

RECEPTION THRU STATIC AND INTERFERENCE*

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Since the birth of radio telegraphy, serious difficulty in reception has existed due to natural electrical disturbances. These disturbances produce in the receiving telephones crackling noises which drown out the signal and are commonly called static, atmospherics, or strays. In what follows the word "static" will in general be used in referring to these disturbances, whatever their nature or origin.

As the distance over which radio telegraphy was worked increased, and it became necessary to use increasingly longer wave lengths, it was found that the troubles from static continually increased and in the case of the most important of long distance circuits, namely those between Europe and the United States, caused such great interruptions to the service that the continuity of communication compared very poorly with that of cable working. It was found that static disturbances were most severe in summer and less troublesome in winter, also that they displayed a daily variation in intensity, being at a minimum between sunrise and noon, and increasing very rapidly to a maximum about sunset, from then on remaining practically constant until shortly before sunrise when the intensity fell off very sharply to a minimum again.

Accumulated experience shows that these disturbances are more severe in locations near or in the tropics than in those of the temperate zone or frigid zone, and also that at any given location they vary from day to day somewhat in accordance with the variations in temperature, being greater on warm days and less on cool days as a rule, altho not invariably so.

A great deal of study has been made in attempts to determine the nature and origin of these disturbances and innumerable attempts to secure methods of reducing their effects at the re-

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ceiving station, but so far as the writer is aware, no success of a major order was obtained with any of these methods prior to the work which is about to be described. One of the most common of these previous arrangements known to the writer made use of a transmitter of undamped waves and beat reception. How far short of meeting the situation in trans-Atlantic working this method fell, may be judged from the fact that from June to October good reception from such continuous wave stations as Carnarvon, Wales, and Nauen, Germany, was usually possible only between sunrise and noon, while during the rest of the day it varied from very poor to totally impossible. An idea of the magnitude of the problem to be met can be gathered from the fact that during these summer months the energy collected by a receiving aerial from static is often many thousands of times as great as that of the normal signal from the above-mentioned stations.

It is a well recognized fact that static disturbances are of different sorts which are apparently due to a variety of causes, and of these different varieties those due to local lightning and snowstorms will be dismissed for the present with the statement that they occur so infrequently as to be of negligible consequence. There then remain three other major types which have been generally recognized and which Eccles has classified under the names of "grinders," "clicks," and "hissing." The last of these types, due generally to an actual discharge from antenna to earth, produces very little disturbance and is not present when antennas are used which have no earth connection. Of the two remaining types, namely, the grinders and the clicks, it is found that the former constitute the major source of difficulty in the reception of trans-Atlantic signals, the intensity of which is that of Nauen or Carnarvon, and when the receiving station is located in the United States. It is this form of static which rises to overwhelming intensity in the summer months and which has hitherto produced such serious interruption in trans-Atlantic radio communication. It should be noted, however, that both types of static are generally present, but that as the grinders increase in intensity, in general the clicks diminish. As will develop in the course of this paper, these two types of static are, apparently, of totally different nature and origin.

To make clear the various steps in the developments which are to be described, reference to certain fundamental facts, which are a matter of common experience in radio reception, is neces-

sary, and, briefly, to various methods of overcoming static troubles which have been tried. In this latter respect it is not to be understood that an exhaustive statement of all the various methods of solution is presented nor an accurate comparison of their relative values, but merely such reference as is necessary in order to trace the steps of the writer's work. It is also to be understood in what follows that the major portion of the work which is here referred to has been with signals from Europe of wave lengths varying between 5,000 and 15,000 meters. Some work has also been done with shorter wave lengths and the results secured were in substantial agreement with those obtained in the range above mentioned, but this work has not been of an exhaustive nature.

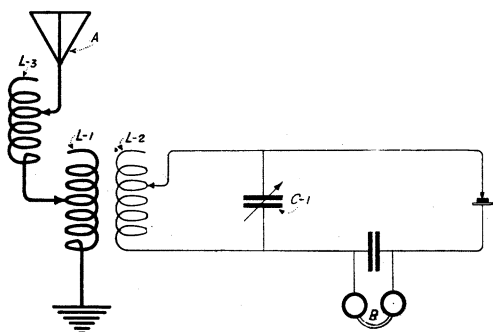


FIGURE 1

Referring now to Figure 1, there is outlined a simple form of common receiving system, the elements of which need no description. When such a system is tuned and adjusted to give best response to the incoming signal it is found that the disturbances from static are also invariably a maximum, regardless of the frequency to which the system is adjusted. A study of the behavior of such a system when acted upon by static very clearly brings out the fact that the disturbing currents which flow therein have a period and damping which is determined by the circuit itself; a fact which shows that the disturbance is in the nature of a shock, the system, when so shocked, vibrating in a way which is analogous to that of a tuning fork struck by a hammer.

It is curious to note the number of experimenters who, while apparently recognizing this principle, immediately attempt

to secure relief from static disturbances by detuning methods which result simply in the reduction of both signal and static currents in substantially equal proportion, and consequently with no appreciable improvement. This result is due to the fact that while detuning the aerial circuit does not reduce the intensity of the static in the antenna circuit, it does change the frequency of the currents due to it; and the loss in transfer of energy to the secondary circuit, since the latter is tuned to the frequency of the incoming signal and therefore a different frequency from the detuned antenna, is of exactly the same order as the loss in intensity which the signal currents experienced when the antenna circuit was detuned. Another simple expedient which has been resorted to, has been the employment of loose couplings between the antenna circuits and the secondary circuits, and this method does give some help when the difference in damping between the signal currents and static currents is marked. Attempts to make this difference as large as possible have been made, involving the introduction of resistance into the antenna and secondary circuits, but this always results in the reduction of both signal and static currents by a substantially proportional amount, with a resulting negligible order of improvement. A large number of arrangements with which it was hoped to secure differentiation, and depending on this principle of difference in damping of the two currents involved, have been tried but, so far as is known to the writer, without important results.

Another fundamentally incorrect method of attack is that of differentially combining two circuits, of which the Fessenden interference preventer circuits shown in Figure 2 are typical.

The antenna circuit here shown is split into two branches, each coupled to a common secondary and detector circuit, or these individual branches may be connected to two different antennas. One of the branch circuits was supposed to be detuned slightly with respect to the incoming signal, materially reducing the signal current in that branch, but not appreciably affecting the static current, which was assumed to be a *forced* oscillation and which would not therefore have either its frequency or intensity affected by an amount of detuning which would greatly affect the signal. The remaining static currents would then, supposedly thro the common coupled circuit connected in opposition, cancel the static due to the other branch, leaving a signal current equal to the difference between that existing in the two branches. Several other methods of adjust-

ment were proposed, among which was that of adjusting one branch to a period slightly below the incoming signal, and the other to a period slightly above it. There are many fallacies

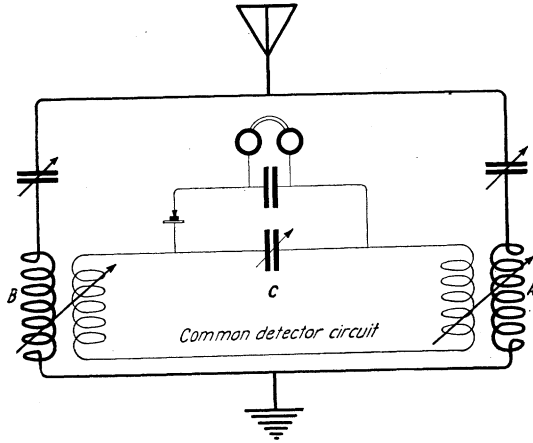


FIGURE 2

in this proposal, but it is sufficient for present purposes to point out the facts stated in connection with Figure 1, namely, that the detuning of one branch circuit affects the intensity of both the signal and static currents in the secondary circuit in the same ratio, and the additional fact that if one circuit is tuned to a period differing from that of the other, the frequency of the static in the first named circuit is different from that in the other circuit, and two alternating currents of different frequencies obviously cannot neutralize each other, but on the contrary, in order that such neutralization may be accomplished it is necessary that the emfs. which are to equalize each other must be of the same frequency, the same wave form, and of opposite phase. Also when these emfs. are due to the flow of damped oscillating currents, these currents must have the same damping factor. If this requirement is complied with in the arrangement of Figure 2, the static currents will cancel out but so also will the signal currents. Many variations of the arrangement of Figure 2 have been tried, including some in which the differentiation is attempted in the audio frequency instead of the radio frequency circuits, but if any of them have seemed to work, the result secured has been entirely due to the looseness of coupling involved.

