The RADIO ENGINEERS' DIGEST

DECEMBER 1944 VOL. 1, NO. 5

. . . CONTENTS . . .

Season's Greetings to All

To all our friends in the radio, electronics and allied fields—a very Merry Christmas and a Happy New Year.

A year of successful achievement for the electronics industry is now drawing to a close. Much has been accomplished; much remains to be done.

Ahead of all else we must first win the war. We must build lasting peace. We must look to the future.

We must harness our knowledge, our war-born research, our genius for "know-how" for the good of a world that some day will know peace.

If we accomplish these things—and we can and we will—we can then face the future with courage and hope.

THE RADIO ENGINEERS' DIGEST

JOHN F. C. MOORE, *Editor*

Vol. 1, No. 5 December 1944

Published monthly at Brooklyn, N. Y., by The Hudson American Corporation.

Editorial Office, 300 Pearl Street, Brooklyn 1, N. Y.

Subscription rate, $5 per year. Single copies 50 cents.

Printed by Criterion Products Corporation, New York, N. Y., U. S. A.

6 KEYS TO ENGINEERING SUCCESS

Reprinted from Electronic Industries

By Dr. Allen B. DuMont

President, Allen B. DuMont Laboratories, Passaic, N. J.

Study eternally, practice salesmindedness, win executive responsibilities, high spots in message to Rensselaer graduates.

FOR the technical man, tomorrow's world means change and progress and new openings on a positively fantastic scale. The very last ounce of knowledge and skill and effort is being poured into the desperate global conflict which is to decide the future of mankind. Thus it is not surprising to find technological advances on an astounding scale. In most fields the advances already amount to 25 years of usual peacetime progress. For example, the text books in many fields are probably 2 to 3 years behind times, already. One can have had excellent training in the fundamental sciences, but unless you continue your own education, your opportunities will necessarily be definitely limited.

DR. ALLEN B. DuMONT

Awarded the degree of Doctor of Engineering, Dr. DuMont cited six principles of growth for the modern engineer:

1. Present-day world offers tremendous opportunities.
2. Ceaseless study is necessary to keep abreast.
3. Growing complexity demands more technicians.
4. Engineers must stop thinking negatively.
5. Be salesminded. Be business-minded.
6. Hold yourself in proper esteem.

KEEP UP WITH PROCESSION!

My second point is the need to keep up with this rapidly-moving technological procession. If you would get up-to-date and stay up-to-date in your chosen field, by all means cultivate a craving for information. To offset the rapid obsolescence of knowledge and experience and practice these days, we have engineering and technical journals covering every field of technology. To top it all, we have engineering and technical societies which meet regularly for the presentation and discussion of papers that bring us right up to the present moment. The proceedings of such societies are indispensable in the working library of the successful technician. Keeping up-to-date is of the very essence of success.

For a third point, consider the intricacies of modern development, design, production and control of various technical items, particularly in meeting the stringent specifications of global war, which require a greater range of conditions than ever before encountered, and which will continue in the postwar world. In radio and electronics, we have such conditions as flying in rarefied atmosphere, with temperatures down to minus 40 deg. F.; operation in tanks, with temperatures up to 125 F.; fungus growths and cain-raising insects of the jungles; intense vibration and mechanical shock of the order of 100 and above; high-humidity conditions even approaching 100 per cent saturation; corrosive effects of salt water spray, and so on. All these conditions must be studied by the technician. Laboratory setups, approximating actual conditions are now commonplace, so that equipment can be tested and checked for intended conditions of operation. Never before has there been such need for technicians in the development, design, production and control of almost all products.

My fourth point concerns creative thinking—and doing. It has been my observation that too many engineers and technicians have a basically negative approach to any new idea. The average technically-trained man knows, of course, the inherent technical difficulties in a given technical situation, almost at a glance. He knows why it can't be done, offhand. And often he makes no attempt whatsoever to do anything further about it. He stops at the first technical objection.

As a jibe to such negative thinkers, however, many war plants these days have this sign very much in evidence: "The difficult, we do immediately; the impossible takes a little while longer." It is in that spirit that our country, in three short years, has caught up with and surpassed the Axis powers who had a twelve-year head start on our production.

Faced with the negative attitude of many of his co-workers in the great research laboratories of General Motors, Dr. C. F. Kettering, patron saint of modern industrial research, has this to say on the subject: "Tell me just why it can't be done. Once you have mentioned all the reasons in sufficient detail, you have the problem more than half solved."

Yes, the negative attitude accounts for the financial predicament in which many technicians find themselves. They work for others. They are under others. They take their orders from the business and sales departments. And when there are extra financial rewards to be divided, the technicians usually come in at the very tail end, if at all.

My fifth point, then, is to urge you to develop a commercial viewpoint, along with your technical outlook. Remember, your salary will ultimately come out of sales. A business lives or dies by its income. And yet so many technicians are not interested in the slightest in the selling end. Nevertheless, I say to you: To be a successful technician, be a salesman. Be sales-minded. See that your efforts have a direct bearing on selling more and better goods for bigger and better profits. In this way you will be fattening your own pay envelope. You will enjoy more prestige. You will be more successful.

And also do not hesitate to aspire to an executive position in the organization. Too few organizations, even though highly technical in character, have engineers in executive positions. Rather we find erstwhile bookkeepers or stenographers, salesmen or bench workers, bankers or clerks, or others of similar non-technical training, heading the destinies of such companies, while their engineers simply carry out their orders. But the fault lies with the technicians. They have failed to appreciate the importance of a business-mindedness.

HIGH SELF ESTEEM

Sixth and last, hold yourself in high esteem if you would have others appraise you at your true worth. In this regard I like the way the French refer sometimes to engineers. Their military engineers especially are called the "GENIE." And genie means the genie or supernatural spirit in Arabian folklore, capable of doing fantastic things at the bidding of their master. Remember Aladdin and his wonderful lamp? Precisely so with you engineers and technicians in the world of 1944.

You are invited to take your rightful place in the bigger brighter world now in the making.

ANTENNAS FOR FM STATIONS

Reprinted from *FM* and Television

By John P. Taylor

Engineering Products Department

Radio Corporation of America

RCA Victor Division, Camden, N. J.

Relation of Antenna Design to Area of Coverage; Types of Antennas and Their Characteristics.

ASSUMING that a site has been selected, the next step in planning an FM station is to decide on the type of antenna to be used. Considerable importance is attached to this decision because of the increased coverage, for the same transmitter power, which can under some circumstances be obtained by using an FM antenna of one of the so-called *multi-element or multi-layer* types.

ADVANTAGES OF MULTI-LAYER ANTENNAS

The desirability of carefully considering the possibilities of the multi-layer design can hardly be overstressed. An example is probably the best way to illustrate this. Assume a 1-kw. FM transmitter feeding power to an antenna on the top of a 300-ft. building. If this antenna is of simple single-layer design, for instance, a one-bay turnstile, coverage[1] will be approximately 31 miles. Now suppose that there is substituted for this single-layer antenna an antenna of the same type but having six layers. By this substitution, the 50-micro-volt line will be moved out to 44 miles and the area covered increased from 3017 square miles to 6.079 square miles. In terms of equivalent power the difference is even more striking. To obtain the same increase in coverage by increasing power while retaining the single-layer antenna would have meant going to a power of 8.6 kw. In terms of cost this makes an interesting comparison. Depending on the mechanical difficulties of installation, a six-bay turnstile installed may cost from three to six or eight thousand dollars more than a single-bay turnstile. But a 10-kw. transmitter installed will cost at least fifteen thousand dollars more than a 1-kw. transmitter. Moreover, the larger transmitter will require more space, involve greater installation problems, and cost more to operate. *Thus, other things being equal, obtaining increased coverage by use of a higher-gain antenna is usually preferable to an increase in power.*

LIMITATIONS OF MULTI-LAYER ANTENNAS

There are, however, some definite limitations which must be reckoned with in considering the use of high-gain antennas. The most important of these are the mechanical limitations imposed by the supporting structure. A six-bay turnstile, for instance, is approximately 60 ft. high, at FM frequencies. It is mounted on a pole which is 12 ins. in diameter at the base and 5 ins. at the top. The whole antenna weighs about 3,500 lbs. Moreover, it presents considerable wind resistance, so that at high wind velocities the overturning moment is rather large. The supporting structure, whether building or tower, must be able to stand this weight and overturning moment, and must be adaptable to mounting the supporting pole. When these requirements are combined with the desirability of having a high location, a compromise

[1] The distance to the point where the signal has fallen to 50 microvolts per meter.

is often required. For instance, it may be found that there is available a 300-ft. building which is ideal in all respects except that it will not support more than a two-bay antenna, whereas the only building on which a six-bay antenna could be located is only 100 feet high. Reference to the coverage curves will show that in this case the first location would be the better even though only the two-bay antenna could be used. The same consideration may apply where an FM antenna is to be mounted on an existing AM tower. Most such towers will not support an FM antenna of more than two bays. However, the extra height afforded by such mounting may be an advantage that outweighs this.

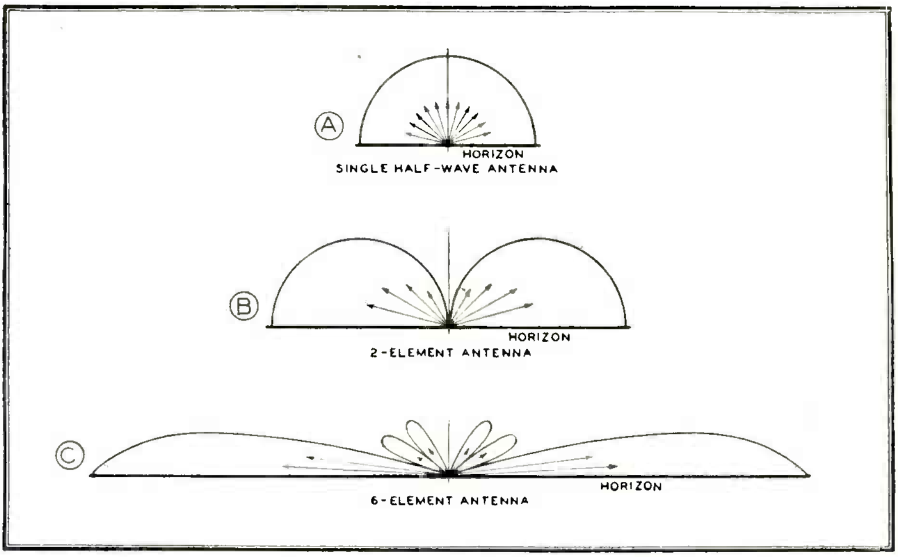


Fig. 1. Antenna gain is achieved by reducing power radiated upward.

INTERRELATION OF HEIGHT, GAIN, POWER

Even an elementary consideration such as the above serves to show that it is not always possible to follow the logical course in FM station planning of first, determining coverage required; second, selecting a site; third, deciding on antenna type, and finally, determining the necessary power. In many cases the site and type of antenna must be considered together. In not a few cases transmitter power will also enter into this consideration. And, in a few extreme cases, the limiting conditions may be such that the coverage originally set up as desirable may have to be scaled down to meet practical conditions. This, in turn, may involve a change in the type or classification of station to be applied for. Thus, considerations of antenna type and design which at first thought seem to be chiefly of engineering interest, may actually turn out to be matters affecting station policy. As such, they are of interest not only to the station engineer but also to the station manager and the station owners.

HOW ANTENNA GAIN IS OBTAINED

The increased effective power and the increased coverage referred to above are obtained by the us of multi-element antennas. These consist essentially of from two to ten or more separate antenna elements arranged in some fixed configuration and fed power effectively in parallel. Ordinarily, the individual elements are about a half wavelength long and they are usually spaced a half wavelength or more apart. Multi-element antennas have been used for years for radio communications purposes. They have not been used for AM broadcasting, except to obtain special directivity patterns intended to reduce interference, because of the fact that, at AM broadcasting frequencies, a half-wave is from 330 to 1,000 ft. long and it is not practical to use multiples of such distances. At FM broadcast frequencies, however, a wavelength is only about 20 feet, so that multiple configurations up to ten or so are often practical.

It should be noted that the total power radiated is not increased by the use of a multi-element antenna, for obviously this power can be only as great as the transmitter power less whatever small losses may occur in the feed system. Rather, the gain which is achieved is a gain in *effective* or useful power. It is obtained by reducing the power radiated in the upward direction and increasing the power radiated in the horizontal direction, i.e., along the earth's surface. It is the latter which constitutes the useful signal component.

The manner in which extra coverage is obtained by suppressing the *skywave* is illustrated in Fig. 1. Fig. 1A shows the radiation pattern, in the vertical plane, from a single half-wave antenna. As the arrows indicate, power is radiated equally at all

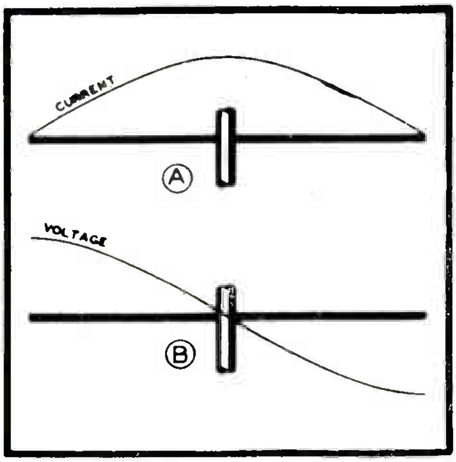


Fig. 2. (above) Current and voltage waves on a single turnstile element.

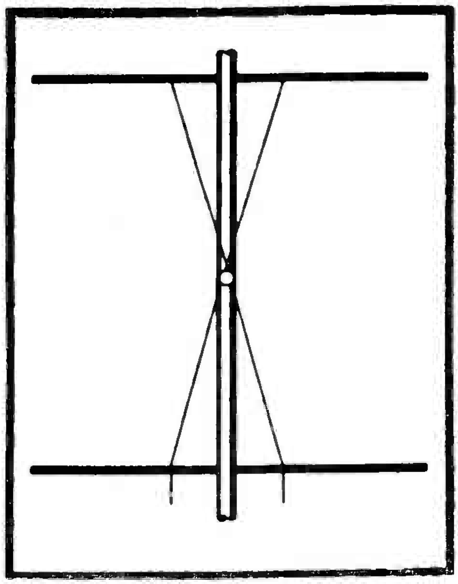


Fig. 3. (right) Method of feeding power to the elements of a turnstile.

angles to the horizontal. Of this power only that radiated at the horizontal or at very small angles to the horizontal serves any useful purpose; all the rest travels out into space and is lost. Now consider Fig. 1B, which is an approximation of the vertical radiation patterns from an antenna consisting of two elements stacked vertically. In this case there is no radiation directly upward and that at high angles has been greatly reduced. The radiation at low angles and along the horizon has been increased greatly. Thus the *effective* or useful power is much greater even though the total power radiated is the same. In Fig. 1C is shown the vertical radiation pattern for a six-element antenna. The pattern has been still further squashed down and the radiation along the horizontal still further increased. As more elements are added beyond six, the horizontal radiation continues to increase. However, the amount of increase per added layer decreases so that the diminishing return hardly justifies going beyond ten layers, and in many instances six layers is considered the best practical choice.

