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Volume 12 November, 1935 No. 4

PROBLEMS OF ALL-WAVE NOISE-REDUCING-ANTENNA DESIGN

BY

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Delivered before the Radio Club of America
November 14, 1935

The radio antenna is the gateway through which come the signals to the radio receiver. When radio was in its infancy, problems of antenna design were given detailed consideration; early text books were replete with the mathematics of the theory of antennas; much experimentation was done in the determination of their characteristics. Then came, in rapid succession, a series of inventions of apparatus and circuits culminating in radio receivers of almost unbelievable sensitivity, while at the same time, however, the antenna itself both figuratively and literally was relegated to the attic. Meanwhile, other electrical apparatus performing their usual function, continue also in their production of high frequency energy radiated through space or conducted along power lines.

This has resulted in a veritable bedlam of noise whenever stations other than the most powerful locals were to be received and interference reduction has become a necessity. As most radio receivers possess more amplification than can be used without undue noise, it follows that noise reduction, even at the expense of a little signal strength, is essential to the operation of the receiver at full capacity.

Antenna design underwent another radical change with the advent of popular short wave broadcasting, especially from foreign countries. Whereas, a simple Marconi Type antenna was sufficient for the 500-1500 K.C. band, it is inadequate for the 6-20 M.C. band particularly from the interference standpoint, and the Hertz type dipole or doublet largely superseded the simple Marconi antenna for short waves.

TYPES OF INTERFERENCE:

The purpose of this paper is to present some facts concerning the nature of interference, the remedies available, and some suggestions concerning the antenna and transmission line for best performance, not from purely theoretical consideration but also from the practical viewpoint.

It is a common experience with radio engineers and service men that what is good in one place for interference elimination is bad in another. Many engineers have found certain schemes that promised unqualified success in the laboratory, but as soon as they are put in practice they fail miserably. In fact, most of us have to confess failure at some time or other in the development of anti-noise circuits and apparatus. This has been due mainly to the fact that interference has been assumed to be just one sort of an animal to be hunted down and annihilated while, in reality, there is whole species to be exterminated.

The most deceiving circumstance is the multiplicity of ways through which interference enters the radio receiver. Accordingly, it may come in - (1) By the antenna; (2) by the downlead; (3) by the power line; (4) by the ground connection or by a combination of all these.

(1) The only remedy is to place the antenna as far above the roof as possible and some times at right angles from the source of the strongest interference. Obviously, the most suitable type of antenna for the wave lengths to be received should be selected, and experience has shown that a horizontal wire about 60 or 70 feet long with a gap in the middle so that it may constitute a doublet, as well as T antenna in conjunction with a transmission line downlead, is the most practical form of all-wave antenna from the standpoint of simplicity and facility of erection. Improvements upon this may be secured by the use of "X" or "V" doublets, multiple doublets, and other various forms of dipoles well known to the radio art.

(2) The downlead is subject to electromagnetic induction just the same as an antenna. There are two ways of preventing its effects - by shielding it and by substituting for the downlead a balanced transmission line. For practical reasons the second expedient is to be preferred for short wave reception.

The electrostatic coupling is by far the strong-

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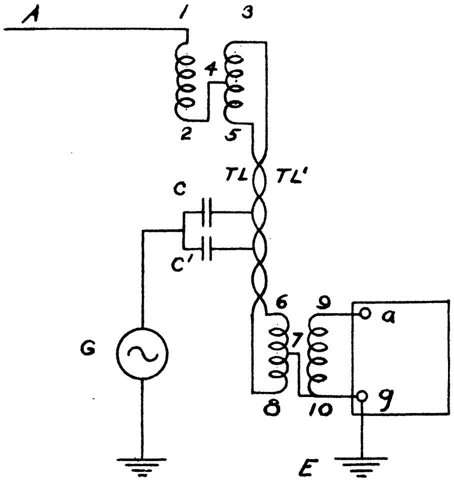

Fig. 1

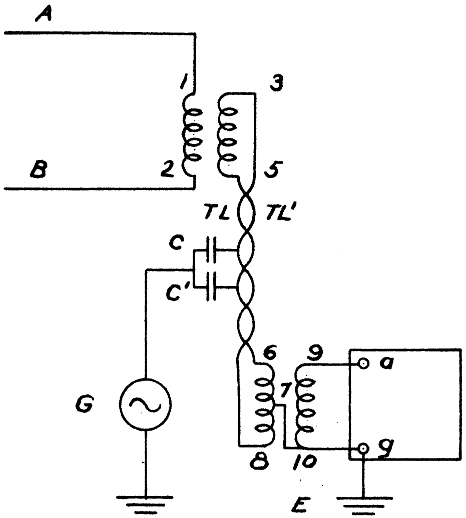

Fig. 2

est of the two components. Schematically, the circuits for signal and interference may be represented as in Fig. 1, in which we substituted the open downlead by a balanced transmission line, with two transformers at each end. We may represent the circuit of the interference by two equal capacities from the source G to the two wires of a twisted pair transmission line. Following the circuit from G through C, C' to the lines TL, TL', and entering at opposite ends of the center tapped coil 6, 7, 8, the current will go to earth from the center 7, to E and return to the generator G.

