (necessarily low for good high frequency response) and substituting the capacity values given in formula (1):

$$3.4 + 3.6 + 3.4(1+7) = 34.2 \text{ mmf.}$$

Note that the third term in this expression is derived from the stage which the plate circuit under consideration drives. Compensation must be made in the preceding stage for the stage whose plate circuit is being considered. Now, if we assume an additional capacity of 10 mmf. due to wiring, this brings the total value of C to 44.2 mmf., which at 3 mc. represents a reactance of only 1200 ohms shunted across a 3,000 ohm load resistor (R_c, Fig. 3B).

This last term in the formula for total capacity, that is, 3.4(1+7) is known as the *Miller effect* and is seen to be a major factor in calculating total tube capacity. It is, therefore, important that some method of reducing this effect be found if we are to have any effective overall decrease in the total capacity. In the first place, the use of another tube, such as the 56 type which has a maximum gain of 13.8 and the following capacities: $_{g-c}$ = 3.2 mmf., $_{p-c}$ = 2.2 mmf., and $_{g-p}$ = 3.2 mmf., would give us considerable capacity reduction, but not enough. The next thing is to look for a tube type having an extremely *low grid to plate* capacity rating. Such a reduction is accomplished in a screen grid tube by the introduction of the shielding screen between the grid and the plate. Although this shielding effect increases the gain of the tube, it also increases the plate resistance and in such proportion that nothing is gained in the use of this type of tube in the amplification of high frequencies. For example, in the case of the 6J5 having a plate resistance of 7,700 ohms and a plate load of 3,000 ohms, we obtained a maximum gain of approximately 7. Now, taking the case of a tube having a screen grid such as the 6J7 with a plate resistance greater than 1,000,000, an amplification factor of better than 1500, and using the same 3,000 ohm plate resistor as in the case of the triode, we could expect a maximum gain of approximately 3, less than half that of the triode! Although there was a reduction in the circuit capacity, there was also a distinct loss in the stage gain, so that we are no better off than we were originally. Since the mutual conductance of a tube is the ratio of its gain to its plate resistance ($G_m = Mu \div R_p$), this may well be taken as the *figure of merit* to guide in the selection of a satisfactory tube.

As a result of the stringent requirements placed upon amplifiers used in television design, the tube manufacturers were forced to build special tubes to meet these requirements. The type 1231 offered by the Hygrade Sylvania Corporation has a mutual of around 6,500 and others, such as the RCA 1851 and 1852, have a mutual of approximately 9,000. Now, using the same 3,000 ohm plate resistor as in previous calculations, we can expect an approximate gain of 25 from an 1851 type tube. The interelectrode capacities of this tube are as follows:

Grid to plate = .02 mmf.
Input capacity = 11.5 mmf.
Output capacity = 5.2 mmf.

Substituting these values in the formula for total capacity, we have $11.5 + 5.2 + .02 \times (25 + 1) = 16.7 + .52 = 17.22$ mmf. Of this total amount, it is seen that only .52 mmf. is contributed by the Miller effect; hence, for practical calculations involving the average screen grid type tube, we may neglect this factor entirely. In the case of the 1851 tube, a real gain has been made, for in addition to increasing the stage gain, there has been an effective reduction in tube capacity by a factor of approximately 2:1 over the 6J5 triode. By exercising extreme care in the circuit wiring, we may be able to reduce the stray capacity from 10 to 5 mmf., giving an overall capacity of 22.22 mmf. Although this provides for an increase in the high frequency response, the amplifier as it stands is still inadequate for a high definition television picture (involving signals well above 2.5 megacycles).

Fortunately, as was previously suggested, we may actually neutralize the effect of tube and circuit capacity. One of the most satisfactory methods in use to date accomplishes this result by the insertion of a small amount of inductance L in series with the plate load resistance as shown in Fig. 4. It is immediately apparent that any value of inductance L which may be selected will form a parallel resonant circuit with C at some definite frequency. The impedance across the terminals of a parallel resonant circuit is maximum at its resonant frequency, but the absolute value of this maximum may be limited by *resistance in the circuit.* Hence, for a satisfactory high frequency response, there must be a very definite relationship existing between the values of R_c, L, and C (Fig. 4). Since at parallel resonance X_L equals X_c (not L = C), we must choose a value of L such that its point of resonance with C will be well above the frequency band we wish to pass; otherwise, there may be a very definite peak at some frequency within the band. The procedure of peaking is used sometimes in compensating for certain circuit losses (aperture distortion). *In order to obtain a uniform frequency response over the high end of the band, it has been found that the value of L should be such that X_L equals one-half X_c and that the resistance of R_c should equal X_c.* (Values for X_c and X_L should be calculated at the highest frequency to be passed.) Slight variations from this general rule will be noted later in the study of control room amplifiers.

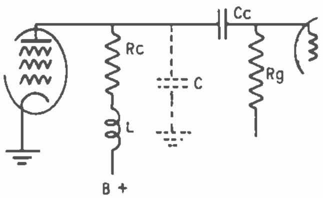


Fig. 4 A high frequency compensated video amplifier (X_c = R = $2X_L$ at top frequency, fo).

In a correctly compensated stage, the load offers more or less constant impedance to all frequencies of the band we wish to pass and, therefore, has a gain which is approximately constant and equal to $G_m \times R_c$ at all frequencies, including the top frequency f_o. This gain of $G_m \times R_c$ per stage, resulting from compensation, is equal to the gain the stage would have with zero capacity and no compensating choke, *which proves that the compensation is entirely adequate.* Without the compensating choke (but with $R_c = X_c$), the gain at the top frequency f_o is only $.707 \times G_m R_c$. However, it should be pointed out that even with compensation, the top frequency f_o cannot be increased indefinitely. As f_o increases, the value of X_c decreases and, consequently, the output load resistance R_c must also be decreased, since R_c must equal X_c. Since in a compensated stage:

$$\text{Gain} = G_m \times R_c \tag{2}$$

$$\text{and } R_c = X_c$$

$$\text{and } X_c = \frac{1}{6.28\ f_oC}$$

we may substitute the value of X_c for R_c in (2), so that now:

$$\text{Gain} = G_m \times \frac{1}{6.28\ f_oC} \text{ or } \frac{G_m}{6.28\ f_oC} \tag{3}$$

The highest frequency, therefore, which may be used in a compensated stage is reached when the value of f_o in (3) is such as to cause the stage gain to equal 1.

$$1 = \frac{G_m}{6.28\ f_oC} \text{ or: } f_o = \frac{G_m}{6.28\ C} \tag{4}$$

To clarify the procedure in video compensation, let us assume two amplifier stages using the 1851 type tube and proceed to calculate the actual values of R_c and L required for a flat frequency response up to 3 megacycles. We will assume the total capacity (tube and circuit) to be 22 mmf. Since the value of the plate resistor required must equal the reactance of the stage capacity at f_o:

$$X_c = \frac{1}{2\pi F_o C}$$

Substituting,

$$R_c = X_c = \frac{1}{6.28 \times 3{,}000{,}000 \times \frac{22}{1{,}000{,}000{,}000{,}000}}$$

$$= \frac{1{,}000{,}000{,}000{,}000}{6.28 \times 3{,}000{,}000 \times 22} = \frac{10^{12}}{6.28 \times 3 \times 10^{6} \times 22}$$

$$= \frac{10^{6}}{6.28 \times 3 \times 22}$$

$$R_c = 2410 \text{ ohms.}$$

Since X_L should equal one-half R_c:

$$X_L = \frac{2410}{2} = 1205$$

$$X_L = 2\pi f_o L = 1205$$

$$L = \frac{1205}{2\pi f_o} = \frac{1205}{6.28 \times 3{,}000{,}000}$$

$$= 64 \text{ Microhenries.}$$

In practical design a load resistor of 2500 ohms and a compensating inductance of 65 microhenries would satisfy our requirements. Since gain in a compensated amplifier is equal to $G_m R_c$, we may expect an approximate gain of 22 for this stage. $(9{,}000 \div 1{,}000{,}000 \times 2500)$.

The top frequency which can be amplified with this type tube may be obtained by use of equation (4). Substituting the known values from the previous problem:

$$f_o = \frac{9000 \div 10^{6}\,*}{6.28\ (22 \div 10^{12})}$$

$$= \frac{9000 \times 10^{12}}{6.28 \times 22 \times 10^{6}}$$

$$= \frac{9000 \times 10^{6}}{6.28 \times 22}$$

$$= 65 \text{ megacycles (approximately).}$$

* (Gm is expressed in micromhos, so must be changed to mhos.)

A few years ago, the amplification of such frequencies was considered impossible.

Of course, in order to design a stage of amplification with a gain of 1 at 65 Mc., it is necessary to substitute the value of f_o = 65,000,000 and solve as in the previous problem for the values of R and L.

Since a complete understanding of the mathematics involved in the solution of video amplifier problems is of great importance, suppose we solve several such problems. Take, for instance, the case of f_o = 65,000,000 c.p.s. given above. It would be interesting to know what values of R_c and L would be required (assume c = 22 mmf.).

$$R_c = X_c = \frac{10^{12}}{6.28\ (65 \times 10^6)\ 22}$$

$$R_c = 111 \text{ ohms (approximately)}$$

To check:

$$G_m \times R_c = 1 \text{ (stage gain)}$$

Substituting known values of G_m and R_c:

$$\frac{9,000}{1,000,000} \times 111 = 1 \text{ (approximately)}$$

Now to find the value of L:

$$X_L = \frac{R_c}{2} = \frac{111}{2} = 55.5 \text{ ohms.}$$

Also:

$$X_L = 6.28 \times 65,000,000 \times L$$

$$L = \frac{55.5}{6.28 \times 65 \times 10^6} = .136 \text{ microhenries.}$$

This value of L is so small that inductance due to circuit wiring alone will exceed this amount unless considerable care is exercised.

Another and easier way of finding the value of R_c (since we know the stage gain) arises from the fact that G_mR_c = 1.

$$\frac{9,000}{1,000,000} R_c = 1$$

$$R_c = \frac{1,000,000}{9,000} = 111 \text{ ohms.}$$

Finally, as a third example, let us go back to the original case of the 6J5 and 6J7 tubes and this time calculate the size of R_c and L required for high frequency compensation to 3 Mc.; also note the stage gain under these conditions. As previously given, the total capacity for the 6J5 tube was listed as:

$$3.4 + 3.6 + 3.4(1+7) = 34.2$$

Now the third term, 3.4(1+7), is based upon the use of a resistor of 3,000 ohms in the plate circuit which gave a tube gain of 7. Since experience has taught that for an amplifier stage compensated out to 3 Mc., the gain for the 6J5 is more likely to be of the order of 3, the C just given now becomes:

$$3.4 + 3.6 + 3.4(1+3) = 20.6 \text{ mmf.}$$

Assuming 10 mmf. stray capacity, we have a total of 30.6 mmf.

$$R_c = X_c = \frac{10^{12}}{6.28 \times (3 \times 10^6) \times 30.6} = 1700 \text{ ohms (approx.)}$$

$$X_L = \frac{X_c}{2} = \frac{1700}{2} = 850 \text{ ohms.}$$

$$850 = 6.28 \times (3 \times 10^6)\ L$$

$$L = \frac{850 \times 10^6}{6.28 \times (3 \times 10^6)}$$

(Numerator is multiplied by 10^6 in order to reduce the answer to microhenries.)

$$= 45 \ \mu h. \text{ (approx.)}$$

Similar calculations for the 6J7 follow. Since the Miller effect may be ignored in the screen grid tube, the sum of the input and output capacities of this tube equals 19 mmf. Allowing 10 mmf. for stray capacity, the total capacity becomes 29 mmf. This value is so near that obtained for the triode (30.6 mmf.) that the circuit requirements for correct compensation may be considered as being identical. The G_m for a 6J5 is 2,600 micromhos and for a 6J7 is 1225 micromhos. Hence, the gain for the 6J5 stage is:

$$\frac{2600 \times 1700}{10^6} = 4.42$$

Likewise, the gain for the 6J7 stage is:

$$\frac{1225 \times 1700}{10^6} = 2.08$$

5. LOW FREQUENCY CONSIDERATIONS. All that has been said previously about video amplifier design has related to the high frequency end of the band. It now becomes important to investigate what is happening at the lower end of the band, say, around 25 c.p.s. The low frequency response of an amplifier is determined largely by the grid coupling circuit, C_c and R_g in Fig. 4. In this region, the peaking coil L and shunt capacity C have negligible effects. Fig. 5a shows the equivalent circuit used in the calculation of attenuation at the lower frequencies. Now, the ratio of the signal voltage delivered to xy; that is, e_g to the available voltage of the plate circuit e_p is given by the expression:

$$\frac{e_g}{e_p} = \frac{R_g}{\sqrt{R_g^2 + X_c^2}}$$

(the ratio of R_g to the impedance of the circuit).

If R_g = 100,000 ohms and C_c = .1 mf. and assuming a frequency of 25 c.p.s., substituting these values in the foregoing equation, we have:

$$\frac{e_g}{e_p} = \frac{100{,}000}{\sqrt{(100{,}000)^2 + [(10)^6 \div (6.28 \times 25 \times .1)]^2}}$$

Solving this equation gives .84, which is to say the voltage e_g is 84% of the voltage of e_p, a loss of 100-84, or 16%, due to the C_cR_g combination. Now, this could be reduced by increasing the size of either C_c, R_g, or both. However, such procedure is not practical for reasons which we shall see. If the size of C_c is increased sufficiently to be satisfactory, besides being bulky and occupying valuable space, it becomes a source of increased circuit capacity effecting the high frequency compensation in a manner previously discussed. If we increase the size of the grid leak resistor R_g, we may run into trouble, due to grid currents. (Most of the tubes used in television amplifiers require grid leaks in the order of 100,000 ohms.)

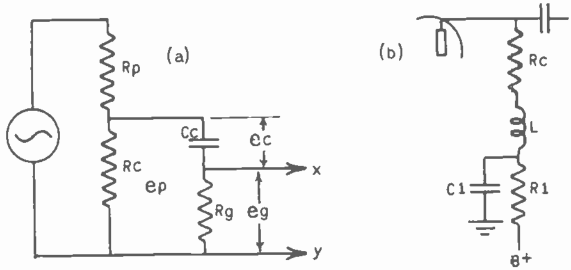


Fig. 5 (a) Fig. 4 reduced to its equivalent low frequency circuit. (b) Method for obtaining low frequency compensation.

The student should understand, however, that the important fact relating to C_c and R_g is the time constant T, since it is this factor which determines the low frequency response of RC coupled amplifiers. Since $T = C_c \times R_g$, it is apparent that the *product* is important and not the absolute value of either C_c or R_g. The significance of this time constant (discussed in a previous lesson) is that the condenser C_c will discharge to within 37% of its original value in C_cR_g seconds. (C_c must be expressed in *farads* and R_g in *ohms*.) Now, take, for example, the values given in the previous problem where C_g = .1 mf. and R_g = 100,000 ohms. The time constant T will equal $(.1 \times 100,000) \div 1,000,000 = .01$ second. (.1 is divided by 1,000,000 because it must be changed from microfarads to farads.) Now, this time constant being .01 second indicates that the combination will be satisfactory for a frequency of 100 c.p.s., but in order to be satisfactory for 25 c.p.s., it would have to be four times as great, or .04 second. This, of course, can be obtained by multiplying the value of either C_c or R_g by 4, or multiplying them each by 2. However, there are many cases where this would not be satisfactory for the reasons already discussed. We should, therefore, look for some method by which low frequency compensation can be accomplished. Low frequency response is important if the receiver is to transmit the slow changes accompanying the gradual shifting of background illumination; otherwise, the received picture will contain false values of lights and shadows. Another matter of importance at these low frequencies is phase shift; however, this subject relates more to control room video amplifiers and will, therefore, be discussed later.

Now, if the value of R_c can be made to increase automatically at the lower frequencies without affecting operation at the higher frequencies, naturally, the amplification would tend to remain at a constant value. One of the simplest and most effective means of holding this amplification constant at the low frequencies is shown in Fig. 5b. R_1 is a series resistance in the plate load shunted by a condenser C_1; C_1 acts to short circuit R_1 at the higher frequencies, but as the frequency becomes lower, its reactance becomes greater and greater, thereby causing the resistance of R_1 to become more and more effective. The values of C_1 and R_1 may be so chosen that they will compensate for the low frequency loss due to the coupling condenser C_c and grid leak R_g.

Although the frequency response curve remains practically constant as the low frequency end is approached, the student should understand that the total load impedance is increasing and, therefore, the amplification increases, but that this increase is just sufficient to take care of the loss caused by R_gC_c, so that the overall change in signal amplitude is zero. Although R_1C_1 form a very effective filter for the higher frequencies, an additional section must be employed, using a greater RC value if it is desirable to obtain effective filtering at the very low frequencies (to prevent motorboating).

Ordinarily, the value of C_1 is around 2 or 3 mf. and should, therefore, be a paper condenser; economic reasons, however, may require the use of an electrolytic. In this case, C_1 should be shunted by a small paper condenser in the order of .1 mf. for the reason that an electrolytic condenser becomes increasingly ineffective as we go above 100,000 cycles. Hence, in a circuit involving high frequencies, if an electrolytic condenser is used, it should be paralleled with a small paper condenser. For example, when using self-bias, the 1851 tube requires between 160 and 300 ohms in the cathode circuit and, if the low frequencies are to be satisfactorily bypassed, condenser values of 200 to 350 mf. are necessary. In this case, an electrolytic would be used, but shunted by a small paper condenser. This method of low frequency compensation gives best results only when R_1 is large compared to R_c (Fig. 5b). This arises from the fact that the time constant of this plate circuit is based on the paralleled effect of R_c and R_1; instead of being R_1C_1 it is $[(R_cR_1) \div (R_c + R_1)] \times C_1$. This problem relates more to the design of a chain of video amplifiers, such as used in the control room, rather than the one or two stages following the second detector in a television set.

