STATIC ELIMINATION BY DIRECTIONAL RECEPTION*

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In the early days of radio communication, those disturbances which have been variously called "static," "atmospherics," "X's" and "strays" were either attributed to distant lightning, or more vaguely and correctly to "atmospheric electricity." While it is still true that our knowledge of static causes is far from satisfactory, we have at least progressed to the point where the distant thunder-shower has ceased to be considered an important source of static, and are now able to concentrate our attention on the higher levels of the atmosphere. Such disturbances as may exist at these levels are unquestionably electrical, so far as they concern our receiving circuits, and are due to a supply of electricity which in some way is generated in or supplied to the atmosphere. The normal electrification of our atmosphere, observed as a rather marked potential gradient in the lower and more accessible layers, accompanied by downward electrical currents and attended from time to time by high level auroral displays and magnetic storms, is undoubtedly due to ultra-terrestrial sources. According to Arrhenius¹ the sun is the ultimate cause of electrical phenomena in our atmosphere, and altho his original theory has suffered certain modifications and additions in the past fifteen years, it will well serve as an introduction to this paper.

The sun being an intensely heated body must in consequence have emitted electrons in such abundance as to have acquired a very large positive charge. This charge, estimated by Arrhenius as three billion volts, forms a powerful center of attraction for stray electrons and negative ions, which are gathered in even from space far beyond the confines of the solar system. An electron or a negative ion, moving in toward the sun under this

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force, will eventually reach the outer and cooler solar atmosphere, where it will form a nucleus for condensation. A droplet, perhaps consisting of iron or calcium, will grow around this nucleus until it attains a diameter of the order of a wave-length of visible light. At this point in its growth, the pressure of light upon its surface considerably exceeds the solar gravitational pull upon its mass, and the droplet moves away from the sun. Such of these minute particles as may reach the vicinity of the earth fall into our upper atmosphere, and as they carry with them their original electrical charges, they constitute an important source of electricity. There are, however, two other sources, also solar, but differing materially in their mechanism. One of these is the ionization produced by the shorter wave-lengths of the sun's light, as it impinges upon the gas atoms in the upper strata. The other consists of a direct emission of either electrons (Beta rays) or, according to Chapman², charged helium atoms (Alpha rays). This direct emission apparently does not take place all over the sun's surface, but jets out in streams, presumably most vigorously from sunspot areas, in consequence of the great thermal gradients and magnetic forces existing at such spots. When such a stream, which may be ten or more degrees wide, sweep across the earth, it makes itself evident as magnetic storms and intense aurora.

The aurora, or Northern Lights, give us a certain illumination as to the manner in which these charged particles arrive and move in the upper levels of our atmosphere. Perhaps the most striking part of this phenomenon is the streaky or discontinuous structure of most aurora. It would appear as if, instead of a steady shower of charged particles, they arrived in clouds, these clouds being eventually drawn out into streaks or lines roughly parallel with the lines of force in the earth's magnetic field. This is exactly what we would expect of a charged particle in rapid motion, when it encountered a magnetic field. It would tend to spiral its way down a magnetic line of force, at least until it reached and penetrated the upper level of the atmosphere, whereupon it would begin to spend its energy in ionization, with light as one of the less objectionable by-products.

The writer is well aware that a theory is at the most tentative, and under suspicion of unsoundness, until it yields confident forecasts. Until such time as it may have been proven by this acid test, it is unwise to overburden a theory by speculative extrapolation. However, even at this risk, as well as the graver one of diversion from the subject matter of this paper, the writer

cannot refrain from a speculation as to the possible connection of the auroral structure, above outlined, with certain facts as to the difference between east-and-west, and north-and-south radio communication. If, as would certainly appear from the visible aurora, east-and-west bound waves encountered a celestial hurdle, while north-and-south waves ran peacefully between the ionized filaments, the ease of north-and-south, and the comparative difficulty of east-and-west radio communication would be readily explained. One might go a step further, and attribute, at least at times, a sufficiently periodic spacing to these ionized clouds for the formation of a gigantic reflection grating, and thereby account for de Forest's³ observation of the easy transmission of certain wave-lengths, and the high absorption of others. Certainly the visible aurora frequently has a very regular spacing, and it might be interesting to ascertain if it be of the right order to account for these effects.

But for the purposes of this paper it will be sufficient to assume only that the charged particles enter our atmosphere in a discontinuous manner. Charged clouds will be formed at some high level, probably drawn out so that their greatest length lies approximately north-and-south and, in a manner similar to that observed in a thunder-storm, there will be equalizing discharges between these clouds. At first, because of the low dielectric strength of the atmosphere at the higher levels, such discharges will occur at small potential differences, and hence will tend to be of small individual intensity but of frequent occurrence. As the charges sink toward the earth, they will reach denser air, and there the discharges will become of greater individual intensity but less frequent.

