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THE SEIBT DIRECT INDICATING WAVE METER.*

By Emil J. Simon and Dr. Alfred N. Goldsmith

A conducting ring placed in front of a coil in which flows an alternating current will be repelled from the coil. The cause of the repulsion is the interaction of the current induced in the ring by the alternating magnetic field in which it is placed, and the magnetic field itself. This repulsion is known as the Thomson [(1)] or dynamometer effect. The exact magnitude of the effect, and the conditions under which it is most readily produced and measured, can be ascertained from the articles mentioned in bibliography at the end of this article. The industrial applications of the dynamometer effect have been many. In a braking device on induction motors and in alternating current wattmeters it has been widely utilized. It has even been employed by Mandelstam and Papalexi [(2)] in a special form of double, alternating current, mirror galvanometer whereby the radio frequencies can be very precisely measured. Tho measurements of wave length by the method of Mandelstam and Papalexi are of a high order of precision, the convenience of their method is hardly as great as that of the familiar method of Bjerknes, and it is not well suited for use except under laboratory conditions. A pointer and scale instrument of this type would be difficult to construct. It has remained for Dr. George Seibt to place on the market a wave meter based on the Thomson effect, portable, and direct indicating. We shall describe this instrument in further detail.

As shown in Figure 1, when an alternating current passes thru the coil S, the ring R will be repelled. If two coils, S_1 and S_2 (Figure 2), be placed on opposite sides of the ring R, they will exert on this ring the opposing forces K_1 and K_2. If the ring is free to move it will assume an intermediate position of equilibrium between the two coils. If the two coils are alike,

(1) Elihu Thomson, Electrical World, May 28, 1887.
(2) Mandelstam and Papalexi, Annalen der Physik, 1910, Vol. 33, Page 490.

*Partially based on Dr. George Seibt's French Patent No. 446,251 and English Patent No. 16,874.

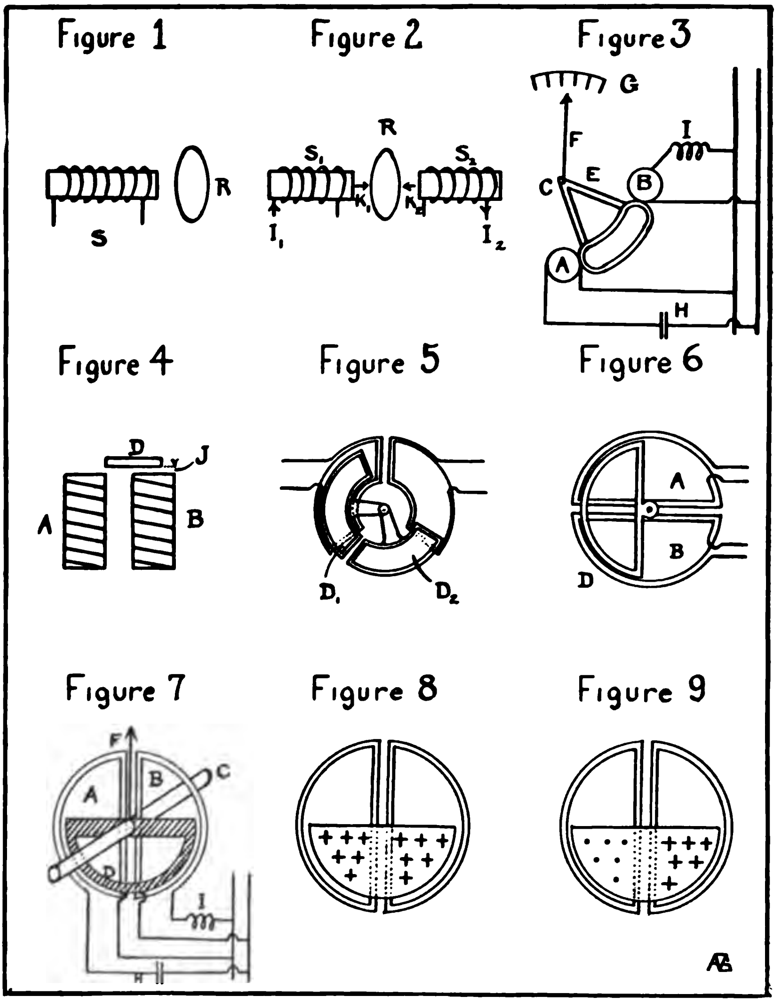


Figure 1
S
R
Figure 2
R
S_1
S_2
K_1
K_2
I_1
I_2
Figure 3
G
F
I
E
C
B
A
H
Figure 4
D
J
A
B
Figure 5
D_1
D_2
Figure 6
A
B
D
Figure 7
F
A
B
C
D
I
H
Figure 8
Figure 9
AB

the currents thru them equal, and if no external control force acts on the ring, it will place itself exactly half way between the coils. But if the currents are unequal, the ring will move toward the coil carrying the smaller current. The problem of constructing a wave meter on this basis then resolves itself into the following: What arrangement of circuits connected to the coils S_1 and S_2 will ensure a division of the total current between them, such that the relation between the currents in S_1 and S_2 shall be dependent only on the frequency of the total current, but not on its magnitude?

A number of methods of constructing the instrument will be given. Referring to Figures 3 and 4, coils A and B are placed approximately 90° apart relative to the axis C of the instrument. Over them is mounted on the frame E the armature D, consisting of a piece of metal forming a closed circuit or of a number of short-circuited windings. Both armature and frame are free to rotate about the axis C, carrying with them the pointer F, which moves over the graduated scale G. It will be seen that this arrangement is equivalent to that shown in Figure 2, inasmuch as an alternating current thru either coil A or B will tend to repel the armature D toward the other coil. As before, the stable position of the amature is determined by the relation between the currents in the coils A and B or the fields due to these currents.

The variation of the fields or of the currents with the frequency may be obtained in various ways other than that mentioned above, which was finally adopted. Thus the coil A may be connected to the circuit the frequency of which is to be determined thru the condenser H, and the coil B thru the inductance I.

The form of armature construction shown permits of placing it very close to the coils A and B. The closeness of coupling between the coils and the armature can be varied by altering the distance J.

The sensitiveness of the instrument and also the operative angular range on the graduated scale are increased if the surface enclosed by the armature, and also the surface enclosed by each of the coils A and B, subtends a greater angle at the center than 90°. In Figure 5 is shown an arrangement in which the surface of the armature and coils of the instrument are angularly measured, and relative to the axis of the instrument, each greater than 90°. The armature is here split into two parts D_1 and D_2. The theoretical maximum angle of deviation is 120°; but in practice, owing to the weakening of the forces of deflection at larger angles of deflection and the consequent inaccuracy in the readings of the instrument, deflections greater than about 60° are not used. The arrangement shown in Figures 6 and 7, in which the surface of the armature and fixed coils are, angularly measured relative to the axis of the instrument, about 180° wide is still more sensitive. The maximum theoretical angle of deflection reaches 180°, and the maximum angle used in practice about 110°.

Another possible way of constructing the armature is to shape it as part of a cylindrical surface, the axis of which is the axis of the instrument at the pivot. The surface of the armature is then parallel to the axis of the instrument, and the end surfaces of the fixed coils are preferably arranged also to be parallel to this axis.

An interesting phenomenon which has been observed in connection with the arrangement shown in Figure 7 may be here mentioned. If the coils A and B are so connected that their fields have one and the same direction and are in phase with each other, the armature does not come to rest in some intermediate position of equilibrium as before. It swings toward the coil carrying the smaller current, and comes to lie entirely in the field of that coil with the pointer thrown against one end of the graduated scale. This condition is shown in Figure 8. The lines of force are represented as circles or crosses, depending on whether they are to be regarded as emerging from the plane of the paper or entering it. If the fields of the fixed coils are equal to each other, the resultant force *tending to produce rotation* of the armature is zero independently of the position of the latter. There will therefore be no definite position of rest, the movable armature being in what may be called a "floating" state. The above phenomenon is rendered quite explicable when one considers that, in Figure 8, coils A and B are in effect but a single coil; and that the motion of a conductor in an alternating magnetic field is toward regions of least magnetic force. A careful consideration of Figure 9, wherein the fields of the coils A and B are represented as in opposite phase, leads to the conclusion that we may have an equilibrium position in this case.

The occurrence of the phenomenon of "floating," which may take place even tho large currents are flowing in the armature, would render the instrument practically useless if no means were provided for avoiding it. For example, if we used such an instrument for measuring rapidly alternating currents, the indications would be quite unreliable because the "floating" is caused not by the relation between the absolute values of the currents, but by the relation between the phases of the fields.

Referring again to Figure 7, if the condenser H is made so small that its equivalent alternating current resistance is greater by a certain amount than that of the coil A, then the currents in the coils A and B will have a phase displacement of 180°. Whether the fields will have the same phase displacement as the currents depends on the sense in which the coils are wound, and on the way in which they are connected to the circuit the frequency of which is to be measured. The phase displacement between the fields can always be brought to 180° by simply interchanging the connections of one of the coils.

Experiments have shown that when the arrangement shown in Figure 7 is used to measure the frequency of damped alternating currents, as produced for example by spark discharges, the values obtained are very inaccurate (as compared with the true values of the wave lengths.) The cause of this inaccuracy is that an oscillating circuit is formed by the condenser H, the inductances A and B, and the inductance outside the instrument which serves for coupling purposes. In this circuit free oscillations are induced, these oscillations having in general a different frequency from that to be determined. Calibration of the instrument with sustained alternating current would therefore introduce a continuous error when measuring damped oscillations, the magnitude of this error increasing with the damping of the oscillations, and with the closeness of coupling of the instrument to the circuit of which the frequency is to be measured; since the frequency of the current in the instrument would be a function of the coupling to the exciting circuit.

In order to overcome the serious objection just mentioned, the free oscillations of the instrument are strongly damped. The instrument may even be made completely aperiodic. The damping of the instrument is accomplished by inserting an ohmic resistance in parallel or in series with the condenser, or by entirely dispensing with the condenser. For instance, if the condenser in

Figure 7 is replaced by a non-inductive resistance, the "free period" error is eliminated.

The insertion of this resistance is unfortunately accompanied by an energy loss. This disadvantage may become so great as to prevent the use of the instrument in radio telegraphy, where small energy losses are essential. For example, a wave meter which consumes 50 watts may be said to be unsuitable for such work since that amount of power would be quite sufficient for signalling over a distance of about 100 kilometers, and, as a loss, could be justified only in very exceptional cases.

The energy loss may be reduced by making the resistance to be inserted in the circuit of the coil A very small. The disadvantage which then arises is that the ratio of the currents flowing thru the fixed coils varies but slightly with the frequency, and the divisions on the scale corresponding to the various frequencies are excessively close. This crowded scale is overcome by the arrangement shown in Figure 10. Here a resistance K is arranged in series with the fixed coil A and a resistance L in parallel with the fixed coil B. Theory and experiment have shown that by these means a graduated scale with widely spaced divisions can be obtained, in spite of the fact that the energy consumption is substantially decreased. Another advantage of the arrangement of Figure 10 is that with suitable electrical constants the divisions of the graduated scale can be made substantially equal, so that the deflections are proportional to the wave lengths.

Considering the phase displacements of the fields in the case shown in Figure 10, it is impossible to obtain a displacement of 0° or 180°, the displacement lying between 0° and 90° or between 90° and 180°, without ever reaching the extreme limits. The "floating" effect previously referred to is observed in the arrangement of Figure 10 but to a smaller extent. It is advisable in consequence to lead the currents thru the fixed coils A and B in such a manner that the phase angle is as great as possible, that is to say between 90° and 180°. If, after this has been done the connections to one of the coils is reversed, it can be immediately noticed that the directive force is considerably reduced, and that the armature then tends to "float."

The "floating" phenomenon can occur only when the armature has a well defined circuit reaching into the fields of the fixed coils. A definite circuit is missing in the case shown in Figure 11. The armature being a semi-circular solid disc, each of the

Figure 10

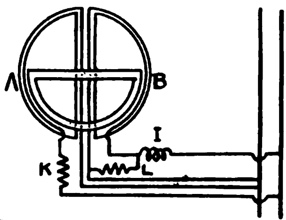


Figure 11

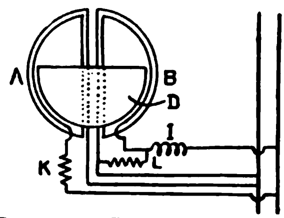


Figure 12

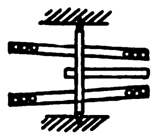


Figure 13

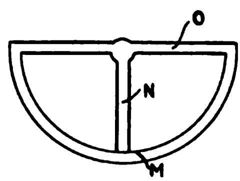


Figure 14

Figure 15

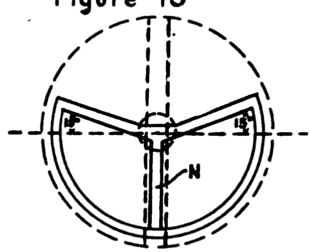


Figure 19

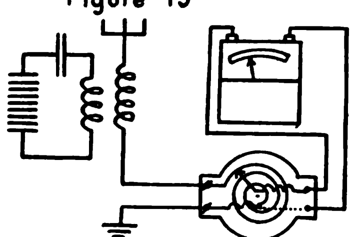
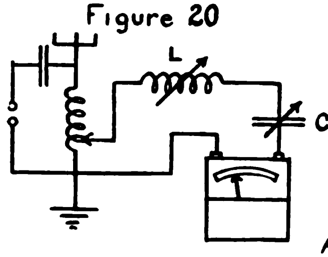


Figure 20



fixed coils will induce in it mainly separate currents. It will be readily seen, however, that this construction is disadvantageous for other reasons. The short-circuited eddy currents, induced by each of the coils, flow within each field radially toward the axis of the instrument and then back toward the periphery with nearly the same strength. The forces produced will nearly neutralize each other, and only a small difference will be left to rotate the armature. It may be stated that the use of a well defined circuit, which is as free as possible from eddy currents, and is under the influence of two fields alternating with a proper phase difference, has been found to be an essential requirement for the success of the instrument. It is further to be noted that if the instrument is constructed in this manner, at most a small current will flow thru the armature after it has reached its position of equilibrium. In the arrangement of Figure 7, no current whatever will flow thru the armature since the phase displacement may be made 180°; and in the arrangement of Figure 10, where this displacement cannot be attained, the armature current can still be made very small by the proper connection to the outside circuit of coils A and B.

In order to attain the requisite sensitiveness, the movable parts of this instrument must be made very light, and for this reason it is desirable to reduce the current in the armature as far as possible to avoid overheating.

To secure still greater sensitiveness and a still wider scale, the modified construction illustrated in Figure 12 is adopted. It will be seen that the fixed coils A and B are mounted slightly inclined to the surface of the armature D. The increased sensitiveness and wider range of the scale are due to the gradient of field intensity, and consequent directive force, found when using this disposition of parts. The condition of equilibrium is that the electromotive forces induced in the armature by the two coils shall be equal and opposite, consequently the angle of rotation will be greater when the field intensity of the coil toward which the armature moves is larger at the entering edge than when it is constant. The inclined coils therefore produce a greater variation in the deflection angle for a definite change in frequency than parallel coils.

To reduce the weight of the armature as far as possible, it has been constructed of sheets of aluminum 0.05 to 0.3 millimeters thick, and this range of thickness has been found satisfactory.

