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CONTENTS

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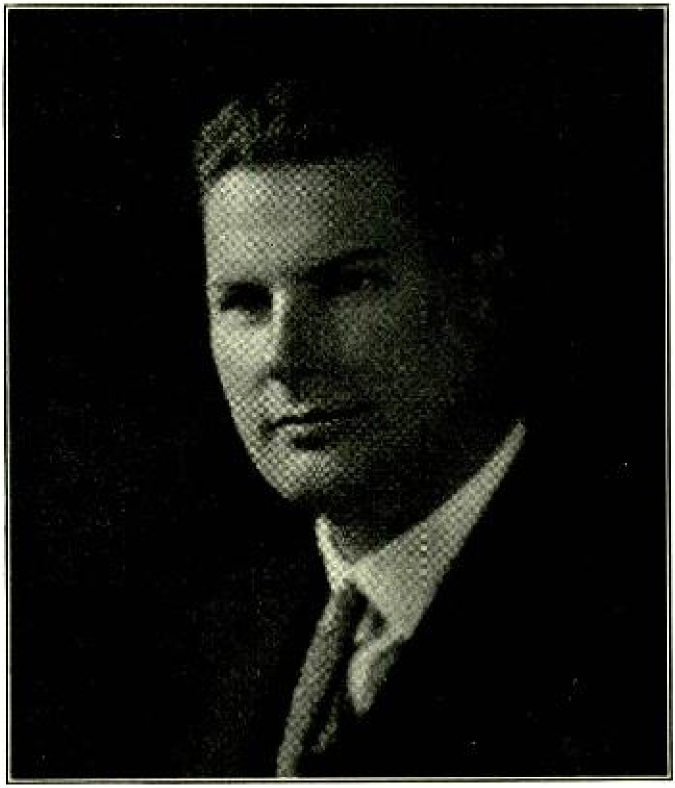


HAROLD H. BEVERAGE

Through the election of Harold H. Beverage as President of the Institute of Radio Engineers the Institute gains a highly capable and popular leader for 1937. The membership has had opportunity of noting his energetic activities in committee work and other contributions in furtherance of I.R.E. aims and principles. I.R.E. honors were also bestowed upon Mr. Beverage fourteen years ago when he was awarded the Morris Liebmann Memorial Prize for outstanding contributions in the development of a "wave" antenna system known as the "Beverage Antenna".

Other noteworthy achievements in his line of work are marked to the credit of Mr. Beverage, who is an alumnus of the University of Maine. He spent five years in the General Electric Company with Dr. Alexanderson and during the World War was engaged in research work at the Marconi high-power station at New Brunswick and at the Otter Cliffs Naval radio station. Later he became Research Engineer for RCA, and in 1929 was appointed to his present post of Chief Research Engineer of R.C.A. Communications, Inc.

EDWARD WASHBURN KELLOGG

At the banquet of the Society of Motion Picture Engineers, held at Rochester, N. Y., October 14, 1936, a scroll was presented to Edward W. Kellogg, whom the Journal Award Committee and the Board of Governors of that Society had selected to receive the S.M.P.E. Award for 1936. Mr. Kellogg's paper entitled "A Comparison of Variable-Density and Variable-Width Systems," was designated as the most outstanding paper originally published in the Society's Journal during the preceding year.

In the "Citation of the work of Edward Washburn Kellogg", by Dr. Alfred N. Goldsmith, Past-President of the Society, reference was made to Mr. Kellogg's "career of industrial research and engineering, notable not only for the importance of its accomplishments, most of which were either directly or indirectly related to the sound motion picture art, but also for its versatility."

In outlining his professional career, Dr. Goldsmith included mention of Mr. Kellogg's several noteworthy accomplishments and closed the citation with the remark: "I am doubly pleased that this honor should come to one who combines, in such outstanding degree, original thinking, scientific thoroughness, technical skill, and manly candor and courage."

Thirty years ago Mr. Kellogg was graduated as a civil engineer from Princeton University, later studying mechanical and electrical engineering at Cornell. From his first employment with a public utility company in Chicago, he turned to instruction in electrical engineering at the Universities of Missouri, Texas, and Ohio. Shortly after the entry of our nation into the World War, he left the academic world and joined the Research Laboratory of the General Electric Company, at Schenectady, to assist in submarine-detection work. Since the advent of sound motion pictures, Mr. Kellogg has been concerned with nearly every technical phase of the art, at the laboratories of the RCA Manufacturing Company at Camden. He is now in charge of the Advance Development Section in the Photophone Division of that Company.

THREE DECADES OF RADIO*

BY

DAVID SARNOFF
President Radio Corporation of America

HISTORY in the making is always out of focus. But time and memory have the saving trick of discarding the trivial and emphasizing the significant. We need the perspective of the years to judge the importance of past events with a true sense of proportion. And—since our decimal system places an accidental emphasis upon numbers divisible by ten—the conclusion of a thirty-year period seems to be an appropriate time to make a survey of the past.

It was my good fortune to go to work in the infant industry of radio thirty years ago this Fall, and it has been my privilege to be actively and continuously associated with it ever since. I mention this fact, not because my remarks tonight are to be autobiographical—for they are not—but simply to establish my excuse for being here; which is that I have observed at first hand and participated in the phenomenal growth of radio, almost from the day it began to be something more than a scientific curiosity.

Marconi, it is true, had in December, 1901, achieved the first radio communication across the Atlantic Ocean. It could hardly be called a "message": just three tiny clicks—the letter "S" in Morse code—and so feeble in strength that one can well imagine the mingled hope and fear written on Marconi's face as he stood on that bleak hillside in Newfoundland. He handed the earphones to his assistant, Mr. G. S. Kemp, and said, "Can *you* hear anything?" Mr. Kemp did hear the feeble clicks. After that first meager but momentous transmission over the Atlantic, a whole year elapsed before a single coherent sentence came across. It was not until the World War that anything which approached dependable transatlantic wireless communication was realized.

But we would have to go back many years before Marconi's time were we to attempt to give credit to all the men of science who have shared in the development of radio. To name but one, our own Benjamin Franklin in the middle of the 18th Century made invaluable

* *A lecture before The Franklin Institute, Philadelphia, Pa., November 18, 1936.*

contributions both to our knowledge of electricity and to the ability of all science to express itself in clear and unmistakable terms. Radio is a true descendant of this learned society's godfather and the first great American scientist. It can trace its lineage to Franklin's methods and discoveries. Even his immortal kite had its direct successor in the early experiments with antennas used in wireless telegraphy.

THE GROWTH OF RADIO

As we now look back upon the past thirty years of radio history, they divide themselves into three fairly distinct periods.

The first was the marine decade. During this time radio was utilized mainly in ship-to-ship and ship-to-shore communication. It was a period during which wireless telegraphy was used almost exclusively for maritime purposes. But it was a decade of active research and experimentation, in which were sown the seeds of important future devices and services. This is a statement that can be made also of both the ten-year periods which followed. Every decade in radio is an experimental one.

The second period was the war decade. In this period, I include the early post-war years during which the tremendous advances made by radio as an arm of the military and naval services were consolidated for the uses of peace. This decade was marked by expansion of radio from the field of telegraphy to that of telephony, an expansion which made possible the achievements of the next period.

The third decade is marked preeminently by the development of broadcasting. The National Broadcasting Company, the first organization to establish and operate a nationwide radio network, was created just ten years ago this month.

Simply to recite the chronology—item by item, year by year, decade by decade—of the technical progress of the radio art is to unroll a fascinating tapestry which grows ever more brilliant in color, ever more intricate in design. Such a recital, however, is merely a story of "art for art's sake." It omits the very motif of radio's history and of its future, the keynote in the approach to every problem that confronts the industry.

For radio has never been an esoteric art. It has never dwelt in an ivory tower. It is "of the people, by the people, for the people." Its real history is the adjustment of revolutionary scientific instrumentalities to the changing needs and emotions of humanity. By the success or failure of that adjustment radio must be judged, no matter how much homage we may pay our scientists for their mastery of galloping electrons captured in a tube.

The Marine Decade

First, let us survey the marine decade of radio. Marconi's early achievements had caught the public imagination, but they seemed remote from the affairs of every-day life. Quietly and slowly, a few shore stations were established and a number of larger vessels were equipped with wireless apparatus. Then, in January, 1909, in a thick fog off the Island of Nantucket, the transatlantic liner *Republic* was rammed and sunk by another ship. Her wireless call for help — the CQD of that day — brought vessels to her aid. All but six were saved, and the Marconi station at Siasconset, on Nantucket Island, relayed to the press the messages from the sinking ship and the rescue ships as fast as the words came through the fog. Here was a drama as ancient as the sea itself, with an unexpectedly happy ending, and, for the first time, with all the world in breathless attendance. Wireless leaped from obscurity to fame. Congress passed the Radio Act of 1910, prescribing radio equipment and an operator on every deep-sea vessel carrying more than fifty persons — legislation which quickly expanded the facilities and personnel of radio.

That act was amended and amplified in July, 1912. It now called for a constant radio watch on shipboard, with two operators and an independent auxiliary source of power. This action was the result of the horrifying disaster to the *Titanic* in April of that year. Her SOS had been heard over a wide area — the *Carpathia* rushed to the scene of the tragedy and picked up 706 survivors — but 1,517 perished, many of whom might have been saved. A ship much nearer than the *Carpathia* did not hear the *Titanic's* call. She was equipped with wireless, but her single operator was off duty and in bed when the call was sent into the air.

It almost seemed as if the gods of progress had demanded human sacrifies. An enormous price in human lives had to be paid before marine radio attained its full importance in the public consciousness.

The War Decade

Then — to the accompaniment of an infinitely greater cost in human suffering — the war put radio into the armament of nations, and through the achievements of the war decade, wireless became an instrument of worldwide communication.

For the purposes of this survey, we are concerned, not with what radio did in the war, but with what the war did to radio. However far the world conflict fell short of achieving the idealistic outcome demanded of it — to "make the world safe for democracy" — it did make radio an instrument of democracy. It took it out of the hands of the few and gave it to the many.

The World War brought to fruition the important but obscure discoveries of the preceding decade. High-vacuum tubes and regenerative circuits; improved detectors and amplifiers; continuous wave generators of much higher frequencies — all became radio's stock-in-trade. Nor was it by any means entirely a development of isolated, individual inventions that was promoted by the war; of even greater importance was the effective coordination of all known radio devices into a single, integrated structure.

Radio is the product not of one mind but of many; not of one discovery, or a handful of related discoveries, but literally of thousands of inventions originating in many diverse fields of science and of industry. At the time the United States entered the World War the radio industry was hopelessly deadlocked in a snarl of patent litigation, actual or potential. A's invention was useful only in combination with B's; B's invention was useless without A's; and A and B would not or could not get together. Multiplied many times over, this was the wartime situation.

The United States Navy Department ended the impasse by declaring, in effect, a moratorium in the operation of the patent laws, as applied to radio, for the period of the war. It assumed financial responsibility for all infringements of radio patents, and ordered American manufacturers to produce radio equipment embodying every needed principle or device known at that time, regardless of patent ownership. Thereupon the radio industry threw away its crutches, stood erect, and walked for the first time. Fortunately, the industry has never since then suffered a return of the disease of patent paralysis.

The bulky, stationary equipment of the marine decade became transformed into the compact, portable field equipment of the war decade. The very difficulty of quickly building a large technical personnel out of unskilled men forced the development of relatively foolproof apparatus. What had been complicated was simplified; what had been difficult to service was made easy; what had been intermittent and unreliable in operation became regular and dependable.

In historical importance, the one development that overshadowed all others was the gradual perfection of the radio telephone. Ability to transmit the spoken as well as the recorded word — the addition of voice to code — gave to radio a new function and a new meaning. The radio telephone, however, presented one serious difficulty — especially serious in time of war. It offered none of the privacy of the ordinary wire telephone. What one had to say was for everybody to hear. Plenty of critics had pointed out this fatal limitation ever since the days of the earliest experiments in radio-telephony.

The Broadcasting Decade

But there were others who saw in this very limitation radio's greatest opportunity. They envisaged the possibilities of a new system of mass communication by radio, which would enable a single voice to be heard at the same instant by countless millions everywhere. In other words, they looked upon radio not only as a means of narrowcasting but also as a method of broadcasting. And that broadcasting gave its name to the third radio decade.

It was a method by which a liability was converted into an asset. The very non-privacy of the radio telephone gave to it universality of application. Had our telephone messages over the air been confined to secret and private use, we might never have had any radio broadcasting.

But while the war was on, the custodians of radio were too preoccupied with international communication and military equipment to develop broadcasting. It was not until 1920, when the Harding-Cox election returns were broadcast to an audience of several thousand amateurs with home-made sets, that the idea took hold. This "stunt" marked the birth of radio broadcasting.

Radio promptly proved that an old adage was out of date. We used to say, "Necessity is the mother of invention." Radio demonstrated that the opposite is true. Invention has become the mother of necessity. Create some attractive new instrumentality, and even though there has been no demand for it — even though the public has never dreamed of such a thing — millions of people suddenly discover that they can't get along without it.

Broadcasting in America

Harding was elected and the word "normalcy" became part of the everyday language. But it was a word that had no meaning in the world of radio. Like derricks in a new oil field, broadcast transmitting stations sprouted all over the United States — in less than two years after that first broadcast there were 500 of them. With no effective allocation or regulation of wavelengths, the resulting interference and confusion were indescribable. It was as though all those broadcasters had conspired to build a new Tower of Babel.

It was not until 1927, when the Federal Radio Commission was created by an Act of Congress, that the unique problems of broadcasting were first recognized by law. Provision was then made for assignment of wavelengths and regulation of stations from a viewpoint of service to the public. This purpose was emphasized by Congress in the Act of 1934, when it placed the supervision of radio in the hands of the Federal Communications Commission, and directed it to regulate radio by the standards of "public interest, convenience and necessity."

In localities where broadcasting stations were established, there followed an overwhelming demand on the part of the public for receiving sets. At first, the nature of the programs the broadcasters were sending out was of little moment; the only thing that mattered was to get hold of a set that would catch the signals of as many stations as possible, and to build up an imposing-looking list of those caught.

Naturally, this phase passed quickly. The listening public soon became conscious of the quality of broadcast programs. Then the station owners, absorbed at first in mastering a new engineering technique, found that they had another big problem on their hands — a double problem, of showmanship and economics. To build a good radio show cost money; the money came from advertisers; but advertisers were interested primarily in attracting an audience, not in buying a show. To the advertiser, the circulation cost of broadcast advertising had to justify itself in some sort of relation to the circulation cost of magazines and newspapers. No single station could supply a sufficiently large audience to warrant the expense of providing first-class radio entertainment.

It was a vicious circle. Until enough radio sets were in use to make radio advertising profitable there would be no radio advertising, and consequently no radio programs to make receiving sets worth buying. That is why we organized the National Broadcasting Company in November, 1926: to give the public programs on the air that would encourage it to buy radio sets. These programs were expensive, but by using telephone lines to connect a series of radio stations across the continent, it was possible to broadcast the same program at once to listeners in many states of the Union.

The demand for receiving sets was instantaneous and nationwide. All radio stations profited by the new listeners, and their advertising clients made better programs possible. Better programs sold more radio sets; stations installed finer equipment; improved transmitters meant better reception, further sales of sets, more advertising revenue, and even additional radio chains.

This, in a nutshell, was the genesis of the nation's broadcasting networks. They were dictated, not by the soaring imagination of radio technicians, but by the everyday business requirements of business men, who wanted value received for money spent.

The nation-wide network has enabled radio in the United States to introduce to great masses of people the foremost artists in the world of music and entertainment, and to do so with frequency and regularity. Their services have been paid for by the goodwill of their listeners — a goodwill voluntarily expressed through purchases of radio-advertised products. The networks in turn have been enabled to put on at their own expense a great number of sustaining programs of high artistic and educational merit, and to broadcast important news events, crop and weather reports, and the messages of our leaders in public life.

To summarize: we enjoy in America radio broadcasting services that are truly comprehensive in scope of programs, truly lavish in talent, truly national in coverage. The rural listener is served on a parity with the city dweller — the voice of the President of the United States may be heard at one time by the entire electorate. Yet after we have said all this, we still have not named the most important, the most vital aspect of our American broadcasting method. It is this: that in the United States radio broadcasting is a truly free and democratic institution. No license is required and no fee is charged for the privilege of owning a broadcast receiver and listening to the finest radio programs in the world.

Broadcasting in Europe

This is a significant statement, for it cannot be made concerning broadcasting in any nation in Europe today. During a recent visit to Europe, I had the pleasure of hearing some beautiful concerts, broadcast from various cities on the continent. But I also listened to some very poisonous nationalistic propaganda. If it is true that "music hath charms to soothe the savage breast," it is also true that reckless political propaganda has the power to make the human breast savage.

Under our system programs are supported by public goodwill voluntarily expressed. The American public can, and not infrequently does, vote a program off the air by its collective and voluntary twist of the dial. In those countries where radio programs are provided through a governmental tax on receiving sets, and sending stations and programs are under direct control of the government, broadcasting is neither free nor democratic. Its programs are subject to bureaucratic dictation and censorship. Radio has been made a slave of governmental politics; a perquisite of the party in power; a mouthpiece for the propaganda of autocrats. There, the public possesses no franchise —

as it so emphatically does in this country — to elect the programs it desires to hear, and to reject those it does not.

Broadcasting in Tune with its Times

The expansion of radio from a specialized, commercial, point-to-point message service to a wide popular usage — from individual to mass communication — reflects many of the social characteristics of the period during which it took place. It was the same period which saw the greatest development of the automobile, the airplane, the motion picture, and innumerable time- and labor-saving devices in the home. It was the period during which our daily lives were speeded up and given unprecedented hours of leisure. Radio broadcasting filled a newly-awakened need and was therefore attuned to the spirit of the times. More than that, it drew the most distant places, the most forgotten lives, within the orbit of modern civilization.

It should be remembered that when international radio communication was perfected, the ship-to-ship and ship-to-shore services which gave it birth were in no measure lessened; on the contrary, they progressed consistently, both in magnitude and precision of operation. In the youthful aviation industry, the ships of the air have also found in radio an indispensable ally, quite as thoroughly as the ships of the seven seas. And radio broadcasting, in turn, did nothing to slacken the steady forward march of all the earlier radio services. Instead, it gave to them a new advertising and a new impetus. Radio at all times consolidated its gains and abandoned none of the territory it had conquered.

Only a week ago — on Armistice Day — it was my privilege to take part in a four-way radio telephone conversation which illustrated the present state of radio's technical development. The participants were Senatore Guglielmo Marconi, two distinguished gentlemen from Europe now visiting in this country — Monsieur Robert Jardillier, French Minister of Communications, and Monsieur Maurice Rambert, President of the International Broadcasting Union — and myself. Marconi was on his yacht in the Mediterranean off the coast of Italy, our European visitors were travelling in two separate airplanes between Buffalo and Washington, D. C., and I was seated at my desk in the RCA Building in New York. We chatted together for ten minutes. Each of us could hear all the others perfectly. This unique experiment was broadcast by the National Broadcasting Company and heard by listeners in America, Europe and in other parts of the world. The land, the sea and the sky were linked across thousands of miles by radio.

RCA Is Organized

Within its own organic structure, radio did as other major American industries have done: it moved out of individual hands into those of the organized business group. It turned to the investing public for its capital funds. Almost midway in the thirty-year period we are considering — in October, 1919 — the company which I have the honor to represent, the Radio Corporation of America, came into existence. The history of this company is so inseparably linked with that of the entire industry that any review of this kind, however brief, would be incomplete without reference to it.

The war made obvious the vital importance of radio to the future development of international communications. Abortive efforts were made in Washington to nationalize the industry — efforts which neither then nor at any time since were in harmony with the American temper and tradition. Congress rejected the idea. Then, on the recommendation of the Navy Department, the war-time custodian of radio, the Radio Corporation of America was organized.

Two objectives were sought and — within a comparatively brief time — attained: first, to insure American ownership and control of radio facilities in this country; second, to perpetuate the benefits to the public of an integrated patent structure, originally achieved purely as a war emergency measure. Definite and controlling considerations of public policy have guided the conduct of the Radio Corporation ever since its inception. It is today the largest radio organization in the world, and the only one actively engaged in every field touched upon by the radio industry, and in no other.

I think it has become fairly well established that the great modern industrial organization bridges the gap between pure and applied science far more effectively than does the individualistic, "one-man" type of organization. It reduces the temptation to sacrifice the value of future services for the sake of a quick profit. It substitutes the long-range for the short-range viewpoint. It can afford to approach its problems from the angle of public interest rather than from self-serving opportunism, and it does so, not by reason of any fanatical moral attitude, but because the most enlightened self-interest dictates such an approach.

In the domain of applied science, the trend from individual to collective industrial research has been of unquestionable benefit to the public — in the quantity, quality, and rapidity with which useful new products and services have been brought forth.

The Future of Radio

This brings me to the second part of this discussion—the future of radio. While its progress during the past thirty years has been impressive. I look for even greater accomplishments during the next ten.

As our knowledge and employment of ultra-short waves increases progress will be speeded up. The most conspicuous of these advances during the next ten years will be the addition of sight to sound in the service of radio.

Facsimile

Radio transmission of pictures and reproductions of printed or written material has been an accomplished fact for several years. It is now in daily service between Europe and America. The broadcasting of a facsimile newspaper into every business office and home — in half-hourly installments if desired — is perfectly feasible. The establishment of such a service is now an economic rather than a technical problem. I feel reasonably certain that American ingenuity will presently discover some way to make this potential national service available to the public.

On June tenth of this year, Chancellor Harry Woodburn Chase of New York University and Vice-President W. Chattin Wetherill of The Franklin Institute exchanged pictures and greetings by radio facsimile. Their messages inaugurated the public service of RCA's ultra-short wave radio circuit connecting New York and Philadelphia, with two automatic radio relay stations at intermediate points.

This event was a new milestone of man's progress in conquering time and space. It represented not only a marked advance in the speed with which facsimile messages are transmitted, but a new achievement in multiple transmission. The new circuit made possible simultaneous employment, on the same radio wave, of two facsimile channels, two automatic typewriter channels, and a telegraph channel — five channels in all. The association of New York University and The Franklin Institute in the opening ceremonies was a happy and appropriate one, since these are the two institutions which, a century ago, first publicly recognized the genius of Samuel F. B. Morse and the importance of his electric telegraph.

Television

When it comes to transmitting and receiving the instantaneous, flowing image of moving objects the problems are enormously increased. These are the technical problems of television.

The Radio Corporation of America has just concluded an elaborate series of preliminary field tests to bring television from the laboratory into the sphere of practical use. These tests began only on June 29th of this year. That date marked the beginning in this country of organized television experiments between a regular transmitting station and a number of homes. Since then we have advanced, and we are continuing to advance, simultaneously along the three broad fronts of television development: research and engineering, which must point the road to effective transmission and reception, and then translate this progress into practical receiving sets for the home; program production tests to develop a television service suitable for network syndication; and economic studies to create a sound business basis that will support so costly an enterprise as television programs are bound to be. On all these fronts our work has made definite progress and has brought us nearer the desired goal.

We have been transmitting experimental programs from our television station on top of the Empire State Building in New York City, by remote control from the NBC television studios in the RCA Building. We have observed and measured these transmissions through a number of experimental receivers installed in the homes of RCA engineers and located in the metropolitan area and adjacent suburbs. The results thus far have been encouraging and instructive. As we anticipated, many requirements that must be met by a commercial device have been made clear by these tests.

We have successfully transmitted through the air, motion pictures as well as living talent before the televisor. The distance over which these television programs have been received has exceeded our immediate expectations. In one favorable location, we have consistently received transmissions as far as 45 miles from the television studios.

The tests have been highly instructive. We have learned much that is new about the behavior of ultra-short waves and how to handle them. We know more about interferences, most of which are man-made and susceptible of elimination. The difficulties of making apparatus function outside of the laboratory have been surmounted. We have confirmed the soundness of the technical fundamentals of our system. Theory has been put into practice, and the experienced gained through these tests enables us to chart the needs of a practical television service.

In our present field tests we are using 343-line definition. In cooperation with the industry, we have recommended to the Federal Communications Commission the adoption of 441-line definition as a standard for commercial operation. Our New York transmitter will be rebuilt to conform to the recommended standards. That also means building receivers to conform to the new standards of the transmitter.

The necessity of synchronizing transmitting and receiving equipment carries with it serious responsibilities. On the one hand, standards cannot be frozen prematurely or progress would be prevented; on the other hand, frequently changing standards would mean rapid obsolescence of television equipment.

Another major problem in television is that of network syndication. Our present facilities for distribution of sound broadcasting cover the vast area of the United States and serve its 128,000,000 people. Similar coverage for television programs, in the present state of the television art, would require a multiplicity of transmitters and network interconnection by wire or radio facilities still to be developed.

From the standpoint of research, laboratory development, and technical demonstration, television progress in the United States continues to give us unquestioned primacy. We lead in research which is daily extending the radio horizon, and in technical developments which have made possible a transmitting and receiving system that meets the highest standards thus far obtainable.

The chief distinction between television in this country and abroad is the distinction between experimental public services undertaken under government subsidy, and commercial development undertaken by the free initiative, enterprise, and capital of those who have pioneered the art in the United States.

Television Programs

The National Broadcasting Company is making an intensive study of television studio technique. During the next few months we will expand the engineering field tests into a series of dress rehearsals of various types of programs. Ultimately television will create its own individual art form — a fresh and unique world of illusion. It will, to be sure, borrow from the older arts of stage, motion picture, and sound broadcasting. It will supplement them all, and supersede none. The character of the new medium, with its inherent advantages and limitations, provides new scope for the imagination.

In the world of creative and expressive art the hardest question which television propounds is that of supplying talent. It suggests a reversal of the usual comparison between American methods of production and of distribution. Industry, it is said, has learned how to produce efficiently and cheaply, but distributes its wares inefficiently and wastefully. Here is television, on the other hand — youngest and most glamorous of industry's children — preparing to deliver its programs with the speed of light into the centre of every home. Perfect distribution! But television's problem of program production is a different matter. It is still unsolved, and much work must be done before the solution has been achieved.

Television broadcasting, even more than sound broadcasting, will be the great consumer of art. It will constantly demand more and better writers, musicians, actors, and scenic designers — new thoughts, new words, new songs, new faces, new backgrounds. Unlike a play on the stage or a motion picture which may run for a year, the television program, once it has been shown to a national audience, is on the scrap-heap. It is finished. Television will call for a whole new generation of artists. It should help materially to solve the unemployment problem.

The way things look today, it is not improbable that in a few more years a man with three sons may train one for business, one for government service, and one to be an artist. Perhaps this thought comes to my mind because I have three sons still to be trained for a useful life.

We have lately heard in our own homes the voices of the Presidential candidates. Political campaigns will take on added interest when people can see as well as hear the speakers, with television sets in the home. Each Presidential year since radio began to participate in the campaigns, the number of voters has increased by many millions. Whereas 27,000,000 people voted in the election of 1920, the vote in 1936 was 45,000,000. Television will increase the usefulness of radio in the cause of popular government.

While the problems of television are formidable, I firmly believe they will be solved. With the establishment of a television service to the public which will supplement and not supplant the present service of broadcasting, a new industry will have been created.

Radio Contributes to Other Fields

I have touched upon the major developments of radio and its prospects for further development in its recognized fields of service. I shall not attempt to review those collateral contributions with which radio science has helped to quicken the pulse of other industries. It is a fact worthy of mention, however, that radio tube technique and photo-electric controls not only are being applied more and more in the engineering branches of industry, but are welcome adjuncts to the tool-kit of pure science. The cyclotron which disrupts the atom — suggestion that the alchemist's dream of transmutation may some day come true — utilizes magnets originally devised for radio arc transmitters. Astronomers and meteorologists, motion picture studios and electric power plants, doctors of medicine and electric welders, all have been beneficiaries of the radio research laboratories.

Radio has also pointed our attention upward. Until our own generation the wealth of the world came from below the surface of our globe — from the mines and waters and fertile soils. It is only in the last thirty years that humanity has raised its eyes from the ground and commenced to look upward for new wealth — into the air, into the stratosphere. It is only a small beginning we have made, and it is fascinating to speculate upon the potential resources that still lie untouched in ultra-short waves, in sun-energy, and in the stratospheric lines. Once we faced the frontiers of geography. Today we face the infinite frontiers of science.

Radio, a Science and an Industry

If science has taught us anything it is to be humble; to realize that our knowledge weighs lightly in the scale against our ignorance. Toward the close of his long and illustrious career, Sir Isaac Newton said:

"I seem to have been only like a boy playing on the seashore and diverting myself, in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me."

That statement reflects the view of the true scientist and philosopher.

Pure science acknowledges only truth for her master, and no matter where that master leads, science must follow. Industry translates the truth revealed by science into products and services for humanity. For enlightened industry is the servant of humanity, even as science is the servant of truth.

Radio is both a science and an industry; it exists to serve both truth and humanity. As long as it retains its independence it will continue to do so. The freedom of radio is inseparable from the freedom of speech, freedom of the press, freedom of education and of worship.

Here in Philadelphia, you treasure one of America's earliest instruments of broadcasting. Upon it are inscribed these words:

"Proclaim liberty throughout all the land, unto all the inhabitants thereof."

No other broadcasting instrument ever sounded forth a more momentous message for the human ear to hear, and the human heart to cherish. May the message of America's Liberty Bell ever remain the inspiration of radio.

PARTIAL SUPPRESSION OF ONE SIDE BAND IN TELEVISON RECEPTION

BY

W. J. POCH and D. W. EPSTEIN

RCA Manufacturing Company, Inc., Camden, New Jersey

INTRODUCTION

EARLY television development followed the precedents established in sound broadcasting. A radio carrier was amplitude modulated by the video signals resulting from scanning and the transmission included both side bands. In the receivers the selectivity or bandwidth was made such as to pass both upper and lower side bands when the carrier was modulated with the highest desired modulating frequency. Progress in television development has been marked by a continual increase in the number of scanning lines and requiring, in turn, increases in the communication band. This race, as it became, between the terminal apparatus—ability to increase resolution, i.e., number of lines—and the communication portions of the system—ability to increase band width in the amplifiers and circuits exhibiting selectivity characteristics—first found one element in the lead and then the other. At times when the receiver band-pass characteristics were more limiting than other elements, it was early determined experimentally that a better picture was obtained when the receiver was slightly detuned. Thus, by detuning, the picture carrier was placed near one edge of the selectivity characteristic.

Later when this condition was more thoroughly appreciated, an analysis was made of its importance and usefulness. Suppose we deliberately design a receiver so the resulting intermediate frequency is placed near one edge of the intermediate-frequency circuit selectivity characteristic and so that carrier and all of one side band but only a small portion of the other side band is accepted, with the over-all selectivity being insufficient to remove entirely the second side band. We shall term this a selective side-band receiver. An immediate advantage is that we nearly double the modulation frequency range that the receiver will pass. This is of great importance where the band width for one side-band approaches the limits of circuit and tubes and where it is inadvisable to reduce gain or selectivity.