Other investigators have attempted to secure relief from these disturbances thru the use of detectors of different characteristics, differentially connected, as in the balanced crystal and valve methods of Round, and in this way some appreciable improvement from the point of view of the operator has been effected by limiting the maximum noise, thus saving the operator's ear from the dulling effects of the heavy strokes of static but not thru a real differentiation between the static and signal currents. Devices of this general class are sometimes referred to as maximum limiting devices, the idea being that adjustments shall be so made that the arrangements are unable to respond to currents of much greater intensity than those due to the signal and therefore are irresponsive to the heavy strokes of static. It is a well-recognized fact that a signal is easily readable when static energy is anything less than from three to six times that of the signal, depending upon the capability of the particular operator who is receiving, and upon the quality of the note which the signal produces. In connection with the beat method of reception of undamped signal waves, it is of interest to note that a useful effect can be realized by changing the pitch of the note from time to time, due to the fact that the ear, like the eye, grows tired after awhile, of a particular rate of vibration, and so responds better when occasional changes are made.

This idea of a maximum limit, as usually stated, and so far as an implied change of ratio of static to signal is concerned, appears to the writer to be fallacious, due to the fact that while it is possible to construct devices which will limit the current thru a given circuit or the emf. across chosen terminals to a definite amount, as usually practiced the current limited consists of a mixture of both signal and static energies in exactly their original proportions.

In addition to the investigations of circuits of various sorts, much work has been done in determining the usefulness of various sizes, shapes, and types of aerials. Many have conceived the idea that relatively low aerials of the common types might give a material improvement in the signal-to-static ratio as compared to those of greater height and size commonly employed, but the general experience does not confirm this hope when the difference is a matter of size only. Differences of form, however, have been found to be of appreciable consequence and much work has been done with a large number of these forms, of which two at least show important and definite advantage as compared with the usual vertical arrangement as

regards this ratio. These two types are the closed loop antenna shown in Figure 3 and the horizontal linear aerial shown in Figure 4.

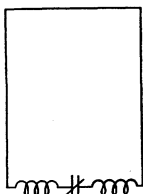


FIGURE 3

Among the early workers with the loop were Bellini-Tosi and Braun, both of whom brought out interesting facts in connections with its capabilities in the matter of directional working, but neither of whom, so far as the writer is aware, have reported particularly with respect to its operation under static conditions.

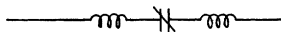


FIGURE 4

The advantage of this type of antenna was first brought to the writer's attention some years ago thru work which he was carrying out with the Bellini-Tosi directional antenna system, and which showed that the closed loop antenna had a signal-to-static ratio two or three times as good as the same antenna when tuned to earth.

The horizontal linear aerial of Figure 4, which was first used by Mr. Marconi, was used by the writer during some work conducted in the spring of 1914 at the New Orleans station of the United Fruit Company, and gave a distinctly better ratio than a large earthed antenna, and later comparisons with the loop showed the two to be substantially identical in this respect. This identity of signal-to-static ratio called the writer's attention to some other features of similarity existing between these two types of aerial. The usually accepted explanation of the working of the horizontal aerial is that the wave front of the signal wave is tilted forward and that consequently there is a component of electric force in the direction of its length. It

is to be noted, however, that under some circumstances such an aerial may equally well be acting as a loop; such an aerial is shown in Figure 5 lying on the surface of the ground and it is evident that by virtue of its capacity to the true conducting earth, a return path between its ends exists and therefore that it is a form of loop; which method of consideration will account for many of the observed facts, such as its directivity, in a satisfactory way. It will also account for one observed fact which

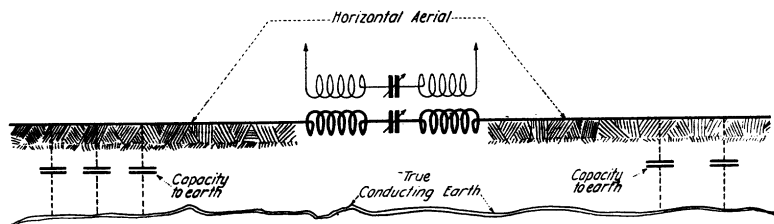


FIGURE 5

the usual methods of explanation do not account for, namely, that when an aerial of this type is laid on the ground, or buried underneath it, its effectiveness as an antenna does not increase indefinitely with length but rapidly reaches an optimum value dependent on the circumstances obtaining. This can readily be accounted for under the present hypothesis by the fact that as the length increases its capacity to earth increases and at some point becomes sufficient to close the loop.

As this capacity increases, however, the currents originating in the increased length have various paths in which to flow, one of which includes the receiving apparatus, but others which are thru the capacity to earth between the conductor and the receiving apparatus, and the larger this gets the greater is the proportion of the currents originating in the ends of this antenna, which are diverted and do not flow thru the receiving apparatus. This method of considering such an antenna is further supported by the fact that the greater the capacity per unit of length which exists between the conductor and the true underlying earth, the shorter is the maximum length which can be used to advantage. This capacity is a maximum of course when the antenna is actually buried in the ground or under water, becoming less when the wire is run on the surface of the earth and still less when the wire is suspended at some height above the earth, tests having shown that wires suspended some 10 feet

(3 m.) above ground can be used up to some six miles (9.6 km.) in length, the signal increasing with length; that a length about one-half of this is effective when the wire is laid on the ground and of approximately 2,500 feet (760 m.) when the wire is placed under brackish water.

I have also found that as the distance of such an antenna above ground is increased, its action becomes more nearly that of an ordinary antenna, and that therefore on account of its position relative to the incoming signal, it becomes less effective in collecting this signal energy.

While the two forms of antennas just referred to result in a distinct and important advance over other types of antennas, the improvement in results secured there from falls very greatly below that which is necessary to meet the conditions of continuous trans-Atlantic reception.

Another method of attack is the screen arrangement suggested by Dieckmann and de Groot which has no basis, so far as the writer can see, for differentiating between static and signal, but must, if it has any effect at all, operate on both alike. Furthermore, in attempting to investigate screening arrangements of this sort, it has been found that the problem of screening out an electro-magnetic wave of any sort, either signal or static, is not solved by the methods mentioned by them.

One of the most important investigations of static effects was that carried out by Mr. C. H. Taylor, of the Marconi Company, in which the Bellini-Tosi direction finder arrangements were used in an attempt to find out in what, if any, horizontal direction static disturbances were propagated. Altho this work showed that at times there was some definite evidence of direction of propagation, it did not warrant the hope that a successful method of separation could be based thereon. The writer's observations made at this time, and with the same installation used by Mr. Taylor, and with a similar arrangement erected at the Marconi Company's New Brunswick station, showed that so far as the dominant type of static—namely the grinders—was concerned, no direction whatever could be found, but on the contrary there appeared to be an equality of disturbances from all points of the compass. A further check on this result was made at this time by rotating a loop, shown in Figure 6, about a vertical axis; this also showed equality of average disturbances, regardless of the direction of the plane of the loop and led to the conclusion that if static disturbances of the grinders type were being propagated horizontally, they

must be moving in all possible directions; that is to say, one stroke might arrive from the north, the next one from the east, a third from the west, and so on, these occurring at random in such rapid succession as to give no opportunity to deter-

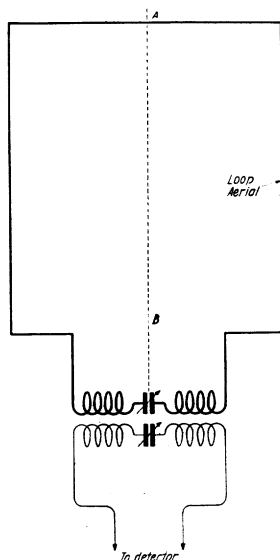


FIGURE 6

mine their direction. There appeared to the writer, however, another possible explanation of this result, which is that these disturbances instead of moving horizontally, might be moving in a vertical direction, the source being under foot or overhead. This latter possibility was of exceptional interest since, if it were correct, the direction of propagation of static waves, assuming of course that they were waves, would be at right angles to the direction of propagation of signals, and such a difference might conceivably be used to separate the two.