The disadvantage of the construction shown is that the part M (Figure 13) of the armature is easily bent. To avoid this weakness the sheet is formed with a rib, as shown on an enlarged scale in Figure 14, and an insulated reinforced arm N is connected between the parts O and M of the armature, as shown in Figure 13. Instead of using the rib construction, the sheet may be T-shaped, bent into tubular form, or otherwise suitably reinforced. The reinforcement of the armature is especially required in the case where the armature has a surface angularly greater than that of the fixed coils. (Such an increased angular surface increases the sensitiveness of the instrument. For instance if the surface of the armature is increased 15° on each side (as in Figure 15), the resistance in series with coil A can be reduced to half its former value without affecting the range of the scale.)

So far as the form of the fixed coils is concerned, it is advantageous to make them as flat as possible in order to bring the windings into close proximity with the armature. It is also preferable to divide each coil into two separate coils arranged one above the other with the armature lying between them, the separate coils being connected in parallel with each other, and not in series. Their arrangement in parallel prevents the production of high potential differences which might give rise to sparks jumping to the armature or from coil to coil. Moreover, this arrangement reduces the total reactance of the instrument and makes it possible to operate it with small potential differences. The connection of the instrument to existing installations is thereby considerably facilitated.

The wave meter is to be connected in the grounded side of the antenna or other circuit in which high potential differences exist. Experiment has shown that electrostatic forces will slightly influence the movable portion of the instrument; so that, in the absence of a ground connection the instrument should be connected to that point of the circuit where a potential node is found. The error which is produced in the wave meter readings by electrostatic forces may be avoided by exciting the instrument not directly, but inductively by means of a transformer.

A further error in the readings may be caused by the action of powerful exterior fields which pass thru the coils of the meter and alter the distribution of the lines of force. However in the case of radio frequency currents this error can be avoided by surounding the working parts of the instrument by a copper or aluminum casing; and in the case of low frequency currents preferably by the use of an iron casing.

The scale of the instrument may have more than one range of wave lengths, and the only change necessary in the electrical connections of the instrument in passing from one range to the others is a variation of the non-inductive resistance K of the instrument. This can be readily accomplished by a switch which short circuits a part of the resistance.

In the arrangements so far shown, the fixed coils A and B serve for two functions. Firstly, they induce in the movable armature D alternating currents. And secondly, they produce the turning force on the armature thru the interaction of their fields and the induced currents in the armature.

One can construct a modification of the instrument, wherein the two functions mentioned above are separately performed by individual coils. The coils A and B are semi-circular as before, and serve to induce currents in the armature. They do not, however, exert any appreciable mechanical force on the armature because certain portions R_1 and R_2 of the armature are considerably removed from the neighborhood of the coils. In addition extra coils X and Y are provided in close proximity to the portions R_1 and R_2 of the armature. These coils are intended to produce highly uniform fields, which fields will cause a torque on R_1 and R_2. Coils X and Y may be made semi-circular, but are preferably complete circles, for they will then induce no currents in the armature. Adopting such an arrangement, the energy consumed by the instrument is again substantially reduced and the sensitiveness increased, because the number of turns of the coils A and B may be considerably increased without in any way increasing the energy consumption. The coils of this instrument, when used for radio frequencies are preferably wound with "litzendraht" or multiply stranded wire.

A number of other applications of the constructions given may be mentioned. The instrument may be used as a relay or controlling device. In this case the pointer connected to the movable armature is arranged to press against fixed contacts whenever definite frequencies are reached. The points of the pivot being mounted in insulating bearings, special means of making contact are necessary. This may be accomplished by connecting a very fine and flexible wire to the pivot or by means of double contacts. The instrument may also be employed as a tachometer or indicating speed meter. It is merely necessary to connect its terminals to a small alternator which is belted or direct-connected to the rotating machinery, the speed of which is desired. The advantage of this instrument as compared to the usually employed voltmeter in tachometers is that the voltage of the alternator of the tachometer may drop considerably thru weakening of the *permanent* field magnets (which are usually used) thereby affecting the reading of the usual instrument. And there is no necessity of calibrating the instrument with the particular alternator to which it is to be connected as is the case when a voltmeter is used as the indicator.

It need hardly be said that in the form of meter used for measuring wave lengths in radio telegraphy no iron cores are employed in the coils. Great care is exercised in this instrument to minimise bearing friction and to balance the armature very carefully.

The portable model of the instrument is shown in Figure 16. The terminals of the instrument are seen on the top. To the right is the switch which, by short circuiting a portion of the resistance permits the use of either the upper or lower scale. The upper scale runs from 150 to 1,500 meters, each division being 10 meters and the lower scale from 500 to 3,000 meters, each division corresponding to 100 meters. Directly above the scales is seen an indicating lamp which serves the following purpose. Theoretically the indications of the wave meter are independent of the current flowing, but in practise it is necessary to keep the current between certain major and minor limits. The objections to a very small current thru the instrument are that there will be no certainty that the friction in the pivots exerts no effect on the reading, that slight unbalancing of the armature is not rendered negligible in its effect, and that the slow motion of the pointer to its final position under the action of small currents makes the reading uncertain. To readily ascertain that the current flowing thru the meter has a correct value, the small indicating tungsten lamp above the scale is watched. This lamp is chosen so that the slightest dark red glow indicates the minimum allowable current, and a bright white light the maximum permissible current. It is not important that any particular degree of brightness be obtained, but in order to obtain long life for the lamp it is desirable to work nearer the lower current limit.

As will be seen from the theory of the instrument, its indications are reliable only when there are alternating currents of a *single* frequency in the exciting circuit. If there are currents of

Figure 16

Seibt Direct Reading Wavemeter—1912 Portable Model

Range { Scale I—300—1500 M
" II—500—3000 M

Figure 17

two or more frequencies present, unless the amplitude of all but one of them are negligibly small, the arrangement shown in Figure 19 must be used. The wave meter is here connected in the resonance circuit L C which is tuned until the lamp brilliancy is a maximum. Two positions where this is the case will be found in an ordinary closely coupled spark set, and the readings of the meter at each of these positions gives the wave length of each of the "coupling" waves. Such an arrangement is naturally unnecessary in the case of quenched spark sets where but a single frequency should be present.

The energy consumed by the form of wave meter shown in the photograph is about 4 watts on the short wave length scale, and about 1 watt on the long wave length scale. A switchboard type of the instrument having the same electrical constants is also constructed. For work covering wide ranges of wave length, the instrument may be built with a scale covering from 800 to 4,500 meters in steps of 100 meters. The even spacing of the scale divisions is seen on Figure 16.

As previously mentioned, the instrument is to be connected in the ground connection of the station. The meter is constructed for currents not exceeding three amperes, and it is usually necessary to connect a purely inductive shunt in parallel with the instrument or else to use a current transformer. Since the amount of inductance required in the shunt is dependent on the current flowing in the antenna circuit, it is always best for a first trial reading to use a very small value of the inductance as a shunt. If no glow occurs in the indicating lamp, the current may be increased by increasing the inductance of the shunt and the process continued until a moderate glowing of the lamp is obtained.

Realizing that this process might be somewhat troublesome in practical work, a specially designed current transformer has been devised which, if properly employed, obviates all risk of burning out the wave meter but still permits of rapid manipulation. The transformer is shown in Figure 18, and the means of connecting it in circuit in Figure 19. The entire ring is connected in series with the antenna at the grounded end and the wave meter is connected to a separate pair of terminals, the inductance across which is adjustable. Because of variations in the antenna current such an adjustment is desirable. These inductive couplers for the wave meter are made in two sizes, and the type used depends on the output of the set with which the wave meter is to be used. The smaller coupler is for antenna currents of 3 to 30 amperes and is suitable for 2 and 5 kilowatt sets. The larger coupler is intended for use where the antenna current lies between 20 and 100 amperes, and is therefore appropriate for 10 to 50 kilowatt sets.

The advantages of this type of wave meter may be shortly recapitulated: Direct indication of the wave length by a needle moving over a calibrated scale, freedom from adjustment to resonance (unless two waves are present), rapidity of manipulation and reading, readings independent of irregularities in action of spark gap or arc, readings independent of current thru instrument between wide limits, self-contained, light, and rugged construction, long scale, with *even* divisions, long wave length range with high accuracy by use of two scales on the same instrument.

The instrument weighs 5 lbs. (or 2.3 kilograms).

Its dimensions are 9″ by 8″ by 3⅝″ (or 23 cm. by 21 cm. by 9 cm.).

SUMMARY: A direct indicating wave meter depending for its action on the balancing of the repulsive forces exerted by two fixed coils on a movable ring armature is described. Circuit arrangements are shown whereby the division of current between the coils is made dependent only on the frequency. Electrical and mechanical means for increasing the sensitiveness of the instrument, diminishing its energy absorption, obtaining an even wave length scale, and eliminating the so-called "floating effect" are described in detail. Other industrial applications of the instrument are given.

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DISCUSSION.

LEE DE FOREST: Are the indications of this wave meter independent of the applied electromotive force? The currents thru each of the branches must depend on the electromotive force.

EMIL J. SIMON: Dr. Seibt states that theory and practise agree in the conclusion that within certain limits (indicated very well by the glowing of the lamp in the meter) the readings are independent of the applied electromotive force. However, I have found that the readings may be as much as 5% off if the lamp does not light owing to too loose coupling to the oscillating circuits.

ALFRED N. GOLDSMITH: The reason for this is obviously that sufficiently strong repelling forces are required to render friction at the pivots and air friction negligible in comparison with these forces. Otherwise even a correct choice of the inductances and resistances of the two deflection-controlling circuits will not ensure a correct equilibrium position of the moving system, and one dependent only on the applied frequency.

EMIL J. SIMON: It is found that varying the current thru the instrument between limits of about one-half to three amperes causes no change in the reading provided the frequency is kept strictly constant.

LEE DE FOREST: What are the dimensions of the fixed coils?

EMIL J. SIMON: They are about 5 or 6 cm. (2 inches) in diameter.

LEE DE FOREST: Is the fixed reactance arranged so that its field is far from the armature?

EMIL J. SIMON: The fixed reactance is placed as far away as possible from the armature and at right angles.

LEE DE FOREST: Which of the binding posts is grounded?

EMIL J. SIMON: In practise we use the right-hand post. It is probably connected to the metal lining of the case.

LEE DE FOREST: It would appear as tho Dr. Seibt had tried the resonance type of indicating wave meter first, but unsuccessfully. As regards novelty of the device, he cannot be said to have adopted the frequency meter construction (of the Weston company, for example).

The resonance principle could be applied by placing a light condenser in jewelled bearings in series with an inductance. It would assume the resonance position. Such a device might work up to 100 meters wave length.

ALFRED N. GOLDSMITH: The resonance principle can be applied much more simply, as in the Hirsch direct reading wave meter, made in Berlin by Dr. Erich Huth. It consists, in brief, of a fixed inductance connected to a rotary variable condenser, the variable condenser being kept in continuous rotation by a small motor. Connected across the terminals of the condenser is a small vacuum discharge tube, which is arranged as a pointer of the variable condenser, and rotates with it. It lights up at the resonance position provided the inductance of the circuit is sufficiently closely coupled to the exciting circuit; and, owing to the effect of persistence of vision, a bright line of light is seen at a certain point of the condenser scale. The condenser scale is graduated in wave lengths. The advantage of this arrangement is that it uses even less energy than the Seibt meter, that the damping of the wave meter circuit is low because the tube is of very high resistance except when it glows at the resonance position, that the damping of the exciting circuit is roughly indicated by the width of the indicating line of light, and that both wave lengths of closely coupled transmitters can be determined, and examined for relative intensities.

H. E. HALLBORG: Such a device might be made in a hand-operated form where it was desired to use it only intermittently.

JOHN L. HOGAN, JR.: Is the wave length indication of the Seibt meter dependent on the damping of the exciting circuit?

EMIL J. SIMON: This point has not been accurately checked, tho measurements on circuits having widely different dampings have been successfully made. It is believed that the indication is entirely independent of the decrement of the exciting circuit.

H. E. HALLBORG: Is connection to the transmitter made thru a fixed coil in the transmitter circuit?

EMIL J. SIMON: The coupling to the transmitter circuit may be either direct or inductive. Seibt uses a 3 turn spiral of 3,000 cm. inductance with a variable contact as an auto transformer. Those so far constructed are usable up to thirty amperes in the transmitter circuit.

ROY A. WEAGANT: Does this wave meter stand continuous service?

EMIL J. SIMON: After using the instrument for two or three hours continuously, no change in the reading was noted.

ROY A. WEAGANT: What is the over-all accuracy of the instrument?

EMIL J. SIMON: Dr. Austin found an average accuracy thru the entire scale from 200 to 3,000 meters of 1%. The meter certainly does not stand excessively rough treatment. Readings should be taken in the horizontal position. Such readings differ by 1 to 2 per cent from those taken in the vertical position.

The upper scale of the meter reads from 150 to 1,500 meters, the lower scale from 500 to 3,000 meters.

It was found that the instrument was not affected by the vibrations in an aeroplane. The only difficulty in using it in a strange station is that it is not known how closely to couple, and there is danger of burning out the indicating lamp.

Dr. Seibt is at present designing a switchboard type of this instrument. I have not found that low frequency fields affected this instrument. Radio frequency fields might. It must be remembered that there is no iron in the meter.

ROY A. WEAGANT: Might not a neighboring transmitting inductance affect the readings?

EMIL J. SIMON: I presume that would depend on the field intensity of the coil in question. The effect is probably small, because the internal field is concentrated, and the instrument shielded by an aluminum lining inside the case.

LEE DE FOREST: The stray field would be the same for both of the deflecting coils of the wave meter, and hence the effects would tend to compensate.

EMIL J. SIMON: The first U. S. patent application was filed in November, 1911, in the United States. The German application was filed six months previous to that.

A. E. KENNELLY (by letter): The application of the principle of the repulsion, exerted between an alternating current-carrying coil and a closed loop, to wave-length indication, by the differential action of two circuits of different impedances, is very ingenious, and must have required much experiment to develop. The great advantages of such a wave-length meter are its direct-reading property, and its swiftness of indication; whereby the judgment of a trained observer is rendered unnecessary.

In the case of a two-phase motor device, operated by phase-splitting branch circuits from single-phase mains, the purpose is to split the phases to as nearly 90° apart as possible, with the minimum difference between the two branch current strengths. In this wave-length measuring device, the purpose is to split the currents in the two branch circuits, and make the splitting ratio depend sensitively on the frequency in the main circuit. These branch circuits may be called ratio-splitting branch circuits.

THE HIGH POWER TELEFUNKEN RADIO STATION AT SAYVILLE, LONG ISLAND.

By FRITZ VAN DER WOUDE, Engineer of the Telefunken Company, and ALFRED E. SEELIG, Manager of the Atlantic Communication Company.

INTRODUCTORY.

As indicated by the title of the paper, we shall not concern ourselves in this article with any theory of the transmission of electric waves thru the ether, excepting where the occasion may specially demand. We shall confine ourselves to a description of a commercial radio station, recently built for long distance communication, and fairly representing a modern high power "wireless" station of the Telefunken type.

THE TOWER.

Near the South Shore of Long Island about half way between New York and Montauk Point, at the little town of Sayville, a piece of land covering about 100 acres was purchased. Here a steel tower 150 meters (about 500 feet) in height has been erected to support the antenna or aerial wire system, of the dimensions required for the radiation of the electrical energy. As this tower is quite interesting in its construction, and as the design has become closely identified with Telefunken radio stations, a short description will not be amiss.

Given the problem: To erect a steel tower of great height, whose one function shall simply be to support a few antenna wires at a minimum of material and cost.