If we make coil 6, 7, 8 so that there is unity coupling between the two halves 6-7 and 7-8, and that their mutual inductance to the secondary coil 9, 10 absolutely equal, no E.M.F. will be induced therein by the passage of currents through the circuit G,C and C', L and L', 6-7 and 8-7 to E, while the signaling current from the antenna A through primary 1-2 will induce a secondary E.M.F. across the transmission line TL-TL' which will produce a current flowing down one wire and up in the other at the same time, and which we shall call "circulating current". It will enter the primary at 6 and leave at 8, inducing an E.M.F. across 9-10 which feeds the radio set terminals a-g.

If nothing else happened, there would be a complete elimination of the interference from capacity coupling to the downlead. Unfortunately, current from the generator G through capacities C-C' will not only flow to earth but will also flow upwards towards the antenna. In so doing it will traverse the primary 2-1 which will thereby induce an E.M.F. across the transmission line L-L' and force circulating currents just in the same manner as the signal in going to earth through the primary 1-2. This explains why the interference is not totally eliminated, unless the antenna impedance was infinite. It is fortunate, however, that the impedance of the branch from C-C' to earth is much smaller than the reflected impedance of the antenna, and this explains the success of the devices in the market based upon this principle of operation.

For a more complete reduction of interference, the complete severance of the metallic connections between the transmission line and the antenna coupling transformer is necessary. In Fig. 2, the signal voltage is derived from the difference of potential between two wires of a different effective height, that is, between an antenna A and a counterpoise B. The latter may be substituted in some cases by a ground connection, if such is available, or from a large metallic surface so that it will act as an effective ground rather than the surface of the earth. It must be free from other currents traveling downwards towards earth.

In the event that the wave length of the signal to be received is not much longer than twice the length of the horizontal wire, the upper coupling unit may be dispensed with, and the two wires of the transmission line connected to the center of the wire where a gap is opened, thereby converting it into a Hertz doublet. In this case all the considerations concerning the paths of signal and interference currents just discussed for long waves will still hold true, except that currents traveling upwards from the capacity coupled interference source cannot bring back circulating currents. A method of combining in one horizontal wire (with a gap) the Marconi or "T" antenna and the Hertz or doublet and a transmission line will be described later.

(3) Interference introduced by the power supply line. Next to the lead-in pickup, the power line brings in the greatest amount of interference. To understand the modus operandi, let us consider the circuit of Fig. 3 which shows schematically a source of radio frequency voltage G' across the impedance Z' of the line to earth. Measurements show that this impedance is extremely low at 60 cycles but at broadcast frequencies it is one or more hundreds of ohms depending upon frequency, distance to earth, etc. The impedance of the ground return of the radio receiver is not negligibly small either; let it be represented by Z in Fig. 3. It is obvious that the electromotive force of the source G' will send a current through the radio receiver (directly like in A.C.-D.C. sets, or indirectly by capacity coupling in other sets) and return to earth through the impedance of the ground connection Z which is common to the antenna pickup circuit made of the antenna proper, A, the effective capacity of the aerial to

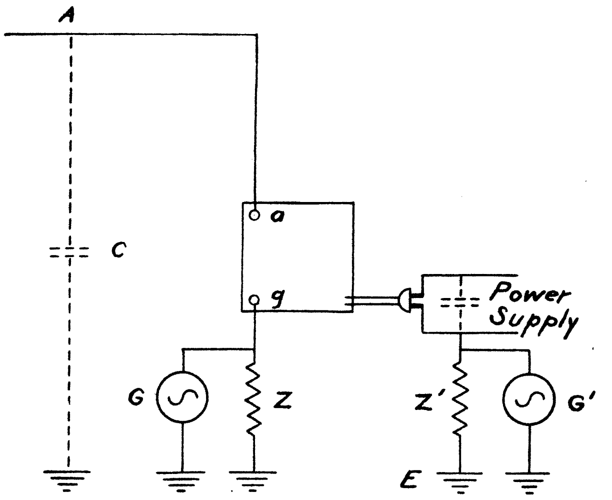

Fig. 3

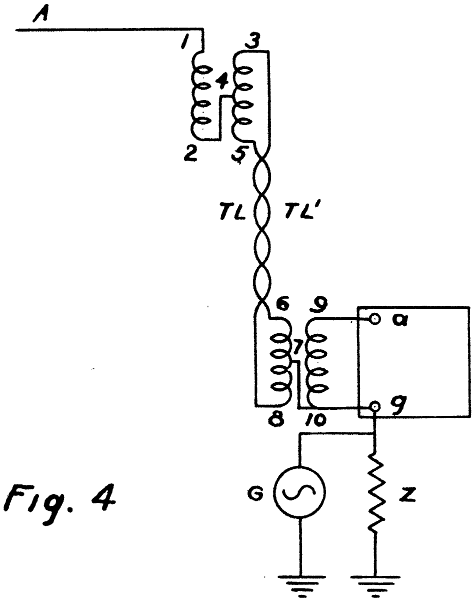

Fig. 4

ground, C, and earth, E. This constitutes two circuits with a common impedance, Z. If the distance from the radio set to earth is not very small, return currents to earth from some other sources of radio frequency disturbance such as G will also introduce an interference in the antenna pickup circuit. The existence of voltages in the ground return circuits, such as steam or water pipes, fire escapes and other conductors can be demonstrated by the common practice in many apartment houses to connect the antenna post of the radio receiver to such conductors leaving the ground post free, and obtaining sufficient radio frequency voltage to receive local as well as moderately distant stations.

