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AN ANALYSIS OF ALL-WAVE RECEIVING ANTENNA SYSTEMS

BY

JULIUS G. ACEVES*

Delivered before the Radio Club of America, May 12, 1938

In this paper we propose to review and analyze the various circuit arrangements employed in receiving antenna systems with the object of clarifying certain fundamental ideas with respect to noise interference reduction which at present are not generally understood. In this we refer particularly to antenna systems used for multiband broadcast reception, rather than for commercial communication purposes.

The first question quite naturally to be considered is: Why is not an ordinary wire some 20 to 60 feet long good enough for operating any radio broadcast receiver?

The answer is, of course, that it may well be good enough when there is no extraneous radio noise or radio frequency energy near the receiver or antenna from sources which will interfere with the signals coming from the desired transmitting station. Since in cities and other populous areas this happy condition is the exception rather than the rule, the problem of eliminating the effects of the so-called "man-made static" assumes considerable importance.

With this in mind, let us consider:

I The present status of this phase of radio engineering progress.

II The methods of determining the comparative merits of various antenna systems and the standards by which these systems may be judged, and

III The principles of design involved in order to raise the figure of merit of a given system.

I. PRESENT STATUS OF THE ART:

Antenna Systems for broadcast reception may be classified according the purpose of design as:

1. Having noise reduction features in all the important wave bands.
2. Having noise reduction in only one band.
3. Having no noise reduction features.
4. Freak systems, masquerading under the guise of those of classes 1 and 2.

In the first class, we have systems including at least two coupling units, one adjacent to the antenna proper and another at the receiver.

In the second class, one or both coupling units may be lacking, or the dipole antenna especially useful for short wave reception may be omitted.

In the third class, belong simple indoor or outside antennae of the elevated capacity type without couplers.

To the fourth belong a number of systems containing units ostensibly for noise reducing purposes, but not fulfilling any other function than the dubious purpose of avoiding good engineering principles and circuits. Others comprise nothing more than two soldered joints and are sold under the guise of better class kits.

The basic theory of noise reduction antenna systems was presented by the writer in a previous paper before this Club, in November, 1935 (1). It was then shown that noise commonly enters the radio receiver by two well defined paths; i.e. by downlead pickup and by coupling between the circuits of an interference source and the antenna-to-ground circuit of the receiver. Of course other forms of interference pick-up are found to be troublesome and may, indeed, be quite uncontrollable, such as the pickup of interference by the antenna proper. Keeping this in mind let us briefly review the typical antenna systems and coupling units now in common use. For the present we will not consider multiple outlet distribution systems, but only single receiver systems.

In Figure 1, some typical examples are illustrated. The letters BC and SW designate the particular band which the transformer is designed to transmit most efficiently.

The antenna units, "*a*", "*b*" and "*c*" are used with

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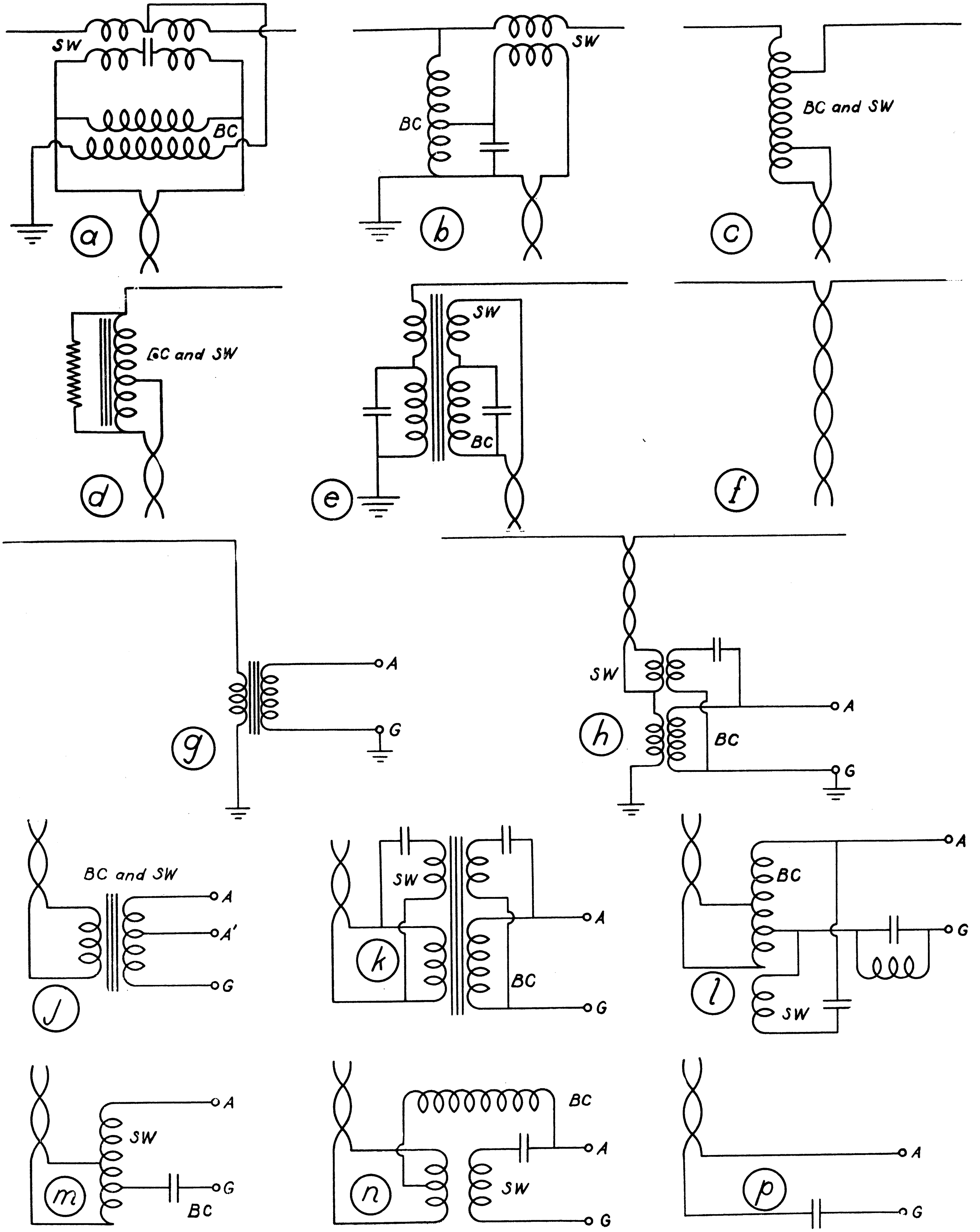
*Chief Engineer, Amy, Aceves & King, Inc.


SW
BC
a
BC
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b
BC and SW
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h
BC and SW
A
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BC
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SW
A
SW
G
BC
m
BC
A
SW
G
n
A
G
p

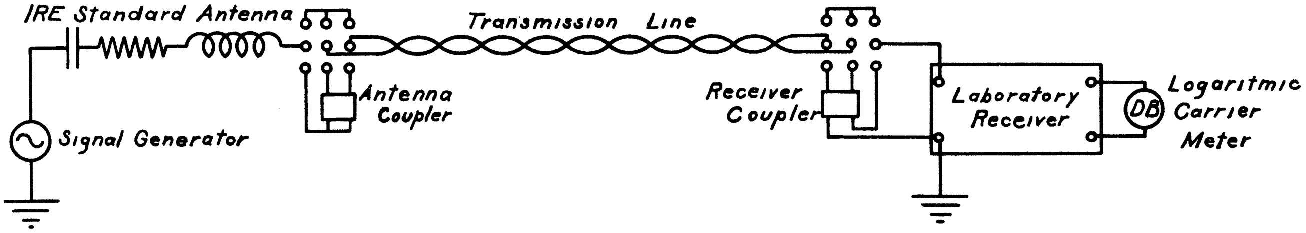
Fig. 1

doublets, and when used in conjunction with receiver units, "*j*", "*k*" or "*l*", offer the maximum signal to noise ratio in the frequencies between .5 to 1.7 and between 6 to 20 M.C. with varying degrees of efficiency and noise reduction. Unit "*b*" when including a suitable iron dust core extends its good performance down to 150 K.C.