Steps were then taken to determine which of the two possible explanations given above was correct, and the investigation seemed to establish clearly and definitely that static of the grinders type produces effects similar to those which would be produced by electro-magnetic waves originating overhead or under foot and propagated in a direction perpendicular to the earth's surface at the point of observation. This investigation also established that static currents produced

in loops, the planes of which are perpendicular, cannot be combined to neutralize each other, which result can be explained by assuming that the electro-magnetic waves responsible for static currents are heterogeneously polarized; that is, the axes of the oscillators producing them assumed all possible angles in space. To sum up then, *these results showed that static disturbances of the grinders type behaved as tho due to heterogeneously polarized, electro-magnetic highly damped waves propagated in a direction perpendicular to the earth's surface.*

The apparatus and method used in this investigation resulted in a perfectly practical receiving system which, while retaining useful amounts of signal currents, enormously reduced the currents due to static of the dominant type. The methods and apparatus used in carrying out these tests were as follows:

Two single turn loop antennas were erected 400 feet (122 m.) high each with a base line of 1,000 feet (305 m.) and their centers approximately 5,000 feet (1,520 m.) apart. These loops were in the same plane and the line connecting them was in a direction toward the Carnarvon station of the English Marconi Company. This arrangement is shown schematically in Figure 7. Leads

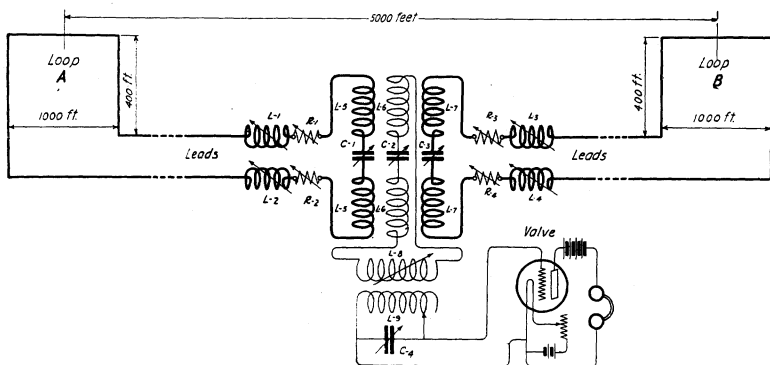


FIGURE 7

were brought from the loops to a receiving station midway between them. These leads, which were six feet (1.82 m.) apart, and in the same horizontal plane, were supported by poles about ten feet (3.05 m.) high. The diagram of connections is shown in Figure 7.

Connection from the leads were made thru inductances L_1 , L_2 , L_3 , and L_4 symmetrically arranged relative to the coils

L_5 and L_7 , which were arranged perpendicularly to each other, as shown in Figure 8. The winding of each fixed coil L_5 and L_7 was divided into two equal parts, and condensers C_2 C_3 inserted between the halves. Associated with the two fixed

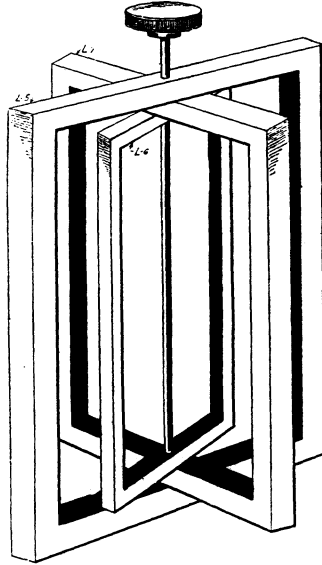


FIGURE 8

coils was a third coil L_6 capable of rotation on a vertical axis, the three coils constituting the well-known Bellini-Tosi goniometer. In the circuit containing L_6 were condensers C_2 and coupling coil L_8 which was associated with a receiver of conventional type with valve detector. The theory of the tests made with this arrangement is as follows:

Assuming that static waves were traveling perpendicularly to the earth's surface, then the electromotive forces generated in the two loops would be equal in intensity and of the same direction at any instant, and therefore if the circuits were properly tuned, the resulting currents in the system would be in phase. The emfs. generated by the signal would, on the other hand, be out of phase by an amount depending on their distance apart, and a maximum if this distance were one-half the length of the wave received, since the signal wave would arrive at the antenna nearest the transmitting station before it would arrive

at the antenna farthest away from the transmitting station. In other words then, the static waves would arrive at the two antennas at the same time, while the signal waves would arrive at the two antennas at different times. It therefore follows that if, at the receiving station, connections and adjustments were so made that the emfs. generated in the rotating coil L_6 by static disturbances were equal and opposite, the emfs. generated by the signal currents would not be equal and opposite, but would combine, giving a resultant depending on the separation of the loops. If this separation were one-half wave length then the emfs. generated in coil L_6 by the signal currents from each loop would be in phase and would therefore be equal to the arithmetical sum of these two emfs. If the loop separation were equal to one-quarter of a wave length, then the emfs. acting on the coupling coil would be 90 degrees apart and the resultant would be equal to 1.4 times that of the individual emfs.; that is, they would continue in quadrature. If, on the other hand, the hypothesis that static of the grinders type arrives from all possible azimuthal angles, and in a horizontal direction, were correct, then the static currents arriving at the receiving station from the two antennas would be out of phase an amount depending on the separation of the antennas and the azimuthal angle which the direction of their propagation made with the base line of the system.

If the apparatus in the receiving station were assumed to be adjusted in such a way that the signal currents were combined vectorially and in accordance with the aerial separation, then the static currents would be similarly combined; and the curve of reception of the system so adjusted for static impulses equally distributed in all azimuthal angles would be that of Figure 9, which is nearly the same as that of a single loop antenna, and therefore the whole system would show nearly the same signal-to-static ratio as the single loop. If, on the other hand, adjustments were so made that the phases of the currents from one loop were shifted a suitable amount with respect to the phases of the current in the other loop, then the curve of reception would change from that of Figure 9 to that of Figure 10, which indicates that reception through one-half of the azimuthal angles has been moderately reduced, and which would therefore give rise to an improvement in the signal-to-static ratio of the whole system as compared with the single loop of the order of the decrease of the area included by the curve of Figure 10. It will thus be seen that under the three sets of conditions specified

and under the two hypothesis considered, there were three possible results, namely, a very large improvement in the signal-to-static ratio under the first hypothesis, a small improvement if the second hypothesis were correct, and the first method of adjustment followed, and a moderate order of improvement under the second hypothesis and the second method of adjustment.

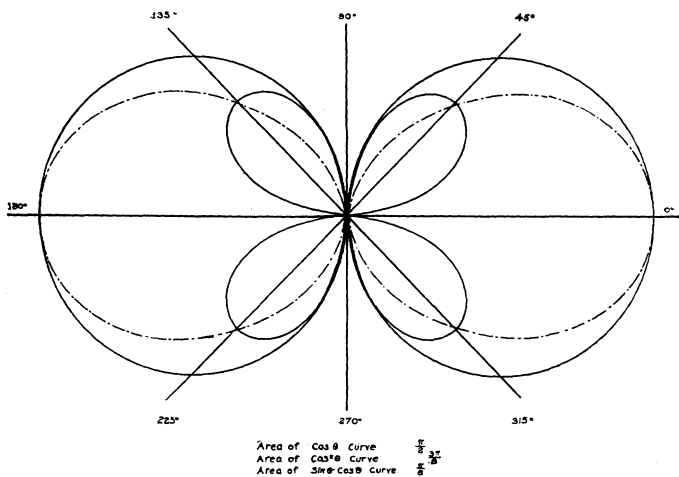


FIGURE 9

Referring now to the arrangement actually used, the spacing between the loops was slightly over one-quarter wave length, for a wave length of 6,000 meters, which was that used by Nauen during some of the tests. Signals were also received from Nauen

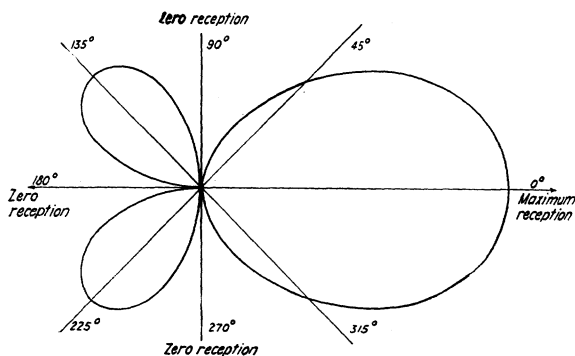


FIGURE 10

at 12,000 meters, Clifden 5,600 meters, Carnarvon 14,000 meters, Eilvese 9,600 meters, and Glace Bay 7,600 meters. In all cases it was found that when the adjustment of the circuits was so made that static disturbances of the grinders type were cancelled or reduced to a minimum, the signal received from the two loops combined, as might be expected from the spacing between them, and the wave length of the incoming signal. In the case of the 6,000-meter signal from Nauen, the resultant signal was approximately forty per cent greater than that due to either aerial alone, while in the case of Carnarvon, with a 14,000 meter wave length, for which the spacing was equal to only one-ninth of a wave length, the resultant signal was materially less than that due to either loop alone.

Since the order of improvement of the signal-to-static ratio of the system as a whole was very great as compared to the single loop, and consequently a given signal was readable thru static disturbances of a very much greater order than was possible with the single loop, it was concluded that the hypothesis of an apparent vertical propagation of static waves (or an electric action of equivalent effect) more nearly expressed the true facts than did that which assumed a uniform azimuthal distribution of their horizontal direction of propagation.