The Sayville tower is of a type which the Telefunken Company has found to be the best answer to this problem, and one which is coming to be widely recognized as the most satisfactory solution. From Figure 1, it will be noted that instead of using the customary large polygonal support, sometimes referred to as the "Eiffel Tower Type," the base of the Sayville tower is brought to what is practically a point—or rather a ball and socket joint at the bottom. The tower is therefore not self-supporting and depends entirely on its guys for maintaining it in its upright position. The joint at the base, however, gives great flexibility for resisting wind pressure. This pressure, of course, is the main load, and as the majority of radio stations are erected near the coast, wind velocities of 90 to 100 miles an hour must be reckoned with.

For towers more than about 120 meters in height it has in fact been found advisable to put another joint into the structure, and in the figure there will be observed such a second point, or node of vibration about three-quarters of the way up the tower. There is then a small super-tower which rests on the main lower structure. Both towers are triangular in section, the triangular shape resulting in a further saving of material as no cross bracing is required.

GUY ANCHORAGE AND INSULATION.

The insulation of the tower from ground is effected by a large glass insulator upon which rests the entire weight of the tower. Six large concrete and brick anchorages, one of which is shown in Figure 2, are distributed in two sets of three, spaced 120° apart on circles. The circles are of 235 feet (73 meters) and 430 feet (130 meters) radius, measured from the base of the tower. From each anchorage two guys, each consisting of linked steel rods run to the tower. Heavy glass insulators, which have been specially developed for this class of duty, electrically separate each guy from ground.

THE ANTENNAE AND COUNTERPOISE.

The main antenna is of the umbrella type, and consists of twelve wires radiating from the top of the tower in two segments of six wires, each segment covering an arc of about 120°.

The ends of each antenna wire are connected thru large bell-shaped insulators to steel wire ropes. These ropes are attached to the tower at the top and at the lower end to wooden poles about 30 feet (9 meters) high.

These wooden poles form a circle of approximately 2,300 feet (700 meters) diameter. Each antenna wire has only about one-third of the total length of the line from the top of the tower to the outer pole end. The long stretches of steel rope are

Figure 1

Figure 2

Figure 3

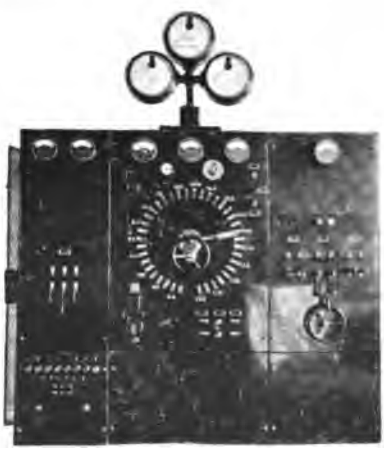

Figure 4

furthermore each subdivided into about six sections, which are joined thru porcelain insulators of the so-called "egg" type. This careful insulation of the antenna is of even greater importance than in the construction of a high tension power transmission line, for in the antenna leakage means not only a loss of considerable energy but also a change in the constants of the secondary or antenna circuit and in the damping of the radiated waves.

The antenna wires are of hard drawn copper, as are also the vertical leads connecting the upper end of each element to the main junction point near the base of the tower, from which point the antenna circuit is led into the station building. A special form of leading-in insulator is used where the antenna is brought thru the building wall.

The Sayville antenna has a capacity of approximately 10,000 cm., and a natural wave length of 1,800 meters.

As ground water is not conveniently available at all times, a counterpoise ground consisting of 56 wires, about 5 meters (16 feet) above the ground, radiating from a center and covering a complete circle was erected as the most satisfactory way of earthing the considerable amount of antenna current.

The antenna, the counterpoise, and the tower itself are each connected to earth thru a lightning switch provided with safety air gaps, for use in lightning storms or severe atmospheric disturbances.

We consider next the transmitting apparatus, and, beginning with the source of energy, pass thru the station.

THE POWER SOURCE.

The 2,300 volt lines of the Long Island Lighting Company, part of a three-phase 60 cycle system, comprising several power stations so joined as to make current available at all times with practical certainty, are tapped at the boundary of the station grounds and stepped down to 440 volts in a small transformer house. From this point the current is led thru an underground conduit into the station building, there operating the main motor-generator charging set. This set, which was made by the General Electric Company, is shown in Figure 3, to the right. It consists of an induction motor driving a 220-volt D. C. generator, which in turn charges a 600 ampere-hour storage battery. From this battery, the entire station apparatus draws its current.

Primarily the battery current is used to feed the two 500 cycle motor-generator sets. The high power set is driven by a 75 H. P. motor (Type 35 T. K.), and the smaller set has a motor of approximately 15 H. P. (Type 5 T. K.).* The smaller set has been used for regular ship and shore communication and as a reserve for the larger outfit, which it resembles closely in principle.

The switchboard in the generator room carries the end-cell switch for the storage battery and also the main feeder switches. The end-cell switch is shown in the upper portion of the central panel of the switchboard. (Figure 4.) A small control room is situated between the generator room and the transmitting room. It is shown in Figure 5. The partition walls of the control room are practically large windows, one on each side, so that the electrician in charge, who, from this point controls the entire apparatus, is enabled to see both the generating and transmitting equipment at all times.

Moreover, a system of small signal lamps as well as a speaking tube and call gong serve to maintain communication between the control and operating rooms.

TRANSMITTING EQUIPMENT.

The 60 K. V. A. 500 cycle single phase generator of the high power set feeds the main transformer, which raises the voltage to about 60,000. A simple hand and solenoid switching device placed between the generator and the transformer, when opened, disconnects the transformer and the entire transmitting apparatus without stopping the generator or reducing its field. Thus a single throw of this switch renders the entire transmitting system instantly accessible for any quick repairs or adjusments; without danger and with a minimum loss of time (which latter consideration may be of great importance in the midst of telegrapn service).

The high voltage secondary of the transformer feeds the primary oscillating circuit thru a series choke coil which protects the transformer against excessive voltage due to surges.

The capacity of the primary circuit is made up of Leyden jars totalling 40,000 cm., that is, 0.044 μf. They are of the

*The term "T. K." is used by the Telefunken Company to designate actual kilowatts output, measured in the antenna. (Editor.)

Figure 5

Figure 6

Figure 7

familiar Telefunken type, long and narrow, with tin foil coverings on glass 0.25 inch (0.6 cm.) thick.

The charged condenser in this circuit discharges itself thru a series of quenched spark gaps. Figure 6 shows the gaps and jars, as well as a smaller set to the right. The gaps are held in eight frames, arranged on a stand. A motor driven blower is provided for cooling the gaps. Each frame or set has 13 gaps, and the distance between plates of each gap is about 0.1 to 0.2 mm. The well-known quenching effect is thereby produced. Any frame can be easily disconnected and lifted out of the stand, and any plate quickly removed from its frame, whenever inspection or repair is desired. The plates now generally used are of the ribbed type, having four or five concentric circular ribs. This type of gap was found to give better results than the smooth type.

The gap completes our primary circuit, the inductance of which is coupled in part conductively and in part inductively with the inductance of the secondary or antenna circuit. These two circuits, primary and secondary, must of course be in resonance (or nearly so). As the clearness of the tone, as well as the efficiency of transfer of energy, depend on the value of the coupling, the closeness of coupling is made variable, one of the coils being moved nearer to or further away from the other. The adjustment of coupling is operated directly from the control room, where a hand wheel connects thru a system of sprockets, chains, and levers to the movable coils which are raised or lowered as desired.

RELAYS.

As the large amount of current in the transformer primary circuit cannot be broken directly by a telegraph key, a relay system must be provided.

At Sayville the current is controlled in steps by a system of three relays. The main relay, which breaks the full current, is installed in duplicate so that either one of those provided can be used by simply switching over to it. Each of the main relays has eight contacts, which are cooled by an ordinary electric fan. The 220 volt battery current is used thruout to energise the coils of relays or other automatic control devices.

ANTENNA SWITCH.

One other piece of apparatus in the transmitting room is of considerable interest. This is the automatic antenna switch, operated by a small motor thru a solenoid switch, which in turn is controlled by a foot-pad contact in the operators' or receiving room. This switch is clearly shown in Figure 7. Each successive pressure of the operator's foot alternately switches the antenna from the receiving to the transmitting circuit and vica versa.

The same foot-pad alternately starts and stops the blower used for cooling the quenched spark gaps. In fact, the special conditions in Sayville require a very large number of functions to be performed at each switch-over. Thus in addition to what has just been outlined, the following must be provided for automatically:

1. When connected for receiving, it must be impossible for the operator to produce a spark discharge by closing his key—as he might easily do accidentally.

2. If the small set is working, the high power apparatus must be entirely disconnected (without necessarily stopping the generator) and vica versa.

3. The procedure in changing over from receiving to sending must be:

   (a) To disconnect the receiver.
   (b) To transfer the antenna connection from receiver to transmitter.
   (c) To close the relay contacts which are on the transformer supply circuit.

Then these steps must be reversed in switching from transmitting to receiving.

It is interesting to note that in order to perform all these functions successfully it was necessary to lay about a hundred wires between the two rooms.

OPERATING ROOM.

Separated from the rest of the station by sound-proof walls and double doors, and close to the land line telegraph room is the operating room. The telegraph room serves as the collecting and distributing link for the traffic. In the operating room the receiving apparatus and the transmitting keys are conveniently mounted on tables arranged somewhat like large, flat-top desks. In order to avoid possible confusion of the operator, all the apparatus handled, such as keys, switches, levers, knobs and plugs have been painted either red or white according as they are part of the high power set or of the smaller set for the local ship and shore work. In this way the operator immediately knows whether he is handling the particular set desired even tho the various parts, as for example the transmitting keys of the two sets, may be very similar in appearance and placed side by side.

RECEIVING APPARATUS.

The receivers are of the familiar Telefunken upright type, serving for a wide range of wave lengths and therefore available for all classes of service. Diplex reception (of two simultaneous messages) is easily accomplished by a simple device which alternately connects first one and then the other receiver to the antenna at a high frequency; so that each receiver is in circuit three or four times during the lapse of time required for a Morse signal. With the aid of this device and careful tuning we have had no difficulty in receiving simultaneously three messages, one on a long wave length, and two on shorter waves. In fact, there is no reason why, with the equipment at Sayville, it should not be possible to receive six messages simultaneously, if proper care is taken in the choice of wave lengths and in tuning.

SOUND INTENSIFIER.

In the receiving room is another ingenious device that has been identified with the Telefunken system—namely the sound intensifier. It is visible in the background of Figure 9. Without going into the details of its construction, it will suffice to state that this apparatus depends on the principle of acoustic resonance. If the incoming signals have an acoustic pitch of one thousand cycles per second, there will be one thousand current impulses per second from the detector circuit acting on the membrane of a combined telephone receiver and microphone transmitter in the

Figure 8

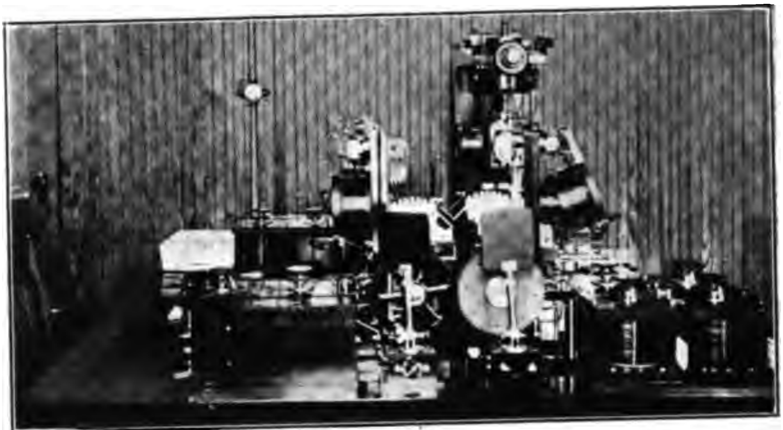

Figure 9

Figure 10

sound intensifier, thus producing in turn a thousand stronger impulses in another circuit. In the latter circuit is a local battery and another combined receiver and microphone. By stepping the current up thru a series of such circuits, a detector current of 10^{-7} or 10^{-8} ampere can be increased to one of 10^{-2} ampere or more. This not only produces sounds distinctly audible at considerable distances, but is capable of operating a Morse recorder in addition, if desirable.

Furthermore, as the sound intensifier responds only to impulses of a given frequency, thereby adding the effect of acoustic resonance to the radio frequency resonance of the receiving circuits, a very high degree of selectivity is obtained.

AUTOMATIC TRANSMISSION.

In connection with the transmission of long messages such as are encountered in press work, it is usually desirable to make the procedure as nearly automatic as possible. For this purpose Sayville is provided with an automatic transmitter consisting essentially of two pieces of apparatus:

1. The perforator ,in which a paper strip is unrolled at any desired speed and punctured by small holes; the separation between the holes representing either the dots or dashes produced by an ordinary telegraph key. Figure 10 gives a view of this apparatus.

2. The automatic transmitter. The punched tape is then run thru the automatic transmitter at any desired speed, the holes in paper controlling spring contacts, which open and close the transmitting circuit. Thus the rate of punching or preparing the tape, and the final rate of transmission are entirely independent of each other.

TONE CONTROLLER.

This simple device for indicating the number of spark discharges per second remains to be described. It is a miniature receiving circuit placed in the immediate proximity of the transmitter, and having as its discharge gap a small Geissler (helium) tube mounted on a rotating disc. This disc is driven by a small motor at constant speed. If the spark discharges have a constant frequency, and if their number is a simple multiple of the revolutions per second of the disc, the rotating tube will appear as a stationary illuminated star. The number of sparks per second is equal to the product of the number of revolutions per second of the tube and the number of arms or rays in the star. Moreover, the width of each illuminated area, or broadness of each ray of the star, is proportional to the length of time during which the discharge voltage is equal to or above a certain value, and therefore is an indication of the amount of damping. Thus a highly antenna current will produce very thin rays.

DISTANCE RANGE.

Thoro tests of the range of the Sayville station have not yet been made. However, the daily press message, sent out each evening at about 9 o'clock has been distinctly received by vessels at Gibraltar and in the English Channel, i. e., at distances of 3,000 to 3,500 miles.

DISCUSSION.

CHARLES A. LE QUESNE, JR.: Do the vertical antenna leads consist of a vertical wire connected to each antenna wire?

A. E. SEELIG: Each antenna wire has a separate vertical lead. But an arrangement whereby each group of antenna wires was connected to one large vertical lead would not differ electrically to any great extent from that used.

HAROLD R. ZEAMANS: What was the maximum range attained by the station?

A. E. SEELIG: From Sayville to Gibraltar, that is, 3,200 miles.

JOHN L. HOGAN, JR.: Was that a day message?

A. E. SEELIG: This was press message sent at night.

JOHN L. HOGAN, JR.: May I ask how early the ball and socket joint at the base of the antenna was used by the Telefunken company?

A. E. SEELIG: Since 1904. More than twenty such towers are in use.

H. E. HALLBORG: What protective devices are used on the meters and generators?

A. E. SEELIG: Outside of the usual fuses, no protective devices are used. I may mention that all the wiring is in iron conduit.

FRANK FAY: What lightning protective device is used?

A. E. SEELIG: There is a large lightning switch provided. The receiver is also protected by a vacuum gap.

JOHN L. HOGAN, JR.: The diplex system used involves a rapid change from one set to another. Will there not be a click in the receiver each time the change is made due to the atmospheric charging of the antenna?

A. E. SEELIG: Such an effect is not found in practise. The musical tone is somewhat altered. It must be remembered that time of change is short while the time of contact is long with the arrangement used.