Next come antenna units not intended to be used with doublets, such as "*d*" and "*e*", which offer maximum signal to noise ratio in the frequency range of .5 to 1.7 M. C. but not as high a ratio as "*a*", "*b*" and "*c*" in the frequency range of 6 to 20 M. C. when used with "*j*", "*k*" or "*l*". Unit "*e*" has a higher degree of noise reduction than "*d*" because of the local ground connection and the isolation of the transmission line circuit from the circuit of the antenna proper, but by grounding the bottom of the auto transformer of "*d*", in many cases the signal-to-noise ratio is increased.

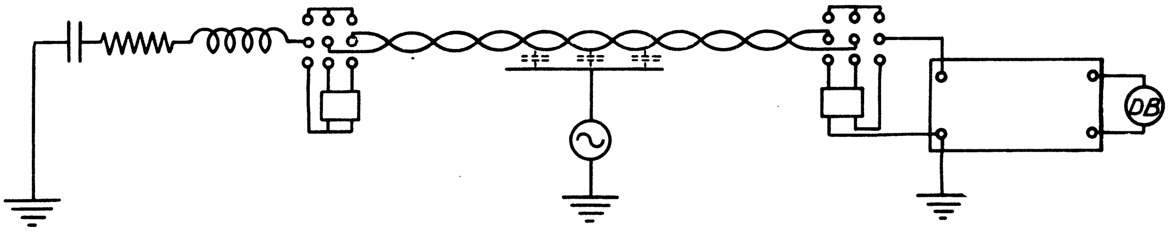
Next comes the symmetrical doublet in the short wave band which affords as much noise reduction as any of the preceeding antenna arrangements, but provides no noise reduction on the broadcast band except when used with a separately grounded receiver coupler as in "*h*".

Next is an ordinary Marconi antenna as shown in "*g*" with a "quiet" ground and an isolation coupler, such as "*j*" or "*k*". Units "*m*", "*n*" and "*p*" used with a simple doublet as in "*f*", give the same or a little better noise reduction than the simple doublet on short waves, but give no advantage on broadcast frequencies except the small signal gain due to the tuning of the antenna to some broadcast frequency by the short wave choke of unit "*n*" when the receiver has a comparatively low input circuit impedance.



SIGNAL TRANSMISSION TESTS AT BROADCAST FREQUENCIES

FIG. 2



NOISE BY DOWNLEAD PICKUP AT BROADCAST FREQUENCIES

FIG. 3

The couplers in "*g*" and "*h*" have that same property to a greater degree in the broadcast band, when the effective inductance is about 100 microhenries and when used with high impedance receiver input circuits.

An analysis of the various types of doublets, is beyond the scope of this paper. It should be said, however, that much improvement in signal strength may be obtained by special designs of doublets, such as the "V" the multiple doublets, the especially short doublets for ultra-high frequency reception, and by sectionalizing a doublet by reactive circuits to make it of the optimum length for special frequencies.

II. METHODS OF MEASUREMENT AND STANDARDS:

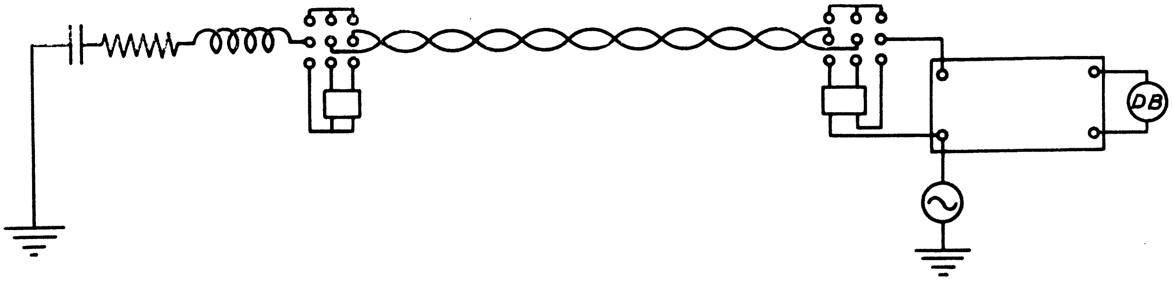
A number of methods have been described in the Proceedings of the Radio Club of America, (1) and elsewhere by such authorities as H. A. Wheeler (2), R. C. Dome (3), Von Eppen und K. Muller (4), W. L. Carlson and V. D. Landon (5), L. C. F. Horle (8), etc., but so far no standard method has been adopted, nor a figure of merit specified or defined.

The Association Suisse des Électriciens (A.S.E.)[6] has investigated this subject in detail as has the Canadian Radio Commission, but as yet a figure of merit of an antenna system has not even been mentioned.

The importance of the establishment of a figure of merit expressing the capability of an antenna system to give more nearly noise-free reception and the standardization of suitable methods for its measurement cannot be too greatly emphasized.

We wish, therefore, to suggest the following measurement procedure as adopted sometime ago in our laboratory.

For measurements in the standard broadcast band we proceed as follows: Compare the signal voltage at the terminals of a radio receiver having a perfectly definite input impedance, (4000—j0 ohms, representative of that of commercial models) when fed from an antenna with an open downlead, to the signal voltage similarly re-

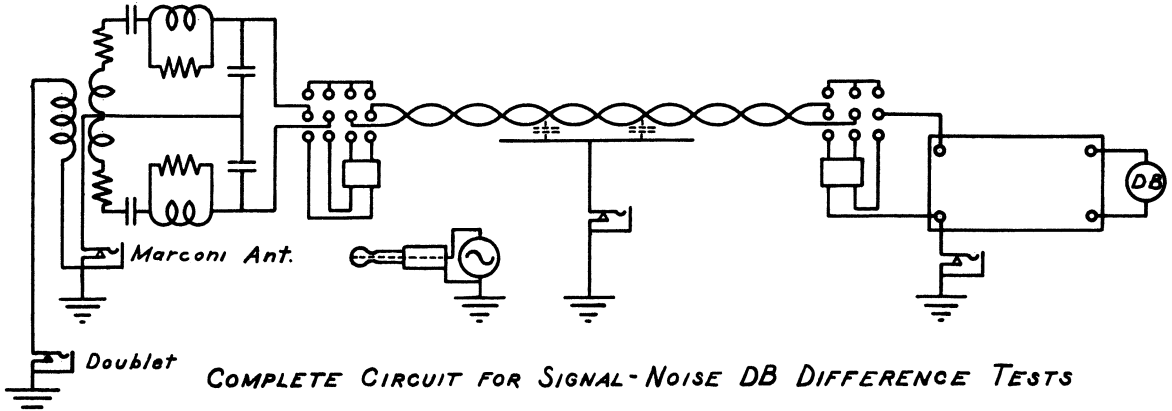


NOISE BY POWER LINE AND GROUND CIRCUIT COUPLINGS

FIG. 4

ceived from the same antenna, equipped with the system under test. Let these two voltages be E_1 and E_2. This comparison is effected by the schematic circuit shown in Figure 2.

Let the logarithmic ratio E_2/E_1 be expressed in decibels and called A. Then let an interference voltage be introduced, first by coupling into the open downlead and then in series with the ground connection, as indicated in Figs. 3 and 4, thus simulating the two principal modes of entry of noise energy into antenna systems. according to the manner in which the interference voltages enter. Then subtract algebraically B and B′, respectively, from A, and call the differences C and C′. Then $C = A - B$ and $C' = A - B'$ will be the advantage expressed in decibels obtained by the use of the system at any given frequency, for the two types of interference introduction. This procedure is repeated for other frequencies in a given band and curves of A, B, B′, C and C′ versus frequency are drawn. Typical of such data as this are those shown in Fig. 7. The figure of merit



COMPLETE CIRCUIT FOR SIGNAL-NOISE DB DIFFERENCE TESTS

FIG. 5

Measure the voltage across the input of the receiver from the same antenna, when supplied by an open downlead and then by the system under test, by means of the switching arrangement shown in the Figs. 3 and 4. Call these voltages e_1 and e_2 when the interference is introduced into the down lead, and e'_1 and e'_2 when the interference source is introduced in series with the ground lead.