To determine the extent of the improvement in reception made possible by this work, tests were carried out thru the worst summer months, namely, July and August, on various European stations, and it was found possible to receive the 6,000-meter Nauen signal some five or six hours per day during the worst periods when reception otherwise was totally impossible. Complete, continuous reception was not, however, yet possible, since there were times when, due to fading, the strength of Nauen's signal fell so low that it was no longer possible to receive it. Very interesting, and surprising also, was the fact discovered thru the constant use of this arrangement, that the heavier the static disturbances were, the more perfect the balance which could be secured, and the greater the improvement in the static-to-signal ratio which resulted. This very significant observation led to a careful study of the character of static disturbances under conditions of weak and strong disturbance, and it was noted that invariably the strong static consisted mostly of the grinders type, the percentage of this type increasing with the increase of total static energy and decreasing with the decrease of the total, and it may be said that the results of long and continued work since these first experiments has established the

facts referred to definitely and conclusively, the occasional variations therefrom being of such infrequent occurrence as to be negligible. It was also noted at this time somewhat unexpectedly, that the disturbances from a nearby thunderstorm were at times quite markedly reduced, the amount being seemingly dependent upon the position of the storm with reference to the receiving station. This improvement, however, was not of a sufficient order to render reception, thru local lightning, generally possible.

Many attempts were made to measure the improvement under various conditions in the signal-static ratio of this system, as compared to a single loop thru the use of the well-known audibility method, and the results obtained varied from more than a thousand times, under very severe conditions, down to five or ten times for very light static conditions. Now the audibility method measures the current in the telephone circuits from which it follows that the energies represented by two different audibility measurements are proportional to the square of the audibility factor; consequently the ratio of one thousand-to-one in audibility means one-million-to-one in energy. Unfortunately this method is a poor one for measuring static disturbances accurately and I cannot say that the above ratio is accurate. I find, from continuous use of this method of measurement, that, while it gives reasonably good results where the sound in the telephones is of a musical character, when this musical character is lacking the ear is unable to judge relative intensity accurately. In addition to this difficulty there is the fact that static disturbances are of extremely irregular intensity and that at any two successive instants widely different energies may exist. No other suitable method being available at the time, it was decided to depend on comparisons of readability of the signal resulting from the use of the complete system, as compared to the single loop, and this method has been used chiefly since that time.

A new method of measuring static intensities has recently been developed, which is the joint suggestion of Mr. G. H. Clark, expert radio aid of the Navy Department, the Research Department of the Marconi Company, and the writer—and which has been put into practical form by the Research Department. It measures the intensity of static disturbances in terms of the signal intensity necessary in order that the signal may be read, and it is hoped that a large number of measurements made by this method can be presented in a later paper.

Since the continued operation of systems of this type has so clearly emphasized the existence and characteristics of the two types of static referred to as grinders and clicks, a brief reference to some of the distinguishing characteristics may be of interest. It is found that the grinders type is most prevalent in the warm season, during warm days, and between the hours of noon and sunrise the following morning. The sounds which they produce in the telephone are generally a sort of continuous rattle, with occasional heavier crashes. This type behaves as tho vertically propagated, *and appears to affect antennas, separated considerable distances, simultaneously.* It can therefore be excluded, thru the use of the system described, while the signal is retained. The clicks, on the other hand, which sound like relatively widely spaced crashes, are most noticeable during the cooler periods of the year and day, but do not, except on very rare occasions, reach an intensity which is sufficient to interfere with the reception of signals, the strength of which is equal to the normal strength of Carnarvon or Nauen, or even Lyons. When the signal to be received, however, is of a lesser order of strength, such as that from Clifden, Ireland, or Eiffel Tower, or when the signals from the previous stations are abnormally weak, as occurs during sunset and sunrise fading periods, the intensity of this type of static is sufficient at times to cause great difficulty. It was found also that this type of static could not at that time be sufficiently reduced, thru the use of the system just described, to overcome the difficulty, and that adjustments which reduced it resulted also in a reduction of the signal. It appears probable, therefore, that this type of static follows the second of the two hypothesis previously given, and that it is in fact a true stray wandering in from all directions in haphazard fashion. How this vagrant was successfully dealt with will appear presently, but before getting to this point, which involves somewhat different arrangements than those shown, a brief reference will be made to certain modifications of the system with which experiments were conducted.

Midway between the loops of Figure 7 a third loop of similar dimensions and disposition was erected and used in conjunction with either of the two loops of Figure 7. This variation is shown in Figure 11, and it is to be noted that while the end loop has the long, horizontal lead, the middle loop has none, it being brought directly into the receiving station. It was with some interest that this arrangement was found to give rather better results than that secured with the loops separated the maximum distance

available, and the improvement was found to be in the perfection of balance, which was found to be sufficiently greater than that obtained with the arrangement of Figure 7 to more than offset the loss of signal on balance, due to the shorter spacing. This seemed to indicate, at first, that the farther apart the loops were the less perfectly could the static currents be balanced and the converse. Small loops of a large number of turns were

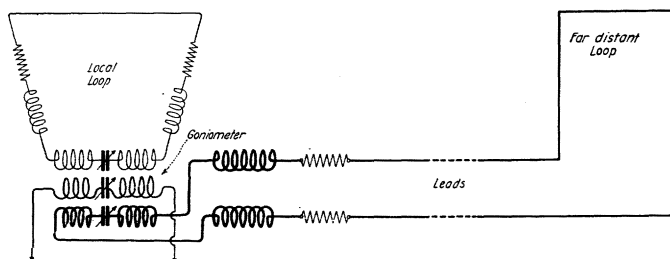


FIGURE 11

then erected at distances varying from ten feet (3.05 m.) up to 1,000 feet (305 m.), symmetrically located with respect to the receiving station, and in the same line with the big loops. Tests with these showed, however, no more perfect balance than that obtainable with the spacing of Figure 11 which was 2,500 feet (760 m.), and it therefore became evident that something besides the spacing accounted for the improvement in Figure 11 as compared with that of Figure 7. It would take too long to describe the very numerous experiments which were made in the attempt to run down this very elusive matter, but it was finally discovered that the reason for the performance above noted was the action of the long horizontal leads which, notwithstanding the fact that these were in the same horizontal plane and that the system had no earth connection, proved to be very effective aerials, picking up both signal and static. It was found that the static currents generated in them were in a definite direction and that consequently they must be connected to the loop in the same sense, that is, in such a way that the static currents generated in both the loop and the leads tended to flow in the same direction at any instant, so that when balancing at the receiving station all of the static currents generated in each half of the system were similarly affected. Before this fact was found out the arrangement of Figures 7 or 11 was so con-

nected that when adjustments were made which balanced out the static currents generated in the loop, those generated in the leads were added. The method of getting the right connection was simply to connect in a reversing switch, as shown in Figure 12 and to try the balance with the switches in each side of the system in the various possible positions. The best, of

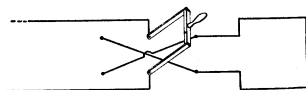


FIGURE 12

course, was that which gave the most perfect balance and was very easy to find. The results obtained thereafter were found to be better for the long than the short separation by an amount proportional to the separation, and it is interesting to note at this point that in all subsequent work the perfection of balance of static currents obtainable was the same, regardless of the overall length of the system which, as will appear shortly, has been in some instances as much as six miles (9.6 km.), while the signal combined always in proportion to the spacing.

In Figure 13 is shown an arrangement in which all three antennas were used. In this arrangement the two antennas at

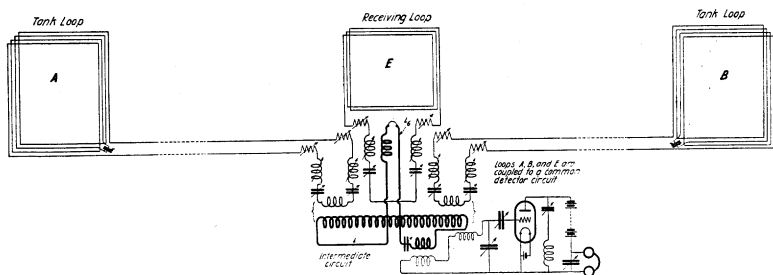


FIGURE 13

the ends were so coupled and adjusted that the signal was cancelled out, leaving most of the static. This arrangement has been termed the "static tank" since it was a source of static currents of any desired frequency without being a source of signal current. When this adjustment was accomplished the circuits

connected to these two antennas were opened and the third antenna connected in and tuned. This third antenna provided both signal and static currents in whatever ratio they happened to exist in this loop. The next procedure was to connect the two other loops in again and to adjust the intensity of the static currents from the middle antenna until they were equal to those due to the two end loops by use of suitable resistances, couplings, and so on. This third loop was connected into the system in such a way that the static currents due to it were opposed, leaving the signal due to the third loop. This arrangement resulted in a material improvement in working over those previously tried. From a consideration of the hypothesis of vertical propagation of static waves, it was not possible to account for this improvement, so far as the grinders are concerned, so that it was ultimately concluded that the improvement might be due to the elimination of some of the static of the other type. This possibility was somewhat supported by the fact that it is occasionally not possible to distinguish between the two types from the sounds which they make in the telephones since it happens occasionally that those of one type have the characteristic sound of the other. An analysis of the action of this system when affected by horizontally moving static waves, assumed to be uniformly distributed, brings out some most interesting facts.