Some of the advantages of this type of low frequency compensation may be listed as follows: First, the use of a physically small coupling condenser C_c is made possible. As stated previously, this has constructional advantages; also, the danger from hum is reduced. It is well known that resistance coupled amplifiers are quite susceptible to hum pickup, and a large grid coupling condenser only tends to aggravate this condition. Second, the value of the grid leak R_g can be kept relatively low, thereby eliminating grid charging effects, but, at the same time, aiding in the further reduction of hum effects. Third, the use of small coupling condensers (smaller cap., but higher voltage rating) provides a safeguard against the possibility of DC leakage currents which might charge the grid positive and cause instability. This is of particular importance in the first of a chain of amplifiers where extremely small leakages in the coupling condenser can cause very annoying results in the output. Fourth, the compensation device R_1C_1 forms a very satisfactory decoupling device between stages (except at the frequencies below 50 cycles), thereby assisting in the elimination of frequency instability caused by interstage coupling. Fifth, this type of compensation gives a fairly sharp cut-off to those frequencies below the low end of the band. This is preferable in a chain of amplifiers for the reason that if cut-off is too gradual, the amplifiers will respond to the lower frequencies in a manner so as to cause a "grid choking effect" when changes are made in any volume control located near the head of the chain. This is the result of strong DC impulses which develop surge voltages when such a volume control is changed; these surges charge the grids (positive or negative) so that the tubes may cease to amplify, sometimes for several seconds.

6. DC CONSIDERATIONS. Attention has already been called to the necessity for passing what amounts to a DC current through the video amplifier. In Fig. 6 is shown a single stage video amplifier, coupling the output of a diode detector to the grid of a picture tube. Here, the grid of the amplifier tube is shown directly connected to the output of the detector. The plate of the video amplifier tube should also be directly coupled to the grid of the picture tube, but it is not practical for several reasons. To begin with, the life of the cathode ray television picture tube is governed to a certain extent by its emission current and this, in turn, is controlled by the bias voltage. Now, if the grid is directly connected to the plate of the video amplifier, it would be subjected to sudden surges affecting the bias and resulting in abnormal beam current. If, for example, the plate current of the video amplifier is reduced to zero, the bias on the picture tube would be reduced as a result in the changed IR drop across R_c and R_1. With this reduction in bias, the screen would be brilliantly lighted by the full emission of the cathode. (Protective circuits have been designed that will overcome this difficulty, but additional tubes are required.) Hence the practical way is to connect the grid of the picture tube to the plate of the video stage in the usual manner. This of course means the use of the coupling condenser C_c. To prevent plate current surges, condenser coupling is often used between the detector and the video stage. From our knowledge of condensers, it would seem that this would render impossible the passage of the much desired DC signal.

Fortunately, there is a method by which the effect of the DC component can be restored, This is accomplished by use of T_2 in connection with correct circuit constants. A thorough understanding of the action of this circuit can best be had after we study the transmission of a television signal with its DC component. At this stage, the student must accept the fact that we will have a satisfactory DC restoration (lost due to condenser Cc) if we are able to bring the synchronizing peaks of successive lines to a common level such as indicated by line x in Fig. 6. That is the purpose of T_2, and its action can best be explained if we first examine a few lines of a video signal.

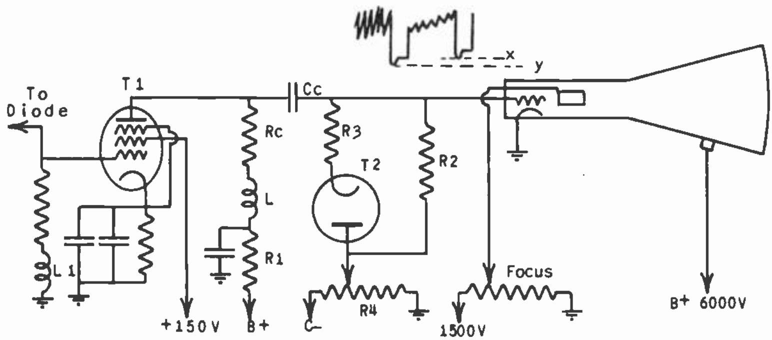


Fig.6 A video amplifier incorporating a DC restoring circuit.

In Fig. 7(a) are shown four lines of a video signal as they might appear at the grid of a cathode ray picture tube when preceding amplifier stages are direct coupled. Here it should be noted that the tops of the B.O. signals have a common level as represented by line nn', and that this level represents black in the picture (voltage sufficiently negative to bias a picture tube to cut-off). This black level may be referred to as the picture reference point since all like shades of gray in the picture will occur at equal voltage levels above nn'.

Had this picture signal been amplified in an AC (condenser) coupled system, the approximate result might be as illustrated in Fig. 7(b) (greatly exaggerated for illustration purposes). Here it is seen that a definite level for black no longer exists and that the video signal arranges itself about the bias axis pp' (fixed bias on the picture tube) in such a manner that the areas above this axis will equal those below. (A detailed description of this effect will be given in the next lesson). It must not be overlooked that this shift about the bias axis takes place over a definite period of time (the circuit time constant), determined by the coupling condenser and grid leak values. This accounts for the slope in line 2, which in most instances might be continued over a period of many lines. A comparison of the lines in (a) with the same lines in (b) reveals this interesting difference: In (a), the picture signal of lines 2 and 3 is very definitely in the white region; that is, the background or average signal level is very bright, while in (b), line 2 shows the effect of the shifting of voltage above the bias axis pp' in that the start of the line is in the white region and the finish has progressed in the direction of dark; line 3 then has its entire average level shifted in the dark direction so that in the reproduced picture, line 2 would appear bright at the start and taper off to a darker level which would be continued through line 3. If the picture tube bias represented by pp' is such that the signal level indicated by nn' is sufficient to cut the tube off, any signal having a greater negative voltage (such as shown at xx') will produce no visible effect at the black end. The light portion of the picture signal [case of line 3, Fig. 7(b)], however is shifted with relation to the picture tube bias (pp') so that what was originally (Fig. 7a) a line of picture with an average background of almost white has become the same picture with an average background of gray.

From these facts it becomes evident that such a condition must result in false values of light and shadow in the reproduced picture. Hence, it is the purpose of the diode T_2 of Fig. 6 to automatically restore, as nearly as possible, the variations of video signal amplitudes as represented by Fig. 7b to the condition shown in Fig. 7a.

The operating point (point pp' in Figs. 7b and 7c) of the cathode ray tube is set by the bias resistor R_4 (Fig. 6). Any value of signal extending below pp', such as xx', will cause the diode to conduct (cathode becomes negative with respect to plate) and thereby automatically reduces the negative bias on the grid of the cathode ray tube. In other words, the bias will for the time being shift to a less negative value such as represented by LL' (Figs. 7b and 7c). This changes the grid operating point so that the signals having a maximum negative value will be shifted in a sufficiently positive direction so that the synchronizing peaks will reach the qq' level. This action is pictured in Fig. 7c. Here the solid lines of the video signal represent the result of AC coupling and pp' is the bias operating point of the tube; the change in bias due to the diode is represented by the dotted lines with LL' representing the newly established operating point for the tube. (Follow figures carefully.)

In normal picture reception it is usually desirable to select the values of C_c and R_2 (Fig. 6) so that the circuit time constant will be sufficiently slow to maintain an average brightness level over a whole picture frame (441 lines).

The resistor R_3 is used to reduce the possibility of capacity from T_2 affecting the high frequency response of the video circuit.

In some instances where more than one stage of video amplification is used, it may be desirable to restore the DC component in a stage having opposite signal polarity to that on the grid of the picture tube. In this case, the connections to the diode would have to be reversed.

Another method is sometimes employed when the synchronizing is positive with respect to the picture at the grid of the amplifier tube. In this case, the tube bias is adjusted to a value such that minimum synchronizing peaks will drive the grid up to zero bias; all peaks above this minimum will, therefore, drive the grid positive, with the result that grid current flows and the bias shifts to a more negative level, thereby tending to hold all synchronizing peaks at a common level.

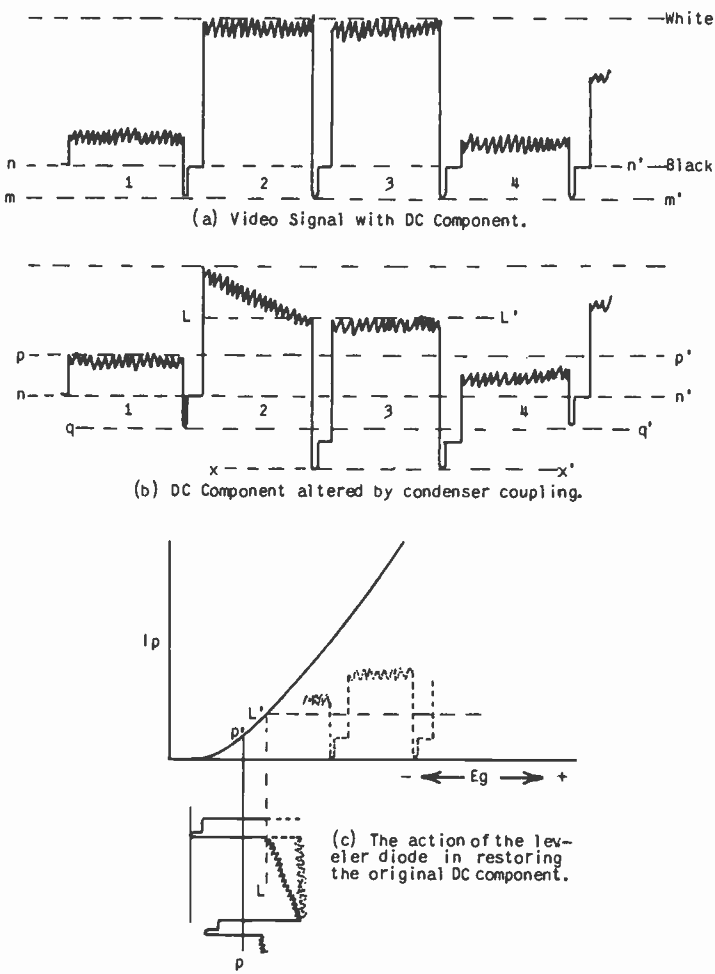


Fig.7 Reproducing the DC component in an AC coupled amplifier. (Drawings greatly exaggerated)

7. SIGNAL VOLTAGE REQUIREMENTS. Now, if in Fig. 6 we have an output from the second detector of 3 volts, peak to peak, and we use an 1851 tube at T_1 with the correct circuit constants to obtain an amplification factor of 22, we shall have around 3×22, or 66 volts peak to peak picture signal to apply to the grid of the cathode ray picture tube. Of course, the amount of signal required for the correct operation of the picture tube will vary somewhat with different types of tubes, but for the average tube in use today, this amount of signal should be quite sufficient.

If for any reason it should be desirable to use two stages of video amplification in place of one, the design should be comparatively simple if the student understands the fundamentals which we have discussed in connection with the design of a single stage. In a later lesson when we study the design of control room amplifiers, successive stages of video amplification and their problems will be discussed in detail.

Finally, it should be pointed out that since this is a single stage amplifier, the input capacity of T_1 should be compensated for in the output circuit of the diode detector. Likewise, the input capacity of the cathode ray tube must be taken into account when calculating the values of R_c and L necessary for compensation.

EXAMINATION QUESTIONS

INSTRUCTIONS. Before starting to answer these examination questions, you should have studied the lesson material at least three times. Be sure that you understand each question--then proceed to write the best answer you can. Make all answers complete and in detail. Print your name, address, and file number on each page and be neat in your work. Your paper must be easily legible; otherwise, it will be returned ungraded. Finish this examination before starting your study of the next lesson. However, send in at least three examinations at a time.

1. Why is it preferable to use a minimum number of video amplifying stages?

2. Assuming 100% for total video signal amplitude, what is the maximum percentage that is allowable for picture signal (in the U.S.) amplitude?

3. Name two ways of changing the polarity of the video signal applied to the grid of the picture tube in a television receiver (at the receiver).

4. What picture quality is related to the low frequency response of the video amplifier?

5. What tube characteristic may be taken as the figure of merit for a television amplifier?

6. Give a rule for compensating an amplifier at the high frequencies.

7. Assume an amplifier stage having a total capacity of 20 mmf. (tube, stray, etc.); calculate the required size of plate resistor and peaking coil for flat frequency response out to 3.5 megacycles.

8. What circuit constants are effective in reducing the low frequency response of an amplifier?

9. How may amplifier compensation be accomplished at the low frequencies?

10. What picture information is contained in the DC component?

RADIO MANUFACTURERS ASSOCIATION
TELEVISION TRANSMISSION STANDARDS

1. *TELEVISION CHANNEL WIDTH*
The standard television channel shall not be less than 6 megacycles in width.

2. *TELEVISION AND SOUND CARRIER SPACING*
It shall be standard to separate the sound and picture carriers by approximately 4.5 Mc. This standard shall go into effect just as soon as "single side band" operation at the transmitter is practicable. (The previous standard of approximately 3.25 Mc. shall be superseded.)

3. *SOUND CARRIER AND TELEVISION CARRIER RELATION*
It shall be standard in a television channel to place the sound carrier at a higher frequency than the television carrier.

4. *POSITION OF SOUND CARRIER*
It shall be standard to locate the sound carrier for a television channel 0.25 Mc. lower than the upper frequency limit of the channel.

5. *POLARITY OF TRANSMISSION (NEGATIVE)*
It shall be standard for a decrease in initial light intensity to cause an increase in the radiated power

6. *FRAME FREQUENCY*
It shall be standard to use a frame frequency of 30 per second and a field frequency of 60 per second, interlaced.

7. *NUMBER OF LINES PER FRAME*
It shall be standard to use 441 lines per frame.

8. *ASPECT RATIO*
The standard picture aspect ratio shall be 4:3.

9. *PERCENTAGE OF TELEVISION SIGNAL DEVOTED TO SYNCHRONIZATION*
If the peak amplitude of the radio frequency television signal is taken as 100%, it shall be standard to use not less than 20% nor more than 25% of the total amplitude for synchronizing pulses.

10. *METHOD OF TRANSMISSION*
It shall be standard in television transmission that black shall be represented by a definite carrier level independent of light and shade in the picture.

11. *SYNCHRONIZING*
The frame synchronizing shall be serrated with double line frequency impulses preceding and following the serrations as shown on RMA Drawing 1-111. (This drawing is reproduced in the following lesson.)

12. *TRANSMITTER MODULATION CAPABILITY*
If the peak amplitude of the radio frequency television signal is taken as 100%, it shall be standard for the signal amplitude to drop to 25% or less of peak amplitude for maximum white.

13. *TRANSMITTER OUTPUT RATING*
It shall be standard in order to correspond as nearly as possi-

ble to equivalent rating of sound transmitters, that the power of television picture transmitters be nominally rated at the output terminals in peak power divided by four.

14. *RELATIVE RADIATED POWER FOR PICTURE AND FOR SOUND*
It shall be standard to have the radiated power for the picture approximately the same as for sound.

CHIEF DIFFERENCES IN THE ENGLISH TELEVISION SYSTEM

5. *POLARITY OF TRANSMISSION (POSITIVE)*
It is standard for a decrease in initial light intensity to cause a decrease in the radiated power.

6. *FRAME FREQUENCY*
25 per second and a field frequency of 50 per second, interlaced.

7. *NUMBER OF LINES PER FRAME*
405 lines.

9. *PERCENTAGE OF TELEVISION SIGNAL DEVOTED TO SYNCHRONIZING*
30% of total signal amplitude devoted to synchronizing pulses.

Notes

(These extra pages are provided for your use in taking special notes)

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UNIT NO. 5

TELEVISION SYNCHRONIZING AND DEFLECTING CIRCUITS

LESSON NO. 10

THE PROCESSION OF LIFE

.....from primeval era to Television.

We who are faced with the problem of making a substantial living today, may be inclined to believe that fifty years is a long, long time. Some people are even reluctant to devote one or two years to preparing themselves for more profitable employment. While we know that you are not so inclined, let us for a moment talk about the history of our earth.

Millions of years ago, life on earth began with the creation of queer looking creatures which lived in the water. They had neither skeleton nor external shell. Then in slow succession came creatures with a hard covering and vertebrae; the age of fish and the first sign of ground with its primitive trees, creatures with lungs; then serpents, lizards, and fern choked swamps.

Then came the age of reptiles, great queer shaped creatures which lived on land and in water; followed by the appearance of grotesque mammals and reptiles, which took to the air. Reptiles now ruled supreme....later to vanish during the age of mammals which evolved into huge dinoceras. Bones from these mammals are being dug from the ground by archaelogists today.

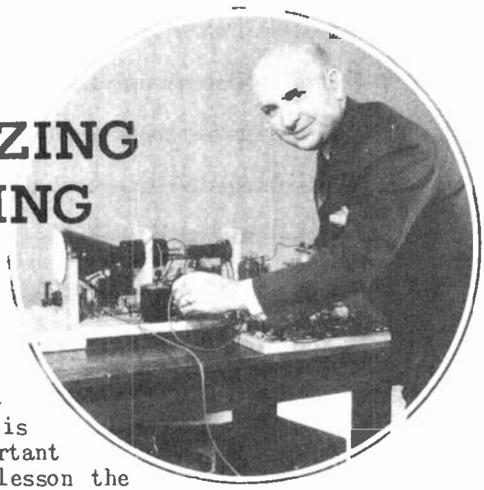
Time passes....years....millions of them, and we come to the age of animals preceding the creation of man. While science and the Bible differ on the evolution of the earth, regardless of our beliefs, we cannot help but agree on this one point....the perplexing and marvelous development of our earth was not accomplished over night.

The development of human life upon our earth was spread over millions of years. The development of your success may be spread over only one, two, or three years. Great accomplishments take time. The earth as we know it today evolved over a tremendous period of time. Your success can be achieved in so short a time that it will not even be measured in history.

Television represents an ultimate in human achievement. You, Mr. Student, are taking an active historical part in THAT GREAT ACHIEVEMENT.