We recognize to-day two important, that is to say bothersome, varieties of static. One of these is the "click," consisting of rather widely separated but very strong disturbances, reminiscent of the discharges of that aptly-named apparatus, the static machine. The other is the "grinder," which runs the gamut of noise from a grating or grinding sound thru something resembling handfuls of gravel thrown against a window, with perhaps slushy or even hissing sounds at the other end of the scale. The clicks are most probably relatively low level discharges. This is supported by the fact that local thunder-storms give rise to clicks which can sometimes be identified with visible discharges between cloud and cloud, or cloud and ground. Grinders, however, would seem to have two possible origins. In the first place, they might arise from very high level discharges of con-

siderable tho irregular frequency. The writer has succeeded in imitating, with a disconcerting fidelity, grinding static by the simple process of discharging a small condenser thru a series circuit of a wet string and a vacuum tube, replenishing the condenser from an influence machine. Grinding static might also arise from the summation of many distant clicks. There is some experimental evidence of the existence of these two varieties, either singly or mixed, and to this a later reference will be made. For the present, our principal interest is in the manner in which the static waves arrive at the receiving station. If we assume a more or less uniform distribution of discharges in the upper atmosphere, the condition of affairs with respect to the receiving station might be pictured somewhat as in Figure 1.

FIGURE 1

Here a discharge stratum, $H-H$, forms a portion of a sphere concentric with the earth's surface $E-E$. This stratum is not only above the receiving point R , but envelops this point in all directions, even to the horizon. It is at once apparent that individual discharges, as at a , b , and c , will set up waves or pulses which will arrive at the receiving station with intensities inversely proportional to their distances $a-R$, $b-R$, and $c-R$. This may be approximately expressed by saying that the intensities will vary as the sine of the vertical angle, save near the horizon. To state the law exactly would obviously require a knowledge of the height of the stratum $H-H$ which we do not yet possess. However, it is apparent that the intensity on the horizon, as at d , is far from being zero, and is most probably between five and ten per cent of the zenith intensity. The maximum static intensity, tho by no means confined to the zenith, is evidently distinctly *above* the receiving point R . At first thought it would seem that the total amount of disturbance produced by static would be represented by the product of the individual intensity by the frequency. Inasmuch as the number of individual

discharges included in a given small solid angle near the zenith, as at e , is much smaller than the number included in the same solid angle taken nearer the horizon, as at f , varying in fact approximately as the square of the cosine of the vertical angle, it would seem that the total effect should *increase* as we pass from the zenith to the horizon. In general, the writer finds this to be the fact, altho it not infrequently happens, particularly in the forenoon, that light static comes down from above, with very little from the horizon. This may be explained by considering such horizontal static as consisting of weak discharges at great distances from the receiver, and of so great frequency (because of the summation of so many individual discharges) as to blend into a distinctly "soft" disturbance. Bearing in mind that static acts upon a receiving circuit by pure impact, a not inapt analogy is that of a bell set into vibration by irregularly spaced impacts. For the same amount of energy in a given time, a bell will give the greatest response when the taps are individually strong and fairly well separated in time, rather than when the taps are weak but frequent. Furthermore, at least until such time as all reception is photographic, the psychology of the receiving operator must be borne in mind. There is doubtless an illy defined, but none the less existent frequency of maximum disturbance. For example, the writer finds irregularly spaced disturbances most troublesome when their mean frequency is about twice that of the signal element.

If the discharging clouds are drawn out in a north-and-south direction we should expect that the waves arising from such discharges would show a certain uniformity in their planes of polarization. Altho it would be absurd to think of the discharging clouds as accurately oriental linear oscillators, nevertheless there should be a certain preponderance in that direction.

The writer's theory of static might be summed up as follows: According to the assumed character and location of the discharging masses, static waves may be expected to come in on the receiving stations from all angles in altitude and azimuth, with a maximum individual intensity from above, and a maximum frequency in the neighborhood of the horizon. The total disturbing effect will in general come in from points nearer the horizon than the zenith, altho the altitude of the ring of maximum disturbance is indefinite. The individual planes of polarization may take all possible angles, but with a preponderance in a direction determined by the earth's magnetic field. Finally it would seem that the most probable static wave form was a single highly

damped pulse, because of the low conductivity of the discharging masses.

According to the above theory, the problem of the elimination of static and the preservation of the signal consists simply of the reception of a wave-train originating at a definite point, and the exclusion of static pulses originating at all points in altitude and azimuth. In a broad sense, there are two solutions for this problem, one involving a separation of signal and static based upon their difference in wave form, and the other a separation based simply on sharply directional reception. It is quite clear that if we could restrict reception to a small solid angle including the distant station, there would be relatively little static included. To use an optical analogy, the problem is essentially like that of receiving monochromatic light signals in full daylight. A spectroscope or a filter screen would be one solution, and directive reception as by a telescope another, but best of all would be a combination of the two. In present day radio communication we have already highly developed the spectroscopic or filter separation of signal from static, as by sharply resonant circuits and beat reception. But altho we have had two practicable types of sharply directional receiving circuits for the past twelve years or more, very little use of these appears to have been made until quite recently.

In a paper entitled "Absorption and Reflection of Electrical Waves," read before the New England Wireless Society on December 7, 1912, the writer, after discussing the probable relation between ionization conditions in the upper atmosphere and electrical wave transmission, went into some detail of his early experiments to determine the nature of static. At his first experimental station, at Blue Hill Observatory, Milton, Massachusetts,⁵ he conducted a long series of tests which apparently showed a relation between the wind velocity and the number of disturbances in a given time, which led to the conclusion that effect was a local one, possibly consisting of an actual discharge to the receiving aerial from electrified masses of air moving past the antenna wire. This theory was rudely upset by his further work in 1901, when comparison of tapes at Galilee and Brielle, New Jersey, about twenty miles (32 kilometers) apart, showed the same dots and dashes from static, day after day. It was clear from this that some static, at least, came from discharges at considerable distances from the receiving aerial. He then said:

"A little later, I surrounded a receiving aerial by a F raday

cage⁶ constructed with loading inductances to avoid shielding the aerial inside from the desired signal. This seemed to eliminate a small portion of the static—probably that portion due to direct discharge to the wire from the atmosphere—but had no observable effect upon the distant variety.”