The interference elimination circuit of Fig. 1 will be found ineffective in totally reducing this kind of interference. In Fig. 4 we can see how the interference currents will follow an upward path to the antenna. It will be apparent at once that the source G will force a current upwards which eventually will pass through coil 1-2 and into the antenna. Circulating currents will be immediately sent up and down the transmission line and the interference will appear as voltage across a-g. Hence, this system will not eliminate altogether interference of this type. We say altogether because the impedance matching of the source of interference is not as good as that of the antenna to the system, and hence there will be discrimination in favor of the signal. There is, however, a very simple way of stopping the passage of interference currents upwards into the antenna, and it is the insertion of an "isolation" transformer, as shown by windings 11, 12, 13, 14, in Fig. 5. It is of 1/1 ratio designed for about 100 ohms input and output impedances, or for some other value of the line impedance. The windings should have as nearly 100% coupling as is possible so as to avoid appreciable insertion losses, while the capacity between windings should be kept very low to prevent substantial flow of current from the source G up the transmission line and into the antenna.

Another way of producing the same results would be to break the ground connection between the primary center tap and the chassis, that is, between 7 and 10 in Figs. 1, 2 and 4, and eliminate the capacity coupling by means of a Faraday screen or other form of shielding. Unfortunately, shielded transformers are not very efficient because the presence of the shield introduces magnetic leakage and distributed capacity. Another serious trouble arises from unequal distributed capacity between the shield and the two ends of the primary winding which would result in an unbalanced flux for parallel currents. This effect is best illustrated by the schematic diagram of Fig. 6, where the distributed capacity of the primary 6-8 to the shield S is represented by condensers C, C'. Assuming that C and C' are unequal, it will be noted that more current flows in the first turns of the winding 6-8 to ground through C than through C' (if C is larger than C'), and hence there will be more ampere-turns in one direction than in the opposite, and therefore, there will be a resultant field inducing voltage in the secondary 9-10.

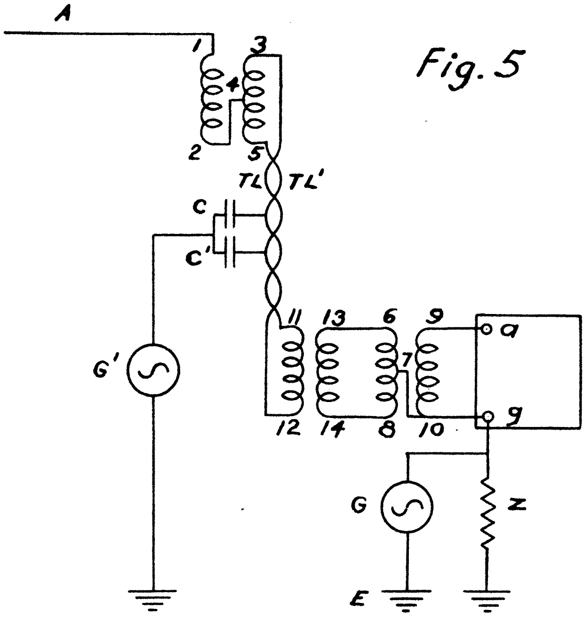

Fig. 5

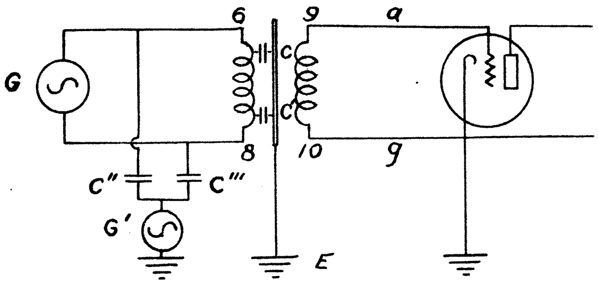

Fig. 6

The recent progress in the development of ferromagnetic substances suitable for cores of R.F. transformers is going to simplify R.F. transformer design by providing a higher mutual inductance with a minimum of turns and distributed capacity, and it is possible that a good isolation transformer may be built with a shield between windings that will introduce a small attenuation for signalling currents.

Another expedient to prevent the passage of currents from the ground connections upwards consist in isolating the set from ground as far as possible, and to effectively do so it is necessary to introduce R.F. chokes in the power line leads and not to connect the chassis to earth. After all, the only voltage that eventually produces an appreciable sound in the loud speaker is only the difference of potential between antenna and ground terminals of the radio receiver, and the chassis of the set may be considered as ground as far as reception is concerned. In practice, it is very hard to predict which is the best way to operate a radio receiver; grounded or not grounded, and if so, to what metallic bodies. It has been found that connection of the chassis to the "B.X." that encloses the power lines in one instance was the only remedy to stop severe interference from a neon sign in the same building, while in some other cases complete isolation was best. When an antenna is not in a completely "dead" field for interference, it has been possible to balance out induced interference in the antenna by allowing the downlead to pick up interference but in opposite polarity. At any given frequency it has been possible in the Laboratory to balance out the interference as completely as it is done in making measurements in a Wheatstone Bridge. In Fig. 7 is shown an arrangement whereby the E.M.F. across the a-g posts of the set is made of the vectorial sum of the induced secondary voltage across 9-10 and the drop across the impedance l-r-c made of three variable units so that the magnitude as well as the phase is under control. In order to make it possible to balance out any E.M.F. from the transmission line wires TL, TL', a reversal of these lines may be necessary so that the secondary voltage always may be opposed by the drop across l-r-c. In practice, a very satisfactory partial balance may be secured by the use of resistance only in lieu of the l-r-c combination, and there are coupling units in the market made with this arrangement.