Lesson Ten

TELEVISION SYNCHRONIZING & DEFLECTING CIRCUITS



"A complete knowledge of television requires the study of a wide variety of actions. However, as with other fundamental studies, there is usually one action more important than the others. In this lesson the material covered is of utmost importance. Therefore, I hope you will study it thoroughly.

"If you have been studying each lesson three times, this one should be covered six times before progressing to the next lesson."

1. INTRODUCTION. In the preceding lesson, special attention was paid to the circuits handling the video signal between the output of the second detector and the grid of the picture tube. Also, mention was made of the fact that the video signal contains two parts in addition to the picture signal. In this lesson, we shall see how these two parts of the video signal are utilized; that is, the blanking out and the synchronizing.

In a previous lesson, information was given on the various types of sweep circuits, sometimes called scanning circuits; now it becomes necessary to be more specific as we relate the scanning circuits to the actual television receiver. In Fig. 1 is shown a block diagram of the various parts of a television receiver with the exception of the power supplies. The circuits we are about to study are extremely important in that all picture transmission and reception is more or less at the mercy of these circuits; that is, the synchronizing separating circuits, the horizontal deflecting circuits and the vertical deflecting circuits. To be more specific, we may have a perfect video signal delivered to the grid of the picture tube, and the deflecting circuits which trace the pattern on the end of the picture tube may be functioning perfectly, in that the pattern is free of all distortion, but unless the synchronizing separating circuits are functioning correctly, the received picture may be of little value. The pattern produced by the combination of the vertical and horizontal sweep circuits may not be perfect; there may be distortion along the edges, or there might be some defocusing of the beam itself, but such deficiencies could be tolerated in the picture more readily than a failure in synchronizing. This is understandable when we realize that it is the synchronizing signal which causes each line and each frame of the received picture to be in exact step with each line and each frame of the scanning circuit in the camera which is picking up the picture for transmission. In these circuits, we speak of time in the terms of a millionth of a second (a microsecond); time so infinitely short that it is impossible for the mind to comprehend. The fact that one millionth of a second variation in the time of the horizontal synchronizing signal will make a change in the actual picture itself seems incredible; it should serve to remind us all of the importance of little things. The study of television is really one revelation after another of the importance of the very little things; the received picture is a result of the unifying of a great number of details at exactly the correct time to produce astonishing and almost miraculous results. It cannot be overemphasized that the overall quality of the television picture will be very largely determined by the careful attention given to these details all along the line of transmission and reception.

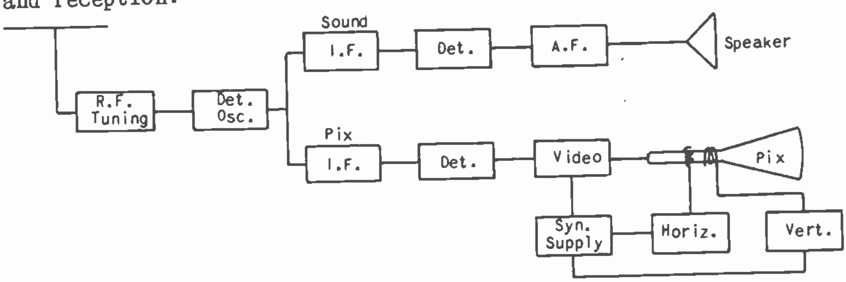


Fig.1 Block diagram of a Television Receiver (Less Power Supply).

At present, there is no set commercial practice as to the chassis construction or location of these various units in the receiver. Although all units may be placed on a single chassis, design considerations may make it desirable to construct the deflecting circuits on a different chassis; the synchronizing separating circuits may be either a part of the deflecting circuit chassis or located on the main video chassis. If the cathode ray picture tube is comparatively lengthy, particularly the 9" or 12" type, it will very likely be mounted vertically in the cabinet. Then the picture would be viewed as a reflection from a mirror in the top lid of the cabinet which could be raised or lowered to suit the viewer's requirements. Some manufacturers prefer to have separate units so that their manufacturing tests may be simplified, or production speeded up, while others may use a single chassis as a means of cutting production costs. In the final analysis, the overall design will be determined largely by the manufacturer's design and production practices.

2. SEPARATION CIRCUITS THEORY. Since the synchronizing separating circuits form the only connection between the video amplifier

and the sweep circuits, it is desirable that we begin the study of such circuits at this time.

These separating circuits perform two acts of separation; the first being the one of separating the synchronizing from the video signal, and the second, the separation of the vertical from the horizontal synchronizing impulses. In order that there will be no confusion regarding the action of the synchronizing separating circuit, the student should understand that somewhere between the output of the second detector and the grid of the picture tube, there is a fork in the road, so to speak, which the video signal travels so that part of the signal goes to the grid of the next amplifier, or perhaps the picture tube, while the other part travels the highway of the synchronizing separator circuit, there being no difference in the general appearance of the signal in either circuit. Now, when this signal reaches the synchronizing separating circuit, it finds the door closed to everything except the synchronizing signals themselves; in other words, the synchronizing signals are literally clipped from the picture signal. These are passed on to a second circuit which separates the vertical from the horizontal synchronizing signals.

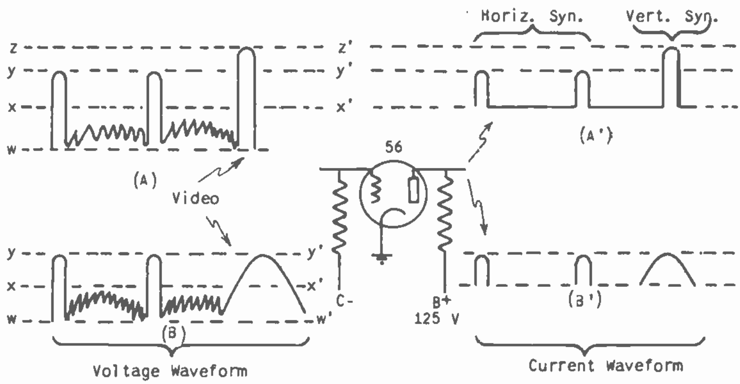


Fig.2 The action of a synchronizing separating circuit. (a) and (b) represent two lines of a simple video signal. (a') and (b') represent the separated synchronizing signals.

In order to understand this action, let us refer to Fig. 2. Here we have the simplest type of picture signal in which the blanking out and synchronizing are one and the same thing. Both Figs. 2A and 2B represent the two last lines of a picture, the only difference being that in A the vertical synchronizing signal has greater amplitude than the horizontal (represented by the distance between y and z), while at B the vertical synchronizing signal is of the same amplitude as the horizontal, but has much greater width or time duration. Now when such a signal as represented by either A or B is fed to a circuit such as shown, employing a tube such as a type 56, the action of the circuit in clipping the synchronizing signal from the picture is shown at A' and B'. Special attention is called to the fact that the synchronizing impulses shown at A' and B' represent current waveforms and, consequently, the waveform of the voltage would be in opposite phase; that is, the synchronizing voltage would be negative instead of positive. The waveform of current was used in order to simplify the explanation. The action of this separating circuit is extremely simple and very easily understood if we refer to Fig. 3. The grid-voltage, plate-current characteristics for two values of plate voltage are shown for a type 56 triode. It will be seen that the curve for a plate voltage of 100 will have a cut-off at approximately -8 volts bias; hence, the tube will

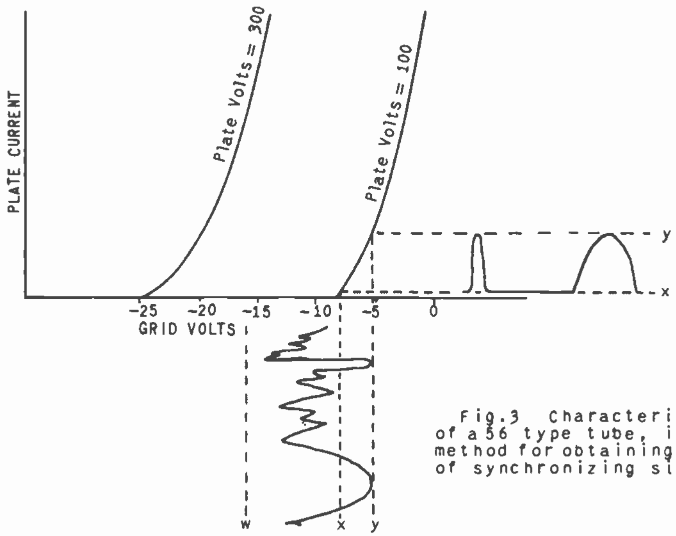


Fig.3 Characteristic curves of a 56 type tube, illustrating method for obtaining separation of synchronizing signals.

not allow plate current to flow unless this bias value is reduced. (When radio tube specifications state that plate voltage should be 250 volts or screen voltage should be 100 volts, these values are to be applied directly to the elements and, therefore, the plate supply to an amplifier employing resistance coupling would, necessarily, be greater than the specified plate voltage by the amount of the drop in the plate resistance under ordinary operating conditions.) Now, if a video signal such as shown in Fig. 2B is applied to the grid of the separator tube so that the picture signal itself does not exceed the amplitude represented by x, which in this case is cutoff for the tube, then only the synchronizing impulses as represented by the amplitude x-y will be passed by the tube. The correct adjustment of the bias voltage will depend upon the total amplitude of the video signal and the method of grid coupling employed. This brings up a subject not so generally understood and will, therefore, require further explanation. Before proceeding with this explanation, however, this can be pointed out: the process of separation may be accomplished by using any value of plate voltage from 25 to 250 volts, the choice being determined largely by the amplitude of the video signal itself and the sharpness of cut-off desired. As we decrease the value of plate voltage used, the cut-off point for the tube becomes sharper and the grid voltage required for cut-off is decreased; the reverse, of course, is true for an increase in plate voltage.

Now, we shall see how coupling and video amplitude affect the value of bias used to obtain satisfactory separation of the synchronizing from the picture signals. In Fig. 4 are shown two conventional types of amplifiers: (A) Condenser coupled; (B) Direct coupled. Although the same signal is fed to the grid circuit of each of these amplifiers, the signal output of A is different from that of B. Your understanding of the fundamental reasons which cause these two signals to differ will largely determine how well you will be able to understand certain actions later in the discussion of control room amplifiers. For this reason, the student is urged not to pass up this explanation until he has made sure that he thoroughly understands it. It is further recommended that he refer to Lesson 11, Unit 1, and review condenser theory.

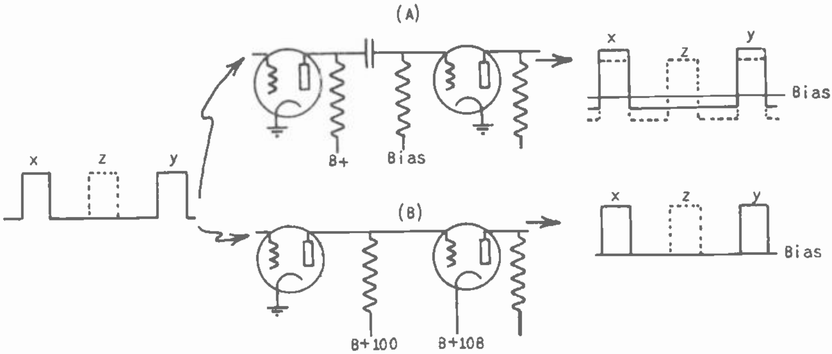


Fig.4 (A) AC-coupled amplifier. (B) DC-coupled amplifier.

Referring to Fig. 4A, let us assume that a signal having a waveform represented by the two impulses x and y be applied to the grid of this amplifier circuit. The output of this amplifier now appears to have exactly the same waveform as the input; however, there is this one particular difference, the impulses x and y have now assumed a definite relationship with respect to the bias of the output tube. *Now, this bias forms a fixed axis about which the signal will vary in such a manner that the area represented above the axis equals that below.* If the original signals x and y be increased to three signals x, y, and z (by change in fundamental frequency) as indicated by the addition of dotted impulse z, it will be noted in the output that another shift in the position of the signal with respect to the bias axis has occurred (shown by the dotted lines).

This action is one that the radio engineer has had very little reason to consider, but its tremendous importance in television will become more and more apparent as we proceed with the study of the subject.

Now, suppose the amplitude of this new signal as shown in the dotted lines x, y, and z is just sufficient to drive the grid of a third stage of amplification to zero; then if the third impulse z be removed from the input (frequency reduced), the output waveform will be shifted in a positive direction so that the impulses x and y will actually drive the grid of the following amplifier positive. The amplification of the signal has not changed, but its position about the bias axis has changed.

Of course, the result of AC coupling a signal such as shown in Fig. 4A is rather extreme because of the very special type of waveform selected. It should be understood that to complete the shift about the bias axis may require a number of cycles, depending upon the time constant (RC) of the circuit and the nature of the input signal. If in the original case, when the frequency of the square - top waveform was increased, a corresponding reduction in the time duration of x, y, and z had been made (narrowed in the drawing), there would have been no shifting about the bias axis.

In the case of the direct-coupled amplifier shown in Fig. 4B, there is no change in the relationship of the original signals, x and y, to the bias axis, even after the increase in frequency.

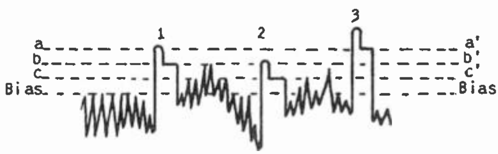


Fig.5 Three lines of video signal having variations in synchronizing impulse level due to AC-coupled amplifiers.

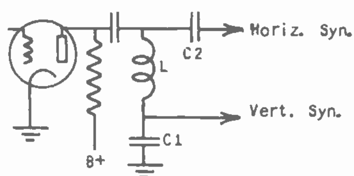
With AC or condenser coupling in mind, let us return to the problem of correct bias for the separation of the synchronizing signal from the picture signal. Fig. 2 illustrated how, if we apply a bias to an amplifier stage of such a value that the level xx' in either A or B occurs at tube cut-off, we would obtain the desired output shown by A' and B'. The picture signal is a series of impulses having amplitude and frequency variations, depending upon the type of picture being transmitted. Bearing this in mind, it is understandable how, in a condenser coupled system, that the level of the synchronizing signal peaks might be continually shifting so that a fixed level for the synchronizing signal (important for satisfactory synchronization) would not exist. An example of such a condition is illustrated by Fig. 5. Here, three lines of video signal have shifted their voltages about the bias axis, as a result of condenser coupling, so that all synchronizing signal peaks are at different voltage levels with respect to the bias. If the separating circuit has been adjusted to clip the synchronizing signal at a level such as aa', only the number 3 impulse will be effective as a synchronizing signal. On the other hand, if selection has been set to occur at the cc' level, B.O. and parts of the picture signal are clipped as parts of the synchronizing signal. This condition operates to reduce the effectiveness of the synchronizing signals.

For this reason, therefore, the separating circuit should take its input either from the load circuit of the 2nd detector, which contains the DC component, or from some point in the video amplifier circuit where this DC level has been restored.

Now, the value of bias required to satisfactorily clip off the synchronizing signal is not necessarily the cut-off voltage of the tube. It may be above or below this value, depending upon the total amplitude of the video signal and the method used to couple the signal to the grid.

In order that the synchronizing signal be free of picture signal, that is, no picture signal occurs in the base line of the separated signal, it is desirable that the separating tube have a sharp cut-off point. It should also have a high transconductance so that additional amplification of the synchronizing signal would not be necessary. Such tubes as the 6C5, 6J7, and the 1852 serve this purpose very well.

Fig.6 Fundamental circuit for separating horizontal and vertical synchronizing signals (Frequency selection).



After the synchronizing signals have been separated from the picture signals, it becomes necessary to separate the vertical synchronizing from the horizontal synchronizing signals. The vertical synchronizing signal shown at Figs. 2A' and 2B' represent two distinct types, each requiring a different method of separation. The signal at A' has greater amplitude than the horizontal synchronizing and can, therefore, be separated in exactly the same manner as the synchronizing and picture signals, that is, by *amplitude selection;* as previously suggested, this is accomplished by adjusting the bias on the pick-off tube so that the level y'y (Fig. 2A') will occur at cut-off. Since the voltage represented by the output of our pick-off circuit is actually negative, we cannot run the output of this clipper stage directly to the grid of a second clipper stage and expect it to work satisfactorily since this type of pick-off requires that the synchronizing impulse be in a positive direction. There are several ways, however, of obtaining the desired results; one being to connect a second stage in parallel with the first stage, that is, the two grids are tied together, the vertical pick-off tube having the greater bias so that in its output there will appear only the vertical impulse as represented between the levels y and z. The other tube would have the normal output as shown at A'. By employing a different type of pick-off method which we shall presently discuss, it would be possible to take the signal directly from the plate of our present signal tube.

At B', the vertical synchronizing impulse is of the same amplitude as the horizontal synchronizing impulses and will, therefore, require an entirely different method of separation. It will be noted that the vertical synch. signal has a much greater *time duration* than the horizontal; because of this, it will be passed by low frequency circuits (with very little loss in amplitude) while the comparatively short duration horizontal synch. signal will be completely lost. Hence, this action is known as *frequency discrimination*.

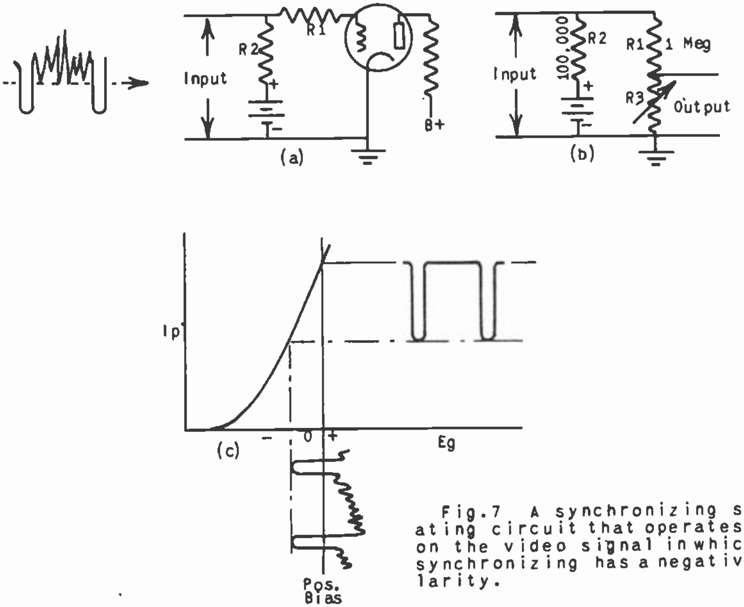


Fig.7 A synchronizing separating circuit that operates only on the video signal in which the synchronizing has a negative polarity.