At this point, the writer wishes to call attention to the careless manner in which members of this Institute refer to the Faraday cage antenna shield as a “Dieckmann cage.” Dieckmann, in 1912,⁷ first published his description of an aperiodic shield or cage around an aerial, so designed as to permit the passage of signal waves, but to be opaque to static pulses. The writer has published, in a patent⁶ filed six years before Dieckmann’s date, this exact thing. Reference to Figure 2 will show the antenna wires *A, A*, surrounded by a cage, sectioned off into short elements which are connected together by impedances and grounded thru other impedances so that an aperiodic shield results. While he is inclined to agree with Weagant¹² that the device is of small utility as against the most bothersome varieties of static, it seems only fair that he, and not Dieckmann, should receive whatever credit is due for this invention. While the

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Inventor:
Greenleaf Walter Pickard
by *Phyllis Farmer* Atty.

FIGURE 2

shielded antenna is open to attack from clicks and grinders, it is a complete solution of the hissing variety of static, due to a direct discharge to the aerial. Where a series condenser is employed in the antenna circuit, this is very apt to charge up to the limit of its dielectric strength, and then spill over, giving an excellent imitation of pistol shot static. This occurs most markedly during snow-storms; and, on shipboard, where the aerial is slung immediately over the funnels, the vessel manufactures this type of static in abundance, and delivers it effectively to the waiting antenna. Shielding is of distinct value in such cases.

FIGURE 3—Pre-Dieckmann Shield

Continuing his paper before the New England Wireless Society, the writer then describes his early work with directive aerials, particularly with the ungrounded coil or loop aerial.

Again, as with the Dieckmann cage, the writer must pause to correct a heresy. Altho it has been fashionable of late to attribute this invention to Messrs. Bellini and Tosi, it should be noted that these gentlemen first published an account of their work on November 14, 1907¹³. The writer began his development of the coil or loop aerial in 1902, and published an account of his work on June 15, 1907¹³, almost exactly five months prior to Messrs. Bellini and Tosi. It is of interest in this connection

FIGURE 4—Pre-Dieckmann Shield

to note that the writer, on September 13, 1907, demonstrated one of his coil aerals at Dorchester, Mass., to Lieutenant-Commander S. S. Robinson, detailed by the United States Navy for this purpose. This particular coil aerial is shown in Figure 5, and consisted of two turns of wire forming a square about nine meters (27.45 feet) on a side. Altho but two turns are shown,

from one to ten turns were actually employed, depending of course upon the wave-length. Exceedingly accurate bearings of a number of distant stations were taken, some over sixty kilometers (38 miles) away from the loop, with a maximum error not greater than 2 degrees of arc.

FIGURE 5

Further on in the 1912 paper, the writer said:

“But the worst summer static appears to be at a very considerable distance from the receiver, and I believe it originates at some of the higher levels already discussed in this paper; probably many miles over our heads. I also believe that static is simply a discharge from one high level cloud of ions to another

similar cloud, very like what we see from cloud to cloud in a thunder-shower; that is, an equalizing discharge. Like lightning, static appears to be non-oscillatory, as may be readily found by experiment."

The writer does not claim novelty for the "static from above" theory. In fact, Airy⁴ said in 1911:

"It was concluded that most of the disturbances were not due to local weather conditions, but to discharges taking place in the upper atmosphere, and at very great distances from both stations. He thought it would be eventually proved that these atmospherics were connected with magnetic disturbances, and that they had the same common origin—that is, the arrival of negatively charged electrons from the outer space into the earth's atmosphere."

The writer concluded his 1912 paper with the following up-to-date treatment of the static problem:

"I believe, as a result of considerable experimental work, that the real solution of the static problem lies in the use of sharply directional receiving antenna. Provided only that the static does not originate at the same point as the signal, good directional reception should eliminate most of it."

As already stated, there are two practical methods of obtaining sharply directional reception. In the first method, originally suggested by Elihu Thomson⁸ in 1899, patented in England by S. G. Brown in the same year⁹, more fully disclosed and patented in this country by Stone in 1902¹⁰, elaborately worked out for two, three, and four collecting circuits by Braun in 1906,¹¹ and more recently used by Weagant¹², two or more separate collectors are employed, spaced apart a material fraction of a wave-length in the line of propagation, as shown in Figure 6. These collectors act upon a common secondary circuit in such wise that when the collectors are simultaneously affected by any disturbance, the current set up therein will arrive in phase at the center of the system, and there, by opposed windings, be placed 180° apart in phase in their effect upon the secondary. Because of this opposition, such currents will not affect the detector, and no signal will be produced. On the other hand, the signal wave, passing the collectors successively, will set up currents therein which will arrive at the center of the system in an out-of-phase relation, and such signal currents will add in their effect upon the secondary and affect the detector. This is very well shown in Figure 7, and clearly explained in the specification of the Stone patent of which Figure 7 is the drawing. The writer, in 1905, devised

FIGURE 6

a system in which two aeries, tuned to the distant station and separated on centers by some thousands of meters (about a mile),

No. 718,955. J. S. STONE. Patented Dec. 30, 1902.
METHOD OF SIMULTANEOUSLY TRANSMITTING AND RECEIVING SPACE
TELEGRAPH SIGNALS
(Approximate Date Jan. 20, 1901.)
(No Model.)