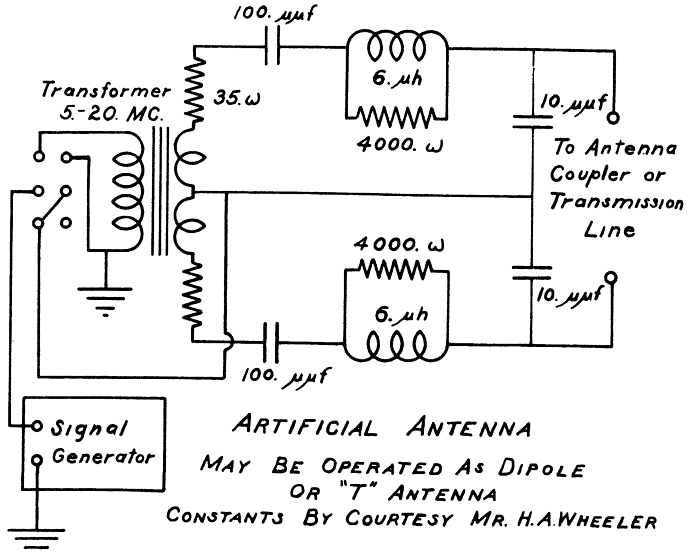
Figure 5 shows a diagram of a laboratory set-up for these measurements, and Fig. 6 gives the details of the artificial antenna used. This may simulate a Marconi or a dipole antenna, according to the position of the switch. The circuit constants are those suggested by Mr. H. A. Wheeler of the Hazeltine Corporation.

The signal gain or loss obtained by the use of the system under test is:

$$A = 20 \log \frac{E_2}{E_1}$$

The two noise reductions are:

$$B = 20 \log \frac{e_2}{e_1} \quad \text{and} \quad B' = 20 \log \frac{e_2'}{e_1'}$$



ARTIFICIAL ANTENNA

MAY BE OPERATED AS DIPOLE OR "T" ANTENNA

CONSTANTS BY COURTESY MR. H.A. WHEELER

FIG. 6

for a given band will then be the average of curves C or C′.

For example: at 650 KC, say that we gain 6 decibels by the use of a given antenna system over an open downlead attached to the dummy antenna in a laboratory tests with a standard signal generator. Then, by injecting interference in series with the ground circuits, say that we get 18 decibels less when the antenna system under test is used in place of the open downlead. The "advantage" expressed in decibels would be 6+18=24 decibels at 650 KC. We then do likewise at every 10 KC throughout the broadcast band and plot curves. Then by taking the average of curves "C", we obtain the figure of merit of this antenna system for the particular frequency band for the two types of interference.

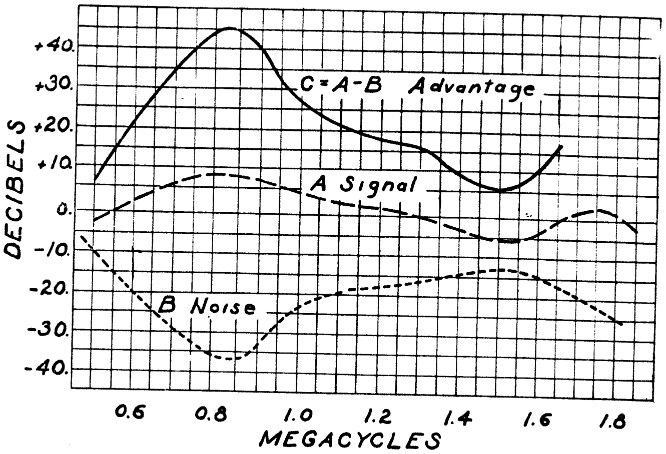


FIG. 7

There are several ways of measuring the voltages E_1, E_2, e_1, e_2, e', e'_2, but in practise it is simpler to measure A, B and B′ directly. Remembering that A, B, and B′ are logarithmic differences, it would be easier to obtain them directly if we have a meter that measures the carrier frequency on a logarithmic scale, because the difference in the two meter readings then give A, B and B′ at once. This has been accomplished by taking advantage of the closely approximate logarithmic characteristics of the variable μ tubes, such as the 58, 78, 6K7, etc., commonly used in the RF and IF stages of broadcast receivers.

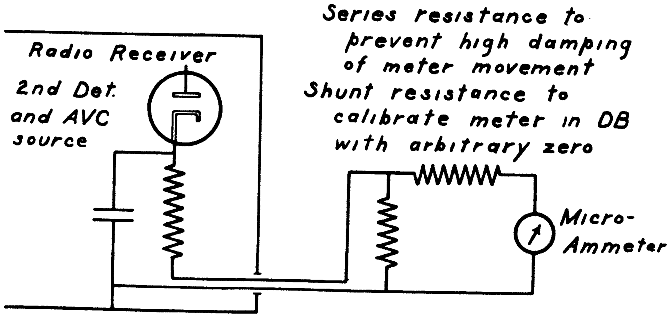


FIG. 8

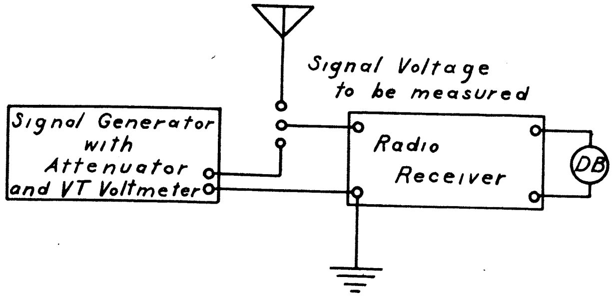


FIG. 9

In our laboratory receiver, for example, by connecting to the a. v. c. supply a suitably shunted micro-ammeter as shown in Figure 8, it may be made to read signal level differences directly in decibels, the zero being immaterial. (EDITORS NOTE: The plate current change of the tubes controlled by the avc circuits is commonly found to provide a logarithmic relation to the input signal voltage and thus provides for its measurement on a logarithmic scale with the advantages of higher current levels and the possible use of simpler and more rugged meters than is commonly possible when the measurement is made of the second detector current). To obtain the absolute value of a given input voltage, a direct comparison between this voltage and that from a well calibrated signal generator (Fig. 9) equipped with R.F. voltmeter and attenuator will give the answer. For certain types of antenna and receiver couplers requiring local grounds, Fig. 4 should be modified accordingly. The use of a transformer between the signal generator and the doublet, together with the double throw swtich enables us to quickly change over from Marconi to Doublet operation.

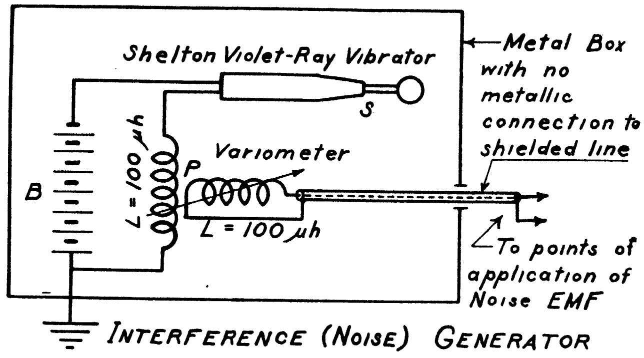


FIG. 10

As was pointed out above, the interference voltage is introduced as in Figures 2, 3 and 4. There remains, however, the question as to what kind of wave shape it should have to simulate actual conditions.