MEANING OF FIELD GAIN AND POWER GAIN

In comparing the advantages of multi-element antennas engineers use the terms *field gain* and *power gain*, and these same terms are used in the Rules and Standards of the FCC.

The field gain is defined as *the ratio of the field intensities,* that is, the signals that would be measured with a field intensity meter, at a point a mile from the antenna. This is clearer, perhaps, if we say simply that the field gain is the increase in field intensity which results when we replace a vertical half-wave antenna with a multi-element antenna. If this happens to be a six-bay turnstile, the increase in field intensity, expressed as a ratio, is 2.07 times.

Thus:

$$\text{Field gain} = \frac{\textit{Field intensity with multi-element antenna}}{\textit{Field intensity with vertical half-wave antenna}}$$

The field intensities are supposed to be measured at a point one mile distant. It can be shown mathematically that a half-wave vertical antenna, fed with a power of 1 kw. will have a signal of 137 millivolts/meter at one mile. Hence, the field gain of any particular antenna can also be expressed as the ratio of the signal it produces per kilowatt at a mile to 137 millivolts/meter.

The power gain is defined as: *The ratio of the powers* that would be required to give the same field intensity at a point one mile distant. Here again it will be

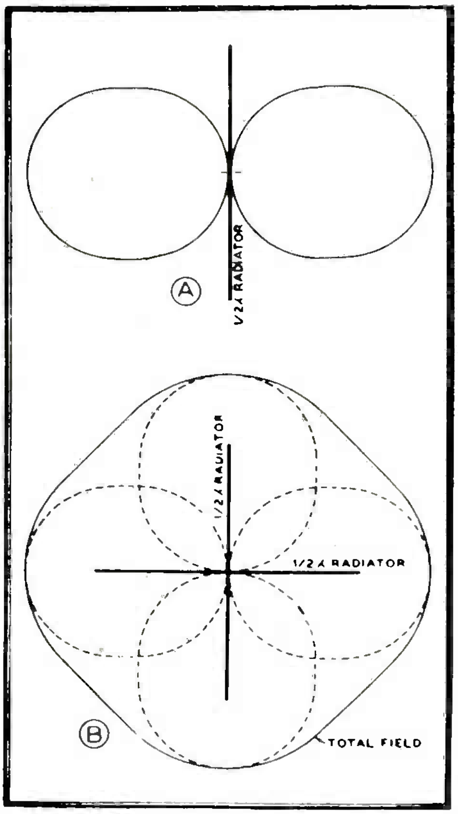


Fig. 4. Radiation pattern from two turnstile elements at right angles.

more easily understood if we say simply that the power gain is the increased power, expressed as a ratio, which we would have had to feed the vertical half-wave antenna to obtain the same increase in field intensity. Thus:

$$\text{Power gain} = \frac{\textit{Power required with vertical half-wave antenna}}{\textit{Power required with multi-element antenna}}$$

It is obvious that there is a simple relation between the *field gain* and the *power gain* of an antenna. It can be shown that for a given antenna, the increase in field intensity at any point is always equal to the square root of the increase in power. If the power is increased four times over, the signal intensity is increased twice. Thus:

$$\text{Power gain} = (\textit{Field gain})^2$$

and

$$\text{Field gain} = \sqrt{\textit{Power gain}}$$

In studying propagation characteristics, engineers find the field gain the easiest to use in caluculations. However, in planning an FM station the power gain is the most useful form since it gives a direct answer to the question of how much transmitter power will be saved by the antenna under consideration.

It should be noted here that the power gain of all multi-element antennas is referred to that of a half-wave vertical antenna and not to a single layer antenna of the type specified. Single layer antennas of the types used for FM broadcasting

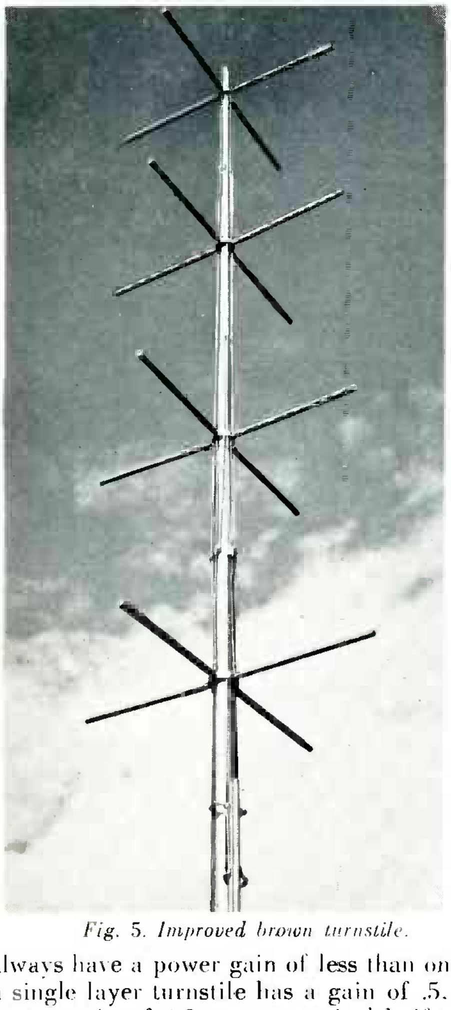


Fig. 5. Improved brown turnstile.

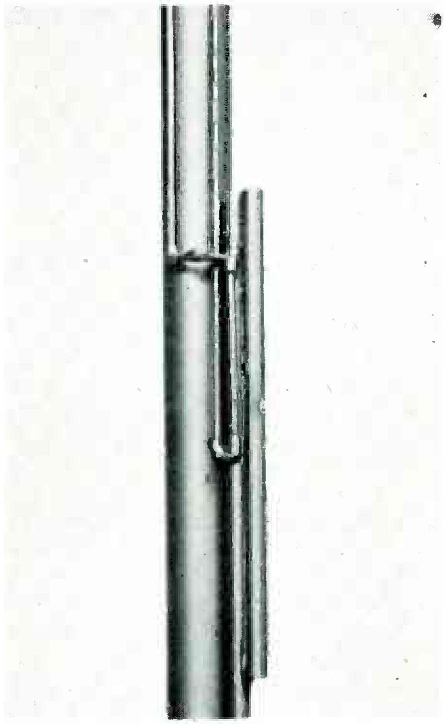


Fig. 6. Phasing unit at the base of the improved array.

always have a power gain of less than one for reasons explained below. For instance, a single layer turnstile has a gain of .5. This means that a six-bay turnstile with a power gain of 4.3 over a vertical half-wave actually has a power advantage of 8.6 over a single-bay turnstile.

PRACTICAL TYPES OF FM ANTENNAS

Originally, both vertically and horizontally polarized transmission were used for FM broadcasting. However, horizontal polarization is now specified and this means that the elements in the antenna must lie in horizontal position. The practical antennas of this type so far devised fall into four general categories: a) the original

Brown turnstile and the improved "coaxial" version, b) modifications of the original turnstile such as the deMars turnstile and the ¾-wave spaced turnstile, c) variations of the circular or ring antenna, and d) variations of the square loop antenna.

All of these types are in use today, although the first two are by far the most widely used.

ORIGINAL BROWN TURNSTILE

The first antenna designed specifically to provide directivity in the vertical plane, as contrasted to the earlier communications-type antennas which were designed for directivity in the horizontal plane, was the original turnstile antenna. This antenna, developed by Dr. G. H. Brown of RCA Laboratories, was described in the April 1936 issue of *Electronics*. The striking similarity to the moving element of a turnstile gate, from which it derives its name, is evident.

The first model of the turnstile was of exceedingly simple construction. Metal rods a quarter-wave long were attached directly to the supporting pole. Four such rods, arranged in 90° spacing about the pole, made up each layer or bay. The complete antenna was composed of from two to ten such layers, depending on gain required, supporting structure, etc.

The action of the turnstile antenna may be described in simplified fashion as follows. Each pair of opposite-placed quarter-wave rods forms a half-wave dipole antenna. Fig. 2A shows the current wave on such a dipole and Fig. 2B the voltage wave. Since the center of the dipole is at zero voltage with respect to ground, the rods can be fastened directly to the grounded pole at this point. Power is fed to the dipole by connections shown in Fig. 3, spaced at the proper distance from the pole to provide an impedance match. The horizontal field of a single one of these dipole antennas is shown in Fig. 4A. Obviously this would not be satisfactory for broadcasting practice where, as a rule, uniform transmission in all directions is desired. This is the reason for the second set of rods in each layer. When this second set is fed an equal amount of power which is, however, of opposite phase, the patterns of the two radiating dipoles are as shown by the dotted lines of Fig. 5B and the combined field is the solid line. The latter, it will be noted, is very nearly a circle.

In order to achieve the kind of horizontal directivity noted in Fig. 1, all of the dipoles in one plane must be fed equal amounts of the same phase. If the layers are spaced a half-wave apart, this can be conveniently done with a transmission line which is crossed over between each layer, thereby counter-balancing the phase shift that occurs along this line between layers. Two such lines, one for each set of dipoles, run up the tower, twisting around it as they go and being set off from the tower by stand-off insulators. At the base of the tower, the two lines are fed oppositely phased currents by one of several methods.

The first model of the turnstile antenna was carefully tested and a large number of field measurements made of signals transmitted with it. These tests indicated that the turnstile met the primary requirements of a good high-frequency broadcast antenna in that it had a uniform directivity pattern in the horizontal plane (i.e., the same signal strength in all directions), and offered a convenient and easy means of obtaining high directivity in the vertical plane (i.e., high-gain in useful signal strength). In addition, it was obvious that such an antenna had the other necessary qualities of simple mounting and rugged construction.

Because of its unique qualities, the turnstile was adopted by almost all of the pioneer FM broadcast stations and its familiar contour has become a symbol of FM to engineers and layman alike.

IMPROVED BROWN TURNSTILE

Field experience with the original turnstile antennas. as shown in Fig. 3, brought out two minor drawbacks. One of these was that the matching of the feeder lines was extremely critical and required that adjustments be made in the field. As most stations lacked experienced personnel, this was a major difficulty. The second was that the open wire transmission lines invited the formation of ice which tended to increase the wind resistance of the antenna and to detune the radiating system.

To overcome these difficulties, Dr. Brown and his associates at RCA Laboratories developed a modification of the original turnstile in which coaxial transmission lines replaced the open wire lines previously used.

A photograph of the newest turnstile antenna, using coaxial feed lines, is shown in Fig. 5. Four coaxial lines phased progressively 90° apart, run up the tower from a phasing unit at the base of the array, Fig. 6. All of the quarter-wave radiators pointing north are fed from one of these lines, all those pointing east from another, and so on. The radiators in layers 1 and 2 are fed from a point in between layers. Similarly, radiators in layers 3 and 4 are fed from a point between these. In this way, balanced power distribution is assured.

The arrangement of radiators and lines in the new turnstile has several advantages. The first is that the antenna can be completely "pre-tuned" during fabrication. It comes as a finished assembly, with no engineering required in its erection. The second is that since phasing is accomplished at the radiators, there are no phasing adjustments to be made at the bottom of the tower, all line impedances are exactly matched and there are no standing waves on the lines. The third is that the frequency range, both as to line termination and field intensity, is much wider than is required for wide-band FM, so that the system is not critical in any respect.

Insofar as the radiating properties of the new turnstile are concerned, these are the same as in the original design. The field is very nearly symmetrical; the gains achieved compare favorably with the theoretical values. In the gain that can be achieved within practical limits, the new turnstile exceeds any FM antenna yet devised. RCA engineers believe that wherever the supporting structure will allow the use of a multiple-layer turnstile, this antenna is to be preferred over all other types.

The new turnstile is furnished as a "package" item, including pole, radiators, transmission lines and, if desired, lights, steps, and sleet-melting units. This is of great advantage since the cost and labor of cutting and fabricating all the necessary parts of an FM antenna is one which few stations will wish to undertake. This new design was introduced just previous to the war, and hence not many were built. Nevertheless, the same half-dozen which were installed have given excellent performance.

Fig. 7. Characteristics of the Coxial Turnstile

Number of Layers	*Power Gain*	*Field Gain*	*Maximum Pole Height Above Tower or Roof*	*Minimum Distance in Tower or Roof*	*Outside Diameter Pole Butt*	*Estimated Complete Weight of Pole, Elements, Transmission Lines on Turnstile, Etc.*
2	1.25	1.12	20 ft.	4 ft.	5 ins.	725 lbs.
4	2.75	1.64	42	8	8⅝	2,100
6	4.24	2.037	64	10	11¾	3,500
8	5.75	2.38	87	13	14	6,000
10	6.70	2.6	110	18	16	8,700

Some of the characteristics of the new turnstile as manufactured by John E. Lingo & Son are shown in the table of Fig. 7. Power gains of the turnstile as compared to other types are shown in Fig. 8.

MODIFICIATIONS OF THE TURNSTILE

A number of variations of the original turnstile are in use and deserve to be mentioned briefly. The best known of these is the deMars turnstile used by the Yankee Network and others. The essential difference between this antenna and the turnstile is in the use of a separate coaxial feed line for each radiator. Thus, for a six-bay antenna there are 24 feed lines. These lines run all the way down the tower to a phasing room at the base. The advantages claimed for this system are that it enables the phasing to be done at a sheltered and convenient point and a more accurate match is obtained. As compared to the original turnstile, these were quite important advantages. It is believed, however, that they represent no advantage over

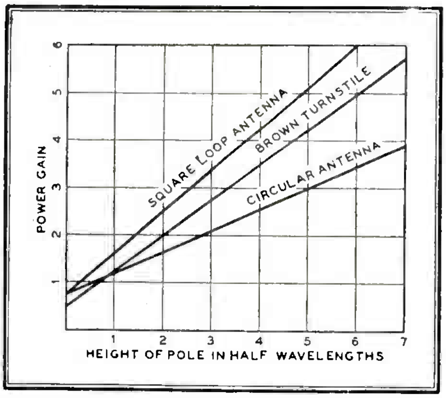


Fig. 8. Power gain plotted against required height of supporting pole.

the new design. On the side of disadvantage there is the cost and work of installing the greater number of lines and the extra wind resistance and ice hazard which they form.

The antennas designed by deMars also incorporate a number of structural innovations. The most notable of these is the antenna on Mt. Washington in which, because of the extreme weather conditions and continued ice formation, truck springs were used as the radiating elements.