Referring now to Figure 13, assume that the two aerials there shown have a spacing which is one-half the wave length of the signal received. Also assume that a static wave is arriving from the same direction and with the same velocity of propagation, and that this wave is so highly damped that no forced oscillation is produced in the aerial but that the only oscillation therein has a frequency and damping which is determined by the constants of the circuit. When this static wave, if it may be so called, arrives at the first aerial, an electromotive force is generated therein and currents start to flow thru it and the connected circuits. Current then begins to develop at the terminals of the detector. The wave continues its motion until it similarly affects the second loop and the resulting currents flow back to the receiving apparatus. Owing, however, to the spacing which has been chosen, the currents from the first loop have had time to go thru a complete half cycle before that from the second arrives. Suppose now that the connections and position of the goniometer coil L_6 are such that the emf. produced in it by the signal is equal and opposite and therefore the signal cancels out.

Under these circumstances the results due to static will be as indicated in Figure 14, in which the solid line shows the damped oscillation due to the first loop, while the dotted line shows that due to the second loop when the method of connection is that just described. This diagram brings out the interesting fact

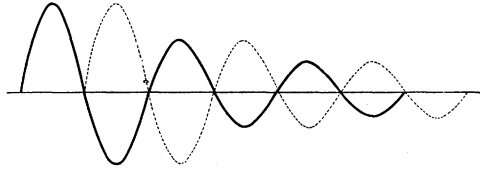


FIGURE 14

that the first half oscillation arriving from the first aerial is unopposed; that the first half oscillation from the second aerial is opposed to the second half oscillation from the first aerial which, because the oscillations are damped, is of smaller amplitude than the one opposing it. This condition obtains thruout the entire train so that the resultant of the two oscillations is not zero.

If now, the aerial circuits are heavily damped thru the addition of resistance, the wave train due to static becomes shorter and shorter, until when the limit is reached, all of the energy is in the first half swing. Therefore, under these conditions, while the circuits are so adjusted that the signal completely cancels out, yet the entire static current remains and we have the curious condition shown in Figure 15 of the two half oscillations, both in the same direction. It should be here noted that the first half oscillation of the signal is also unopposed, but if the signal current be undamped the percentage of the total signal energy which affects the detector is, roughly, $1/7,000$ th part of that which arrives during the time occupied by a dot at an ordinary rate of sending.

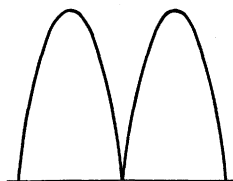


FIGURE 15

If we assume now that static disturbances are uniformly distributed thru all horizontal azimuthal angles, then as the angle, with the direction of the system increases, the intensity of these pulses decreases in proportion to the cosine of the angle; at the same time the effective phase difference between the loops decreases so that these pulses begin to overlap. It is also assumed that the intensity of the oscillation which these pulses can give rise to is proportional to the maximum ordinate as a first rough approximation. It follows then that as these pulses overlap, a distorted curve, as shown in Figure 16, results, but its effectiveness is not materially increased until the maximum ordinate of the resultant curve rises above that of the single pulse.

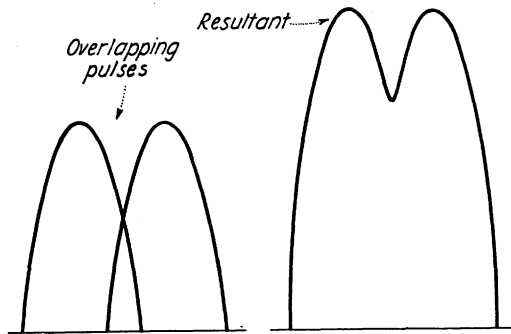


FIGURE 16

It will thus be seen that thru part of the azimuthal angle the intensity of the oscillations produced by static varies along the cosine curve, spreading out somewhat, however, as the angle increases. If, therefore, a third antenna is employed, the curve of reception of which is the cosine curve and in which both signal and static currents are flowing, and if this antenna be oppositely connected to the system just described, the static currents due to the click type of static will oppose and the residue will be of the order of the difference between the dotted curve shown in Figure 17 and the cosine curve shown in solid lines in the same Figure, from which it appears that a very large order of reduction is possible while at the same time utilizing the full signal strength developed by the third antenna. This explanation does not purport to be a rigorous analysis of the system described, but is presented merely as a rough approximation to the facts observed.

The arrangement just described realized these possibilities to an appreciable degree, but in the form then used was not capable of utilizing the possibilities above outlined to their fullest extent, and reference will be made later to another modification which displayed greater capabilities.

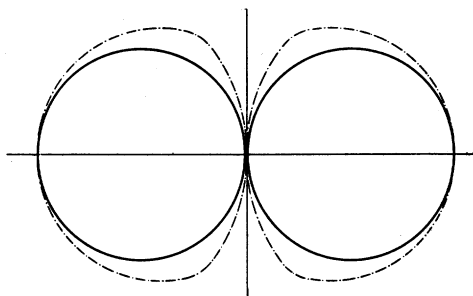


FIGURE 17

Various other combinations of the installation at Belmar were made. In Figure 18 the leads were disconnected from the loops and their ends joined, thus making of them horizontal aerials tuned to earth. It will be noted that this arrangement consists

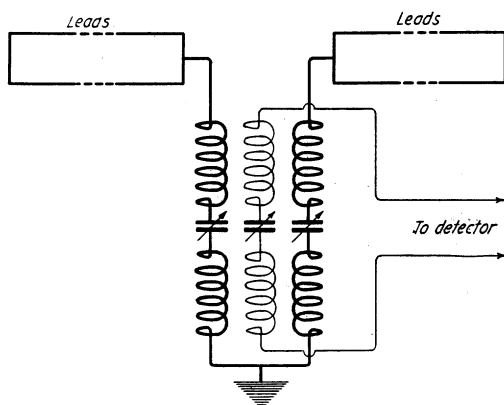


FIGURE 18

of two directive Marconi antennas and that the ratio of length to the height is unusually large. From this it follows that the aerial, which is pointed in a direction away from the transmitting station is a much better receiver of the signal energy than that

aerial which runs in a direction toward the transmitting station. Both aerials, however, pick up the same amount of static. From this it is evident that the two aerials may have a very marked difference in their signal-to-static ratio, and this effect will add to the effect resulting from their phase separation particularly when this separation is small, and constitutes at times a factor in the results obtained. This principle operates in all of the arrangements which will be described in which horizontal aerials are used, regardless of whether they are above the earth's surface, on the earth's surface, or underneath it. Figure 19 shows one of these in which the loop leads were connected together and each loop converted into an ordinary antenna tuned to earth. In

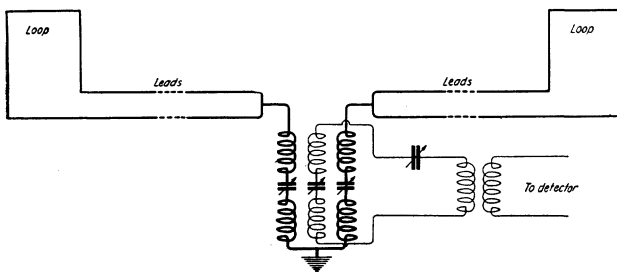


FIGURE 19

Figure 20 one loop was used in its normal way and balanced against the leads of the other loop tuned to earth. Figure 21 shows one loop connected in its normal way while the other one was arranged as an earthed antenna. All of these arrangements gave good results, but since it was impossible to investigate them all at once, the loop arrangements were chosen for first attention. Variations in the circuits were also tried. Figure 22 shows the parallel condenser arrangement, which was quite useful in se-

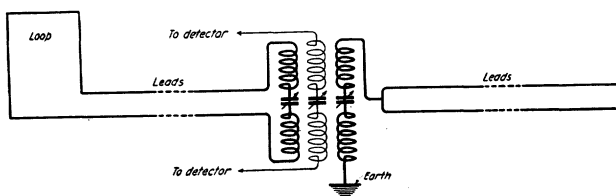


FIGURE 20

curing tuning to wave lengths shorter than could be obtained from the series condenser arrangement. Figure 23 shows another arrangement, in which most of the tuning was effected by condenser C_1 and inductance L_1 common to both circuits. Condensers C_2 , C_3 , C_4 , and C_5 , in addition to taking some part in the tuning, provided phase control and coupling.