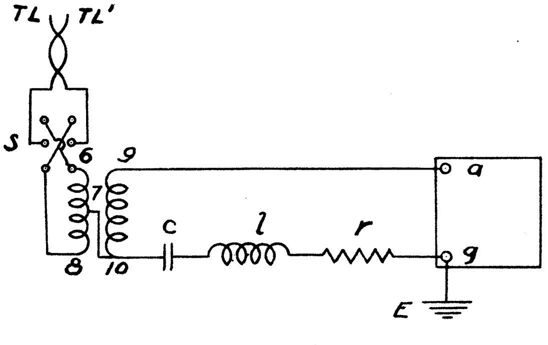

Fig. 7

PERFORMANCE ON SHORT WAVES:

When the antenna has such length that it is possible to use the horizontal wire as a dipole, the problem is considerably simplified. The signal voltage is obtained by virtue of a difference in phase of the electromagnetic wave at the various points in the wire which tends to send a circulating current into the transmission line without the necessity of introducing transformers such as those shown in Figs. 1 to 5. Interference traveling upwards along the transmission line cannot bring back circulating currents, and a simple transformer such as shown in Fig. 8 will be found quite satisfactory. Connection between 7 and 10 is necessary to provide neutralization of capacitative coupling between the primary winding and the "live" end of the secondary. The connection from 7 to either 10 or the g post of the radio set must be very short, as at high frequencies the inductance of the wire will introduce a considerable reactance between these points, the drop across which will produce a voltage in series with the induced secondary voltage across the secondary 9-10 and interference will thusly be reintroduced into the radio set. If the connection 7-10 is broken, a shield should be interposed between windings as in Fig. 6, but with some extra attenuation to signal currents for the reasons discussed above in connection with broadcast frequency reception.

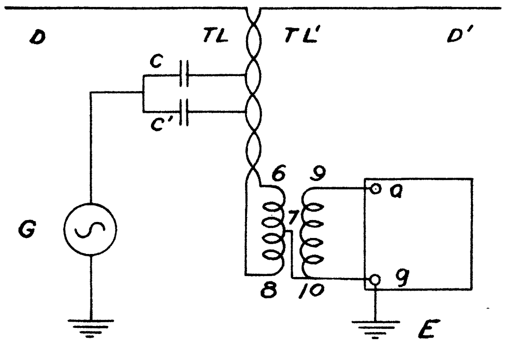

Fig. 8

COUPLING UNITS FOR ALL-WAVE RECEPTION:

If it was possible to design a transformer that would cover the whole frequency spectrum, the lower coupling unit would be nothing else than a single center-tapped transformer like in Fig. 1.

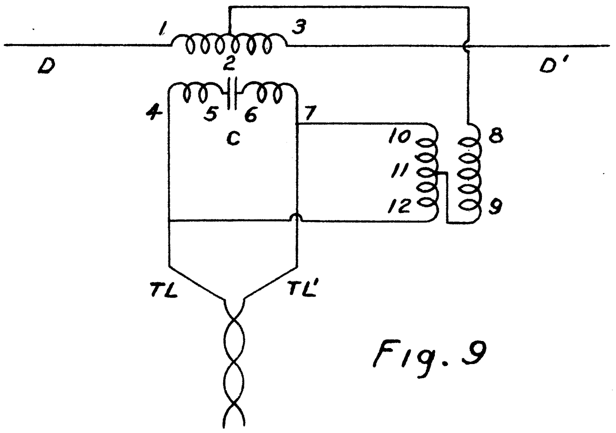

Fig. 9

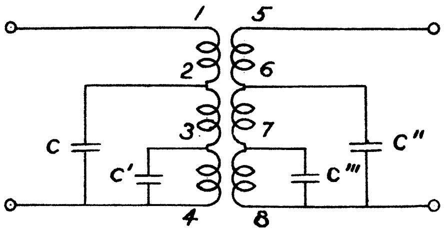

Fig. 11

The antenna coupler, however, has to be more complicated because it is necessary to produce circulating currents at low frequencies and at the same time transfer the energy from the dipole at high frequencies without interference from each other's operation.

In Fig. 9 it is shown a magnetically coupled R.F. unit consisting of the primary 1-2-3 between the two branches of the dipole, and a split secondary 4-5, 6-7 across the transmission line TL, TL'. It includes a condenser C that has low reactance for high frequencies but high for low ones. The low frequency transformer is similar to the one shown in Fig. 3 and the primary winding starts from the center of the primary winding of the H.F. unit and terminates in the mid-tap of the secondary of the low frequency unit, this latter winding being connected across the transmission line.

In Fig. 10 is shown capacitative coupling between the dipole and the transmission line. The frequency selection is accomplished by suitable choice of the electrical constants of the circuits.

At frequencies bordering the low and high frequency bands both transformers will act to some extent and the transition is very gradual, and care must be taken so that they never may act in opposition to each other by using the correct polarities. Anti-resonant circuits may be inserted in series with the two transformers tuned to frequencies in the border line, so as to make the change-over more definite and avoid losses due to phase opposition when both transformers are operating at low efficiency on some frequency near the limit.

The set coupler may be made of a number of transformers with condensers in series of multiple, as for example in the diagram of Fig. 11. In practice, however, only two units are found to be required for ordinary all-wave reception. Fig. 12 shows a unit consisting of a low frequency transformer with its primary center tapped at 7 and grounded to the chassis of the radio set g, the secondary grounded at 10. The high frequency transformer has condensers, C and C' inserted in series with the primary winding 11-12-13. The secondary 14-15 is connected in series with a small condenser and in parallel with the other secondary; both of them feed the input circuit a-g of the set.