Fig. 6 shows a fundamental diagram of a frequency separating circuit. The action of this circuit is as follows: Condenser C_2 is of sufficiently small capacity to offer high impedance to a low frequency signal such as the vertical synchronizing impulse, but it will pass the horizontal synchronizing impulse with practically no attenuation. The inductance L offers very high impedance to the frequency of the horizontal synchronizing impulse, but practically no impedance to the low frequency vertical synchronizing impulse. Hence, it will pass the vertical minus most of the horizontal synchronizing. The small amount of horizontal synchronizing which may actually get through L is passed to ground through the condenser C_1 which is sufficiently small to offer high impedance to the low frequency vertical impulse but acts practically as a short circuit to ground for the higher frequency horizontal impulses.

The type of separator circuit shown in Fig. 2 requires that the synchronizing signal be positive with respect to the picture. Fig. 7a shows another circuit for accomplishing the same results, but this time the synchronizing signal must be negative with respect to the picture signal. R_1 is a very large resistor in series with the input circuit; R_2 is the conventional grid leak resistor, but the bias is made positive instead of negative. The amount of positive bias required depends upon the peak amplitude of the video signal. For the sake of clearness, the circuit at (a) is reduced to its equivalent and values are assigned to R_1 and R_2 in Fig. 7b. R_3 represents the input impedance of the tube; its value varies with the signal amplitude and makes this type of separator circuit possible. For example, when R_3 is large (grid is negative) in comparison with R_1, a major portion of the input signal will appear across R_3. If, on the other hand, R_3 is very small (grid is positive) in comparison to R_1, most of the input signal will be lost across R_1. Let us see what happens when a signal is applied to the grid of the circuit shown. Since positive bias lowers the input impedance of the grid, the more we increase this positive bias, the more we will decrease the input impedance. With the picture signal positive with respect to the synchronizing and producing positive voltage variations on the grid, the tube is caused to draw grid current; this in turn reduces the input impedance R_3 to such an extent that it becomes low in comparison with R_1. Consequently, most of the picture signal voltage is lost across R_1. The synchronizing impulses drive the grid in a negative direction, below zero grid bias, thereby increasing the grid impedance R_3 so that now most of the signal (synchronizing) appears across R_3. This action is shown in Fig. 7c.

A third method which is often used for separating the synchronizing from the picture signal is shown in Fig. 8. Here, a diode is connected across a portion of the picture amplifier circuit. In this stage the synchronizing polarity is negative with respect to the picture. The diode cathode is connected to the plate circuit and its anode, through the high resistance R_1, to the center of the potentiometer R_2. The purpose of the potentiometer is to enable one to adjust the voltage at the anode (point n) of the diode to a level indicated on the video waveform (top of Fig. 8) by the line xx'. Here again, the actual value of this voltage difference will be dependent upon the actual peak to peak amplitude of the video signal.

The level xx' is the operating threshold for the diode T_2 and occurs when the voltage on the cathode equals the voltage on the anode. Any signal voltage occurring above this level causes the cathode to become more positive than the anode (i.e., the anode is negative with respect to the cathode), so that the diode will not function. However, signal voltages below this level cause the cathode to become negative with respect to the anode and conduction occurs. Current will flow in the circuit and produce a voltage drop across R_1; this is the synchronizing voltage shown at X.

A video signal of opposite polarity would require that the diode connections be reversed. Regardless of diode connections it is advisable to obtain the filament supply from a separate transformer since the cathode may be several hundred volts above ground.

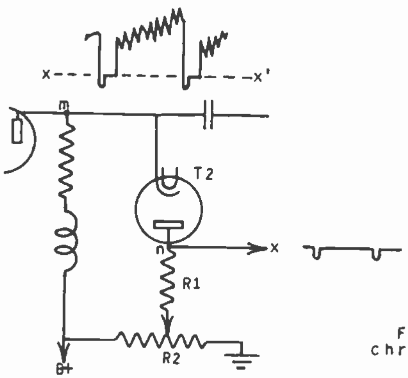


Fig. 8 Diode tube used in synchronizing separating circuit.

3. SELECTING A SEPARATOR CIRCUIT. Since several general methods have been described by which the synchronizing signal may be separated from the picture signal, let us see some of the factors which might determine the circuit to be used under different conditions. The first type discussed in connection with Fig. 2 is more or less common in its application, due to the fact that it will operate from either weak or strong (high amplitude) picture signals and consume a minimum of current from the power supply. This circuit normally produces a gain in the synchronizing signal amplitude; however, any input *variations* in the levels of the synchronizing will also be amplified in the output. As previously noted, this type of separation requires that the synchronizing signals be positive with respect to the picture signal and, consequently, the output of the circuit will contain negative synchronizing impulses. If synchronization of the sweep circuit oscillator is to be accomplished in its grid circuit, and the synchronizing signal is to be positive, an inverter stage will be needed.

The type of separation circuit shown in Fig. 7 has the one main disadvantage of heavy current consumption with a consequent shortening of tube life. Since the polarity of the video signal on its grid is opposite that used in the first case, this particular type of circuit could be used at a point in the picture circuit where the synchronizing is negative with respect to the picture signal. Unlike the first case where small differences in amplitude of the synchronizing signal produced amplified differences in the output, this particular circuit will tend to show a decrease in these differences in the output. Also, in this case, the synchronizing impulses in the output circuit are in a positive direction.

Coming now to the third case which uses a diode for separator as shown in Fig. 8, the most outstanding feature here is that the diode may be used in any circuit regardless of the polarity of the synchronizing with respect to the picture. Had the synchronizing been positive with respect to the picture instead of negative as shown in Fig. 8, it would have been necessary to reverse the diode connections; that is, connect the plate of T_2 to the plate circuit of T_1 and the cathode of T_2 to the resistor R_1. This of course will make it necessary to change the adjustment on the potentiometer R_2 so that it now occurs nearer the B+ end. Another interesting feature of this particular circuit is that the output impulses of synchronizing voltage are always of the same polarity as those in the original video signal. Also, there is no amplification of the synchronizing impulses in the output circuit; hence, this type of separator might not prove as satisfactory as either of the other two when used in connection with video signals having rather low amplitudes.

Finally, the choice of separator circuits must depend entirely upon such factors as circuit design and cost. The point in the circuit between the second detector and the grid of the cathode ray picture tube, where the separator circuit is connected, will influence the choice of circuit, since the amplitude and polarity of the video signal changes in each stage.

This, therefore, brings on a discussion of an important matter: at what point in the video circuit should the separating circuit be connected?

Fig. 9 shows a schematic diagram of a typical video amplifier. The synchronizing separator tube connections may be made at any one of three points, A, B, or C, and, as previously stated, the point selected will be determined by selector tubes and circuits employed. Since it is desirable that the grid of our selector tube be coupled directly to the picture circuit, point B in all probability will be eliminated since the full plate voltage is across this point and ground. The only DC voltage at A will be that due to the drop across the resistor R_1, which is in the order of only a few volts. At C the DC voltage is the bias voltage of the picture tube and this varies as a result of the leveling action of the diode T_2.

Remove the diode T_2 from the circuit and point C is no longer desirable due to the loss of the diode leveling action. This leaves only one desirable connection, that at point A. However, the pick-off position will be governed in commercial practice largely by the manufacturer's own circuit and production practices, and there are many variations in this type of circuit design.

For the purpose of illustration, assume that point A is the connecting point for the grid of the pick-off tube. Since the video signal at this point is comparatively low in amplitude, it is desirable to employ a separating circuit that will amplify the separated synchronizing signals. Such a tube as the 1852 operated so as to get sharp cutoff is one way of obtaining a gain in the output synchronizing signal. The correct operating point of a synchronizing pick-off tube is obtained by adjusting the bias voltage on the cathode of tube T_3 (Fig. 9). To point X some type of frequency selective circuit is connected to separate the two types of signals (horizontal and vertical). One such type of circuit has already been shown in Fig. 6. Since the synchronizing impulse is negative at this point, an additional amplifying stage will be required to invert the signal so that it may be correctly applied to the grid of a sweep circuit oscillator.

By now, the student has seen that there are many choices which the manufacturer must make in the design of a complete television receiver. For this reason, it is well to discuss some of the factors which will govern decisions in many instances. In the first place, there are three general types of manufacturers; those who build to quality specifications, regardless of price, those who build to meet a price, quality secondary, and the third group, composed of manufacturers operating between the first and second groups in which both quality and price are of equal importance. This observation applies not only to radio manufacturers, but to manufacturers of all kinds and classes of products. In the case of the first group, their product is designed and built to sell to these individuals who demand and can pay for the best. Consequently, cost is a secondary consideration for this manufacturer.

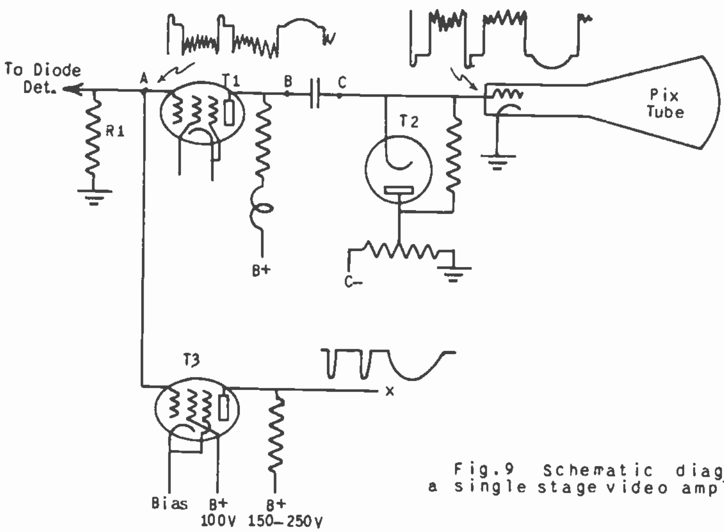


Fig.9 Schematic diagram of a single stage video amplifier.

The second group can be considered as being opposite the first in that here the first consideration is price. Their product is built to meet keen competition. The attitude in their case is, more often, "How cheaply can we build it and still have it work satisfactorily enough to produce a volume of sales?"

The third group finds itself always between two factors; they must produce a good quality product, but at a fair price. This kind of manufacturer as a rule has a fair idea of the quality which his customers are going to demand in a product such as his. Consequently, his chief problem is to meet this quality standard and, at the same time, hold production costs low enough so that he can feel reasonably assured of a suitable volume of the business. Now, the above discussion is for the sole purpose of bringing out this idea, namely, that in any lesson on television only the fundamentals can actually be explained and, therefore, the student must understand that these fundamentals will find their application in different types of circuits, depending upon the manufacturer.

For example, the writer knows of more than a dozen different types of circuits and arrangements in connection with the synchronizing pick-off tube, but a discussion of them at this time would serve no useful purpose.

4. SWEEP CIRCUIT CONSIDERATIONS. A general discussion of sweep circuits was given in a previous lesson. It is now necessary that we be more specific and select a type of sweep circuit satisfactory for use in a television receiver. In Fig. 10 is shown the circuit diagram for a cathode ray picture tube deflecting circuit.

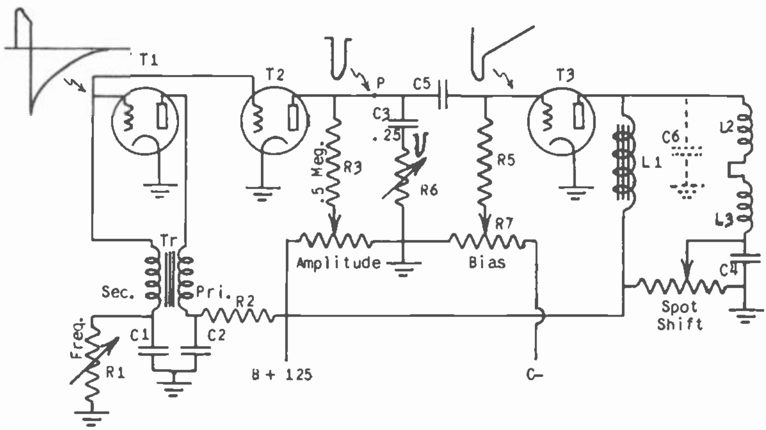


Fig.10 Sweep Circuit diagram (magnetic deflection).

The fundamentals of this circuit have been discussed in a previous lesson and will, therefore, not be repeated here. There are, however, many details in the system which will be gone into presently in order to give the student a more complete knowledge of this particular system. This circuit may well be divided into three sections: the one associated with T_1, known as the oscillator circuit, T_2 and the components associated with its plate circuit, generally called the discharge circuit, and T_3 with associated plate circuit components, known as the output circuit. The discharge circuit in this instance is fundamentally the same as would normally be used in any other type of sweep circuit.

A blocking tube (abbreviated B.T.) type of oscillator is used. This type of oscillator is not so critical in its adjustment as the gaseous discharge tube type; also it is not affected by line voltage variations to the same extent as many other types of oscillators. Although much serious effort has been spent in an attempt to improve the original blocking tube oscillator and associated circuits, the complete circuit shown in Fig. 10 contains only minor changes from that shown in the original patent application (Tolson & Duncan); hence, those acquainted with literature on the subject will recognize having seen practically the same circuit before, although the values of most of the circuit components may have been quite different from those shown in Fig. 10, a testimony to the extreme flexibility of the circuit. Since the circuit diagrams of both vertical and horizontal are fundamentally the same, the statements which will be made regarding circuit performance will, therefore, apply equally well to both; later, however, the actual difference in circuit constants will be discussed. Three tubes are shown in the circuit in Fig. 10 for the sake of clearness; however, it should be understood that the use of dual purpose tubes makes possible the reduction in actual tube count to only two. It is even possible to go further and use only one tube. Such circuits have been designed and used, but due to interaction of the various circuit controls, such a design is not ordinarily considered satisfactory.

There are many interesting things to be learned concerning the blocking tube oscillator, relating to its operation and also to numerous changes possible in the circuit.

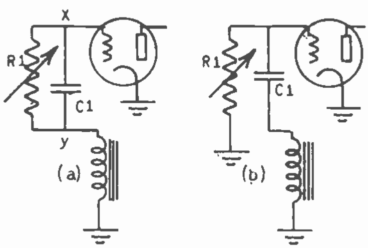


Fig.11 Variations in placement of B.T. oscillator frequency control.

As an illustration, the frequency control R_1C_1 is open to several variations, two of which are shown in Fig. 11. However, the connections shown in Fig. 10 are believed to be the most practical for reasons which follow. Normally, the frequency is controlled by a rheostat R_1, which as a rule is placed in a convenient location on the receiver. When using the connection shown in Fig. 11a, this is impractical from several standpoints. In the first place, there is the possibility of body capacity, since R_1 is on the high side of the transformer with one end connected directly to the grid. In the second place, there are the long rheostat leads between points x and y which might cause crosstalk in the circuits unless properly shielded. Then, of course, there is the capacity to ground serving as an additional load on the grid of the oscillator. In Fig. 11b, R_1 is connected directly from grid to ground so that it shunts the entire grid circuit, thereby forming a load which, in many instances, may be sufficient to materially reduce the signal amplitude of the oscillator. The frequency control shown in Fig. 10 (R_1C_1) has none of these undesirable features. Moreover, it makes little difference how far R_1 is located from the transformer, since the high frequency components of the grid signal are not found in this circuit; also, only one long wire will connect to the rheostat since the other may be grounded at any convenient point near its location. These are minor precautions but they relate to the actual sweep circuit performance and are matters of design well worth knowing.

Since the grids of T_1 and T_2 are directly coupled, it is advisable that the transformer be designed to have its low impedance winding in the secondary in order to minimize frequency changes in the oscillator when the amplitude control in the plate of T_2 is varied. A condenser and grid leak may be used in the conventional manner between the grids of T_1 and T_2, but the output voltage of T_2 will be materially reduced and the circuit costs increased. R_2 and C_2 form a filter circuit which may not be needed in some cases.

A Class B type of tube should be used as T_1 and T_2, since the grid voltages reach high positive values of 50 to 100 volts. As a rule, the functions of these two tubes may be combined in one tube such as the 6N7. This tube has been found to give very satisfactory results, but, due to the wide differences in individual tube characteristics, the replacements are sometimes unsatisfactory.

In Fig. 12 are shown the different waveforms as they appear in the various circuits from the grid of the oscillator tube to the deflecting coils in the output circuit. These are shown in their approximate time relation to one another so that the student may see exactly what is happening in any one circuit at a given time. The waveform on the grid of the oscillator as shown in Fig. 12a is actually composed of two waveforms; that above the tube's plate current cut-off level has an entirely different function from that of the waveform below this cut-off level. To further explain, the oscillator tube is in actual operation only during the production of the positive impulse represented in time by the period t_0 to t_4. The portion of the cycle below the cut-off level is actually the discharge voltage waveform of the condenser C_1 (Fig. 10) and is shown separately in Fig. 12b. This covers a period of time represented by t_4 to t_5. During this time the tube is biased beyond cut-off and is of no value whatsoever to the circuit. The part of this waveform represented by the time t_2 to t_4 occurs while the condenser C_1 is receiving a negative charge. (Grids of T_1 and T_2 are drawing current.)