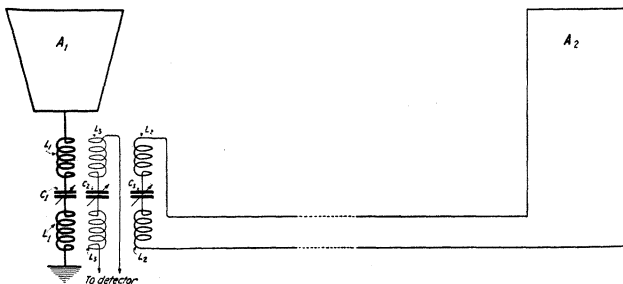


FIGURE 21

In addition to the capabilities of the arrangements described for receiving thru static, they have marked capabilities in working thru interference from other stations. When adjusted to

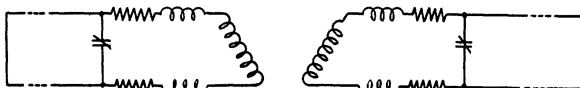


FIGURE 22

annul static of the grinders type this system has a reception curve of the form shown in Figure 9; its equation is $v = V \cos^2 \theta$, while that of the single loop is a cosine curve. It will be noted that the directional effect in this case is materially greater than with the single loop. When desired, adjustments can be so made

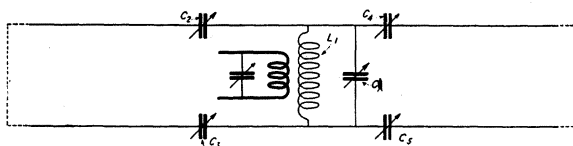


FIGURE 23

that the reception curve becomes that of Figure 10. Between $\theta = 0$ and $\theta = \pi$, the curve is a $(\cosine)^2$ curve while between the angles $\theta = \pi$ and $\theta = 2\pi$, the curve is a $(\sin) \cdot (\cosine)$ curve when the loops are one-quarter wave length apart. This curve indicates that while reception in one direction is a maximum, reception from the opposite direction is zero, while it is also materially reduced in the third and fourth quadrants. This line of zero reception can be swung around at will thru the third and fourth quadrants by alteration of the phases of the currents in the two loops so that interference from any station arriving in this quadrant can be annulled, while reception is maintained from signals arriving in the first and second quadrants. It is to be noted that advantage can be taken of this property to eliminate strays, if they happen to be coming from a direction other than that from which the signal arrives, and this fact is of great help when a thunderstorm is gathering in the vicinity of the station. The necessary method of adjustment is as follows:

Suppose that the two loops of the system are one-quarter wave length apart and that the desired signal arrives from right to left. Then the currents in the left-hand loop are 90 degrees behind those of the right-hand loop, if the circuits are accurately tuned, and they will add in quadrature. Next, suppose a signal arrives from left to right; then the currents due to this signal in the left-hand loop are 90 degrees ahead of those in the right-hand loop and therefore also combine in quadrature. Then currents due to both signals exist in the common receiving circuit.

Suppose now, the phases of all currents in the left-hand loop are shifted forward 90 degrees; then the currents due to the desired signal in this loop are shifted around until they are in phase with those from the right-hand loop, while the phase of the currents due to the interfering signal in this loop, and which were previously 90 degrees ahead of those due to the right-hand loop, are now 180 degrees ahead of those in the right-hand loop, so that they oppose and neutralize. Because of the unusual characteristics of the antenna used, this shift in phase is readily accomplished by a small adjustment of the condenser in the loop circuit. If the interfering signal is not in line, the phase shifting can be made the right amount to take care of it, and this general order of result is obtainable to some extent with any spacing between the loops, although one-quarter wave length is best. The reception of Carnarvon's signal, 14,200 meters, thru the powerful interference of the 200-kilowatt

Alexanderson alternator at New Brunswick, only 25 miles (40 km.) away, working at 13,600 meters, has been an everyday performance of the system, while at the same time preserving a good static balance. All forms of the arrangement described have capabilities of reception thru interference, these capabilities varying with the type of antenna employed, the loop antennas and the horizontal aerials giving similar curves.

Work with the original installation soon indicated the desirability of increasing the spacing between loops both to secure greater signal intensity and also to determine whether or not the static currents would be simultaneously generated in the two aerials, when the spacing was thus increased. Antennas were therefore erected approximately 8,000 feet (2,430 m.) apart, each antenna consisting of 12 turns approximately 77 feet (23 m.) long by 30 feet (9.2 m.) high, supported from cross-arms attached to telephone poles. This construction is shown in Figure 24. The receiving apparatus was located at a point near the

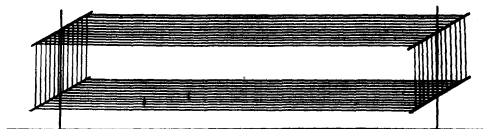


FIGURE 24

northeast loop instead of in the middle, and leads similar to those of the original arrangement run out to the southwest loop. When this was tried it was found that the leads picked up more signal and static than the loops and that the intensity of all currents from the southwest loop was so much greater than that from the northeast that successful working could not be obtained. Leads running along the ground, spaced at various distances, were then tried, and it was found that their effect was a minimum when the leads were close together. Next, a duplex lead-covered cable was tried and the effect of the leads very greatly reduced thereby. These leads of course had enormous capacity for a circuit of this sort with the result that the southwest loop was connected to the receiving station thru a capacity coupling of very small value, and in order to get equal signal from the distant end it was necessary to use four similar loops at that point connected in series-parallel. It was also found necessary to have a tuning condenser and inductances,

shown in Figure 25, located at the remote loop and an operator stationed there to make adjustments in accordance with instructions telephoned to him by the observer in the receiving station, using the cable wire for this purpose. It was also neces-

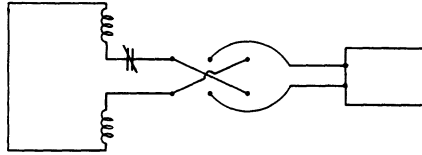


FIGURE 25

sary to use the reversing switch previously described, since even the lead-covered cable picked up signal and static in appreciable amounts.

By the time this work was completed the season had advanced well into the winter and the amount of static available for working was so small that the results obtained were inconclusive and the work was abandoned for the time being.

In view of the entrance of the United States into the war and the great national importance of the improvements previously described, a full disclosure of the most fully developed two-loop arrangement was made to the Navy Department and an official test carried out by Mr. G. H. Clark, expert radio aid of the Bureau of Steam Engineering of the Navy. The following is a quotation from the report received by the Marconi Company from the Bureau relative to this test:

“The Weagant circuit in its present form will enable trans-Atlantic reception to be carried on without interruption in so far as elimination of static is concerned.”

The next experiments were conducted at Miami, Florida, where loops were arranged at varying distances, the maximum being six miles (9.6 km.) and the minimum about 100 feet (30.5 m.). Having in mind the difficulties due to the leads, a special lead construction was used in which a pair of number 18 wires*, spaced about two inches (5.08 cm.) apart, were run thru paste-board tubes about three inches (7.62 cm.) in diameter, these tubes being in short lengths joined together and covered on the outside with tinfoil. It was thought that this arrangement would give a reasonable value of capacity between the leads

* Diameter of number 18 wire = 0.041 inch = 0.16 cm.

while the tinfoil covering might act as a screen in preventing signal and static currents from being picked up by the leads. This latter result was a desirable one since the greater the extent to which the leads act as aërials, the shorter is the effective spacing between the two aërials for a given total length. The results obtained with this lead construction were slightly better than those obtainable with any other, but the improvement over the results secured from the use of two similar wires, similarly spaced, but not surrounded with a shield, was of too small an order to warrant the expense and trouble of the other type of construction. Two loops of the type shown in Figure 24 but 150 feet (46 m.) in length and three miles (4.8 km.) apart, were connected to a receiving station located midway between them, and tests were conducted with various European stations, and it was found that the balance of static currents secured was as good as that obtainable with loops a short distance apart, while the signal strength at balance was much greater. This arrangement was not, however, generally satisfactory, as the loops were not large enough to give a satisfactory intensity of signal for practical working, while the effect from the leads was about equal to that from the loop. Two other loops were therefore constructed 7,200 feet (220 m.) apart, of the same general type and height, but of twice the horizontal length, and with these two, very satisfactory practical working was secured. With both of these arrangements the local tuning at the loops previously described was necessary, and this always involved a tedious adjustment until the correct setting for a given wave length was obtained, and even when this setting was known, it was necessary for some one to go to each of the loops,—not a convenient procedure with antennas three miles (2.2 km.) apart.