INTERFERENCE ELIMINATION TESTS:

There are many coupling units in the market intended to be noise reducing outfits. What criterion and by what means can we ascertain their merits?

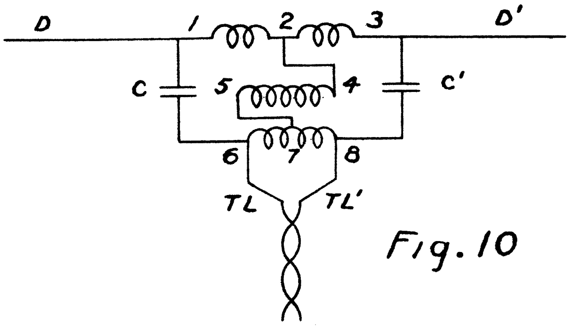

Fig. 10

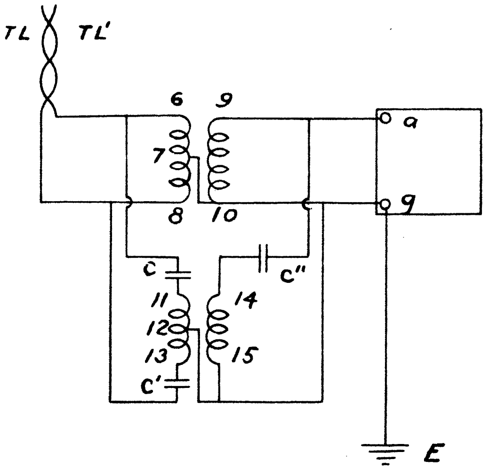

Fig. 12

At present there is great diversity of requirements and methods of measurement of interference in the various countries, as was well pointed out at the I.R.E. convention last year in Rochester, N.Y. Various committees are working with the object of submitting a set of standards of performance as well as methods of testing noise reducing devices and also radio receivers themselves. Until we have something to go by, it seems that the following method can give fairly satisfactory guidance in measuring the comparative ability to pick up interference of two systems, one of which usually is an open downlead and the other is a combination of coupling units and their transmission line, connecting the same length of horizontal antenna wire in both instances, to a calibrated radio receiver.

The method which has been used in the development of noise reducing antenna systems will be described below. It involves the use of a sinusoidal, single frequency interference, instead of some artificial source of damped oscillations produced by sparking apparatus. The assumption is made that any pulsating current may be decomposed into an infinite number of frequencies very close together, according to Fourrier's integral. It is also assumed that the receiver is substantially unaffected by disturbances the frequencies of which are outside the narrow band intended to be passed through the various tuned circuits. Cases of shock excitation may be said to form an exception, but, even then, the frequency that causes any response in the speaker is within the band admitted by the tuners. Consequently, if we can eliminate an interfering sinusoidal oscillation (modulated at some convenient audio frequency so as to make it audible), it may be safely assumed that all other forms of interference within reasonable magnitude will also be eliminated to the same extent.

A microvolter is used as source of interference and it is connected to the system in the various forms shown in Figures 1 to 8. In order to establish a direct comparison between an open downlead without coupling units and a system consisting of the same length of horizontal antenna conductor with a switching arrangement that will permit the same total length of wire to act in both as an ordinary "T" antenna and open downlead and as a noise reducing system. Fig. 13 shows the circuit schematically. When S and S' are thrown up, the antenna and transmission line act as a "T" antenna directly connected to the antenna post, a, of the set, and with S and S' down, the units U and U' are thrown into the circuit in the manner called for by the system.

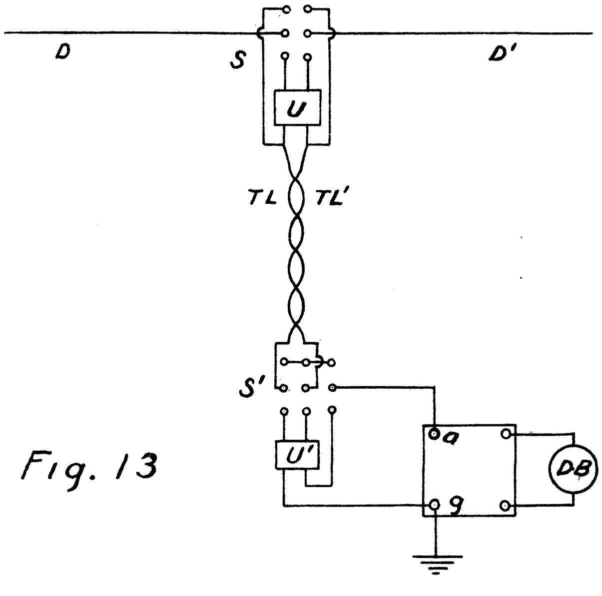

Fig. 13

When making measurements with actual signals, the output level should be observed first with the system on, and immediately with the "T" antenna, using the same station, and noting the signal strength difference, preferably in D.B. A graph should be plotted with frequency as abscisae and D.B. differences as ordinates.

Then the source of interference is connected in the manner to be selected; by means of two small and equal capacities from the microvolter to the lines of the twisted transmission line as in Fig. 2, or in series with the ground lead across a low resistance as in Fig. 4, and readings of the output meter and attenuator taken to determine the D.B. difference in output and a second graph plotted as previously, this will show how much interference reduction is there and then the difference between the two graphs will show the effective interference elimination properties of the system in D.B.