The upper portion (above cut-off) of this cycle determines the length of the cathode ray beam's return time and affects the amplitude of the sweep voltage; the lower waveform has to do only with the frequency of the operation of the oscillator. Normally, the time occupied by the return line is approximately 10% of the total scanning line period (scan and return). If at any time between t_4 and t_5 a positive impulse of sufficient amplitude is introduced into the grid circuit, the oscillator may be forced into operation. For example, if a synchronizing impulse be introduced at the time indicated by the dotted line xx', it will start the oscillation cycle over again provided this impulse is of sufficient amplitude (volt-

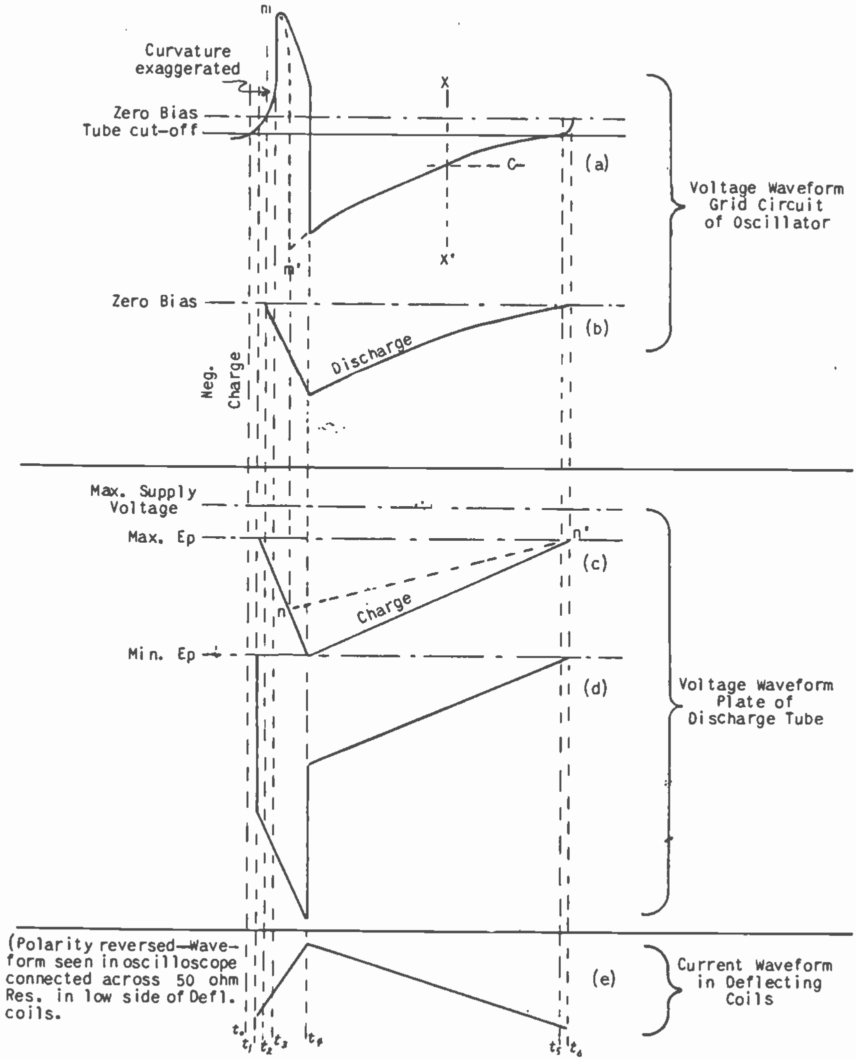


Fig.12 Sweep Circuit waveforms and their time relationships.

age) to raise the grid voltage at that instant up to cut-off or beyond. Suppose cut-off for this particular oscillator occurs with -11 volts on the grid, and the positive synchronizing impulse is introduced at a time when the discharge of C_1 (Fig. 10) has reached a negative value of 15 volts (C- = -15 in Fig. 12a), it will require at least a positive 4 volts, preferably a little more to "trip" the oscillator.

It follows then that in order for the synchronizing to be effective, the frequency of the oscillator must be slower than that of the synchronizing. It is important to remember that for synchronization at some definite frequency, the further below this frequency the oscillator is run, the greater will be the synchronizing voltage required, because the synchronizing occurs sooner (in the direction of from t_5 to t_4) on the discharge curve shown on Fig. 12a.

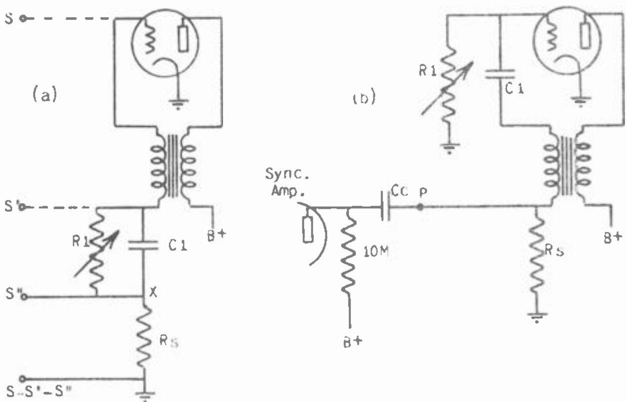


Fig.13 Introducing the synchronizing signal into the grid circuit of the B.T. oscillator.

Since synchronizing is such an important subject, let us investigate how it may be introduced into the oscillator circuit, and also some of the circuit requirements for most effectively using this synchronizing. Thus far, no mention has been made of the point in the oscillator circuit where the synchronizing is introduced. In Fig. 13 are shown some of the more common points of application. Again, the student is reminded that the thing to be accomplished by the synchronizing is a reduction of the negative charge accumulated on the grid side of condenser C_1; this must be sufficient to allow the plate to again draw current and thereby initiate a new cycle. Any impulse that can accomplish this will act as a synchronizing signal. Some common points for the introduction of the synchronizing signal are shown at S, S', and S" in Fig. 13a. Only in the case of S" is the resistor R_s used; otherwise the point x is grounded. However, this is probably the connection most commonly used by a number of manufacturers. Ordinarily, the value of this resistor R_s is around 1,000 ohms; if it is made much larger, it will interfere with the action of the oscillator. The problem of unduly loading the grid circuit must be watched if the point S or S' is used. When the synchronizing input is at S", the plate of the tube furnishing the synchronizing is likely to be loaded by R_s since it has a comparatively low value.

This brings up another reason why the frequency control circuit shown in 11b is undesirable. (The same circuit is reproduced in

13b with the addition of the provision for synchronizing.) The loading effect of R_1 reduces the effectiveness of the synchronizing, since it is comparatively a low resistance shunt across the input impedance of the tube. Also, consideration must be given the design of the synchronizing input circuit, for the loading due to R_s, as already mentioned, is an important factor. Suppose, for example, a switch located at point P (Fig. 13b) is opened so that a reading may be made of the peak to peak voltage of the synchronizing impulse across the 10,000 ohm plate resistor in the synchronizing amplifier tube. Suppose this measures 10 volts; now, if the switch at P is closed so that R_s, which is only 1,000 ohms, is shunting the 10,000 ohm plate load, we shall find that the synchronizing voltage has been reduced from 10 to slightly less than 1 volt. Also, this 1 volt will be effectively reduced by the action of R_1 as previously mentioned. Under circumstances of this kind, the coupling condenser C_c will offer additional attenuation in the case of the 60 cycle vertical impulse unless it is comparatively large.

For these reasons, therefore, it is seen that this method is highly inefficient, although used by a number of experimenters. The connection shown at S' is perhaps the most satisfactory point of application in the grid circuit; in some cases it may be desirable to increase the gain of the synchronizing voltage and this may be accomplished by use of the resistor R_s in connection with the circuit as shown in Fig. 13a. Whether or not it is desirable to use this resistor will depend largely upon the size of the condenser C_1 used. The larger it is, of course, the more necessary it will be to use the resistor.

So much has been said about the use of the synchronizing as a positive impulse that perhaps the student may have gained the impression that it would be impossible to use a negative impulse of synchronizing; such is not the case. It is possible to introduce a negative impulse in either the cathode or the plate circuit of a tube. In either case, however, there are certain considerations which must be taken into account. In order to use the cathode as the point of synchronization, a resistor of some value must be included between the cathode and ground. This, of course, will increase the bias on the tube and, also, since a condenser cannot be used across this resistor, degeneration will result and the amplitude of the oscillator output will be materially reduced. Furthermore, if a double purpose tube is used at this point (oscillator and discharge tube), it will be necessary to have two cathodes instead of one to prevent further difficulties in the discharge circuit.

It is possible to introduce synchronizing signals into the plate circuit of the B.T. oscillator due to the fact that the transformer is connected in such a manner that the negative signal will be transferred to the grid side of the transformer with a positive polarity. However, in such procedure the inductive effects of the transformer tend to distort the synchronizing signal so that the overall result is sometimes unsatisfactory. In this case, a great deal depends upon the design of the transformer.

In discussing the synchronization of oscillators, this fact should be made clear: *that the more unstable an oscillator is in its manner of operation, the less difficult it will be to synchronize.* The student should not confuse unstable with erratic operation. Unstable is used in this connection to denote the ease with which the oscillator frequency may be influenced by the introduction of an external voltage, while erratic operation means irregular or unpredictable performance.

The amount (voltage amplitude) of synchronizing necessary for satisfactory operation of the sweep circuits in a television receiver is dependent upon several factors; it is a safe rule to state that *sufficient synchronizing amplitude is reached when the sweep circuits of the receiver will remain synchronized under the conditions met in general television reception.* Of course, there are standards governing the amplitude of the synchronizing signal as transmitted in connection with the picture signal (the amplitude of the picture signal is divided as follows: not over 80% picture and not less than 20% synchronizing signal), but in the actual reception and separation of the synchronizing signal, the amplitude may be changed over wide ranges. It is particularly important that the synchronizing should have major control over the frequency of the oscillator operation; otherwise, unwanted interference signals, such as man-made static, may become of sufficient amplitude to take over the functions of the synchronizing. This, of course, relates directly to the field intensity of the video signal that the transmitter is laying down at the receiving antenna. As previously pointed out, the amount of synchronizing necessary will depend largely upon the point along the oscillator grid condenser curve at which we wish synchronization to occur. The more we increase the oscillator frequency, so that it approaches the frequency of the synchronizing impulse, the less will be the amount of synchronizing signal necessary, but unfortunately this applies also to the unwanted noise signals as well. However, it is possible to design noise suppression circuits which will operate to exclude major interferences which might occur between synchronizing periods (during the picture signal) and also to limit the amplitude of the interference during the actual period of synchronization.

There is another effect which may occur if the synchronizing signal, as applied to the oscillator, has too great a magnitude. For example, referring again to Fig. 12a, if the synchronizing impulse shown at xx' has not only sufficient amplitude to raise the grid voltage at that point up to cut-off, but also additional amplitude extending well above the tube cut-off level, it will become a part of the positive impulse of the oscillator and, consequently, change the size of the impulse. Since this impulse is one of the determining factors in the amplitude of the sweep circuit voltage, too much synchronizing voltage at this point can actually affect undesirable amplitude changes in the output of the sweep circuit. There remains some important information relating to synchronizing requirements for good interlacing which must be considered a little later in the lesson.

Thus far, the student has been accepting the statement that the positive impulse of the grid voltage is the controlling factor in the output of the circuit. Let us examine the reasons why this is true and, in order to do so, we must go more into the details of the discharge circuit itself. (See Fig. 10) First let us eliminate the possibility of any misconception regarding the nature of a voltage impulse. Referring again to Fig. 12a, the positive impulse in this case did not appear suddenly in its entirety as it appears in the drawing, but must be considered as the result of a succession of changes in voltage over a period of time. To be more specific, if we start with cut-off which we assumed to be -11 volts and follow along the line of voltage increase until the zero bias line is reached, there will of course have been a change of 11 volts (in the positive direction). As the potential is caused to increase through the action of the oscillator, we find it becoming more and more positive, until finally, perhaps it reaches a peak of 75 or 80 volts; even at this level there is still no impulse--simply a changing potential. Now, due to the oscillator operation, this potential can no longer increase, but begins to decrease; at this instant, we have an impulse which changes in size with each change in potential. Hence, a voltage impulse assumes the nature of an area; this conception is fundamental to an understanding of the explanation which follows.

It would be quite possible to increase the amplitude of this positive impulse and, at the same time, decrease the time of its duration so that the output of the discharge circuit would not be changed; hence, the idea of amplitude alone is not sufficient. The same would be true if the amplitude had been decreased, but the time increased. Ordinarily, this area, bounded by the path of the varying potential (or transient voltage) and the tube cut-off level is thought of as the energy content of the impulse. Now, let us see how these observations may apply to a discharge circuit. To simplify the explanation, let us make the following assumption (see Fig. 10): First, the oscillator is operating at 60 cycles; R_3 = .5 megohm; C_3 = .25 mf.; and R_6 is turned to zero. (For the time being, the amplitude control is omitted from consideration.) During the charging time (t_4 to t_6, Fig. 12c), the time constant for this circuit equals $R_3 \times C_3$. Normally, the time constant should be $(R_3 + R_6)C_3$, but the value of R_6 is so small that it may be omitted in this calculation; the same is true for any portion of the amplitude control that may be in the circuit. However, during the discharge period t_1 to t_4, the grid of the discharge tube reaches a high positive potential, so that the plate is drawing a very large instantaneous current, with the result that the plate impedance which was practically infinite during tube cut-off, now perhaps, reaches a minimum value in the neighborhood of 300 ohms. (2500 ohms is assumed in calculations that follow.) Since the tube plate resistance becomes so small during the time of discharge in comparison with the value of the resistor R_3, we may, for all practical purposes neglect the value of R_3 so that the time constant for the discharge is R_pC_3. (Assume R_6 = 0, otherwise its value would have to be added to R_p.) Substituting known values, we find the time constant for both charge and discharge to be as follows:

$$T\ (\text{charge}) = R_3C_3$$

$$= 500{,}000 \times \frac{.25}{1{,}000{,}000}$$

$$= .125 \text{ second, or } 125{,}000 \text{ microseconds}$$

Similarly:

$$T\ (\text{discharge}) = R_pC_3$$

$$= 2500 \times \frac{.25}{1{,}000{,}000}$$

$$= .000625 \text{ second, or } 625 \text{ microseconds}$$

From this it is seen that the total time constant for one complete cycle of charge and discharge is 125,625 microseconds. Since the vertical oscillator is operating at 60 c.p.s., or 1 complete cycle in 16,600 microseconds, it is seen that a very definite limit is placed upon the operation of the discharge circuit so that it is necessary to determine how this 16,600 microseconds is to be divided between the return time and the go time. Assume that the width of the positive oscillator impulse is such that the discharge time t_1 to t_4 is equal to the time required for five horizontal lines. (The horizontal frequency is 13,230 c.p.s., or 75.6 microseconds for the time of one complete line or cycle.) Then the time for the vertical return is 5 × 75.6 or 378 microseconds. Now, since the time for one complete cycle is 16,600 microseconds and only 378 microseconds of this is consumed by the return time, then the difference, 16,600 - 378, or 16,222 microseconds is the time actually allowed for the charging cycle; this is the period between t_4 and t_6. Comparison of these periods of charge and discharge with those calculated above reveals that the return time (discharge) is about half the natural period, and that the *charging time allowed* is only 16,222 microseconds when the *time constant* is 125,000 microseconds. We have seen in a previous lesson how it is necessary to use only a small portion of the charge curve in order to reduce nonlinearity distortion. It is good practice to select the value of R_3 or C_3 (Fig. 10) so that this charging period is never greater than about .07 of the circuit time constant. If circuit operation is such as to reduce the charge to .07, it therefore follows[1] that the voltage is reduced accordingly so that instead of having a possible maximum of about 250 volts of sawtooth voltage in the plate circuit, we shall have only .07 × 250, or 17.5 volts. The discharge circuit then, operating as it does with the greatly reduced plate voltage likewise requires less grid bias to shut off the plate current. This is the reason why only a portion of the positive impulse (Fig. 12a) impressed on the grid of the discharge tube appears in

[1] The charging formula for a condenser is $Q = CE$, where Q equals the charge in coulombs, C equals the capacity of the condenser in farads, and E equals the applied voltage.

the plate circuit. By referring to Fig. 12a, you will note the position of the bias line for oscillator cut-off; however, since the voltage of the discharge circuit through a cycle of operation is a great deal less, the cut-off point for the discharge tube is moved up toward zero bias at some such point as indicated by the intersection of the time line t_1 and the oscillator voltage curve. This, therefore, accounts for the shift in time of the sawtooth waveform shown in Fig. 12c where it begins at t_1 and ends at t_6, instead of starting at t_0 and ending at t_5. From the foregoing discussion we are able to understand how the width or the height, or both, of the oscillator impulse affects the actual sawtooth amplitude. Suppose, for example, a width or a time duration of this impulse be reduced as indicated by the dotted line mm' so that the return time instead of being five scanning lines long is now only three. Assuming no change in amplitude of the impulse, there will be a *reduction in the return time* and *an increase in the charge time* with a loss in sawtooth amplitude as indicated by the dotted line nn' in Fig. 12c. Suppose, without changing the width of this narrowed oscillator impulse, we increase its amplitude. This increased amplitude will drive the discharge tube grid even more positive, thereby increasing the plate current (reducing the plate impedance) so that now the discharge time is decreased due to a reduction in the plate impedance. This, therefore, will increase the amplitude of the sawtooth, since the decreased time constant of the discharge circuit will permit greater discharge for a given time.

Since a decrease in the width of the positive oscillator impulse will produce a decrease in sawtooth amplitude, it seems quite logical that an increase in width would produce the opposite effect, that is, a gain in sawtooth amplitude. Such, of course, is the case, but with certain limitations as we shall see. Suppose that the width of this impulse be increased without changing the amplitude. If the circuit's constants are such that the discharge period is equal to 625 microseconds and the impulse width occupies a period of 1,000 microseconds; it is quite apparent that if we discharge a condenser in a certain length of time, nothing will be gained by extending this time beyond the necessary period. Of course, you must remember that the time constant is based on the time required for the condenser discharge to reach approximately $\frac{1}{3}$ of its full charge value and, of course, if the discharge time actually extends beyond this period, there will naturally be a slight amplitude gain, but also increased curvature in the discharge trace.