In order to overcome the objection just mentioned, the arrangement of Figure 26, which was the joint suggestion of Mr. Frank N. Waterman, and the writer, was constructed. As is indicated by the Figure, each loop consisted of a single turn extending from the station out and back again, thus being both loop and lead simultaneously, and being free from points where abrupt changes in circuit constants take place, as in the previous arrangement. The loops of this form which were constructed varied in length from 1,000 feet (305 m.) each up to approximately 9,000 feet (2,750 m.) each, the upper wire being supported on stakes only three feet (92 cm.) above ground, while the lower wire ran along the surface of the ground. Much difficulty was experienced in maintaining this construction long enough to

get satisfactory observation, due to the fact that about 2,500 feet (760 m.) northeast from the receiving station, they had to cross a canal, while at other places they ran thru cow pastures and were frequently broken.

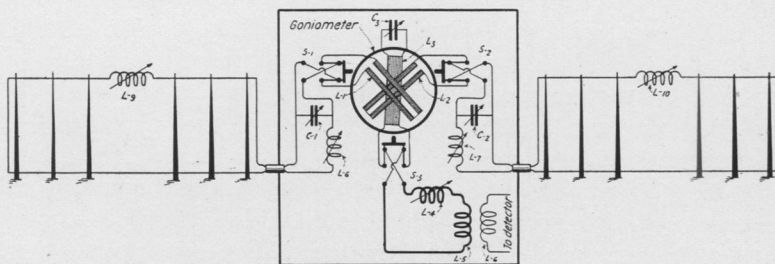


FIGURE 26

When first tested it was found that the loop then used, which was approximately 3,600 feet (1,100 m.) long, would not tune, the inductance and capacity inserted at the receiving end of the station apparently having no effect. This result was believed to be due to a current distribution in the loops of such a nature that there was a current node at the point of insertion of the tuning devices. It was therefore determined to attempt to alter this distribution by the insertion of inductance at some suitable point. An inductance such as L_9 , L_{10} in Figure 26 of 30 millihenrys was inserted successively in the upper wire at a large number of points between the receiving station and the other end of the loop. It was found that the tuning improved constantly as the coil was moved from one end toward the middle, and constantly became poorer as the coil moved from the middle toward the end, the curve of the resulting effect being of the form shown in Figure 27. Insertion of the inductance in the lower wire produced no result and in fact if inserted in the middle point of the lower wire at the same time that inductance were inserted in the middle point of the upper wire, the effect of the latter was annulled. Having determined the best point for the inductance, its best value was next obtained, and while the results showed that a value of 30 millihenrys was about right for a wave length of 12,000 meters, and 5 millihenrys for a wave length of 6,000 meters, either value was sufficiently acceptable for both wave lengths.

As soon as tuning control of this type of antenna was ac-

complished it was found possible to use this system in a most satisfactory way for the elimination of static. The effective spacing of two such loops was found to be approximately the distance between the centers and complete control could be

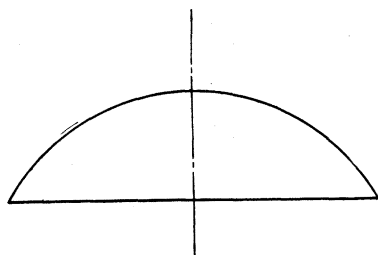


FIGURE 27

effected at the central receiving station, the over-all results obtained being even better than those obtained with the previous forms. A variation in the form of this type of aerial is shown in Figure 28, in which the area enclosed is approximately a triangle, it being assumed that this arrangement would give a greater effective separation if the loop receiving antenna extracted energy from a passing electro-magnetic wave in accordance with the usually accepted theory. Conclusive results on this form were



FIGURE 28

not obtained until later work at Lakewood, New Jersey, and they showed that the very long triangle there used, *did not* behave in accordance with this assumption. In fact it may be stated that this whole work has demonstrated that our ideas of the mechanism by which a loop antenna extracts energy from a moving electro-magnetic wave, will have to be considerably modified, but this matter is too extensive to go into in detail at this time. The exact mode of vibration of the long, low loops just described is also a matter of great complexity and can only be determined by an exhaustive experimental and mathe-

mathematical analysis. This work is already quite well under way, Mr. Louis Cohen having kindly consented to undertake the mathematical work for me, but it is not yet completed.

During the early part of the work at Miami, the Navy Department was experimenting with underground antennas, several of which had been installed by Mr. G. H. Clark. This afforded an opportunity for the writer to try these in the system described. These were tried in a large number of combinations, which are shown in Figure 29. As will be seen from the Figure, these ar-

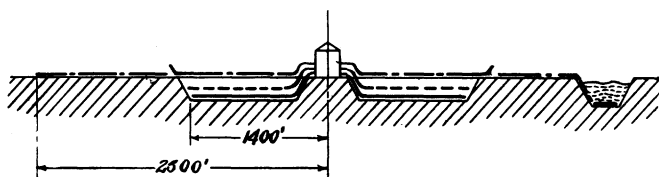


FIGURE 29

rangements were essentially the same as those of the original Belmar installation, resembling most closely that one which employed the horizontal lead wires and differing from it only in the fact that the wires were buried under ground or laid on the surface instead of supported some distance above the ground. All of these various combinations operated satisfactorily, but there was no material difference between those laid on the ground, those under ground, or those under water, which was present only a few feet under the surface. The lengths used were not great enough to give a material fraction of a wave length effective spacing, and attempts were made to extend this by increasing the length of the wire. It was found, however, that this could not be done, but that, on the contrary, increasing the length of the wire made the performance poorer rather than better, and this is probably due to the loop action and other causes referred to in the preliminary description of this type of aerial. The best working of all these arrangements was the combination of one of the ground wires with one of the loops, due to the fact that this gave a much greater effective separation, the loop being situated 3,600 feet (1,100 m.) away from the receiving station.

Having secured a practical form of this system which could be operated with the half-wave-length spacing, namely, the long, low loop, an installation was made in the spring of 1918,

in the vicinity of Lakewood, New Jersey, in accordance with the results of the Miami tests. This installation consisted of two aërials, each three miles long, of number 14 hard drawn copper*, in a line directed toward France. These antennas were supported by telephone posts 30 feet (9.2 m.) high and were at first triangular in form, having a vertical leg 28 feet (8.5 m.) high at their outer ends, and brought together at the receiving station. This is shown in Figure 28. This form was later modified to a rectangle three miles (4.8 km.) long, ten feet (3.05 m.) in vertical dimension, the lower wire being about ten feet (3.05 m.) above ground, and this modification was found to be appreciably more satisfactory. Inductance coils of 30 millihenrys were inserted in the middle points of the upper wire of each loop. This station was operated continuously from the middle of July until the end of September with a force of three operators, each working eight hours, copying messages sent out by Lyons, Carnarvon, and Nauen regularly, and occasionally other stations. This continued operation was undertaken to determine the capabilities of the system in a practical, commercial way, during the worst period of the summer and at all hours of the day. The results secured were most gratifying, the total interruptions experienced being of no greater total duration than those of good cable working between the same points and at the same time of year. It was found that when the signal from the European stations was of normal intensity the heaviest static experienced at any time was unable to interfere in the slightest, but that on the contrary it might have been very much more severe without causing trouble. Reception under this condition was almost invariably good enough for high speed automatic reception. A few thunder storms occurred during this time and some, but not all of them, prevented reception while they lasted. There were also periods recurring regularly every day between four and six o'clock in the afternoon and between twelve and two o'clock in the morning when the intensity of the received signals from Carnarvon and Nauen fell off enormously, on some occasions falling as low as 1/100th of their normal intensity. During a few of these fading periods interruptions were experienced varying from five or ten minutes to perhaps one hour. The worst of these periods was usually, but not always, the midnight-to-two-a.m. period when, altho the static was generally lighter than during the afternoon fading period, at which time its maximum intensity occurred, the decrease of signal strength was rather greater.

* Diameter of number 14 wire = 0.064 inch = 0.162 cm.

A careful study of the conditions during these fading periods convinced me that the difficulty was due to the fact that when the signal weakened greatly the click type of static was present in sufficient quantities to cause the trouble, and that when the signal intensity was greatly amplified in order to be heard, the amplification also brought up this disturbance with its ratio to the signal unaltered.

As has already been pointed out, the two-aerial arrangement has not as yet shown itself capable of sufficiently differentiating between this horizontally moving type of static and the signal to meet the severest conditions of signal fading. In the hope of successfully overcoming even this condition, existing occasionally during the fading periods, recourse was had to the three-aerial arrangement, but in a modified form, as shown in Figure 30.