The details of the receiver are interesting. The actual model used in the Laboratory is a superhetrodyne with band pass filter input circuit of the inductively coupled antenna type. In Fig. 14 only the essential parts of the circuit are shown. The terminals a-g constitute the input. Across it there is a resistance R_1 which represents the input impedance of the receiver and can be made of any value desired. A potentiometer of much higher total resistance serves as attenuator. In lieu of this potentiometer a better form of calibrated attenuator should be used when very accurate measurements are required. Resistance R_2 is large compared to the effective impedance of the primary of the first R.F. transformer T_1, so that the potentiometer setting may be almost independent of its load and also that the band pass filter of the set (not shown in Fig. 14) may not become inoperative. V_2 is an R.F. or I.F. amplifier, and there are a number of such tubes in the actual receiver. The I.F. stage immediately preceding the detector tube is provided with means for the modulation of the carrier of the station being received by means of 60 cycles. A low tension transformer such as bell ringing transformer with its secondary in series with the cathode of the last amplifier tube V_2 will modulate the R.F. or I.F. which, after it is amplified, will be fed to the detector V_3 of the linear diode type so that the output shall be proportional to input voltage as far as possible. In the output stage V_4, an output transformer tuned to 60 cycles feeds a copper oxide rectifier DR and a current indicator, M.A. The advantage of modulating the I.F. is very great, as the output current in the mili-ammeter will be independent of the modulations in the program of the station and will be proportional to the carrier which is modulated in the tube V_2.

The tuned output transformer reinforces the 60 cycle modulation and reduces the modulations from the signal. In this manner the signal strength is easily measured by means of a commercial type radio receiver equipped with little extra apparatus and controls. It must be thoroughly shielded and isolated from the power line connections by means of chokes. The A.V.C.

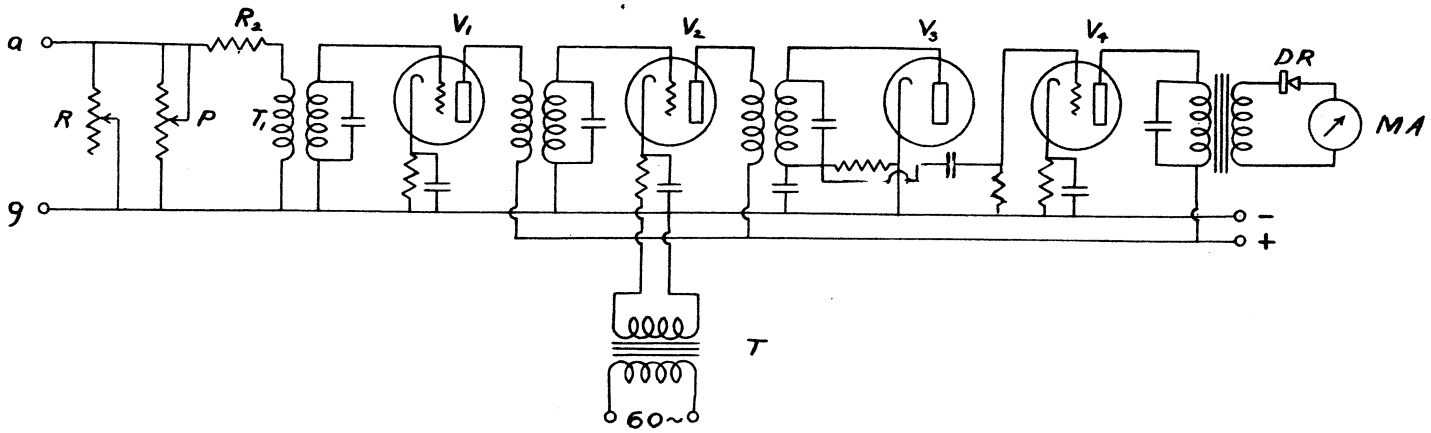

Fig. 14

must be rendered inoperative by using fixed biases or otherwise.

By means of this method, the antenna and transmission line characteristics may be studied experimentally.

ANTENNA DESIGN:

We shall not attempt to cover this broad subject from theoretical or statistical considerations; this is obviously impossible.

From a commercial standpoint, an antenna should be -

a. Easy to erect
b. Inconspicuous
c. Capable of picking up signals throughout the all-wave band
d. Particularly efficient at the regular broadcast band, 15, 19, 25, 31 and 49 meter bands.

Starting with the last requirement, a dipole of some form is necessary which will have no anti-resonant frequencies within the specified short wave band. Straight doublets are preferred for the fulfilment of (a) and (b) but, if these requirements are not very stringent, multiple doublets, "X" doublets or cage doublets are preferable. The "X" doublet of Fig. 15 has the advantage over the straight doublet of the same length, in that its impedance is more uniform and can be used more efficiently at the longer wave band of 49 meters. Characteristic resistance, impedance and power factor curves for this type of antenna are also shown in Fig. 15 (by courtesy of the Hazeltine Corporation).