H. E. HALLBORG: Have you used the Einthoven galvanometer in receiving?

A. E. SEELIG: We do not send rapidly enough generally to justify the use of the galvanometer.

FRANK FAY: How many words per minute can you send with your automatic key?

A. E. SEELIG: The key is of such construction that we can send more rapidly than any operator could receive.

H. E. HALLBORG: Is the telephone receiver used, or the "tone amplifier" with recording device?

A. E. SEELIG: We have each of them in our equipment. Which is used depends on the type of service and the convenience of the operator.

H. E. HALLBORG: What is the capacity of each jar?

A. E. SEELIG: About 10,000 cm. (0.011 μf.) The jars are arranged in five groups, partly in series and partly in parallel.

EMIL J. SIMON: How many gaps are used in series, and how many kilowatts are drawn from the transformer?

A. E. SEELIG: There are 40 or 50 gaps in series. About 40 kilowatts are drawn by the transformer.

ROY A. WEAGANT: What is the antenna current?

A. E. SEELIG: About 120 amperes.

EMIL J. SIMON: Have you measured the current in the closed circuit?

A. E. SEELIG: No.

LESTER ISRAEL: What is the radiation resistance of the antenna?

A. E. SEELIG: At a wave length of 3,000 meters, it is about 3 ohms. We put 30 to 35 kilowatts into the antenna. The efficiency is 75 to 80 per cent from the generator to the antenna. The motor is one of 75 H. P., but is used at a constant load of 50 kilowatts.

EMIL J. SIMON: The efficiency of the motor-generator is 80 per cent?

A. E. SEELIG: That is its value. The generator is of the special inductor type developed at Nauen for this type of service.

H. E. HALLBORG: How is the proper leakage in the high tension transformer obtained?

A. E. SEELIG: It is a closed core transformer in series with which is a choke or inductance coil.

ROY A. WEAGANT: What are the open and closed circuit voltage of the generator:

A. E. SEELIG: They are 600 and 350 volts respectively.

EMIL J. SIMON: What is the generator current at full load?

A. E. SEELIG: The power factor is 0.8. Hence you can calculate the current from the voltage values and kilowatt output.

THE DAYLIGHT EFFECT IN RADIO TELEGRAPHY.

By A. E. Kennelly.

(Professor of Electrical Engineering, Harvard University.)

It is now generally admitted that the range of radio-transmission of signals is materially influenced by solar radiation; not only in regard to false signals or "X's"; but also in regard to the attenuation of the transmitted electro-magnetic waves.

This attenuating influence of solar radiation on the transmitted waves ordinarily consists of (1) a nearly steady action during the daytime, together with (2) certain marked disturbances occurring near sunrise, or sunset, or both.

In regard to the first or steady effect, we may consider that during the day, whatever the weather may be; i. e., the conditions of wind, temperature, pressure, cloudiness or precipitation in the first few kilometers of air nearest to the ground surface, the sun's rays are steadily falling upon the upper layers of the air; where the air density is relatively very low. It is known from physical laboratory experiments, that ultra-violet light, passing thru attenuated air, ionises it; or decomposes electrically neutral air molecules into positive and negative constituents, the energy of decomposition being absorbed from the radiation. If the ultra-violet radiation is then withdrawn, these constitutents attract each other and recombine, perhaps converting the energy of recombinaion into heat energy or molecular oscillations. For a given intensity of received radiation of assigned wave-length in the ultra-violet region of the spectrum, we may suppose that there exists, in the final state, a certain corresponding number of free electrons per unit of air-volume. It is also reasonable to consider that after the ultra-violet rays in the sunlight have penetrated deeply into the air, they become: (1) scattered and diffusely reflected by the air-molecules, thereby giving us the blue color of the clear sky, and (2) absorbed in decomposition and ionisation of the air-molecules. Consequently, but little ultra-violet light from the sun reaches the ground, after passing thru the atmosphere. The solar spectrum at the ground, or ocean level, may be considered as terminating near to and only a little beyond, the violet, when the sun's rays fall perpendicularly as at the tropical noon-day. At morning or evening, when the sun's rays pass aslant thru much greater distances of air before reaching the ground, the violet, and even the blue rays largely disappear, leaving a predominance of red in the light that remains, and thus producing the ruddy hues of dawn or evening landscapes.

If the upper regions of the atmosphere are appreciably ionised by full and sustained solar radiation during daylight hours, we may consider that these regions are thereby rendered partially conducting. That is to say, instead of being a perfect insulator, like free space or un-ionised air, ionised air has a certain small conductivity. This would involve a loss of energy in any electromagnetic waves traversing it, which, in turn, would involve additional attenuation of such waves. Moreover, if the ionisation-conductivity were not uniform but developed in clouds or patches, there would be scattering as well as absorption of energy.

It seems therefore possible to explain the weakening effect of broad sunlight upon radio-transmission signals by attributing conductivity, distributed either uniformly or non-uniformly thru the sunlit upper atmosphere, where the ultra-violet waves are likely to be more intense than in the region near the ground. We have no direct evidence, however, as to whether such ionisation-conductivity is quantitatively sufficient to account for the observed effects. It has been pointed out by Zenneck that the observed conductivity of air near the earth's surface for continuous current is far too small to account for the effects in question; but we have no experimental evidence as to what the conductivity may be at high atmospheric levels to alternating electric intensities.

If we assume, for simplicity, a tropical sun sending its rays perpendicularly down thru normally distributed air towards the earth, the degree of ionisation should be uniform over any surface situated at a uniform level. That is, the ultra-violet radiation would be most intense at a great height, and gradually weaken by absorption as it penetrated downwards. On the other hand, the number of air molecules per c.c.; i. e., the air density, would be relatively very small at a great height, and would increase exponentially with the downward penetration. In any one horizontal layer of air, the number of free ions might be assumed uniform.

Commencing, say, at zero, with sufficient height; it might increase to a maximum at a moderate height, and then dwindle down to a minimum near the earth's surface. If the sunlight ionisation, instead of varying gradually in this way terminated suddenly, so that, at some particular elevation a bounding surface formed with non-conducting air on one side, and conducting air on the other; then this boundary surface might be expected to develop strong reflecting properties, on the principle that wave disturbances are subject to reflection at surfaces of discontinuity. Thus clouds, or diffused masses of water vapor, reflect both sound and light. A travelling compression wave, or sound wave in air, reflects light. Any change in a medium for wave transmission, occurring at a surface, is known to set up a reflection. If the change is sudden and well-marked, so that the bounding surface is sharp, the reflection will be definite and powerful. If the change is gradual, and by easy transition; so that the bounding surface is not clearly defined, the reflection will be diffusely scattered and weak.

Consequently, if the ionisation of the air developed a sharp transition layer, or succession of layers, we might expect reflection to occur at and from such layers, with a lessening of attenuation; whereas, if the ionisation were gradually varying from layer to layer, with no clearly marked transition, there would be mere dissipation of energy by conduction or scattering without any gain by reflection, thereby increasing the attenuation.

It was pointed out by Dr. J. J. Thomson [1] that rarefied air at a pressure of 0.01 mm. of mercury in a glass chamber devoid of metallic electrodes, conducts electricity in the laboratory as well as an aqueous solution of sulfuric acid. At an elevation of about 70 km. (43.5 miles) above the sea level, and a uniform temperature of -60° C., such an air density may be expected to exist. If this free rarefied air conducts electricity in response to the feeble electric intensities of radio telegraphy, as well as it does in vacuum tubes to the more powerful intensities used in the laboratory; then, whether the sun is shining on this or not, we should expect a conductivity in it of the same order of magnitude as in ocean water. If such a conducting layer developed suddenly at a certain elevation, so that a definite bounding surface separated the conducting air above from non-conducting air be-

(1) J. J. Thomson, "Recent Researches in Electricity and Magnetism," 1893, page 101.

low, we should expect that surface to behave electrically like an inverted sea. Electro-magnetic waves, reaching this surface from below, would not penetrate it appreciably, but would be reflectively guided over it, as they are guided over the salt-water ocean below, and the waves would then spread over the surface of the globe in two dimensions only, like the growth of a stone-throw ripple in a pond, instead of in three dimensions, like the growth of a soap bubble. This would much reduce the natural three-dimensional attenuation, and increase the intensity of signals received at long distances. It has been suggested that some of the abnormally long signalling ranges occassionally reached at night may be due to the presence of such a reflecting layer (2). If, on the other hand, the conducting layer exists, but is not sharply defined, the conductivity gradually increasing to a maximum as we approach from above or below, we might expect marked conductive dissipation with little or no reflection; so that long-distance signals might be weakened instead of strengthened, owing to the presence of the conducting layer.

Whatever the facts may be concerning the action of the air near the 70 km. level, it seems likely that, during full daylight, the solar ionisation cannot develop any sharp transition layers or reflecting boundaries in the atmosphere. That is, the daylight effect should tend to increase the attenuation of electromagnetic waves.

In order to form a definite conception of the relations between air-pressure and elevation above the sea, Figure 1 has been prepared on certain assumptions; namely, that the temperature of the air is uniformly -35° C. for the sea-level up to a height of 12 miles or 19.3 km. where the observed air-pressure is (3) 1⅞ inches (4.76 cm., or 0.0625 of normal sea level pressure). Up to this level, the "height of the homogeneous atmosphere" (4) is taken as 7 km. Above this level, the temperature has been assumed constant at -60° C. and the height of the homogeneous atmosphere uniform at 6.23 km. No correction has been made for changing chemical composition of the atmosphere at different elevations. (5) Thus premised, Figure 1 indicates that at the ele-

(2) "On the Elevation of the Electrically-Conducting Strata of the Earth's Atmosphere," by A. E. Kennelly, Electrical World and Engineer, Vol. 39, No. 11, March 15th, 1902, page 473.

(3) A. L. Rotch, "The Conquest of the Air," New York, 1909.

(4) J. Clerk Maxwell, "Theory of Heat," London, 1875.

(5) W J. Humphreys, "On the Physics of the Atmosphere," Jour. Franklin Inst., March, 1913.

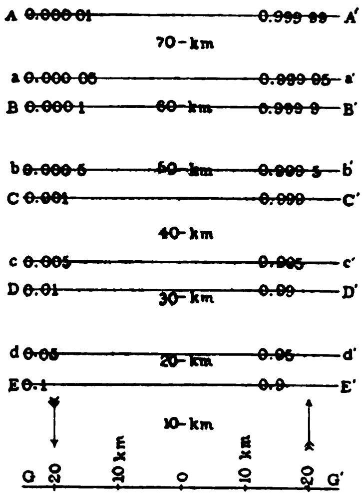

Figure 1. Air-Density and Penetration at Different Atmospheric Levels. Sun's Rays Vertical

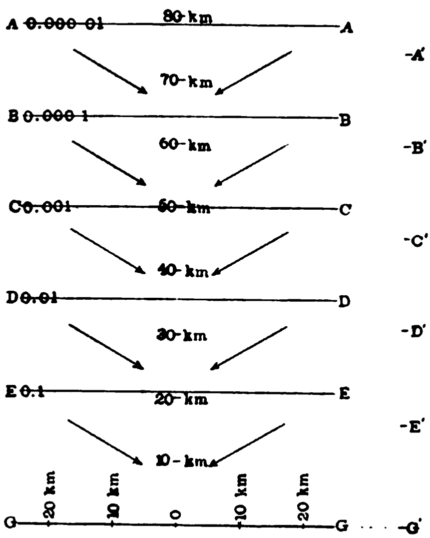

Figure 2. Penetration of Inclined Solar Rays at Different Atmospheric Levels

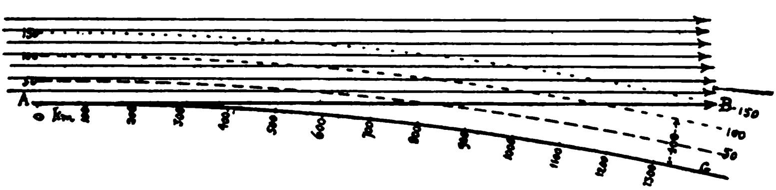

Figure 3. Diagram representing the Surface of the Globe with Three Atmospheric Levels 50, 100 and 150 Km. above the sea. Rays of Sunlight following Parallel Straight Lines are Tangential to the Globe at A and are Penetrating the Atmosphere above the Line AB which Marks the Bounding Surface between Light and Shadow. The Sun's Parallax and Atmospheric Refraction are

vation bb′, 50 km. above the sea level GG′, the air pressure and density are 0.05 per cent of those on the sea, while 99.95% of the air lies below this level. Again, at an elevation of approximately 60 km., the density has fallen to 0.01%, and 99.99% of the total atmosphere lies beneath. In each 10 km., the air pressure is falling to one-fifth. A vertical sunbeam, reaching the level BB′, has passed thru 0.01% of the total atmosphere. The successive levels AA′, BB′, are lines of equal penetration, and there should be equal intensities of ionisation over each such level; but there should not be any layer of sudden transition.

Figure 2 represents the same atmosphere conditions as in Figure 1; except that the sun's rays are supposed to be entering the atmosphere at an inclination of 60° with the zenith, as indicated by the arrows on either side. Along these inclined paths, the sunbeam will encounter approximately twice as much air between any two given elevations as in Figure 1. Consequently, at the 50 km. elevation, the sunbeams have traversed 0.1% of a vertical atmosphere, instead of only 0.05%. The levels AA′, BB′, CC′ of 0.001%, 0.01% and 0.1% respectively are all raised about 5 km. with respect to those on Figure 1. Otherwise, there is very little change between the conditions of penetration by rays from an overhead sun at the equator, and those from the sun at either 8 A. M. or 4 P. M. There should be no sudden transition layer or surface of discontinuity in ionisation, in either case.

When, however, the sun's rays are striking tangentially over a place on the globe as in Figure 3, there tends to be a transition along the line AB, between air in the shadow and air in the sunshine. If the condition represented is that of sunrise, then the air still in shadow is presumably air that has become neutralized during night, with a relatively low conductivity. The illuminated air on the other hand is rapidly becoming ionised and more conductive. While, therefore, we cannot expect the moving shadow plane to be a sharply defined surface separating ionised from neutral air, we might reasonably expect a roughly defined bounding surface, such as might produce some diffuse reflection of electromagnetic waves. No attempt is made to indicate the lines of equal penetration or ionisation, owing to the complexity of the actions. It is known that there is a very appreciable refraction of the beams of light. We should also expect absorption to take place at different elevations, and inoisation to increase to some extent with time. The shadow boundary AB steadily advances toward G in the diagram. All that can be asserted definitely is that there is a greater probability of a transition layer, or partially reflecting layer, being formed between sunshine and shadow at sunrise and sunset, than at any place in the sunlit region of daylight. The ionised layer boundary cannot coincide with the shadow boundary AB, but will lag behind it, and will rise more nearly vertically, owing to the effects of atmospheric absorption, and of building up with time. We may call this hypothetical transition layer, or boundary between daylight and darkness, the "shadow wall" accompanying sunrise or sunset.

In Figure 4 we have a stereographic projection of part of the northern hemisphere. The lines of longitude at hourly intervals may be considered as representing the positions occupied by either the sunrise or sunset shadow walls, at successive hourly intervals at the equinox, when the sun appears on the equator. The shadow, considered as an imperfect electromagnetic mirror, may only extend upwards say from the 30 km. level to the 130 km. level; or may only occupy a height of say 100 km. in all; but, if it exists, it extends northwards and southwards for thousands of kilometers. In summer, the wall would slant from S. E. to N. W., and in winter from S. W. to N. E., across the globe.