Theoretical considerations point to the fact that pulses can be considered as a summation or integration of sinusoidal wave forms with variable co-efficients. The components having frequencies that may be passed by the filters comprised of the tuned stages of the radio set are the only ones that have an effect upon the set and all others may therefore be disregarded, provided that their amplitude is not so great as to result in appreciable modulation in the first tube.

Another way of viewing this is to consider sharp pulses as providing shock-exitation of the first tuned or filter circuit and there originating damped oscillations. In this case, we will have again sinusoidal waves with variable co-efficients.

From these considerations, it seems logical to conclude that sinusoidal voltages with variable co-efficients such as may be obtained from a commercial signal generator, should give the same results in a measurement of noise reduction as a shock-excited interference generating device.

Several types of interference generating devices have been tried out, consisting essentially of an interrupter (mechanical or electrical), a step-up transformer, and some form of circuit capable of giving sharp RF pulses of a very broad frequency spectrum (7).

In our own experience, a violet ray vibrator has been found very effective, and we believe it to be the nearest laboratory approach to the most common forms of man-made noise interference, such as buzzers, oil burners, defective neon signs, diathermy machines, etc. In practise we use a Shelton Vibrator S, Fig. 10, operated from a battery B. In series is the fixed coil of a variometer P. The rotor coil will deliver interference voltage to a shielded conductor so that it may inject the interference at any desired point of the circuit of an antenna system and by varying the coupling, the amount of interference delivered may be readily controlled.

Not all sparking devices are suitable for these measurements because, as has been pointed out above, there are several ways in which noise enters the antenna system and it is absolutely necessary to examine the effects of these several modes of entrance **one at a time.**

It can be shown experimentally that measurements made with a shock-excited generator give the same results within the errors of observation and experiment as if they were made with a signal generator.

The advantages of the signal generator over sparking contact devices are quite obvious: stability, reliability, ease of control, ease of shielding, and of great importance, the fact that the signal generator is a standard laboratory apparatus. All contribute to the far greater desirability of the use of the conventional standard signal generator.

For best results at all signal levels, care should be used in selecting for these measurements, a radio receiver having linear detection, and one in which there is negligible cross modulation in the RF and first detector at the signal levels used.

Aside from the matter of signal source it should be noted that there are some antenna systems that require a local ground, such as in Figure 1-a. It is essential that these conditions be carefully simulated in the test circuits. Here let us warn the experimenter against cross currents and spurious couplings in grounding the various pieces of apparatus, lest the results of measurement be completely deceptive and generally useless.

When the tests just described are to be made on short waves, using doublets on the circuits as well as the standards of comparison become more involved. Laboratory equivalents to doublets have been given by several authorities. However, what is going to be the standard of comparison? We are given a noise reducing system claiming substantial improvements in short wave reception over an "ordinary" antenna. What is this ordinary antenna? Obviously, here we are in sad need of a standard and we hope that some form will be suggested and some standard eventually accepted. The 200 mmf—25 ohm—20 microhenry dummy receiving antenna was accepted as standard by the I. R. E. for broadcast; however, the 400 ohm resistance standard for short wave is obviously inadequate.

Mr. L. F. Curtis, of the Hazeltine Service Corporation, used a 25′ vertical wire for comparative tests. It may, therefore, be assumed that this is somewhat representative of actual conditions, but here again the formation of nodes and loops in this wire would change positions with frequency and, therefore, it would make a difference at which point the interference is coupled. Something here ought to be suggested. (EDITORS NOTE: The forthcoming report of the Standards Committee of IRE, including the report of the Technical Committee on Radio Receivers will be found to include a standard dummy antenna for use up to at least 30 M.C.).

The problem of comparing two systems for short wave reception using the same doublet antenna is much simpler, as it suffices to have a changeover switch between the artificial doublet and the antenna coupler, and between the set coupler and the radio set itself. However, some systems use a balanced transmission line, while in others, one conductor of the transmission line is "grounded", i.e., connected to the chassis. In such case, a transformer having the minimum possible mutual capacity between windings, and maximum magnetic coupling should be inserted between the signal generator and the artificial doublet as shown in Fig. 6.

Noise elimination in short wave circuits employing doublets is accomplished by eliminating all straight antenna pickup of both the doublet wires acting as Marconi antenna and its associated transmission line. The same method of coupling the interference used for broadcast frequency tests may be used without any modifications other than those outlined above.

In this connection it is interesting to note that for maximum noise reduction in the broadcast band, a complete electrical isolation between the transmission line and the radio set is best, whereas for short wave reception with doublets, the connection of the midpoint of the transmission line to the chassis by a very short conductor is the most desirable. This is explained by the fact that in this manner practically all Marconi antenna effect is excluded, leaving only the true Hertzian or doublet action effect.

It is pertinent, therefore to ask why then is this not also true for broadcast reception?

Through the power line and/or ground circuits EMFs are coupled into the entire receiving system producing the equivalent effect of an RF generator inserted in series with the ground lead. A current will flow up through both wires of the transmission line, enter the antenna transformer, pass through the primary winding, go through the antenna (like a transmitted wave) and be radiated into space. The magnetic field produced in the antenna coil will thus generate an EMF across the secondary winding precisely as does any incoming signal, sending a "push-pull" or "balanced" current down the transmission line which will reach the receiver exactly as if it was a signal. By blocking the path of this interference current as it tends to go up through the line (as parallel currents) the generation of "push-pull" or "balanced" currents is prevented, or at worst, greatly diminished. The break may be placed at the receiver unit, at the antenna unit, in both, or at any place in the transmission line by the insertion of a one to one transformer having both extremely low magnetic leakage and low mutual capacity.[9]

In all the preceeding tests, noise reduction is the keynote because the raison d'etre of an antenna system is to allow the use of all the amplification of which radio sets are capable and only in comparatively few cases to increase the distance range of the receiver by supplying all the available signal strength. But in practice, everybody wants to know how much greater distances can be reached with a new antenna equipment. This brings in the subject of total response curves and with this comes the controversy as to what constitutes the effective height of a flat top, say 60′ long and a transmission line, say 100′ long with, an antenna transformer between the flat top and the line, and with another transformer at the input to the radio set. Still more involved does this become when the primary of the antenna transformer is grounded at the roof and the transmission line rendered incapable of signal pickup.

An experimental answer is not difficult to obtain if we very broadly define the effective height in meters, as the ratio of the EMF at the receiver terminals to the field strength. In this case, having an open type antenna of known effective height, H, in the same field as the antenna system under test, its effective height h, will be given by:

$$h = H\frac{E}{e} = \frac{1}{20}\log^{(-1)}\frac{D}{20}$$

where D is the decibel difference indicated by the meter of the radio receiver of Fig. 1 as in signal voltage measurements as described above.

When receiving short waves by means of doublets, it is very difficult to predict what is the EMF across the gap, even when a pure resistance equivalent to an infinite transmission line is there inserted. It can be calculated for some special cases by knowing the equivalent impedance of the doublet which will be considered as being in series with the equivalent resistance of the lines, but only for waves of a given direction and angle of polarization. This is only an approximation because in order to obtain a more rigorous mathematical analysis, an integration of the induced EMF's at each infinitesimal element of the doublet is necessary, with proper attention to the phase distribution along the doublet. These remarks are made to show that it is misleading to assume that because a response curve is thusly obtained, it will therefore give the signal voltage across the line, for any received station of known field strength. Indeed experience indicates that response curves are good only for the purpose of providing a relation between frequency and percentage of the maximum EMF obtainable across the gap when an infinitely long line of given impedance (usually 100 ohms) is attached thereto. Typical response of a doublet 30x30 feet with a 100 ohm line at the gap and for waves of optimum direction is shown in Figure 11.