Another variation of the turnstile which had a short vogue employed a between-layer spacing of three-quarters of a wave-length, instead of the half-wavelength spacing of the original. It can be shown mathematically that a three-quarter wave spacing gives a slightly greater gain than the half-wave spacing and, therefore, an antenna of this type has more *gain per layer*.

It should be noted, however, that gain per layer is not the true criterion of worth. Actually, extra layers add little to cost or weight; what is most important is the overall height of the supporting pole, since it is the weight of this pole and the means of mounting it that determine what can and what cannot be used on a given structure. In this respect, the three-quarter wave spacing offers no advantage. For instance, a three-layer antenna of this type requires a total pole length of one and one-half wavelengths (30 feet at 45 mc.) and has a gain of 1.6, whereas a four-layer antenna of one-half wave spacing also requires one and one-half wavelengths and has a gain of 1.65. Moreover, the three-quarter wave spacing requires either separate feed lines for each radiator, as in the deMars antenna, or else a full wavelength of line between layers, which is an unwieldy alternative. For these reasons this type of antenna is not widely used.

CIRCULAR OR RING ANTENNAS

The circular or ring antenna which has recently achieved some prominence is essentially a folded dipole antenna bent around into a circle.

Folded dipole antennas have been usd for some time for communications purposes. They have been used for a number of years for television transmission at the Empire State Building.[2] The general advantages of this type of antenna have been discussed by P. S. Carter[3] of RCA Communications in an article entitled "Simple Television Antennas" published in the *RCA Review* for October 1939. In Fig. 9A the folded dipole is shown in its simplest form. Essentially it consists of two half-wave radiators, one of which is broken at the center and the system fed at this point. Since the two radiators are mounted very close together, the currents in them flow

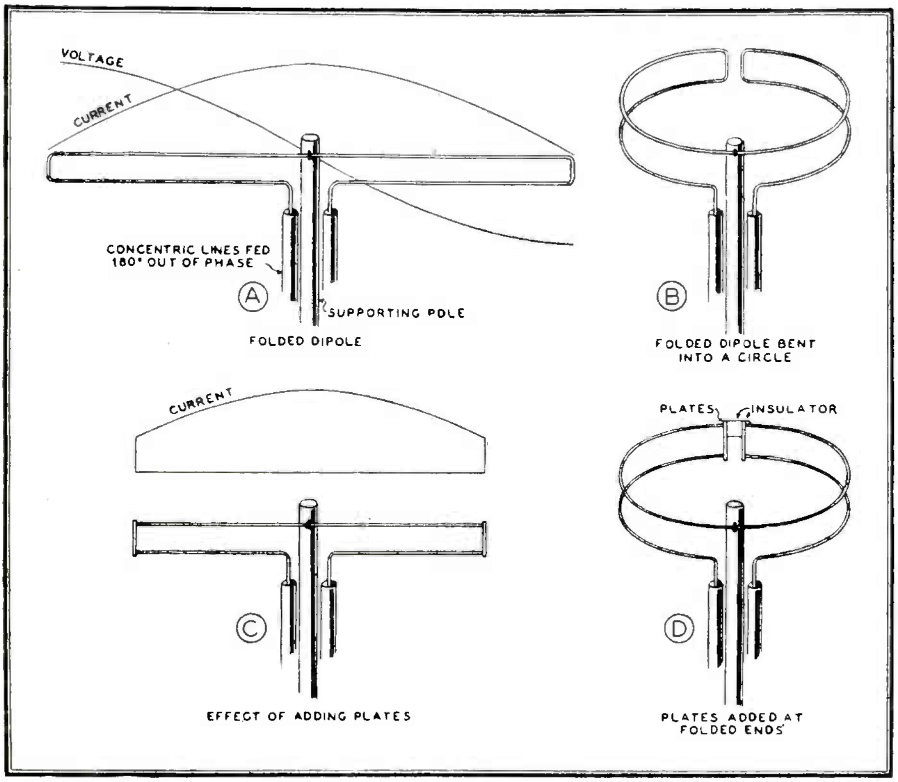


Fig. 9. Design details illustrating evolution of the circular antenna.

in the same direction and the current distribution on both is a sine wave as shown by the light line. As the voltage to ground at the center is zero, the unbroken radiator can be attached directly to the supporting pole at this point. The ends of the lower radiator can be fed power by an open balanced line or by a pair of concentric lines, oppositely phased as shown in Fig. 9A.

The radiation characteristics of the dipole as shown in Fig. 9A are the same as that of one pair of radiators on the turnstile. The pattern in the horizontal plane is a figure 8 which, of course, is undesirable for broadcast purposes. To overcome this and attain an approach to uniformity of transmission in all directions, the dipole is bent around into a circle as shown in Fig. 9B. This, however, will not of itself give a circular pattern as the current distribution is not uniform around the radiator. To improve on this situation, a pair of large metal plates is fastened at the folded points as shown in Fig. 9C. These plates have the effect of adding end capacity to the radiators and change the current distribution something as shown in Fig. 9C. The current is now approximately uniform around the loop and the signal radiated approaches a circular pattern to the same degree.

The circular antenna presents a neat appearance and has a higher gain per layer than the turnstile. However, in order to keep down the mutual impedance, the layers must be placed a full wavelength apart. Thus, the *gain per height* is less than with the turnstile for cases when more than one layer is used. For instance, a three-bay circular antenna which is two wavelengths high, 40 feet at 45 mc., has a power gain of 2.6, whereas a five-bay turnstile having the same height has a power gain of 3.5. As noted before, it is the height which is the important parameter, since it is the weight and upsetting moment of the supporting pole which determine the practicality of a given design.

Fig. 10. Six-Layer FM Antenna at WBRL, Baton Rouge, on AM Tower.

The off-center mounting of the rings is also a disadvantage in that it makes for mechanical and electrical dissymmetry. Thus, while the loops are of the same approximate weight as the turnstile elements, the fact that they are off-center requires a stronger supporting pole. The dissymmetry also affects the electrical properties in that currents are induced in the pole which are opposite in phase to those in the radiators. Because of these mechanical and electrical difficulties, it is believed impractical to go beyond three or four layers in this type of antenna.

SQUARE-LOOP ANTENNAS

The antennas previously described are all mounted on supporting poles of the flagpole variety. Where such a pole can be mounted on an existing structure or where the ground height is in itself sufficient, one of these standard types of antenna should definitely be used.

In some cases, it will not be possible to mount a flagpole on the building chosen —either because the building structure will not support it, or because of the configuration of the building itself. Similar difficulties sometimes arise when it is desired to mount an FM antenna on an existing AM tower. Most such towers were not built for and will not support the heavy pole used with multi-element turnstiles or ring antennas. In such cases, several variations of what, for want of a better term, may be called a square-loop antenna have been used with some success.

The square loop antenna consists of four dipole radiators arranged in the form of a square which may or may not be closed at the corners. In the case of a large building tower, the dipoles may project from the four sides. They may take the form of folded dipoles or of simple dipoles fed at the center, according to the method used to obtain impedance matching. Several antennas of this type have been designed by RCA engineers and are now in operation.

A type of square loop antenna which can conveniently be mounted *around* a standard AM broadcast tower has been designed by Dr. G. H. Brown of RCA Laboratories (U. S. Patent No. 2,207,781). While various configurations are possible, including a three-sided type, the most usual arrangement is to employ 4 sides.

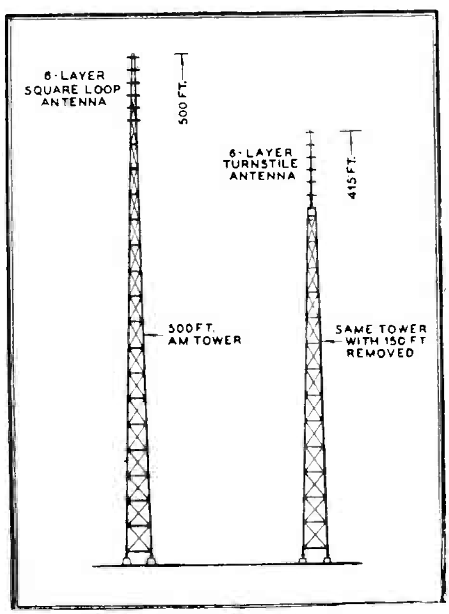


Fig. 11. How 85 ft. in height were saved by use of square loops.

The radiators are half-wavelength sections supported at the ends by pieces of tubing which run diagonally across the square and are attached near the center to the framework of the AM tower. These supports have shorting bars placed at points a quarterwave in from the corners. Since the points where the shorting bars are located represent voltage nodes, the supports can be at ground potential.

Several one-and two-layer arrays of this kind have been built, and at WBRL, Baton Rouge, La., there has been in operation for the past three years a six-layer antenna of this type. In this case, the FM antenna is mounted at the top of a 500-ft. AM tower, as shown in Fig. 10. The original intention had been to put a six-bay turnstile at the top of this tower. However, querying the tower manufacturer brought out the fact that to provide adequate support for the turnstile, some 150 ft. of the tower would have had to be removed. The saving in tower height effected by this use of the square-loop antenna is illustrated in Fig. 11.

The *gain per layer* of the square-loop antenna is greater than that of either the turnstile or the ring antenna. The reason will be evident when it is noted that each layer has effectively twice as many radiators as the turnstile. Moreover, because the vertical radiation is very low, the layers can be mounted at half-wave intervals. Comparative gains of the several types of antenna are shown in Fig. 8.

Despite its high gain and mounting advantages, however, the square-loop antenna should be considered only when the other types cannot possibly be used. There are three reasons for this statement. First, such an antenna must be laid out and probably built on the location. This is because each one will be slightly different as to arrangement and mounting details. Second, the tuning is quite critical and must be done with the radiators in place. In the case of WBRL the top section of the tower was set up on the ground and preliminary adjustments made before it was raised to the top of the tower. Third, it is very difficult to design such an antenna to withstand a heavy ice load—although this, of course, does not mitigate against its use in the South.

Lindenblad, *RCA Review*, April, 1939.
[3] Simple Television Antennas, *RCA Review*, October, 1939.

SUMMARY

In summing up the information on FM antennas developed out of experience to date, the best advice that can be given to station engineers setting out to plan an FM station is:

1. Choose an antenna which can be purchased complete—a packaged item.
2. Select an antenna type which can be pretuned so that engineering adjustments will not have to be made at the time of installation.
3. Get as much antenna gain as possible, but remember that the building or structure on which the antenna is to go may set a definite limit.
4. Note that it is the height of the supporting pole which determines the type of antenna that can be erected—hence *gain per height of pole* is the true figure of merit.
5. Remember that adequate provision must be made for wind-resistance and icing conditions, where they exist.

A second article on FM antennas, giving further quantitative design data, will appear in an early issue of FM AND TELEVISION.

Editor, FM AND TELEVISION

TELEVISION TODAY AND TOMORROW

Reprinted from Air Tech

By Ben Talbot

AIRPLANES and electronics will have a closer affinity after the war than ever before. Aside from the multiple electronic controls, the robot pilots, beams for blind flying, and automatic landing devices, the air passenger will be constantly kept conscious of electronic wonders by the television receiving set which will be built into the air giants of the future.

Right now, technical men are asking, "How good will the post war television picture be?"

The present picture, consisting of images made with dots similar to the halftone engraving, is equal to a fifty-line screen and has the equivalent of 250,000 dots in each picture. Television projects thirty such pictures a second, compared with 24 in motion pictures.

However, there is a problem in television image projection that does not occur in movies. Television pictures, due to the fact that they are made with rows of light and heavy dots, which are projected from the base of the cathode ray tube onto its face, depend for clarity on the number of such dots.

The present standard television image, as you see it on th television set, is made up of 525 dots horizontally, and 480 dots vertically. Technically this is called a 525 line picture. With 250,000 dots in each picture (to be exact, 252,000, or 525x480) the number of dots per inch is approximately that of a fifty-line halftone cut as used in printing. Blowing up this picture to the size of an eighteen-inch screen results in a loss of definition because the dots and the white spaces between them also are increased in size and their density is impaired. Yet an eighteen-inch screen, to be viewed from six or eight feet distant, is about what will be required.

To overcome the lack of definition, a greater number of dots per picture, furnishing a finer screen, with the dots closer together, has been proposed by the Columbia Broadcasting System.

CBS issued a report recently in which it laid before the public the facts about post war television which it claimed "has hitherto been almost wholly the inside knowledge of engineers." This report proposed increasing the number of lines to approximately 750 per picture, which means about 585,000 dots per picture.

On the present television transmission of thirty pictures a second, with 250,000 units per picture, there are 7,500,000 dots on the television screen to make one second's pictures. With the increase in lines or dots per picture, the transmitter would send out 17,550,000 dots per second, which would give pictures of about the fineness of an eighty-line halftone screen in printing.

CBS claims that this higher definition picture could be increased in size to eighteen inches without impairing definition and that it would practically eliminate eye strain which becomes apparent on present television after about two hours.

To accomplish the finer-definition transmission, however, it would be necessary to transfer the television broadcast band to the very high frequencies in the radio spectrum. The frequency of electronic impulses controls the number of dots per picture per second. The present television broadcast band in the radio spectrum runs up only to the 400 megacycle limit. CBS proposed moving the whole television band above the 400 megacycle band and in this area the company claimed that not only would the picture be improved, but there would be more room for more stations.

However, the whole television industry is alive to its possibilities and obligations after the war and the proposal to move the broadcast band to the higher frequencies has not stopped experimentation in the present band and with the present equipment. All the companies, including Dumont, NBC, CBS, General Electric, Balaban & Katz and the Don Lee studios have gone forward with programming plans.

With respect to program policy, Worthington C. Miner, manager of Columbia Broadcasting Television Department, recently stated: "The primary obligation upon the producers of television programs is to recognize that television is itself a unique and individual form. It cannot be made to fit into preconceived patterns of radio, motion pictures or the theater. For this reason there is no guarantee that any type of program, or any type of acting technique, can immediately be transmitted into effective television. The stage play demands a more pictorial treatment, the stage actor must be untaught the instinct of projection. The radio scrip is dependent upon a monosensory impression, which is a complete denial of television's basic contribution. The radio actor must learn not to listen to his own voice. The motion picture form is uneconomical because it is capable of a wider coverage than is feasible within the confines of a continuous performance within a single studio.

"In each of these media, however, there is some basically sound principle of showmanship which may be serviceable in the creation of program patterns for television. In 1941 television station WCBW undertook to borrow the pattern of the radio quiz as a television form. Most persons with a background of radio were convinced that the effort would fail, that the quiz was so generically radio that it could never be adapted to another medium. The first few months of quiz production on television were dismal indeed, because the quiz-master brought to television a radio sense of pace. Over the course of two or three months a new pattern was created for television quiz, taking advantage of visual opportunities.