If the boundary surface between day and night; or the shadow wall, possesses roughly reflecting or scattering influence on electromagnetic waves, we should expect to find the following series of phenomena in relation to two stations east and west, on or near the same parallel of latitude, as indicated in Figure 5; where the observer is supposed to be at the earth's south pole looking at the rotating pole beneath him.

(1) When both stations are in full shadow, as at 20, 20′; 21, 21′; 22, 22′; 23, 23′; 0, 0′; 1, 1′; 2, 2′; 3, 3′; 4, 4′; the signals exchanged should be normal, in the absence of thunderstorms or meteorological disturbances.

(2) When, shortly before dawn, at the eastern station, the shadow wall gets behind that station, it should act as a partial reflector to that station, and intensify the signals.

(3) When the shadow wall advances to a point between the stations, as at 6, 6′, the wall should act as a partial barrier between them and weaken the signals.

(4) When the wall reaches a point a little beyond the western station, as at 7, 7′, it should act as a temporary reflector to the latter, and temporarily strengthen the signals.

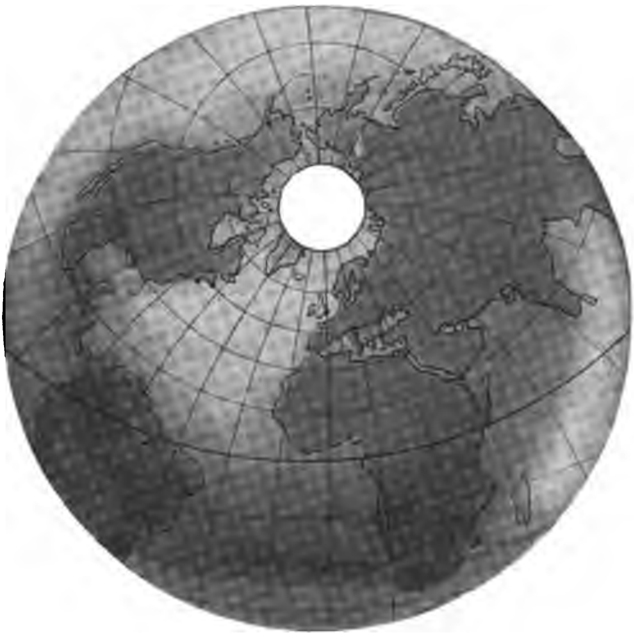

Figure 4. Projection of the Globe

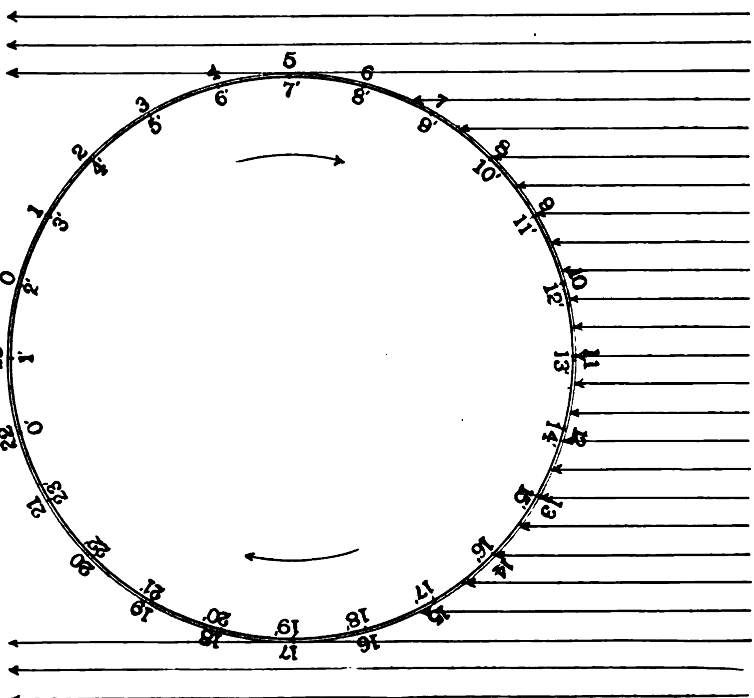

Figure 5. Rotation of the Earth with Regard to Sunlight as Viewed from South Pole.

(5) When both stations are in full sunlight, their signals are subjected to daylight attenuation, by diffused conduction in the upper air.

(6) When the sunset wall gets behind the eastern station, as at 17, 17′, the wall will temporarily serve as a reflector behind the latter, and strengthen the signals.

(7) When the sunset wall intervenes between the stations, the wall will act as an intercepting barrier, reflecting waves back, and markedly weakening the signals.

(8) When the sunset wall gets behind the western station, there will again be a temporary increase of signals by reflection. After this the conditions should approach those of permanent shadow, or night time.

In one revolution of the earth, therefore, we should expect to find maximum strength on full night shadow, a lowered strength in full daylight, and a marked weakening of the signals, with the wall between the stations, either at mid-sunrise, or at mid-sunset. [6] Each of these dips in the strength of signals should be both preceded and followed by a brief interval of stronger signals, due to partial reflection, in the same way as a rough or imperfect sheet reflector behind a lamp intensifies its rays.

On the other hand stations on the same parallel of longitude should have no dip on signals on the equinoxes; but should have a dip at sunrise and sunset with the sun near the solstice. (December and June.)

Stations north and south might expect a longer signaling range than those east and west owing to the aid of partial reflections along the shadow wall.

We may now compare the foregoing deductions with recorded observations. Figure 6 is taken from observations by Mr. G. W. Pickard in 1909, [7] as published in Figure 97 of Prof. G. W. Pierce's book on Wireless Telegraphy. It will be observed that there is a marked dip in the intensity of signals received at Amesbury, near Boston, Massachusetts, when sunrise was about midway between Amesbury and the sending station at Glace Bay, Nova Scotia. Both of these stations are indicated in Figure 4 by

(6) This provisional theory of the sunrise and sunset dips was first put forward by the writer at the Radio-Telegraphic Discussion of the Dundee meeting of the British Association, September, 1912.

(7) "Principles of Wireless Telegraphy," G. W. Pierce, New York, 1910, page 135.

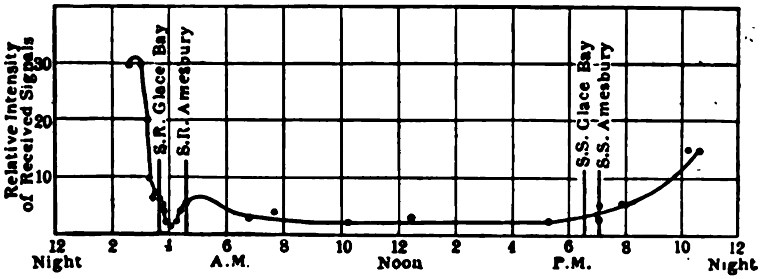

Fig. 6. Observations taken by Mr. Pickard on the relative intensity of signals received at different hours of day and night.

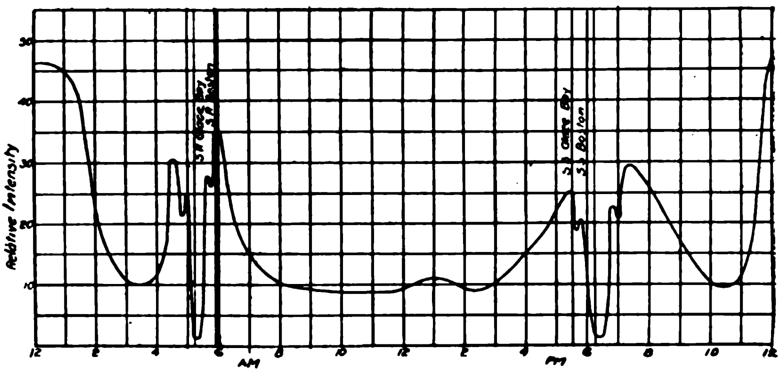

Fig. 7. General average of all curves taken at Somerville and Revere March, 1911.

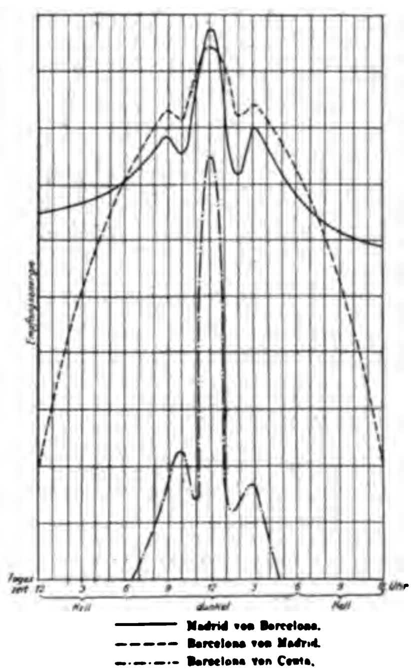

Figure 8

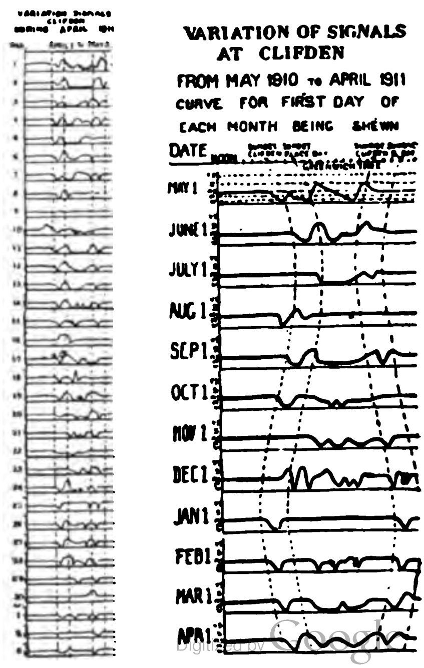

Figure 9

black dots. There is a reinforcement after the dip, and perhaps also before it. On the other hand, at sunset, no dip is indicated, such as the foregoing theory would indicate.

Figure 7 is taken from observations by Messrs. Dolbear and Proctor [8] in March, 1911. Here Glace Bay is again the sending station; while there were two independent receiving stations, one at Somerville, and the other at Revere; both suburbs of Boston. The diagram, taken from the published article, purports to give the general average of all the observations made at both receiving stations, at a period of the year near the vernal equinox. It will be seen that there is a dip both at mid-sunrise and at mid-sunset, with reinforcements both before and after each dip. There is a nocturnal maximum and a daylight reduction. The results set forth in this particular diagram are in closer accordance with the hypothesis here put forward than almost any others, but no explanation was offered or theory advanced in the article, by its writers.

Figure 8 gives some observations reported from Madrid, and Barcelona in Spain, and also Ceuta, in Africa, nearly opposite to Gibraltar. Here the nocturnal maximum is very short. There is a sunrise and sunset dip, with reinforcement before and after.

Figure 9 gives a published series of observations reported from Clifden, Ireland, as to the diurnal strength of signals from Glace Bay, N. S. One column gives the diurnal chart for each day in April, 1911. Here the agreement with the theory is not so good. There is usually, but not always, a dip at mid-sunrise and mid-sunset. Sometimes the sunrise dip is missing, and sometimes the sunset dip. There is often a reinforcement in the signals before and after a dip; but in many instances such a reinforcement is not indicated.

The records appear to have been made in all cases by shunting the receiving telephone with non-inductive resistance down to the point of inaudibility. The strength of signals is then estimated from the conductance of the limiting shunt.

It appears, therefore, that there is sufficient warrant from the observations at hand in giving the theory here suggested for the sunset and sunrise dips further consideration. It is not claimed

(8) The Effects of Sunlight on the Transmission of Wireless Signals, by B. L. Dolbear and J. A. Proctor, Electrical World, N. Y., Vol. 58, No. 6, Aug. 5th, 1911, pages 321-323.

that the theory is more than a working hypothesis. It is a suggestion to be judged according to such further evidence as may be accumulated. The information at present available is insufficient to demonstrate any theory of the subject. The records indicate that the phenomena are complicated. It may be that there are meteorological disturbances of the upper air which superpose their effects upon a normal diurnal regime. Our knowledge of the atmosphere by direct exploration with manned balloons is limited to an elevation of about 11 km. By means of small "sounding balloons," carrying up self-registering instruments, we obtain occasional records of pressure and temperature up to about 30 km. Above this level, we have no immediate prospect of securing observations by direct exploration. Nevertheless, the twilight limit of atmosphere, or the height at which the air can reflect twilight, is taken at 75 km. Auroral discharges in air, and shooting stars in air, are located much higher.

It would seem as tho information concerning the upper atmosphere might be obtainable thru concerted observations of radio telegraphic signals. The apparatus required for this purpose is simple and inexpensive. It would consist essentially of a receiving aerial, a detector and receiving instruments, with some means of estimating the strength of received signals at different hours of the day and night. The radio telegraphic amateurs might here render valuable service, by co-ordinating their efforts in observing signals regularly. There is no part of the world where an amateur, who is in the range of some large fixed station might not help in this work. It is to be expected that the accumulation of amateur observations in this way would be useful not only to radio telegraphy, but also to the general sciences of meteorology and solar physics. THE INSTITUTE OF RADIO ENGINEERS might aid greatly in this work, by enlisting observers using printed instructions for executing observations, collecting, collating, condensing and publishing the results. Fifty observing stations, grouped at various azimuths and distances around a single powerful radio sending station, would be none too many for the proper checking up of the measurements. In this way, the energy and enthusiasm of any number of amateur radio-telegraphists could be utilized to advantage. Once the system was inaugurated, the large sending station would probably be willing to assist by furnishing a continuous record of the current and voltage in their sending antenna.

SUMMARY: The influence of solar radiation on radio transmission is discussed. The changes of intensity of signals near sunrise and sunset are explained by reflecting effects which may be expected at the boundary surface or "shadow wall" between darkness (air of small conductivity) and illumination (ionised air of marked conductivity). The theory and recorded observations are found to be in reasonable agreement.

It is proposed that amateur radio telegraphists shall co-operate with THE INSTITUTE OF RADIO ENGINEERS in gathering data on the strength of received signals under various conditions.

DISCUSSION.

DR. J. A. FLEMING (by letter): The subject of Dr. Kennelly's Paper is one which continues to attract great attention from radio-telegraphists on account of its practical importance. Unfortunately, it is a large scale effect, and one not very amenable to laboratory experiments. Much, however, may be done by systematic observations of stray atmospheric waves and on the signals sent out from large stations.

At the British Association Meeting last year, at Dundee, I had the honor of opening a discussion on "Some of the Unsolved Problems of Radiotelegraphy," and at the conclusion of that paper made the suggestion that the British Association should appoint a Radio Telegraphic Committee to bring conjoint investigation to bear on some of these questions. That suggestion was adopted, and the Committee appointed with Sir Oliver Lodge as Chairman. The Committee has already held one meeting. I hope that, as one result, an attempt will be made to organize systematic observations on the number and intensity of atmospheric stray waves during the hours of day and night, and over large areas. This is a work in which we may enlist the assistance of amateurs, and it has the advantage that it is entirely receptive work, and involves no production of waves or disturbance of the ether. Much of the amateur work hitherto done has been merely playing at radio-telegraphy, and has had no other result except to disturb commercial work.