FIGURE 7

were connected to a common secondary by way of phase adjusting means, so that the currents were added in the secondary in such phase as to produce the maximum signal. This method was first published in a patent filed in 1907,¹³ and is shown in Figure 8. The particular case discussed in this publication

FIGURE 8

involved two large loop or coil aerials, arranged in an east-and-west plane for the purpose of trans-atlantic reception. These loop aerials consisted of long, low rectangles, and were tuned to the desired wave-length by inserted series capacity and inductance. With this system it is possible to so adjust the phase relations of the currents arriving at the secondary that interference or static arriving from any particular direction is cancelled out in the secondary, and does not affect the detector. A further advantage of this system, which has recently been pointed out by Weagant¹⁴, is the fact that it has materially greater or sharper directional reception than any single type of collector. This is obvious when we consider the fact that the loop aerials M^2 and M^4 have simple cosine reception curves in the horizontal plane,

and that a pair of open or non-directive aerials, separated as are M^2 and M^4 , in Figure 8, by a considerable fraction of a wavelength, with currents combined in a common secondary, have also a cosine curve characteristic. The combination of two loop aerials in the manner shown in Figure 8 has therefore a cosine square reception curve.

This same publication also states that combined loop and open aerials may be used at such points as M^2 and M^4 . It is of interest to note the reception curve of this system, when one, two and three separate collectors of this form are employed. In Figure 8-A is shown in dotted line the reception curve of one collector. This is a cardioid, or heart-shaped figure, with maxi-

FIGURE 8-A

mum reception in the direction O - A . With two such collectors, the reception curve is shown in dot-and-dash line, and is markedly more sharply directional than the curve for one collector. A still further improvement results when three collectors are employed, this being shown in full line.

The second method of directional reception, devised by the writer²¹, does not involve, even for long wave reception, such geographical dimensions as the systems shown in Figure 8. This

second method consists simply of a closed tuned circuit or coil aerial, of dimensions small as compared with a wave-length. In its most effective form, consisting of a coil aerial combined with a so-called "open" aerial, this method gives true unilateral reception. The coil may be of quite small dimensions, particularly when it is employed simply as a radio compass. In Figure 9 is shown the first portable radio compass, which was employed by the writer in 1907-1908¹⁶ for mapping out the wave-front around a transmitting station. This radio compass consisted of a three-turn loop, one meter (3.05 feet) in diameter, shunted by a variable air condenser and a crystal detector.

FIGURE 9

Heretofore, the reception characteristics of aerials have been studied principally, if not exclusively, in the horizontal plane. The writer is not aware of any publication dealing with the three-dimensional characteristics of aerials, altho for quite some time past, points of wave origin other than the horizon have been common, for example, static, and more recently transmitters on aircraft. Just why radio engineers have elected to live in a two-dimensional world is rather puzzling, and if this paper has no other effect than to add another dimension to their life the writer will feel fully repaid for his labor.

In Figure 10 is shown the now familiar reception curve of a vertical loop or coil antenna in the horizontal plane, consisting of a cosine curve drawn in polar co-ordinates. This is an ideal curve; actually a coil aerial gives a more or less distorted figure-of-eight, sometimes tending to an hour-glass shape, and usually more or less unsymmetrical. The reasons for this distortion have only recently been worked out in detail, and some of the more important causes of distortion will be explained later in this paper.

FIGURE 10

In a vertical plane, including the plane of the loop itself, reception is obviously symmetrical, and the reception curve in this plane is a circle, as shown in Figure 11. If the loop is near the ground, the lower half of the reception curve is normally without interest, because signals do not often originate from under foot, and hence is shown in dotted line.

If, however, a loop is placed aloft, as in aircraft work, the useful reception curve in this vertical plane is a full circle. Finally, the complete three-dimensional reception surface of the

FIGURE 11

loop is a torus. This torus is shown in Figure 12, and differs from the conventional anchor ring or doughnut in that it has no hole in the center, this peculiarity making its representation somewhat difficult. The significance of this last figure is obvious—the loop receives more or less from all points in space, excepting only along a line passing normally thru its center. The further

FIGURE 12

meaning of this figure is that maximum reception occurs only in all directions in the plane including the loop, and the significance of this fact is perhaps best brought out by Figure 13. This figure represents a plan of the hemisphere over the loop, just as if one were looking up at the zenith, and the shading indicates the amount of reception from different points in this hemisphere by a loop placed in an east-and-west vertical plane. The zone of maximum reception is a belt passing across the sky from east to west, reception decreasing to zero on the horizon at points north and south of the loop.