It is a well-known fact that for circuits passing broad bands, the gain per stage is inversely proportional to the band width. This means that n intermediate-frequency amplifiers having the same number of stages, one for selective side-band and the other for double side-band operation, will have a difference in gain of 2^n, where n is the number of stages. For six stages this means a difference in gain of 64 to 1. If the gain per stage of the selective side-band receivers were 8, the double side-band receiver must have three additional stages to have the same over-all gain.

Before taking the important step of making this change in the receivers, it was thought necessary to make a further investigation of this problem. An experimental transmitter and receiver system, whose condition of operation could be controlled and upon which measurements could be easily made, was set up. This apparatus was arranged so that it would be used either as a double or a selective side-band system with a simple and quick changeover arrangement. It was also arranged so that part of the suppression of one side band was done in the transmitter, to determine whether this would introduce any special difficulties. The data taken on this system were also verified by a mathematical investigation.

Because of the profound influence selective side-band suppression is likely to have on practical systems of television, it is considered of interest and importance to describe these early tests and to outline the mathematical verification.

Apparatus Used in Experimental Work

Fig. 1 is a block diagram of the transmitter and receiver equipment. The only adjustment necessary for changing from double side-band to selective side-band operation was to shift the master oscillator frequency from 4.25 to 4 megacycles. Suppose that the master oscillator was generating 4.25 megacycles, the condition necessary for normal double side-band operation. The modulator then delivered an 8.5-megacycle modulated carrier at the input of the transmitter intermediate-frequency amplifier. Care had been taken to make the modulation amplifier and the modulator itself with a fidelity characteristic flat to 1000 kilocycles. The output of the intermediate-frequency amplifier, still an 8.5-megacycle carrier but with side bands trimmed to 500 kilocycles on each side, was used to modulate another oscillator operating at 63.5 megacycles. Only the resulting lower side band was used. This was a carrier at 55 megacycles with side bands extending to 500 kilocycles on both sides. The receiver was also tuned in such a way that the incoming carrier was located in the center of the receiver selectivity characteristic, so that again both side bands were treated alike. The second detector and video frequency amplifier which were adjusted to have a fidelity characteristic good to 1000 kilocycles, brought the modulated signal to the grid of the "Kinescope.*"

Now suppose that the frequency of the master oscillator was shifted from 4.25 to 4 megacycles, the condition for selective side-band operation. The carrier output of the modulator doubler was now at 8 megacycles which brought the carrier to one edge of the transmitter intermediate-frequency pass-band characteristic. The output of this ampli-

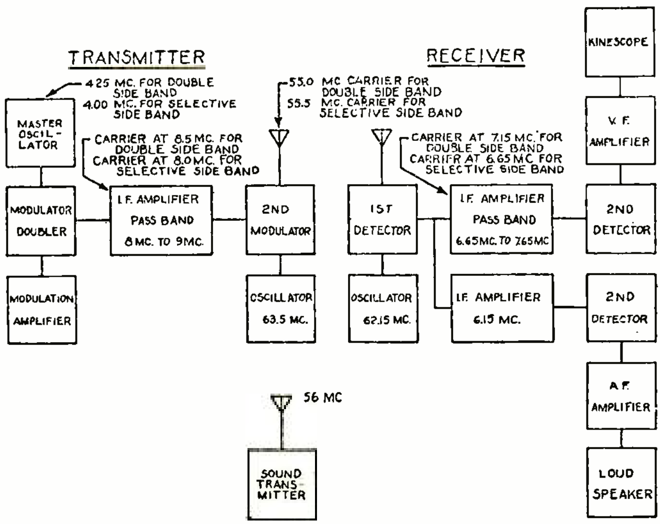


Fig. 1—Block diagram of the transmitter and receiver equipment.

fier was still a carrier at 8 megacycles but with the upper side band extending to 1000 kilocycles and the lower side band greatly attenuated, except at low modulation frequencies. Similarly, in the receiver whose tuning adjustment had not been altered, the carrier was also moved to one edge of the selectivity characteristic, causing one side band to be reduced still more. At low video frequencies normal demodulation of a carrier and both side bands occurred at the second detector. At the higher video frequencies only the carrier and one side-band were present. In between was a range of frequencies in which one side-band was being rapidly attenuated. This problem of detection will be discussed in more detail later.

The sound transmitter and the sound channel of the receiver which

* Trade Mark Registered U. S. Patent Office.

had a sharp selectivity characteristic compared with that of the picture channel, were used to check the tuning of the receiver. The frequency spacing between picture and sound transmitters was checked by tuning a broadcast receiver to the difference frequency.

Selectivity Measurements

Figs. 2 and 3 show the selectivity characteristics of the transmitter and receiver intermediate frequency amplifiers. These were taken in

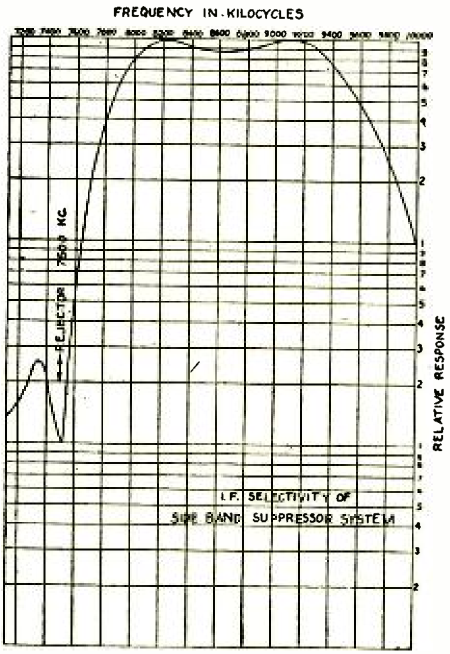


Fig. 2—IF selectivity of side band suppressor system.

the usual manner with a calibrated oscillator and vacuum tube voltmeter. Rejector circuits were used in both of these amplifiers which increased the attenuation of the unwanted side band. In the receiver, the rejector circuits were tuned to the sound intermediate frequency to prevent interference from the sound transmitter in the picture channel. Note that these curves show a generous 1000-kilocycle band width. An over-all selectivity measurement was not made but should correspond to the product of the two curves shown since the radio-frequency output circuit at the transmitter and the input system of the receiver did not have sufficient selectivity to affect the other curves.

Measurement of Fidelity and Phase Characteristics

Measurements of fidelity and phase characteristics were made in the video frequency range between 10 and 1000 kilocycles since no effects due to suppressing one side band were found below 10 kilocycles. The fidelity characteristics were taken with a beat frequency oscillator and vacuum tube voltmeter having an upper frequency limit of 1000 kilocycles. A cathode-ray oscillograph also having a 1000-kilocycle frequency range was used in conjunction with the beat frequency oscil-

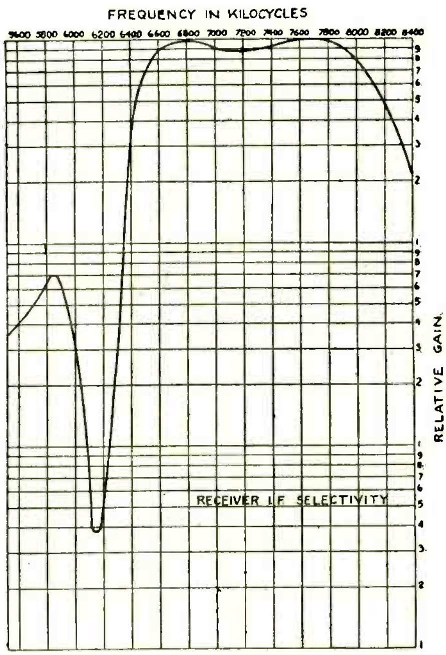


Fig. 3—Receiver IF selectivity.

lator to obtain the phase characteristics. This was done by the familiar method of connecting the output of the beat oscillator to the horizontal deflecting circuit of the oscillograph and the output voltage of the circuit being tested to the vertical deflecting circuit. From measurements of the resulting ellipse the phase angle between the input and output voltages can be calculated. To avoid wave shape errors, modulation on the transmitter was kept below about 25 per cent. The most desirable characteristics are, naturally, to have a flat frequency response and to have the phase shift proportional to frequency.

Fig. 4 shows the resulting fidelity curves. The over-all curve for double side-band operation shows the expected loss in response above 500 kilocycles due to trimming of the side bands. The over-all curve for selective side-band operation is perhaps better than might be an-

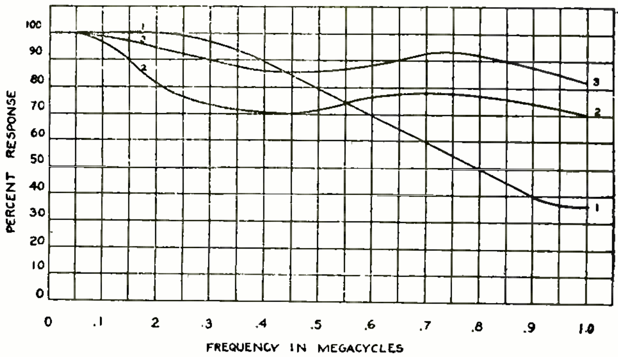


Fig. 4—Measured fidelity. 1. Over-all fidelity double side-band operation. 2. Over-all fidelity selective side-band operation. 3. Picture amplifier fidelity of receiver.

ticipated. Since at low modulation frequencies both side bands are present at the second detector and at the higher frequencies only one, we would expect the fidelity curve to drop down approximately 50 per cent at a fairly low frequency and then continue to about double the frequency limit for double side-band operation before dropping down

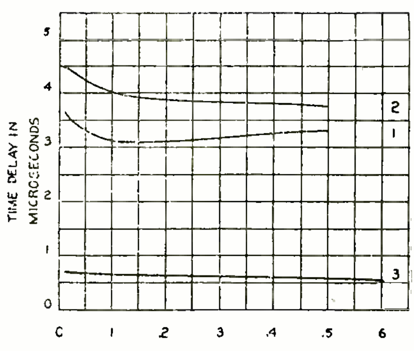


Fig. 5—Measured phase delay. 1. Over-all phase delay using double side-band transmitter. 2. Over-all phase delay using selective side-band transmitter. 3. Receiver picture amplifier alone.

again. This effect, however, is also dependent upon the exact position of the carrier on the edge of the selectivity curve. The farther down we put the carrier on the side of the curve, the less will be the first dip downward in the response curve. It is possible, of course, to carry this procedure so far that the high-frequency response will actually be greater than the low-frequency response. In this particular case, the over-all selectivity curve of the system and the position of the carrier relative to it were such that the response curve shown in Fig. 4 was produced.

Fig. 5 shows the phase delay characteristics corresponding to the previous frequency characteristics. The phase shift, as measured by

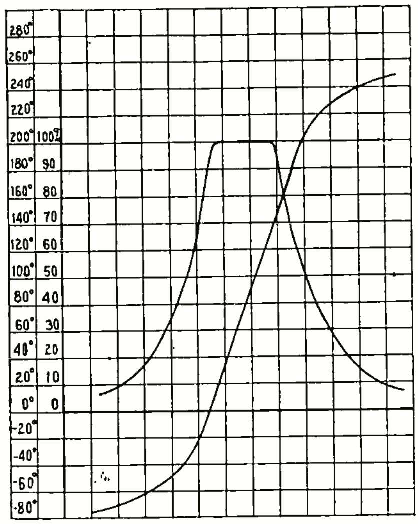


Fig. 6—Selectivity and phase of intermediate-frequency transformer.

the ellipse method, was converted to phase delay by the following equation:

$$\text{Phase delay} = \frac{\text{phase angle}}{360^\circ \times \text{frequency}}.$$

This expression gives the actual time required for a cycle of a given frequency to go between input and output of the amplifier system being measured. Obviously, if this time is the same for all video-frequencies, there will be no phase distortion. This condition for a constant phase delay is equivalent to the previously mentioned condition for having the phase shift proportional to frequency. The variation in phase delay over the video frequency band may be taken as a measure of the phase distortion. Note that this variation is greatest for selective side-band operation but that the difference in variation between double side-band and selective side-band operation is not very great.

Fidelity and delay characteristics for conditions similar to those in this experimental work were also calculated and are given in the next section.

CALCULATION OF FIDELITY AND DELAY CHARACTERISTICS

In order to calculate these characteristics it is necessary to know the over-all selectivity and phase characteristics of the system. Accordingly, the selectivity and phase curves for one of the coupling transformers used in the intermediate-frequency system were calculated. These curves are shown in Fig. 6. Assuming no radio-frequency

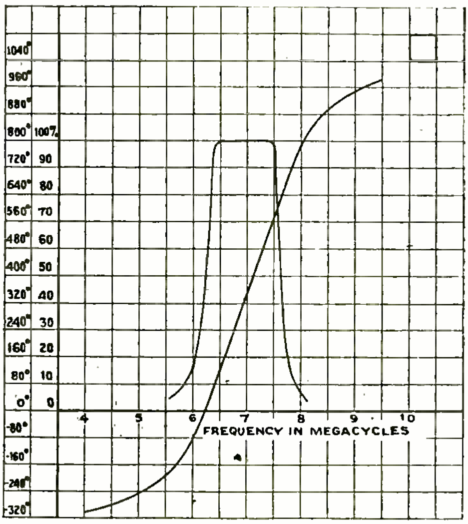


Fig. 7—Selectivity and phase characteristics of the intermediate-frequency amplifier.

selectivity and that all the coupling circuits are identical, the selectivity and phase characteristics of the receiver or receiver and transmitter may be deducted from Fig. 6 by merely raising the ordinates of the selectivity curve to the nth power and multiplying the ordinates of the phase curve by n, where n is the number of identical coupling circuits used in the system. Fig. 7 shows the selectivity and phase characteristics for four intermediate-frequency coupling circuits is cascade as obtained from Fig. 6. These curves may be taken as the selectivity and phase characteristics of the receiver or transmitter alone.

Before proceeding with the calculation of the fidelity and delay characteristics as obtained from the selectivity and phase curves of the intermediate frequency, it is worth reviewing, for the sake of clarity, the action of the intermediate frequency and second dectector on a carrier modulated by a single frequency. For this purpose, consider the simple case of a receiver in which the input to the intermediate-frequency amplifier consists of a carrier of frequency f_0 modulated with the video frequency f_1. The input to the intermediate-frequency amplifier may then be written as

$$e = E \cos \omega_0 t + \frac{mE}{2} \cos (\omega_0 + \omega_1)t + \frac{mE}{2} \cos (\omega_0 - \omega_1)t \tag{1}$$

where $\omega = 2\pi f$, E is the amplitude of the unmodulated carrier, and m is the percentage of modulation. After passing through the selective circuits of the intermediate-frequency amplifier, the voltage output becomes

$$v = E\left[A_c \cos (\omega_0 t + \phi_0) + \frac{mA_u}{2} \cos \left\{(\omega_0 + \omega_1)t + \phi_u\right\} + \frac{mA_L}{2} \cos \left\{(\omega_0 - \omega_1)t + \phi_L\right\}\right] \tag{2}$$

where A_c, A_u, and A_L are the amplitude ratios of output to input of the intermediate-frequency amplifier for the frequencies f_0, $f_0 + f_1$, and $f_0 - f_1$, respectively, and ϕ_0, ϕ_u, and ϕ_L are the phase shifts introduced by the selective circuits of the intermediate frequency for the respective frequencies.

Equation (2) gives the input to the second detector. The output of the second detector may be obtained by first determining the envelope of the modulated carrier given by (2). To determine the envelope at the input to the second detector it is but necessary to transform (2) into the form

$$v = V_e \cos (\omega_0 t + \phi)$$

and then gives the form of the envelope. Performing this transformation there results that

$$V_e = E\left[A_c^2 + \frac{m^2}{4}\left\{A_u^2 + A_L^2 + 2A_uA_L \cos (2\omega_1 t + \phi_u - \phi_L\right\} + mA_c\left\{A_u \cos (\omega_1 t + \phi_u - \phi_0) + A_L \cos (\omega_1 t + \phi_0 - \phi_L)\right\}\right]^{1/2} \tag{3}$$

Equation (3) thus gives the shape of the carrier envelope at the input to the second detector.

It is worth noting, in passing, that the phase of the modulated carrier, ϕ, is given by

$$\tan\phi = \frac{A_c \sin\phi_0 + \dfrac{mA_v}{2}\sin(\omega_1 t + \phi_u) - \dfrac{mA_L}{2}\sin(\omega_1 t - \phi_L)}{A_c \cos\phi_0 + \dfrac{mA_u}{2}\cos(\omega_1 t + \phi_u) + \dfrac{mA_L}{2}\cos(\omega_1 t - \phi_L)} \tag{4}$$

and that in general when one of the side bands is partially suppressed $\tan\phi$ is a function of time so that some phase modulation exists.

Referring to (3) it may be seen that for low percentages of modulation the output of an n-law detector* is given by

$$V_e^n = E^n\left[A_c^n + \frac{nm}{2}A_c^{n-1}\{A_u\cos(\omega_1 t + \phi_u - \phi_0) + A_L\cos(\omega_1 t + \phi_0 - \phi_L)\}\right] \tag{5}$$

Equation (5) shows that for small percentages of modulation the detector will reproduce only the original modulation frequencies. Assuming, therefore, a small percentage of modulation one may, with the aid of (5), calculate fidelity and delay characteristics from the selectivity and phase curves of the intermediate frequency. Thus the output of the second detector at the frequency f_1 is, by (5), proportional to

$$A_u\cos(2\pi f_1 t + \phi_u - \phi_0) + A_L\cos(2\pi f_1 t + \phi_0 - \phi_L)$$

where A_u and A_L are the ratios of output to input amplitudes for the frequencies $f_0 + f_1$ and $f_0 - f_1$, respectively, as obtained from a selectivity curve such as that shown in Fig. 7 and where ϕ_0 is the phase of the carrier and ϕ_u and ϕ_L are the phases for the frequencies $f_0 + f_1$ and $f_0 - f_1$, respectively, as obtained from the phase curve of Fig. 7. Adding the above two terms there results that

$$A_u\cos(2\pi f_1 t + \phi_u - \phi_0) + A_L\cos(2\pi f_1 t + \phi_0 - \phi_L) = Vf_1\cos(2\pi f_1 t - \theta)$$

where,

$$Vf_1 = \sqrt{A_u^2 + A_L^2 + 2A_uA_L\cos(\phi_u + \phi_L)} \tag{6}$$

and,

$$\tan\theta = \frac{A_u\sin(\phi_u - \phi_0) + A_L\sin(\phi_0 - \phi_L)}{A_u\cos(\phi_u - \phi_0) + A_L\cos(\phi_0 - \phi_L)}. \tag{7}$$

* $n = 1$ for a linear detector, $n = 2$ for a square detector, etc.

The fidelity and phase characteristics may then be calculated by using (6) and (7) and the curves of Fig. 7. As was mentioned previously, the phase delay in seconds at any frequency f is $\theta/2\pi f$ where θ is in radians and f in cycles per second.

Fidelity and delay characteristics corresponding to various intermediate-frequency carrier frequencies were calculated with the aid of (6) and (7) and are shown in Fig. 8. These fidelity curves correspond to those of a receiver with no radio-frequency detector or video

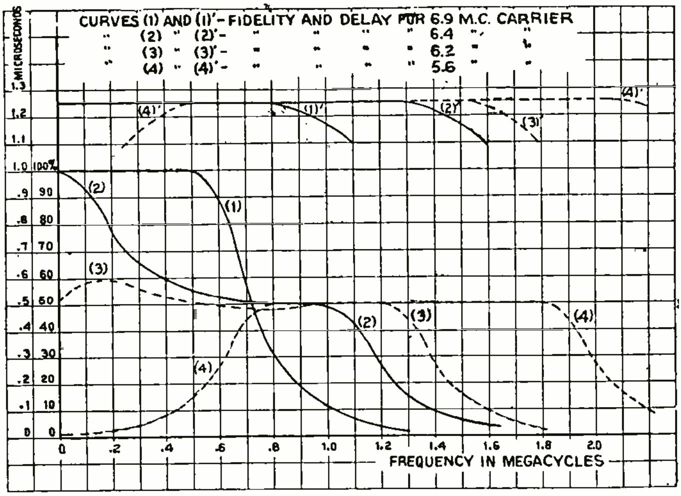


Fig. 8—Fidelity and delay characteristics.

distortion and with the selectivity shown in Fig. 7. Curves (1), (2), (3), and (4) of Fig. 8 correspond to the fidelity of the receiver for intermediate-frequency carrier frequencies 6.9, 6.4, 6.2, and 5.6 megacycles, respectively.

In obtaining Fig. 8 it is assumed that the transmitter passes both side bands. If the transmitter partially suppresses one side band, it may still be assumed that the transmitter passes both side bands but that the receiver selectivity has been increased. Fig. 9 gives the selectivity and phase characteristics corresponding to those of receiver and transmitter. The fidelity characteristics for such a receiver calculated from Fig. 9 are shown in Fig. 10. Thus Fig. 10 gives the fidelity of a receiver having the selectivity shown in Fig. 1 when the transmitter has the same selectivity. Curves (1) and (2) of Fig. 10 correspond to a carrier at 6.4 and 6.25 megacycles, respectively.

Referring to Fig. 8 it is to be seen that: Curve (1), corresponding to double side-band reception, is practically flat in the frequency range 0 to 0.6 megacycles. No phase distortion is present in the frequency range 0 to 0.8 megacycles. Curve (2), obtained with the carrier on one

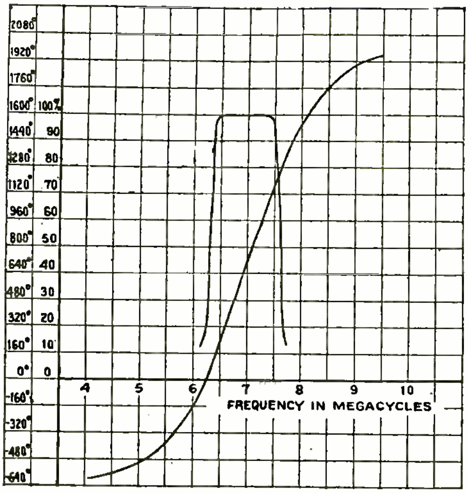


Fig. 9—Selectivity and phase equivalent to that of receiver and transmitter.

edge of the selectivity curve, emphasizes the lower frequencies more than the higher. No phase distortion is present in the frequency range 0 to 1.3 megacycles. Curve (3) is the best fidelity characteristic and is

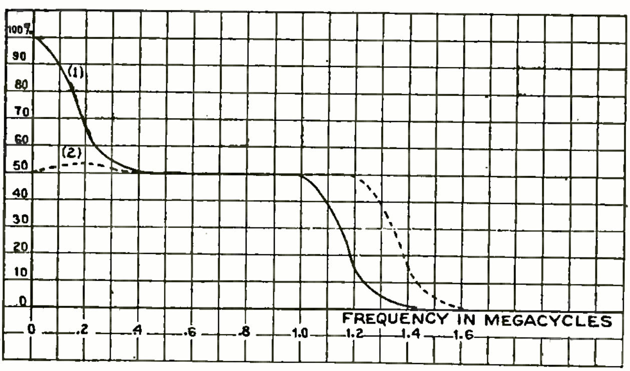


Fig. 10—Curve (1) fidelity for 6.4-megacycle carrier, obtained from figure. Curve (2) fidelity for 6.25-megacycle carrier, obtained from figure.

obtained when the carrier (with two side bands) is located halfway down the selectivity curve of Fig. 1. The delay characteristic given by curve (3) of Fig. 8 is flat in the frequency range 0 to 1.5 megacycles, and hence there is no phase distortion, as all frequencies are delayed by the same time. The time of delay is seen to be about 1.25 microseconds. The characteristic is practically flat in the frequency range 0 to 1.3 megacycles. Curve (4) shows the low frequencies badly attenuated. Phase distortion exists for low and high frequencies.

The curves of Fig. 8, therefore, show that with the assumptions made and with the transmitter passing both side bands, it is best to tune in about halfway down on the selectivity curve in order to obtain the optimum fidelity curve with a given selectivity curve of the receiver.

The curves of Fig. 10 similarly show that with the transmitter partially suppressing one side band it is best to attenuate the carrier at the transmitter and receiver so that the total attenuation is down to 50 per cent. Thus if the transmitter attenuates the carrier to 71 per cent and the receiver to 71 per cent of this the result is about 50 per cent. However, as is shown by curve (4) of Fig. 8, the carrier should not be attenuated by transmitter or receiver any further than to 30 per cent, for at 30 per cent and below phase distortion appears. With phase distortion objectionable transients occur.

Results with Picture Modulation

Coming back to the experimental transmitter and receiver setup again, tests were made on the system using both double and selective side-band operation. The previous measurements and calculations should lead us to expect that with selective side-band operation, there should be much better detail due to the additional high-frequency response. At the time these measurements were made, the picture scanning equipment had an upper frequency limit of 500 kilocycles so that when pictures under both conditions of operation were compared, most observers agreed that there was very little difference between the two. Since that time the upper frequency limit of the picture pickup equipment has been increased and the expected increase in detail clearly demonstrated. Changing from double side-band to selective side-band operation, therefore, means an approximately two-to-one improvement in detail which results in a distinctly clearer and sharper picture.

Second-Detector Distortion

The conclusions drawn from the calculated fidelity characteristics shown in Figs. 8 and 10 were based on the assumption that the detector distortion is negligible. This was shown to be true for any detector so long as the percentage of modulation is sufficiently small. The conclusions have to be modified when detector distortion with large percentages of modulation is considered.

Referring to (3) it may be seen that for double side-band reception where $A_u = A_L$ and $\phi_u - \phi_0 = \phi_0 - \phi_L$ the form of the carrier envelope becomes

$$V_e = E\left[A_c + mA_u \cos\left(\omega_1 t + \frac{\phi_u - \phi_L}{2}\right)\right] \tag{8}$$

so that a linear detector will introduce no distortion for any percentage of modulation. If one of the side bands, say the lower, is completely suppressed then $A_L = 0$ and (3) reduces to

$$V_e = E\left[A_c^2 + \frac{m^2}{4}A_u^2 + mA_cA_u \cos(\omega_1 t + \phi_u - \phi_0)\right]^{1/2} \tag{9}$$

Hence, the output of a square detector will be

$$V_e^2 = E^2\left[A_c^2 + \frac{m^2}{4}A_u^2 + mA_cA_u \cos(\omega_1 t + \phi_u - \phi_0)\right] \tag{10}$$

so that no distortion is introduced if a square detector is used. If one of the side bands is but partially suppressed then it follows from (3) that, for high percentages of modulation, there is, in general, no detector which will reproduce only the modulating frequency.

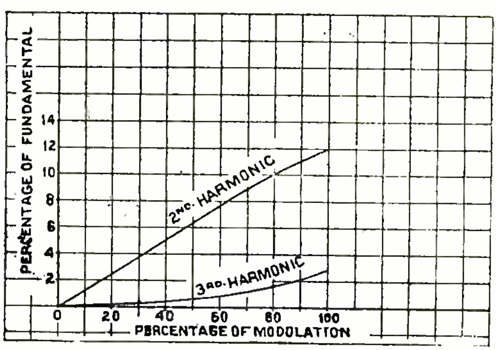


Fig. 11—Variation of harmonic distortion with percentage of modulation.

Some estimate of the second-detector distortion may be made by assuming that one of the side bands is totally suppressed and that a linear detector* is used on the envelope given by equation (9). Figure

* 100 per cent modulation means a carrier modulated to 100 per cent with both side bands present.

10 gives the per cent of harmonics introduced by a linear detector as the percentage of modulation† is increased. It is seen that the introduction of these harmonics occurring at high percentages of modulation would be objectionable in the case of sound reception. However, in television it is not the frequency per se but rather the wave form of the signal that is important. The solid line of Fig. 11 shows a single

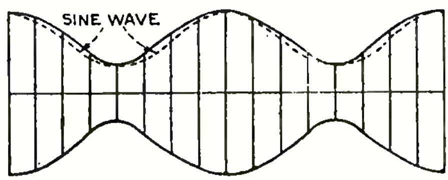


Fig. 12—Single side-band carrier envelope.

side-band carrier envelope (the upper half of which is the output of a linear detector) and the dotted line shows the fundamental sine wave. In television reception the two wave forms would appear as practically identical.

In discussing detector distortion for large percentages of modulation it is not sufficient to consider the envelope given by (3), but rather it is necessary to consider the envelope of a carrier modulated with any number of frequencies. By a method identical with that used in deducing (3) it may be deduced that the envelope of a carrier modulated with n frequencies is at the input to the second detector.

$$
\begin{aligned}
V_e = E\Bigg[A_c^2 &+ \frac{m^2}{4}\sum_{i=1}^{n}\left(A_{L_i}^2 + A_{u_i}^2\right) \\
&+ \frac{m^2}{2}\sum_{i=1}^{n} A_{L_i}A_{u_i}\cos\left(2\omega_i t + \phi_0 - \phi_{L_i}\right) \\
&+ \frac{m^2}{4}\sum_{i=1}^{n}\sum_{\substack{j=1 \\ i\neq j}}^{n}\Big\{A_{L_i}A_{L_j}\cos\left[(\omega_i - \omega_j)t + \phi_{L_j} - \phi_{L_i}\right] \\
&+ A_{u_i}A_{u_j}\cos\left[(\omega_i - \omega_j) + \phi_{u_i} - \phi_{u_j}\right] \\
&+ 2A_{L_i}A_{u_j}\cos\left[(\omega_i + \omega_j) + \phi_{u_j} - \phi_{L_i}\right]\Big\} \\
&+ mA_c\sum_{i=1}^{n}\Big\{A_{L_i}\cos\left(\omega_i t + \phi_0 - \phi_{L_i}\right) \\
&+ A_{u_i}\cos\left(\omega_i t + \phi_{u_i} - \phi_0\right)\Big\}\Bigg]^{1/2} \qquad (11)
\end{aligned}
$$

† Since a linear detector is usually used in practice.

It is to be noted that for large percentages of modulation any detector will reproduce not only the original modulation frequencies but also a great many others resulting from various combinations of the modulating frequencies.

With the effect of the second detector in mind, picture signal was again put on the experimental transmitter operating to suppress one side band and effects due to this type of distortion looked for. The picture modulation was increased to a value where saturation in the modulator began to be noticeable. All observers agreed that up to this value of modulation no difference in the picture compared to one at a lower value of modulation could be noticed. This supports the theory that distortion of this type causes no appreciable hurtful effect in the picture. It also indicates that the amount and type of distortion which can be tolerated in a picture signal is quite different than that in a sound signal.