In order that we may test our theories of atmospheric action on long electric waves, we require the prolonged collection of statistics as to the variation of the atmospheric stray signals over long distances. This work would be greatly assisted by the establishment of numerous stations sending out time and weather signals over large areas. Such a system will come into operation to some extent on July 1st, 1913, when time and weather signals will be sent out from many radio-telegraphic stations at regularly appointed hours. If these signals are made with constant antenna currents, they will afford the means of testing the transparency of the atmosphere to electric waves over large distances, and assigning to the received waves a numerical value as regards intensity. I am now engaged in working out an improved method of measuring the intensity of the signals as received on any given antenna, which, I think, will be an improvement on the shunted telephone method now used. If we suppose that intelligible signals could be made at any place without intermission day or night, and all the year round, and of exactly the same strength at the transmitter, they would be received 1,000 miles away with different strengths at different times of the day and year and probably of a cycle of years. Before we can find an adequate theory to explain this variation, we must tabulate the variation and express it by curves like the variation of terrestrial magnetic force or the frequency of sun spots.

There is an increasing body of evidence to connect the variation with atmospheric ionisation. One of the most useful inventions, in this connection, would be some automatic device for registering atmospheric ionisation, which could be sent up to various heights in an unmanned balloon and then recovered again like a self-registering barograph or thermometer. If we could in this way determine the ionisation at various heights and various times, we should lay a firm basis for a true theory. As yet we know very little with absolute certainty about the ionisation in the atmospheric region which begins at about 7 miles elevation, and is variously called the *stratosphere* or *isothermal* region. In it the temperature gradient is constant, or nearly so, in an upward direction. If the ionisation is to be measured by atmospheric conductivity, then we need, above all, some solid information on this subject.

I suggest, therefore, that THE INSTITUTE OF RADIO ENGINEERS (in the United States particularly) should take up this question experimentally, and should endeavour to lay a firm foundation for a theory of long-distance radio-telegraphy by accumulating information on the important question of the electric conductivity and ionisation of our atmosphere at various heights above the earth's surface. Something might be done by the use of a Gerdieu's ionimeter in dirigible balloons or in aeroplanes.

University College, London; June 24th, 1913.

ALFRED N. GOLDSMITH: There are a number of effects in the transmission and reception of signals by radio communication which are as yet only partly explained. Those most closely related to the present paper may be classified as follows:

(1) The superiority of transmission over water as compared with transmission over land.

(2) The superiority (under certain conditions) of transmission on high wave lengths as compared with transmission on short wave lengths.

(3) The clinging of electromagnetic waves to the earth's surface, in spite of the considerable curvature of the globe.

(4) The superiority of transmission by night as compared with transmission by day.

(5) The "daylight effect," or change in intensity of received signals at or near sunrise and sunset.

Before classifying the proposed explanations of these effects, we shall consider briefly the bibliography of the propagation of electro-magnetic waves thru space and over the surfaces of more or less perfect conductors. The classical papers of Hertz and his immediate followers have rendered wave transmission thru space alone thoroly clear. The next problem in order of complexity is the radiation from a Hertzian doublet (dumb-bell oscillator) thru the equatorial plane of which a perfect conductor of indefinite extent stretches. Such a plane conductor may be regarded as a first approximation to the "ground" of a radio-telegraphic station.

M. Abraham, in 1901, gave the mathematical solution of this case [1] and its physical interpretation. Considering the wave at a distance from the oscillator, he found that

(a) The lines of electric force were perpendicular to the conducting plane, the lines of magnetic force parallel to it.

(b) The electric and magnetic field intensities are in phase.

It will be noted that these conditions apply only when the equatorial plane is a *perfect* conductor. This is nearly the case for sea water, but not at all for dry land. J. Zenneck considered this problem in detail for the case of an imperfect conducting plane. [2] For the case of the partial conductor he found

(a) The lines of magnetic force are parallel to the plane, the lines of electric force are inclined in the direction of motion of the wave.

(b) The electric force has a horizontal component which is nearly in phase with the magnetic force.

(c) The vertical component of the electric force and the horizontal component of the electric force are out of phase with each other.

There is a resultant rotary electric field at the surface of the plane.

Zenneck gives the following values for the field forces at a distance from an antenna of height h, of form factor α, in which flows a current I_m, and from which are radiated waves of length λ:

$$\text{Electric Force} = 4\pi \frac{\alpha h}{\lambda} I_m \frac{\varepsilon^{-\beta s}}{s} 3.(10)^{10} \text{ C. G. S. Units} \quad (1)$$

$$\text{Magnetic Force} = 4\pi \frac{\alpha h}{\lambda} I_m \frac{\varepsilon^{-\beta s}}{s} \quad (2)$$

where β is a constant. It will be seen that the values of these forces are dependant on the wave length.

The effects of the conductivity of the ground plane and of underground water or rock have been exhaustively studied by F. Hack [3] and P. Epstein [4] has given figures for the electric lines of force of actual waves (of length of 2,000 meters) passing over soil of high conductivity, and at considerable distances from the antenna.

Of particular interest in these latter papers is the proof of the existence of a varying horizontal component of the electric force on the wave front. Such electric forces exist on wires along which guided or surface electric waves are passing, and the question naturally arises whether we are not dealing with surface waves if the case of terrestrial radio transmission. Among the earlier investigators of such guided waves and of their probable part in radio telegraphy are A. Blondel [5], E. Lecher [6], and K. Uller [7], [8]. However, it remained for A. Sommerfeld in 1909 [9] to give a broad theoretical treatment of the spread of electromagnetic waves over a partially conducting sheet placed, as before, in the equatorial plane of the oscillator; the sheet being plane. Because of their importance, Sommerfeld's explanations and his conclusions will be considered in some detail.

He first discusses the fundamental energy distinction between space and surface waves. Space waves, such as electromagnetic (Hertzian) waves and sound waves, spread three-dimensionally. Their energy (per unit area of wave front) is therefore proportional to the inverse square of the distance from the source. Surface waves, such as ripples on water, electric waves on wires, and elastic waves of surface distortion in solids, decay according to a different law of energy diminution. Thus, for waves spreading circularly over water, and neglecting dissipative absorption in the medium, the energy varies inversely with the distance; not as the inverse square.

Sommerfeld defines a quantity U in his paper as follows:*

$$U^2 = \frac{K \mu n^2 + j \mu \sigma n}{c^2} \qquad (3)$$

where K is the dielectric constant, μ is the permeability,
σ is the conductivity, j is $\sqrt{-1}$,
n is the frequency, c is the velocity of light.

From U_1 and U_2, the values of U for air and the conducting sheet respectively, he builds up a new quantity ρ, which he calls the "numerical distance." If S is the actual distance, ρ is defined by the following equation:

$$\rho = \frac{U_1^4}{U_2^4} \cdot \frac{U_1^2 - U_2^2}{U_1^2} \cdot \frac{U_1 s}{2} \qquad (4)$$

Sommerfeld sets up the partial differential equation for his problem, introduces the necessary boundary conditions, and, after a series of elaborate analytical transformations, arrives at the following value for Π, the vector potential at any point:

$$\Pi = P + Q_1 + Q_2 \qquad (5)$$

Herein P represents that portion of Π. which is due to a true surface wave, and Q_1 and Q_2 represent space waves in the two

*The quantity U is Sommerfeld's "k". The notation here employed is, where possible, that recommended by the Standardisation Committee of THE INSTITUTE OF RADIO ENGINEERS.

media (that is, in space, and in the partially conducting sheet).

The relative importance of the space and surface waves is found to be determined by the value of ρ. The value of ρ for sea water is 0.03, for pure water 30, for wet earth 6.5, and for dry soil 300 (for a wave length of 2,000 meters at a distance of 2,500 km.) It is seen that the numerical distance increases with the real distance, diminishes with increased wave length, and is less for equal distances over sea water than over land. Furthermore, Sommerfeld's analysis shows that the assumption of perfect conductivity of the ground is allowable only for short distances over sea water. The distance from the antenna at which the surface or space waves predominate is determined as follows:

(a) For small values of the numerical distance, the space waves predominate.

(b) For larger values of the numerical distance, surface waves predominate.

(c) For very large values of the numerical distance, the space waves may again predominate, but this last effect may be neutralized by the effect of the curvature of the earth, and is probably not important in practise.

The surface wave is the more desirable one for long distance reception because it decreases far more slowly with distance than the space wave. The numerical distance should therefore be kept small so that the surface waves soon predominate. This may be secured by the following means:

(a) Increasing the wave length.

(b) Increasing the conductivity of the ground.

(c). Increasing the dielectric constant of the ground.

These conclusions are well borne out in practise. Sommerfeld has also suggested that daylight absorption is due to higher conductivity of the air causing an increase in U_1, and thereby increasing the numerical distance. In support of this, he mentions that Ebert found that the conductivity of air at a height of 2,500 meters was 23 times greater than at the earth's surface. It is, however, the opinion of other investigators, notably Messrs. Zenneck and Pierce, that the ionisation of the air due to sunlight is entirely insufficient to account for the magnitude of the observed effects.

Sommerfeld's work has been carried further by H. March (10), H. Poincaré (11), (12), J. W. Nicholson (13), and W. V. Rybczynski (14). The practical conclusions to be drawn from all these papers relate to the superiority of long wave transmission, and transmission over water. A further aspect of the problem is considered in them, namely the effect of the curvature of the conducting sheet or ground.

It will be remembered that Sommerfeld regarded this conducting sheet as plane, and it would certainly seem that the transmission of electromagnetic waves over an earth quadrant despite the curvature requires explanation. The papers just cited supply this explanation. They show that

(a) For a spherical, perfectly conducting ground, the energy of the wave decreases not as $\frac{1}{S}$ but as $\frac{1}{S}\sqrt{\frac{\theta}{\operatorname{Sin}\theta}}$ (6)

where θ is the angular separation of the points considered measured along a great circle of the earth (neglecting "scattering").

It follows, therefore, that the amplitude at any distance from the antenna will be greater than for a plane ground, and may even rise to considerable values at the antipodes. There is, however, a second consideration, namely, the failure of the energy to fully follow the earth's surface and its consequent re-radiation or "scattering." It results in the introduction of what I shall call the "concentration factor."*

The theory shows that for a spherical, perfectly conducting ground

(b) The energy of the wave, taking account of scattering or re-radiation of energy from the surface wave, is obtained by multiplying the value obtained under statement (a) above by the concentration factor:

$$\varepsilon^{-0.0019 \sqrt[8]{\frac{s}{\lambda}}} \qquad (7)$$

where λ is the wave length (wave length and distance expressed in kilometers).

The calculated values of the concentration factor for a distance of 5,000 km. is 0.0025 for a wave length of 4,000 meters and 0.0086 for a wave length of 8,000 meters. The advantage of using long waves is again apparent.

The expression for the energy of the wave obtained according to statement (b) above is in reasonable agreement with the results obtained experimentally by Dr. Louis W. Austin [15].

*Usually called "Zerstreuungs Faktor," or "scattering factor."

A complete theory of propagation of electromagnetic waves on a sphere of material of *finite* conductivity has not yet been developed.

There is another source of loss of energy in transmission which is generally not considered, namely, the loss thru ground currents in the immediate neighbourhood of the antenna. Inasmuch as considerable absorption of energy undoubtedly takes place in this vicinity, some interest is attached to conclusions drawn by Brylinski [16] relative to the resistance to alternating current of a homogeneous plane conductor of indefinite extent, the current flow being parallel to the plane. (It has been shown experimentally that this is very nearly the case for actual transmitting stations). Brylinski shows that the resistance increases with the specific resistance of the material, with the frequency of the current, and with the damping of the current. Remembering that the nearest approach to an ideal Hertzian doublet, radiating without loss in the surrounding medium would be attained by having a perfect conducting mass extending thru the equatorial plane of the doublet, and that this implies that the ground resistance to an infinite distance is zero, we find that long distance transmission is best attained by the use of sea water grounds, long waves, and continuous radiation of energy. The first two of these conclusions are in accord with the facts, the third point is one requiring further investigation.

Returning to the effect of atmospheric ionisation on transmission, an ingenious explanation of daylight absorption has been suggested by J. A. Fleming [17], [18]. If the upper layers of the atmosphere are strongly ionised by sunlight, the ions produced may act as nuclei for the condensation of water vapor. As a result of the presence of the water drops, and the high dielectric constant of water (namely, 80) the upper layers of air have a higher dielectric constant after exposure to sunlight. Fleming experimentally found that the dielectric constant of steam-laden air varied between 1.004 and 1.026. Therefore the electric waves will travel more slowly in the upper layers of air than in the lower, and the wave front will be tilted backward relative to the direction of transmission. In consequence of this tilting back of the wave surface, the entire wave may pass directly over the receiving station. The effect is quite similar to diminishing the concentration factor. On Fleming's hypothesis, daylight absorption should be least for

(a) Long waves, because their concentration factor is larger, that is, they follow the earth more closely. In fact, in

(b) Any conditions where surface waves predominate, e. g., over water.

The increased dielectric constant of moisture laden air may account in part for certain well-defined interference effects, as explained by Dr. Lee de Forest [19].

Dr. W. H. Eccles [20] gives a theory of wave propagation in ionised air which, under certain conditions, leads to conclusions directly conflicting with those of Fleming. Thus, according to Eccles, as a result of ionisation of the upper layers of the atmosphere, the wave front may be tilted forward so as to follow the earth's surface more closely; in fact, ionisation might thus assist long distance transmission. There are, then, two opposing effects, the relative preponderance of which determines whether the wave front is tilted forward or backward.

(a) It is tilted backward if, because of ionisation there is a deposition of water on the ionic nuclei, with a consequent increase in the dielectric constant.

(b) It is tilted forward if the presence of ions of molecular dimensions increases the velocity of the waves.

Further experiment on these points is highly desirable.

It will, however, be noted, that regardless of whether effect (a) or (b) predominates, Professor Kennelly's explanation of the sunrise and sunset effects as due to reflection at the boundary surface between ionised and un-ionised air still holds. Effect (a) would provide a more nearly complete reflection.

It has been further suggested that the antenna may be actually discharged by ultra-violet light in sunlight falling on it (Hallwachs effect). This, and other interesting points relative to the influence of atmospheric conditions on transmission and reception are fully treated in a recent publication by M. Dieckmann [21]. The attention of the experimenter in this field is directed particularly to Professor Fleming's valuable paper before the British Association [22] and to the chapter on electric wave transmission in Professor Zenneck's "Leitfaden der Drahtlosen Telegraphie" [23] to both of which sources I desire to acknowledge my indebtedness for suggesting some of the material given in this discussion.

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Dr. L. W. AUSTIN (by letter): An idea, held some time ago, that the difference between the strength of signals by day and those by night was due to the ionization of the air around the sending antenna, caused by the ultra-violet light from the sun, has been entirely abandoned.

An alternative explanation, that the increased strength of signals at night was due to diminished conductivity in the upper conducting layers of the atmosphere at night, seems improbable in view of data in the possession of the U. S. Navy Department.

This data shows that: (1) In certain regions and at certain wave lengths the ground absorption is greater than over equal stretches of salt water in the ratio of as much as twenty to one. Yet signals are sometimes received in such regions at night with the same strength as if there were no absorption at all. The sunlight can hardly affect ground absorption. (2) When working with sustained waves from arc radio-telegraph sets, the strength of signals may be great on certain wave lengths and very weak at other slightly different wave lengths. Thus a change of two or three per cent. in wave length produces enormous changes in intensity of signals. The probable explanation of this effect is, in accordance with Dr. de Forest's suggestion, (Proc. Inst. Radio Engineers, Vol. I, No. 1, page 37, 1913) that interference between a set of waves travelling along the earth and another set which have been reflected from conducting layers of the upper atmosphere takes place. There is no doubt as to the existence of this effect. The probable reasons for the failure to observe it with spark sets is partly because of the greater changes of wave lengths employed with such apparatus, and partly because the shorteness of the wave trains does not permit the direct and reflected waves to overlap and interfere for any considerable number of wave lengths.