FIGURE 13

A so-called open antenna consisting of a vertical wire, short as compared with a wave-length, has in the horizontal plane a simple circle diagram, that is, it receives equally well from all points on its horizon. In any vertical plane passing thru the antenna, a quite different reception curve results, as reception is a maximum on the horizon, and decreases to zero at the zenith. The complete reception in any vertical plane passing thru the antenna is shown in Figure 14, and is, of course, the familiar cosine curve. The portion below the horizon is shown dotted in the figure; if the open antenna consisted of an ungrounded linear oscillator considerably removed from the earth, the lower portion

of the curve would interest us. Actually, just as with the loop or coil aerial, and for similar reasons, this ideal curve usually suffers considerable distortion, partly because actual vertical aerials have an appreciable horizontal length in most cases, and partly because of unsymmetrical or electrically warped surroundings. The complete three-dimensional reception surface of the

FIGURE 14

open antenna is therefore just like Figure 12 laid down flat, or, more exactly, laid down flat and half embedded in the ground, if the open antenna is on the earth's surface. It will be seen from this that the loop and the open antenna have identical reception surfaces, but in planes 90° apart. Similarly to the loop, Figure 15 shows a plan of the hemisphere over an open antenna. In this

FIGURE 15

figure, the reception belt rings the horizon, and reception is zero from the zenith. If static came solely from above, an open antenna would make an ideal eliminator. Equally, if static came in on the receiving point with the same intensity from all points in altitude and azimuth, it would be difficult to account for the well-known freedom of the loop from static.²⁰ But if we assume that in general static is at its worst near the horizon rather than the zenith, a comparison of Figures 13 and 15 will show a reason for the relative immunity of the loop.

In Figure 16 is shown the method referred to above, which combines open antenna reception with loop or coil reception. A

No. 876,996. G. W. PICKARD. PATENTED JAN. 21, 1908.
INTELLIGENCE INTERCOMMUNICATION BY MAGNETIC WAVE COMPONENTS.
APPLICATION FILED JUNE 10, 1907. 2 SHEETS—SHEET 2.

Fig. 5.

FIGURE 16

glance at the date of this drawing—June 10, 1907—will make it obvious that the combination of loop and open reception cannot be attributed to Messrs. Bellini and Tosi, often as this has been attempted of late. In this figure is shown the coupling of a loop and an open antenna to a common secondary, by way of phase-adjusting means, so that the currents in the loop and the

open antenna, normally 90° out of phase, are added in phase in the secondary circuit. If now, as by suitable dimensions of the loop or by coupling adjustment, or by both, the currents from the open antenna are made equal, in their effect upon the secondary, to those from the loop, the result of this addition, in a reception curve on the horizontal plane, is shown in Figure 17. Reception is at a maximum from the direction $O-A$, is zero from the direction $O-B$, and has intermediate values from other directions, the complete curve being a cardioid. Such a circuit, employed as

FIGURE 17

a direction finder, gives the true bearing of the distant station, and does not, as with the simple loop, leave the direction indeterminate by 180° . In a vertical plane including the loop the reception curve is also a cardioid, as shown in Figure 18, with a maximum on the horizon at A , and zero on the horizon at B . Reception from the zenith, that is, along the line $O-Z$, being limited to the loop, has half the value of reception along the line $O-A$. In a vertical plane at right angles with the loop, that is to say, at right angles to the plane of Figure 18, the reception curve is that shown in Figure 19. In the center of this figure is shown the loop $L-L$ and the open antenna $V-V$. A static source at $S-S$, in the vertical plane $C-Z-D-N$, is at an angle A with the vertical, and has an orientation or polarization angle B .

The current set up in the loop will be proportional to $\cos A \sin B$, while the current excited in the open antenna will be $\sin A \cos B$. The sum of these currents will be $\cos A \sin B + \sin A \cos B$; that is, for all possible orientations and vertical angles it will be a constant, so that the reception curve in the vertical plane normal to the loop will be, as shown in the figure, a circle.

FIGURE 18

The complete three-dimensional reception surface is difficult to show in a two-dimensional figure or plan. Figure 20 shows its sections in three perpendicular planes. As will be apparent from this figure, the complete reception surface is a cardioid of revolution, which may be more simply described as an apple, with the pit at the origin O .

From a consideration of the three-dimensional unilateral reception of the combined open and loop antenna, as shown below in Figure 20, it will be obvious that static originating at points other than on the horizon in the direction of the distant transmitter will either be weakly received, or, if it happens to originate on the horizon at a point 180° from the transmitter, it will not be received at all. The circuit shown in Figure 16 is not at present, however, the best arrangement for this method of static reduction. As the effect of static on a receiving circuit is practically pure impact excitation, complex waves will be set up in the

two coupled circuits—the loop and the open antenna—with the result that the just shown ideal diagrams of reception curves and surfaces are but roughly approximated. These diagrams are, of course, only true for undamped wave reception, or for static reception on substantially aperiodic circuits.