"In approaching any type of entertainment for television, it is necessary to recognize that many blunders will be made, much time will be spent before the first fully polished television form will be brought into being."

A survey shows that WCBW has been able to type as more or less "telegenic" about five or six programs. Topping all of these, of course, is the news program, which lends itself automatically to television because illustrations, maps and moving arrows, pointers, photos and the like can accompany the broadcast of the newscaster. Everett Holles, the news analyst at WCBW, usually reads his material and, after a short rest on him at the opening of his fifteen minute broadcast, the cameras pick up maps and photos to visualize what he is broadcasting.

The Visual Quiz show is another program that has won wide popularity and rates as the second oldest program on television with eighty-six productions on CBS. Another distinctly television program is Opinions on Trial staged every Friday night at station WCBW.

All present television transmissions are now in black and white. The Columbia Broadcasting System, however, has ready for post-war introduction a three-color sequential system with electronic color mixer and automatic color phasing. With the proposed system of higher frequency television, coupled with color, the post-war video image should show as much advance over present (unimproved from pre-war) as the smooth running high compression motor car over the old chugging four-cylinder affair of the era prior to the last war.

RECORDING SOUND ON FILM

Reprinted from Electronic Industries

By Gilbert Sonbergh, Associate Editor

Factors in the selection or design of equipment for recording and reproducing television motion picture sound

THE commercial sound motion picture is less than two decades old, although the idea itself dates back nearly half a century. Motion picture sound track was recorded in 1900, although satisfactory reproduction of its record was not possible until the later development of electronic amplification. Today, the technic of simultaneously recording motion pictures and their accompanying sound has reached a high state of perfection, thanks largely to the vacuum tube. With the advent of large scale television, the sound motion picture will have ample opportunity to repay its debt to the science of electronics.

It seems inevitable that the expansion of television ultimately will result in greatly increased use of sound motion picture recording. News events* worth telecasting are more likely to occur during the day than at night, but they must be shown during the evening hours for widest audience coverage. Events occurring simultaneously at different locations must be separated in time for presentation via the television transmitter. In live dramatic presentations, television studio limitations can be overcome by interspersing previously filmed shots made outdoors or under other conditions not feasible on the stage. In short, the commercial success of home television may greatly extend the production and utilization of picture and sound-on-film recording equipment. Certain deviations from established technics may be desirable for optimum television results.

In general, the ideal of motion picture sound recording is to reproduce rather better than faithfully the sounds fed into the microphone. There are several good reasons why it is not sufficient merely to reproduce the original. First, the conventional commercial recording system is monaural, or without perspective. Humans with two good ears and related mental processes are able to single out a sound to which they desire to listen, differentiating it from background noise and other sounds partly because of minute phase differences resulting from the time-difference in the arrival of the desired sound at each ear. This, obviously, the single-channel recording system cannot do.

Second, reverberation time of the auditorium (or living room, in which the film is to be reproduced) is just as much a factor in the final result as is reverberation time in the studio where the recording was made, the final effect being the sum of the two.

Third, the volume range of the reproduced sound must be less than that encountered in nature, because of equipment limitations as well as audience comfort. Fourth, raising the average volume level of the reproduced human voice, which must be done in theaters or large rooms, introduces effective amplitude/frequency distor-

* The Republican National Convention in Chicago, middle of June, was handled in this way, motion pictures being flown to New York for transmission from WNBT and other stations.—Editor.

tion, making the reproduction boomy or unnatural. When voices are raised in real life, the energy distribution center shifts to the higher sound frequencies.

Fifth, sound to accompany pictures allows no play of the listener's imagination, as in radio broadcasting, but must "match the picture" at all times. An outdoor shot,

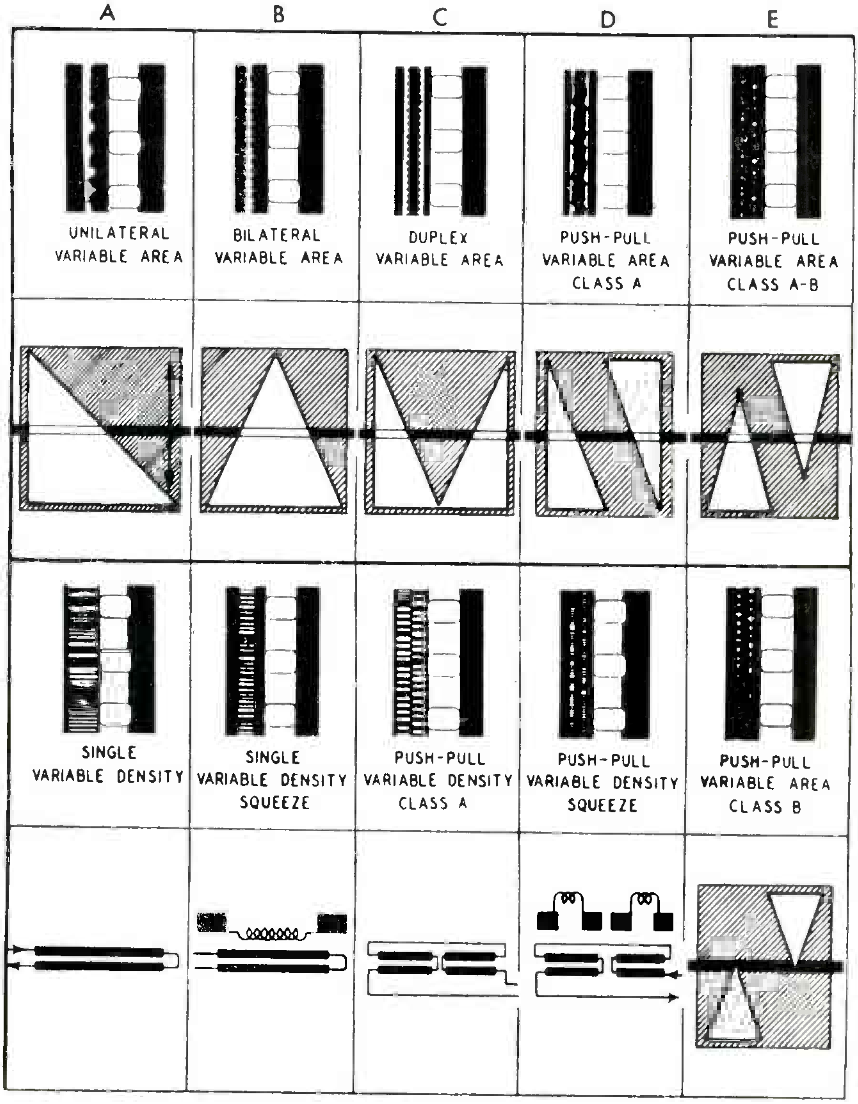


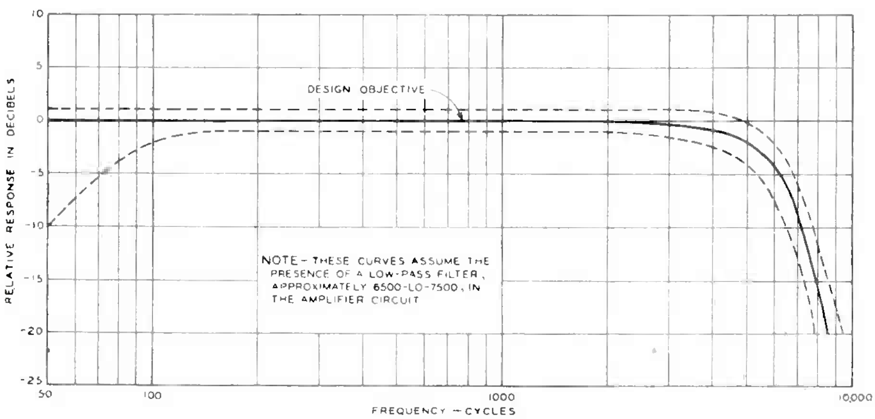
Figure 1.

Positive prints of representative sound tracks. 1-A is simple variable area track, made by deflecting wedge-shaped light-beam across slit. 1-B and other variable area tracks are produced by changing shape of light source image with masks, as shown under each track. Arrow under 1-A shows direction of beam deflection from mean (no signal) position, as well as direction (either way) of film travel under slit. The push-pull tracks require two beams, deflected as a unit. Classes of push pull tracks are axactly analogous to classes of push-pull v-t amplifier operation, having to do with the proportion of the cycle during which each of the two reproducing photo-tubes receives light and passes current. Track 2-A is conventional density track produced by ribbon-type light valve, to which auxiliary shutter-type noise reduction has been added in 2-B. Class A pp density only is shown, as other classes are similar in appearance. Both types of light-modulators are described in accompanying text. Sound tracks from ERPI chart.

for example, must sound like the outdoors, even if it has been photographed inside studio walls. These and other limitations will be taken up in more detail in the following.

In brief, a motion picture sound recording system includes a microphone, an amplifier, an optical system to provide a recording light in the form of a concentrated, thin, rectangular beam or slit, a light modulating device to vary the amplitude or intensity of the beam, and an accurate mechanical system to impart uniform motion to the film recording stock, providing the linear time-base required.

To this equipment may be added various equalizers and filters to correct for inherent deficiencies in various parts of the system or to introduce intentional amplitude/frequency distortion to achieve certain effects. Facilities for mixing the output of several microphones or preamplifiers may be provided. The main amplifier



Proposed American War Standard for 16 mm. projector response. Hi cutoff is to reduce dirt noise.

usually incorporates some form of avc or volume compression to simplify the work of the sound-recordist "riding the gain" and avoid overloading the amplifier or light-valve, overexposing the film itself in variable density recording, or "clipping" high-amplitude wave peaks on a variable area track.

SOUND TRACK TYPES

The simplest form of variable area sound track is an oscillogram of the amplifier output with the area to one side of the trace dark and the area to the other side transparent. Such a track is produced by a mirror-galvanometer as the light-modulator, varying the height or length of the illumination of the slit under which the unexposed film passes.

The simplest form of variable density sound track consists of transverse striations or variations in density corresponding in opacity to the instantaneous values of the amplifier output. Such a track may be recorded either by a gas-discharge lamp in which the light output varies with the impressed voltage, or by a light-valve which varies the width of the recording slit above or below a mean value corresponding to the ac axis of the sound wave.

The gas-discharge device is no longer used because of the limited light output, lack of linearity, and poor dynamic response at the higher audio frequencies. A conventional Wente type light-valve consists of two thin duralumin ribbons in a magnetic field. Passing the signal currents through the two in opposite directions causes the separation to increase or decrease from the mean spacing, admitting more or less light to the film. Many variations of these simple sound tracks are possible. A few representative types are illustrated.

Much has been written about the relative merits and demerits of the two types of sound records. The Hollywood studios are perhaps equally divided between variable density and variable area. Producers of commercial or industrial films favor variable area. The best possible area recording compared with the best possible density recording probably would yield identical results, but relatively it is easier to secure a good variable area track.

The H&D curve of a photographic emulsion is a record of the material's opacity plotted against exposure time, under given conditions of development. Such a curve is quite analogous to the anode-current vs. light-flux curve of a phototube or the plate characteristic curve of a vacuum tube. At the toe of the curve as well as at the shoulder, a change in exposure fails to bring about a corresponding increase in opacity sufficient to maintain a linear relationship.

As with single-ended vacuum tube amplifier operation, the variable density sound record's density variations, including positive and negative peaks, must be kept on the straight-line portion of the curve if audio distortion is to be avoided. This requires stringent correlation between exposure and development technics in variable density recording and an absolute accuracy in both. Variable area, while not automatic, merely requires a clean white and a good black, for average quality work. It is much less critical with regard to placement on the H&D curve. In the early days of television sound motion picture photography, there is danger that there may be much hasty photography and little cooperation between recordists and film processing laboratories, which conditions definitely indicate the desirability of variable area.

Comparing present-day, improved 16 millimeter picture definition with that of the television process, the latter will probably for some time be the limiting factor on picture quality. Thus, if strict economy should be a factor, 16 millimeter might be used exclusively. On this substandard film size the status of the art of variable area recording is considerably better than that of variable density. Whether the recording be on 16 or 35 mm. film, a possibility worth considering is that of shooting at 30 frames per second instead of 24, improving sound track quality and the smoothness of pictorial motion as well.

Since the motion of film must be intermittent for picture making or projection and uniform for sound recording or reproduction, the sound record is always placed a convenient distance ahead of the corresponding picture on the film. This inherent requirement imposes restrictions on the cutting, splicing, and editing of finished sound film because there is no practical way physically to separate the sound track from the adjacent frames of pictures.

To escape this limitation, most sound motion picture work utilizes the double system, in which pictures and sound are recorded simultaneously on two lengths of film running in synchronism through the camera and through the sound recorder. Driving the two units are synchronous motors, selsyn motors or, for field work, a dc interlock type. Another advantage of the double system is that additional sound effects, music or narration may conveniently be added to the original record before it is combined with the picture record in the final print for projection.

The single system has the inherent advantage of simplicity; both records are made simultaneously on the same film in the same camera-recorder, a compact, combined unit. Such equipment is more portable. It has enjoyed considerable use in the newsreel field, where what is often wanted is a truthful record of what took place visually and audibly, without later editing or rearranging. The fact that the sound is wedded to the picture is not a disadvantage under such conditions. Single system must make some compromise between picture and sound track quality, since no one photographic emulsion is ideally suited to both types of records. However, satisfactory results for newsreel-type work can be obtained. It is quite possible that the single system technic would be ideally suited to wide scale news event recording for later television release.

It is safe to say that much of the commercial sound-on-film recording being done today is of poor quality. The modern Hollywood product is generally reliable—it is the non-theatrical type of film, usually released in 16 mm., that often offends. Such prints may be imperfect reductions of older Hollywood products or they may be direct 16 mm. work poorly recorded due to faulty equipment or personnel. Film making in the field, whether originals be 35 or 16 mm., is the type of work which television broadcasters will have to learn. Many variables which have been successfully "tied down" in the film studios still plague the efforts of the non-theatrical film producer, but much of the difficulty is a result of the misapprehension that expensive recording equipment is foolproof.

Factors affecting final sound quality in the projection print may be divided roughly into four categories: Mechanical and optical perfection of the recording unit; quality of the electronic equipment and associated elements such as microphones and mirror-galvanometer or light valve; the film, exposure, processing combination; and the human element in maintenance and operation of the total equipment. If re-recording is employed, these same factors apply to that process as well.