Location of the Carrier on the Selectivity Curve

The calculated fidelity curves showed how the over-all frequency characteristic was greatly influenced by the exact position of the carrier at the edge of the selectivity curve. When the carrier was tuned at the 50 per cent response point of the over-all selectivity curve a very good over-all fidelity curve was obtained. At this point, however, the selectivity curve is quite steep and slight variations in tuning cause considerable changes in the over-all frequency characteristic. It also means that to obtain uniform results from a number of receivers their selectivity and tuning characteristics must be held to very close tolerances. We have found that a reasonable compromise is to have the carrier approximately 25 per cent down from maximum response. At this point the selectivity curve has not yet become very steep and the slight drop in high frequency response can be compensated for in the video frequency amplifier following the second detector.

Transmitter Considerations

Since the time these measurements and calculations were made a moderate power test transmitter was installed in Camden to provide a signal at a receiver location a mile away. No attempt was made to suppress one side band in the transmitter but all the receivers used with it were of the selective side-band type. Excellent results were obtained with this system and the difference in detail between double side-band and selective side-band operation could be easily demonstrated by tuning from the center to the edge of the receiver selectivity curve. The suppression of one side band at the transmitter becomes a very difficult problem at the frequencies which are used for television. If this can be successfully done then the band width of one channel for television transmission can be considerably reduced. The power requirements of the transmitter are expected to be approximately the same, whether the double side-band or selective side-band operation is used. While the input signal may be thought of as being reduced due to the absence of one side band, the gain in the input circuits can be increased due to the smaller band width necessary. This increases the signal-to-noise ratio on the grid of the first tube which compensates for the loss of one side band.

Conclusions

This investigation has shown that no serious difficulties are encountered when a television system is operated with the carrier at one edge of the over-all selectivity curve. The necessity for fewer stages of amplification in the intermediate-frequency amplifier of the receiver makes it very desirable to adopt this system. In addition to this, if one side band can be suppressed at the transmitter there will be a considerable saving in channel requirements.

EQUIPMENT USED IN THE CURRENT RCA TELEVISION FIELD TESTS

By

R. R. Beal

Research Supervisor, Radio Corporation of America

THE development of the RCA high definition television system has been advanced by a step-by-step program of research in the laboratory and tests in the field over a period of more than ten years. These developments have passed through many stages during which effort has been continually directed toward producing a system to provide a standard of performance of lasting value. Many new devices and methods have been evolved. Mechanical arrangements used in the early phases of the work have been entirely replaced by electronic methods through which much higher standards may be achieved. The RCA all-electronic system employs the "Iconoscope"* as the device which converts the light image into electrical impulses for transmission as radio signals, and the "Kinescope"* for transforming these signals back into visible images.

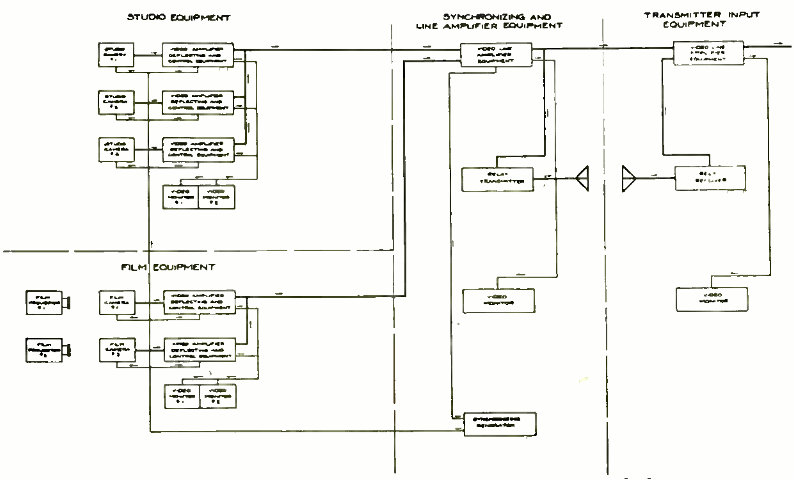
This system is now undergoing experimental tests in the field in furtherance of its development by progressive and evolutionary steps. These tests are being conducted in the New York City area. They are comprehensive in scope and embrace studies of the functioning of the equipment under field conditions; propagation studies to determine the service area; studies to determine the source of and corrective measures for interference; measurements to determine the necessary signal levels in Metropolitan New York and the surrounding suburban localities; experiments in program technique; studies related to receiver installation and operation; and observations on receivers in the field by technical personnel for determinations of standards for an acceptable and satisfactory system. These field tests began on June 29, 1936 and will continue for several months.

The equipment provided for the field tests is installed substantially as it would be employed in a radio broadcasting service. Studios for programs in which artists perform and for motion picture film programs are located in the RCA Building, Radio City. The transmitting

* Trade Mark Registered U. S. Patent Office.

equipment is installed in the Empire State Building and the transmitting antenna is on top of the building. Ultra short waves are used for transmitting the "video" or picture signals and the accompanying sound. The picture signals are transmitted on a frequency of 49.75 megacycles and the sound on a frequency of 52 megacycles.

The system is now using standards of which the essential elements are 343 lines per frame, a frame frequency of 30 per second, a field frequency of 60 per second (interlaced), negative polarity of transmission, and a video-audio (picture-sound) carrier spacing of 2,250 kc. In cooperation with the radio industry, RCA has recommended the adoption of standards which include images of 441 lines and a video-



TELEVISION TERMINAL EQUIPMENT FOR RCA FIELD TEST SYSTEM

Fig. 1

audio carrier spacing of approximately 3,250 kc. The RCA field test system will be changed to conform to these standards at a time convenient in the experimental program.

The principal groups of equipment and the continuity of the system are shown diagrammatically in Figures 1 and 2. Figure 1 shows the terminal equipment installed in Radio City, and Figure 2 the video and audio transmitters in the Empire State Building.

The terminal equipment at Radio City, Figure 1, includes three "Iconoscope" cameras for direct pickup in the artists studio and their video amplifier, deflecting and control apparatus. Each of these "Iconoscope" cameras includes a preamplifier for amplifying the video output of the "Iconoscope". This output is delivered by cable to amplifying and control equipment from which it is fed to a video line amplifier for transmission to the Empire State Building.

In the film studio, two film projectors of special design are provided. Two "Iconoscope" cameras are furnished and, as in the direct pickup studio cameras, these include preamplifiers for amplifying the video output of the "Iconoscope". The camera output is delivered to the video amplifier and control equipment, after which the picture signals are fed to a video line amplifier for transmission to the Empire State Building.

The picture signals may be transmitted to the Empire State Building either by a radio relay channel or by an experimental coaxial

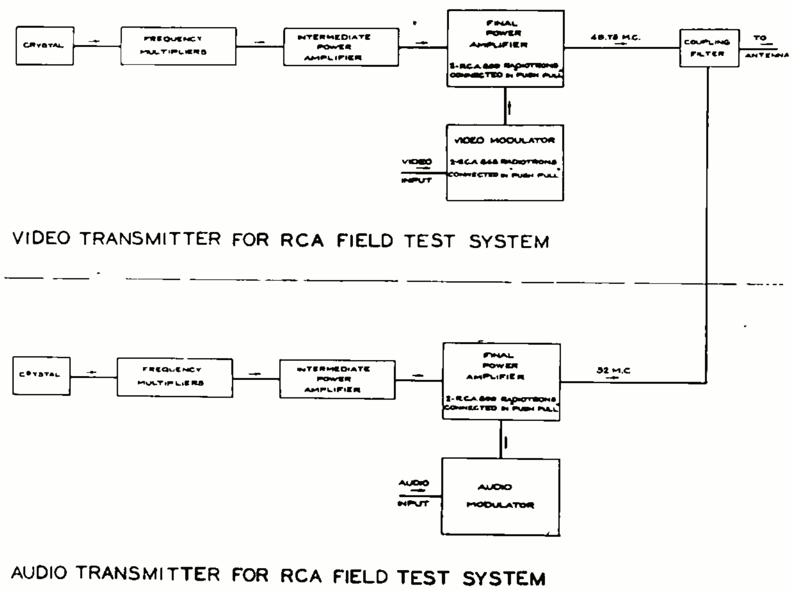


Fig. 2

cable. The radio relay transmitter and the common generator of synchronizing impulses which supplies the entire system, are located at Radio City.

The video and audio transmitters installed in the Empire State Building, are shown diagrammatically in Figure 2. The frequency control of both transmitters is provided through conventional temperature controlled crystals. Frequency multipliers are employed to produce the carrier frequencies. The outputs of both transmitters are passed into a coupling filter which permits delivering both signals to a common transmission line and antenna without reacting on each other in the power amplifiers.

Television Studio

The equipment in the Radio City television studio is shown in Figure 3 as it is used for picking up programs for transmission. A light image of the scene to be transmitted is focused through a lens system on a mosaic composed of a large number of separate photo-sensitive elements in the "Iconoscope" in the camera. An electron beam produced in the "Iconoscope" scans the mosaic and converts the light image into a train of electrical impulses with amplitudes rep-

Fig. 3—Television studio equipment at Radio City

resenting the various intensities of light as it is distributed from point to point over the image. These electrical impulses are the picture signals.

In the scene shown in the photograph, two "Iconoscope" cameras are employed for picking up close-up and distant views to be transmitted in sequence by switching from one camera to the other. The cameras are movable as units, adjustable with respect to height, and the upper section containing the "Iconoscope" is movable horizontally and vertically for "panning" or following the action. The camera attendants are equipped with telephone receivers and microphones for receiving and acknowledging instructions from the studio control room.

The lighting equipment is flexible to enable comprehensive studies of a variety of effects in experimental programs. Incandescent lamps are used in the equipment shown in the photograph. Studies of light intensities in relation to the subject to be picked up and of various types of lights constitute one phase of the engineering work related to program experimentation. Other phases of the work involve studies

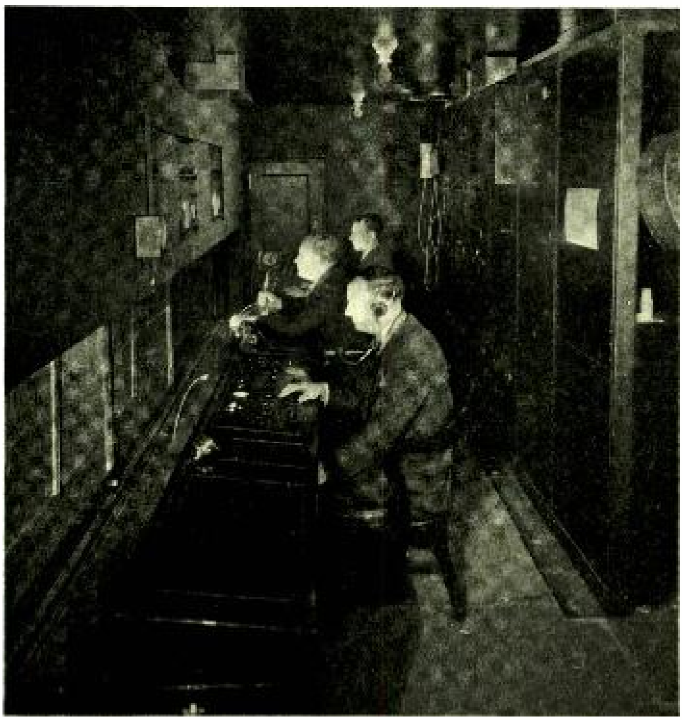


Fig. 4—Television studio control room

of program technique and research and engineering on methods of expanding the program capabilities of the system.

The sound which accompanies the television scene is picked up with a boom type of microphone and delivered to the studio control room after which it is fed to the Empire State Building over high quality telephone circuits.

Studio Control Room

The studio control room, Figure 4, is at one end of the studio and at such an elevation that the engineers have a clear view of the floor on which the pickup is made. The control console position in the foreground of the photograph controls the sound from the studio. The video circuit controls are at the opposite end of the console. Two video monitors are mounted on the wall in front of the video control position. One monitor shows the scene that is being transmitted and the other, the scene picked up by the second "Iconoscope" camera preparatory to transmission. The engineer at the video control posi-

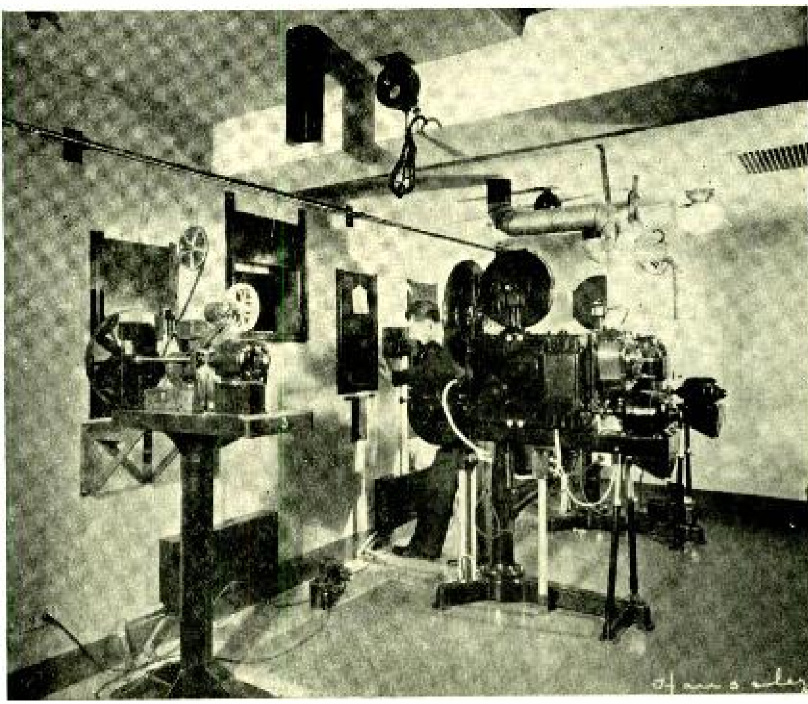


Fig. 5—Film studio equipment

tion performs the operation of switching from one camera to the other.

The racks of equipment behind the engineers include the video amplifiers and the synchronizing and control equipment associated with each of the "Iconoscope" cameras.

Film Studio

The film studio equipment, Figure 5, consists of two motion picture projectors of special design to permit the use of standard 24 frame motion picture film to produce television pictures at 30 frames per second. In these projectors a changing rate of intermittent drive is used for the picture portion of the film and a constant 24 frame rate of feed for the sound portion. Pictures from the projectors are focused on the mosaics of the "Iconoscope" cameras located in the control room beyond the partition separating the two rooms.

Film Studio Control Room

The equipment in the film studio control room, Figure 6, includes two "Iconoscope" cameras with their video voltage amplifiers and associated synchronizing and control equipment and audio equipment, and

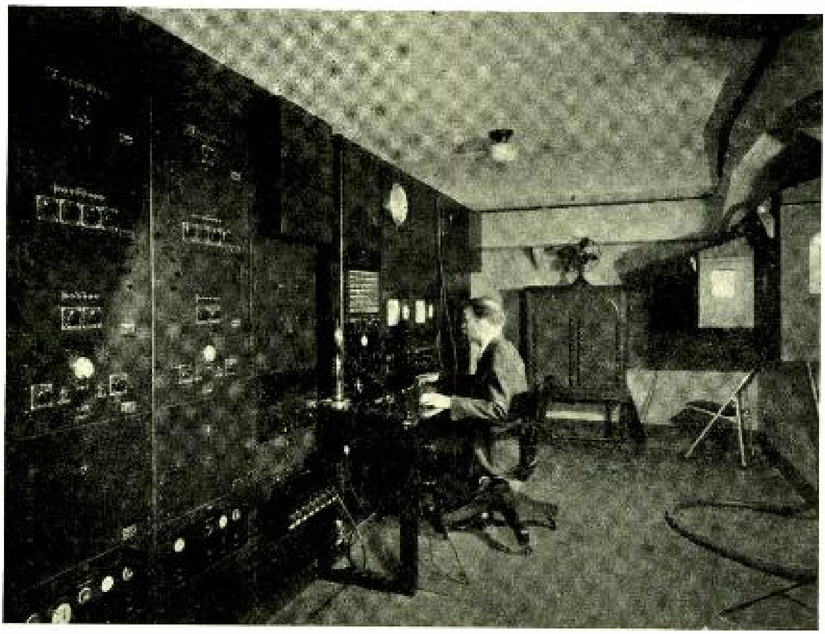


Fig. 6—Film studio control room

controls for the sound from the film. The two "Iconoscope" cameras are so mounted that they may be shifted from side to side for use with either of the film projectors.

Adjustments of signal levels and switching are accomplished by the engineer at the control console. Two video monitors are furnished, one for each film projector channel, to provide for continuous transmission from film.

Synchronizing Generator and Time Amplifier Equipment

The panels containing the electronic synchronizing generator equipment and the video line amplifiers which feed the video signal to the

Empire State Building are shown in Figure 7. Synchronization at the receiver is obtained by transmitted impulses. The horizontal and vertical impulses have the same amplitude and wave shape selection is employed.

INTERBUILDING RADIO RELAY

The ultra short wave radio relay transmitter, Figure 8, is installed on the 10th floor of the RCA Building. It operates on a frequency of

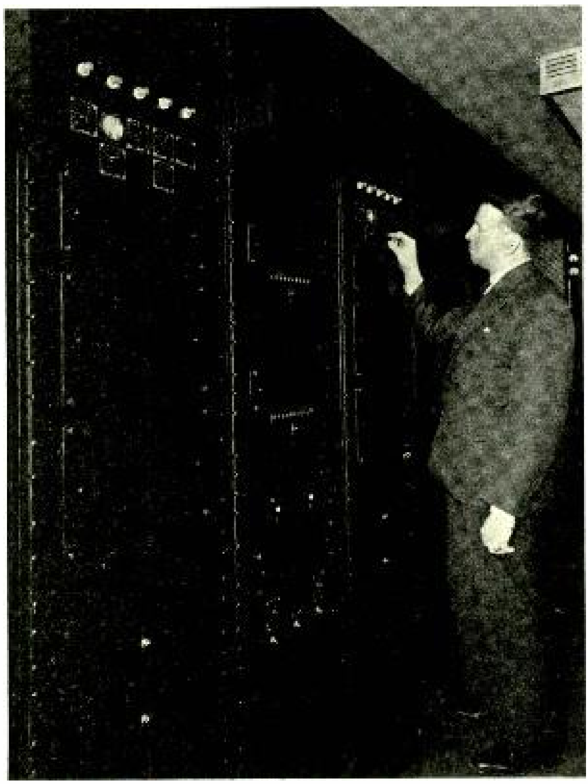


Fig. 7—Synchronizing and video line amplifier panels

177 mc. The circuit has a channel width of 3 mc. to carry the video frequencies up to 1.5 mc. with double side band transmission. Video signals from the studio are delivered to this transmitter by coaxial cable. Video monitoring equipment is provided for the signal at this point.

The radio link transmitting antenna is located at about the 14th floor level on the south side of the RCA Building to provide an unobstructed transmission path to the receiving antenna placed at the

85th floor of the Empire State Building. The receiver for the radio relay circuit is installed in the Empire State Building transmitter control room. The air-line distance between the two buildings is about .87 mile.

The overall frequency characteristic of the radio relay circuit is substantially flat over the range from 20 cycles to 1500 kc. This

Fig. 8—Ultra short wave radio relay transmitter

circuit is practically free of noise and the picture quality over it is equal to that obtained over the coaxial cable.

Empire State Building Control Board

The coaxial cable and radio relay channels and the channel for the sound accompanying the picture from the studios in Radio City, terminate at the Empire State Building control board (Figure 9). From left to right, the control board consists of the sound channel panels, a video monitoring panel, the radio relay receiver panel and battery and switching panels. The video monitor may be switched either to the radio relay or the coaxial cable channel. The video signals are delivered to the transmitter by coaxial cable.

Empire State Building Transmitters

The video and audio transmitters installed in the Empire State Building are shown in Figure 10. The tubes used in the final power amplifier of these transmitters are especially suited for the frequencies employed. Their plate dissipation rating is 30 kw. per tube. The filament power is sufficient to produce an electron emission of 18 amperes

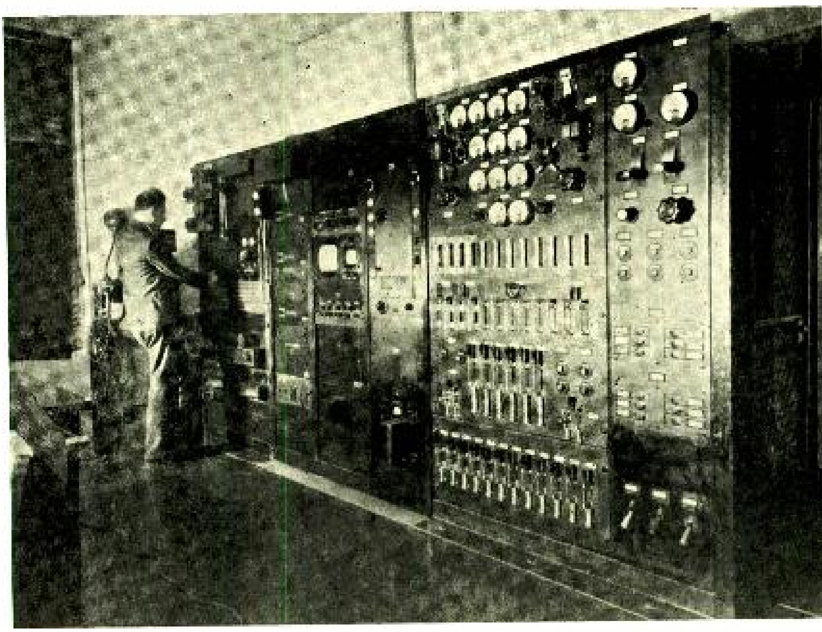


Fig. 9—Left to right, sound channel panels, video monitoring panel, relay receiver, battery and switching panels

per tube which permits of a video carrier power of 8 kw. with a tank circuit loading to pass the 1.5 mc. sidebands.

The audio carrier final power amplifier is plate modulated in the conventional manner. In the video carrier final power amplifier, grid modulation is employed to reduce the video voltage that must be developed. The complete video modulator is impedance coupled.

Empire State Building Antenna

A single antenna structure is employed to radiate both the audio and video signals. In this antenna, the fundamental radiator unit consists of three dipoles arranged in the face of an equilateral triangle. Three of these units are so positioned vertically as to increase the concentration of radiation in the horizontal plane. A horizontally polarized field is produced with an essentially circular pattern in the horizontal plane. The power gain in the horizontal plane is about 2.1 to 1 or 3.2 db. as measured with reference to a vertical dipole.

The frequency band of the antenna is practically flat over the upper side band of the video transmitter, namely 49.75 to 51.25 mega-

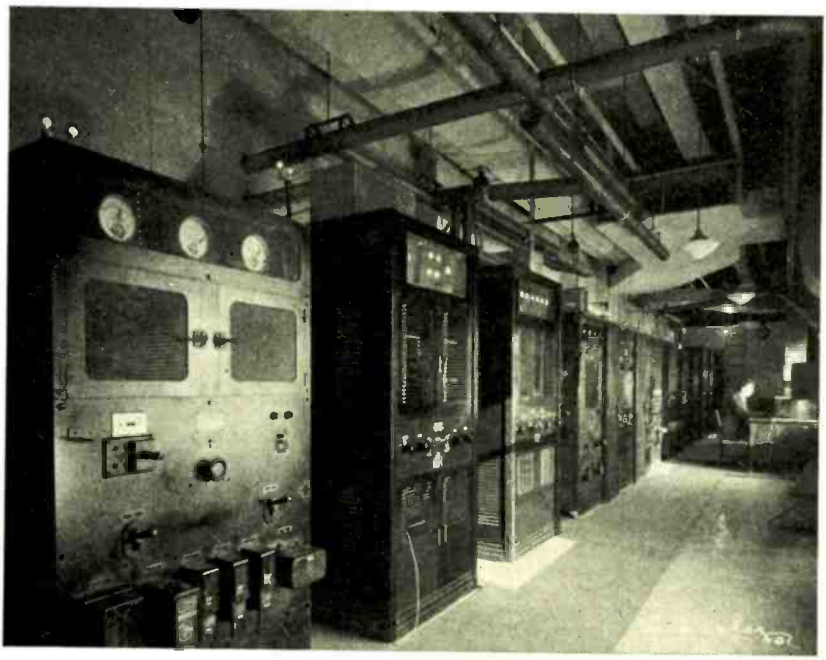


Fig. 10—Video and audio transmitters

cycles, and its flat characteristic includes both side bands of the audio transmitter, 52 megacycles plus and minus 10,000 cycles.

Due to the quasi optical properties of the ultra short waves employed in television the transmitting range increases with the height at which the transmitting antenna is placed. The Empire State Building, having a height in the order of 1250 feet, provides a location from which a maximum transmitting range may be obtained.

Experimental Field Test Receivers

The field test receivers are of the superheterodyne type and have a tuning range of 42 to 84 megacycles. They receive both sound and picture simultaneously. The head end circuits accept both carriers and one picture side band. Tuning is accomplished by a single knob controlling the radio frequency circuit and the single oscillator which heterodynes both carriers to produce the intermediate frequencies. These are separated by the spacing of the transmitted carriers, namely, 2,250 kc.

Figure 11 shows a photograph of the television field test receiver

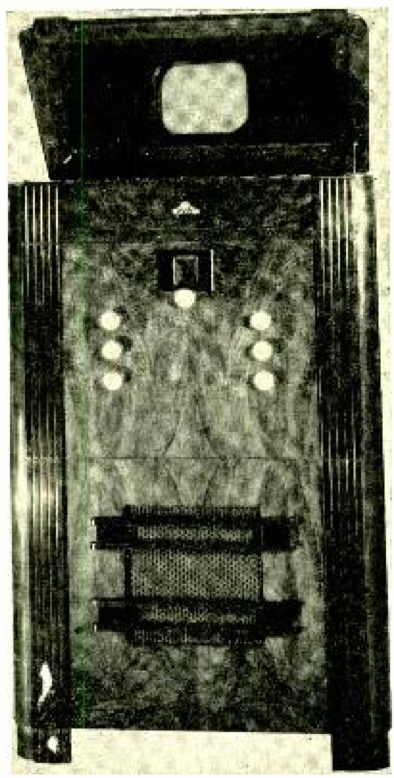


Fig. 11—Television receiver used in tests

with the cover raised to the viewing position. The television image is produced on the luminescent screen of a "Kinescope" 9″ in diameter which provides a picture size of approximately 5½″ x 7¼″. The "Kinescope" is mounted vertically and the picture is viewed in the chromium plated steel mirror mounted inside of the cover of the cabinet.

Of the seven knobs on the front of the receiver, the center knob tunes both the picture and the accompanying sound. The three knobs on the right from top to bottom are the sound volume control, the treble tone control and the bass tone control. The three knobs on the left are the picture contrast control, the detail control and the background control.

The receiver operates from the usual 110-volt, 60-cycle power supply and draws about 350 watts of power. Since the synchronization is controlled entirely by impulses sent from the transmitter, it is not necessary that the power supply frequency of the receiver be synchronized with that of the transmitter, although it should have the same nominal frequency.

The experimental receivers have 33 tubes including the "Kinescope". Horizontal dipole receiving antennas are used in the field installations.

As the field tests have advanced the soundness of the technical fundamentals of the system have been confirmed. Engineering studies related to program technique are broadening the program capabilities of the system. Good progress has been made in adapting the system to practical operating conditions in the field. Live talent and motion picture programs have been satisfactorily transmitted and received over distances of 25 miles from the Empire State Building at typical apartment house and suburban home locations. The height of the transmitting antenna has made possible consistently good reception at one favorably located suburban home over a distance of 45 miles.

Measurements of signal field strength and noise intensity are in progress to determine the requirements for service in the area under test. Electrical interference on the frequencies employed consists almost entirely of man-made noise originating in automobile ignition systems, diathermic apparatus and other electrical devices. Propagation studies and measurements are under way to obtain data on the interference range of the ultra short wave signals used for television. The tests of the system are incomplete, but as they progress the engineering and technical data, and the experience obtained by operating the system under field conditions, are expanding its capabilities and pointing the way toward realization ultimately of a satisfactory high definition television system for broadcasting service.

AUTOMATIC ALARM

By

I. F. Byrnes and H. B. Martin

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MORE than ten years ago it was recognized that safety at sea would be improved if some means could be developed to enable a ship in distress to summon aid at any time by radio from a nearby vessel, especially during those periods when the radio operator on the nearby vessel might not be "on watch". Early development and tests indicated that a special distress signal, international in scope and known to all radio equipped ships, would be desirable. Such a signal would then actuate an automatic receiving device on vessels in the vicinity of the ship in distress and by means of bells or other means call attention to the fact that a distress call was being transmitted. This special signal (which supplements and does not supersede the conventional S O S . . . ––– . . . signal) is known as the automatic alarm signal and the special receiving apparatus is called the auto alarm. The auto alarm signal is transmitted by the ship in distress just prior to sending the normal S O S signal.

The form of the alarm signal was specified at the International Radio Telegraph Convention held in Washington in 1927 and later at the International Telecommunication Convention of Madrid, 1932. It consists of a series of dashes and spaces, each dash having a duration of four seconds and each space between dashes a duration of one second. Twelve such dashes and spaces can be transmitted in a period of one minute. The auto alarm apparatus is then designed to actuate the bells when a certain number of consecutive dashes and spaces are correctly received. European practice provides for auto alarm operation after three correct dashes and spaces are received, while present United States practice is based on four dashes and spaces. Reasons for this difference are discussed later.

An "International Convention for the Safety of Life at Sea" was held in London in 1929 and attended by representatives of the principal maritime nations of the world. At this convention certain regulations were adopted pertaining to radio aboard ship and particularly with reference to "watches" in the radio room of cargo vessels. It was ruled that cargo vessels of over 5500 gross tonnage, not fitted with an auto alarm, shall, while under way, keep a continuous watch by means of an operator or operators. On ships which are fitted with an auto alarm, this apparatus must be in operation at all times when the operator is not on watch.

Before auto alarms may be installed aboard ships to meet the requirements of the various international conventions, the type of apparatus used must be approved by the Government having jurisdiction over the vessel. The Government of the United States deposited its ratification of the 1929 Safety at Sea Convention on Aug. 7, 1936.

In October, 1935, the Federal Communications Commission prepared specifications and test procedures for the guidance of American manufacturers in the development of a satisfactory auto alarm. Some of the outstanding technical conditions that must be satisfied and the manner in which the various requirements are met in the Radiomarine auto alarm, are discussed in the following paragraphs. Part I covers the principal design requirements. Part II describes the technical design of the AR-8600 Auto Alarm.