FIGURE 19

Shortly after America entered the war, the Wireless Specialty Apparatus Company equipped a radio station for Mr. Alessandro Fabbri, at Otter Cliffs, near Bar Harbor, Maine. When the station was completed, Mr Fabbri donated it to the Navy, and it was first used as a low power spark station. However, it was very shortly found that the location was an excellent one for trans-atlantic reception, and this eventually became its principal service, the station finally becoming the premier reception point.

in this country. The summer of 1917 having shown that altho the Otter Cliffs station had excellent signals, it also had overwhelming static on occasion, Mr. Fabbri invited the writer to install directional receiving circuits for static elimination, adapted to the requirements of trans-atlantic service. Within a few days after this request, the circuit shown in Figure 21 was installed, combining open antenna reception with loop or coil reception. This was immediately found successful in improving

FIGURE 20

the signal-static ratio, and was at once placed in service. The loop A consisted of a solenoidal coil of four turns of number 16 Brown and Sharp gauge (1.3 mm. diameter) copper wire, with the turns spaced apart 30 cm. (12 inches). This loop was in the form of a long low rectangle, 30 meters (97.5 feet) long, and 6 meters (18.3 feet) high, the lower part of the loop being about 4 meters (12.2 feet) from the ground. The plane of this loop was approximately north-east by south-west, that is, it was in the great circle bearing of the more important European stations. This coil aerial was tuned to the desired wave-length by series inductance L_3 and capacity C ; a fixed coil L_3 of 22 millihenrys

being used in most of the work. The open antenna of this combination consisted of the conductor of the loop itself and a connection to earth at G by way of a coupling coil L_1 of 22 milli-henrys inductance, a variable inductance L_2 for tuning this open antenna circuit, and a variable resistance R , and was tuned to the same wave-length as the loop. The coils L_1 and L_3 were quite closely coupled together, and coil L_3 rather more loosely coupled to the secondary or detector circuit S . This secondary circuit, as shown in Figure 21, employed the static coupled audion circuit due to Lieutenant Eaton of the United States Navy.

FIGURE 21

Two steps of audio frequency amplification were usually employed, in addition to the circuit shown, and the normal signal strengths from Rome, Lyons, and Carnarvon were above 1,000 times audibility. The resistance R was found to be an important element of the circuit, and in its absence the results were decidedly inferior. The amount of resistance required was surprisingly large, being about 3,000 ohms.

The operation of this circuit is substantially as follows: As it is a development of the circuit shown in Figure 16, and consists of a combination of a loop and an open antenna, with the currents added in phase in the secondary circuit, it has a reception surface which is essentially like the upper half of Figure 20, with a maximum reception only on the horizon in the direction of the distant transmitter. Static pulses from any direction other than that of the distant station itself are either received weakly or not at all if it happens to originate to the rear of the system.

Reaction between the open and closed circuits, with resultant complex wave formation, is prevented by the high damping of the open circuit, which with 3,000 ohms inserted is practically aperiodic. The reason why so large a resistance can be used in the open circuit and still have substantial equality of open and closed circuit current is due to the fact that a loop of the dimensions employed is much less effective than an open antenna of the same height at long wave-lengths. The currents from the open circuit, reduced to the same amplitude as those in the loop by the inserted resistance and degree of coupling, are shifted thru 90° in phase by the transfer from the open to the closed circuit by way of the coupling, between L_1 and L_3 , and hence are added in phase in the loop circuit, and then transferred, by the coupling between L_3 and S , to the secondary circuit. It will be seen that the change in phase accomplished in the original circuit of Figure 16 by a phase adjuster in the form of a variable artificial line, is here done by the simple expedient of coupling together tuned circuits.

The performance of this circuit may be judged from a typical set of audibility meter readings taken by the writer, which are tabulated below:

Time A.M.	Station	Loop alone		Loop+Open	
		Signal	Static	Signal	Static
11.25	Nauen	2,500	800	400	60
11.35	"	5,000	1,500	3,000	800
11.45	"	3,000	1,000	400	120
11.50	"	5,000	1,500	—	—
12.00	"	3,000	1,500	—	—
P.M.					
2.35	"	1,000	1,000	250	60
2.40	"	—	—	1,000	200
3.10	Carnarvon	1,000	4,000	600	100
3.15	"	1,500	5,000	600	160
3.25	"	800	5,000	200	80
3.30	Nauen	1,000	5,000	250	80
3.35	"	1,000	4,000	600	160
3.37	Carnarvon	1,000	5,000	600	160
3.41	"	1,000	4,000	500	160
3.55	Nauen	1,000	5,000	300	80
4.00	"	600	2,000	300	60

The static intensities in the above table were taken in each instance over a period of five seconds, and no attention was paid to the clicks, which were of several times the intensity of the grinders. It will be noted that during the forenoon, with strong signals and weak static, the system had little effect. But during the afternoon, with weaker signals and much stronger static, the improvement in the ratio is rather striking. As a matter of fact, the circuit of Figure 21, during periods of severe static, enabled the solid, uninterrupted copying of stations which would on the ordinary circuits be so broken up as to be unreadable.

Continued use of this circuit at the Otter Cliffs station developed the fact that the earth connection of the open antenna was not attached symmetrically to the aerial, the result being that a certain amount of current in the open circuit was flowing directly thru the loop and coil L_3 , of course 90° out of phase with the loop current. This tended to decrease the sharpness of the unilateral reception, and hence the degree of static elimination. As this effect is often present in the simple loop or coil aerial when used for direction finding, it may not be out of place to explain it briefly here.