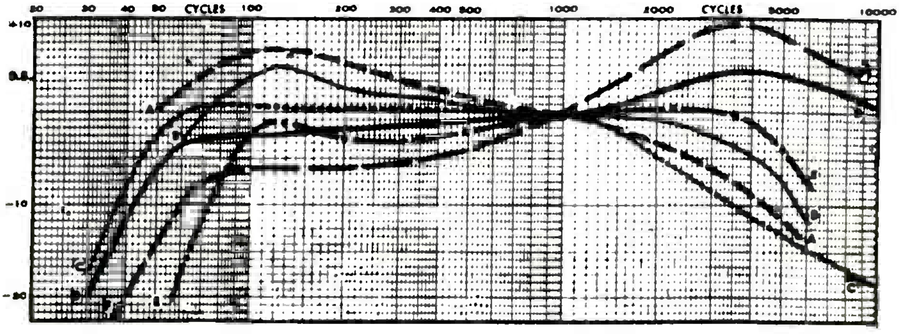
MECHANICAL PROBLEMS

Two major problems in recording equipment design and maintenance are the achieving of uniform film motion and a narrow, sharply focused, and correctly orientated recording light beam. Non-uniform film motion may be divided under three major categories: Slow speed-variations resulting in frequency modulation of the recorded sound audible as "wows"; sprocket-tooth flutter, faster speed-variations; and gear-tooth clash, frequency modulation at higher frequencies.

Good mechanical design minimizes all film motion problems. Sprocket-tooth design attempts to compensate for the inevitable varying degrees of film shrinkage and consequent non-uniform spacing of perforations. Good design and long "running in" procedures reduce gear-meshing and other mechanical troubles. In spite of all such precautions, however, it is impossible to secure sufficiently uniform film flow without mechanically isolating that point in the film path where the recording exposure is made. Usual practice involves passing the film around a rotating recording drum which is part of a flywheel driven through a filter. This filter may be mechanical (springs), hydraulic (oil-drive) or magnetic (lines of force provide the coupling). Each method is capable of good results. Tests of a given piece of equipment for film speed variations are best made with the cathode ray oscillograph and a constant frequency test film.

If an original sound recording is played back on a so-called film-phonograph for the addition of musical score or to "dub in" speech or sound effects not present when the shot was filmed, all of the reproducing and recording units employed must likewise be free of film motion irregularities which would cause any of the various types of frequency modulation of the combined sound track.

Sound recording on film approaches theoretical perfection only as the recording light beam is reduced to a mathematical line having no width. Since the beam must have finite width to provide light for exposure, certain distortion products are inevitably introduced, particularly at the higher frequencies, where the dimensional width of the beam becomes appreciable in terms of the linear distance the film stock travels during one cycle of the frequency being recorded. This is true both for variable area and variable density. In variable density recording, moreover, since the wanted signal causes varying exposure by increasing or decreasing the mean or no-signal width of the beam, high frequency sound signals are further distorted with increasing amplitude because of too great widening of the beam on that side of the signal's ac axis calling for more light and exposure.



Typical pre-war 16 mm. projector performance (Victor Animatophone). Curve D, amplifier alone, tone control normal; C, low; F high. Curves B and E indicate overall response, at normal and high tone control settings, to frequency film whose inherent characteristic is given in Curve A.

A satisfactory compromise between the requirements of frequency response and recording light efficiency, using presently available recording emulsions, is .0005-in. slit-width for variable density and .0002-in. for variable area on 35 mm. A still further downward revision of these figures is necessary to secure comparable results in 16 millimeter, due to the reduced linear speed of the film. A high quality direct 16 mm. variable area recorder may use a light beam only slightly wider than one ten-thousandth inch. These slit widths are achieved by optical reduction of the actual physical slit or mask image.

Sharpness of the beam at the film surface, or clear demarcation between the area of light and the areas of no light, is a prime requisite of the optical system, since any light scattering would effectively increase the slit width. Accurate focus and precise azimuth orientation at 90 deg. to the direction of film travel are other requirements. Any adjustments, of course, must be made under a suitable microscope. Certain types of recording units, adjusted during manufacture and sealed, require no field servicing under conditions of normal operation. Highest quality is obtained when ultra-violet is used for the recording, since its effect on the emulsion is to confine the exposure to the surface and reduce diffusion effects.

Suitable microphones for sound recording on film are conventional types with a rather narrow unidirectional characteristic and substantially uniform output over the required audio frequency range. Except for noise reduction circuits, amplifiers for sound-on-film are likewise conventional high-quality components, "flat" to eight or ten thousand cycles. It is important that the output contain very little total harmonic distortion or phase distortion since these products will be added to distortion products contributed by the film itself, not to mention the reproducers.*

*From studio to audience, the sound may pass through two acoustical states, six mechanical, four electrical, six optical, four chemical, and one radio wave energy stage, yet the final total harmonic distortion should be held to three or four per cent!

Since very little power output is required for operation of a light valve or mirror-galvanometer (on the order of 1/10 watt) the problem is not complicated. Recording amplifiers frequently use push-pull throughout to minimize second and other even-order harmonic distortion. Volume-compression circuits help prevent overmodulation of the film record. Transformer coupling has been popular in the design of motion picture electronic equipment but equal or superior results at lowered cost and with less weight have given impetus to the use of straight resistance coupling wherever impedance matching problems are not severe. Inverse feedback is widely employed to provide uniform output over a wide range of input levels and to reduce distortion.

One of the most important distinguishing features of electronic equipment for motion picture recording work is the almost universal employment of some scheme for film-noise reduction.

In variable area tracks, the necessity for noise reduction will be evident upon consideration of the fact that, during reproduction, any dirt, dust, scratches, or partially exposed, developed silver grains obscuring the transparent area will cause unwanted modulation of the scanning light beam. Similar defects on the dark side or portion of the track will have little effect on reproduction because this exposed portion is nearly opaque. The common form of noise reduction operates to reduce the lateral dimension of this clear portion of the track to a value just sufficient to accommodate the peak amplitude of the envelope or oscillogram of the sound being recorded. This may be done in either of two ways.

If a portion of the amplifier output be rectified and filtered, a direct current is obtained whose value is in proportion to the average amplitude of the ac signal. This dc may be applied either to the mirror galvanometer or light-valve or to another galvanometer actuating one or two spring-tensioned shutters which under no-signal condition close down on the illumination from the outside of the track, opposite the side corresponding to the ac axis of the oscillogram, or both sides in bilateral or variable density work. This will be made clear by inspection of drawing 1-A in Fig. 1, if it is remembered that this is a positive photographic print of the track as exposed in the recorder. In the bilateral track, 1-B, the biasing current may conveniently be applied to the galvanometer itself.

Any such system reduces noise by maintaining a constant signal to noise ratio for any level of modulation amplitude. If no noise reduction is used, on low level modulation the recorded envelope occupies a small portion of the lateral dimension of the track and dirt or silver grains on the wider clear area introduce spurious modulation of the scanning light beam of a relatively large magnitude.

Since the noise reduction bias is obtained from the signal itself, electrical and mechanical inertia ofen prevent the track-width from "opening up" in time to record the first waves of a large amplitude signal. This effect, known as "clipping," is reduced by designing for the lowest possible time-constant, in the bias amplifier and rectifier circuits, and reducing weight and inertia of the shutter or galvanometer. The problem is not generally difficult.

Several alternative technics have been the subject of considerable experimentation. One method employs two microphones, one a few feet closer to the sound source. The first controls the noise reduction amplifier channel and shutter bias, and, by proper adjustment, opens the track adequately by the time the sound wave has arrived at the second microphone.

In recording variable density track, the bias may be similarly applied to the light valve itself. In this case, the ribbons are closed down under no signal conditions, opening up with increasing signal only sufficiently to reach the proper means spacing to accommodate the negative peaks of the signal at any given amplitude without over-closing and producing "clash." This technic yields a sound recording whose average density is always as light as possible for a given signal-voltage input, so that the print for projection is always as dark as possible. When shutters are used with variable density for the noise reduction current, the so-called "squeeze" track of 2-B is produced.

Another method of noise reduction depends on the fact that most of the film ground-noise is in the higher frequency range. Thus, pre-emphasis in recording and de-emphasis in reproduction of the higher frequencies give some noise reduction without affecting the amplitude frequency fidelity of the signal itself.

The majority of commercial theater sound reproduction systems are not capable of doing justice to the products of the recording systems in general Hollywood use. Most 16 mm. reproducers available commercially are inferior to the best available 16 mm. sound track, made either by optical reduction from 35 mm. or by direct-on-16 recording. This is regrettable from the television standpoint, since much of what will be telecast will probably be on 16 mm. film. Again it should be pointed out that the final distortion in the home is the sum total of all distortion introduced along the line. Television motion picture sound being dispensed at present is not of highest quality, and the available projectors are currently one of the most important limitations.

Only one 16 mm. projector on the market provides for precise focus of the scanning light beam on the emulsion. Since emulsion position of 16 mm. prints frequently varies from the standard (toward the screen) some provision for accurate, pre-set change of focus should be made. Moreover, most 16 mm. projectors are subject to non-uniform film-flow problems of one kind or another. Uniform motion is no less a requirement in the projector than in the recorder.

REFERENCES

"Vacuum Tube Engineering for Motion Pictures," by L. C. Hollands and A. M. Glover, Research and Engineering Dept., RCA, Harrison, N. J.

"Motion Picture Sound Engineering," Research Council, Academy of Motion Picture Arts and Sciences, Hollywood, Calif. New York. D. Van Nostrand Co., Inc.

Journal of the Society of Motion Picture Engineers, Hotel Pennsylvania. New York, 1930 to date.

SILENT RECORDING METHODS

Reprinted from Radio-Craft

By I. Queen

New Developments Will Reduce Noise on Both Disc and Film

JUST prior to the war, sound recording for commercial and home use was rapidly increasing. Many of the larger radio receivers were being sold as combined radio-recorders and reproducers (disc) so that not only could a direct home recording be made, but incoming radio selections could be taken off the air and recorded for future playback. It is natural to wish to repeat the performance of a famous comedian, favorite orchestra or world leader, just as it is for us to photograph faraway places, scenci wonders, friends or important events. The recording of sound or picture enables us to bring forth at will events of the past.

It is confidently expected that the postwar period will bring widespread use of electronic equipment. This will be especially true of television, which is expected to follow within a few years of our conversion to peaceful endeavors. Just as the development of radio brought with it a wide interest in recording on disc, we may expect the advent of television to make us more sound-plus-picture conscious.

We may wish to record our favorite actress, football game or political leader. Possibly the television program may call for a particularly interesting experiment in chemistry, a "how to make it" stunt or the exhibit of a rare document. By means of a sound-on-film camera and recorder we may make a permanent record of the scene as it appears on the television screen and are then at liberty to repeat it for friends who may have missed it or to file it away for future reference.

SOUND RECORDING METHODS

The principles involved in recording sounds are not particularly complicated or different from those with which the radio technician is acquainted. Disc recording is the simpler of the two methods in common use, but film recording is not much more difficult to understand. Many articles have appeared in *Radio-Craft* magazine during the past few years on both subjects. The writer, for instance, covered "Sound on Film" in three parts beginning November, 1937, and "Sound on Disc" in the March, 1941, issue. The former method is used where an accompanying moving picture exists, while the latter is the simpler and less expensive of the two.

The technician and serviceman may well consider recording and reproducing of sound as an extension of radio. He should accordingly be prepared to handle work in these lines. Judging by requests for articles on sound recording it is apparent that high interest exists among *Radio-Craft* readers. Accordingly, this article will describe several new developments pertaining to this field.

SOUND ON FILM

Sound on film utilizes the principle of a narrow light-sensitive track which travels uniformly before a varying light source. Fig. 1-a shows a piece of variable density recording wherein the beam of light extends through the entire width of the track and is varied in intensity either by a mechanical valve or a varying light source. Fig. 1-b is a variable-area recording wherein the light source is constant, but the film area exposed is changed. These changes correspond to changes of acoustic

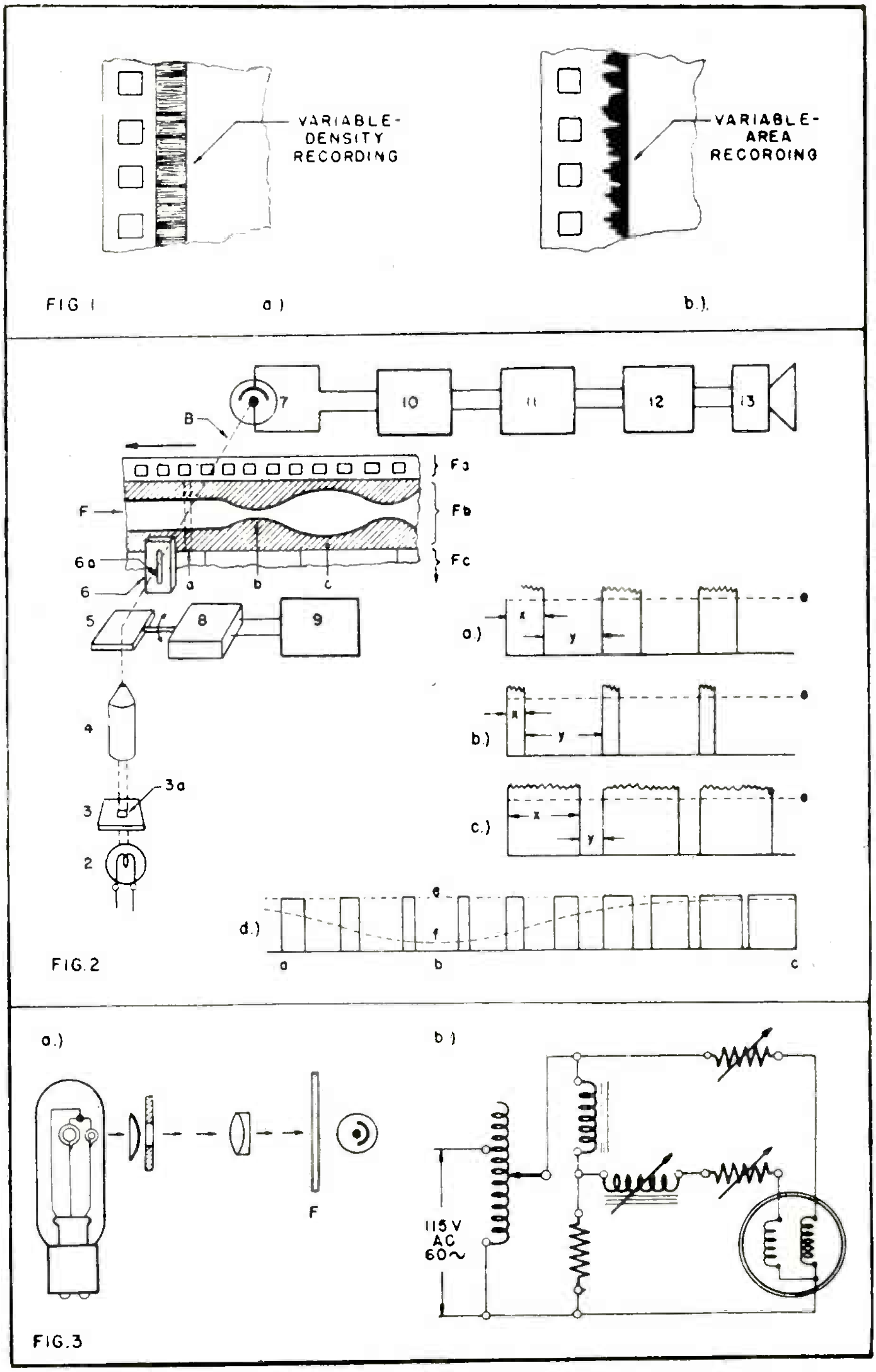


Fig. 1—The two common types of sound-on-film. Fig. 2—An improved system of noiseless sound-on-film reproduction. Fig. 3—A special circuit for eliminating the exciter-lamp hum.

energy at the microphone. During the recording the film is everywhere masked off except for the small slit on which exposure is desired. For reproduction the film travels uniformly in front of a similar slit. A constant light source shines through this slit onto a photoelectric cell so that the modulated beam results in corresponding electrical vibrations.