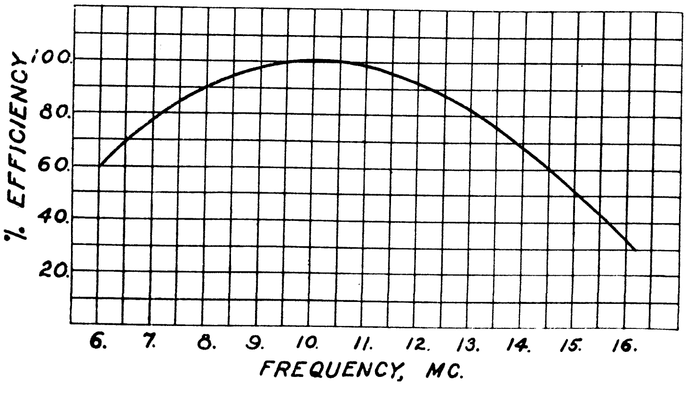


FIG. 11

III. PRINCIPLES OF DESIGN FOR THE IMPROVEMENT OF ANTENNA SYSTEMS.

We all know that the general principles of transformer design require a large primary reactance, with secondary open; low eddy-current, dielectric and other losses; high magnetic coupling between windings and low capacities across windings and between them. Several of these requirements are difficult to reconcile with each other, and the result is a definite restriction in the frequency limits of usefulness. For this reason most antenna and set couplers comprise at least two transformers, one to efficiently cover the frequency range of .5 to 1.5 MC and another to cover the frequency range of 6 to 20 MC. Between and beyond these frequency bands the insertion losses of antenna couplers are comparatively high. The use of iron dust cores help to reconcile the various opposing requirements, such as low leakage reactance and high primary reactance with open secondary as well as high mutual inductance and low self and mutual capacities. Several types of antenna systems are available in which one transformer is intended to cover the frequency range from .5 to 20 MC, although tests show that towards the upper frequency limit the distributed capacities transmit as much or more signal energy than the mutual inductance of the windings.

The advantages of iron cores in antenna units are still the subject of a serious controversy. However, if we keep the following facts in mind, it is readily possible to decide from a technical although perhaps, not from a commercial point of view, the relative merits of iron vs. air core transformers. It is hoped that the following consideration will clarify this subject.

With proper design the leakage reactance of an antenna transformer, when used over at a limited frequency range, say 500 to 1600 KC, may become a friend rather than a foe. If we make the leakage reactance equal to the reactance of the antenna at the geometric mean frequency of the band, an increase in signal voltage over a "perfect" transformer will result. Consider the circuit in Fig. 12, where c, l, r represents the constant of the

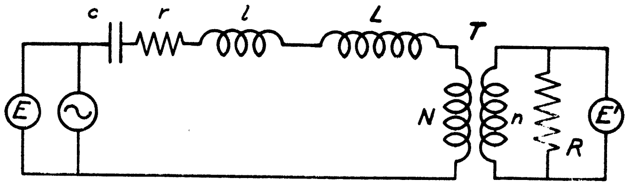


FIG. 12

antenna such as the I.R.E. standard, L the leakage inductance of a transformer T, feeding a resistance R, which is the impedance of an infinitely long or a suitably terminated line.

Let ω_1 and ω_2 be the extreme frequencies of the band, expressed in radians per second. Let ω_o be their geometric mean: $\omega_o = \sqrt{\omega_1 \ \omega_2}$. The EMF, E,′ across the load R, at ω_o , will be

$$E' = E\frac{n}{N} = E\ \frac{1}{\tau}$$

where τ is the ratio of transformation and neglecting τ in comparison with, the reflected resistance τ^2R.

Let the reactance at ω_{o1} be:

$$X_o = \frac{1}{\omega_o C} = \omega_o\ (L + l)$$

and calling α the frequency ratio $\frac{\omega}{\omega_o}$, the ratio of the voltage E′ across the load R to the impressed voltage E will be:

$$\eta = \frac{E'}{E} = \frac{1}{\sqrt{\tau^2 + \frac{X^2}{\tau^2 R^2}\left[\alpha - \frac{1}{\alpha}\right]^2}}$$

Calling Q the ratio of the reactance X_o to the reflected resistance:

$$Q = \frac{X_o}{\tau^2 R}$$

Then:

$$\eta = \frac{1}{\sqrt{\tau^2 + Q^2\left[\alpha - \frac{1}{\alpha}\right]^2}}$$

By giving different values to the ratio of transformation τ, a number of curves can be obtained, such as those given in Fig. 13, from which we can select the proper ratio of transformation τ, according to the degree of uniformity of response desired. A value of $\tau = 3$ is satisfactory for broadcast band reception. It is the actual value of X_o, figure 12, is what counts, and not the percentage leakage reactance which is here of importance.

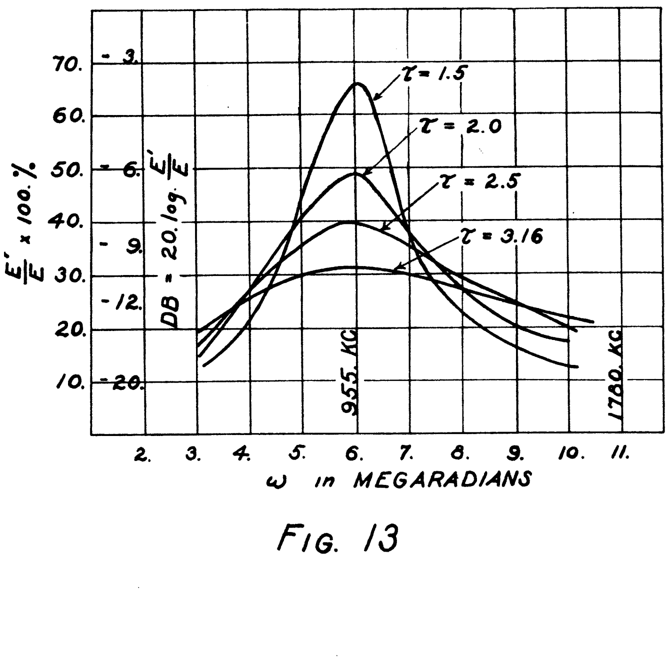


FIG. 13

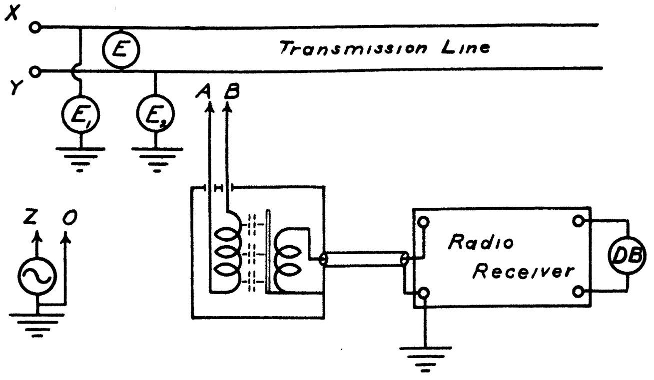


FIG. 14

For the standard IRE antenna, and to cover the band from 550 to 1600 KC, the mean frequency is 940 KC. which gives a value of L = 106 microhenries.

This value can be obtained by making the primary inductance large and the coupling tight or by loosening the coupling but also reducing the primary inductance. As it is best to have a large primary inductance, so as to increase the lower frequency range of the transformer, tight coupling will be advantageous, and it can be secured by the use of iron cores. Hence, an iron core will be markedly useful when we wish to provide further reception of sub-broadcast frequencies, as in receivers for use in Europe.

There is an additional advantage of iron cores. For a given primary inductance less turns are required than in air core coils, and a winding of lower distributed capacity may therefore be constructed. In this manner the upper frequency limit may be extended.

The iron losses in the broadcast band can usually be quite safely ignored and the final selection of iron or air core determined by the required frequency band width of a single transformer, as we have seen from the preceding considerations. For reception of the standard broadcast band only, the advantages of the iron are, in general, not worth the extra cost, as shown by actual comparisons of signal voltage measurements (Fig. 2). In comparing two models in the laboratory, an average gain of 1.5 to 2 decibels in the broadcast band in favor of the iron core was found. However, at 150 KC (2000 meters) there was a 12 decibel advantage.