The most probable explanation of the increased strength of night signals is to be found in an increase of energy received by the reflection of the waves from the upper layers of the atmosphere rather than in any diminution of absorption. This implies a stratified structure of an ionized atmosphere at night, this structure being broken up by convection currents of air and changing illumination during the day.

Observations at Brant Rock and at Arlington show that, tho the difference between the strength of signals by night and by day is much less at long wave lengths than at short, still there is no approach to actual equality in strength of day and night signals even for very long waves. Thus, with Clifden sending at 7,000 meters, at Brant Rock the received current thru 25 ohms resistance was from 35 to 55 micro-amperes by day, rising to 100 micro-amperes by night (for autumn and winter). In summer, the day signals were generally inaudible, varying between 7 and 12 micro-amperes. The night signals were much louder in this case also.

ROBERT H. MARRIOTT: The Standardisation Committee of the INSTITUTE will consider the shunted-telephone method of recording the strength of signals, as well as other methods intended for the same purpose, in order that Professor Kennelly's suggestion of the coöperation of amateur and commercial stations in scientific investigation of transmission may be put into practise shortly.

ROY A. WEAGANT: It is quite certain that much of the value of data obtained by amateurs on the strength of signals of certain commercial stations will be lost unless the commercial stations can be induced to keep a definite record of their radiation at various times. The current value in the antenna, the quality of the note, and the wave length are necessary for such a record. This is not usually done.

GUY HILL: According to your theory of reflection from conducting upper layers in the atmosphere, might not continuous ("undamped") waves be reflected more perfectly than damped wave trains? This question has a bearing on an effect we wish to explain, namely the apparent greater range achieved by given amounts of energy when in the form of continuous radiation. More observations on this point are needed.

A. E. KENNELLY: I think that if a steady stream of waves were emitted, they might show these reflections more markedly; and possibly greater ranges might also be attained by their use for a stated amount of energy. But it is as yet an obscure point.

JOHN L. HOGAN, JR.: The point that Mr. Hill suggests regarding the prominence of reflection (and interference) effects with sustained waves is well substantiated by some observations presented by Dr. de Forest before this INSTITUTE. (Proceeding of the Institute of Radio Engineers, Vol. 1, Number 1, page 37.) He shows that if continuous waves pass from a transmitting station to a receiving station by two different routes, one of which is direct and the other of which is caused by reflection of waves which strike elevated cloud layers, very marked interference effects will be produced at certain frequencies. That is, at definite wave lengths the signals will be either markedly weakened or strengthened. Change of wave length may bring the signals to normal strength.

It is possible that these selective absorption effects are phenomena based on slow resonance, and that therefore they should be more marked with sustained than with damped waves. Instances of marked reflective amplification may be responsible for the transmission of long-distance signals which have brought forward the contention that the range to be attained by the use of sustained waves is greater for equal output than with damped waves. I have discussed this claim with Dr. Austin while in Washington, and he appeared very sceptical concerning it. We felt that we had not enough data to warrant acceptance of it and that there should be no great difference in the transmission of sustained waves as compared with those of low decrement.

It seems to be a wonderful confirmation of Professor Kennelly's hypothesis that even such observations as those taken between Clifden and Glace Bay (where signals were graded in strength by simple aural classification as "very strong," "strong," "moderate," "weak," and "very weak"), are in such good accord with the theoretical conclusions.

In connection with abnormal daylight absorption treated by Dr. Kennelly, it is interesting to note that the value and relation for normal daylight absorption have been partially confirmed.

In 1911, Drs. Austin and Cohen, on the basis of experimental work performed from Brant Rock, gave the following law for the received antenna current I_2 in terms of I_1, the transmitting antenna current, h_1 and h_2, the heights of transmitting and receiving antennae, λ the wave length, and s, the distance between the stations.

$$I_2 = \frac{4.25\, I_1\, h_1\, h_2}{s}\, \varepsilon^{-\frac{\alpha s}{\sqrt{\lambda}}}$$

where α is a constant, equal approximately to 0.0015.

These experiments covered several types of antennae, and distances up to 1,000 miles (1,600 km.) with various antenna currents. The current for audibility (thru an equivalent resistance of 25 ohms) was taken as 10 microamperes. It appears that we need only 5 microamperes, or with the heterodyne receiver less than 2.5 microamperes. Making this change in the equation above, the results had in the recent Arlington-Salem tests offer good substantiation of the relation. With a sending antenna effectively 450 feet (138 meters) high, and a receiving antenna of 130 feet (40 meters), groups of thirty-word messages have been consistently received by daylight up to a distance of 2,383 miles (3,830 km.). From this it can be shown by a graphical solution of Austin-Cohen equation that the daylight range of an Arlington-type station to a similar station is 2,920 miles (4,700 km.) at a wave length of 4,000 meters; and rises to 3,400 miles (5,500 km.) at a wave length of 10,000 meters. (Further details of these heterodyne experiments, and the Arlington-Salem tests are given in the latter portion of the next paper in this issue of the Proceedings. Editor.)

I wish to endorse Professor Kennelly's suggestions. I trust that the observations will cover all parts of the twenty-four hour day, and that transmitting station records, as recommended by Mr. Weagant, may be secured.

LLOYD ESPENSCHIED: Such experiments as just proposed can be best carried on by the Navy. They would materially add to the efficiency of the Weather Bureau's work, if properly planned.

CAPT. F. J. BEHR (Coast Artillery Corps, U. S. A.): This subject is one of great interest to us; particularly the relative advantages of "damped" and "undamped" waves. These meetings of THE INSTITUTE OF RADIO ENGINEERS are doing yeoman service in calling attention to these points and the proper method of investigating them.

H. E. HALLBORG: We should try more transmission experiments between stations lying north and south, so as to be able to compare ranges with those lying east and west. It has already been noted by ship stations that the transmission of signals in a north and south line is superior to that in an east and west line.

GUY HILL: Referring to the surface waves, Marconi has used wires on the ground for long distance reception, and some time ago Fessenden received messages over 600 miles on ground antennae.

A. E. KENNELLY: We may assume, in the present state of the theory of radio-telegraphic received signals, that the voltage of a signal received from a given steady wave-train is directly proportional to the maximum height of the receiving antenna above the plane of the equivalent perfect ground surface. The electric energy of the signal, however, is of course proportional to the received voltage and the received quantity. The quantity probably depends on the extent of wave surface area on the wave-front intercepted by the antenna. If this way of considering the matter is correct, a very low antenna of great length might give as strong a receiving signal as a high antenna of small width or surface area.

ALFRED N. GOLDSMITH: There seems to be a non-reciprocity of sending and receiving properties, on which Lord Rayleigh has already commented. A high antenna is necessary for transmission, but since reception of messages is largely accomplished on surface waves (at least for long distances) a low receiving antenna suffices.

CHARLES A. LE QUESNE, JR.: In a recent number of the Telephone and Telegraph Age I find a reference to some experiments by Austin Curtis on an effect of moonlight on reception of signals. The effects presented were similar to those for sunlight.

ALFRED N. GOLDSMITH: These experiments were originally disclosed in The London Electrician for March 21, 1913, (page 1104) and May 2, 1913, (page 143), and they have been considered by Dr. Eccles in the same periodical for March 28, 1913, (page 1144).

AUSTEN CURTIS (by letter): In connection with the erection of a station in Boa Vista, Amazonas, Brazil, for the Brazilian Department of Agriculture (Commissao da Defeza da Barracha), I had the opportunity of making some highly interesting observations on atmospheric influences on radio signals. I am indebted for the opportunity to Dr. Roderick Crandall, Chief Engineer of the Commission for this section. Boa Vista is in the extreme northern part of Brazil, latitude 2° 52′ N., longitude 60° 40′ W., in open prairie country, at a low elevation.

The observations covered the period between November, 1912, and May, 1913. During this time practically no rain fell, dew being absolutely unknown. The humidity was from 50 to 65 degrees, and it was possible to see thru the very clear air 50 to 100 miles.

The effect of moon rise on the strength of radio signals will first be considered. It has been observed with the following stations: NPG (Trinidad), 600 miles north, 600 meter wave; DQC (unknown ship), 600 meter wave; Y (Yquitos), 870 miles west, 1,800 meter wave; Z (Lima), 1,250 miles southwest, 1,600 meter wave; MA (Manaos), 390 miles south, 1,350 meter wave. All but the first two of these (on which observations were taken only once) are Telefunken stations, 500 cycle, and low damping.

In the tropics, full moon rise is at about 6 P. M., and falls about 50 minutes later each successive night. Since no stations within range began sending before 7 P. M., no observations were possible on the night of full moon or the night thereafter; this restricted the range of measurements to the third, fourth, and fifth nights after full moon. After this, the moon light is much reduced, and the effect disappears.

The curves given in Figures 10 and 11 are typical of the complete cycle of changes. This cycle consisted in general of a rise in signal strength, a drop, a second rise, a second drop, and a final rise to a constant strength which was maintained the remainder of the night. The time after moon rise at which this effect occurred varied considerably, being sometimes as much as 20 minutes later. In one case (Yquitos sending), it was noted that after moon rise at Yquitos, the signals received at Boa Vista (in full moonlight) increased suddenly and remained thereafter at the higher value.

Particularly worthy of notice is the following peculiarity: in all cases where the distant station continued to send for a sufficient

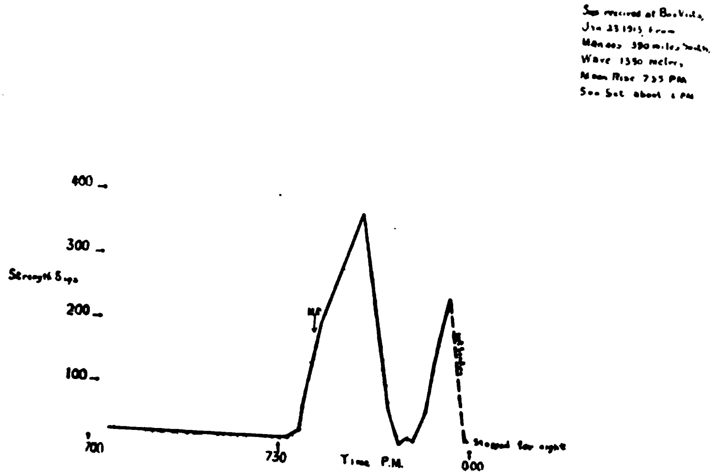

Figure 10

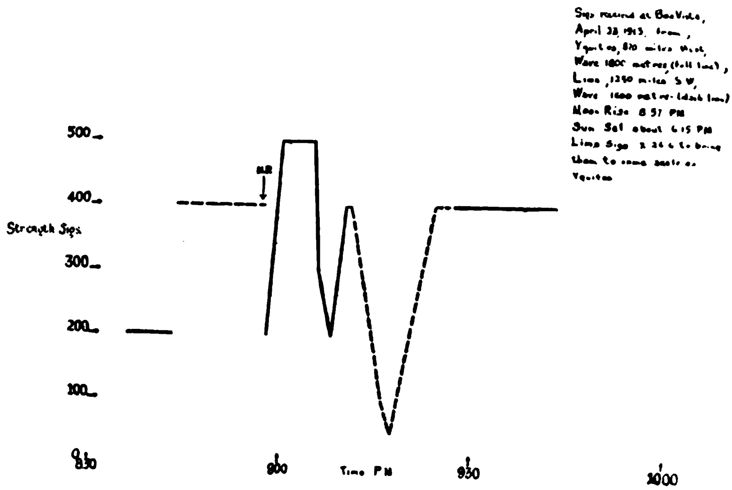

Figure 11

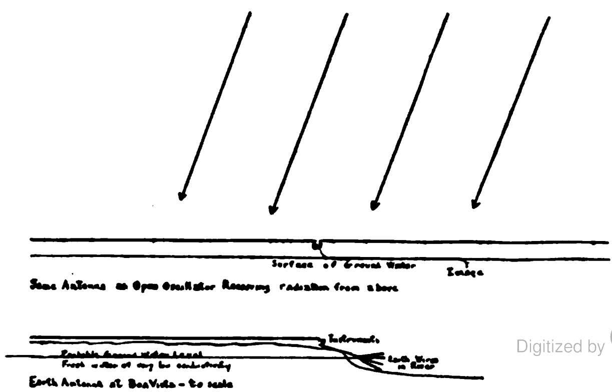

Figure 12

length of time, there were *two minima* in the strength of signals with *9 to 10 minutes* between them.

The fact that the time at which the effect occurred was independent of the distance and bearing of the sending station, and that in two cases two different stations followed the same cycle of signal variation, is conclusive evidence that the effect is either at the receiving station, or in the atmosphere directly above or almost directly above the receiving station. This reasoning leads me to the belief that the waves received (on the particular ground antenna used) were free space waves, coming from a height great enough to make the angle of incidence with the earth and the ground antenna used not very far from 90°.

Dr. Eccles has attempted to explain the moon rise effect by considering it as a continuation or complication of the sunset effect. A little consideration of tropical conditions will show this to be very improbable. The sun sets in the tropics at about 6 P. M., and it is dark in fifteen minutes. Yet I have observed the moon rise effect as late as 10.30 P. M. and nearly twenty times.

Considerable difficulty is experienced is obtaining a complete curve of the cycle of signal intensity changes because of the irregular times of transmission of the stations. So far as the magnitude of the drop was concerned, it varied enormously; all the way from 2 to 1 up to 10 to 1. When static from a distant source was heard, its intensity change always followed that of the signals received, keeping the same relative strength. The method of deciding the distance at which the static originated was rough but fairly reliable. Remembering that it was possible to see nearly 100 miles from the station, on evenings when distant lightning could be seen, and the static was sharp and snappy in character, the static was termed local atmospherics. When the night was perfectly clear, no traces of lightning could be seen, and yet there was a continuous muffled roar of static of about 500 times audibility in the telephones, the static was assigned to distant sources.

Two aerials were employed in the experiments, and these will be described in detail. The ground antenna was 450 meters long to the instruments, 5 to 6 meters high, made of 2 No. 12 copper wires. The ground consisted of a fan of 10 wires 50 meters long in the river bed. The natural period was 3,000 meters. (During the first month, long leads to the instruments brought the natural period up to 4,000 meters.) The bearing of the antenna was N. and S., the instruments were at the S. end, and the free end of the aerial was open. The ground underneath was absolutely dry and sandy, and there was no rain or dew. The underlying strata consisted of an "ironstone" conglomerate, about 10 meters deep and 10 meters thick; under this a layer of clay, with ground water at the junction of the clay and the conglomerate. The second aerial was a T antenna, on the bank of the river, bearing N. E. and S. W., 40 meters above water level, 200 meters long, 2 wires, and of natural wave length of 1,200 meters. A list of stations heard is given at the end of this note.

The ratio of the strengths of the signals received on the two antenna was fairly constant for a given station provided that the signals showed no tendency to "swing," that is, vary suddenly; but when the signals did swing, they swung *independently* on the two antennae. This leads to the belief that, at night at least, the types of wave received on the two aerials were different. It may be mentioned that the two aerials were far apart, and that one was always ungrounded while measurements were being made on the other.

The following experiment was then tried as a further comparison between the two antennae. Half of the long antenna was lowered to the ground, the T antenna remaining undisturbed. This change reduced the signals received at night by about 33 per cent, while it reduced day signals by 87 per cent. That is to say, the influence of the height of the long antenna on its capacity for reception was 2.6 times as important during the day as at night. This is evidence that the radiation received in the daytime is principally in the form of surface waves, and that at night the energy is in the form of free space waves reflected or refracted from the upper layers of the atmosphere.