Suppose, without changing any other component part of the sweep circuit, we change the frequency (by varying R_1) of the vertical oscillator from 60 to 30 cycles; what will happen to the amplitude of the output voltage? We have already seen that only approximately .07 of the charge time is actually used, so a reduction of oscillator frequency will naturally cause a greater portion of the charge curve to be used, thereby increasing the output sawtooth amplitude but at the same time decreasing its linearity. Increasing the oscillator frequency would, therefore, have exactly the opposite result. These assumptions, of course, are made on the basis that the oscillator transformer characteristics do not enter into the results which, of course, is not the case. The amplitude control provides a means of varying the output of the discharge tube by changing the voltage on the plate.

In order to produce a sawtooth of current in the deflecting coils, it is necessary to employ a combination of two waveforms, sawtooth and impulse (discussed in a previous lesson). The action of the resistor R_6 produces this additional impulse which is added to the sawtooth. Suppose that the inductance of the deflecting coils L_2 and L_3 is such as to require that the resistance of R_6 be 3,000 ohms; since R_3 is very large in comparison with R_6, we have seen how it is practical to neglect R_6 in the calculation to determine the charge period of the circuit. Such is not permissible, however, when figuring the discharge time. Based on the assumption that an average R_p equals 2500 ohms, we now have in series with it R_6 (3,000 ohms), so that the time constant for discharge becomes $(R_p + R_6) \times C_3$. Substituting in this expression, we have $(2500 + 3{,}000) \times .25 \div 10^6 = .001375$ second, or 1375 microseconds. The resistor R_6 affects a reduction in the amplitude of the sawtooth portion of the wave; in other words, as the amount of the peaking resistance R_6 is increased, the peaking component of the waveform shown on the grid of T_3 in Fig. 10 is increasing, but the sawtooth component is decreasing.

Due to the fact that the grid circuit of T_3 is condenser-coupled to the plate circuit of T_2, changing this waveform in the manner described produces a general shift of the entire wave with respect to the bias axis. For this reason and also another which we shall mention presently, it is desirable to have this bias (R_7) a variable which may be easily adjusted by the serviceman. Now, let us see why adding this peaking produces a reduction in the amplitude of the sawtooth component. Assuming that the positive part of the oscillator cycle is such as to give a return time equal to five horizontal lines or 378 microseconds, the time is fixed and nothing in the discharge circuit will change it. With the addition of peaking, the constants in the discharge circuit are changed so that where before its discharge time equaled 625 microseconds, it now equals 1125 microseconds. Therefore, due to this slowed-up action or increased time constant, the condenser C_3 can only discharge a little over half the amount in the given 378 microseconds as previously when the time constant was 625 microseconds.

Some interesting things happen in the discharge circuit for a short period after the receiver is first turned on which should be investigated at this point. During the interval between the time the set is first turned on and the discharge tube cathode has been heated sufficiently so that the tube will conduct current, the voltage from the power unit has reached its maximum and the voltage at the plate of the discharge tube actually equals the supply voltage (since the plate is not conducting, there is no IR drop across the plate resistor), the condenser C_3 (Fig. 10) is charged to its maximum at that potential, as represented by point b on the curve shown in Fig. 14. Meanwhile, the combination oscillator and discharge tube has been sufficiently warmed to start operation. In previous calculations, we have figured that with no peaking present, the discharge time of the circuit is 625 microseconds. Now, if the width of the positive impulse is such that the discharge actually lasts 378 microseconds, that is, 5 horizontal lines, then approximately ½ of the full charge, which the condenser took a comparatively long time to reach during the initial charging time, is now discharged in only 378 microseconds as indicated by the line bc, Fig. 14. At this time, the effect of the oscillator positive impulse is

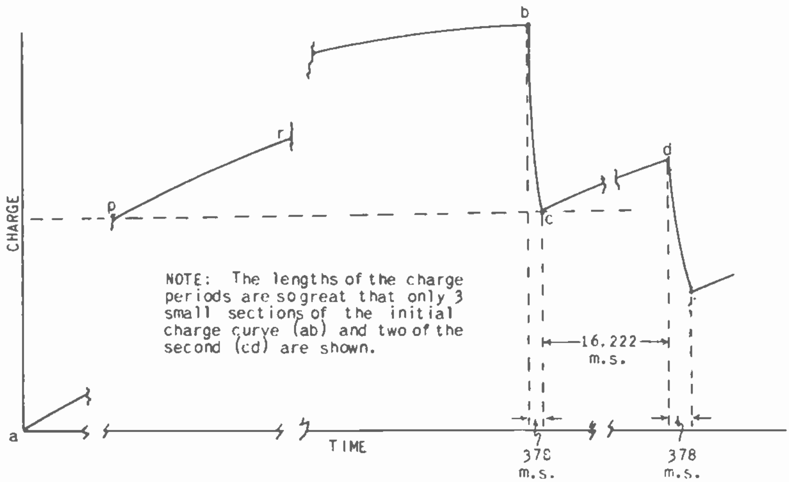


Fig.14 Conditions existing in one type of discharge circuit during starting period of operation.

terminated and the charging cycle is begun. If we use previous figures, the oscillator is now operating in such a manner that only 16,222 microseconds are allotted for the condenser to recharge. During this charging time, it will be seen that the charging current will follow some line such as cd (a duplicate of pr) which occupies a space of 16,222 microseconds on the original charge curve. The general trend of the charge cycle is downward on the initial charge curve (into a straighter portion of the curve), and the discharge portion of the cycle is also downward toward a more complete discharge (gradually reaching a more curved portion of this discharge curve). These operations (charge and discharge) will finally assume a position of equilibrium when the discharge during the return time (378 microseconds) is equal to the charge given C_3 during the comparatively long scan period (16,222 microseconds). This is made possible by changes in the actual charging potential across C_3.

The discharge circuit can be so designed that the method of operation just outlined as occurring during the first few instants when a set is turned on may be just reversed. This is illustrated in Fig. 15. In this instance, the discharge tube is biased to cut-off, but the application of the positive impulse on its grid causes a flow of plate current; this causes C_3 to charge and also produces a voltage drop across R_6 (the peaking resistance) during the time that C_3 is charging. The sawtooth portion of the waveform is due to C_3 discharging through R_3 when the positive impulse is removed from the grid of the tube.

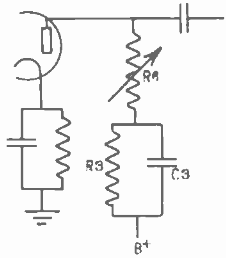


Fig.15 A discharge circuit in which the line scan occurs during discharge of C_3.

There are some very interesting differences to be pointed out in connection with this type of operation. The time constants for charge and discharge have been reversed so that now the time for charge is $(R_6 + R_p) \times C_3$, and for discharge is $R_3 \times C_3$. Instead of the circuit starting operation with a fully charged condenser, as in the previous example, and working back down the charge curve to a point of equilibrium, this time it begins with no charge and works up the charge curve until it reaches that point of curvature where the amount of charge accumulated on C_3 during its short period of charge will equal the condenser discharge during the much longer discharge period. Now scanning occurs on the straighter portion of the discharge curve instead of the charge curve as in the previous example.

The circuit is interesting in that it offers a second method of achieving the same results but in a directly opposite manner of operation.

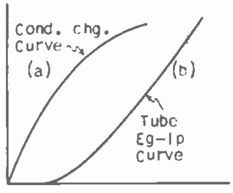


Fig.16 Showing how distortion in a sawtooth voltage, due to curvature in condenser charge curve, may be compensated for by the opposite curvature in a tube Eg-Ip characteristic.

A variable bias control on the output stage of the sweep circuit has been mentioned as being desirable in that it will enable the operator to compensate for a shift in the signal position along the bias axis which may result from a change in value of the peaking resistor. The chief reason for this variable bias, however, is explained by reference to the two curves of Fig. 16; (a) the charge curve of a condenser, (b) the grid-voltage, plate-current curve of an amplifier tube. Since the curvature of one is opposite that of the other, it is possible to compensate for slight curvature in the charging voltage by shifting the axis of its application on the grid of the amplifier tube; that is, by changing the bias.

5. THE HARMONICS OF A SAWTOOTH WAVEFORM. Repeated reference has been made to both 60 cycle and 13,230 cycle sawtooth waveforms so that the student may have gained the impression that any circuit which will pass a 60 cycle or a 13,230 cycle sine wave will pass the sawtooth waveform with equal fidelity. Such is far from being the case, due to the harmonics present in the sawtooth waveform. The number and amplitude of these harmonics depend upon the fundamental frequency and the time duration of the return line. A sawtooth wave is actually composed of a great number of sine waves of different frequencies called "harmonics," since they are multiples

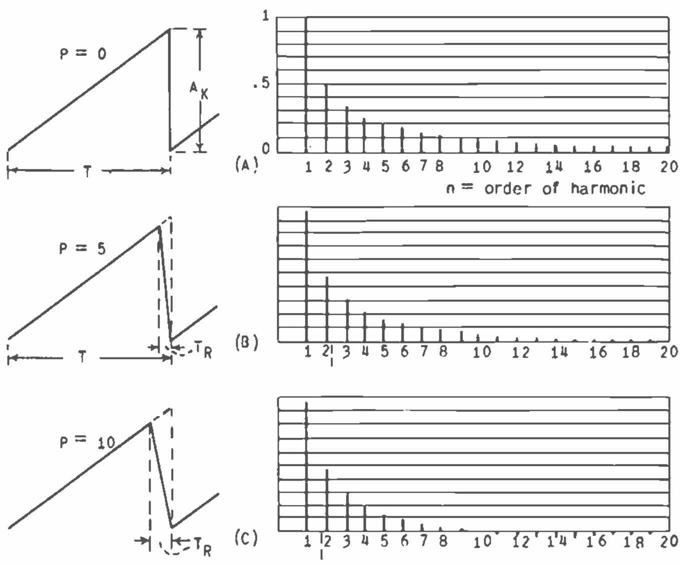


Fig.17 Harmonics present in a sawtooth waveform.

of the fundamental frequency. In Fig. 17 is shown the frequency spectrum of sawtooth waveforms having various return times. The graph on the right in each case indicates how the amplitude of the various harmonics compares with that of the fundamental. In the waveform shown at A, where the return time is zero, the amplitude of the harmonics decreases in inverse proportions to the order of the harmonics; that is, the amplitude of the second harmonic is exactly half that of the fundamental, the tenth is one-half that of the fifth, etc. While only the harmonics up to the twentieth are shown, actually for an amplifier to faithfully reproduce this sawtooth, it would be necessary for it to pass a band of infinite width. The sawtooth waveform shown at B is different from A, due to the return trace covering a period equal to 5% of the total time required by the sawtooth. Here, the amplitude of the successive harmonics decreases faster than in the case of A, so that the highest harmonic has diminished to zero amplitude. In the sawtooth waveform shown at C, the return trace occupies 10% of the total sawtooth time and the decrease in amplitude of the harmonics is so rapid that zero amplitude is reached with the tenth harmonic. These three examples indicate quite definitely the relationship existing between the retrace time of a sawtooth and the number of harmonics required to faithfully reproduce the sawtooth. The expression 100 ÷ T_r, where T_r represents the percentage the retrace time is of the total sawtooth time T, will serve as a very satisfactory rule for determining the required order of harmonics. For example, suppose the return trace is only 5% of the total time. Substituting 5 for T_r in the above expression, we have 100 ÷ 5 = 20. In this case, therefore, the twentieth would be the highest harmonic required. If the retrace time occupied 10% of the total, then only harmonics up to the tenth would be necessary. As a further example, suppose, for instance, we assume the retrace time of the horizontal sawtooth to be 10% of the total sawtooth time; the frequency band required for transmission of such a sawtooth would, therefore, include the tenth harmonic of 13,230 cycles, or 132,300 cycles. Any reduction in these higher frequency components will result in a rounding of the otherwise sharp peak of the sawtooth.

6. OUTPUT CIRCUIT DESIGN. With this additional information concerning sawtooth waveforms, it should now be easy to understand some of the problems involved in the design of the output circuit for either the horizontal or vertical sweep. The output circuit shown in Fig. 10 illustrates several features common to sweep circuits in a television receiver where the plate of the amplifier tube feeds directly into the deflecting coils. The maximum number of turns that can be used in L_2 and L_3 is limited by the distributed capacity represented by C_6, since this capacity tends to bypass the higher harmonics present in the sawtooth output of T_3.

Another factor limiting the number of turns that can be used in the deflecting coils has been mentioned in a previous lesson; namely, the magnitude of the peak induced voltage which appears across the deflecting coils when the current is reversed suddenly at the end of a scanning cycle; that is, during the return trace. It is not unusual for voltages in this circuit to reach values of 1,000 volts or more. The peak value of this voltage may be calculated by means of the equation:

$$E_R = \frac{2\,I_m}{T} \times L$$

Where E_R = peak volts,
L = total deflecting coil inductance in henries,
I_m = maximum scanning current in amperes,
T = time required for the return trace in seconds.

As an example, suppose that we have a peak current of 100 ma. flowing in deflecting coils having a total inductance of 50 mh. and suppose that the return trace occupies a time equal to approximately $\frac{1}{10}$ of the total time of a horizontal scan, or $7\frac{1}{2}$ microseconds. Substituting these values in the above equation gives:

$$E_R = \frac{2 \times .100}{.0000075} \times \frac{50}{1,000} = 1330 \text{ volts (approximately)}$$

This is an astonishingly high value of voltage, but it will be increased if the peak value of current in the deflecting coils is increased or if the time of the return trace is decreased. Such voltages are apt to cause damage to the tube itself.

The tube used in the output circuit, such as that shown in Fig. 10 is ordinarily a triode; for the horizontal circuit, the 6A3 or 6L6 type of tube may be used. If a 6L6 is used, the screen grid and plate are tied together. For the vertical output circuit, a tube such as the 76 or 6C5 is generally used. Complete formulas for calculating the number of coil turns required to deflect the cathode ray beam are rather involved and for that reason will be omitted. However, a very simple formula has been found satisfactory for average purposes. For the horizontal coil, a sufficient number of turns should be used to produce an inductive reactance at the horizontal frequency equal to approximately three times the plate resistance of the output tube. For the vertical coil, a sufficient number of turns should be used to produce an inductive reactance at the vertical frequency equal to approximately the plate resistance of the output tube. In the circuit (Fig. 10), L_1 is always made large compared to the value of $L_2 + L_3$; something like 10 times as great is sufficient. The value of C_4 should be chosen so as to have negligible reactance at the fundamental sawtooth frequency. In the case of the vertical sweep circuit, this is normally an 8 mf. electrolytic, while for the horizontal sweep, a 1 mf. condenser is usually sufficient.

There are several reasons why it is advisable to have some means whereby the spot of a cathode ray tube may be shifted. Sometimes the gun in a cathode ray tube may be slightly off-center; that is, its center does not coincide with the center of the tube screen; again, magnetic disturbances near the location of the receiver may influence the position of the beam, and, finally, the earth's magnetic field always exerts an influence on this beam. For example, a television receiver may be located so that its front faces north. Then if we turn this receiver so that its front faces east or west, we shall find in most cases that the position of the beam, and therefore the pattern, has been shifted slightly on the screen of the tube.

7. DEFLECTING YOKES. Although considerable has been said about the deflecting coils, there has been no indication as to the physical appearance of the yoke itself or the problems involved in its construction. The diagram for a simple form of yoke is shown in Fig. 18. In this type of yoke construction, it is seen that that iron which forms a portion of the flux path is common to both horizontal

and vertical coils and, as a result, there are leakage flux paths between the horizontal and vertical pole faces as indicated by the dotted lines. Since in magnetic deflection, the beam acts as a conductor in a continually varying field, then according to the rules learned in the study of electric motors, the cathode ray beam will be deflected in a direction which is at right angle to the flux at that particular point. Hence, with a field flux pattern such as that shown in Fig. 18, it is impossible to obtain a symmetrical rectangular pattern on the screen of the cathode ray tube. A pattern resulting from such a field will show both distortion and defocusing effects in all four corners.

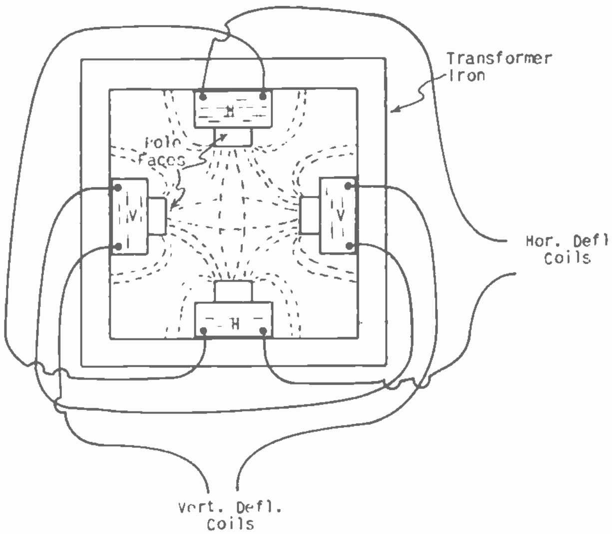


Fig.18 One simple type of magnetic deflecting yoke showing flux pattern (all coils in same plane).

Now in order to eliminate the effect of this interaction between the two magnetic circuits, it is possible to mount each set of coils on an individual yoke, as shown in Fig. 19. These yokes are built up of a number of laminations. The thickness of the lamination and the number used will be determined largely by two considerations, namely, the deflecting frequency and the amplitude of the deflection desired. In the case of a deflecting frequency as high as the horizontal (13,230 cycles), the lamination should be high-grade transformer iron (some form of silicon steel) about .014" thick. However, when using frequencies this high, it is possible to eliminate the laminations entirely. The lamination for the vertical yoke need not be of high-grade steel and may be .03" thick or better, depending somewhat upon the material available.