In the short wave band of 6 to 20 MC, the use of iron is important only when the capacity between windings must be reduced to a minimum. In making certain measurements such as the voltage across transmission line wires, without reference to their actual potential with respect to ground, the problem of eliminating energy transfer by capacity coupling is a very serious one. In our laboratory it is often necessary to find the distribution of the balanced or "push-pull" voltage along a transmission line as in Fig. 14, in which E represents the voltage between the conductors, while E_1 and E_2 are the EMFs to ground. Suppose we desire to measure the EMF across XY. We can compare the voltage across XY, to the known voltage across a signal generator ZO, provided that we have a voltage or decibel indicator independent of ground connections. This can be realized only if we have a transformer having an infinite input impedance or one which is very large as compared with that of the line and having no capacitative coupling to the indicator, which is a radio receiver with a decibel meter (see Fig. 8).

The insertion of an electrostatic shield immediately suggests itself for the elimination of this objectionable capacity coupling. Unfortunately, however, it does not work as expected for the reason that an EMF to ground say E_1, Fig. 14, will send a current through the primary winding via distributed capacity to the shield, when B for example is touched to Y. Although there may be no direct capacitative coupling between windings, there is the magnetic coupling of the transformer itself which will induce a secondary voltage by the passage of the current from B through the primary, and distributed capacity to the grounded shield. The conclusion is that unless this capacity is very low and symmetrical, measurements of E will be spurious due to the effects of E_1 and E_2 through the distributed capacity of the transformer. This is an example of an instance where the iron core will offer a great advantage by permitting the use of very much smaller coils, farther apart, and consequently with a greater ratio of inductive to capacitative couplings. Then, by reversing A and B, with respect to X and Y, and taking an average of the two readings of the meter, the effect of the small assymmetric voltage effects may be cancelled out.

The measurement of voltage distribution of this sort are very frequently necessary and are greatly useful in the design of antenna systems for multiple operation. This subject would require in itself another paper and can therefore only be here briefly referred to.

MULTIPLE RECEIVER ANTENNA SYSTEMS

What are the essential differences in the noise-reducing, signal transmitting problems of multiple operation as compared to those of individual set operation?

The noise reducing considerations are essentially the same with the exception of the fact that noise may be injected in the transmission line by defective or otherwise poor radio sets.

The signal transmission considerations are, however more complicated.

First of all, there must be a minimum of reaction upon the line not only from tuning operations of any and all receivers, but the distribution of signal energy must likewise remain unaffected. That is, the total amount of energy delivered through the transmission line may be constant, but due to wattless components introduced into the line by the radio receivers and their connections to this line, there may be quasi-stationary waves found along the line, with consequent complaint of poor reception at a given outlet and with reference to a particular station.

Second; The attenuation which the line is bound to contribute due to signal energy delivered by the line to the several outlets must be uniform.

Assuming that all the radio receivers provided pure resistances inputs of a given value it can be shown theoretically that for a maximum average signal level the ratio of transformation of the "ideal" transformers at each outlet should be inversely as the square root of the number of outlets.

If sets have, say, 4000 ohms in the broadcast band and the line is 100 ohms, for one set the ratio of transformation should be $\sqrt{\frac{4000}{100}}=6.324$ but if we had 10 outlets, it should be $\sqrt{\frac{4000}{100\times10}}=2$ and for 20, it will be 1.414. In practice, however, we cannot assume that sets have $4000+j0$ ohms. There is bound to be a short transmission line between set and outlet, unequivocal instructions to the contrary notwithstanding. Radio listeners want the set at a very special location in the room, whether it is 40 feet or 40 inches from the outlet. The service man will surely use a twisted pair to connect the set, and unless we design the coupler with this practical condition in mind, low signal level will be the result, and reaction upon the line will follow.

In the design of radio set couplers, we find it good practise to assume that the impedance of the "load" is that of a 300 mmf condenser within the 550-1500 KC band and approximately 100 ohms in the short wave band. We here say "approximately" because it is impossible to ascertain the terminal impedance of a twisted pair of 5 to 50 feet in length connected to goodness knows what kind of a radio set.

Hence, here we can readily see that the signal level delivered to a radio set is dependent upon the attenuation of the line plus that of the coupler and local connections.

When we design the coupler, we have to be very sure that, by making the "local" attenuation low, we do not increase excessively the line attenuation and accompanying reflections. If the coupler introduces high attenuation so as to offer high impedance towards the line, then the latter will have small attenuation and if, properly terminated, greater uniformity of signal levels.

Between these extremes lies the correct design of an individual coupler.

The grounding of the transmission line circuit is very important, depending upon whether or not there is electrical isolation and where it takes place. Experience shows that a ground close to the antenna proper, especially if this "ground" is a large metallic surface, contributes the most greatly to noise reduction, particularly for community aerial systems. A large counterpoise may be the best for noise reduction in certain cases.

Recapitulating, we have reviewed the various antenna systems now in use; the extent to which they have contributed to better reception; and the direction that improvements in design may best take. It has been pointed out that there is a serious lack of standards of performance, and of comparative merit and most importantly, of methods for measuring them. Our task in this paper is not complete, unless we urge our fellow-members and the radio engineering profession in general, to take up this problem of standardization, as has been done in the past in other phases of the art. We sincerely hope that valuable suggestion may be forthcoming.

In closing, we express our sincere appreciation of the valuable assistance in the preparation of these notes and experiments to Mr. Ernest V. Amy, past president of the Radio Club of America and Mr. Edward Sieminski, Assistant Engineer of Amy, Aceves and King, Inc., and welcome any comments and suggestions, particularly in this most important matter of standardization.

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NEW PATHS TO GUIDE CENTIMETER RADIO WAVES

BY

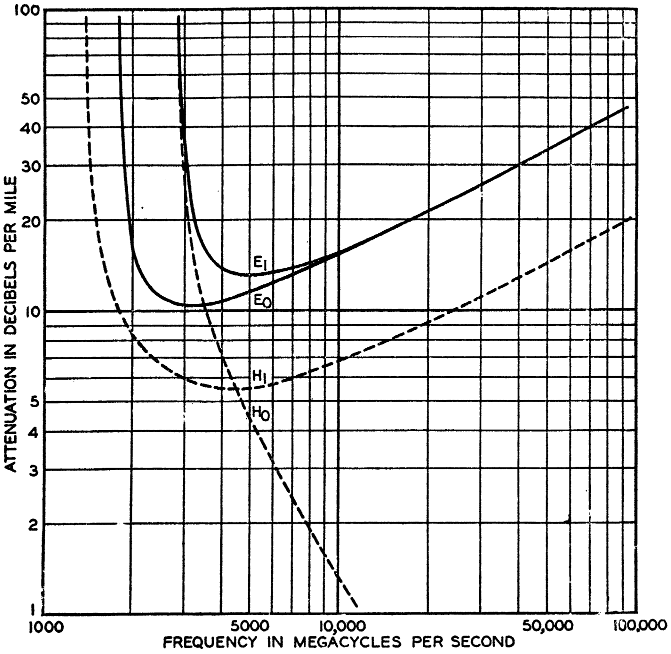
G. C. SOUTHWORTH*

Delivered before the Radio Club of America, January 13, 1938

"Since Mr. Southworth's paper has not been submitted for publication, the Editor has prepared this abstract of the paper as gleaned from his notes and other publications by Mr. Southworth."

In the early days of electrical communication, it seemed axiomatic that there must be a completed circuit to permit the flow of electric current or power. A return path, either in the form of another wire or the earth, was apparently essential. With the advent of radio this seemingly fundamental law was broken, because for radio transmission no return path in any ordinary sense is required. Radio, however, was very evidently a distinctly different type of transmission. The radio waves simply traveled in all directions through space as does light or radiant heat.