For less noisy reproduction it is desired that at low modulation levels the area of the slit be reduced so that the grains of the film will cause less noise. Therefore a masking device (in the variable-area method) follows the envelope of the sound so that the exposed area is only that necessary for sound reproduction.

A very recent invention by a Maine man, John R. Cooney, will result in the complete elimination of noise due to film grain, etc. Fig. 2 shows a constant light source, 2, passing through an aperture, 3, and an optical system, 4. A vibrating mirror, 5, is connected to a piezo crystal unit, 8, which is actuated by a 25 Kc. oscillator, 9. The beam after passing through the masking plate, 6, is approximately .001" square and scans from one side of the sound track to the other and the film, on to a photocell, 7. An amplifier, 10, feeds into the limiter, 11, and detector, 12, and then into the loud-speaker, 13.

As a result of the 25 Kc. vibration of the mirror, the scanning beam will travel back and forth across the track. Referring to Fig. 2a, we plot light intensity (vertical) against time (horizontal). The time interval shown as x is that in which the beam travels along the transparent part, y corresponding to the opaque part. Note that the intensity during x is not constant. This is due to the film grain, dust and other imperfections, which will result in noise.

Fig. 2b shows what happens when the film has moved so that section b is now in front of the beam. Evidently, the opaque sections are now greater than the transparent. Fig. 2c corresponds to film portion c. We therefore have pulses of light which the photocell sees as almost constant, but are really modulated by feeble changes in amplitude.

The limiter, 11, is set to a pre-determined level to slice off these irregularities as in Fig. 2d, resulting in noise-free reproduction from the speaker.

Another recent improvement in sound reproduction is shown in Fig. 3. One source of difficulty has always been in connection with the exciter bulb. This requires a heavy current for intense illumination, and an A.C. source provides a loud hum in reproduction. One solution has been to use a source of super-sonic power; which, however, results in a complex arrangement. In the present case we make use of a bulb containing two filaments, a thin one and a massive one.

As illustrated, a 60-cycle source connects to an auto transformer, the output going to the heavy filament (at the right in Fig. 3a). Due to a phase-changing arrangement consisting of choke and resistor, the lighter filament is supplied with a voltage 90° out of phase. The maximum brilliancy of one filament is reached at the instant when minimum brilliancy of the other is attained. With both filaments focussed for the same spot, one overlaps the other, resulting in a minimum of hum. This new type of bulb is due to Robert L. Haynes of Indianapolis.

SOUND-ON-DISC

The utility of disc recording is limited to cases where synchronized moving pictures are not desired. However, this method is well adapted to accompany non-synchronized pictures or single frame pictures. For instance, until the start of the war, great interest was shown by the public in the single-frame cameras exemplified by the Leica. This type takes only one still picture at a time, and because of the compactness, convenience and low cost, this type of photography was most popular.

A method of sound recording which would automatically accompany slide-film strips, such as an explanation of the scene, pointing out certain persons involved or date and time of exposure would naturally be of great interest and add to its usefulness. This method also would have great advertising and commercial possibilities, besides home use.

Such a recording method has been recently patented by Conkling Chedister of Livingston, N. J. Since the speed of the phonograph is uniform, the strip of film must be advanced one frame at a time automatically in step with the talk. Use is made of a super-audible frequency as the control, (above 10 Kc.).

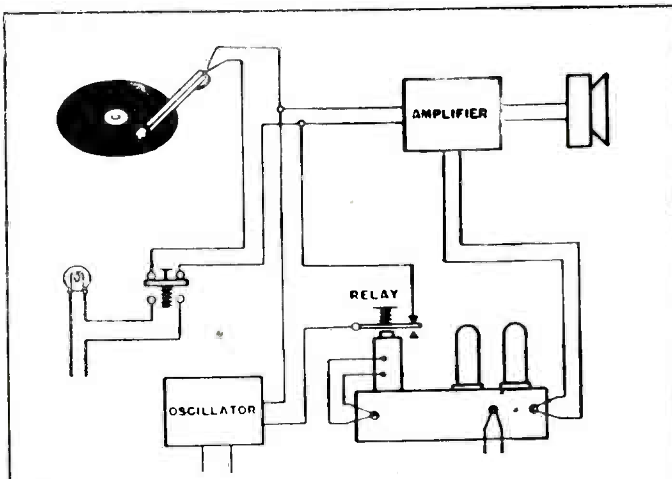


FIG. 4

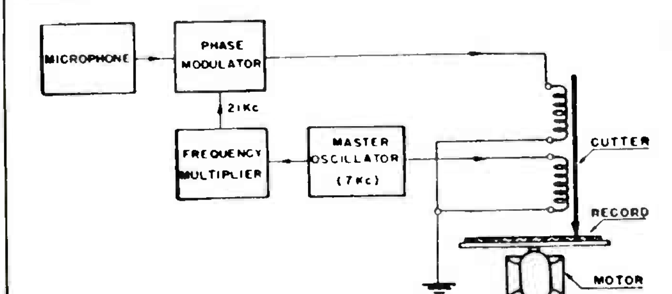


FIG. 5

The sound sequence is recorded through the microphone and amplifier on the disc (Fig. 4). While the microphone is energized, power will be supplied through a second amplifier to actuate the relay which closes and cuts off the source of super-audible oscillations. During periods of silence, however, the relay opens as shown and these oscillations are recorded instead. Normally then, either audible or inaudible frequencies are recorded. Now, when it is desired that the next frame be moved into place, the double-pole switch is thrown so that a completely silent portion exists on the disc. A pilot light acts as monitor.

In playing back use is made of a motor which will move the film strip one frame every time a silent piece is encountered. If either audible or inaudible recording is on the disc, the motor remains stationary. A relay in series with the motor opens while any frequency is recorded. The picture will then be synchronized with comment.

PHASE MODULATED RECORDING

The great advantages of phase modulation are now available for sound recording. An invention by Walter van B. Roberts of Princeton, N. J., makes possible noise elimination and a high fidelity system. Referring to Fig. 5, incoming sounds at the microphone phase modulate a carrier of 21 Kc. The latter frequency is first generated by a master oscillator at 7 Kc., which passes through a tripler. Both the original 7 Kc. and the phase modulated 21 Kc. actuate the cutter as shown.

Fig. 6 shows the set-up for playback. The reproduced frequencies are amplified. They are separated, each passing through its own limiter which slices off any irregularities which in other systems cause noise. The two channels (both now 21 Kc., one modulated) are combined in the phase modulation detector, which converts changes of phase to changes of amplitude. A conventional A.F. amplifier follows. Even though the cutter may discriminate between frequencies, the action of the limiter will eliminate this amplitude modulation and result in high fidelity and wide range without distortion.

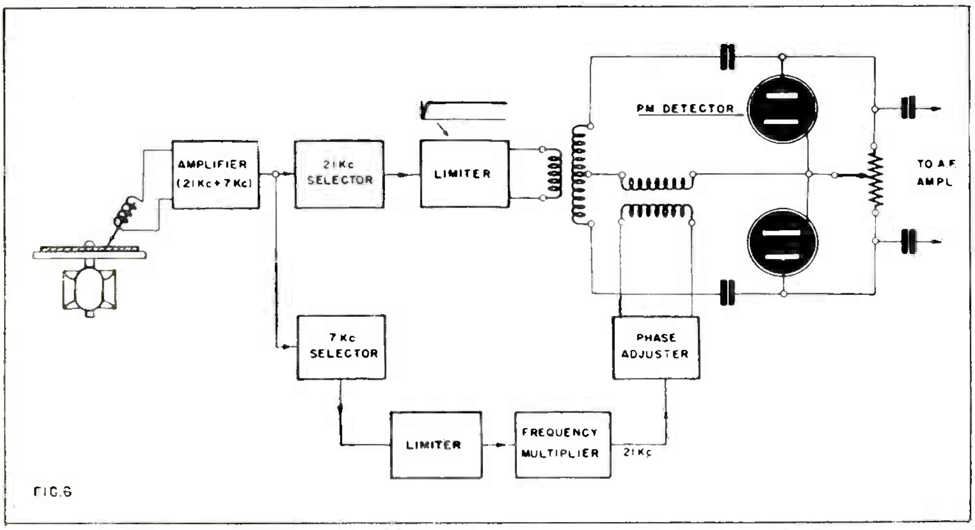


Fig. 6—Playback arrangement for phase-modulated records. Limiters and discriminators cut off noise, give high-quality reproduction.

COMPRESSION-EXPANSION

It is well known that in all types of recording and even in broadcasting, it is necessary that the dynamic range be compressed at the source. In other words, the softer passages must be brought up so that they will not be lost in the noise level while the louder passages must be toned down so that they will not overload the system. This is a necessary procedure due to the limitations of all recorders and, of course, results in destroying to some extent the wide range of the original.

In order to restore the reproduction range, an automatic system has been invented by Chester M. Sinnett, Westmont, N. J. In Fig. 7 we show that the A.F. source connects to a controlled amplifier whose gain depends upon the bias across the rectifier output. This bias in turn depends upon the strength of sounds to be recorded. Therefore, the louder the sound the less the gain.

This bias simultaneously acts upon a reactance tube to vary the frequency of a super-audible oscillator. As the incoming sound becomes louder it raises the oscillator frequency and vice versa (Fig. 7a). Two frequencies are thus recorded on the disc, the actual sound and a super-audible modulated frequency.

When being played back the recorded frequencies are passed through an amplifier (Fig. 8) and separated. The super-audible control frequency goes to a discriminator-rectifier which serves to vary the amplifier gain in a reverse sense (to expand the range). Therefore, the range which has been automatically compressed in recording is now automatically expanded so that the original dynamic range is available at the speaker.

The above-described developments are all very recent and it should be kept in mind that the basic ideas involved are protected by patents.

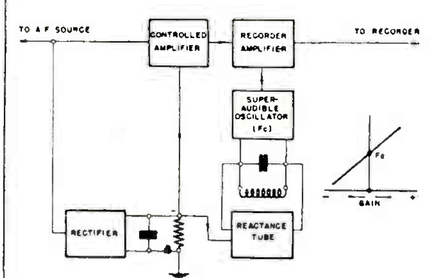


FIG 7

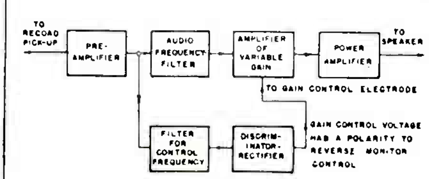


FIG. 8

Knowledge, in truth, is the great sun in the firmament. Life and power are scattered with all its beams.

DANIEL WEBSTER.

MATHEMATICS IN RADIO

Reprinted from Radio News

By Rufus P. Turner

Consulting Engineer, Radio News

A review of the mathematical knowledge required to attain success in the various branches of radio.

MATHEMATICS is in the forefront today. Formerly, all but a scant minority conceded this science unquestionably to be the dullest subject in any school curriculum and promptly abandoned it after stumbling through required courses. But the unprecedented war demands for mathematically-trained technicians have encouraged mastery of the subject by workers whose dislikes in the past have been pretty plainly expressed. Groups of new books promise to sugar-coat the entire subject—from arithmetic to calculus—for the man in the street. Scarcely a popular magazine now is without a slide rule ad. Advertising copywriters would have us believe that no citizen, male or female, can possibly go about his normal endeavors or make any advancement in the postwar world unless he has mastered the intricacies of higher mathematics.

The radioman is a particularly conspicuous prospect for a mathematical bill of goods. Several new mathematical textbooks have been written especially for him. Many of the courses offered in the larger towns for his benefit are strongly mathematical in texture. Indeed, we know of one resident course in *radio servicing*, conducted by a public school evening division, which was so unnecessarily mathematical as to discourage most of the students before the work was half through. These instances have caused some confusion among radio men, particularly among the younger set, and as they look around them they question the necessity of mathematics to their advancement.

The increasing frequency of such questions prompts us to outline briefly in this article the relationship of mathematics to the various branches of radio. It is not our aim to endanger the business of any individual whose purpose it is to teach mathematics. Our sole purpose is to point out *how much* and *what branches* of mathematics are essential to the various radio pursuits and thus to save the radio student and radio worker lost motion as well as inadequate preparation.

For the purpose of this discussion, we have separated all radio practitioners into the following groups: engineers, designers, operators, experimenters, and servicemen. These are, of course, broad classes, but it will be conceded that they are specific enough in their lines of demarcation to admit of group treatment with regard to mathematical requirements. The needs of each class will be described separately.

THE ENGINEER AND MATHEMATICS

Radio engineering today is widely diversified and the conditions of its practice divergent. There are practicing engineers, whose work has been restricted to certain lines, who will declare that they have had no occasion since leaving college to apply any branch of mathematics higher than plane trigonometry. Some of these men have not seen the occasion; others have side-stepped the mettle-testing problems; still others have stuck to the time-wasting, roundabout methods of solution. In spite of the divergent conditions of practice, however, it must be admitted that the live-wire radio engineer, who is prepared for any evenuality, has mathematics in his tool-kit and can swim literal circles around the fellow who is not adept at the "arm-chair science of figures."

The successful practice of radio engineering presupposes a sound working knowledge of all branches of mathematics from elementary arithmetic to calculus. Any techniques the engineer may possess beyond calculus is additional fortification for the battles he is certain to have to wage in the field. In the mathematical lineup are all of those subjects encountered in grade school, high school, and college: arithmetic, algebra, plane and solid geometry, analytical geometry, plane and spherical trigonometry, vector analysis, differential and integral calculus, and differential equations. We question the value of *descriptive geometry* to the prospective radio engineer except as an aid to mental stimulation.