As regards the number of laminations used in stacking a core, that is, the length of the pole face as indicated by d in Fig. 19, the following information is of value. The power required for a given deflection is inversely proportional to the length of the deflecting yoke. For example, a certain amount of power is required to deflect the cathode ray beam a given distance, but if the length d of the yoke is doubled, then the amount of power required will be halved. However, design and cost considerations usually limit the practical length of such a yoke to only a small portion of the total distance between the end of the gun and the screen. Since in a television picture pattern the horizontal deflection is normally greater in amplitude than the vertical (picture ratio 4 to 3), the logical placement of the horizontal yoke should be the one nearest the gun of the cathode ray tube, since the closer the yoke is placed to the gun, the greater will be the deflection on the screen.

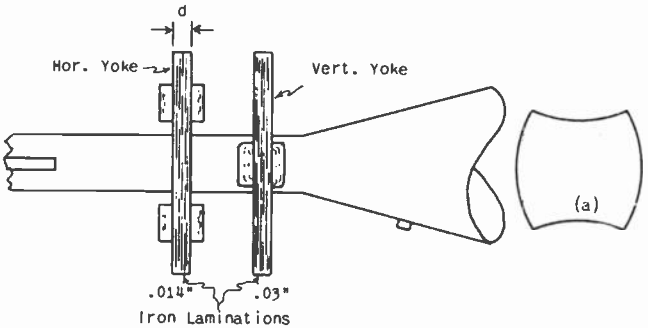


Fig.19 Simple type of deflecting yoke in which horizontal and vertical coils are in separate planes.

Thus far in discussing the yoke shown in Fig. 19 we have considered general yoke construction problems; now we come to the important factor: what kind of a pattern will this type of yoke produce on the screen? Although this arrangement does eliminate much of the defocusing found in each of the four corners of the pattern produced by such a yoke as shown in Fig. 18, there is another serious defect which results from the use of separate planes of deflection for the horizontal and vertical. Following the path of the beam as it leaves the gun (Fig. 19), we will note that it is first deflected in a horizontal direction by the horizontal yoke; when it comes under the influence of the vertical yoke, the beam, at the extreme ends of its travel back and forth, is very near to the deflecting pole faces. Now, due to leakage flux, the field intensity near each pole face is somewhat greater than midway between the two pole faces; as a result of this increased field intensity, the vertical deflection will be greater when the beam is nearer the pole faces than at intervening points. As a result, the pattern on the screen of the tube will have an appearance similar to that shown at 19a. The type of distortion shown on the sides of this pattern is known as "barreling," while that at the top and bottom is called "pin-cushion." The amount of this distortion is reduced if the two yokes are moved closer together, but the defocusing effects noted in the previous type of yoke will tend to increase. There is a compromise on the separation of these two yokes which will give a usable pattern. Much depends, however, upon the degree of magnetic field uniformity we are able to obtain between each pair of pole faces. Although the use of long pole faces (long in the direction of beam deflection) tends to reduce the deflection flux density, at the same time it has the effect of making a more uniform field through which deflection occurs. By a slight variation of yoke and coil design, it is possible to obtain a satisfactory pattern using separate deflection yokes as shown in Fig. 19.

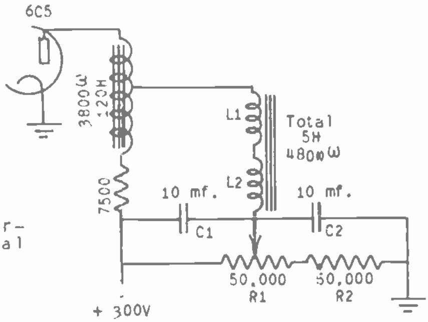


Fig.20 A typical output circuit for the 60 cycle vertical sweep.

A more desirable type of yoke, particularly from the commercial viewpoint, has been designed for use in connection with output circuits differing in design from the one we have just studied. In Figs. 20 and 21 are shown two methods of transformer coupling the deflecting coils to the plate circuit of the output tube. The type of circuit shown in Fig. 20 is designed particularly for use in connection with the vertical sweep circuit. The use of a transformer in this position makes possible a better energy transfer between the plate of the output tube and the deflecting coils; that is, a better impedance match is obtained between the plate circuit and the deflecting coils than in the circuit shown in Fig. 10. The 7500 ohm resistor between the plate supply and the auto transformer has two functions; namely, it improves sawtooth linearity and provides sufficient voltage drop at the input of the deflecting coils to permit satisfactory operation of the spot centering control R_1. The extra, fixed resistor shown at R_2 is a safety measure used to prevent any possibility of the low end of the coils becoming grounded and thereby shorting the voltage supply through a portion of the transformer and the coils with probable damage to both.

In Fig. 21 is shown a slightly different arrangement of the output circuit. In this case, a transformer having separate primary and secondary windings is used. The circuit is designed for horizontal frequency operation, but by changing the transformer and deflecting coils to the correct values, it may be made to operate quite satisfactorily at the vertical frequency. In that case, however, for the sake of economy, the transformer would probably be designed to work out of a 6C5 type of tube, rather than the type 42. The transformer must be of very special design since, as we have already seen, the horizontal frequency sawtooth is composed of harmonics which may include frequencies well above 100,000 cycles.

Due to the very rapid change in current in the transformer during the time of the return trace, shock-excited oscillations are set up in the plate circuit of the output stage. It is for the purpose of damping out these oscillations that the 1-v type of tube shown in the diagram is used. Sometimes a small condenser C may be necessary in addition to the damping tube. The action of this damping tube may be described as follows. At the start of oscillation, the primary swings first to a high positive voltage and then to a negative. So long as the cathode of the 1-v damping tube is positive with respect to its plate, the diode will not conduct; but when the primary of the transformer swings this cathode negative with respect to its plate, the 1-v conducts current. In this manner, otherwise objectionable oscillations are quickly damped out.

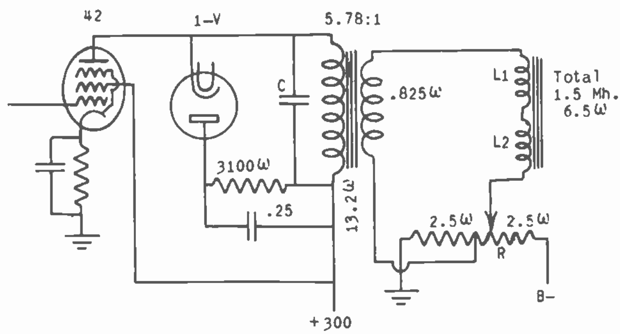
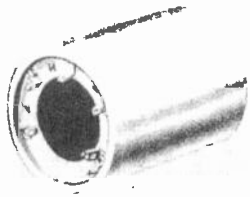


Fig.21 One type of output circuit that may be employed in connection with the horizontal sweep frequency (13,230 c.p.s.).

The student should not become confused with the idea that this damping tube serves to reduce the high back e.m.f. which results during the return trace time. Such is not the case. Actually in these circuits employing transformers, this voltage may reach values as high as 3,000 volts! Because this voltage is much higher than the maximum value for which either the 1-v or 42 are rated, some tubes may have their useful lives materially shortened in this circuit. For this reason, it is suggested that the filament of the 1-v be operated at a reduced value, such as 4 volts, instead of its rated 6.3 volts in order to reduce the temperature of the insulation in the tube and thereby prolong the life of this tube.

In cases where increased deflection is desired, two type 42 tubes may be used in parallel. A single 6L6 used in connection with a transformer of correct design would also give increased deflection. In a design such as this, the deflecting coils L_1 and L_2 are wound with so few turns of wire that the spot shifting arrangement requires a large current in the order of 200 to 300 milliamperes to produce any appreciable shifting of the spot. In order to obtain this current economically, it is advisable to place the controlling potentiometer in series with the power supply. For instance, the 5 ohm potentiometer R shown in Fig. 21 could be placed in the negative return of the power supply.

While the transformer-coupled output circuit gives fairly satisfactory performance it is believed that future advances in the art will give preference to an improved form of direct or condenser coupling. This is particularly desirable from the standpoint of production costs.



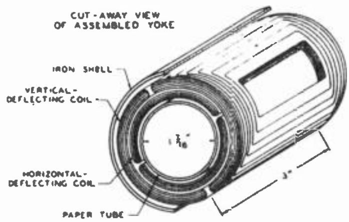


Fig.22 Improved type of deflecting yoke.

The type of yoke used in connection with circuits such as shown in Figs. 20 and 21 is very compact and simple in construction. In Fig. 22 is shown a picture of this type of yoke. The overall length of this yoke is approximately 3¼" and its diameter is approximately 2½". The actual length of the deflecting coils themselves along the axis of the beam is approximately 3".

The horizontal yoke consists of two flat-wound coils, rectangular in shape, bent to fit the curvature of the composition tubing and mounted snugly against the outside of the circumference of the tubing. The inside diameter of this composition tubing is just sufficient to permit it to slip on over the neck of a cathode ray tube. One coil is mounted directly opposite the other, each occupying approximately one-third of the circumference of the tubing with the final one-third of the circumference divided between the separation of the sides of the two coils.

The vertical yoke design follows very closely that of the horizontal, its coils being wound and mounted similarly on a composition tubing, whose inside diameter is just sufficient to allow it to fit snugly over the horizontal yoke. A third tube designed to slip over the vertical coils consists of two or three turns of a thin sheet of transformer iron. This forms a return path for the flux of the vertical deflecting coils. To prevent shorting between the metal and the coil turns, some type of insulation, such as a thin piece of cardboard, is generally used. To give the yoke a finished appearance, the entire assembly is now forced into another composition tube. Four connections to the deflecting coils, as well as a fifth for purposes of grounding the metal tube, are brought out at one end of the yoke. There are, of course, many variations of this general type of yoke construction. It is interesting to note that the design for this type of yoke originated in the stator laminations of a small electric motor and, in the course of its evolution, the horizontal yoke took on the air core type of construction while the vertical yoke section assumed the form of a modified iron core. The construction of this type of yoke is such that a magnetic field uniformity of better than 2% is claimed for them.

In any type of yoke construction, there is always a possibility of cross-talk between the horizontal and vertical. This can be reduced by careful design and the correct deflecting coil connections (arranged so that the undesired induced voltages and currents will buck each other). In this connection, it is sometimes desirable to connect the horizontal coils in parallel and the vertical ones in series, or vice versa; while in other cases perhaps both should be connected in parallel. However, in some instances the two sets of deflecting coils may be placed so as to have a minimum coupling and the cross-talk will not offer any problem.

Thus far we have discussed only output circuits employing magnetic deflection. There is, however, another method which is widely used, particularly in oscilloscope work, known as "electrostatic deflecting." In this case, two pairs of deflecting plates are placed inside the neck of the cathode ray tube. Since this type of construction has already been covered fully in a former lesson, further discussion should not be necessary. It is of interest to note that this type of deflection has found particular favor in other countries, but prevalent practice in the United States at the time of this writing seems to favor the magnetic deflection circuit, an exception being made, perhaps, in the case of the manufacturer specializing in the smaller type of television receivers.

8. INTERLACING. During all previous discussion, a 441-line interlaced pattern has been assumed. It now becomes necessary to discuss some of the problems involved in obtaining an interlaced pattern. One problem has its origin in the synchronizing signal itself, since it is the vertical impulse which controls each field of the television picture. The problem of synchronizing the vertical oscillator is made more difficult by interlacing, because the

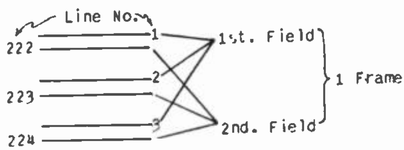
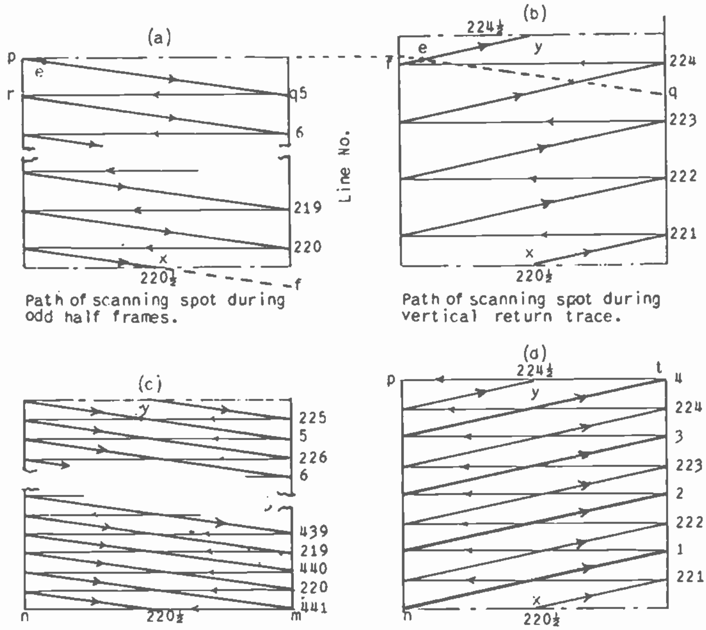


Fig.23 Paired lines in an interlaced pattern.

ending of each set of interlaced lines must be timed very accurately; otherwise, the next set of lines will not occur properly in the spaces left between the lines of the previous scan. Such a condition results in a pairing of the lines (Fig. 23) which may produce a loss in picture detail, depending upon the amount of pairing.

Two major requirements must be fulfilled if we are to obtain satisfactory interlacing. First, consecutive vertical synchronizing impulses must be identical and, second, the waveform of consecutive vertical sweep voltages delivered to the grid of the output tube in the sweep circuit must be identical. In order to satisfy the first requirement, a very special type of synchronizing impulse has been designed. (The simple type of synchronizing signal shown in connection with previous diagrams was used to avoid confusion.) The generation of this special type of vertical synchronizing signal is beyond the scope of this lesson. The second interlacing requirement relates directly to what is happening in the deflecting circuits themselves and, consequently, should be considered at this time. We have seen in a previous lesson how it is possible to produce interlacing by mechanical means, such as the disc, and obtain an interlace ratio of two, three, or more. Methods for accomplishing this same result electrically in cathode ray scanning are much more involved. Satisfactory results depend upon the continuous reproduction of electrical conditions which are subject to all the interferences found in electrical circuits and may not, therefore, be established by the mere correct location of scanning holes as in the case of a mechanical disc. The interlacing to be described is known as the "odd-line" type, with a 2:1 ratio. The "odd-line" name is derived from the fact that the pattern of one complete frame is composed of an odd number of lines; in this case, 441 lines. Another type of interlacing is known as "even-line" interlacing. The 2:1 ratio indicates that the picture (one frame) is made up of two complete vertical scannings or fields. A picture composed of three fields, therefore, would be known as having a 3:1 interlace ratio.

In Fig. 24a are shown top and bottom lines of a pattern during the scanning of the odd numbered field. The first vertical synchronizing impulse occurs at the *end* of 220½ horizontal lines or point x in the figure. The vertical return trace, therefore, begins at x as shown in (b) and is seen to consist of four lines in this particular case and to end at y, the 224½ line point. The second scanning cycle (even numbered field), therefore, starts at y as shown in (c) and the procedure noted in (a) is duplicated with the exception that this time the spot progresses so that the scanning lines fall midway between those originally scanned in (a). If we follow this scanning field through to the end, we shall find that the synchronizing impulse for the even half frame occurs at the end of the 441st line, point m as shown in (c). Hence, it is seen that *consecutive vertical synchronizing impulses are 180 degrees apart with respect to the horizontal deflective cycle*. That is, in their relation to the horizontal deflection, they must always be one-half line apart; it is this relationship, as we shall presently see, which makes odd-line interlacing possible. The return trace for the 441st line is from m to n in (c). Hence, point n in (d) is the start of the number one scanning line so that the first four lines of the odd field are taken up by the vertical in returning to point t at the top of the pattern ready for the start of the fifth line, as shown in (a). It is shown in (b) that the vertical return trace (from x to y) is equivalent to four lines; that is, there are three full lines and two half lines; likewise, the second vertical return trace as shown from n to t in (d) is four lines. *If for any reason, the length of the return traces shown in (b) and (d) are not equal, the pattern will show signs of pairing.* This condition becomes increasingly serious as the difference in these two return times increases, until finally the lines of the odd and even fields are superimposed so that the pattern contains only 220½ lines instead of the original 441. We have seen how it requires only ½ line variation in consecutive vertical return traces to produce a loss of all interlacing



Path of scanning spot during odd half frames.

Path of scanning spot during vertical return trace.

Path of scanning spot during both odd and even ½ frames.

Path of scanning spot during vertical retorn trace of both odd and even ½ frames.

Fig.24 Path of scanning spot during one frame of an interlaced pattern (2:1 ratio).

results. Pairing of the scanning lines becomes objectionable if the period of the vertical return trace varies more than ±.1 of a scan line from the correct value. The actual length of the return line itself as shown at either (b) or (d) is not important as regards interlacing; it might be three, four, or even ten lines long. The all-important factor is: if the return trace of the odd half frame is ten lines, then by all means the return trace for the even half frame should also be ten lines. Anything that disturbs this relationship will influence the effectiveness of the interlacing.

It is commonly said that the synchronizing impulse initiates the start of each line and each half frame, depending on whether it is the horizontal or vertical synchronizing; strictly speaking, this is not the case. In view of what has been previously said in connection with Fig. 12, it will be seen that the synchronizing actually concludes the scanning cycle and that it is the width of the blocking tube oscillator impulse which primarily determines the time occupied by the return trace. (See Fig. 12c.) It is at the conclusion of this return trace that the new line (horizontal) or half frame (vertical) is actually initiated. Thus, the initiation of a new scanning period is indirectly forced by the synchronizing impulse, but its absolute starting time is dependent upon the oscillator impulse which may vary slightly in different receivers.