Research disclosed a new form of transmission for high frequencies. It is unlike radio because the waves are not broadcast through space but follow a physical guide comparable to a wire. No return path, however, is required of the kind that is commonly assumed in the usual case of transmission. With an ordinary concentric conductor, such as is used for feeding a radio antenna, the outer tube forms one side of the circuit and the central conductor the other. If, however, instead of operating such a structure at a frequency of about a megacycle, approximately the average frequency for broadcasting, a frequency of several kilo-megacycles were employed, it would be found that the central conductor could then be completely withdrawn and the structure still able to transmit power. Indeed, the outer pipe itself might also be done away with, and the transmission taking place along a wire or rod of insulating material.



Incredible as these phenomena may seem at first sight, they are readily explicable on mathematical principles that have been known for many years. As early as 1897 Lord Rayleigh obtained solutions for certain differential equations occurring in electrical theory that indicated that wave power could be propagated through either hollow metal pipes or through dielectric rods. So far as is now known, no experimental work was attempted at that early date. As often happens in science these principals were independently discovered by others, both in this country and abroad.

The analytical work of Rayleigh and others has now been greatly amplified. The extensions which have been added to the theory include calculations of characteristic impedence, attenuation, and inductive effects into neighboring wave guides, and particularly the discovery that, theoretically at least, one of the many waves that may be transmitted through a hollow pipe becomes progressively less attenuated as its frequency is raised. This remarkable property appears altogether unique in the field of electrical transmission.

These electric waves that are guided through hollow pipes and dielectric rods are moving configurations of electric and magnetic fields associated in many different ways to provide a wide range of types of waves. To set up any particular type of wave it is necessary, of course, to provide an appropriate launching mechanism.

Wave guides behave somewhat like wire lines in that they have a definite characteristic impedence and a definite attenuation. Also waves travel through them with a velocity that may be predicted with considerable accuracy. The calculated attenuations of the four principal waves are of particular interest. They are shown in the figure for the special case of a five-inch hollow copper pipe.

It will be noted that all waves suffer infinite attenuation at or below certain critical frequencies, and that with an increase in frequency this attenuation decreases very rapidly. For three of the types of waves it approaches a minimum, and then increases for higher frequencies. For the wave that has been designated as H_0 this attenuation appears to decrease indefinitely with increase of frequency.

The question naturally arises as to what use wave guides may be put. This is a difficult question at this early day. For long-distance transmission, the situation is that the art at these extreme frequencies is not yet at a point which permits a satisfactory evaluation of practical use. For transmission over very short distances, however, or for use as projectors of electric waves, or as selective elements under certain conditions, the use of wave guides has definite possibilities.

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*Engineer, Bell Telephone Laboratories

TELEVISION AND THE RADIO ENGINEER

BY

MR. ALBERT F. MURRAY*

Delivered before the Radio Club of America, February 10, 1938

On the evening of February 10, 1938, the Radio Club was privileged to have as its speaker Mr. A. F. Murray whose subject was chosen to acquaint the membership of the club with the progress that has been made in the development of television receiving and transmitting equipment. It will be remembered that Mr. Murray has long been active in this field and is, therefore, preeminently fitted to discuss this subject before the Club.

Before entering upon the presentation of the subject the speaker made a canvass of those present to determine the scope of their several interests, as between television transmission and reception and as between design and servicing and thus was able to more specifically direct the course of his presentation to the interests of the audience.

It was pointed out that the basic elements of television systems are far older than the radio art, notwithstanding the apparently generally accepted notion that television in all of its phases is the newest of the communication arts. To this point Mr. Murray pointed out that the first conception of television was probably associated with the subject matter of an invention made in 1884 by an Austrian, Paul Nipkow, whose patent on a scanning disc was shown and is here indicated in Figure 1.

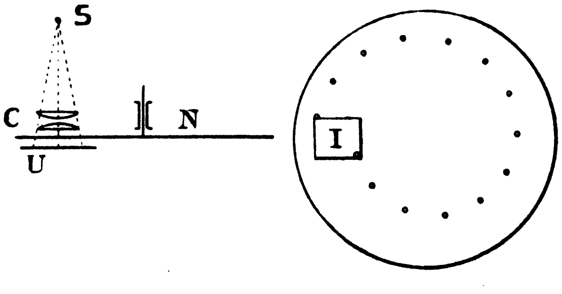

Figure 1

A similarly startling bit of technical history was disclosed by Mr. Murray in his reference to the picture transmission method described by Campbell-Swinton in 1911 as indicated in Figure 2. It will be noted from this figure that this appears to be the prototype of the modern cathode ray tube method of transmission and reception: thus again, indicating that the basis of television systems lies much further in the distant past than is commonly suspected.

Thus by these extremely early processes of scanning the process of dissection of the view requires only that the light available be converted into corresponding electrical values, or the inverse, for the purposes of transmission or reception.

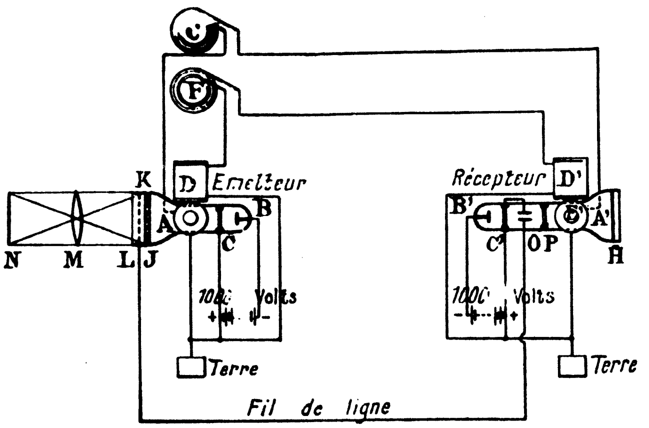

Figure 2

As shown so aptly by the speaker, the progress required for advancing from the elementary television system of the Nipkow to the modern television system while it has been largely a matter of the development of detail of method and equipment was, in fact, the development of these details in such orders of magnitudes as were probably quite unconceived of in the original Nipkow invention. Thus, even with the modern and relatively highly efficient photocells, there was left the need for high degrees of stable and especially uniform broad band amplification between the photocell and the transmission medium—whether it be a radio transmitter, wire lines or other medium—in a degree of uniformity of amplification, both as magnitude and phase, quite beyond the requirements met with in any other phase of communications engineering.

And when to these new demands upon the skill and ingenuity of the radio engineer made necessary by the inherent nature of television transmission there is added the fact that both the broad band of frequencies to be transmitted in television and the limitations upon the choice of radio carrier frequencies to be used for radio television by its late entrance into the field of practical communication resulting, as well we know, in its being assigned by the regulating bodies throughout the world to such ultra-high frequencies as are only now beginning to be understood as to characteristics of transmission and necessary equipment, it becomes quite evident that, not withstanding the early establishment of the elements required for television transmission, the development of practical equipment has been a problem of major magnitude.

Mr. Murray expanded on the details of this problem with reference to each of the many elements in a complete television system from the camera, through the transmitter with its synchronizing arrangements, and the receiver with its reproducing or picture tube, not neglecting the problems to be solved in the development of suitable transmitting and receiving antennas.

In conclusion he indicated most strongly that in addition to the purely technical problem involved in the development and production of equipment there is the serious problem of training the required field service personnel and on this point he had an interesting word to say as to the place and requisite character of the training schools in the solution of this problem.

The delivery of the paper was followed by lengthy discussion from the floor indicating a powerful interest on the part of all that attended in the imminence and future of practical radio television.

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*Engineer in Charge of Television, Philco Radio & Television Corp.