PART I

There are two basic elements in an auto alarm, namely the radio receiver and the selector. Each element requires a design quite unlike that satisfactory for other services. The radio receiver must be arranged to possess uniform sensitivity over a frequency range from 487.5 to 512.5 kc., or a total band width of 25 kc. The normal distress frequency is 500 kc., but provision must be made for the auto alarm receiver to accept signals outside the exact frequency, thereby permitting some variation in the adjustment of the radio transmitter on the vessel in distress. The band width of the alarm receiver must also be fixed as an integral part of the design and not be adjustable by the operator. To meet F.C.C. requirements as to sensitivity the receiver must function with an input of 500 microvolts applied through 500 micro-microfarads, 20 microhenrys and 5 ohms over the specified 25 kc. band. Then, on the basis of the ship's antenna having an effective height of 5 meters, a field strength of 100 microvolts per meter will be sufficient. In actual practice with average shipboard main antennas it is easy to obtain effective heights greater than 5 meters so that the maximum sensitivity of the auto alarm is more apt to be limited by the prevailing noise level.

Selectivity requirements for the auto alarm receiver may be analyzed as follows: Above 512.5 kc. interference may first be expected from broadcast stations operating in the channels around 550 kc.

Broadcast stations whether located along coastlines or considerably inland may be expected to lay down either a strong ground wave which might interfere with coastwise vessels, or a sky wave at night which may be a source of difficulty. F.C.C. specifications state that the auto alarm, when adjusted for 500 microvolts input, must not be made inoperative with an interfering modulated signal of 25,000 microvolts at 550 kc. When the interfering signal is 650 kc. it may have an amplitude of 100,000 microvolts without affecting the auto alarm. Below 487.5 kc. interference may be expected from marine traffic in the band from 375 to 500 kc. Selectivity requirements in this band call for no interference from a 25,000 microvolt signal at 450 kc. and a 100,000 microvolt signal at 375 kc.

Overload characteristics of the auto alarm receiver are of importance. When the operator goes off watch he places the auto alarm in circuit and adjusts the sensitivity control to an optimum value for the prevailing noise level as explained later. The apparatus must then be capable of accepting a very strong signal from a nearby vessel, without blocking or overloading. Automatic volume control used in the conventional manner is of no assistance for this problem because the desired incoming signals are completely keyed, that is, the carrier wave is either on or off. AVC would simply raise the gain of the receiver each time the incoming signal was cut off, and during this interval the noise and static picked up by the antenna would tend to block the receiver. Time delay in an AVC circuit is also inadmissible since the receiver and selector circuits must recognize extremely short "breaks" in incoming signals in order to permit the alarm signal to function through interference on 500 kc. This action is explained further in the selector design. Satisfactory design to meet F.C.C. rules must provide operation with a 90,000 microvolt signal at 500 kc., when the receiver is adjusted to also respond to a 500 microvolt input.

Since the auto alarm when connected in circuit operates as an unattended device for several hours, means must be provided to indicate when operation is not normal. There is a possibility that prolonged static of high level will "hold over" some of the relays in the selector unit. It is therefore necessary to arrange for a warning light or its equivalent to show on the bridge so that the radio operator may be instructed to readjust the sensitivity control. Vacuum tubes in the apparatus may burn out. If this occurs a "no current" relay is used to energize the warning bells which are located on the bridge, in the radio operator's cabin and in the radio room. Failure of the source of energy which rings the bells is shown by continuous burning of the warning lights, located alongside the bells.

After the radio signal passes through the receiver it controls the selector mechanism. To allow for reasonable variations in the timing of the alarm signal the selector must be designed to accept dashes having a duration of 3.5 to 4.5 seconds and spaces from .1 to 1.5 seconds. The question of operation through interfering signals in the 487.5 to 512.5 kc. band as well as the possibility of false alarms must also be considered when determining the selector timing tolerances. The alarm must function through a reasonable amount of interference on the same frequency as the distress signal. This interference may produce two effects on the selector. One effect is to prolong the normal four-second alarm signal in case the interference appears at just the correct time to add to the desired signal. The second effect of interference is to "fill in" the normal one-second spaces. If the spaces are completely filled in at the correct time the selector functions to reject the signals and it will do the same if interference unduly prolongs the desired dashes.

Ordinary telegraphic traffic does not interfere, even though on the same frequency, with normal operation of the auto alarm, especially if the selector unit is responsive to extremely short spaces. The minimum U. S. requirement is one-tenth second and if the design provides performance equal to or better than this value, then the alarm signal will pass through the selector as long as some "break" takes place in the interfering signal when the "space" occurs in the alarm signal.

The possibility of false alarms is determined by a combination of three main factors, namely fortuitous or accidental combinations of signals or noise equivalent to the alarm signal, timing tolerances of the selector and finally the number of dashes and spaces which are selected to ring the bells. As mentioned in the first part of this paper, European practice is to arrange for the bells to ring when three consecutive dashes and spaces pass through the receiver and selector. F.C.C. requirements are based on ringing the bells after four consecutive dashes and spaces are correctly received. The four-dash cycle considerably minimizes the possibility of false alarms since the chances are quite remote for accidental combination of signals to repeat themselves four times to imitate the alarm signal. On the other hand it is somewhat more difficult under conditions of severe interference for the auto alarm to accept the four instead of the three-dash cycle. It may be mentioned that current designs of American auto alarms may be easily arranged to accept either the three or four-dash cycle and in any case no international operating difficulties arise since the vessel in distress always sends twelve or more dashes.

A rugged design of auto alarm is necessary to withstand successfully the operating conditions which obtain aboard ships. In typical cases the auto alarm will be "on the air" for an average of approximately 5000 hours yearly. All the time the alarm is in circuit the receiver and certain parts of the selector are continually responding to ordinary telegraphic signals, static, induction, etc. This entails considerable wear and tear of any moving parts and for this reason moving parts should be kept to a minimum, while relays and the like must withstand hundreds of thousands of cycles of operation. The

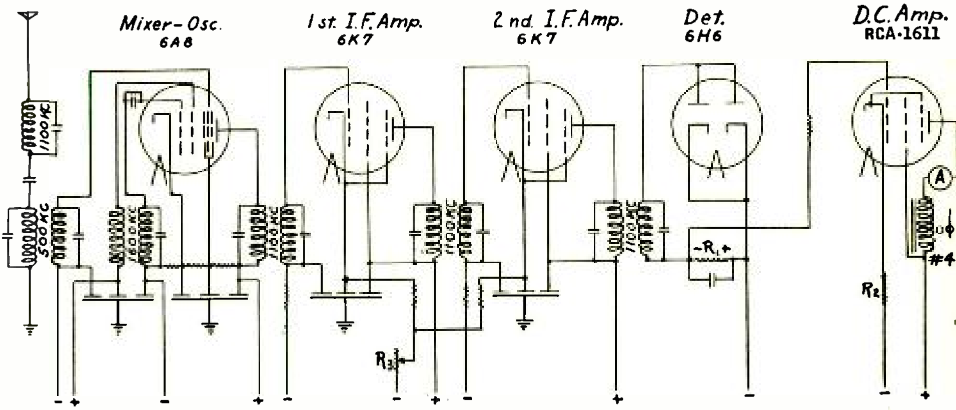

Fig. 1—Simplified receiver schematic circuit diagram

design must also include provision for testing by sending a local alarm signal through the circuits, together with suitable meters and controls to enable the operator to check the overall performance. F.C.C. specifications also call for ability to endure shipboard vibration, humidity and temperature. A single master switch to place the auto alarm in service is required which must be so arranged that power cannot be applied to the alarm circuits unless the main antenna is connected to the alarm receiver and having an interlocking feature to prevent the ship transmitter from being keyed unless the auto alarm receiver is turned off.

PART II

The design of equipment necessary for performance as indicated in Part I can best be considered by using a natural division of receiver and selector requirements; that is, the receiver must have sufficient sensitivity and uniform reception over a band of 487.5 to 512.5 kc. and a selector system to differentiate between static and ordinary communication and the auto alarm signal. In order to start selector operation some form of d-c amplifier is indicated. The plate circuit of this d-c amplifier must have sufficient power and correct characteristics to work a fast operating signal relay, the contacts of which initiate selector action. Certain characteristics of tuned circuits may be used to evolve the receiver design. Band pass intercoupling circuits are indicated from a consideration of the selectivity and band width requirements, as well as considerable amplification, in order to control the grid circuit of the d-c amplifier or signal relay tube. The coefficient of coupling (k) of individual r-f transformers would be of the order of .06 to provide the necessary band width.

$$\text{Band within} = k \times \text{resonant frequency (approximately).}$$

A circuit over-coupled to this extent would have a severe valley at the resonant frequency if modern high Q coils were used. High Q circuits are desirable in order to secure high attenuation outside of the pass band. The effect of double humps with a severe trough between them is even more pronounced when it is realized that several r-f stages must be used in cascade in order to provide sufficient sensitivity. By using a frequency greater than 500 kc. the coefficient of coupling in the band pass circuits may be reduced and still give the required band width, and in addition, the response within the band may be made uniform since the coupling need not be much greater than the critical value. Figure 1 illustrates schematically the tube and circuit layout of a superheterodyne receiver used to produce the required results.

A total of eight tuned circuits is utilized for necessary amplification and selectivity. A signal between 487.5 and 512.5 kc., with attenuation of signals ouside of these limits, is applied to the mixer-oscillator tube type 6A8 where it is mixed with the local oscillator operating at a frequency of 1600 kc. The difference beat between signal and oscillator frequency, or 1087.5 to 1112.5 kc., is amplified by two stages utilizing super control pentodes type 6K7 and then applied to diode detector type 6H6. The d-c voltage developed across diode resistor R_1 is used to control the grid circuit of d-c amplifier RCA-1611, whose plate relay initiates or stops selector action. The selectivity obtainable from such a layout is considerably in excess of requirements. For example, with the sensitivity control set for 500 microvolts, the signal necessary at 450 kc., to produce selector action is well in excess of 100,000 microvolts, which is four times the required amount. Likewise, the same values hold for a frequency of 550 kc. An interfering signal of 25,000 microvolts at the antenna-ground terminals of the receiver, could be as close to 512.5 kc. as 533 kc. and on the other side of the auto alarm band, the same strength signal could be as close as 467 kc., before interference would result. A wave trap directly in the antenna lead is provided for the attenuation of strong broadcast signals utilizing frequency assignments in the pass-band accepted by the intermediate frequency amplifiers.

It is desirable to use the ship's 110-volt line in order to avoid frequent B battery replacements or a dynamotor. This factor is quite important in selecting the tubes and circuits used. All-metal tubes are

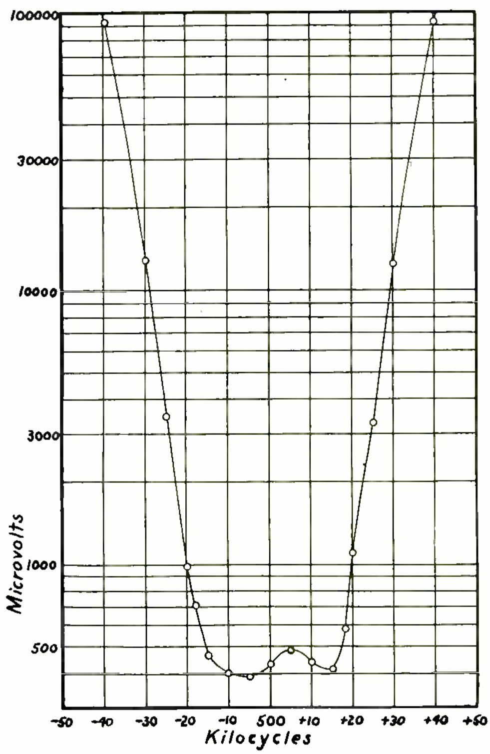

Fig. 2—Selectivity curve

used throughout. A 500-microvolt signal between the limits of 487.5 and 512.5 kc., irrespective of modulation or modulation frequency and including spark signals, must produce sufficient voltage of the polarity shown on the diode load resistor R_1 (Figure 1) to control the grid of the d-c amplifier tube. This tube has a "no signal" plate current value of approximately 7 milliamperes; thus signal relay No. 4 is normally energized. The 500-microvolt signal then reduces this relay current to below its drop-out value of 3 to 4 milliamperes. If the signal remains long enough, selector action obtains as explained later. A signal stronger than 500-microvolts merely produces plate current cut-off in the signal relay tube. "Downwards" operation of the signal relay is desirable inasmuch as a strong signal does not excessively deflect the milliammeter shown as A in Figure 1, and some sort of saturation circuit provision is, therefore, not necessary. A saturation circuit might be subject to a time lag when being restored to normal and thus limit the high speed operation of the signal relay. This is quite important, since this relay must recognize breaks of one-tenth second or less. Sensitivity control R_3 is provided for adjustment to optimum sensitivity, consistent with the prevailing noise level caused by atmospherics and man-made static. Thus to adjust for proper operation, the sensitivity control would be turned to its maximum counter-clockwise position, which gives minimum sensitivity for the receiver, and then turned clockwise until the plate current reading of the signal relay tube is approximately one milliampere less than the former reading. For example, if the plate current which flows through the signal relay reads 7 milliamperes with the sensitivity control set to the extreme counter-clockwise point, the control would be turned clockwise so that the average reading would be approximately 6 milliamperes. Bursts of static would then drive the signal relay current below the drop-out value and the contacts which initiate selector action would be occasionally or continually chattering, depending on existing noise conditions. Quite obviously, a sensitivity control is necessary; since if the auto alarm was permanently adjusted to respond to a 500-microvolt signal, during the heavy static season, and especially in the tropics, the signal relay would be de-energized most of the time and the receiver would be "blocked," insofar as ability to receive the auto alarm signal is concerned. In the event that this condition occurs, that is, where an increase in static level sufficient to drive the signal relay current below the drop-out value occurs, and continues for more than 3.5 seconds, warning lights installed beside each alarm bell will be turned on and will remain lighted until the static reduces in value, or the sensitivity control is set to the proper point for the new level.

The characteristics of an acceptable selector unit will next be considered. Since 16 hours per day or approximately 5000 hours per year of operation are necessary, the selector unit, to be most reliable, should have a minimum of moving parts. As previously mentioned, the standard automatic alarm signal is composed of 12 dashes and spaces, but the alarm bells are to be actuated after the receipt of four dashes with tolerances of 3.5 to 4.5 seconds and spaces with tolerances of .1 to 1.5 seconds. Thus if the space between the first and second dashes is completely filled by interference, the alarm would be actuated at the end of the sixth dash. If interference prolongs the length of any dash beyond 4.5 seconds, or completely fills in the space between dashes, the mechanism used for selection would be restored to normal. Thus, of the 12 dashes composing the signal, 4 consecutive dashes having a space at the beginning and ending of the group, as well as

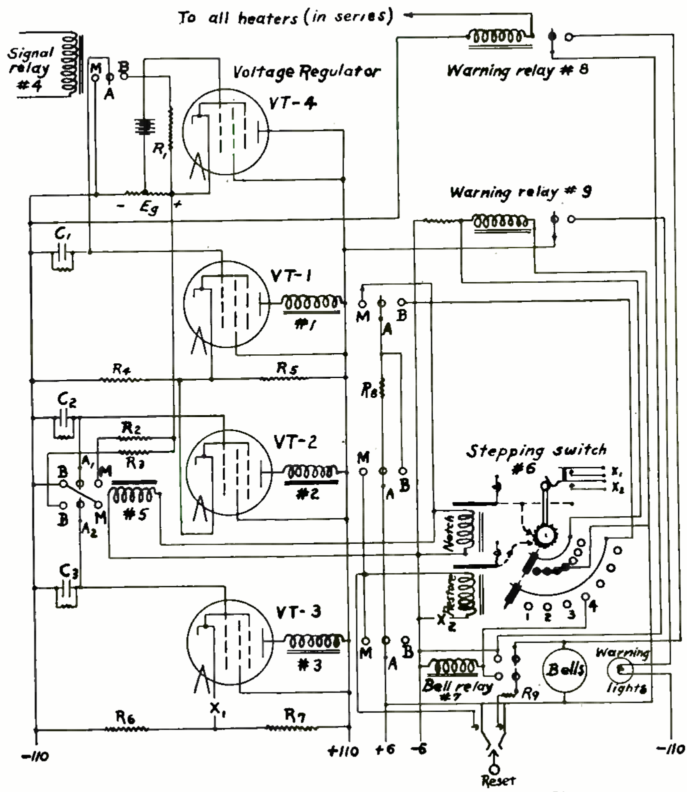

Fig. 3—Simplified selector schematic circuit diagram

between dashes, must be received before the alarm bells will ring. The obvious advantage of a 12-dash signal is that it permits more chances of the alarms being actuated under severe conditions of interference both from a standpoint of prolonging the dashes and filling in the spaces. The aforementioned dash and space tolerances seemingly impose difficult terms for the selector response. For example four dashes and the intervening three spaces might vary in total elapsed time between 14.3 and 22.5 seconds. Obviously the selector must check individual dashes and spaces since any attempt to use the sum would result in the false alarm probability being greatly increased.

The schematic circuits of the receiver and selector units are shown separately for explanation purposes, but are combined on one panel in practice. Figure 3 shows a simplified circuit of the selector unit. Elapsed time of signal duration is measured by RC circuits connected in the grid circuits of individual selector tubes. The principle utilized is the familiar one of current decay in a series RC circuit.

If E_g = steady source of charging voltage
C = capacity
R = series resistance
t = time
i = instantaneous current at time t
ϵ = base of naperian logarithms

then
$$i = \frac{E_g}{R} \epsilon^{-\frac{t}{RC}}$$

If e_c = Capacitor voltage at time t
$$e_c = Eg - i\,R$$

therefore
$$e_c = Eg\left(1 - \epsilon^{-\frac{t}{RC}}\right)$$

At time $t = RC$, e_c = 63% of its maximum value Eg

Referring to Figures 1 and 3, the selector action is as follows. An incoming signal of 500 microvolts or greater, of either A-1, A-2 or B emission, between 487.5 and 512.5 kc. produces a d-c voltage across the diode resistor R_1 of the correct polarity, as indicated in Figure 1, to reduce I_b of the d-c amplifier or signal relay tube below its drop-out value. Contacts *AM* (*A* refers to "armature" or moving contact, *B* to "break" and *M* to "make" contacts when relay is energized) are normally closed since relay No. 4 (Figure 3) is energized when no signals are being received. The reduction of I_b of the relay tube therefore causes contacts *AB* to be closed, which applies charging voltage E_g, developed by the voltage regulator tube, to C_1 through R_1. Since the grid-cathode circuit of VT-1 is connected across C_1, as C_1 charges, the grid of VT-1 becomes less negative and eventually I_{b_1} begins to flow, gradually increasing to several milliamperes. Thus if a signal persists for 3.5 seconds I_{b_1} becomes 5 milliamperes and relay No. 1 closes contacts *AM*. These contacts apply six volts obtained from the storage battery to the "notch" coil of the stepping switch

No. 6, which moves up one step and the warning lights go "on". The coil of auxiliary relay No. 5 is in parallel with the notch coil of the stepping switch and, therefore, contacts A_1M are made. This starts C_2 charging through R_2 and if the signal persists up to or greater than 4.5 seconds I_{b_2} of VT-2 becomes 5 milliamperes, which closes selector relay No. 2, and its contacts *AM,* in turn, apply six volts to the "restore" coil of the stepping relay. As soon as *A* leaves *B* of selector relay No. 2, R_8 is inserted in series with the notch coil and auxiliary

Fig. 4—Front view of Automatic Alarm

relay coil to prevent damage to the low resistance notch coil, due to an over-long signal or continuous "blocking" by static. The warning lights continue to glow until the signal stops or has a slight break in it. A break in the received signal allows signal relay No. 4 contacts *AM* to return the grid of VT-1 to a value greater than that required for plate current cut-off, which allows No. 1 relay contacts *AM* to open, thus removing the voltage from the "notching" coil and auxiliary relay No. 5, in turn allowing the "restore" coil of the stepping switch to return the lever wiper to normal. Contacts A_1B of auxiliary relay No. 5 then bias the grid of VT-2 beyond cut-off and allow selector relay No. 2 to open contacts *AM*, which removes the six-volt supply from the restore coil of the stepping switch. VT-1 thus serves to check the minimum length of a dash (dashes less than 3.5 seconds do not actuate the stepping switch), and VT-2 serves to check the maximum acceptable length of dash (dashes greater than 4.5 seconds energize the restore coil of the stepping switch which "restores" when the signal stops). Four dashes, if greater than 3.5 seconds and less than 4.5 seconds would then actuate No. 1 relay four times and the stepping switch wiper would rest on Contact 4. Then if a break occurs at the end of the fourth dash, Contacts *AB* of No. 1 selector relay are closed which applies six volts to the bell ringing relay No. 7. Once closed, this relay applies six volts to the bells and is held closed by its auxiliary or hold-in contacts. In order to stop the bells the reset button on the auto alarm panel must be pressed. The bells are not allowed to ring until the fourth dash is broken (and within prescribed limits), since if this was not done three correct dashes and the fourth one of *any* length greater than 3.5 seconds would cause an alarm.

VT-3 serves two purposes. If one, two, or three correctly timed dashes are received, the stepping switch wiper comes to rest on Contact 1, 2 or 3 respectively and would remain in one of these positions indefinitely until another dash was received, which would then ring the bells. This is, of course, improper operation. In order to prevent such a condition the grid of VT-3 is normally connected to the charging voltage E_g through charging resistor R_3. The cathode circuit of VT-3 connects through interlock contacts X_1 on the stepping switch, which are open when the stepping switch is on the zero or "normal" contact only. Thus after a "notch" has occurred auxiliary relay No. 5 contacts A_2M are closed which biases the grid of VT-3 to its below cut-off value as determined by voltage divider resistors R_6 and R_7. At the conclusion of the dash auxiliary relay No. 5 contacts A_2B are made and after an interval of five seconds I_{b3} in selector relay No. 3 reaches a value of 5 milliamperes, thus closing No. 3 relay contacts *AM*. These contacts in turn apply six volts to the restore coil of the stepping switch which will then be returned to normal. In the event that the second or following dash is completed within five seconds from the end of the previous dash, selector relay No. 3 does not close contacts *AM*. This then allows the maximum space between dashes to be the difference between five seconds and the initial closing time of relay No. 1, or 1.5 seconds. Such a method is necessary for the proper checking of spaces, since if an attempt were made to check spaces directly, any form of interference occurring during the space would "fill in" and cause an error in timing.

In order to indicate line voltage failure as well as tube heater burn-out, warning relay No. 8 is connected in series with all tube heaters which in turn are heated from the ship's 110-volt line. A failure of either tube heater or line voltage will cause the alarm bells to ring. The bells will, of course, stop ringing if the line voltage is restored. A test button is provided on the auto alarm panel which,

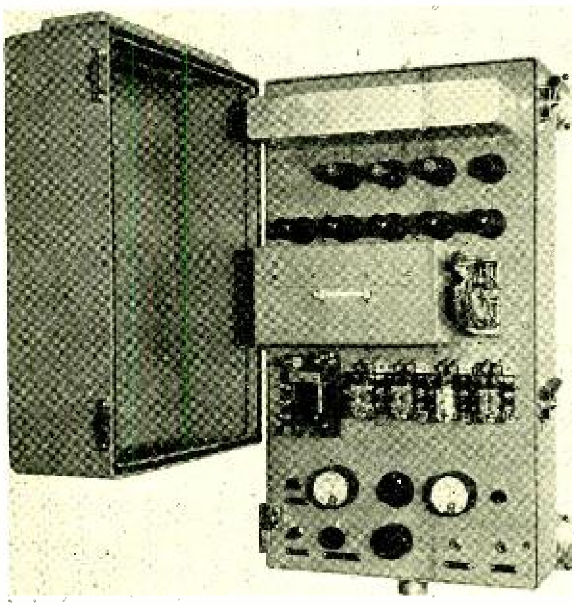

Fig. 5—Front view of Automatic Alarm—cover open.

when held in, prevents the bridge and operator's room bells from ringing during routine testing of the auto alarm receiver and selector.

Warning relay No. 9 is connected across the storage battery through a series resistor. Failure of the battery supply will allow relay No. 9 to de-energize and turn on the warning lights at each bell location point. Warning of power failure is therefore obtained except for simultaneous failure of both the 110-volt ship's line supply and the storage battery. The chances of simultaneous failure are very remote.

Following is a summary of warnings:

(1) *Bells ringing* may be caused by

(a) Receipt of auto alarm signal.

(b) Receipt of a false auto alarm signal caused by a fortuitous combination of static and keyed interference.

(c) Loss of ship's line voltage.

(d) Tube heater burn-out.

(2) *Warning lights burning continuously* are caused by

(a) Receipt of a continuous signal from a transmitter whose key is being held down for a period considerably greater than 4.5 seconds.

(b) Sensitivity control set too high for the prevailing noise level.

(c) Loss of 6-volt battery supply.

(3) *Warning lights burning intermittently* are caused by

(a) Occasional long bursts of static.

(b) Transmitter testing using dashes slightly longer than 3.5 seconds.

(c) Heavy 500 kc. interference caused by several telegraph transmitters transmitting at the same time.

Warnings as under (3) are to be expected and indicate that the auto alarm is functioning correctly. Warnings as under (1) and (2) should be investigated as to their cause.

The complete auto alarm installation consists of:

(A) The auto alarm receiver and selector chassis.

(B) A cable junction box which also provides mountings for

(1) The radio room bell.

(2) The radio room warning light.

(3) Fuses for both 110-volt and 6-volt supplies.

(4) Charging lamps for the 6-volt battery.

(C) An "antenna-on-off" switch which

(1) When in the "receive" position (operator "off watch")

(a) Connects the main ship antenna to the auto alarm.

(b) Opens transmitter key relay power supply circuit.

(c) Connects the 110-volt supply to the auto alarm.

(d) Connects the 6-volt supply to the auto alarm.

(2) When in the "off" position (operator "on watch")
  (a) Connects the ship antenna to the lightning switch.
  (b) Closes key relay power supply circuit.
  (c) Removes the 110-volt and 6-volt tube and relay supply voltages.
  (d) Places 6-volt battery on charge.

(D) Two bells and warning light boxes, one each to be located on the bridge and in the operator's room.

(E) One 6-volt storage battery.

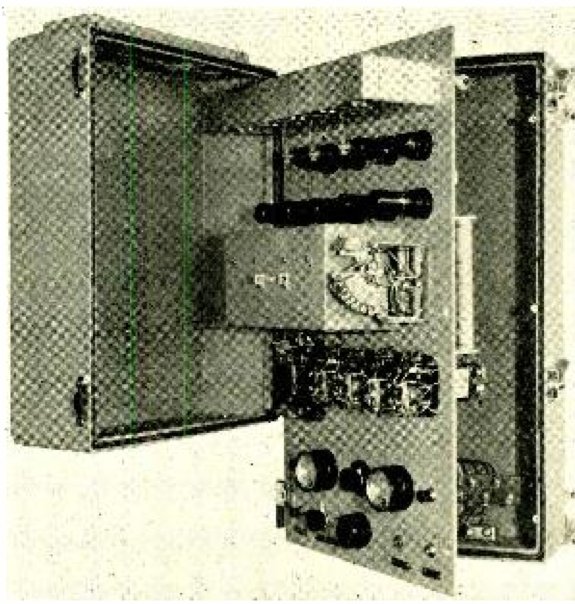

Fig. 6—Automatic Alarm with cover and panel open

A small oven, thermostatically controlled and containing the three selector relays for special protection against the humid conditions encountered at sea, keeps the auto alarm chassis perfectly dry inside. All adjustments which affect timing or band width are made relatively inaccessible by cover plates. Figure 5 shows these plates in place over the r-f transformer shield cans at the top of the panel and over the holes in the oven through which the selector relays are adjusted.

Figure 4 shows the auto alarm receiver in its cast cabinet. The cabinet is made in two sections; the back section, which mounts on a bulkhead by means of rubber shock mounts, is fitted with hinges on which the panel is hung. When the panel is swung into its cabinet, the inside is firmly sealed by means of a hollow rubber tube pressing against the back of the panel. The front section of the cabinet is also hinged to the back section. The hinge is of special construction so that the panel may be lifted off the hinge. The front section of the cabinet covers the upper section of the panel, but leaves the meters, meter switch, phone pack, test buttons and sensitivity control accessible for observation and adjustment. Figures 5 and 6 show how the cover and panel swing open for observation and servicing. The cabinet occupies a space on the radio room bulkhead of 16 x 26 inches. The weight is approximately 60 pounds.

The apparatus described in this paper represents the present-day status of an auto alarm development which has been under way since 1928. Acknowledgment and appreciation is expressed to Mr. Chas. J. Pannill for his cooperation and encouragement during this work.

REPRODUCING EQUIPMENT FOR MOTION PICTURE THEATRES

BY

M. C. BATSEL and C. N. REIFSTECK

Photophone and Test Equipment Division, RCA Manufacturing Co.

EQUIPMENT for reproduction of sound motion pictures is located in two places in every theatre. The loudspeaking or reproducer equipment is on the stage behind the sound screen and the soundhead and amplifiers are in the projection booth, usually located at the rear of the theatre.

The main elements for successful reproduction of sound accompanying a picture are:

1. A soundhead used for translation of the photographic sound record to minute electrical energy.
2. Amplifying equipment to increase the minute electrical energy from the soundhead to a value that will operate the loudspeakers at the required volume.
3. Loudspeaking equipment which translates electrical energy to acoustical energy or sound.

In addition to these three major elements, there are other associated parts which are used as part of the complete equipment to insure proper performance in the theatre. Some of these are: changeover switching systems to transfer the amplifier from one machine to another for continuous performance, a monitor speaker for the projectionist, and, in some installations, a remote volume control located in the auditorium.

(A) THE SOUNDHEAD[1]

The sound reproducing attachment or soundhead is used in conjunction with a standard motion picture projector. It contains all the optical, electrical, and mechanical equipment necessary to convert the variations in opacity of the photographic sound record into electrical currents.

[1] *Journal S.M.P.E.*—Vol. XXV No. 5, Page 449.

A recent High Fidelity soundhead, known as the rotary stabilizer type, is shown in Figure 1. This designation refers to the system employed for imparting a steady motion to the film at the point where the translation takes place. This type of soundhead is considered a decided improvement over previous types used.