Considering only the horizontal plane reception of a simple loop aerial, with a certain unbalanced capacity to ground (either by way of unbalanced leads or unsymmetrical construction of the loop itself), it is obvious that the system will act as a combination of loop and open antenna, with the currents added together, not in phase but in quadrature. As a result of this, the currents will add together irrespective of their direction, with the result that the ideal figure-of-eight reception curve degenerates into an hour-glass shaped figure, the breadth of the neck depending upon the amount of open antenna current. This degeneration is shown in four steps of increasing open antenna current in Figure 22. The remedy for this trouble is a simple one, and consists in balancing the loop to ground, as by a three-plate variable condenser, in the manner shown in Figure 23. By turning this loop thru 180° in its own plane, so that the terminals of the loop come out on top, a material advantage results in direction finding. As the points of highest potential are thus removed as far as possible from the earth, the loop is much less affected by surrounding grounded objects. Of course, this method is at its best with a single turn loop, altho improving a two-turn loop.

A simple loop may also suffer from open antenna current which is neither in phase with the loop current, nor in quadra -

FIGURE 22

ture therewith. This sometimes happens in short wave working with loops of considerable inductance, that is, of considerable

FIGURE 23

conductor length. It also happens with the circuit of Figure 21, because the two open antenna effects, one in phase and the other in quadrature, may be considered as one current. For graphical analysis, it is simpler to keep these currents separate, and this is done in Figure 24, which illustrates the evil effect of out-of-phase current. This is also an unbalance effect, and may be eliminated by suitable construction or by the three-plate condenser arrangement of Figure 23.

FIGURE 24

A more bothersome effect in simple loop working arises from a displacement current across the turns of the coil aerial, added to an open antenna current resulting from unbalance. Inasmuch as the displacement current across the turns of the coil gives a cosine characteristic like that of the loop itself, but displaced by 90° , the resultant characteristic of the system suffers distortion which is particularly noticeable at the minimum points at right angles to the loop. The writer had intended to treat this at some extent, but the interesting paper of Captain Blatterman¹⁸, which issued after this paper was written, makes this unnecessary. It is sufficient to say that, with the exception of the displacement current effect (which can be obviated by using a pancake rather than a solenoidal coil aerial) proper balancing of the loop, either by construction or by the three-plate condenser, is all that is required.

An interesting modification of the circuit of Figure 21, due to a suggestion by Mr. J. A. Proctor, was tried out at Otter

Cliffs, and found to reduce the unbalanced open antenna effect. This circuit is shown in Figure 25, and differs only from the circuit of Figure 21 in that the ground connection from the right-hand end of coil L_3 is taken by way of a second loop, A_1 , closely coupled with the main loop A . Unbalanced current in the loop A is opposed by current in the loop A_1 , with the result that there is a certain cancellation of effect, and a sharpening of the directional action.

FIGURE 25

But the simplest solution, and the one that has given the best result from the combination of vertical open antenna and loop, is shown in Figure 26. This differs only from Figure 21 in that a separate open antenna is used, and the loop circuit remains entirely insulated. A typical performance of this

FIGURE 26

circuit (which had a loop of approximately the same dimensions as that of Figure 21) is given below:

Time P.M.	Station	Open alone		Loop alone		Loop+Open	
		Signal	Static	Signal	Static	Signal	Static
1.45	Nauen	2,000	4,000	300	600	300	60
1.54	Hanover	400	1,500	100	500	200	80
2.38	"	400	1,500	150	500	300	100
2.44	Nauen	800	6,000	200	500	300	80
3.10	"	200	800	300	800	400	80
3.18	Lyons	100	1,000	150	500	150	40
3.27	"	200	2,000	150	1,000	200	60
3.52	"	300	1,500	100	500	150	50
7.14	Carnarvon	300	1,500	150	600	150	80
7.28	"	400	4,000	300	1,000	400	100
7.40	"	400	3,000	200	800	300	100
8.26	Lyons	400	1,500	150	500	300	100
8.57	"	400	1,500	200	1,150	300	150
9.11	Carnarvon	100	800	100	800	150	60
9.20	Lyons	600	8,000	200	1,500	150	100
9.32	Carnarvon	?	8,000	?	1,000	150	100
9.37	Lyons	300	1,500	100	900	100	60

One of the striking things in the above tabulation is Carnarvon at 9.32 p. m. Neither on open antenna nor on loop, taken singly, could sufficient signal be heard to measure on the audibility meter. But on the combined loop and open antenna the signal was well above the static in intensity.

The adjustment of the combined loop and open antenna, in either of the forms shown, is quite critical, the best unilateral reception being when the loop and open antenna currents are equal. In Figure 27 is shown the result of combining different ratios of open and loop current. The uppermost reception curve is the horizontal plane characteristic of an open antenna, with no loop current. The second curve represents equal amounts of open and loop current, and is a cardioid.

The third figure represents the addition of two parts of loop current to one of open, while the fourth shows pure loop reception. It will be seen that the vector *O-A*, in the direction of the distant transmitter, increases uniformly as loop current is added to open current, until the ratio is one to one. Any further

change in this ratio, increasing the proportion of loop current, decreased the vector $O-A$, the reception being only at a maximum when the ratio is unity. Similarly, the amount of reception from the direction $O-B$ decreases steadily as loop current is added to open, being zero when the ratio is unity. Any further change, increasing the ratio of loop to open, results in increasing the amount of reception from $O-B$.