RADIO FREQUENCY CONVERSION CHART

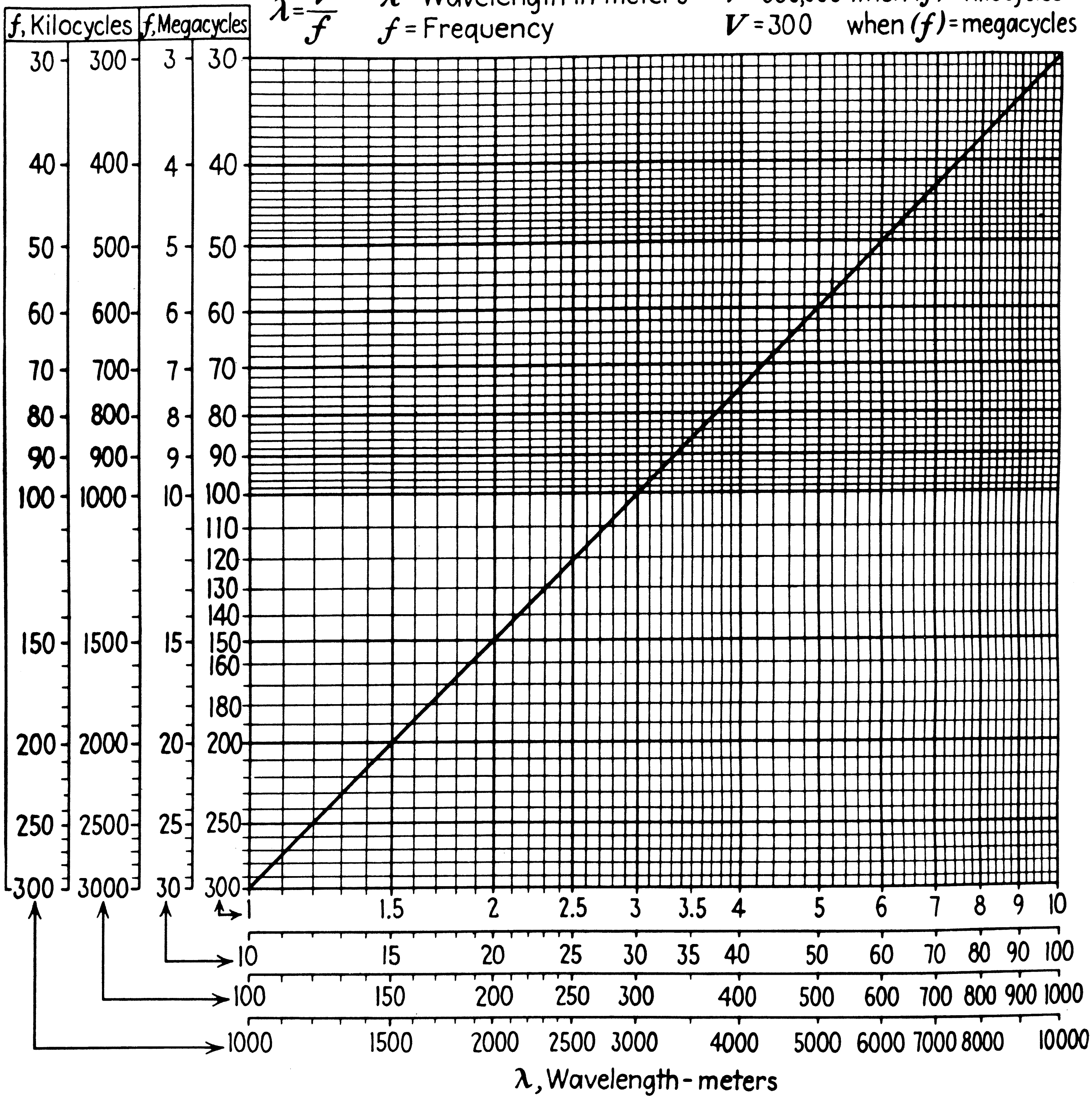
$$\lambda = \frac{V}{f}$$

λ = Wavelength in meters

f = Frequency

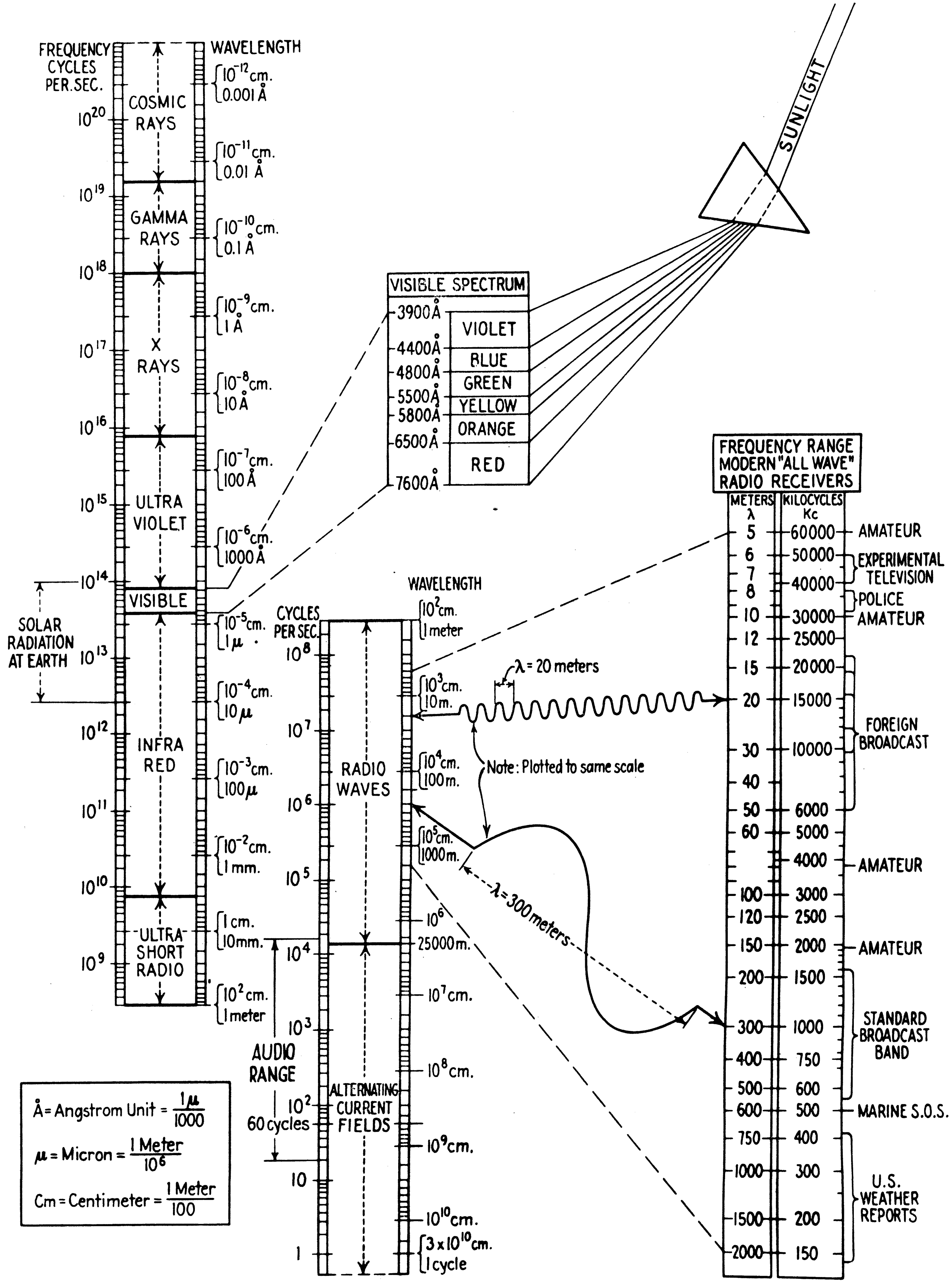
V = 300,000 when (f) = kilocycles

V = 300 when (f) = megacycles



Prepared for The Radio Club of America by E. V. Amy.

THE FREQUENCY SPECTRUM OF ELECTROMAGNETIC VIBRATIONS



Prepared for The Radio Club of America by E. V. Amy.