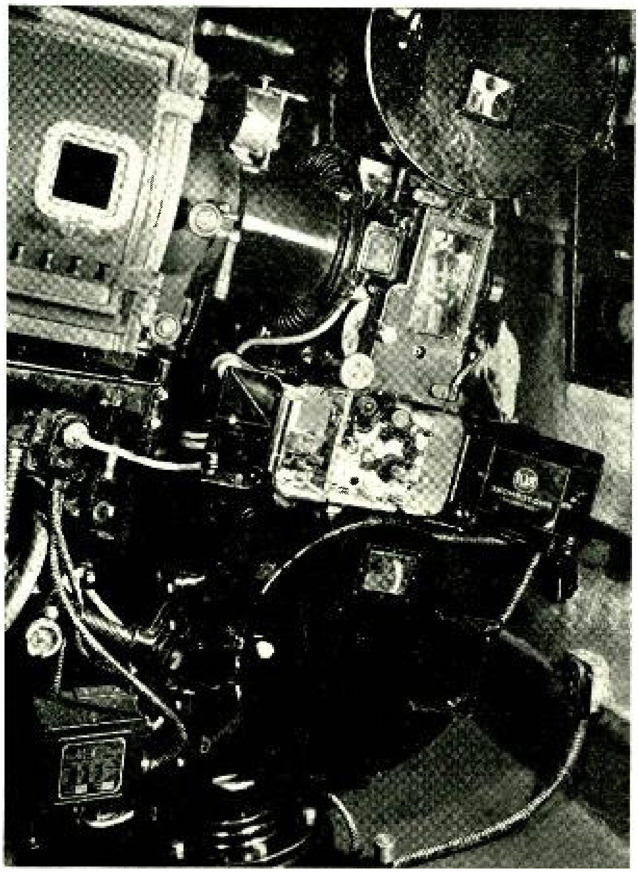

Fig. 1

The first types of soundheads employed fixed sound gates consisting of stationary guide plates and pressure shoes for holding the film in the position where it was pulled by a sprocket past the translation point. Experience demonstrated that these gates required almost constant attention to prevent the accumulation of wax and emulsion on the polished surfaces of the film guides and pressure shoes to prevent the film from chattering or being scratched which would result in noisy reproduction of the sound. The frictional resistance to the film passage resulted in wear of the guides and pulling sprockets.

A major problem in the first types of soundheads was the achievement of a constant speed of the film at the translation point. Many attempts were made to have the pulling sprocket directly below the gate revolve at a uniform velocity by the use of elaborate mechanical filters between the driving motor and the sprocket. In the best of these systems some ripple was present in the sound reproduction from the film, due to uneven motion of the film resulting from imperfect mechanical parts. A serious flutter or rapid variation in the motion resulted from the use of a sprocket to pull the film through the gate by means of the perforations in the film.

The rotary stabilizer type of soundhead was designed to eliminate all the objections of the gate type. This was accomplished by the use of a rotating drum to which is attached the rotary stabilizer elements.

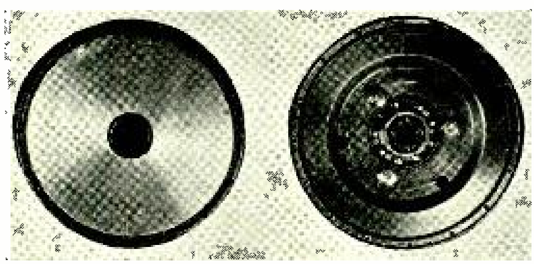

Fig. 1A

Special care was taken to see that the film as it passes through the soundhead is bent into as wide a curve as possible, insuring that it would lie flat and all points of the sound track would be in focus. The free running sound drum shaft is mounted in ball bearings so that the friction is reduced to such a small amount that it is possible for the film to drive this drum without appreciable tension. This tension is so light that the film is never pulled taut except at the start. The film being in contact with the drum rotates with it. This prevents any possibility of film scratching. The film assumes a curved path after leaving the sound drum. The stiffness of the film serves as a compliance which, in conjunction with the mass of the rotating elements, acts as a filter to eliminate variation in the motion of the film at the translation point.

The best known expedient for uniform rotation is the fixed flywheel on a shaft. This, however, is unsatisfactory for control of the drum shaft because the flywheel would continually hunt or oscillate with the springy film loop in the same manner that a weight suspended from a coil spring would oscillate under the slightest disturbance.

The theory of the "rotary stabilizer" principle was discovered several years ago and was later further elaborated and expanded. This work led to a device for controlling the drum speed which fulfilled the conditions required for a satisfactory reproducer, namely that the system be damped so as to prevent oscillation of the mass of the rotating system when propelled by a spring for absorbing irregularities in the motion of the driving mechanism. The practical form of this reproducer soundhead consists of a light case constructed as a short cylindrical casing firmly fastened to the drum shaft. Inside the casing on a hub forming part of the case, a heavy free floating flywheel is carried

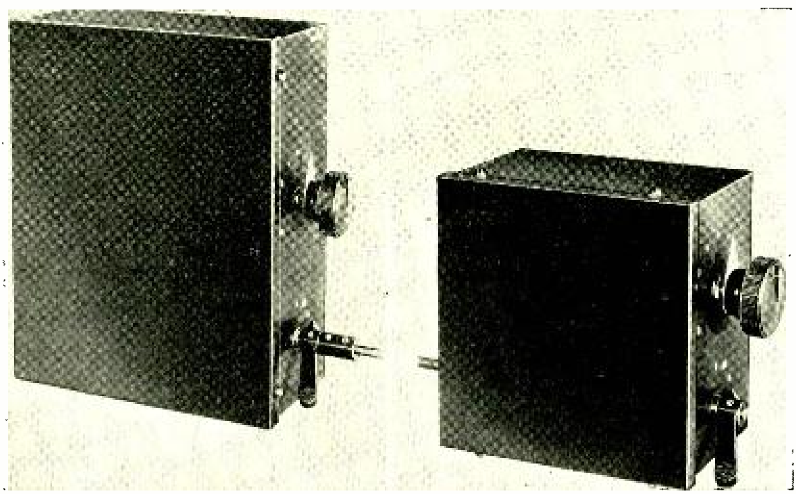

Fig. 2

on a ball bearing. (Fig. 1-A.) A light oil fills the remaining space inside the case. The oil acts as a viscous driving medium between the heavy flywheel and the case. The case is sealed so as to be oil tight. Any tendency for oscillation between the stabilizer assembly and the film loop is prevented due to the fact that the energy of the disturbance is dissipated in the oil when there is relative motion between the casing and the flywheel which does not follow rapid changes in the motion of the casing because of its inertia. The relative moments of inertia of the casing and flywheel are approximately one to eight.

To keep the film in proper position on the drum, it passes between two flanged rollers mounted directly above the drum. To accommodate film of various degrees of shrinkage, one flange is movable. The fixed flange is on the sound track side and is known as the guiding roller.

The flange assembly is also adjustable within limits so that the sound track may be adjusted to the correct position for being scanned by the light beam passed through it to a photocell.

The light beam is approximately .001" by .084". It is obtained by focusing an image of a slit in a diaphragm (five times as large) on the film. The diaphragm in which the slit is put is illuminated by a

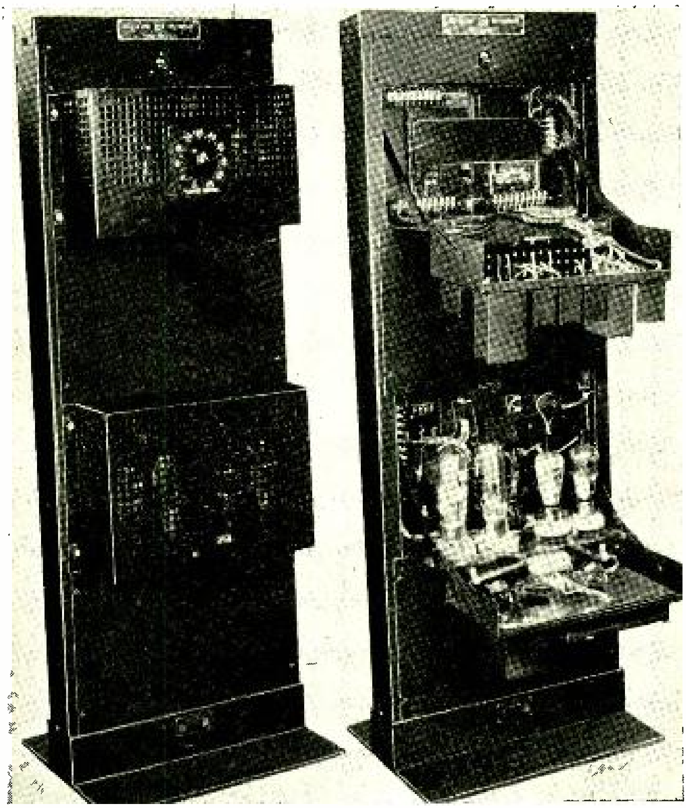

Fig. 3

10-volt, 5-amp. lamp and a condensing lens. A small collector lens is mounted in the drum over which the film passes. This directs the light to a photo-electric cell. This cell is connected through a transformer of suitable impedance ratio for connecting to a 500-ohm line to the amplifier.

To eliminate possible noise due to vibration of the lamps or photocell, the motor is mounted on rubber and the rotating sound drum, optical system, photocell, photocell transformer and exciter lamp are also mounted on one plate and resiliantly mounted to the main case of the unit.

(B) AMPLIFYING EQUIPMENT

A current type of amplifying equipment consists essentially of a fader box (Fig. 2) mounted on the front wall of the projection booth at each projector, a main amplifier (Fig. 3), a monitor speaker amplifier, a monitor speaker (Fig. 4) and an exciter lamp and loudspeaker field supply unit (Fig. 5).

The fader system is used to connect the soundhead to the amplifier at the time the picture changes from one reel to another. It consists

Fig. 4

of a switch for exciter lamp changeover and a 20-db. variable attenuator pad. This pad serves to preset the volume from the machine to a predetermined level or to eliminate changes in volume at the changeover due to different sound level on the film. By this means the projectionist need not leave his position at the projector to make adjustments of volume after the changeover.

The main amplifier in Fig. 3 is the type used in the larger theatres. It is so constructed that all parts can be removed from the front for ease of service. It consists of a voltage amplifier and one or two power amplifiers. The equipment is completely AC operated and self contained. Each amplifier is complete in itself including its own rectifiers for power supply. The voltage amplifier has sufficient voltage amplification to drive the power amplifiers when the input terminals are connected to the line from the photocell transformer. Both voltage and power amplifiers are novel in construction. Each amplifier consists essentially of three parts; namely, a vertical panel, a base proper, and a base support. On the vertical panel attached to the rear of the rack are mounted the heavy power supply parts such as power transformers, filter reactors, etc., and the base support. On the base support are mounted very few parts, as its main function is that of supporting the main base and the inter-panel cabling. On the main base are mounted the main amplifier parts and the tubes. This main base is so constructed that it can be hinged down for inspection and service.

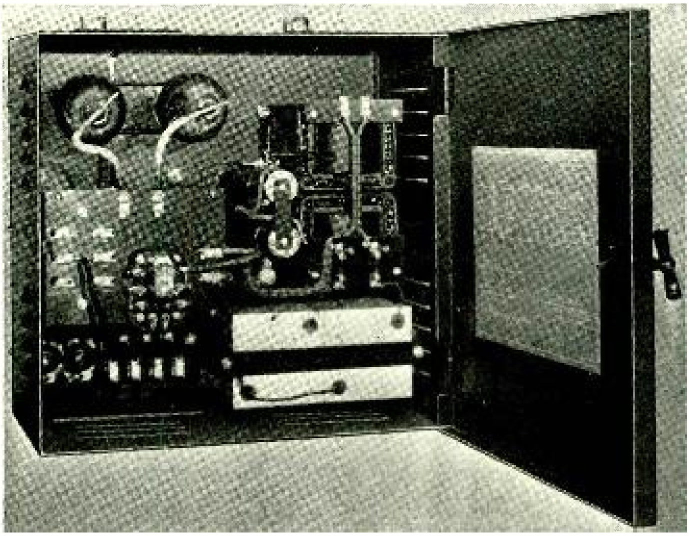

Fig. 5

It can also be completely removed without the use of a soldering iron as all connections are made to the vertical panel through screw terminals. In the circuits employing large capacitors these are segregated into sections in parallel. Important sections of capacitors and points of the circuit are fused against possible trouble. Failure of a section of the filter capacitor which is fused will permit the program to continue until the end or such time as repairs can conveniently be made.

An indicator of the Neon lamp type is placed in the plate circuit of the amplifiers to indicate that this circuit is functioning properly. The lamp is lighted at all times, failure to light indicates no plate current to the tubes. The trend in recent years on electrical equipment has been to eliminate all unnecessary controls and meters. AC operated amplifiers and modern amplifier tubes do not require tube controls or meters for adjustment. Only one manual control is found on the main amplifier. This is the master volume control which can be preset and need not be changed for the entire performance. Experience of projectionists (who are occupied in keeping the show going) with this type of amplifier in the past years indicates that the design is practical and capable of meeting the requirements for uninterrupted service.

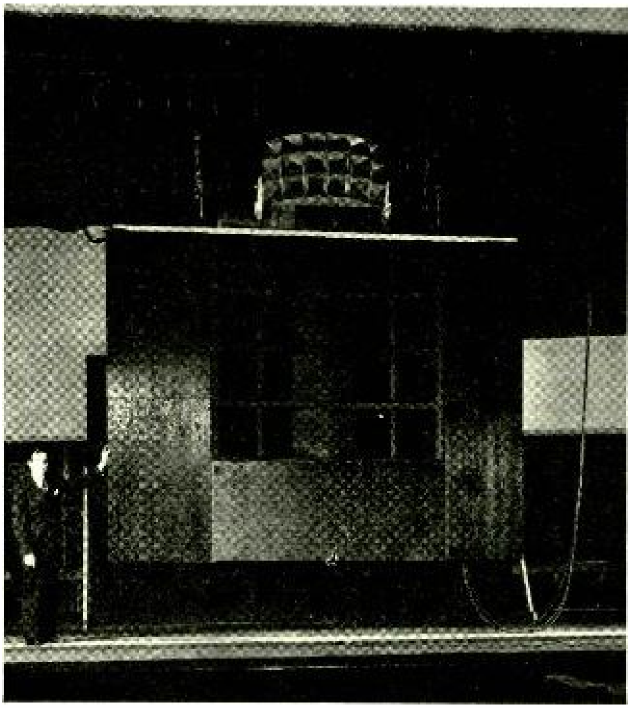

Fig. 6

The monitor amplifier is self contained with its power supply and is mounted in some convenient location on the projection booth wall. It is made to bridge the speech circuit to the stage. It has a separate volume control to permit adjustment for noise conditions encountered in a projection booth. Its output is sufficient to drive the monitor speaker (Fig. 4) to give adequate sound at each projector station. Monitor speakers are primarily used to indicate that the speech circuit to the stage is functioning properly and to give the operator the proper sound cue for changeover from one machine to another.

The exciter lamp and loudspeaker field supply rectifier and filter unit (Fig. 5) supplies power for the exciter lamp in the soundhead (10 v. at 5 amp.) and 18 watts at 12 volts for each of the loudspeakers. Changeover from one machine to another is accomplished by means of a relay controlled by the control switch at each projector station.

(C) Loudspeaker Equipment (Fig. 6)

A recent design of loudspeaker equipment to be installed on the stage consists of two separate speakers, one of these reproduces the

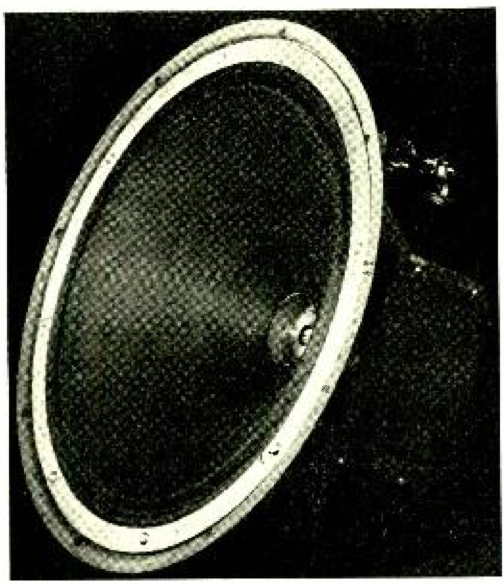

Fig. 7

frequency range below 300 cycles and the other above 300 cycles. A dividing network or filter serves to divide the electrical output of the amplifier accordingly.

The low frequency speaker is made up of two folded exponential horns, each 40″ high by 80″ wide mounted one above the other. Each horn has two 14″ cone type driver units. The frequency range is from 40 to 300 cycles as used with the dividing network.

The high frequency speaker is of the exponential horn type. It consits of a number of small exponential horns, each measuring at the bell opening approximately 7″ x 7″. These small horns are assembled into clusters forming the equivalent of a large horn with partitions dividing it into sections. All sections are driven by two speaker mechanisms through a "Y" throat.

A plain exponential horn has a directional characteristic that varies with frequency. The higher the frequency the more narrow the beam becomes. A single exponential horn mounted in place of the multiple section horn shown in Fig. 6 would give a resultant "bassy" reproduction to that portion of the audience in seats located well off the axis, and the reverse would be true for those directly on the axis.

This effect is eliminated if a cluster of small exponential horns are used. The mouth opening formed by the cluster is spherical in shape.

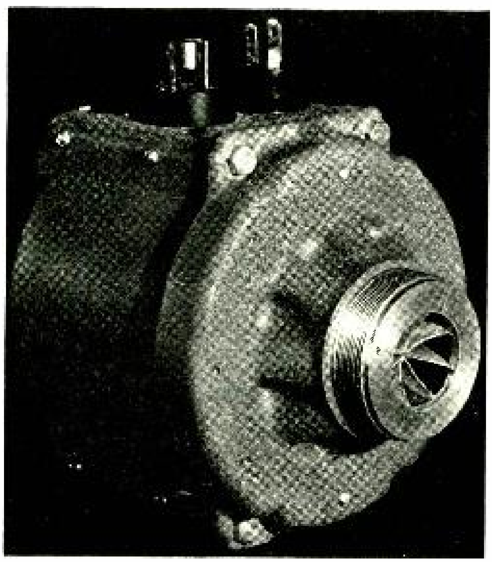

Fig. 8

Four sizes are used for various types of theatres, each three layers of the small horns in height, and varying in angle from approximately $52\frac{1}{2}^\circ$ to 105° in clusters of nine, twelve, fifteen and eighteen of the small horns. The width of the theatre and the acoustical property of the side walls determine the angle used. The high frequency speaker operates over a frequency range from 300 to 10,000 cycles. The 300-cycle crossover was selected as a compromise on high frequency horn length. Moving it to a higher frequency is a disadvantage from the standpoint of division of primary speech sounds. The limitation in depth of the speaker assembly is brought about by the necessity of flying the speakers on theatre stages where stage presentations are given and the loss of lines for scenery drops is a problem.

The low frequency driver mechanism (Fig. 7), is a high efficiency cone type dynamic speaker. Four of these are used per installation. The high frequency driver mechanism (Fig. 8) is a cone type unit. The cone is moulded from a fiber sheet and has no seams. It is treated to make it moisture proof. It has been determined that the strength per unit weight or mass of the diaphragm for this fiber is greater than can be obtained with other materials.

The size of the auditorium and its acoustic properties have a very definite influence on the size of the equipment to be installed and frequently the acoustical characteristics of the auditorium require that the characteristics of the equipment be adjusted to compensate for undesirable effects. It may be necessary, due to high absorption of the low frequencies to supply additional energy to the low frequency speakers and vice versa.

It is customary to rate equipment according to theatre seating capacity and volume of the auditorium. Experience has shown that the following classification of theatres as to size results in a commercially satisfactory arrangement of equipment:

	Cubical contents in cu. ft.
(1) Up to 500 seats	75,000
(2) 500 to 800 seats	120,000
(3) 800 to 1400 seats	200,000
(4) 1400 to 3000 seats	720,000
(5) 3000 up—Special custom equipment	

The type of soundhead used is not dependent on the size of the theatre. For economical reasons the types and sizes of amplifiers and speaker complements are selected as required for the seating capacity and size of the theatre. It is desirable that all equipment be installed under the supervision of factory trained installation engineers who make the final tests and adjustments of the installation.

SOME NOTES ON ULTRA HIGH FREQUENCY PROPAGATION

By

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INTRODUCTION

THE propagation characteristics of ultra high frequencies above 30 megacycles have been studied for many years. While many observations have been made, it is unfortunate that a substantial proportion of these observations have been qualitative only, due to the difficulty in constructing suitable equipment for quantitative measurements. It has also been difficult to build transmitters of sufficient power and stability to make possible the quantitative measurement of signals at considerable distances beyond the horizon. It is the purpose of this paper to review some of the available information concerning ultra high frequency propagation, including some studies which have recently been made by engineers of R.C.A. Communications, Inc. of propagation at various frequencies both within and beyond the optical distance.

The study of ultra high frequency propagation falls logically into three divisions, namely, (1) Propagation within the optical distance; (2) Ground Wave propagation beyond the horizon; (3) Sky Wave propagation.

PROPAGATION WITHIN THE OPTICAL DISTANCE

The theoretical laws of ground wave propagation over optical paths are fairly well known. Several excellent papers have been published on this subject.[1-2-3-4-13-14] It has been shown that the received signal is the resultant of the direct ray and a ray reflected from the ground. For most practical cases the reflected ray impinges upon the ground at nearly grazing incidence and is usually reflected at high efficiency with a 180-degree phase reversal. Consequently, the direct ray and the reflected ray arrive at the receiving antenna at equal intensity and nearly out of phase. The phase difference between the two paths depends upon the location of the transmitting and receiving antenna and the nature of the intervening ground. For flat ground, Trevor and Carter[1] have shown that the phase difference for grazing angles is

$$\Psi = \frac{4 \pi a h}{\lambda \tau} \qquad (1)$$

where h is the height of the transmitting antenna, in meters
a is the height of the receiving antenna, in meters
τ is the distance, in meters
λ is the wavelength, in meters

The direct field E_0 from a half-wave dipole is $7(\sqrt{W}/\tau)$, where W is the watts radiated. The received field for grazing angles then becomes,

$$E = \frac{7\sqrt{W}}{\tau} \times \frac{4 \pi a h}{\lambda \tau}$$

$$= \frac{88\sqrt{W}\,ah}{\lambda \tau^2} \qquad \text{Volts per meter} \qquad (2)$$

From equation (2), it will be noted that for the conditions assumed, the signal intensity is inversely proportional to the square of the distance; is directly proportional to the heights of the transmitting and receiving antennas above ground; and is inversely proportional to the wavelength. For a given height for the receiving antenna, the transmitting antenna height must be proportional to the wavelength to obtain a given signal intensity. For a given wavelength, the signal intensity will increase directly in proportion to the increase in height of either the receiving antenna or the transmitting antenna. For given antenna heights, the signal intensity will be proportional to frequency. All of these factors are favorable to the use of higher frequencies.

The above simple equation applies only for grazing incidence over flat land, free from obstructions. If both the transmitting and receiving antennas are high and fairly close together, as, for example, transmission from the Empire State Building to an airplane, or between the tops of the Empire State Building and the RCA Building[14], the geometry is such that the difference in path length is no longer a small fraction of a wavelength, and the simple equation no longer holds. In general, standing waves occur which may be greatly complicated by reflections from more than one point. The observations on the signals from the Empire State Building with the receiver in an airplane over North Beach, Farmingdale and Patchogue, as reported by Trevor and Carter[1], clearly show and explain these phenomena.

If the transmission takes place over sea water, there should be a marked difference between vertical and horizontal polarization. For sea water, horizontally polarized waves are reflected nearly 100 per cent for all angles, and the phase shift changes gradually from 180 degrees at grazing incidence to about 178 degrees at perpendicular incidence. On the other hand, for vertically polarized waves, the phase angle and per cent reflection change very rapidly with angle of incidence so that transmission over sea water should be excellent.

Trevor and Carter reported on some propagation measurements over sea water transmitting from an antenna a few feet above the water to a motor boat.[1] They found that the propagation of horizontally polarized waves was extremely poor as compared with vertically polarized waves, as predicted by the theory given in their paper. On the other hand, when the antennas are located at considerable elevations on mountains, as was the case during some observations between the islands of the Hawaiian group several years ago,[5] it was found that there was no marked difference between horizontal and vertical polarization, even though the transmission path was mostly over sea water and distances greater than the optical path were involved.

In applying equation (2), it is obvious that if the transmitting antenna is directive, either in the horizontal or vertical plane, or both, the directivity factor should be taken into account, since the equation was developed on the basis of transmission from a simple half-wave dipole.

Ground Wave Propagation Beyond the Horizon

Comparatively few data are available for determining the laws of ultra high frequency propagation beyond the horizon. Handel and Pfister[6] in a recent paper (published in German) have shown that the penetration of ultra short wave radiation beyond the range of optical sight takes place due to both diffraction and refraction. They state that the field due to diffraction at the earth's surface is independent of diurnal and seasonal times. Methods for calculating the diffraction field together with calculated curves and some measured values are included in their paper. The calculated diffraction fields agree very well with the observed fields in most instances, but at times the observed fields beyond the horizon are shown to be considerably higher than the values calculated from the laws of diffraction. The authors attribute this to refraction phenomenon, apparently within the troposphere. The refraction field shows strong variations and produces an effect similar to fading in short wave reception, whereas, the field intensities in the diffraction zone are very stable. The authors point out that the refraction fields appear more frequently and strongly

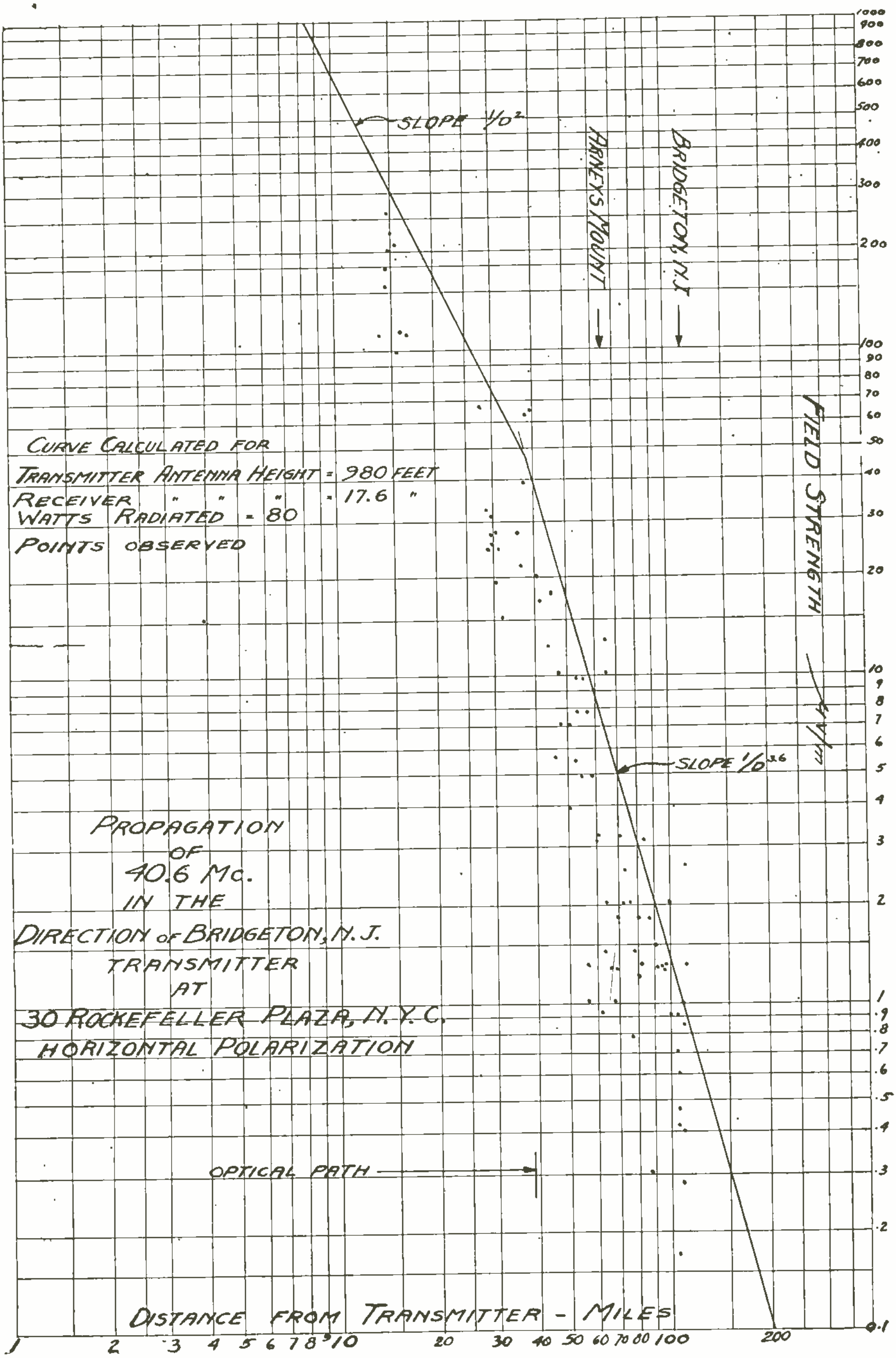

SLOPE 1/D²
ARNEYS MOUNT
BRIDGETON, N.J.
CURVE CALCULATED FOR
TRANSMITTER ANTENNA HEIGHT = 980 FEET
RECEIVER " " " = 17.6 "
WATTS RADIATED = 80
POINTS OBSERVED
FIELD STRENGTH μV/m
SLOPE 1/D³·⁶
PROPAGATION OF 40.6 Mc. IN THE DIRECTION OF BRIDGETON, N.J.
TRANSMITTER AT 30 ROCKEFELLER PLAZA, N.Y.C.
HORIZONTAL POLARIZATION
OPTICAL PATH
DISTANCE FROM TRANSMITTER - MILES
1 2 3 4 5 6 7 8 9 10 20 30 40 50 60 70 80 100 200
1000 900 800 700 600 500 400 300 200 100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1 .9 .8 .7 .6 .5 .4 .3 .2 0.1

Fig. 1

in summer than in winter and that the refraction over sea is stronger than over land.

Ross Hull[7] has made some very interesting studies of the refraction field and has shown that there is excellent correlation between signal intensity and temperature inversion. That is, when warm air masses exist above colder air masses near the ground, the signals are refracted down to earth beyond the horizon by the warm air. The existence of the warm air masses are determined by temperature measurements with balloons or airplanes. Considerably more data are required before it will be possible to evaluate these refraction fields or to predict their frequency of occurrence.