The engineer must be able to hop agilely from the techniques of one branch of mathematics to another, as he solves his problems, and he must be able to handle the numerous processes with accuracy. His "mistake level" must be uncommonly low. All of this means that he must retain his knowledge of the entire field of mathematics—a feat made possible only by continual usage. An unused tool becomes rusty; knowledge not used is soon lost. Like a doctor preparing the right medicine, the engineer selects and uses the *proper* branch of mathematics for a particular problem. He does not cut and try laboriously with arthmetic, hacking and patching, piecing and piling until the answer works itself out, when an expert application of some other branch, say calculus, will give an answer forthwith. Nor does he have to resort to frequent uses of graphical methods, any more so than does an expert calculator have to resort to counting on his fingers.

To summarize, the radio engineer needs *all* mathematics, regardless of the branch of the field in which his major endeavor lies. Whether his concentration is upon tubes, capacitors, resistors, circuits, antennas, or what not, anything short of covering and mastering the entire field represents inadequate preparation. If he has been able to get along on less, it may safely be wagered that he has not applied the rapid methods and complete analysis afforded him by the higher branches of mathematics. This is a situation he cannot avoid. An engineering student, recently interviewed, asserted that the engineering courses are composed of many different subjects, "all mathematics in another form."

THE DESIGNER AND MATHEMATICS

The designer, like the engineer, is taken by his work to the rock-bottom base of the science of radio. In order for the serious professional designer to hurdle the pitfalls he encounters in his regular pursuit of the art, he therefore needs the best mathematical background he can possibly acquire. Otherwise, he must work in close collaboration with an engineer so prepared. The designer is often an engineer, although he need not necessarily be one in fact. But it has been our observation that those successful designers who are not engineers by title do possess a complete store of engineering knowledge, however acquired, including full mathematical skill.

It is the business of the designer to be original. He, accordingly, must be able to get down to sources, to see through every device and operation "down to the main-spring." The worker who does not originate is far from creative effort and is a mere assembler of components and systems developed by the mathematically-trained technician. The designer is at the same time a worker of considerable ingenuity and mental alertness, both attributes which are whetted by mathematical endeavor.

The successful designer, like the engineer, needs all the mathematics he can possibly absorb; and through constant use of his mathematical skill, he must keep this tool sharpened.

THE EXPERIMENTER AND MATHEMATICS

By *experimenter*, we mean the serious investigator, the researcher, who, by trying various processes, systems, or components with respect to other processes, systems, or components, adds to our store of knowledge and gives us new systems and devices. We do not mean the *radio tinkerer*, who we freely admit does occasionally hit upon an invention, but usually in the most uneconomic and unscientific manner. The legitimate experimenter plots his course and knows precisely what he is looking for, although he is alert for the unexpected as well. He does not idly and blindly shuffle along hoping to stumble upon the miracle of the century. He has a searching mind and an analytic sense; he knows how to put together the things he sees. He may have developed these mental traits through rigorous mathematical training.

The purposeful experimenter must have a good mathematical background, although it need not necessarily be as rigorous as that of the engineer. Some radio experimenters are engineers, although all engineers do not experiment. The experimenter who works in close association with an engineer, who supervises his work, seldom requires a mathematical background beyond plane trigonometry unless he is called upon to make more complex analyses and computations than are enabled by that much mathematical knowledge. The independent experimenter who is entirely on his own and must make his own conclusions, on the contrary, needs the mathematical preparation of an engineer.

The amateur experimenter is concerned solely with adding to his personal knowledge or with amusement derived from tinkering with scientific apparatus. Seldom does his interest in radio extend far beyond first principles. Usually, he has no industrial designs. He is in a unique position to determine the amount of mathematical skill he needs in his own case. When the amateur with common mathematical preparation (arithmetic, algebra, and geometry) runs against unanswered problems, he usually senses his need for the next branch of mathematics and usually satisfies himself with only the leading facts from that branch. Generally, the amateur radio experimenter requires no mathematical knowledge except that afforded by arithmetic and first-year algebra. To him any further preparation is usually a luxury. His requirements will, of course, increase should he "graduate" into the class of serious experimenter.

THE OPERATOR AND MATHEMATICS

The *professional* radio operator, as such, needs no extensive mathematical background. His job is the operation and maintenance of radio transmitters, receivers, and monitors, and the design features of this equipment are generally not consequential to him unless he must make repairs in out of the way ports, or at odd hours. The knowledge normally required of him is more qualitative than quantitative, and he thus is able to get along on a more meager mathematical background. From his extensive knowledge of radio circuits and the conventional components employed in them, the radio operator is able to construct or to locate trouble in a wide variety of transmitters, receivers, and associated communication equipment.

To be sure, the operator's acquaintance with circuits and components and the reasons for their sizes, ratings, and employment in specific places may be enhanced by a broad mathematical background, but it is doubtful that the latter would make him a better operator. He may pass the Government professional operator's examinations, and build, test, and maintain a wide variety of communication equipment, radio, television, and facsimile, and do this job well with a minimum of mathematical equipment. The professional operator does not require mathematical knowledge and skill beyond arithmetic and algebra. He can get along with first principles of algebra, at that, and about all the trigonometry he requires is a knowledge of logarithms and of functions of the angle.

The professional operator does not have to be an engineer, and it is very doubtful that advanced engineering knowledge will improve his operating ability. Intimate acquaintance with the circuits and manner of operation of communications equipment will enable him to diagnose all troubles encountered during the operation of such equipment and to make all repairs and emergency replacements. Certain improvements to the instruments or the manner in which they are operated are likewise within his domain. Advanced mathematics is not prerequisite to these qualifications; and the operator's study program should not be burdened with this almost useless information which, while providing an asset from an engineering point of view, is about the equivalent of insisting that a bacteriological laboratory technician have an M.D. degree.

The *amateur* radio operator needs even less of a mathematical background than his professional associate in art. The amateur license examination is exceedingly simple to the radio student and, aside from the code test, presents little difficulty. The amateur operates his station primarily for reasons of personal enlightenment and a kind of scientific amusement. From this operation has come some noteworthy contributions to the progress of radio, but the writer feels that the amateur stepped out of character in these cases and became, even if temporarily, a serious experimenter or even an engineer.

There is absolutely no reason to sell the radio amateur, prospective or established, on advanced mathematics. He does not need this subject. His transmitters, receivers, and instruments are almost always built from standard designs which he finds in his magazines and textbooks. He gleans ideas for certain "personalized" changes in the circuits from his own acquaintance with circuits and constants commonly employed. He just is not concerned with fundamental design; and when he does fancy himself so concerned, he likes to build up his pipe-dream by a cut and try process. In this way, he derives much enjoyment from his activity. To introduce weighty mathematics into his hobby is to remove the enjoyment and exhilaration the amateur feels as he builds and operates his equipment. He is entirely satisfied to let the engineers design the equipment—he will build and use it, making those changes which appeal to him.

THE SERVICEMAN AND MATHEMATICS

The radio serviceman's job is to repair radio equipment, mainly home broadcast receivers. Like the radio operator, first-hand acquaintance with a large number of circuits and an up-to-date status with regard to the equipment on which he works are the serviceman's most invaluable assets. The reasons why the circuits operate and the methods of calculating size for replacement parts may be comprehended fully by the repairman without resorting to higher mathematics. To weigh a radio service course down with unrelated mathematics is ridiculous.

A good serviceman encounters no problems more complex than Ohm's Law, the computation of gain in decibels, or the calculation of a.c. and d.c. power. He accordingly *needs* only a sound foundation in arithmetic and some algebra. He can use a few trigonometric facts—such as the use of a log table, and use of trig function tables—but he does not need to know the entire science. All conversions he will be called upon to make, such as wavelength to frequency, microfarads to micromicrofarads, and the like, may be accomplished by simple arithmetic and indeed he will make substitutions in formulas which he either has memorized or will look up in his handbooks, so that little algebraic knowledge is required.

The normal course of radio servicing does not require the designing of new components or circuit arrangements. The repairman accordingly is not called upon to do the type of design work demanding a thoroughgoing knowledge of engineering mathematics. It is extremely misleading to prospective servicemen or to established servicemen who wish to improve themselves to present long mathematical treatments of repair topics. Such time is more profitably spent in classroom acquiring a more intimate acquaintance with the numerous modern radio and amplifier circuit arrangements and in more rapid methods of trouble shooting. It is perhaps most surprising to youngsters rejected from some of the new "double-differential" classes in radio servicing to learn that thousands of men are making livings at radio servicing throughout the country without knowing, or even caring, what the square of the sum of two numbers is equal to.

ABOUT THE SLIDE RULE

The slide rule has come up for the lion's share of publicity since the war started. Time was when one or two outstanding manufacturers of drafting and surveying supplies were the chief sources of supply for these handy instruments. Today, however, several suppliers offer all manner of rules, starting at 25 cents in price, and recommend them for use by business men, students, housewives, mechanics, engineers, architects, etc.

Unquestionably, the slide rule is extremely useful for all forms of calculation except addition and subtraction, and we recommend its use to all radio men, whether in engineering or sub-professional work. The ability to manipulate the slide rule and interpret its indications with accuracy is a decided asset which pays large dividends in simplification and saved time.

The serious-minded radio man should obtain the best slide rule he can afford and devote himself diligently to its mastery. Like mathematics, knowledge of the slide rule will grow dim too unless used; and for this reason the rule, once employed, should be used in every suitable problem, the complex as well as the simple. There is a pronounced tendency to reserve the rule only for the humdrum calculations and to take pencil and paper for the mettle-testers. In this connection, Raymond W. Dull says in his book *Mathematics for Engineers*: "Although engineers use the slide rule more, perhaps, than any other class of men, we believe that the majority of engineers confine its use to the simplest kind of operations."

SUMMARY

Mathematics is an exact science and is the life-blood of engineering. The domain of mathematics in radio embraces all of the branches of this applied science, but is less required by some branches than by others.

The radio engineer, designer, and serious experimenter require a thoroughgoing mathematical background embracing all branches from arithmetic through calculus. The engineer may well utilize any additional mathematical training beyond calculus, and the experimenter may be able to dispense with some of the higher branches (e.g., analytic geometry, calculus, and subjects beyond calculus) if he is not independently engaged.

The radio operator and radio serviceman require little mathematical equipment in the normal pursuit of their occupations. This is true likewise of the non-professional experimenter and the amateur radio operator. These classes of radio workers will be adequately prepared by a good working knowledge of arithmetic and algebra, with enough knowledge of basic trigonometric facts to enable intelligent use of log and function tables.

The slide rule is an invaluable tool and ability to manipulate it an asset to each of the radio groups.

It is hoped that this explanation will help to quell the confusion arising in the minds of radio men who question the necessity of mathematics to their advancement.

RADIO IN THE ARCTIC REGION

Reprinted from Air Tech

IMPROVED transportational facilities in the far north and the use of the Arctic area for important weather stations and control bases for wartime transportation networks have necessitated the establishment of more reliable communication systems. Conditions of terrain which make traveling on the ground difficult also complicate the maintenance of wire communication lines, so that, whether between plane and ground or between ground points, the only practical method of communication is by radio with equipment of proved reliability.

The first radio transmitters set up in the far north, about 30 years ago, operated on frequencies below 1500 kilocycles. The use of these frequencies was based upon the state of the radio art rather than any known advantage over higher frequencies. Satisfactory transmitters for higher frequencies were not available and the poor communication obtained at 1500 kilocycles discourage development on higher frequencies.

At that time, theorists, supported by a limited number of experimental observations, claimed that all radio waves followed the surface of the earth. The intensity was believed to vary inversely as the distance from the transmitting station. Also, at a given distance from the transmitter, low-frequency waves were found to be stronger than those at a higher frequency. The result of these theories was a tendency to go to lower frequencies for long distance transmission. Very low frequencies required large antennas and high power to have good radiation with the result that transmitting stations became enormous in size.

A few years later, vacuum tubes became available and were used by amateurs in transmitters operating on frequencies above 1500 kilocycles. The astonishingly long distance communication often obtained with low power at higher frequencies quickly drew attention to these frequencies and their use was intensively studied. Finally, it was agreed that high-frequency waves did not entirely follow the surface of the earth. Most of the waves radiated into space and were reflected by a region, often called the Heaviside layer, back to earth. Where they reached the earth they could be detected without much difficulty.

With properly selected frequencies, it was found possible to communicate over distances comparable to that across the Atlantic Ocean with less than one-tenth of the power that would be required at low frequencies. Furthermore, the antennas required for the higher frequencies were relatively small, were much more efficient and could be made directive in order to radiate most of the power in a narrow beam.

It was natural that these higher frequencies should be tried in the far north. It was soon found, however, that all their advantages at lower latitudes could not be realized in the neighborhood of the magnetic pole. In this region magnetic storms often blanketed out the high frequency waves so that communication over any great distance was impracticable even with the maximum of power.

Since 1939, the CAA has been building the airways in Alaska, where communication and transportation are the two biggest words in human living. They are the inseparable twins in development of the Territory, and neither can be fully useful without the other. The airplane flies the radio to the site, and the site then becomes a place on the map, a haven or even a town.

Low frequencies were not seriously affected by the magnetic storms and under certain conditions were found to transmit better under these conditions. The result was that low-frequency transmitters were soon considered necessary adjuncts of radio communication facilities in the region of the magnetic pole. These transmitters had to be designed for: convenience in transportation to isolated localities, reliable operation in cold climates, accessibility of parts, protection of operating personnel, simplicity of operation and complete control from a remote point.

Most of these transmitters would be located either adjacent to or within easy reach of an airfield. Accordingly, they have been designed with aluminum frames and of a size and weight that permits them to be carried in a large transport plane. This makes it unnecessary to limit transportation to these relatively short periods in the summer when land or water transportation is possible.

The entire transmitter operates from a 230-volt, 3-phase, 60-cycle power supply. In cases where the supply does not give this voltage, adjustments are provided so that any voltage between 215 and 250 volts can be used. Power requirements can be economically met with a Diesel-engine-driven generator of the type commonly used in isolated communities.

The Exciter Unit is a complete, continuous wave transmitter in itself and can be used independently of the Power Amplifier and Main Rectifier Unit. It will deliver at least 500 watts of power on any frequency between 80 and 200 kilocycles.

The Power Amplifier Unit is normally used at one operating frequency but it can be set up for use on any frequency in the range of the Exciter Unit. At any operating frequency within this range it will deliver 10 kilowatts of power. This output is obtained through the use of a single, Type 892R, tube with conventional grid and plate turning circuits.

The Main Rectifier Unit employs 6, Type 872A, mercury-vapor rectifier tubes in a conventional three-phase, full-wave circuit. It supplies all of the plate power required by the Power Amplifier Unit.