Double doublets act much the same as double transformers tuned to two frequencies near the ends of the band to be covered. The well known phase reversal of a tuned circuit when the frequency passes from below to above the resonance value, makes it necessary to reverse the doublets with respect to each other to avoid anti-

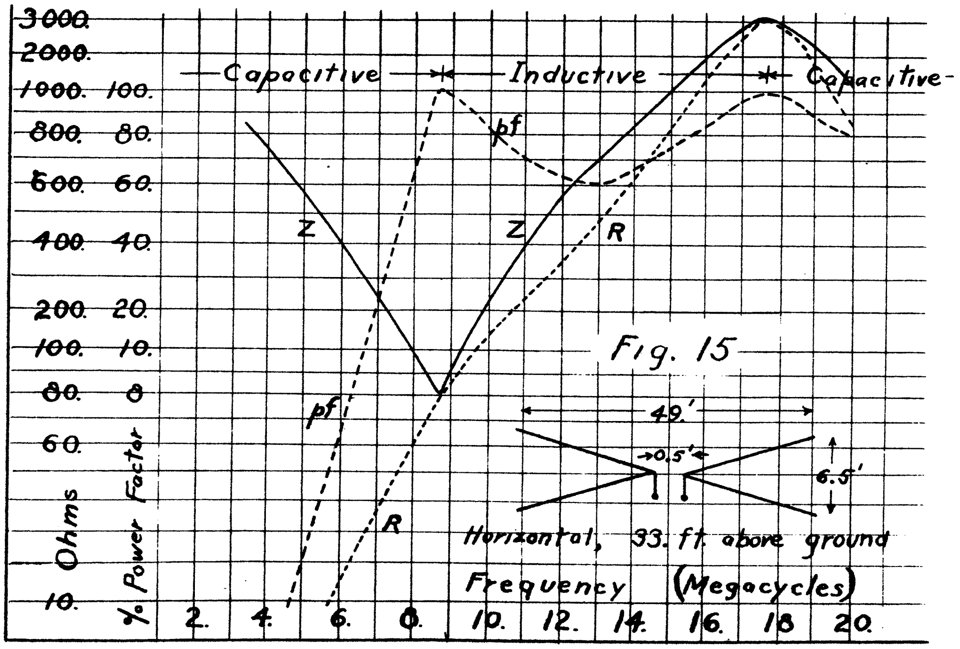

Fig. 15

nodes at some frequency between the two natural periods of the doublets.

If we now use only one of the branches of each of the two doublets, we have an assymmetric doublet. It is used to some extent on account of its simplicity and diversity factor, but as a noise reducer it cannot be as good as a perfectly symmetrical doublet because when interference currents travel upwards on the transmission line, the currents in the two wires are unequal and their difference may be considered as a circulating current which will enter the set coupler just the same as a signal current, as we have already shown in our discussion of interference elimination.

Any of the preceding doublets will act as a flat-top antenna for the broadcast band by means of any of the couplers previously discussed. A pointer in design of these couplers: the leakage reactance of the low frequency transformer, such as 8-9-10-12 of Fig. 9, when the secondary is attached to the line, should tune the capacity reaction of the flat-top antenna at about the middle of the broadcast band, or at a point where desirable signals come in weak.

TRANSMISSION LINES:

The most common forms of transmission line are: a twisted pair cable and a parallel transposed line. The latter has much lower insertion losses, especially in damp weather, but it is much less practical and more difficult to install. With modern receivers of enormous sensitivities, a loss of 4 or 5 db., such as may occur in the cable type line is not serious. The greatest of the losses is ordinarily the dielectric loss between conductors, but, at the very low potentials used, is always small.

The surge impedance of a transmission line is

$$Z = \sqrt{\frac{j\omega L + R}{j\omega C + G}}$$

where L, R, C and G are respectively the inductance, resistance, capacity and conductance per unit length. Lines used as downleads attenuate so little that R and G are very small compared to ω L and ω C and therefore

$$Z = \sqrt{\frac{L}{C}}$$

and Z has unit power factor. This property enables us to measure Z very easily by means of a Wheatstone bridge, as shown in Fig. 16, consisting of a shielded transformer with an accurately center tapped bifilarly wound secondary, a non-reactive resistance R, the value of which may be measured by an ohm meter after the bridge is balanced, and the transmission line terminated by a resistance R', also of the same type as R. When the bridge is balanced, R and R' will be equal and R will be equal to $\sqrt{\frac{L}{C}}$.

When LG = CR, Z is likewise a pure resistance, but in other cases Z will not be a pure resistance; then an approximate balance instead of a dead zero will be obtained, but it is close enough for the determination of Z within a few percent.

Once Z is known, the attenuation of the line may be measured by means of a linear radio receiver (one without AVC and linear detection) and an output DB meter connected as in Fig. 17.

It is interesting to know that transmission lines of the twisted pair type shows a rather low attenuation even at 15 M.C.

The following table shows insertion losses in D.B. per hundred feet of twisted pairs having seven strands of #32 copper wire with 1/32" rubber insulation and cotton braid serving over both conductors.

Frequency in M.C.:	0.5	1.5	5	15
D.B. per 100 ft.:	0.5	0.5	0.5	5.5

Moisture seems to have very little effect. With some of the ordinary twisted pairs there is an increase of 3 D.B. only at about 10 M.C. and up.