FIGURE 27

The writer here wishes to emphasize the fact that the results above tabulated are in no sense exceptional for his system of the combined loop aerial and open antenna, nor were they taken under "freak" conditions. These combined loop and open circuits have been in daily operation, summer and winter, over a period of nearly two years at Otter Cliffs, and have proven consistent performers. During the summer of 1918 the Otter Cliffs station circuits gave unbroken copying of the European

stations at times when all other Atlantic coast receiving points were helpless. In fact, altho a large amount of interesting experimental work was done at various points on the Atlantic coast, it may now be definitely said that the above-described circuit, in the installation at Otter Cliffs, was the only static eliminator that played any part in our war use of trans-atlantic radio communication.

An interesting and as yet unexplained matter is the marked predominance, at least on the northern Atlantic coast, of static originating on the western or south-western horizon. In all probability, this direction of origin accounts for some of the elimination observed on the above circuits. The writer also has a certain amount of evidence which tends to show that this effect is confined to the immediate neighborhood of the coast, and that it vanishes a short distance inland.

As a result of the writer's study of the three-dimensional characteristics of various aerial combinations many novel and useful arrangements have resulted. While a detailed showing of these arrangements will be given in a later paper, a brief description of one of them may be of interest here. Examination of Figure 20 will show that if this figure is turned thru 90° , so that the vertical plane *C-Z-D-N* becomes the horizontal plane, a very favorable reception surface results. No energy would be received from the zenith, and but very little from the rest of the hemisphere, until the horizon was reached.

On the horizon, from static sources having all possible planes of polarization, there would be reception from all directions, but for signals from distant transmitters the predominant reception would be from the loop, so that signal reception would be directional.

In order to turn the reception surface of a circuit thru 90° one has only to turn the circuit itself thru this angle. In Figure 28 is shown the circuit of Figure 26, turned thru 90° in the plane of the loop. It is best to remove this circuit somewhat from the earth's surface, in order to prevent distortion of the open antenna characteristics. Ordinarily, if the lower part of the loop is elevated some five or six meters from the ground there will be no appreciable distortion.

In this connection it must be remembered that, over land at least, wave-fronts are not vertical, but are tilted forward in the direction of propagation. For example, at Otter Cliffs the writer found that waves arriving from European stations were inclined over 15° from the vertical. This tilting of the wave-

front in and over poorly conducting soil is responsible for many curious effects; among others, it is the explanation of the action of the so-called underground aerials. When a tilted wave-front

Static Eliminator at Otter Cliffs with Four Stations for Simultaneous Reception of Trans-atlantic Schedules

Interior of Static Eliminator Station

passes the circuit of Figure 28, it is equivalent to tilting the horizon of this figure, with all that that implies as to the reception surface. Returning to Figure 20, it will be seen that if the plane $C-Z-D-N$ be rotated slightly about $C-D$ as an axis, one half of the reception surface will be more or less submerged, so that

reception will be unilateral. In this manner, by swinging the circuit of Figure 28 thru a slight angle, it is possible to suppress practically entirely one side of the reception, and with the normal south-western static and trans-atlantic reception the circuit is free from disturbance.

FIGURE 28

The writer gives below a typical extract from the performance log of this circuit. The loop A (Figure 28) consisted of seven turns of number 16 Brown and Sharp gauge copper wire (1.3 mm. diameter) spaced 10 cm. (4 inches) apart in a solenoidal coil, 30 meters (91.5 feet) long, 7 meters (21.4 feet) high and with the lower conductors of the loop about 4 meters (12.2 feet) above the ground. The open horizontal antenna A_1-A_2 consisted of a single wire 50 meters (153 feet) long, with a variable condenser C_1 inserted at its center. The coils L_1 and L_3 were of 20 millihenrys each, and the resistance R was 1000 ohms. Preliminary tests having indicated that the open antenna received materially less energy than the loop, the resistance R was removed from the open circuit, and placed in the loop. The secondary S was then coupled with L_1 instead of L_3 , as shown in Figure 28, and the following readings were taken:

Time P.M.	Station	Loop alone		Loop+Open	
		Signal	Static	Signal	Static
2.45	Nauen	150	300	50	15
2.58	"	300	600	60	5
3.14	Lyons	100	500	30	8
3.28	Nauen	800	3,000	200	10
4.12	Carnarvon	100	500	40	5
4.25	"	100	600	60	8
4.32	Nauen	200	1,000	80	6
4.58	"	100	600	80	10

In conclusion, the writer wishes to acknowledge the valuable assistance and co-operation of Mr. J. A. Proctor, and the aid so freely given by Mr. Alessandro Fabbri, whose helpful enthusiasm and encouragement will long and gratefully be remembered.

SUMMARY: The author considers the possible origins of static and inclines toward a solar origin. He finds that static comes from all directions, with maximum intensity from above and maximum frequency from the horizon. The probable static wave form is a single highly damped pulse.

The author then describes his early work with loop directional receivers, his invention of the so-called "Dieckmann cage," and his early work in static elimination.

He gives the three-dimensional reception characteristics of linear antennas, loops, and various combinations of these.

The work carried on under his direction at the Otter Cliffs, Maine, receiving station is then described in detail. Highly successful loop-and-antenna combinations were used in static elimination, and these are discussed with numerical results.

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