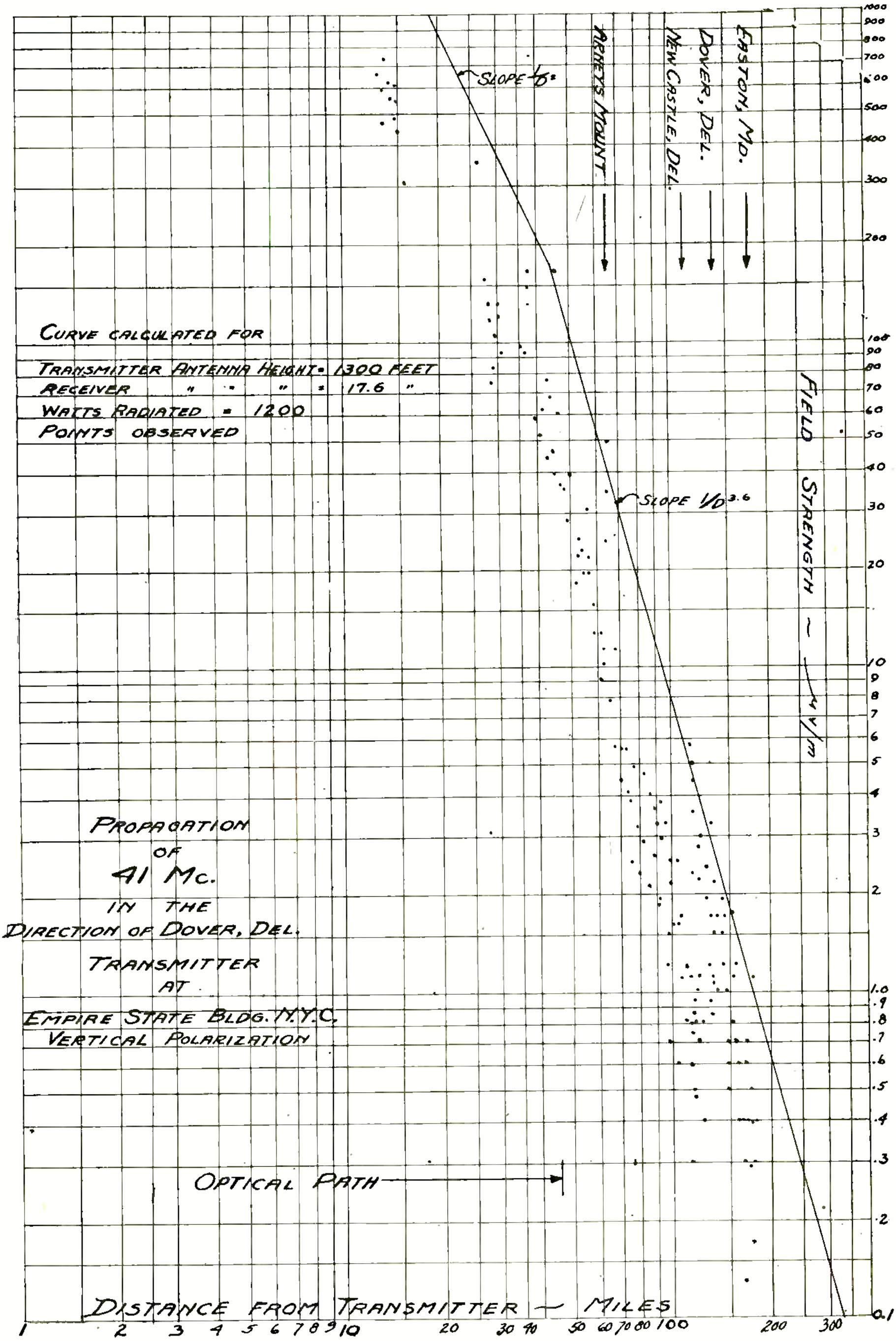
It may be of interest to examine some of the available propagation data which includes the refraction fields beyond the horizon as evidenced by fading.

Figure 1 is a typical set of observations made by Mr. G. S. Wickizer on the signals from the Empire State Building operating on a frequency of 41 megacycles with about 1200 watts in the antenna. The transmitting antenna was about 1300 feet above sea level. The receiving antenna was a dipole mounted on a bamboo pole, the center of the dipole being 17.6 feet above the ground. By substituting the above constants in equation (2) with distance as a variable, the curve marked "Slope $1/D^2$" was obtained. Beyond the horizon the field intensity falls off faster than the inverse square of the distance. A curve with a slope proportion to $1/D^{3.6}$ seems to fit the observations fairly well.

It will be noted that the observed intensities come up to the calculated curve frequently, but seldom exceed it, excepting in a few cases such as the points taken at Arney's Mount, where the receiver was on a high hill unobstructed in the direction of the transmitter. Most of the observations lie between the calculated curve and a similar parallel curve drawn at 10 per cent of the intensity of the calculated curve. The average intensity appears to be about one-third of the calculated intensity. Beyond the horizon, the scattering is probably largely due to fading of the refraction field, as it was found to be difficult to check the readings by returning to the same observation points at different times.

Within the optical distance, the attenuation is probably relatively high due to large buildings and other obstructions. Burrows, Hunt and Decino[3] have shown that the average fields in the City of Boston on a frequency of 34.6 megacycles follow the inverse square law but average 10 or 12 db below the calculated level terrain values.

Holmes and Turner[8], on the other hand, have shown that under some conditions, the observed attenuation in urban areas does not



SLOPE 1/D²
ARNEYS MOUNT
NEW CASTLE, DEL.
DOVER, DEL.
EASTON, MD.
CURVE CALCULATED FOR
TRANSMITTER ANTENNA HEIGHT = 1300 FEET
RECEIVER " " " = 17.6 "
WATTS RADIATED = 1200
POINTS OBSERVED
SLOPE 1/D³·⁶
FIELD STRENGTH ~ μv/m
PROPAGATION OF 41 Mc. IN THE DIRECTION OF DOVER, DEL.
TRANSMITTER AT EMPIRE STATE BLDG. N.Y.C.
VERTICAL POLARIZATION
OPTICAL PATH
DISTANCE FROM TRANSMITTER ~ MILES
1 2 3 4 5 6 7 8 9 10 20 30 40 50 60 70 80 100 200 300
1000 900 800 700 600 500 400 300 200 100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1.0 .9 .8 .7 .6 .5 .4 .3 .2 0.1

Fig. 2

seem to fit the inverse square law very exactly. They also show that the attenuation increases markedly with frequency, so that 100 megacycles is considerably inferior to 30 megacycles in an urban area, whereas, equation (2) indicates that the optical path transmission should be better on the higher frequency in the absence of obstructions. It should be noted, however, that the transmitting antenna used by Holmes and Turner was only 190 feet above the ground. Somewhat different results might have been obtained if the transmitting antenna had been at a greater elevation so as to clear the obstructing buildings more effectively. Nevertheless, the survey reported by Holmes and Turner indicates very definitely that in the presence of obstructions, the attenuation increases greatly as the frequency is increased.

Figure 2 is a set of observations for an entirely different transmitting condition, but with nearly the same frequency as Figure 1. The transmitter was located on top of the RCA Building at 30 Rockefeller Plaza in New York City. The antenna was about 980 feet above sea level and was horizontally polarized. The power in the antenna was about 80 watts. The calculated curve for inverse square law up to the horizon and inverse 3.6 power law beyond the horizon, again seems to fit the maximum signal intensities fairly well.

Figure 3 shows the results of observations made by B. Trevor and R. W. George on the much higher frequency of 91.8 megacycles. The antenna was a simple half-wave dipole on the roof of the Continental Bank Building at 30 Broad Street, New York City. The antenna was about 600 feet above the street level. The power in the antenna was about 50 watts. The antenna was readily adjusted to radiate either horizontally or vertically polarized waves. The receiving antenna was a dipole rigged on the roof of a car, the center of the dipole being about ten feet from the ground.

Substituting the above data in equation (2) gives the curve marked "Slope $1/D^2$." Beyond the horizon a curve with a slope of $1/D^5$ seemed to fit the maximum points with the exception of the points measured on top of hills, as indicated. There was apparently no consistent difference between the transmission characteristics of horizontal and vertical polarization over land.

Observations on transmission from the top of the RCA Building with a frequency of 25.7 megacycles indicate that the signal beyond the horizon falls off about as the 3.2 power of the distance.

Airplane observations on a frequency of 411 megacycles reported by Trevor and George[9] indicate that the signals fall off approximately as the 9th power of the distance beyond the horizon.

Figure 4 shows the observed rates of attenuation beyond the horizon plotted against frequency. The factors determined for the four frequencies fall on a smooth curve, but the data are too few to warrant much confidence being put in this curve. The curve does indicate, however, that the attenuation beyond the horizon increases rapidly for the higher frequencies. Perhaps the attenuation law changes for

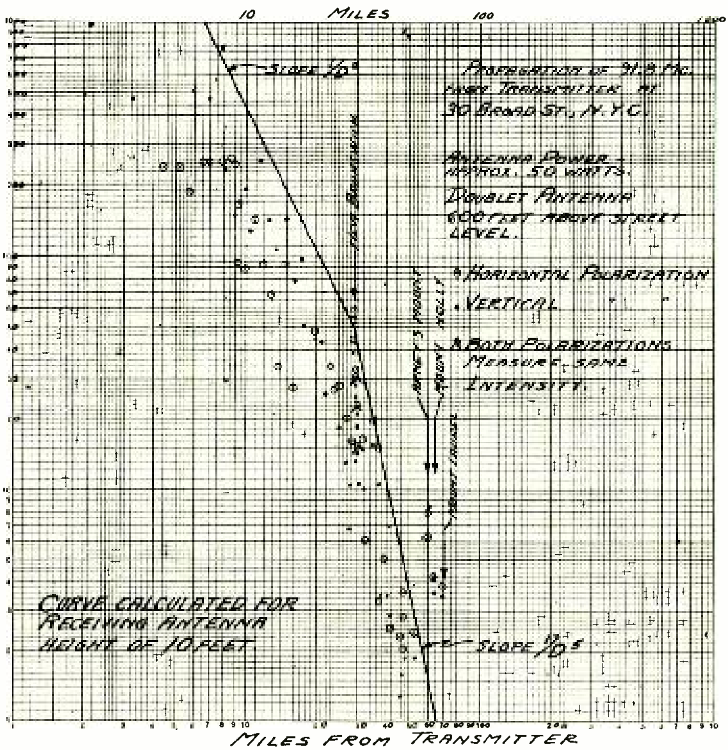


Fig. 3

increasing distance beyond the horizon, but there are insufficient data to indicate whether this is so or not. When higher powered transmitters become available, the attenuation laws beyond the horizon can be determined more accurately.

Sky Wave Propagation

As the frequency is increased, a point is eventually reached where the sky wave is not bent sufficiently to come back to earth. This is an advantage for certain services, such as television, as there is essentially only one path and multiple images are absent. It is also possible to duplicate the frequencies at moderate distances without fear of interference. The lowest frequency that will just fail to have the sky wave returned to earth depends upon several factors. In general, the higher frequencies are returned to earth in the early afternoon. Contrary to what one might expect, there is some evidence that the high frequency sky waves are transmitted better in winter than in summer, particularly over the north Atlantic path[10]. The transmission also is apparently associated with the 11-year sunspot cycle. For example, the high frequency sky waves were getting through quite frequently during 1927 and 1928 when extensive observations on frequencies above 30 megacycles were first made. Subsequent to 1928, high frequency sky wave transmission was relatively poor until the

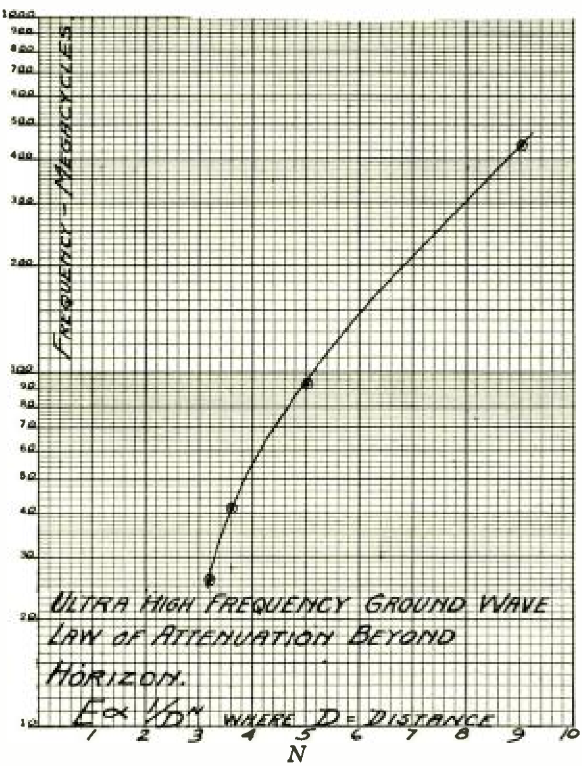


Fig. 4

spring of 1935. Accordingly, there is relatively little information available concerning the transmission of very high frequency sky waves. The long distance transmission on these frequencies is very irregular, which adds to the difficulty of obtaining consistent data. As the frequency is raised, the sky wave transmission becomes more and more erratic. Above about 45 megacycles, the sky wave transmission appears to rarely occur, and when it does occur, it tends to appear as a "burst." That is, the signal comes up very suddenly, remains fairly strong for a few seconds or even minutes, and suddenly disappears, perhaps not to be heard again over that particular path for months. This "burst" phenomenon was apparently first observed by W. I. Matthews on 50 megacycles over a distance of about 240 miles.[5]

In May and June, 1935, amateurs reported hearing 5-meter signals over distances of 900 miles. Amateurs in the vicinity of Chicago heard several New England amateurs working in the 50-60 megacycle band, and at least one two-way contact was established.[11] A similar effect was reported for May 9, 1936.[12] On this occasion, several two-way contacts were made between East Coast and Middle West amateurs. Many signals were heard over a period of some three hours, beginning at approximately 8:30 P.M. Several of the amateurs reported severe selective fading, with part of the signal dropping out and the rest remaining.

It seems probable that the transmissions on these occasions were due to sky waves and not refraction. Probably the suggestion that the signals were bent down by "unusually heavy sporadic *E*-region ionization" is the correct explanation.

From the available information, it would seem that little sky wave transmission takes place above about 45 megacycles, and that such transmissions that do occur above 45 megacycles are produced by unusual ionization conditions which probably will rarely occur. Amateur operators spread over a wide area are in an excellent position to observe these sporadic transmissions and their observations should be extremely valuable for indicating the location, duration and frequency of occurrence of these sky wave transmissions, as well as diurnal and seasonal effects.

Conclusion

There are apparently four mechanisms which may be involved in ultra short wave propagation. These are (1) combination of the direct ray and the ray reflected from the ground; (2) diffraction at the earth's surface; (3) refraction in the troposphere; (4) sky wave transmission.

The first mechanism is the principal effect within the optical path. It shows that the signals are attenuated according to the inverse square law of the distance for grazing incidence within the optical range. The signal intensity can be calculated by simple equations, although scattering and absorption, even in open country, tend to reduce the average intensity to something in the order of 30 to 60 per cent of the calculated value. In urban areas, the scattering and absorption due to buildings, increases the attenuation considerably, particularly at the higher frequencies. The amount of this increase in attenuation on the higher frequencies probably depends to a great extent on the height of the transmitting antenna in relation to the obstructing objects in its vicinity. More data are required before the relative performance of various frequencies in urban areas can properly be evaluated and compared.

The diffraction factor becomes important beyond the horizon. The diffraction field can be calculated by the methods indicated by Handel and Pfister[6]. In addition to the diffraction field, which is believed to be constant and stable, the refraction field is important beyond the horizon. The refraction field is variable and produces fading. There is insufficient information available to calculate the refraction field.

In general, it is definitely known that the attenuation beyond the horizon increases rapidly as the frequency is increased. The slope of the attenuation curve that fits the available observations best is indicated in Figure 4. An approximation of the attenuation for a given circuit may be calculated by using equation (2) up to the horizon and plotting the calculated points on log-log paper. These points will lie on a straight line having a slope of $1/D^2$. At the horizon, another straight line having a slope determined from Figure 4 should be drawn. This line will indicate the order for the attenuation beyond the horizon for a particular frequency. In general, the signal intensity determined in the above manner should represent the maximum, excepting for unusual conditions such as locating the receiver on a mountain top, abnormal refraction fields, sky wave transmission, etc. The available data are based on overland transmission, for which case there seems to be little difference between vertical and horizontal polarization. Over sea water, vertical polarization is superior to horizontal polarization, at least for moderate distances with relatively low antennas.[1]

The optical distance for flat ground is easily calculated from the equation:

$$\text{Distance in miles} = 1.22 \sqrt{\text{Height in feet}}$$

If the receiving antenna is also at a high elevation, the same equation may be applied to determine the horizon for the receiving antenna, and this added to the horizon for the transmitting antenna gives the total optical path for that particular set of conditions.

Too little is known about sky wave transmission on the ultra high frequencies. From available information to date, it would seem that sky wave transmission above about 45 megacycles is too spasmodic to give much concern. However, it is possible that more frequent sky wave transmission may be observed at some more favorable phase of the sun spot cycle.

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FREQUENCY ASSIGNMENTS FOR TELEVISION

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***Foreword**—This article is not a report of original work, but is a correlation or synthesis of information pertinent to the subject, available to the authors within the RCA Services or through published papers. Since the results of all have been taken into account it has not seemed feasible or desirable to give credit to individual sources except to mention the article by H. H. Beverage entitled "Some Notes on Ultra Short Wave Propagation" appearing in this number of* RCA REVIEW, *and the bibliography forming a part of that article. Much credit is due collectively to the many workers in this field, who have made possible the drawing with reasonable certainty of the conclusions here stated. The basic plan of any new service must always be determined by the work of such pioneers, before commercial experience has made everything plain. Because fundamental plans for broadcast television are now in the making, it is hoped that this brief article will be found both timely and interesting.*

INTRODUCTION

IN TELEVISION we are concerned with a broadcast type of service in which adequate coverage of a service area is the prime consideration. The frequency of the radio carrier must be high enough to permit the relatively wide side bands which are required, and so high that reflections from the ionosphere will not regularly occur. The second requirement is necessary to prevent multiple images caused by reflections from the ionosphere, and to permit duplication of frequency assignments with reasonable geographical separation of stations on the same channel. Further, in television we are concerned with a service requiring high signal strength at the receiver locations. Thus the radio carrier must be sufficiently low in frequency to permit generation of adequate power. The carrier frequency must be low enough so that the attenuation caused by obstacles on or near the transmission path is not too great, and so that the shadows cast by obstacles are not too sharp or too dense. All these considerations point to frequencies above 40 megacycles, and not greatly above 40 megacycles, as necessary if television is to be practicable in the near future.

A more specific discussion follows. It is very difficult to make positive statements because our knowledge of the many relevant factors is still so incomplete. Much information has been obtained and correlated, but this is only a small sample of what will be required for a complete and specific analysis. It is believed, however, that this sample is reasonably representative, and therefore that general conclusions convincingly deduced from it are reliable. The following analysis is therefore confidently believed to be correct in its general and major implications, although time may indicate some error in detail.

Propagation Within the Horizon With Respect to the Transmitter Antenna

The theory of direct transmission over a flat earth, taking into account reflection from the earth, indicates that under certain conditions the field intensity is inversely proportional to the square of the distance, is directly proportional to the heights of the transmitting and receiving antennas, and is proportional to the frequency. For these relationships to be theoretically valid, the reflection from the ground must be at grazing incidence, that is, such that the conductivity and dielectric constant of the ground are not significant factors. The angles of incidence which may be called "grazing" in this sense—depend on the frequency. Thus, in any case, the validity of these simple propagation relationships depends on the geometry of the antennas and earth, on the constants of the reflecting earth, and on the frequency. Measurements, made for the most part under conditions such that these relationships were not strictly applicable, have nevertheless indicated that they are approximately correct for these practical cases, although scattering and absorption, even in open country, tend to reduce the average field intensity to somewhat less than would be calculated from the theory.

In urban areas the scattering and absorption due to buildings results in additional attenuation and this additional attenuation is the predominant factor, as far as propagation effects are concerned, in comparing the suitability of different frequencies for a local broadcast service. It increases rapidly as the frequency is increased, so that, for one set-up investigated, the average field intensity at 30 megacycles measured at a distance of 5 miles was 4.5 times that obtained at 100 megacycles for the same antenna power. The transmitter antenna was relatively low over a flat urban area, but was not overshadowed by higher structures, so that this case was typical for a broadcast service. A higher transmitter antenna might be thought more favorable to the higher frequencies, but the high antenna would only remove the region of high attenuation of the higher frequencies to a greater distance.

A factor likely to be overlooked is that the effective heights of simple and practical receiving antennas tend to be proportional to the wavelength, i. e., inversely proportional to frequency. Thus, to obtain a given voltage at the receiver input, the necessary field strength is proportional to frequency. When this is taken into account, the transmitter power needed is at best the same for higher frequencies, and on the average, for broadcast coverage, higher frequencies will require higher powers because of greater attenuation in transmission over urban areas. In the specific investigation already cited, it was indicated that several hundred times greater power would be required at 100 megacycles compared with 30 megacycles.

This tendency to lower effective height of antennas for the higher frequencies may be partially overcome by using arrays which may occupy no more space than a simple antenna for a lower frequency. However, the gain due to the directional characteristics of an array is never as great as its increased physical expanse, so the offsetting effect is only partial. Furthermore, the selectivity of an array increases with its gain, so that the use of extended arrays is not likely to be practicable for television reception. A further objection to a very selective receiving antenna is that such an antenna could not be used for efficient pickup of signals over a band of television channels.

For broadcast service in urban areas the signal path to the receivers becomes complicated. Shadows are cast by obstacles and signal reflections occur. It has been shown that shadows become sharper and more defined as frequency increases. Thus, complete coverage becomes more difficult with increasing frequency, and a more nearly optical path is required.

Reflections cause the signal for any particular receiver in a service area to arrive over a variety of paths of differing lengths and therefore the corresponding times of arrival will be different. It has been shown that the effect of this on the reproduced image is determined by the multiple path structure and the range of video frequencies (width of side bands) and is independent of the frequency of the radio carrier.

Propagation Beyond the Horizon With Respect to the Transmitter Antenna

Comparatively few data are available for determining the laws of propagation beyond the horizon. It is well known that frequencies above 40 mc. fade at points beyond the horizon and that this fading increases as the distance increases. At and beyond the horizon the signal intensity falls off faster than the inverse square of the distance. Such limited data as are available indicate that this increase in rate of attenuation with distance also increases with frequency from approximately a 3.6 power at 40 megacycles to approximately a 5 power at 100 megacycles and to approximately an 8 power at 300 megacycles.

In television it is important that there be no sky wave propagation primarily because this would produce multiple images and secondarily because this would affect duplication of frequency assignments at reasonable distances. American amateurs and others have, on a number of occasions, established communication over long distances by frequencies up to 60 megacycles, apparently as a result of sky wave propagation caused by some sporadic condition in the ionosphere. Because of practical difficulties, quantitative measurements of such propagation have not been made. Since there have been no widespread transmissions at frequencies above 60 megacycles, there has been no opportunity to determine whether such sky wave propagation occurs at these higher frequencies or not. However, it is our opinion, based on such experience as is available, that as the frequency is increased, there is a gradual transition from normal sky wave propagation at about 20 megacycles to a condition of no sky wave propagation at any time at some frequency above 60 megacycles, and that between these limits the time of sky wave propagation becomes less and less and more and more sporadic as the frequency is increased. It is further believed reasonable to assume that sky wave transmission will not occur at frequencies above 40 to 45 megacycles in any but very sporadic instances and that these need not cause concern in the establishment of a television service.

Required Signal Levels

For frequencies above 40 megacycles natural static is not of practical importance. Man-made interference is, however, very serious in urban districts. The major sources of such interference are ignition systems and apparatus for diathermy. In quiet suburban or rural districts, noise generated in the receiver may determine the minimum useful signal. The signal to noise ratio required for satisfactory visual reception has not been very definitely established by experience, but for noise not synchronous in any way with the picture system and not too continuous in character, it is certainly less than is required for sound broadcasting.

It has been found experimently, using frequencies of 40 to 50 megacycles, that a signal of 1 millivolt is required at the receiver input to produce an image satisfactorily free from noise generated in the receiver input circuits. A signal strength of 5 millivolts is required to overcome ignition interference and to produce a satisfactory image in an average residential location. Proportionally higher signal levels are required as the noise interference increases, particularly in areas near disturbing sources, and in congested urban districts. Locating the television broadcasting station in the center of the area to be served is a favorable condition in consideration of noise interference.

Corresponding figures for higher carrier frequencies are not available, because no actual television experience has been had with such frequencies. Effective noise field strengths are somewhat less at higher frequencies, but little quantitative information is available with respect to this. Under assumptions as favorable to the use of higher frequencies as could be made, this could only mean that receiver noise would be the limiting factor, and this would still necessitate an input of over 1 millivolt.

Few experimental data are available as to the magnitude of the interference from another television station on the same frequency channel which can be tolerated in television reception. Assuming that the two carriers are sufficiently spaced to prevent audible beats in the sound channel, say 30 kilocycles, the tolerable signal to interference ratio will be determined by visual conditions, especially image contrast. Such measurements as have been made are not directly useful, since a system having a high inherent noise level was used, but they do indicate, on a conservative basis, that it will be reasonable to assume a carrier signal intensity ratio of about 100 to 1 for allocation purposes.

General Considerations

Signal is propagated out to the horizon for broadcast service in a manner such that for the areas of most interest, the attenuation will increase with increasing frequency. At and beyond the horizon the attenuation rises sharply for all frequencies and more sharply with increasing frequency. Thus the practical limit of service area is the horizon. Power increases will be useful to the point of providing the desired signal at the horizon (and naturally at locations of high noise interference within the horizon). For a given frequency the power required to produce a given signal input to a receiver at the horizon with respect to the transmitter antenna is approximately constant for all transmitter antenna heights assuming flat unobstructed ground.

A desired condition is a radiation pattern circular in the horizontal plane (or of proper directivity characteristics for the transmitter location and service area). Since sky wave transmission is not desired and is not present it is important to concentrate the energy into low angles in the vertical plane so as to obtain a power gain in transmission. This may be done for either vertical or horizontal polarization, but present known simple structures are most effective for horizontal polarization. For broadcast service, in terms of signal intensity, there appears to be no advantage in one polarization over the other (excluding transmission over sea water). The matter of signal reflections in and around building has not been fully investigated, but again there appears to be no advantage in one over the other. In considering noise interference, complete data are lacking, but some experience has indicated a slightly lower noise level for horizontal polarization.

Apparatus Considerations

Present vacuum tube and transmitter circuits place limits on the power levels obtainable for television transmission. The conditions of band width and high signal intensity are severe. Greater powers call for larger dissipating surfaces in the output tubes—affecting dimensions already too large for best efficiency even at 40 megacycles. As the frequency increases smaller dimensions are necessary resulting in lower powers, whereas propagation conditions call for greater powers to produce the same signal intensity. For the present experimental television band of 42 to 86 megacycles, higher powers may be obtained over the lower portion of the band and lower powers over the upper portion. The present specific power limitations will be modified as the technique advances. However, the time when power in tens of kilowatts at frequencies over 100 megacycles will be practicable appears a long way off. Coupled with this is the uncertain practicability of a broadcast service of the present basic type above 100 megacycles in view of the higher attenuation in urban territory which may indicate impracticably high output powers. These higher frequencies appear more suited to point-to-point service than to broadcast service in urban areas.

Conclusions

From the foregoing it is concluded that the television band should start at a frequency between 40 and 45 megacycles. A frequency of 42 megacycles was recommended by Radio Manufacturers' Association as the lower limit, and is satisfactory from considerations of lack of sky wave, modulation with video frequency band, and propagation characteristics. The upper frequency limit is determined by the number of six megacycle channels required. A proposal of 42 to 90 megacycles has been made. This is satisfactory with respect to propagation, apparatus, and distribution of channels at reasonable distances.

BEHIND THE SCENES AT TWO NOTABLE BROADCASTS

NOV. 8, 1936—GEORGE MCELRATH
Operating Engineer
NOV. 11, 1936—G. O. MILNE
Eastern Division Engineer

TWO of the most interesting special events programs in the history of radio were broadcast on November 8th and 11th as features of NBC's Tenth Anniversary celebration week. Nearly every technical development introduced since broadcasting started in 1922 was utilized.

The November 8th program included pick-ups from two streamline trains in motion on different continents, from a submarine, Pikes Peak, a modern tunnel, a Coast Guard ship, Police radio, a six-day bicycle race, the Golden Gate Bridge and a squadron of Navy planes flying over San Diego. The November 11th program demonstrated the feasibility of communication between two airplanes in flight and individuals on the ground, connected by transoceanic radio facilities. These two programs demonstrated the usefulness of radio over short and long distances and furnished a splendid example of the complete coordination of facilities at widely separated points.

NOVEMBER 8TH PROGRAM—3:15-4:00 P.M., E.S.T.

Equipment was tested time and again during the three weeks preceding the program and when the broadcast started at 3:15 P.M. the engineers were sure that every technical item was functioning properly and everything was in order to present a perfectly timed program to the radio audience. Printed herein is a "Cue and Timing Sheet" showing the program location, duration of time on the air, the scheduled time to turn control over to the following point and the all important "cues" by which the technical facilities were rearranged to feed that portion of the program to all stations on the network. These instructions also served to give announcers complete details on the next portion of the program; to start the program instantly or to await a given number of seconds to permit the switching of program circuits. This Cue Sheet is presented for the purpose of giving the reader a backstage view of a program tool used by broadcast personnel:

David Sarnoff (seated) participating in the four-way broadcast. William Burke Miller (standing) in charge of program arrangements.

PICKUP	TIME ON AIR	TIME TO TURN OVER TO NEXT POINT
1) **New York Studios.**	**4 Min.**	**3:19:00**

Cue by New York Studio Announcer to turn over to Cleveland will be: "TAKE IT AWAY CLEVELAND." Switching on this turnover will be instantaneous.

2) **Cleveland Police Short Wave.**	**3 Min. 30 Sec.**	**3:22:30**

Cue from Cleveland Announcer to turn over to Navy Submarine will be: "NOW UNDER THE SEA TO THE NAVY SUBMARINE S-20."

3) **U. S. Navy Submarine S-20.**	**4 Min.**	**3:26:30**

Cue from Announcer aboard U. S. Navy Submarine S-20 to turn over to Pikes Peak will be: "FROM THE BOTTOM OF THE SEA TO THE TOP OF PIKES PEAK." Switching from the U. S. Navy Submarine to Pikes Peak will be on a 15-second basis. Announcer at Pikes Peak will GO AHEAD 15 seconds after cue is given.

Pickup	Time on Air	Time to Turn Over to Next Point
4) **Pikes Peak.**	**2 Min. 55 Sec.**	**See Note**

Denver Announcer on Pikes Peak will conclude with the following: "OUR SPECIAL TENTH ANNIVERSARY PROGRAM WILL CONTINUE IN JUST A MOMENT. THIS IS THE BLUE NETWORK OF THE NATIONAL BROADCASTING COMPANY." Denver Announcer on Pikes Peak should end exactly at 3:29:35 and Announcer in studios will ring chimes at exactly 3:29:40.

5) **Boston Streamline Train and Berlin Streamliner.**	**4 Min.**	**3:34:00**

Announcers on Boston-Providence Streamline Train will GO AHEAD at exactly 3:30—facilities will be all set up so that at exactly 3:30 Boston Announcers will start two-way conversation with German Announcers speaking in English aboard Berlin train. Boston Announcers will start with phrase: "CONTINUING WITH NBC'S TENTH ANNIVERSARY SPECIAL EVENTS PROGRAM WE ARE NOW SPEAKING TO YOU ABOARD THE NEW HAVEN RAILROAD STREAMLINE TRAIN 'THE COMET'." "HELLO GERMANY." Then continue with remarks. Cue from Boston Announcer aboard "The Comet" to turn over to Pittsburgh will be: "WE TAKE YOU NOW TO OUR ANNOUNCERS STATIONED DEEP DOWN IN A COAL MINE IN PITTSBURGH." Switching on this turnover will be on a 5-second basis.