The use of the transmission line is not limited to operation of a single receiver. In apartment houses where as many as twenty radio sets must be fed from one antenna, a system of multiple operation has been developed to couple radio sets to the line and known as the DOUBLET MULTI-COUPLER SYSTEM. Fig. 18 illustrates a typical arrangement. The only difference in design is two-fold: The ratio of transformation of the couplers must be such that the reflected impedance of the twenty units may not be too low that will nearly short circuit the line, or introduce abrupt changes in the continuity of the line constants, thereby originating nodes or loops by the formation of quasi-stationary waves along the line. The other feature is the insertion of a decoupling resistance in each coup-

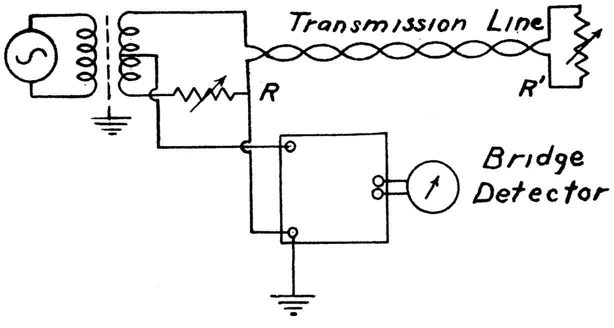

Fig. 16

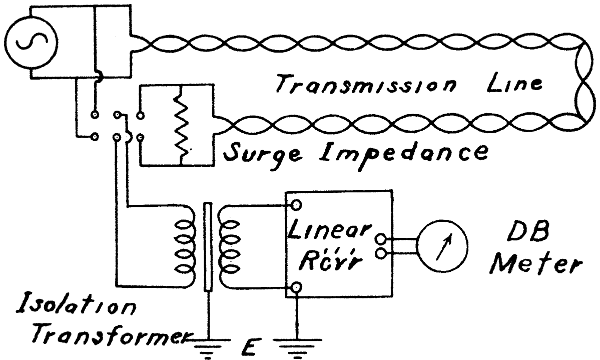

Fig. 17

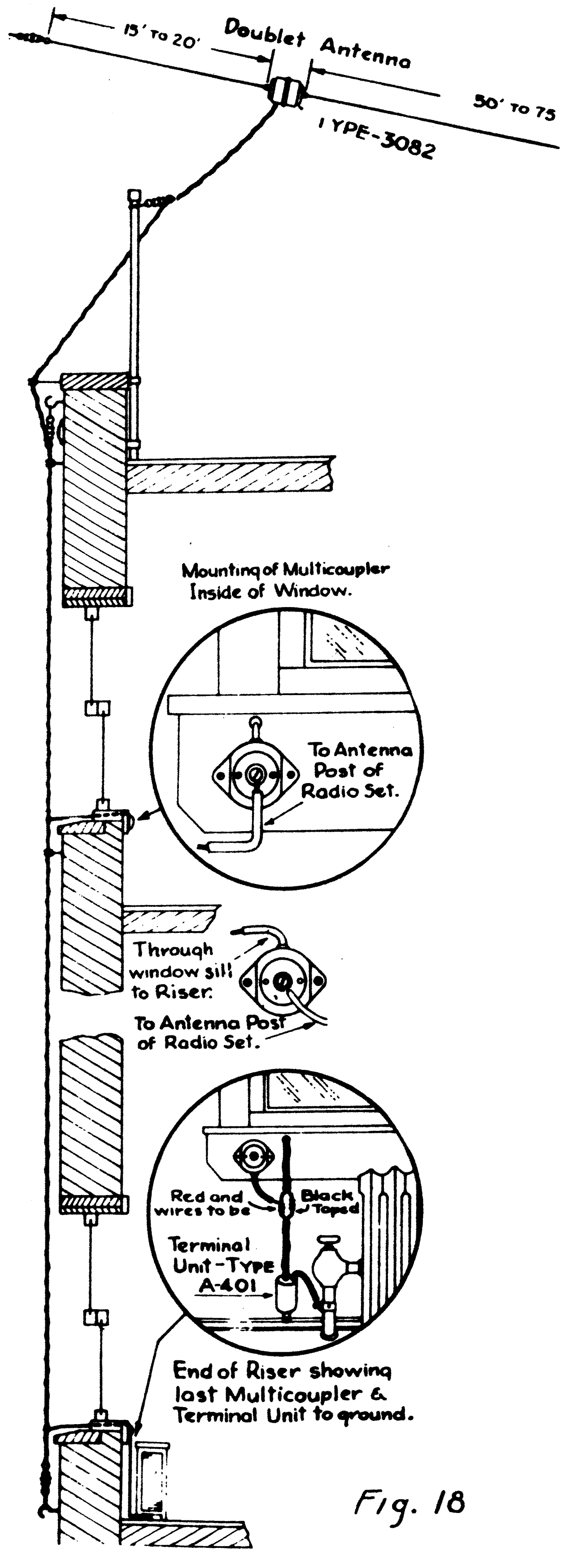

Fig. 18

ler to limit impedance variations due to the tuning of the receivers to various frequencies. A decoupling reactance is not as satisfactory because there is always the danger that some radio set may be adjusted so as to give an equal and opposite input reactance and a short circuit will occur at a certain frequency across the transmission line.

CONCLUSION:

The problem of radio interference is very complex. A segregation of the various components is necessary for its complete analysis. Practical conditions limit the extent to which the existing and proposed remedies may be applied. The design of commercial units has to take all these elements into consideration. The conditions are so variable that experiments, even though very elementary, should be performed in each case to ascertain the choice of grounds. The choice of antenna, its place of erection, and the apparatus should be governed by the relative importance of the various requirements.

In conclusion, the writer wishes to acknowledge his sincere appreciation for valuable advice and cooperation to Mr. E. V. Amy, and for experimental work and assistance in the preparation of this paper to our assistant, Mr. Edward Sieminski.

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