Consequently, anything which may influence this oscillator impulse (referring now to the vertical only), so that consecutive impulses are not identical, will also destroy the proper relationship existing between the times of consecutive return traces and thereby upset the interlacing traces. From this it follows that the ratio of the scanning period to the retrace period should be fixed. Consequently, any factor influencing the time of either of these periods in one field and not in the other will produce pairing. Crosstalk between the horizontal and vertical scanning circuits prior to the grid of the output stage is one common source of trouble. A particularly good example of a case of this kind is found in some types of separating circuits which permit the horizontal oscillator circuit to feed back into the vertical oscillator circuit. Feedback from the horizontal oscillator to the vertical synchronizing circuit normally will produce a dissimilarity in the consecutive vertical synchronizing impulses, causing the synchronizing to be effective at irregular time intervals. If this unwanted voltage from the horizontal oscillator actually gets into the impulse of the vertical oscillator, it will change the size of the impulse, which in turn will effect the relationship existing between the scan and retrace period. Let it be exphasized again, however, that if both vertical periods (which make up a single frame) are affected alike, no harm will be done. Any extraneous voltage in the discharge circuit, induced or otherwise, that will cause a change in the magnitude of consecutive vertical discharges by as much as .4% will completely destroy interlacing.

One method of preventing the horizontal oscillator from feeding back into the synchronizing circuit is to use a separate screen grid type tube to feed the horizontal synchronizing signal to the horizontal oscillator circuit.

9. WHY A PATTERN INTERLACES. It is sometimes rather difficult to understand why a pattern must interlace if given the proper condition. For that reason, let us re-examine Fig. 24 in an effort to clear up the mystery of what really happens. Suppose we assume the attitude, "How do we know the return trace is going to be exactly four lines long as shown in (b)?" Suppose it is a little less than four lines long so that instead of terminating at y, in (b), it ends

at e which is the same point as the e in (a). Such a condition is entirely possible and, should this occur, the path of the scanning spot during the even half frame would be identical to that in (a) with one exception. This time instead of the synchronizing terminating the scan at $220\frac{1}{2}$ lines or point x, the scan would continue on to some point f, which is a half line removed from x. Due to the half line relationship (previously mentioned) existing between consecutive vertical synchronizing impulses and the horizontals, the synchronizing would terminate the vertical scan at this point. Now assuming this return trace to have exactly the same length as in the previous scan, that is, from x to e in (b), the scanning line for the beginning of the second odd half frame must of a necessity now fall at some position one - half line removed from e in Fig. 24b. Thus it is seen that it is entirely possible to have the first two half frames or fields so related that they will not interlace satisfactorily, but this condition cannot exist longer than the third half frame in the normal operation of the scanning circuits.

Before leaving the subject of interlaced scanning, it is well to understand that with this type of scanning, there may be a minor optical effect which can prove slightly objectionable when objects in the scene move very rapidly. For example, if the motion is in a horizontal direction, the edges of the object may appear to be jagged. This, of course, is due to the lapse of time between consecutive lines in the picture, since they are approximately 220 lines apart instead of being adjacent as they appear in the picture. If the object in the picture moves vertically instead of in a horizontal direction, there is no evidence of the jagged edges, but the entire object may appear as if transmitted by a system having only half the total number of lines. This action may be verified by the operator of a 441-line synchronized receiver if he will place his finger at the top of the pattern, and then with his eyes following the movement of his finger as he progresses toward the bottom of the pattern at the correct speed, it will be noticed that at times only half the lines of the pattern will appear to be present. A similar result may be obtained simply by the viewer nodding his head up and down.

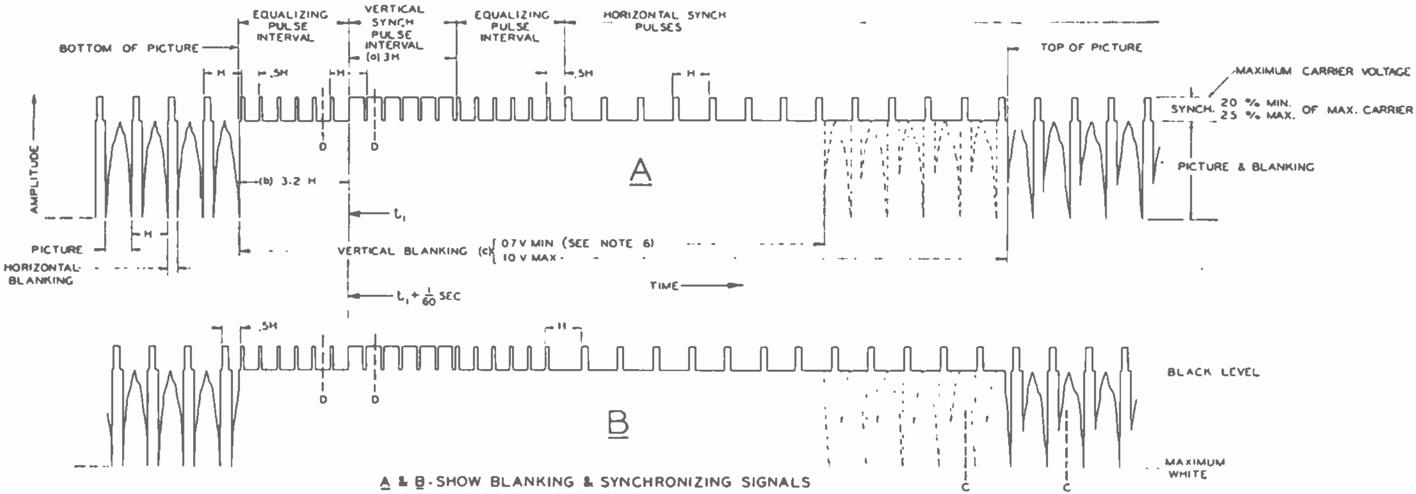
This small loss in detail due to motion in a picture is of no great consequence, because it is largely offset by the fact that since the objects are moving, they actually require less resolution in order to be defined; besides, the eye cannot resolve minute detail in objects that are moving.

To remove any possibility of the synchronizing signal itself being at fault in any case of poor interlacing, and also to meet certain other requirements, it has been necessary to devise a very special composite type of vertical synchronizing signal, such as shown in Fig. 25. Here a few of the horizontal synchronizing signals are shown in connection with two consecutive vertical synchronizing impulses.

The present specifications for the synchronizing signal have been arrived at only through years of laborious experimentation by several companies. Contributing factors in this special design may be listed as follows:

RMA STANDARD T-111
TELEVISION SIGNAL

441 LINES, 30 FRAMES PER SEC., 60 FIELDS PER SEC., INTERLACED



A & B - SHOW BLANKING & SYNCHRONIZING SIGNALS IN REGIONS OF SUCCESSIVE VERTICAL BLANKING PULSES (HORIZONTAL DIMENSIONS NOT TO SCALE ALL DIMENSIONS ARE FROM BLACK LEVEL UNLESS OTHERWISE SPECIFICALLY INDICATED)

Fig.25 (Note instructions)

(1) The need for continuous line synchronization (even during time of the vertical B.O. signal);
(2) The use of odd - line interlacing (consecutive vertical synchronizing signals do not bear the same relationship to the horizontal synchronizing impulse);
(3) The requirements of separating circuits (it must be possible to separate the vertical from the horizontal synchronizing signals);
(4) Economical use of transmitter carrier power (peak carrier power determined by amplitude of synchronizing signals).

Unless line synchronization is maintained during the time of the vertical blanking out signal, the horizontal oscillator will run "free" (at lower frequency) so that when the synchronizing signal is again introduced, it may be ineffective during a period of several lines. This is brought about by a shifting of the horizontal oscillation cycle with respect to the time of the synchronizing signal so that where originally it may have required only three volts, it now may need fifteen or more to synchronize the oscillator.

Since consecutive vertical synchronizing impulses differ in their relationship to the horizontal synchronizing impulse by a time interval equal to one-half line, it has been found necessary to use

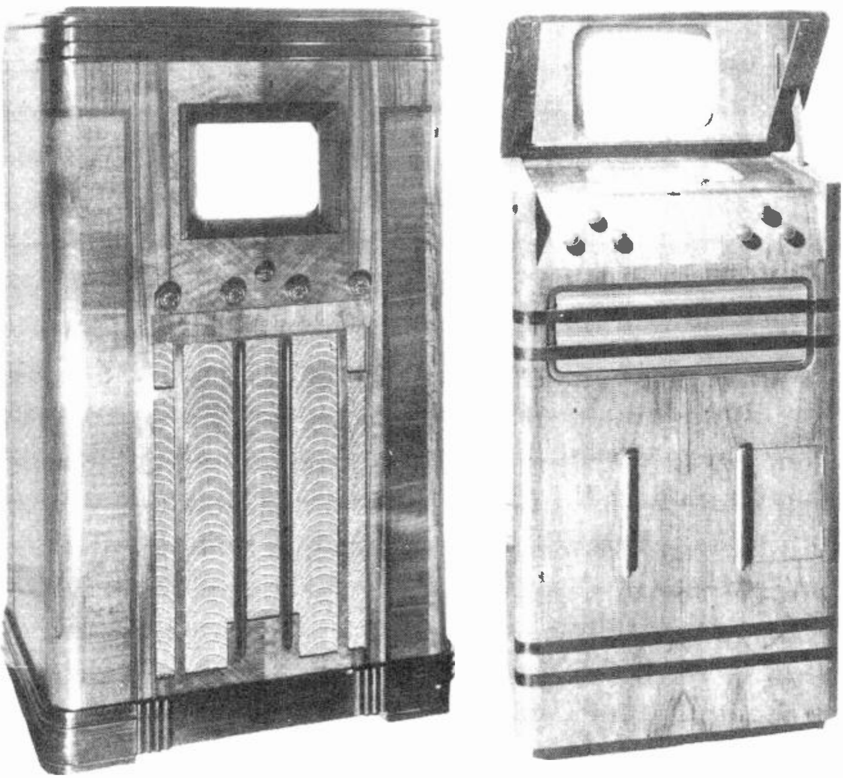


Fig.26 Television Receivers. Left: Direct viewing screen. Right: Indirect viewing screen.

special equalizing impulses as shown in Fig. 25. These are double the horizontal frequency (26,460 c.p.s.) and their use causes the synchronizing separating circuits to operate as though consecutive vertical impulses had identically the same relationship to the horizontal. Otherwise, the separating circuits would "remember" this difference to the extent that the wavefront of consecutive vertical impulses would differ sufficiently (after separation from the horizontal impulses) to cause the lines to "pair" in an interlaced pattern.

As previously pointed out, it is necessary that the vertical synchronizing signal differ in either amplitude or time duration from the horizontal in order that the two may be separated. In this case it was decided that the vertical synchronizing signal should have a longer time duration than the horizontal, but that its amplitude should be the same, since any increase in amplitude would necessitate an increase in the peak carrier power of the transmitter.

Since there are a number of controls on a television receiver, there are naturally some that will require adjustment more often than others; those more apt to be used during any normal picture reception are brought out to a convenient location, such as the front of the cabinet. The most likely controls for this position are as follows: The tuning control (sight and sound), the signal intensity control (sometimes called the detail control), the briliancy or background control of the cathode ray tube (contrast control), and sound volume and tone control. Other controls, such as the cathode ray beam focusing control, the horizontal frequency control, the vertical frequency control, the horizontal and vertical sweep amplitude controls, synchronizing pick-off, peaking, and bias adjustment, may be located on the chassis inside the cabinet in a place convenient for the serviceman.

Two general types of television receivers are pictured in Fig. 26, one the direct viewing type and the other the indirect; the indirect has the image reflected by a mirror located in the lid at the top of the cabinet.

10. POWER SUPPLY. In any television receiver there are fundamentally at least two power supplies; the one supplying the high voltage for the cathode ray tube and the other the plate voltages for the various amplifier and oscillator tubes. Ordinarily they are both mounted on the same chassis; however, in some instances, it may be desirable from the standpoint of the serviceman and testing procedure to use separate units. For this same reason, a separate unit may be designed to supply the necessary voltages for the sound portion of the receiver. We are, however, more concerned with the requirements of these units and, for that reason, nothing more will be said regarding the mechanical details of the power supply. Since the requirements are more stringent if a single chassis unit supplies all voltages, this type automatically becomes the subject for discussion.

The high voltage unit has already been discussed in connection with a previous lesson on oscilloscopes and television tubes. Therefore, let us turn our attention to the low voltage supply. The requirements for the power unit are of the same general type as encountered in radio receiver manufacture, with the exception that the magnitude of the requirements has increased, due to the very nature of the circuits themselves. Fig. 27 shows one arrangement for the power supply. In this particular case, a single transformer supplies all the plate and filament voltages, although in some instances it may be desirable to have a separate transformer for the filament supply. In the better grade of television receivers, this plate transformer must be able to supply between 300 and 400 ma. with minimum regulation; also, it is preferable that there be 110 and 115 volt taps on the primary side in order to compensate for line voltage differences in certain localities.

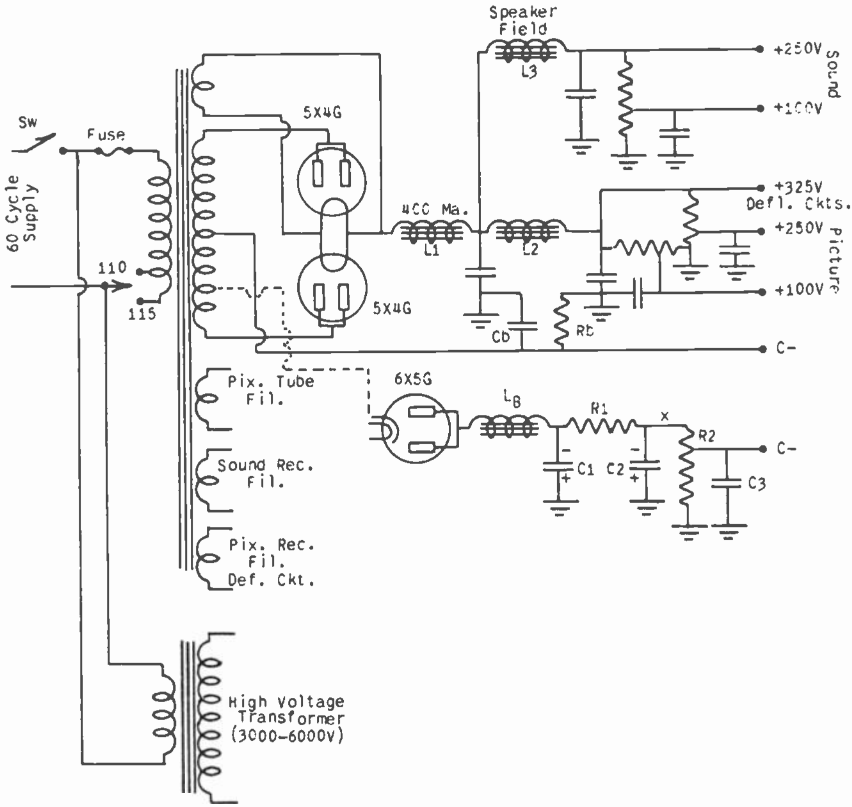


Fig.27 Power supply for a Television Receiver (high voltage for CR tube omitted).

In order to reduce the possibility of crosstalk between the sound and picture circuits, only the first filter stage of the power supply is common, and the sound has its own individual filter stage in connection with the speaker field L_3; the picture and deflecting circuits have a second filter stage in common through L_2. Thus, it is seen that actually the sound and picture circuits are separated by two stages of filtering. The bias supply may be obtained in the usual manner by means of the resistor R_b in series with the power unit return. In many instances, however, it may be preferable to obtain the bias supply from a separate rectifier as shown connected to the transformer secondary by the dotted line. In this case, R_b and C_b are omitted and the transformer secondary center tap is connected to ground. In some instances it may be desirable to have a regulated bias supply; in that case, the resistor R_2 and the condensers C_2 and C_3 may be eliminated and a voltage regulator tube, such as the 874, connected between the point x and ground. The resistor R_1 is used to limit the current flowing through the regulator tube to its normal value (with a maximum of 50 ma.).

In some instances it may even be desirable to have a regulated power unit supplying the plate voltages to the picture and deflecting circuits of the receiver. Due to the cost, such a regulated supply will, in all probability, be found only in the more expensive type of receivers; since the regulated power unit is used quite extensively in control room practice, a description of this type of supply will be found later in the study of control room amplifiers.

Inasmuch as there is so much information of basic importance in this particular lesson, the student is advised to make sure that he has a thorough understanding of the function and operation of these circuits. There is much in television circuits, both in the control room and the receiver, that is so closely related that the student may find it necessary to review portions of preceding lessons from time to time. Failure to understand some particular point about circuit operation may serve as a broken link in your chain of information that will leave you "dangling" through the entire television course.

EXAMINATION QUESTIONS

INSTRUCTIONS. Before starting to answer these examination questions, you should have studied the lesson material at least three times. Be sure that you understand each question--then proceed to write the best answer you can. Make all answers complete and in detail. Print your name, address, and file number on each page and be neat in your work. Your paper must be easily legible; otherwise, it will be returned ungraded. Finish this examination before starting your study of the next lesson. However, send in at least three examinations at a time.

1. What is the purpose of the synchronizing signal?

2. Name the two functions of the separating circuits.

3. How may condenser-coupled amplifier circuits reduce the effectiveness of the synchronizing signal?

4. Illustrate by drawings and explain amplitude and frequency selection.

5. Draw the voltage waveform found at the grid of the blocking tube oscillator, and explain how the oscillation cycle may be controlled by a synchronizing impulse.

6. Approximately what percentage of the normal charge period of the discharge circuit is actually utilized in the formation of the sweep circuit sawtooth?

7. Explain the chief reason why it is desirable to have a variable bias control on the output stage of a sweep circuit.

8. What is the chief factor in determining the amplifier frequency response necessary to handle any sawtooth waveform of voltage?

9. Name the major requirement for good interlacing that relates directly to the deflecting circuits.

10. What is meant by a 2:1 interlace ratio?

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