6) **Pittsburgh Coal Mine.**	**3 Min.**	**3:37:00**

Pittsburgh Announcer in mine will GO AHEAD 5 seconds after cue is given. Cue from Pittsburgh Announcer to turn over to NBC mobile unit on Fifth Avenue will be: "WE NOW CONTINUE FROM NBC'S STREAMLINE MOBILE UNIT WHICH IS SPEEDING UP FIFTH AVENUE, NEW YORK." Switching on this turnover will be on a 5-second basis.

7) **NBC Mobile Unit on Fifth Avenue.**	**3 Min.**	**3:40:00**

Announcer on NBC mobile unit will GO AHEAD 5 seconds after cue is given by Pittsburgh Announcer. Cue from New York Announcer aboard NBC mobile unit to turn over to bike races in Chicago will be: "NOW TO THE SIX-DAY BICYCLE RACES IN CHICAGO." Switching on this turnover will be instantaneous.

8) **Six-Day Bike Races in Chicago.**	**3 Min.**	**3:43:00**

Chicago Announcer at bike races will give following cue to turn over to U. S. Army tanks: "FROM CHICAGO WE JUMP TO THE NATION'S CAPITAL WHERE NBC ANNOUNCERS ARE SPEEDING ABOARD THE LATEST U. S. ARMY TANKS." Switching on this turnover will be instantaneous.

PICKUP	TIME ON AIR	TIME TO TURN OVER TO NEXT POINT
9) **Army Tanks Outside Washington.**	**4 Min.**	**3:47:00**

Washington Announcer speaking from U. S. Army tanks will give the following cue to turn over to Coast Guard: "OUR TENTH ANNIVERSARY SPECIAL EVENTS PROGRAM CONTINUES FROM A COAST GUARD CUTTER IN LONG ISLAND SOUND." Switching on this turnover will be instantaneous.

10) **U. S. Coast Guard Cutter.**	**3 Min.**	**3:50:00**

Announcer aboard Coast Guard Cutter will give the following cue to turn over to the New York Mid-Town Tunnel: "FROM LONG ISLAND SOUND WE HOP TO THE NEW YORK MID-TOWN TUNNEL." Switching on this turnover will be instantaneous.

11) **New York Mid-Town Tunnel.**	**3 Min.**	**3:53:00**

Announcer in New York Mid-Town Tunnel will turn over to San Francisco with cue: "WE CONTINUE FROM SAN FRANCISCO." Switching on this turnover will be on a 15-second basis.

12) **Golden Gate Bridge.**	**3 Min.**	**3:56:00**

San Francisco Announcer on Golden Gate Bridge will GO AHEAD 15 seconds after turnover cue has been given. San Francisco Announcer will give following cue to turn over to U. S. Navy planes flying over San Diego: "TO CONCLUDE OUR SPECIAL PROGRAM WE TAKE YOU NOW TO A SQUADRON OF NAVY PLANES FLYING OVER SAN DIEGO." Switching on this turnover will be instantaneous.

13) **U. S. Navy Planes Over San Diego.**	**3 Min.**	**Sign Off**

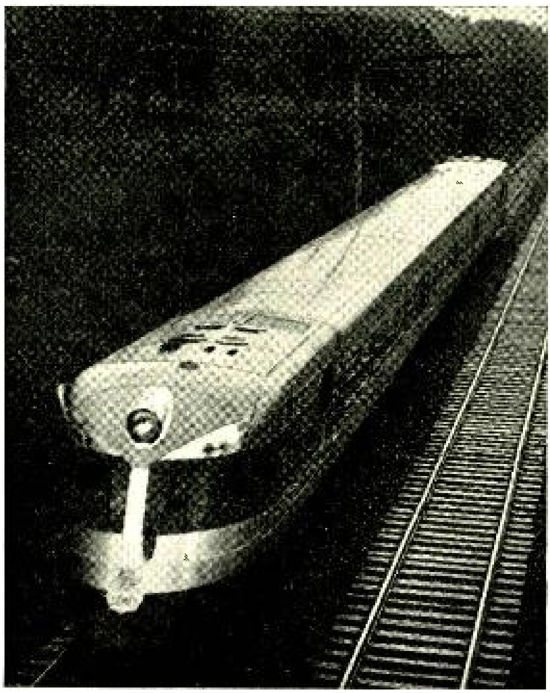
San Diego Announcers will sign off the program at exactly 3:59:35 with the cue: "THIS IS THE BLUE NETWORK OF THE NATIONAL BROADCASTING COMPANY." Announcer in San Francisco studios will ring chimes at exactly 3:59:40.

Standby announcers will be located in the studios at the following places:

Radio City Studios	NewYork
WTAM Studios	Cleveland
KOA Studios	Denver
WBZ-WBZA Studios . . .	Boston
KDKA Studios	Pittsburgh
Chicago Studios	NBC Chicago
Washington Studios . . .	NBC Washington
San Francisco Studios . .	NBC San Francisco
Hollywood Studios . . .	NBC Hollywood

In case any pick-up on the program fails to come through, the announcer who is standing-by in his studios for that particular point will give the cue to turn over to the next point. All points on the program should be standing-by throughout the program.

These broadcasts were planned through to completion by the engineer in charge of technical operations and a member of the Program



The streamline "Comet" between Boston and Providence in two-way conversation with the "Flying Hamburger," D-12, Germany.

Department in accordance with the procedure which is briefly described in the following outline:

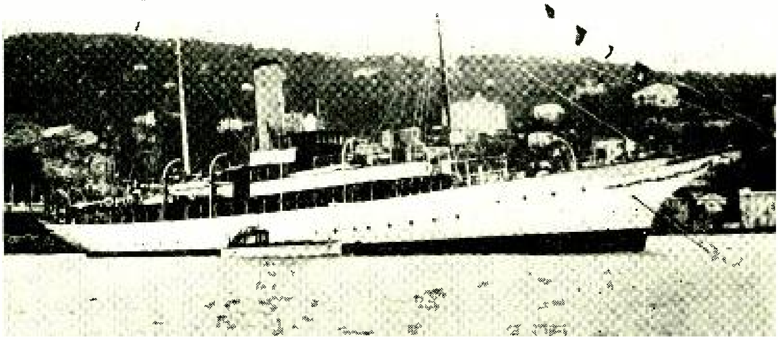
The director of the program first approached various organizations to ascertain if they could participate in the broadcasts. Before that inquiry was made, however, the idea was discussed with the Engineering Department to determine the availability of apparatus and if it would be practical to connect the program to the network of stations. The Operating Engineer then contacted the engineers in charge of each NBC office, advising them of the program requirements and requesting each one to complete tests to insure the success of the program. In due time affirmative reports from all points had been received and technical arrangements were complete. A final check was made prior to the broadcast confirming all technical arrangements.

This program opened at 3:15 P.M. with an orchestral program in Radio City studios and was sent over the network to the associated stations in the conventional manner. At 3:19 P.M. the announcer in the New York studio gave the cue to switch to Cleveland.

Arrangements had been made with the Cleveland Police Department for technical tests using their short-wave equipment between headquarters and a cruising car in the city equipped for two-way conversation. A contact was established between the Cleveland and Massillon Police Radio Stations demonstrating effective communication facilities with highway-patrol law-enforcement agencies in and between nearby cities. Three wire-lines were installed between the Cleveland control room and police headquarters. One was a private-line communication circuit and one was a feed-back or cue circuit connected to the network. The announcer at police headquarters received the cue to start his program over the latter circuit. In this case, the cue originated with the announcer in the New York studio who signed off the preceding portion of the program. The remaining circuit was the program line. The conversations between police and the announcer at headquarters were mixed together in the police apparatus and an audio tap was furnished which was fed to the control room in Cleveland over the program circuit. When the announcer in the New York studios gave the cue the network circuit was opened in the Cleveland control room and the program from police headquarters was sent to all broadcast stations. At 3:22:30 P.M. the announcer in Cleveland gave the cue transferring the control to the U. S. Submarine S-20.

In New York two radio channels had been established between the top of the RCA Building and the submarine. A 100-watt, ultra-high-frequency transmitter sent program information and cues to the submarine. A 25-watt UHF transmitter aboard the submarine supplied a program channel to the RCA Building. Wire lines from the Radio City Control Room to the top of the building connected the cue transmitter to the network carrying the program. One of these circuits, connected to a receiver, extended the radio channel from the submarine to the network. At 3:26:30 P.M. when the proper cue was given the network facilities were opened at Radio City and the program from the submarine was connected to the network. This same 100-watt UHF transmitter also furnished cues to the mobile unit on Fifth Avenue. It was necessary for the announcer and engineering personnel to board the submarine in Brooklyn Navy Yard at 9:00 A.M. in order to place the submarine in position for the broadcast and complete final radio tests.

Fifteen seconds intervened between the end of the submarine pro-



Senatore Marconi's yacht "Elettra" with which communication was established near Genoa.

gram and the start of the program from Pikes Peak. This time was required to reverse line repeaters between Denver and Chicago so that the program could be connected to stations east of Denver. Messrs. Peregrine and Rorher, with two experienced mountain climbers left Colorado Springs at 11:00 A.M. Saturday, November 7 and plodded through four feet of snow to erect a UHF 1-watt transmitter on Pikes Peak for the program channel. A 25-watt UHF transmitter was installed at Colorado Springs as a cue channel. Receivers at both locations completed the two-way communication circuit. One might ask why the higher powered transmitter was not used as a program channel. Storm conditions and snow drifts near the Peak prevented cars from reaching the top, and the weight of the 25-watt transmitter was too great to be carried through snow drifts by the engineers. Two wire-lines connected Colorado Springs and the Denver control room; one carried the network program and the other was connected to the receiver at Colorado Springs, thus a program link from the Peak to the network was made. Fifteen seconds after the announcer on Pikes Peak received a cue from the submarine he started the program which was sent to associated stations east and west of Denver. At the end of this portion of the broadcast another 15-second interval was required to re-establish the line repeaters between Denver and Chicago on a normal basis, thus providing stations west of Chicago with the program service to follow. This was not noticed by the radio audience as the reversal was made during the 20-second interval at 3:30 P.M. while associated stations were making their local station announcements in accordance with the Federal Communications Commission regulations.

The most complicated technical portion of the program followed: a two-way conversation between two streamline trains in motion—The New York, New Haven and Hartford "Comet" in the U. S. and the "Flying Hamburger" D-12 in Germany. The "Comet" was traveling between Boston and Providence and the "Flying Hamburger" between Berlin and Hamburg. An R.C.A. Communications transoceanic short-wave channel from Rocky Point, L. I., to Reichs Post Berlin, Germany provided one side of the two-way radio link between continents. Another short-wave channel from Reichs Post to Riverhead provided the other side of the two-way communication circuit. Two wire-line circuits from Berlin to a point near the speeding "Flying Hamburger" and two radio links from this point to the "Flying Hamburger" completed the facilities on the European Continent.

The radio channel from Reichs Post to the receiving station at Riverhead was extended directly to WBZ, NBC Boston outlet, via the control room in Radio City. Existing wire lines from WBZ's control room to the WBZ and WIXK transmitters completed this channel. Receivers installed on the "Comet" tuned to either of the above stations permitted those on board to hear the conversation from the "Flying Hamburger" in Germany. A 25-watt UHF transmitter on the "Comet" sent a signal to four receivers along the 15-mile right-of-way between Boston and Providence. These receivers were connected to a wire line to the Rocky Point transmitter via the control room in Radio City and this completed the channel from the "Comet" to the "Flying Hamburger." Thus the two-way channel was established between the two speeding trains on different Continents through radio and wire facilities.

Both sides of the conversation were mixed in the NBC New York control room and connected to the network at that point. German broadcasters were so intrigued by this program that they requested us to repeat the two-way conversation in German especially for German listeners. This performance took place as the United States listeners were hearing the Pittsburgh portion of the NBC program.

At this point after the cue by the Boston announcer aboard the "Comet" the program was transferred to the Carnegie Institute Model

Senatore Guglielmo Marconi aboard his yacht "Elettra."

Coal Mine in Pittsburgh, Pennsylvania. The engineering staff at KDKA had installed radio transmitters and receivers in the mine which were connected to the network via their control room over local telephone facilities as described in similar cases above. After a description from the mine and interviews with miners, the Pittsburgh announcer turned over to the NBC mobile unit cruising along Fifth Avenue in New York City. A 25-watt UHF transmitter and receiver on the mobile unit was connected to the network through the receiving station and the 100-watt UHF cue transmitter on the RCA Building in the same manner as the submarine broadcast outlined above.

Next the program was transferred to the Chicago Stadium, Chicago. The program originated from a .2-watt microwave pack transmitter strapped to "Torchy" Peden's back. He was a participant in the six-day bicycle race. A low powered UHF cue transmitter at the track side and receiver strapped to the bicycle completed the local two-way radio circuit inside the stadium. These facilities were attached to local wire lines and connected to the network through the NBC control room in Merchandise Mart, Chicago.

From Chicago to Washington the U. S. Army gave the radio audience a spectacular show. Signals from Army equipment in the new reconnaissance cars maneuvering in Potomac Park and traveling at high speed along roads entering the District of Columbia were intercepted by NBC engineers and relayed to the network through the control room in the National Press Building.

At this point the broadcast hopped immediately to a U. S. Coast Guard Cutter. Engineers and the announcer, with equipment, reported aboard the U. S. Coast Guard Ship "Ponchartrain" in New London Harbor at 9:00 A.M., and the ship proceeded on a routine control cruise. A 50-watt intermediate frequency radio transmitter aboard the vessel transmitted the program to the NBC control room in the RCA Building through the R.C.A. Communications Receiving Station at Riverhead, L. I. The program was transmitted via an RCA Rocky Point transmitter and it was from this source that the announcer aboard the ship received his cue to start his portion of the broadcast. The Coast Guard contribution to the program was connected to the network through the Radio City control room. The broadcast now shifted to the New York Midtown Tunnel. A low-powered UHF transmitter attached to the mid-town tunnel end of a feedback circuit from Radio City carried the switching cue from the Coast Guard "Pontchartrain" to the announcer inside the tunnel. He spoke into a microphone imbedded in the front of a box 6x8x12 inches that housed a microwave transmitter which radiated the program signal to a receiver at the mouth of the tunnel connected to a program circuit to Radio City and then to the network. Fifteen seconds elapsed between the closing cue from the mid-town tunnel and the start of the program from Golden Gate Bridge, San Francisco. During this interval repeaters on the transcontinental circuit were reversed so the program could be broadcast over stations east of Salt Lake City. A UHF 1-watt pack transmitter was installed on top of Golden Gate Bridge and the announcer's description was broadcast to a receiver located in the

U. S. Navy Receiving Ship Observation Tower on Yerba Buena Island in San Francisco Bay. The program signal was then sent to the San Francisco control room over a wire line where the network connection was made. KGO, San Francisco, carrying the network program, provided the announcer on the bridge with a starting cue from the New York mid-town tunnel.

Next the program was switched to a fleet of new U. S. Navy planes flying over San Diego, California. The technical equipment on the

Robert Jardillier, French Minister of Communications, in four-way conversation from airplane.

ground was supplied by station KFSD, and in the air by the Navy. The cue from Golden Gate Bridge was transmitted over regular network facilities and over the cue transmitter on the ground in San Diego to the Commander of the planes in the air. His ship was equipped with transmitting and receiving apparatus and his voice was transmitted to a receiver on the ground which was mixed with the announcer's voice and sent to the network through KFSD's control room. A two-way conversation could be carried on by the KFSD announcer and the Navy flier by mixing the audio and radio channels at the field program originating location.

The program ended with a roar of motors from the sky, picked up by sound-effect parabola microphones on the ground, and the San Diego announcer gave his cue for the NBC San Francisco office to ring chimes, placing the network facilities in readiness for the program to follow and thus ended one of the most intricate special events programs ever presented by NBC.

NOVEMBER 11TH, PROGRAM 2:15-2:45 P.M., E.S.T.

Another special broadcast, notable from the standpoint of world coverage, occurred at 2:15 P.M. on November eleventh. At this time visiting radio executives, enroute by air in two planes, from Buffalo to Washington, carried on an exchange of greetings with Mr. David Sarnoff, President of the Radio Corporation of America, in his office in the RCA Building in New York City, and Senatore Marconi, on his yacht "Elettra" near Genoa, Italy. Robert Jardillier, French Minister of Communications, and Maurice Rambert, president of the International Broadcasting Union, were the principal speakers from the air. Dan Russell was the announcer in the air who also acted as master of ceremonies for the broadcast. The program was carried by the NBC Red Network in the United States and was also relayed by NBC and RCAC short-wave transmitters to Europe where it was re-broadcast over regular broadcast stations in Germany, Denmark, Austria, France, Italy, Switzerland, and Czechoslovakia. Radio representatives of all these countries were aboard the two planes and after the broadcast had been completed, several of them spoke in their native language to people in their home countries.

The program, starting at 2:15 P.M. was opened by six minutes of an international medley played by an orchestra in the NBC Radio City Studios. This was followed by a five-minute description of the occasion by Dan Russell from American Airways plane No. NC16005. At the end of this description, Mr. Sarnoff called the plane and spoke to Mr. Rambert who was aboard. A two-way conversation followed at the end of which Mr. Sarnoff called in Senatore Marconi. The next development was a three-way talk between Messrs. Sarnoff, Marconi and Rambert. Then Mr. Sarnoff called in Mr. Jardillier who was aboard the American Airways plane No. 16030. The peak of the program was reached by the four-way contact then held between the gentlemen in the two planes, Mr. Sarnoff in his office and Senatore Marconi on his yacht. At the conclusion, an orchestra in the studios completed the balance of the thirty-minute broadcast.

Technically, it might appear that such a broadcast would not be difficult, particularly with the facilities and equipment which are available today. However, the numerous circuit connections involved and the many radio links necessary, coupled with the unusual number of unforeseen complications that developed, made this an outstanding technical broadcast that could not possibly have been arranged ten years ago.

The transmitters used on the planes were two standard sets, WIEO operated on 2102 kilocycles, fifty watts 100 per cent modulated on

Jack Hartley and Dan Russell (announcer) aboard one of the airplanes in the four-way contact broadcast.

plane NC16005, and WIEW, twenty-five watts, 2758 kilocycles on NC-16030. These transmitters are crystal controlled and operate from twelve-volt storage batteries through dynamotors supplying the required plate voltages. Messrs. Sturgell and Peck, field engineers, operated WIEO with Messrs. Wies and Whittemore at WIEW. These men are field engineers assigned to the special events technical group. Two receivers were placed on the roof of the RCA Building to intercept the signals from the planes. These receivers and associated amplifiers were manned by two more men from this special group, Mr. Wilbur and Mr. Campbell. The output of each receiver and its amplifier was fed by a separate line to the main control point. The cue transmitter utilized to talk to the planes from the central control point located in the master control room at Radio City was W10XGC. This is a new crystal controlled 25-watt transmitter operated on 40.6 megacycles and located on the roof of the RCA Building. This transmitter was used to line up the plane circuits and also carried the program back to the planes with WEAF, the local outlet, as a secondary means of hearing all other points during the actual broadcast.

Aboard each plane were two receivers, one ultra-high tuned to W10XGC and one tuned to WEAF. The output of either of the receivers was fed to a multiple with taps at each seat. At each seat two pairs of headphones were provided for the passengers so that all the men on each ship heard the complete program. Incidentally, there were twenty-two passengers on each plane. The ship's antenna was used for receiving and a special trailing wire for transmitting.

A set of audio equipment, in duplicate, was installed in Mr. Sarnoff's office on the fifty-third floor of the RCA Building. The output of his microphone amplifier was fed to the mixing and switching panel in the master control room. A return circuit was provided to feed back all the other originating points. This was terminated in several pairs of phones, one of which was worn by Mr. Sarnoff and one by Mr. William Burke Miller, who was in direct charge of all program arrangements. Here also were two field engineers, Messrs. Davis and Jackson to handle the technical facilities.

Senatore Marconi's portion of the show originated from aboard his yacht in the bay at Santa Margherita near Genoa. His voice was fed by local radio and wire line via Genoa to Rome and then transferred to a radio link to R.C.A. Communications at Riverhead. From here it came by wire line to the central control position in Radio City. The return circuit was via wire line to RCAC transmitters at Rocky Point, radio to Rome and wire line and radio back to the "Elettra". All preliminary testing on this portion of the circuit was handled by RCAC. In arranging all these facilities provision was made so that during the preliminary test period the engineers could work with the two planes without interrupting the circuit between Mr. Sarnoff and Mr. Marconi. At five minutes before program time they were all to be tied togethere. Here the unpredictable completely disrupted our plans and almost ruined the broadcast.

The trip was planned so that the planes would leave Newark Airport at 7:30 A.M. and fly to Buffalo where the guests were shown Niagara Falls both from the air and ground. Then a short trip into Canada by car for a greeting with Mr. Howe, the Canadian Minister of Communications, lunch and a return flight via New York direct to Washington. Because of heavy passenger traffic, the planes were not made available until after midnight and the installation of all equipment was not completed on both planes until approximately 6:00 A.M. The men then had about an hour's sleep on some blankets in the

Maurice Rambert, President of the International Broadcasting Union, speaking from the airplane in the four-way contact broadcast.

hangar. Both planes left at 7:30 A.M. Arrangements had been made to have both sets put on the air as soon as the trailing wire could be released. Both planes were to tune in each other and conduct tests between themselves on the way to Buffalo. Any trouble could then be cleared while the ships were on the ground at Buffalo. Everything worked beautifully and all pointed to a successful show. Antennas were reeled in and everything set for the return.

Because of the planes' speed of 180 miles per hour and the limited range of our sets on the only frequencies available for this service, the timing of the ships' departure and therefore arrival at New York had been very accurately set so the planes would be approaching New York when they went on the air and still be within range at closing time. The transmission range was limited to only fifteen minutes because at 180 miles per hour this gave a usable radius of only about 25 miles either side of New York. The first upset came when the ships arrived over New York about 15 minutes too early. When they got up at Buffalo on correct schedule, they found a 45-mile tail-wind, which brought them into New York at over 220 miles per hour. Secondly, this same high pressure area causing the winds, dropped the temperature well below the freezing point. Results, another freak to overcome.

The trailing wire antenna was fed through the floor of the ship from a special reel in each plane. The sudden drop in temperature had frozen the fish or weight on the end of the antenna, to the ship. So after getting up in the air on the return trip, neither ship could get out its transmitting antenna. After about thirty minutes of trying, one fish was loosened, antenna dropped and WIEW came on the air. WIEO, however, never got on the air until they were almost over New York City. It was finally necessary to cut a small hole through the ship's skin, just above the fish, in order to pry that one loose. In the meantime, WIEW was reporting itself over New York, but couldn't imagine what was happening to WIEO. Heavy sighs of relief when WIEO finally came through. It was still only 2:10 and the ships weren't due on the air until 2:21. At their rate of speed they would have been almost to Philadelphia and well out of range before the show was completed. So about 2:12 they were requested to circle New York a few times before heading south.

Simultaneously, there was trouble from a different quarter. RCAC had lined up the circuits between New York and Santa Margherita, and transmission in both directions was excellent. At 1:55 P.M. all tests were completed with that point.

However at 2:00 P.M. one of those intense, irregular magnetic disturbances which have come to be known as the Dellinger effect, set in and out went the Rome circuits. RCAC jumped in, put into service two additional transmitters at Rocky Point and shifted frequencies with Rome until they found two on which speech was still intelligible. All of this took place between 2:00 and 2:15 P.M. while we were still concerned about the planes.

Despite these irregularities the program started on schedule with the orchestra playing in the studio. Testing continued via the cue circuits, however, and we succeeded in getting Mr. Sarnoff and the planes together when suddenly, at 2:16, Senatore Marconi's voice was cut off and Rome advised that the line had failed between Genoa and Rome! Quick orders were passed to the other three points not to call in Senatore Marconi in order to eliminate the possible ghastly pauses on the air which, to the uninitiated, sound like unsatisfactory facilities or improper planning.

The orchestra completed its number and just as Dan Russell started talking from his plane, at 2:21, the circuit to the "Elettra" came up O.K. Orders again passed to all points, to that effect and the show went on as planned. Results—on the broadcast circuits, a perfectly synchronized performance, marred only by slight unintelligibility on the Rome circuit caused by the magnetic storm. Thus despite all the technical difficulties encountered by the engineers behind the scenes, the public was given another example of complicated broadcasting technique.

APPLICATIONS OF VISUAL-INDICATOR TYPE TUBES

BY L. C. WALLER

RCA Radiotron Div., RCA Mfg. Co., Harrison, N. J.

THE visual-indicator tube, known as the 6E5, originally designed as a visual tuning indicator for receivers, has characteristics which make it admirably suited for use in many types of electronic devices where an *indication* of voltage (or current) maxima or minima is desired. In addition to indications of maxima or minima, the 6E5 can be utilized for quantitative measurements in devices which require calibration or which operate on the voltage-balancing principle of

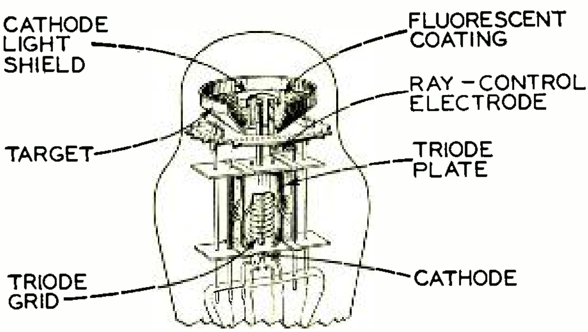


Fig. 1—Cutaway of the 6E5 illustrating its electrode structure.

the "slide-back" vacuum-tube voltmeter. A new type of visual-indicator tube, not so well known at present because of its newness, is the 913. This midget, low-voltage, high-vacuum, cathode-ray tube, shown in Figure 2, is suited for numerous oscillographic applications where the use of a larger cathode-ray tube might be impracticable. Applications of both the 6E5 and the 913 will be described.

OPERATING PRINCIPLES OF THE 6E5

The cutaway drawing of the 6E5 in Figure 1 shows its electrode structure. Essentially, the tube consists of a high-mu triode above which is located a cone-shaped fluorescent target and a blade-like ray-control electrode; the latter is internally connected to the triode plate.

The simple circuit of Figure 3 illustrates the operation of the 6E5. With zero bias on the triode grid, the fluorescent pattern caused by electrons striking the coated target will have a shadow sector of about 100 degrees, as shown in Figure 4. The "electronic shadow" is cast on the target because the ray-control electrode is at a negative potential with respect to the target; the bias on the ray control is caused by the *IR* drop across the plate resistor (R_2) when triode plate current exists.

When the triode-grid bias is changed from zero to some negative value by means of R_1, the triode plate current decreases, the voltage drop across R_2 decreases, the ray-control electrode becomes less negative with respect to the target, and the shadow sector closes to a smaller angle. With about 6 or 8 volts of negative bias on the triode grid, all plate current through R_2 is cut off and the shadow sector is reduced

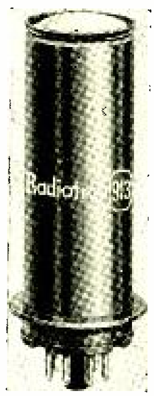


Fig. 2—The new midget, low-voltage, high-vacuum, cathode-ray tube.

to a narrow, dark line, as illustrated by the second part of Figure 4. Slightly more bias on the triode grid may cause the pattern to close completely or even to overclose; in the latter case, the dark line may change into a narrow, luminous line having greater brightness than the remainder of the pattern.

Because the variations of the fluorescent pattern on the target are controlled by the negative bias on the triode grid, it is apparent that the 6E5 is a voltage-indicating device which draws substantially *no power* and hence can be used across high-impedance circuits with little or no loading effect. This feature of the 6E5 makes it valuable as an indicating device. The actual variations of shadow angle, plate current, and target current with respect to grid voltage are shown in the average control characteristics of Figure 5.

6E5 Balance Indicator for a Vacuum-Tube Voltmeter

One of the most useful applications of the 6E5 is that of balance indicator in a slide-back-type vacuum-tube voltmeter. An instrument of this type having a voltage range of 200 volts is diagrammed in Figure 6.* A description of its manner of operation follows.

Referring to Figure 6, assume that the input terminals (test prods) *A* and *B* are shorted and that the movable arm of slide-back potentiometer R_7 is at the positive-voltage end of its range, at which setting d-c voltmeter "*V*" will read zero. The plate current of the triode-connected input-coupling tube (Type 6J7, 6C6, 57 or 954) is practically cut off, due to the biasing action of the 2.0-megohm cathode resistor (R_1).

Because it requires about −14 volts to obtain approximate cutoff of the 6J7 plate current, the cathode end of R_1 is at a potential of +14 volts with respect to the lower, or negative, end of R_6. The "zero-setting" potentiometer (R_5) is next adjusted so that the potential of the 6E5 cathode is about +21 volts with respect to the negative end of R_6. This 21 volts, in series opposition to the 14-volt drop across R_1, places a net voltage of −7 volts on the grid of the 6E5, with respect to its own cathode. Thus, the pattern on the target will be closed to a narrow, dark line, which is the correct initial setting for all vacuum-tube voltmeter measurements.

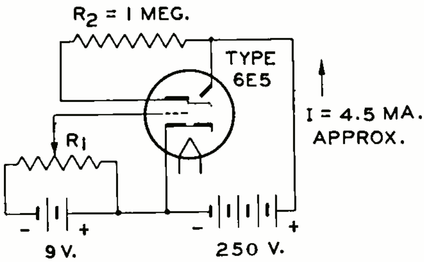


Fig. 3—Circuit illustrating the operation of the 6E5.

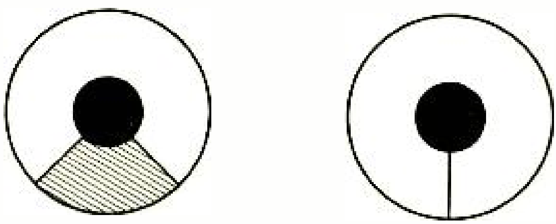
If the test prods *A* and *B* are now applied across any d-c or peak a-c voltage of suitable value (0.5 to 200 volts) which it is desired to measure, the plate current flowing through R_1 will increase by an amount substantially proportional to the d-c or *peak* a-c voltage applied. The action is similar to that of a diode rectifier, except that practically no power is drawn by the negative-grid input circuit. In the case of a-c voltages, rectification occurs on the positive half-cycles and the

* This instrument was described in *Radio Retailing*, Dec., 1935, and in *QST*, Oct., 1936.

large condenser C_1 (shunted across R_1) holds the d-c voltage developed across R_1 at practically the peak value of the a-c wave.