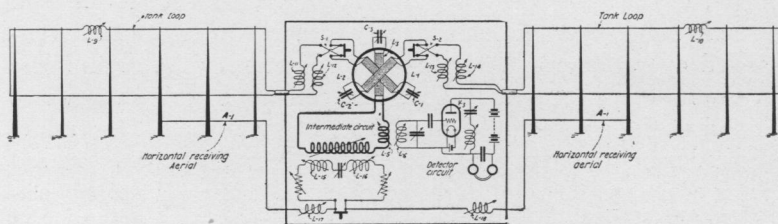


FIGURE 30

This was operated in accordance with the principle previously set forth, namely, the two loops were adjusted to balance out signal instead of static, and the retained static was used to balance out that in the third antenna. The third antenna in this case was a horizontal wire approximately 6,000 feet (1,820 m.) long, about three feet (92 cm.) above the ground, running underneath the loop antennas and supported by the same poles. When this arrangement was operated it was found that all of the hoped-for improvement, and much more, had been realized, in fact that the improvement of reception thru static of the stray or click type was of the same order as the improvement which the two-antenna arrangement made possible thru static of the grinders type; also, most fortunately, that the adjustment which reduced one type of static was the exact adjustment for eliminating the other, so that both types went out together, leaving all of the signal supplied by the third antenna. This was approximately the same in strength as that which could be received

using the two loops so connected that their signal strengths added.

So great was the general improvement in reception made possible by this arrangement that signals from stations in Europe of a very much smaller order of power than Carnarvon or Nauen could then be received. Of these stations it is sufficient to mention Eiffel Tower, working at about 8,000 meters, and Lyons, working at 8,000 meters, the signal strength of Lyons at this wave length being very much less than the signal received from the same station when using his usual wavelength of 15,000 meters, and it is assumed, though not definitely known, that the amount of power being used was much less. The installation at Eiffel Tower is understood to be an arc, the input of which is about 100 kilowatts. Many attempts had been made during the summer to copy these stations with the two-antenna arrangement, but the results were satisfactory only occasionally and when the grinders type of static was that which existed. When the other type was present these stations could not be read. During the test with the three-antenna arrangement on one occasion, in the evening, static of extreme intensity was experienced and the intensity of the signal from Eiffel Tower was much below normal, with the result that with the two-antenna arrangement it was barely possible to tell that the signal was present. Using the three-antenna arrangement the signal was not only readable but of such intensity that it could be read with the telephones a couple of feet from the ear. Continued use has established beyond question that this performance is not occasional or accidental, but consistent, and that with this arrangement trans-Atlantic radio telegraphy can now be carried on free from interruptions due to static of any kind whatsoever except local lightning. This cannot always be neutralized, but since the cables are also interrupted by this latter cause it follows that a continuity of communication equal to that of cable operation is now possible by radio telegraphy, while the latter has the great advantages of cheapness and greater speed of operation. For many years, attempts to work automatic high-speed radio telegraphy have been made, but they have been successful only when static was absent. It is therefore evident that use can now be made of this method of working to a very great extent, thereby greatly increasing the number of messages which can be handled over a given circuit. It may also be stated that the great barrier in the way of successful, practical radio telephony has been removed since static has interfered with radio telephony to a much greater extent even than with radio telegraphy.

One of the outstanding features of the systems thus far described has been their need of a considerable stretch of territory, and it would obviously be an important advance if the same results could be secured without this necessity. It is pleasing, therefore, to be able to state that a considerable number of such arrangements have been worked out, in which the necessity for large space does not exist; in fact some of them are of such small dimensions that the entire equipment necessary, including the antennas, could be arranged in a lecture room, and between the floor and the ceiling. Only one of these arrangements will be described at this time, the others being reserved for a later communication.

Referring now to Figure 31, A_1 represents an aerial of the linear type several times referred to, but so arranged that it can be moved thru a considerable angle in the vertical plane and swung around thru any desired azimuthal angle. If this aerial

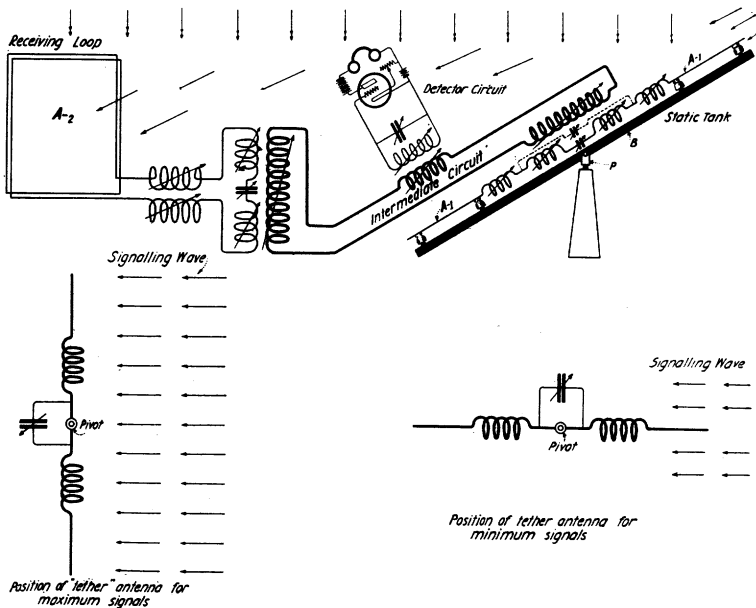


FIGURE 31

is swung from the vertical position to the horizontal position, while being directed toward a desired transmitting station, it is found that a particular vertical angle can be obtained at which the signal goes out entirely while some of the static re-

mains. The arrangement therefore constitutes another form of static tank. If then we take a second antenna, such as the loop A_2 shown in the Figure, which supplies both signal and static, we can, thru the use of the circuits already explained, couple these together in such a way that the static is cancelled, leaving the signal. This arrangement works quite as well as any of those previously described, except the three-antenna arrangement, and the difference is due to the fact that this particular arrangement does not as completely eliminate the static of the horizontally moving type.

To secure the full practical benefit of this arrangement it is desirable that the length of the aerial A_1 be conveniently short, say about 30 feet (9.2 m.), which, for trans-Atlantic reception of course makes necessary the employment of amplifiers of extraordinary capabilities. In the work which I have done with this arrangement I have used two amplifiers, developed by the Research Department of the Marconi Company, of five and eight stages respectively, with which it is possible to receive signals of a satisfactory strength from Nauen or Carnarvon when the antenna is of the dimensions stated. The reason for the use of the very small antenna is simply that it is then possible to secure a conveniently operated mechanical support, the principle of operation holding good, however, when much greater lengths are employed.

No attempt has been made in this paper to set forth exhaustively the complete theories of the arrangements used, but simply to give a brief description of the methods used and results obtained. It is realized that quantitative data of many sorts have not been given, due in part to the unsatisfactory nature of the methods of measurement available, and also to the fact that the whole work was dominated by the practical requirement of securing readability of trans-Atlantic signals, which was of vital consequence to the Marconi Company. It is hoped, in subsequent communications, to remedy the deficiencies referred to and to describe a considerable number of other arrangements which have been discovered, the operating characteristics of which are being more fully investigated.

With reference to the hypothesis stated in the early part of this paper to the effect that static of the grinders type is due to electro-magnetic waves heterogeneously polarized and propagated in a direction perpendicular to the earth's surface, it should be clearly understood that while this hypothesis has been of great use in explaining the very large number of observations

made over a long period of time, it cannot however be regarded in the light of a proven theory, since certain observations have been made which it does not readily cover. It does appear, however, that the most important fact contained in this hypothesis, namely, that static effects of the grinders type are simultaneously produced at points separated a distance of the order of the longest waves at present employed in radio telegraphy, is firmly established. With respect to the rest of the hypothesis, further work, which is at present in progress, will be necessary before the complete truth is proven or otherwise.

The writer would greatly appreciate the opportunity to demonstrate the actual working of the systems described thru a committee to be selected by THE INSTITUTE OF RADIO ENGINEERS should they be sufficiently interested, during the coming summer, when static disturbances are at their worst.

In conclusion the helpful and valuable assistance of the following gentlemen is acknowledged: Mr. C. L. Farrand, Mr. Frank N. Waterman, Mr. George H. Clark, Dr. Alfred N. Goldsmith, Mr. Louis Cohen; and of the Research Department of the Marconi Company. Messrs. Weinberger and Dreher of the Research Department deserve special mention in this latter connection.

SUMMARY: The effects produced by static (strays) are considered, and the Eccles classification of static as grinders, clicks, and hisses is adopted. Previous attempts to eliminate strays are described with explanations of their non-operativeness.

Researches are described which indicate that grinders, the predominantly objectionable summer static, act as if propagated vertically. A balanced antenna structure consisting in effect of two horizontal loops is used to eliminate grinders. Signals in the loops add in the secondary circuit in proportion to the separation of the loops relative to the wave length, while vertically propagated grinders in the loops balance out in the secondary.

Clicks are found to be horizontally propagated strays, and a special three-antenna arrangement for practically eliminating them is described and explained.

Experimental work at various stations using these arrangements is described, and the capabilities of the new systems indicated.