Each of the three transmitter units is provided with convenient terminal boards and is arranged so that interconnecting leads can be placed in sheet metal ducts located in the floor. The radio-frequency connection between the Exciter Unit and the Power Amplifier Unit can be made with a two-conductor, shielded r.f. cable placed in these same ducts. Connections to the Antenna Tuning House can be made with a flexible coaxial cable.

INDUSTRY TIME-SAVER

The two million-volt sealed-off X-ray tube can radiograph in less than an hour thick metal sections. Formerly, it took a week to make the radiograph with the million-volt tube.

POWER AMPLIFIER FUNDAMENTALS

Reprinted from Radio & Television Retailing

By W. E. Moulic

Technical Editor, Radio & Television Retailing

Operating Characteristics and Performance Comparison of Class A, B, AB, and C Power Amplifier Stages. Bias and Grid Voltage Requirements.

THREE forms of distortion of the original signal may be present in vacuum tube amplifiers.

(1) Frequency distortion.—An amplifier which does not have the same gain at all frequencies is said to have frequency distortion. Frequency distortion is primarily a function of the type of coupling used between stages. Frequency distortion is undesirable in audio amplifiers but desirable in amplifiers designed to separate signals on the basis of their frequency. The general frequency response characteristics of amplifier coupling systems were covered in the August issue of RADIO & TELEVISION RETAILING.

(2) Harmonic or amplitude distortion.—A so-called "pure" tone contains only one frequency. If a pure single frequency is to be amplified, and is to remain pure, all amplification must be strictly linear. The best amplifiers approximate this performance closely but in all cases some new frequencies are generated that are multiples of the input tone. This is called harmonic or amplitude distortion. From the standpoint of hearing, the most objectionable harmonics are the 2nd, 3rd and possibly the 5th and 7th for the double reason that they are relatively strong and the frequencies are usually low enough to appear within the audible region.

Amplitude distortion is caused by the non-linear characteristic of the tubes. This is shown by Fig. 1. Large signal amplitudes are distorted more than small values. The general result is a "flattening" of the negative half-cycle which is equivalent to adding a second harmonic 90° lagging the original pure tone. The correct value of grid bias is essential in minimizing amplitude distortion.

In any reasonable design of an audio amplifier, the early stages do not introduce much harmonic distortion, as the signal voltage is still low compared to the tube voltages, and the loads of the tubes are substantially resistive. In the later stages these favorable conditions do not prevail, especially if the load is electro-mechanical, such as loudspeaker or a record-cutting head. Such devices apply a load to the tube that varies not only with frequency, but with amplitude and other factors. Because of this and the high signal voltage applied to the tube, relative to the direct voltage, non-linear distortion appears.

By trial and experience it has been found that about 2 per cent of harmonic distortion is the least which even a trained observer, working with a single pure tone, can distinguish. Beyond this point, harmonic distortion becomes apparent quite rapidly: 5 per cent is not hard to distinguish, and 10 per cent is objectionable. These percentages are totals of all the harmonics because it is comparatively quick and simple to measure them together, and more tedious to sift them out singly.

(3) Phase distortion.—Most signal voltages are not sinusoidal, but have a complex wave shape. This complex wave is composed of a fundamental sine wave and a group of harmonics. If the phase relations of these components are changed, the resultant wave shape will be different. This delaying of certain frequency components is phase distortion. It is not serious in audio amplifiers but must be corrected in wide-band amplifiers such as those used for television.

BASIS OF CLASSIFICATION

Amplifier operation is classified on the basis of the completeness of the plate current cycle. A Class A amplifier is one in which the grid bias applied to the tube and the signal voltage input are both such that plate current flows for 360° of the signal voltage cycle, and no grid current flows. A DC meter in the plate supply lead should show little or no movement with or without the AC grid input voltage. The plate-circuit efficiency is seldom as high as 20 per cent for triodes, a trifle better for pentodes. The theoretical maximum is 50 per cent. Accordingly, the amount of plate heating limits the performance of tubes in Class A. The alternating plate voltage (R.M.S.) is only about 30 per cent of the direct plate voltage, hence the output is small. The grid bias for a triode Class A tube is about 60 per cent of the theoretical cut-off. For a beam tube, cut-off has a less definite meaning. Class A operation is shown in Fig. 2. Practically all voltage amplifiers operate Class A.

The grid bias for Class B is adjusted to "false cut-off" as shown in Fig. 3. The bias voltage must be obtained from a fixed supply and not from self or cathode bias since the average plate current varies with the magnitude of the signal voltage. The value of bias voltage is approximately Eb/μ.

Since the plate current flows for only one-half cycle, great amplitude distortion results. Class B amplifiers are unsuited for audio amplification unless two tubes in the same stage are worked 180° out-of-phase with respect to each other, so that a full cycle of plate current is obtained. This operation is termed push-pull.

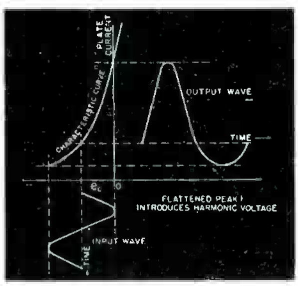


Fig. 1. Amplitude or harmonic distortion caused by curvature of grid control characteristic.

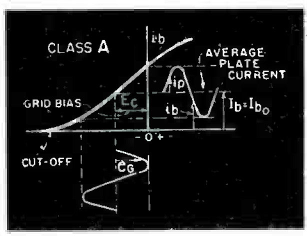


Fig. 2. Theoretical operation of class A amplifier stage, showing bias, grid signal voltage and plate current variations.

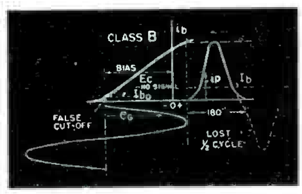


Fig. 3. Bias for class B operation.

Any stage in which there is only one tube (or tubes connected in parallel) is termed single-ended as contrasted to push-pull operation.

CLASS B GIVES HIGHER EFFICIENCY

Class B operation is more efficient than Class A, having a maximum theoretical limit of 78 per cent. Class B amplifiers are sometimes called linear amplifiers because the voltage output is almost a linear function of the grid signal voltage.

Class B amplifiers are used for high power audio and linear radio frequency amplifiers. A Class B grid represents an actual load upon the driver stage during its positive swing, since grid current flows. The driver must therefore be more powerful than for Class A operation.

Class AB_1 is used to indicate an amplifier in which the instantaneous grid voltage is never positive. Class AB_2 is an amplifier in which the grid is driven positive for a short part of the cycle. It delivers more power than Class AB_1 from the same tubes. Classes AB_1 and AB_2 are shown in Fig. 4.

The efficiency depends on the type of triode, tetrode, or pentode used, ranging from 20 per cent to 60 per cent, the last being obtained when the input has been increased to the so-called AB_2 level. Here the grids are driven from below cut-off at one end to a small positive potential at the other end of the swing where grid current just begins to appear and a little actual power is required to drive the grids.

The power output of a Class AB_2 pair of tubes is 2 to 2¼ times that of the same tubes in Class A. The distortion need not be much greater if an adequate driver stage and a good output transformer is used. What is generally overlooked, the plate and bias supplies must have very good regulation—that is, do not change in voltage by more than 5 or 10 per cent as the plate current demand varies from "no signal" to "full signal".

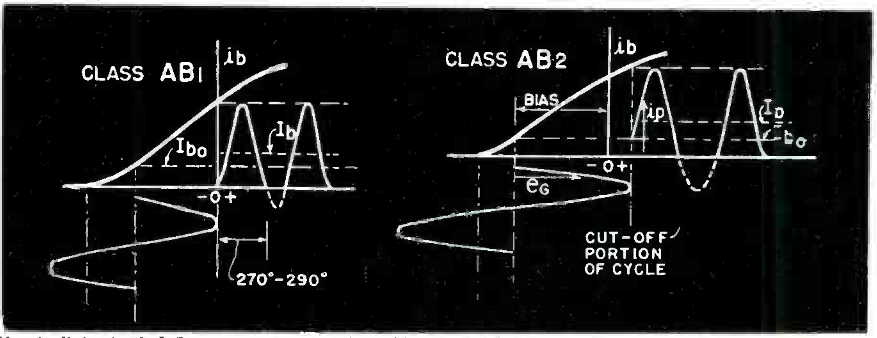


Fig. 4. Principal difference between class AB_1 and AB_2 is magnitude of grid signal voltage at full output. For very small signal voltages, stages are class A. Grid current flows in class AB_2.

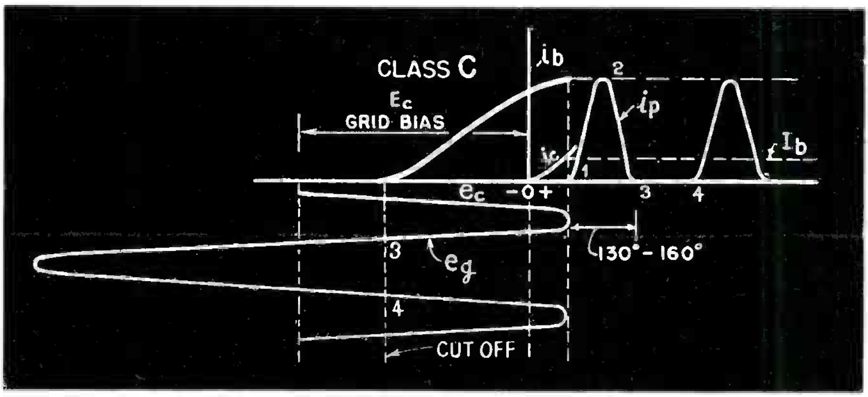


Fig. 5. High efficiency class C operation is not suitable for audio work because of large distortion. Bias is commonly about twice cut-off and grid current flows during part of cycle.

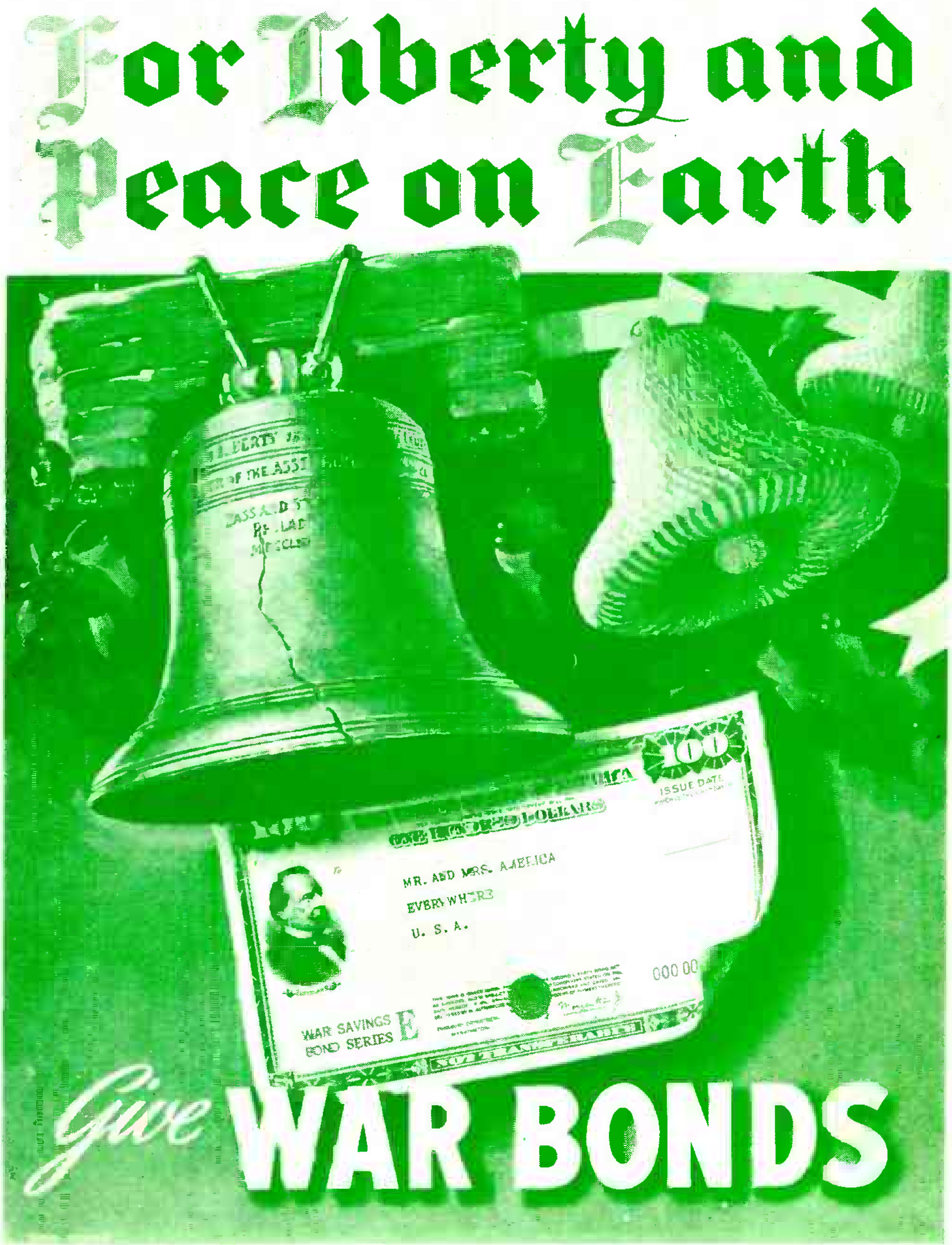
The Class C amplifier operates under conditions of high distortion, yet is frequently used in "single-ended" amplifiers for power amplification of radio frequencies. The actual condition of operation is that a bias of two or more times cut-off is used. The grid signal voltage is large and produces plate-current pulses, which are always shorter than a half-cycle, but have large peak values. A high plate circuit efficiency of 75 per cent or more results. The plate current waveform is so bad that it is useless for audio work. It is used as RF amplifier, in which the tube load is one or more tuned circuits of good "Q" and high capacitance (relatively), so that the harmonics (caused by distortion) will either be wasted or else converted to the fundamental frequency, by the flywheel action of the resonant plate circuit. Class C operation is shown in Fig. 5.

Class A operation is the least efficient but has least distortion. Its use is limited to voltage amplifiers and small power amplifiers. Bias voltage may be obtained from fixed or self bias methods.

Class B is more efficient than Class A but can only be used in push-pull circuits for audio work. It is often used single-ended for radio frequency amplifiers. The grid bias must be obtained from a fixed source.

The Class AB amplifiers are between Classes A and B in both efficiency and distortion. They are most common as push-pull audio amplifiers.

Class C is the most efficient method of operation but is limited to amplifiers of very narrow bands of frequencies such as RF amplifiers.


For Liberty and
Peace on Earth
100
ISSUE DATE
MR. AND MRS. AMERICA
EVERYWHERE
U. S. A.
WAR SAVINGS
BOND SERIES E
Give WAR BONDS