Because of the 2.0-megohm circuit across which it is shunted, condenser C_1 must be of a *high-quality, low-leakage* type; a *good* paper condenser is satisfactory. The capacity value of C_1 depends on the lowest-frequency a-c voltage that might be measured. A value of 4 microfarads is suitable for frequencies of 60 cycles per second or higher. In the case of d-c voltages, terminal *A* of the vacuum-tube voltmeter is always connected to the positive side of the input voltage.

To complete the explanation of the vacuum-tube voltmeter operation, assume that a d-c voltage of 10 volts is applied to the input terminals. The *IR* drop across R_1 will now be 14 + 10, or 24 volts. This places a voltage of 24 − 21, or +3 volts on the grid of the 6E5, causing the shadow sector to open. The slide-back control R_7 will now have to



ZERO GRID BIAS NEGATIVE GRID BIAS

Fig. 4—The pattern on the 6E5 target appears as shown above with zero grid bias and with grid bias near cutoff.

be moved toward its negative end until voltmeter "*V*" indicates 10 volts before the original −7 volts of bias is again restored to the grid of the 6E5. Thus, when the voltage introduced into the circuit by R_7 (read on voltmeter "*V*") is adjusted just to cancel the unknown input voltage, the pattern of the 6E5 will again close to the initial, or narrow-line setting. The 6E5 is, therefore, functioning as a voltage-balance indicator.

The use of a protective resistor (R_2) in the grid circuit of the 6E5 is important, because any input voltage exceeding 7 volts will drive the grid of the 6E5 positive. The *IR* drop across R_2, developed by the 6E5 grid current, automatically biases the tube so that the grid current can not reach a value high enough to be harmful.

Accuracy of the Vacuum-Tube Voltmeter

In general, the accuracy of this type of instrument will depend upon the care with which the fluorescent pattern is adjusted before and after the unknown voltage is applied, as well as upon the accuracy of the d-c voltmeter "V". D-c voltages between about 25 and 200 volts can be read to one volt or better, depending on the readability of the voltage scale on "V". Between 0.5 and 10 d-c volts, the accuracy is plus or minus 0.1 to 0.2 volt. A-c voltages will give readings which are in error by a fairly constant value of 0.8 to 1.3 volts, on the low side of the correct value. This error is apparently due to the reaction of the negative half-cycle on the static value of the 6J7 plate current. For example, a peak a-c voltage of 1.4 and 2.8 volts gave a vacuum-tube voltmeter reading of 0.6 and 1.75 volts, respectively. The percentage error is naturally smaller for larger values of a-c voltage, so that the higher a-c readings are quite accurate.

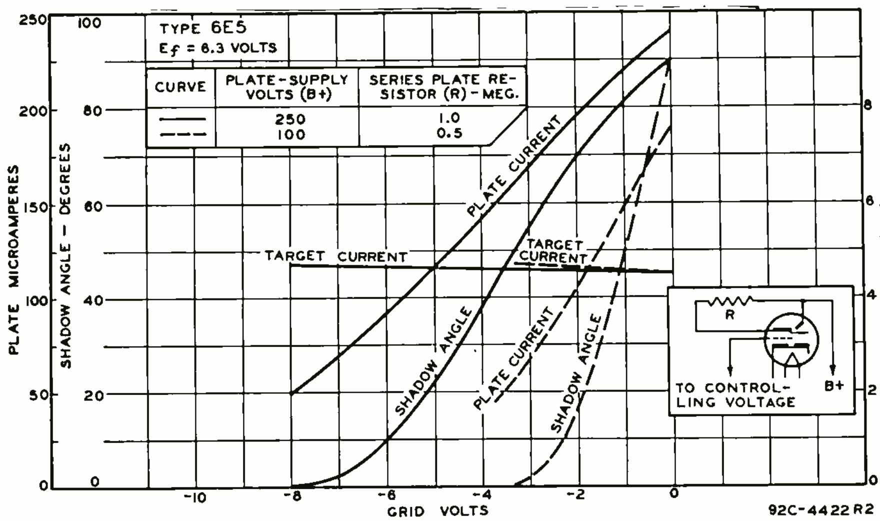


Fig. 5—Operating characteristics of the 6E5.

The error on low a-c voltages is not disturbing, because the instrument can readily be calibrated for these voltages by means of a variable a-c source of known voltage. The calibration can be made in terms of either rms or peak values. It is important to remember, however, that the voltage indicated by "V" is invariably in terms of either d-c or *peak* a-c. If the a-c input voltage has reasonably good wave form, the peak a-c readings can easily be changed to rms values by multiplying them by the factor 0.707.

Other Vacuum-Tube Voltmeter Considerations

A voltage calibration of slide-back potentiometer R_7 can be made if it is desired to eliminate d-c voltmeter "V" from the circuit. This arrangement will not, of course, provide as good accuracy as with a d-c voltmeter having several voltage scales. If many measurements are to be made in the low-voltage range (1 to 10 volts), a 500-ohm potentiometer should be placed in series with R_7, as shown in Figure 7. A single-pole double-throw switch is required to change from the 10 to the 200-volt range. The switch must be thrown to the low-voltage scale and the 500-ohm potentiometer adjusted to zero in order to make the initial zero setting with R_5, even when a voltage higher than 10 volts is to be measured; the switch is thrown back to the 200-volt scale after the zero setting is made with R_5.

The mounting of the input tube is quite important. Where r-f voltages are to be measured, the capacitance of the input circuit must be kept as low as possible. The well-known "goose-neck" probe construction is recommended for this reason. If very many r-f measurements are contemplated, a 954 acorn tube, connected as a triode, should be used in place of the 6J7. The loading introduced by the 954 is relatively small.

APPLICATIONS OF THE 6E5 VACUUM-TUBE VOLTMETER

Because the vacuum-tube voltmeter described has a considerable voltage range, draws no current, and can be used across high-impedance and high-frequency circuits, it has a multitude of uses. A few of these may be worthy of mention, although this is to digress somewhat from the main subject.

The avc circuit of a refractory superheterodyne receiver can easily be checked. Prod *A* is connected to the cathode of one of the controlled r-f or i-f stages and prod *B* to the ground side of the r-f or i-f transformer secondary. The avc bias variation can be measured accurately, either on a signal or with a test oscillator. The 6E5 will at the same time serve as a resonance indicator or as an alignment meter, because the avc voltage varies as the different circuits are adjusted. This method of i-f alignment is not as good, of course, as the double-image method employing a cathode-ray oscillograph and its auxiliary equipment.

Tube screen and plate voltages can be checked with precision, even though a very large series resistance is included in the circuit. The true plate voltage *at the plate* of a resistance-coupled a-f amplifier can quickly be determined, even if the plate load has a value of 0.5 megohm, or more. If the a-f tube is biased correctly, the voltage at the plate will usually be about one-half of the plate-supply voltage.

The operation of r-f or i-f stages can be checked roughly by measurement of the r-f voltage across the transformer secondary. The test lead from prod *A* should be short and should have very little capacitance to ground. The 6J7 may, even with very short input leads, place a capacity load of 5 to 10 micromicrofarads across the transformer; this will detune the circuit under test more or less, depending on its nature. The use of the 954 in the input stage of the vacuum-tube voltmeter is preferable for tests of this kind.

Where an a-f output meter is needed, the test prods can be applied to almost any part of the a-f circuit. If it is necessary to separate an a-f voltage from a d-c voltage, in such applications, a 0.1-microfarad blocking condenser and a 1 to 5-megohm grid leak can be employed at the input to the vacuum-tube voltmeter. In addition to serving as an a-f output meter, the vacuum-tube voltmeter can be used to measure the peak a-c driving voltage applied to the grid of the a-f tube.

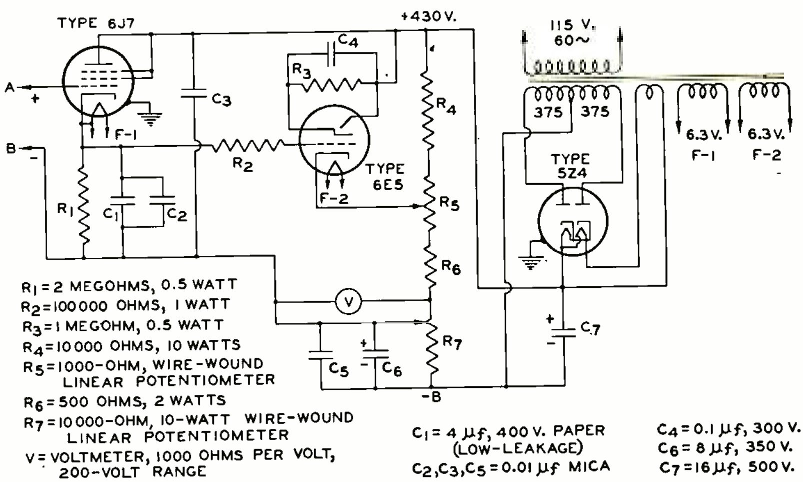


Fig. 6—This v-t voltmeter circuit shows one of the most useful unconventional applications of the 6E5. The instrument is of the "slide-back" type.

The gain of the audio stages can also be measured. A known *peak* a-f voltage (such as a 60-cycle source shunted by a known voltage divider) is applied to the grid of the a-f tube under test. The peak a-c voltage across the plate load is next measured; this value, divided by the known peak input voltage, gives the voltage gain of the stage, at the particular test frequency employed.

The determination of the ratio of a transformer is simple. A suitable a-c voltage is applied to any winding and that voltage measured. The voltage of any other winding is also measured; the ratio of the two peak voltages is substantially that of the two windings.

The power output of an audio power amplifier can be determined with the aid of the vacuum-tube voltmeter and a bit of arithmetic. A test signal voltage of (say) 1000 cycles from an audio oscillator having a reasonably good wave form is applied to the audio system at any convenient stage. A pure resistance load of the correct resistance and wattage is shunted across the primary of the audio output transformer. A value of 7000 ohms, for example, will be used in the case of a single 47 pentode. The secondary load of the output transformer is disconnected. The test signal is then increased until its peak value at the grid of the power tube (or at one grid in a push-pull stage) is the maximum permissible for the stage under test. For a power tube operating Class A or Class AB_1, the peak signal should not cause d-c grid current to flow. The peak a-c voltage across the plate load resistor is then measured. Taking the 47 as an example, we find that the measured peak output voltage (E_{pk}) is 186 volts. Changing this to an rms value, for power calculations, we get, $E_{rms} = (0.707)\ (186) = 132$ volts. From the relation $P = E_{rms}^2/R$, we find that $P = (132)^2/7000 = 2.5$ watts, the power output.

The peak plate current of a mercury-vapor rectifier can be measured as a check on the correct operation of the rectifier tube. A 100-ohm (or other suitable value) resistor is placed in the $-B$ lead of the rectifier between the transformer and the filter system. The vacuum-tube voltmeter will measure the peak d-c voltage developed across the resistor, the rectifier being operated under normal load. Ohm's law gives the peak d-c plate current in the circuit, $I_{pk} = E_{pk}/R$.

The ripple voltage of a high-voltage rectifier can be checked readily, if there is sufficient ripple voltage to measure (0.5 volt or more). A d-c blocking condenser-and-leak input circuit must be used for the vacuum-tube voltmeter, of course, with a condenser of the necessary high-voltage rating. The peak ripple voltage is measured across the filtered output of the supply, in the usual manner for measuring small a-c voltages.

The vacuum-tube voltmeter has a number of useful applications in the adjustment of radio transmitter stages. It may be used as an ultra-sensitive neutralizing indicator, merely by employing it as an r-f output meter across all, or a portion, of the plate-tank circuit of the stage being neutralized. The voltage measured will be at a minimum when the point of best neutralization is found. Test prod B should be placed at the r-f voltage node on the tank coil, because this input terminal has a lower impedance to ground, at high frequencies, than terminal A.

As a modulation meter, the vacuum-tube voltmeter will measure the percentage of modulation with good accuracy, provided the modulation is symmetrical and the carrier is not subject to appreciable shift. A small amount of r-f voltage, picked up at the modulated r-f stage and transferred to the vacuum-tube voltmeter through a low-impedance line (twisted pair), is measured. Assume that this voltage, with no modulation on the carrier, is 10 volts. At 50 per cent modulation, the vacuum-tube voltmeter will read 15 volts; at 100 per cent modulation, it will read 20 volts, or twice the non-modulated value. Only positive modulation peaks can be indicated by this method.

As an over-modulation indicator, the vacuum-tube voltmeter can be operated in a somewhat different manner. Slide-back potentiometer R_7 is adjusted *just to cancel* the non-modulated carrier voltage, picked up as described above, and the d-c voltmeter reading noted. R_7 is then adjusted so that "*V*" reads about 95 per cent higher than the first read-

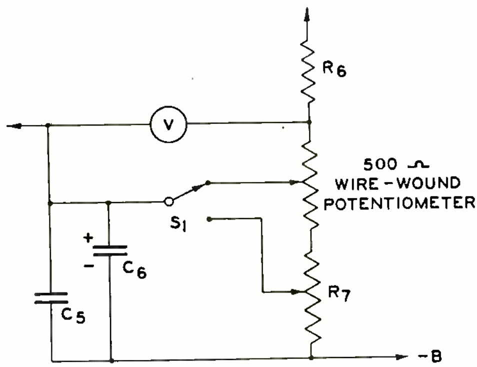


Fig. 7—Partial circuit of vacuum tube voltmeter showing the use of a vernier control for the measurement of low voltages.

ing. This over-biases the 6E5 and over-closes the pattern. Then, when the pattern begins to flip open slightly as the carrier is modulated, the positive modulation peaks are beginning to exceed the 95 per cent modulation point. A disadvantage of both of these arrangements is that the indicator does not show the effects of carrier shift, or of over-modulation on the negative modulation peaks. It is the negative modulation peaks which create the most disturbance when they reach the carrier cut-off point, because of the resultant flattening of the modulation envelope on the one side.

The 6E5 as a Negative-Peak Over-Modulation Indicator

Another application of the 6E5, not involving the vacuum-tube voltmeter, is shown in Figure 8. Here the electron-ray tube is used in conjunction with a high-voltage, half-wave, vacuum-tube rectifier (the 879 is shown, as an example). This arrangement operates as a negative-peak over-modulation indicator in the following manner: When the a-c modulating voltage at point "x" swings positive, the 879 does not pass current because its filament is at a positive potential with respect to its plate. When the modulating voltage swings negative at point "x", the rectifier still fails to pass current until the negative a-f peak *exceeds* the d-c plate voltage applied to the Class C modulated r-f amplifier. When this does occur, causing carrier cut off, the instantaneous voltage at point "x" is negative with respect to the plate of the 879 and the latter then passes a rectified d-c current through the load resistor (R_1). This current, causing a d-c voltage drop across R_1, biases the grid of the 6E5 negatively. The pattern on the 6E5, therefore, flips shut whenever the negative a-f peaks are great enough to cause carrier cut off; this happens irrespective of possible carrier shift.

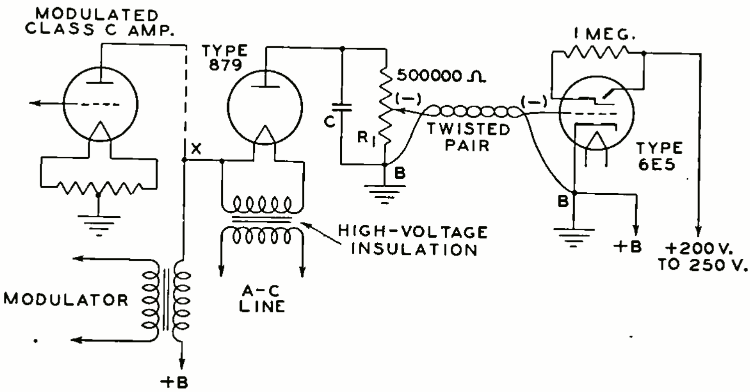


Fig. 8—A negative-peak over-modulation indicator using the 6E5. The value of "C" controls the time lag, and may be 0.05 to 0.5 microfarad. Larger values provide slower action.

It is apparent that this device is exceedingly sensitive to the slightest negative-peak over-modulation, inasmuch as only 7 volts are required to close the "eye" completely.

The sensitivity can be controlled by potentiometer R_1 (Figure 8), which regulates the amount of excess modulating voltage applied as bias to the 6E5. The size of condenser C controls the speed with which the "eye" *reopens* after an excessive modulation peak has passed. That is, although the pattern closes rapidly, it can be made to reopen slowly, to assist the operator in making the observation. This type of over-modulation indicator is much to be preferred to one indicating only positive peaks, for reasons already discussed.

The 6E5 as an Indicator in Non-AVC Receivers

It is, of course, well known that the 6E5 is ordinarily used in receivers employing automatic volume control with a diode detector.

The electron-ray tube can also be used in a receiver having neither avc nor a diode detector. The alternative arrangement is suitable for t-r-f or superheterodyne receivers employing a cathode-resistor-biased detector, as illustrated in Figure 9. Potentiometer R_2 is set at the detector cathode potential. This places a positive voltage, equal to the no-signal bias of the detector, on the grid of the 6E5, opening the "eye". Cathode resistor (R_1) in the 6E5 circuit is next adjusted *just to close* the "eye" to a narrow line. When an r-f signal is tuned in, the plate current of the detector rises, the voltage drop across R_2 and R_3 increases, and the 6E5 pattern opens slightly. At the point of best tuning or resonance, the pattern will have opened to a maximum; detuning the receiver causes it to close again. The 6E5 thus acts as a visual tuning indicator, but operates exactly *backward* with respect to

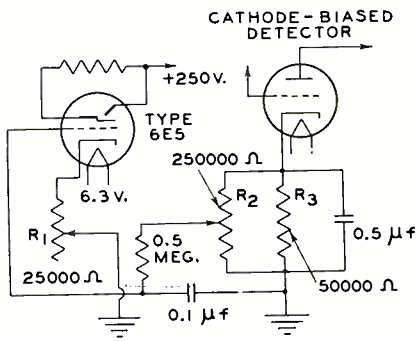


Fig. 9—Circuit using the 6E5 as a visual tuning indicator in receivers not having AVC or a diode detector. The "eye" opens to a maximum when a signal is properly tuned in.

its usual pattern movement. The backward operation of the "eye", however, is not especially objectionable — the larger the shadow, the better the tuning.

If a very strong signal develops so much voltage across R_3 that the pattern opens fully and loses its indicating value thereby, the arm of R_2 should be moved toward ground. R_1 must then also be readjusted for a closed pattern, under no-signal conditions.

Null Indicator Using the 6E5

A more unusual application of the 6E5 is that of a null or voltage minima indicator for bridge circuits. Figure 10 illustrates such a device, including a 6J7 signal amplifier. The input terminals of the null indicator should be connected across the balance points in the bridge circuit. Either a-c or d-c voltage may be used across the bridge circuit, as far as the null indicator is concerned.

The 6J7 is operated as a d-c amplifier, with an adjustable grid-bias supply provided by the 400-ohm potentiometer in the bleeder circuit. The grid-bias and screen-voltage controls are adjusted, under no-signal conditions, so that the plate current is almost cut off. The screen voltage is important as regards the sensitivity of the 6J7 on small a-c signals. A small amount of no-signal current flowing through the plate resistor of the 6J7 will produce about 3 or 4 volts of negative bias on the grid of the 6E5, through the 0.5-megohm filter resistor. This bias voltage will cause the 6E5 pattern to close about half way, or 50 degrees.

If a small d-c or a-c voltage appears across the input terminals, as is the case when the bridge circuit is unbalanced, the plate current of the 6J7 increases, thus placing more bias on the 6E5 grid and closing

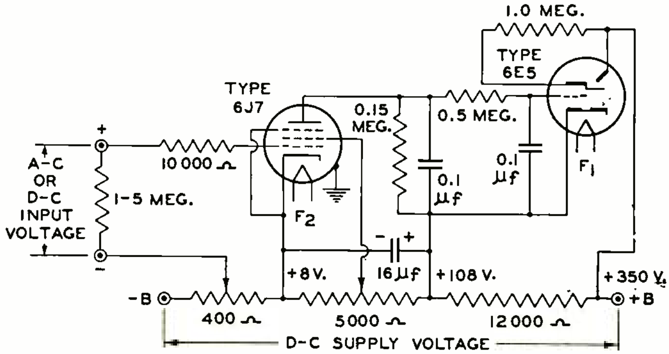


Fig. 10—This arrangement can be used in conjunction with bridge circuits where a sensitive indicator is required.

the pattern to a narrow line. As the balance control on the bridge is adjusted to a point on either side of the correct nodal point, the "eye" will flip entirely shut. At the nodal point, it will open to the same maximum angle at which it rests under no-signal conditions. The nodal point can be accurately determined by noting the position of the balance control on the bridge at the two points, one on each side of the nodal point, at which the "eye" just closes to a narrow line. The nodal point can then be found on the balance control half way between the two points mentioned. The sensitivity of the indicator is estimated to be about 10 millivolts.

The 10000-ohm protective resistor in the 6J7 grid circuit is essential. In case a relatively large voltage appears across the input terminals, this resistor will prevent excessive d-c grid current, due to the extra d-c bias automatically applied to the grid of the 6J7.

SUMMARY — 6E5 APPLICATIONS

A number of applications for the 6E5 have been described, other than its normal use as a visual tuning indicator. Some of these involve quantitative measurements, others only the indication of maxima or minima. Obviously, such applications might be continued indefinitely. It is surprisingly easy to fit the 6E5 into various types of circuits, just as in the examples shown.

THE 913 — A ONE-INCH CATHODE-RAY TUBE

A new type of visual-indicator tube, designed on the cathode-ray principle, has recently been made available. This tube, the RCA 913, has two sets of electrostatic deflecting plates and a fluorescent viewing screen about one inch in diameter. An outstanding design feature is the fact that, although it is a high-vacuum type, the 913 can be operated with anode voltages as low as 250 volts. The metal shell of the 913 serves not only to maintain the other electrodes in a high vacuum, but also to act as the second anode, in which role it assists in focusing the electron beam.

The design of the 913 involves much more than meets the eye upon casual inspection. For example, a similar low-voltage tube in a plain glass bulb would not function properly, due to electrostatic charges building up on the glass wall. These charges would interfere with the focusing of the electron beam. The metal-shell design substantially eliminates this problem, and also provides an excellent electrostatic shield.

Figure 11 illustrates a typical cathode-ray oscillograph circuit using the 913. Features of this circuit are the linear time-sweep oscillator, employing an 885 gas triode, and the two a-f amplifiers, using 57's connected as pentodes. One 57 amplifies the output of the saw-tooth oscillator and provides, through switch S_3, the horizontal time-sweep voltage for deflecting plates D_3 and D_4. By means of switch S_2, the same 57 may be used to amplify an external sweep voltage. An unamplified external voltage can also be applied to the horizontal deflecting plates by means of switch S_3. The other 57, referred to as the "signal amplifier" or "vertical-deflecting-voltage" amplifier, applies through switch S_4 an amplified signal for deflecting plates D_1 and D_2. This voltage produces a vertical deflection on the fluorescent viewing screen. The switches S_3 and S_4 should be of a low-capacity type, because r-f voltages may be applied to either set of deflecting plates, in some applications. The 57 was chosen for this circuit in preference to the 6J7 because the particular power transformer available did not have an extra 6.3-volt

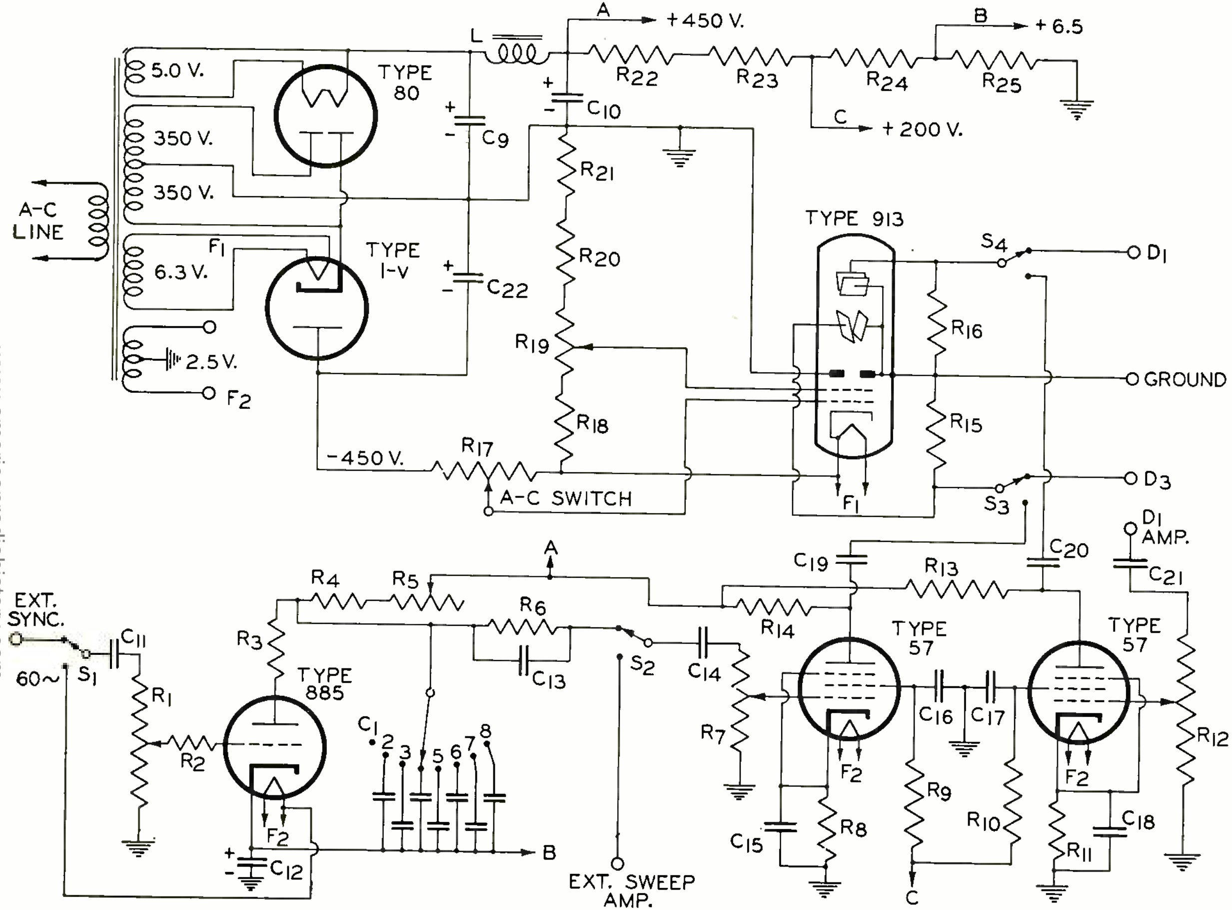


Fig. 11—Oscillograph circuit using the new tube, Type 913. C_{19} should be connected to S_4 and C_{20} to S_3. "D_1 Amp." should be labeled "D_3 Amp."

C_1 = Stray Circuit Capacity
C_2 = 0.0008 uf, 500 v.
C_3 = 0.002 uf, 500 v.
C_4 = 0.005 uf, 500 v.
C_5 = 0.015 uf, 500 v.
C_6 = 0.05 uf, 500 v.
C_7 = 0.15 uf, 500 v.
C_8 = 0.3 uf, 500 v.
C_9 C_{10} C_{22} = 8 uf, 500 v.
C_{11} C_{16} C_{17} = 0.25 uf, 250 v.
C_{12} = 25 uf, 15 v.
C_{13} = 25 uuf, 500 v.
C_{14} C_{21} = 0.5 uf, 500 v.
C_{15} C_{18} = 0.003 uf
C_{19} C_{20} = 0.25 uf, 500 v.
L = 30 Henries, 10 ma.
R_1 = 250000-ohm poten.
R_2 = 25000 ohms, 0.5 watt
R_3 = 500 ohms, 0.5 watt
R_4 = 300000 ohms, 0.5 watt
R_5 = 2.0-megohm poten.
R_6 = 1.0-megohm, 0.5 watt
R_7 R_{12} = 0.5-megohm poten.
R_8 R_{11} = 1000 ohms, 0.5 watt
R_9 R_{10} = 200000 ohms, 0.5 watt
R_{13} R_{14} = 100000 ohms, 1 watt
R_{15} R_{16} = 2.0 megohms, 0.5 watt
R_{17} = 15000-ohm poten.
R_{18} = 15000 ohms, 0.5 watt
R_{19} = 25000-ohm poten.
R_{20} R_{24} = 50000 ohms, 1 watt
R_{21} = 40000 ohms, 1 watt
R_{22} R_{23} = 30000 ohms, 1 watt
R_{25} = 1600 ohms, 0.5 watt

heater winding for the amplifier tubes. The amplifiers should not be operated from the same heater winding as the 913.

The double power supply used in this oscillograph is of special interest. The 80, in a full-wave rectifier circuit, provides about 450 volts above ground for the operation of the amplifiers and the saw-tooth oscillator. The 1-v, in a half-wave circuit, provides about 450 volts below ground for the electrode supply of the 913. Because the positive terminal of this supply is at ground potential, the shell and second anode of the 913 can be directly grounded. This obviates the necessity of insulating the shell of the cathode-ray tube from ground, and eliminates the need for condensers in series with the free deflecting plate leads.

Provision for synchronizing the saw-tooth oscillator is made by means of the double-throw switch, S_1. In one position, synchronization with the frequency of the a-c line voltage is provided through the connection to the heater of the 885; in the other position, the oscillator can be synchronized with an external voltage source.

The linearity of the time-sweep voltage is quite good at frequencies from 30 to 7500 c.p.s. Potentiometer R_5 provides the vernier control for the sweep oscillator. The amplifiers have a flat response curve from about 30 to 20000 c.p.s., their voltage outputs dropping to about 50 per cent at 70000 c.p.s. These characteristics of the amplifiers and of the sweep oscillator are satisfactory for most audio-frequency applications.

Although the viewing screen of the 913 is relatively small, an oscillograph using this tube is suitable for many applications where larger cathode-ray tubes have previously, of necessity, been employed. The 913 lends itself to a compact, light-weight, economical oscillograph design. The oscillograph shown in the circuit of Figure 11 is rather elaborate, inasmuch as it contains most of the features included in commercial equipment using larger cathode-ray tubes. The individual builder can, in many cases, greatly reduce the number of component parts, to meet his particular requirements. In some cases, only one amplifier may be necessary. In others, a linear sweep circuit is not required. Stripped to its bare essentials, an oscillograph employing the 913 might consist only of the cathode-ray tube, a heater transformer, and the bleeder circuit, with provision for connection to an external d-c voltage supply.

In conclusion, the writer wishes to acknowledge the assistance given by Messrs. P. A. Richards, J. F. Dreyer, and F. H. Shepard, Jr., of the Research and Development Laboratory, RCA Radiotron Division, RCA Manufacturing Co., Inc., Harrison, N. J., in the design of many of the circuits shown in this discussion.

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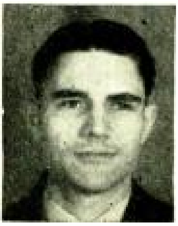

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