The signals received from Manaos and Santarem at night from the middle of February to the middle of April showed very extraordinary and sudden fluctuations. The audibility factor would suddenly change from 25 to as much as 1,000, in a period of five minutes. This effect, which had no connection with the moon rise, disappeared about the middle of April. Yet during the same period the signals received by day from Manaos were perfectly steady.

A study of the weather during this period at different points on the Rio Branco showed that the northern edge of the rain belt was just midway between Manaos and Boa Vista. A brief consideration of the meteorology of the tropics will make this clearer. The rotation of the earth and the higher temperature of the equatorial regions combine to produce the N. E. and S. E. trade winds, which, meeting somewhere near the equator, cause a rising sheet of heated air, which carries with it rain clouds, and thunderstorms. This belt is several hundred miles wide, but its height is problematical. At sea, this region between the trade winds is known as the equatorial calm belt; on land it gives rise to the rainy season. It moves north and south with the sun, being farthest north in July or August.

As practically all the tropical thunderstorms are concentrated in this region, its position determines the intensity of static for the tropical regions. It seems probable that the swirls and air currents which exist at the contact edge between the N. E. trade winds and the rising air currents of the calm belt disturb the electrically stratified structure of the air in that region. This would cause the violent fluctuation of signal strength noted when the edge of the calm belt lay midway between Manaos and Boa Vista. The fact that the strength of signals returned to normal as soon as the northern edge of the calm belt came within 100 miles of Boa Vista shows that the presence of heavy clouds was not the cause of the fluctuations in strength. The occurrence of this swinging at night only, and at times when the point of reflection or refraction of the waves was in a region of disturbance, is further evidence that the waves received at night came thru the upper atmosphere and are refracted or reflected at a point midway between the two stations. They are therefore space waves; while the waves received by day are surface waves.

The co-ordination of all these results leads to the following conclusions:

I. That at night the ground antenna acts as if it were an ordinary Hertzian oscillator laid on the ground, the wire forming one-half and the ground giving rise to the "image." (See Figure 3.) Considered from this point of view, it will receive energy from or near the zenith most readily. (It is to be noted that the river formed the nearest conducting body to Mr. Curtis' ground antenna. Editor.) Further, any change in the height of the reflecting or refracting layer will affect the angle of incidence of the received waves, and consequently their strength. On this assumption, the moon rise effect would be caused by ultra violet light disturbing the definiteness of the reflecting or refracting layer of the atmosphere.

II. The ground antenna acts in the daytime as if it were receiving surface waves only, for its efficiency is markedly dependent on its height above the earth.

III. Either surface or space waves may be received by night as evidenced by the fact that variations in the strength of the received signals at the same time and from the same station on the two antenna are not proportionate. Probably the T antenna receives the surface waves by night mainly, and the horizontal antenna the space waves. Abnormal atmospheric conditions affect the two types of waves to different extents. This makes it possible that a proper combination of a horizontal with a vertical antenna for receiving would minimize the variations in the strength of received long distance signals.

Finally, it was noted that after a heavy rain, when the ground absorption was changed, daylight signals became weaker. The stations heard at Boa Vista were as follows: Using the horizontal antenna, regularly by day, Porto Velho, 700 miles S., 45 K.W. Marconi set, 3,500 meters, 4 to 10 times audibility; Manaos, 390 miles S.E., 45 K.W. Marconi set, 3,500 meters, 10 to 30 times audibility; Manaos, 390 miles S.E., 5-10 K.W. Telefunken set, 3,500 meters, 2 times audibility; Santarem, 500 miles S.E. over a high mountain range, 5-10 K.W. Telefunken set, 3,500 meters, 2 times audibility. In the night time: Manaos, Marconi, 300 times audibility; Porto Velho, Marconi, 200 to 300 times audibility; Manaos, Telefunken, up to 1,000 times audibility; Santarem, Telefunken, up to 300 times audibility; Cape Cod, Mass., 2500 miles N., 1,900 meters, 5 to 15 times audibility; Sayville, L. I., 2,500 miles N., at 1,800 meters, up to 50 times audibility, at 2,800 meters, up to 20 times audibility; Lima, 1,250 miles S.W., 1,600 meters, up to 30 times audibility; Yquitos, 870 miles W., 1,800 meters, up to 500 times audibility.

A. E. KENNELLY (by letter): Mr. Curtis' observations are important as to a direct effect of moonrise, upon received signals, at times other than full moon. As Dr. Eccles has pointed out, a full-moon moonrise effect is not distinguishable from a sunset effect. If, however, Mr. Curtis' observations can be confirmed by other experimenters, to the effect that moonlight influences are distinctly observable long after sunset, the phenomenon has great importance. Since moonlight is accepted as nothing but sunlight reflected to us from the moon, it is reasonable to suppose that the effect of moonlight on received signals must be of essentially the same nature as that of sunlight, but very much weaker in intensity. It would be possible, however, for a moonrise action on signals to be much stronger than would be inferred from a consideration of the relative intensities of moonshine and sunshine, if the surface of discontinuity between ionised and un-ionised air were sharper, or more markedly defined, than in the case of sunlight. In other words, a shadow-wall of feeble moonlight might partly compensate in its sharpness for its lack of differentiation between light and shadow, and so produce reflective disturbances on signals out of proportion to the intensity of the light. The effects described by Mr. Curtis might possibly be explained on such a postulate; but it is not easy to see why the moon's shadow-wall should be relatively sharper than the sun's shadow-wall.

The valuable information contributed by Mr. Austen Curtis, as obtained at a single station, indicates how much knowledge could be secured by co-operative voluntary systematic observation, continued for years, among a number of observers, at many different stations.

It seems difficult to understand why two receiving antennae, such as Mr. Curtis clearly describes, should be responsive selectively to two very different types of wave transmission, such as he suggests. In horizontal extent, the two differ only as 450 meters against 200 meters, and in height above ground water, as 60 meters against 25 meters. Is it not worth exhausting every effort to explain the action of these two antannae, considering the independent swinging, on the basis of their difference of natural wave length (1,200 meters as against 3,000 or 4,000 meters) loaded to syntony, before accepting a theory of two different types of waves acting selectively? The conditions described are certainly unusual, and the phenomena reported are most interesting.

PROFESSOR GEORGE B. PEGRAM, of the Department of Physics, Columbia University (at which the INSTITUTE meetings are held), expressed the hope that, in view of the useful scientific and technical work done by the INSTITUTE OF RADIO ENGINEERS, the cordial relations between that body and Columbia University might continue to exist.

(The Editor, on behalf of the INSTITUTE, heartily shares this desire.)

THE HETERODYNE RECEIVING SYSTEM, AND NOTES ON THE RECENT ARLINGTON-SALEM TESTS.

By John L. Hogan, Jr.

(Chief of Operating and Erection Department, and Research Engineer, National Electric Signaling Company.)

Much interest has been shown in the heterodyne receiver since its use in the recent test between the Fessenden stations of the U. S. Navy at Arlington, Virginia, and aboard the cruiser, Salem. These trials mark the first public use of the heterodyne system, which has often been called the greatest of Professor Fessenden's inventions; but, as a matter of fact, the method has been utilized in the National Electric Signaling Company's plants for a number of years.

It is the purpose of the present paper to explain the heterodyne principle, and to describe the apparatus by means of which it is put into practice. Since the invention involves a number of points which are quite outside the range of observation of the average worker in radio signaling, an introductory consideration of the fundamentals of receiving instruments in general is desirable.

Every radio receiver is composed of two main parts; an energy absorber and an indicator. In some special forms of apparatus these two elements may be physically combined, but functionally they remain as distinct as before. The relation between the energy received and the response of the indicator, together with the process whereby the receipt of that energy effects the indication, probably serves as the best basis for classifying receivers in radio signaling.

In the receiving instruments originally used (which were mainly various arrangements of coherers with auxiliary apparatus), there was provided a local source of potential energy which was capable of operating the indicating mechanism, but was not allowed to do so because of the presence of some obstruction. In general, the energy of the received waves overcame this obstruction and allowed the stored local energy to give a signal upon a sounder, a buzzer, a bell, or some other indicator.

After each action of the indicator the obstruction was automatically set up once more so that the cycle of operations described might recur. This method of reception is typical of the so-called relay-operating receivers, in which the received energy serves only to release energy from a local source, and in which the final indication is not proportional to the received signal intensity. It is true that some forms of "local energy" or indirectly acting devices, such as microphones, restore themselves very quickly, and may give roughly proportional responses; but in all receivers of the relay type a group of received waves operates to change local conditions at the receiver so that energy from a local source may operate the indicator.

The relay class of receivers has been practically abandoned and almost all modern equipments have instruments in which the indication is made by the energy of the received wave itself. This statement may seem somewhat startling to some, for there still persists the old conception that the power received at radio stations is infinitesimal, and can be discovered only by the use of a "very sensitive" apparatus called a detector. Of course, the fact is that the power of the received radio signals is often of the order of magnitude of the largest rates of energy delivery occurring in line telephony, and that the detector of a radio receiving system is ordinarily a much less efficient device than the magnetic telephone used in connection with it.

Almost all receivers used in modern radio stations have as their basis of operation some instrument which rectifies electrical currents. The rectifier may be of the gaseous, liquid or solid type, but in any event it acts solely as an energy transformer linking together the wave absorbing system (the antenna) and the indicating mechanism (which is usually a telephone). In these arrangements the energy which moves the telephone diaphragm is actually received from the transmitting station by radio, and local sources of energy are not relied on to operate the indicator. The result of this type of action is a response very different from that of the relay receivers, for now the signals are proportional to the received power, and are therefore characteristic of the stations sending.

Practically all arrangements proposed or used for the reception of radio signals may be classified as either relay or transformer devices, in acordance with the above outline. The filings coherer with its battery and relay is typical of the first division;

the "crystal" rectifier operating without battery is obviously representative of the second type. It has been experimentally demonstrated that the liquid "barreter" (electrolytic detector) and solid rectifying detectors are of the direct energy-transforming type, the only effect of a local battery on their operation being a change of sensitiveness, but no alteration in the principle of operation.

It is evident that if we could secure a better relay detector than the coherer it would be possible to use radio communication in many ways not now practicable. Unfortunately all detectors of this class seem to become very delicate so soon as their sensitiveness to incoming signal is made great. This delicacy results in false operation by static; and, together with a general instability in the instruments, makes them far inferior to the transformer type detectors. This is true in spite of the fact that all instruments of the second class are limited in their response by the amount of energy actually received from the given transmitting station. The ability to give responses proportional to, and characteristic of, the transmitting station seems to be the feature which has given the transformer or convertor detectors their tremendous superiority. And radiotelephony is strictly dependent on such detectors.

It has been attempted to overcome the energy limitation of the transformer receivers by arranging them to control a microphonic relay which would modulate the current from a battery at the receiving station in accordance with the received signals. All instruments of this sort have increased the delicacy of adjustment at the receiving station and have made operation difficult on account of their large amplification of atmospheric and other false signals. It is apparent that what is needed is a quantitative receiver which permits the use of local energy to assist in giving the indication, but which will operate only upon persistent received waves; that is to say, a *selective* amplifier is needed in order to increase the effectiveness of radio receiving stations.

The only receiver of this selective type is the heterodyne, the name of which (from the Greek words *HETEROS* and *DYNAMIS*, meaning "other" and "force") describes its method of action; viz., to give an indication by using energy both from the received wave and from a local source. The telephonic relay amplifiers which have so far been proposed, act like valves turning on and off a direct current in amounts approximately proportional to any received impulse, The heterodyne acts by the conjoint operation of two alternating currents which mutually add and subtract according to the physical laws governing the interaction of wave motions. These interactions will be next considered.

It is an interesting fact that the same laws of interference or wave addition hold whether one considers periodic displacements in water, air, "ether," or any other medium. If two wave motions occur in the same medium at the same time, the resulting action may be determined graphically by adding the ordinates of curves representing each of the separate waves. These curves are usually drawn to show displacement at a given point as time goes on, or else to show the wave form in a certain region of space at some assumed and definite instant of time. It is unnecessary actually to draw the curves, since the algebraic addition of expressions which give the displacements due to each of the component wave motions as functions of time or space will result in an equation expressing the resultant displacement.

The clearest conception of interacting wave motions may be gained from graphical considerations. Figure 1 represents two sine waves, A and B, progressing thru the same medium, and combining to give a resultant larger wave C. From the curves it is seen that frequencies of the fundamental waves are the same, and that the amplitudes are the same. Since both start at the same instant, they always remain in phase, and their effects are mutually additive, so that the resultant wave has an amplitude twice as great as either of the component waves.

Using the following notations, we can easily express the mathematical relations for the addition of the waves shown in Figure 1: t = time, n_1 = frequency of the wave shown on axis A, i_1 = instantaneous amplitude on curve A, I_1 = maximum amplitude on curve A. The same letters, but with subscript 2 refer to corresponding quantities of the wave plotted along the B axis. The curve A is represented by

$$i_1=I_1 \sin \omega_1 t \tag{1}$$

and that of B is given by

$$i_2=I_2 \sin \omega_2 t \tag{2}$$

where ω_1 and ω_2 are equal respectively to $2\pi n_1$ and $2\pi n_2$.

The sum of these two expressions will result in an equation of which the curve C is the locus, namely:

$$i=i_1+i_2=2 I_1 \sin \omega_1 t \tag{3}$$

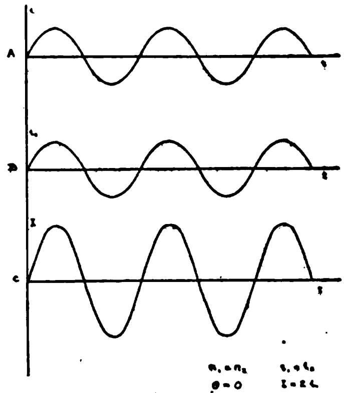

Fig 1

Figure 1

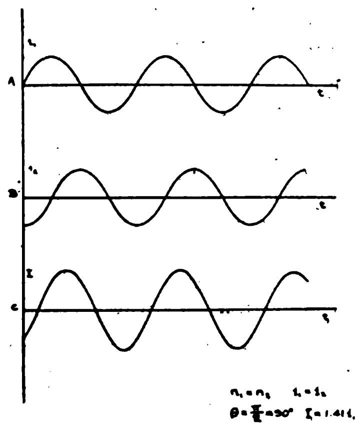

Fig 2

Figure 2

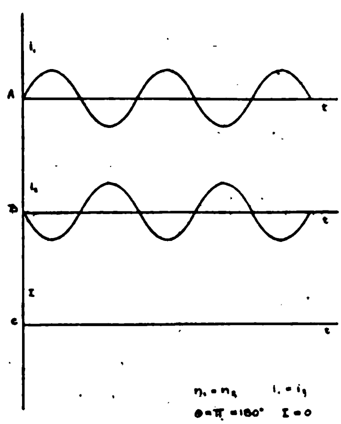

Fig 3

Figure 3

In the case shown in Figure 1, the waves travel, so to speak, hand in hand, and therefore always assist each other. If the wave B had started slightly later than A, for certain portions of time they would be opposing each other. A case of this sort is shown in Figure 2, in which the wave B starts 90° (or $\frac{\pi}{2}$ radians) later than wave A. This angular difference of starting is called the phase displacement of the second wave, and is represented by the letter θ.

By graphically adding the curves A and B, that of C is arrived at, and it is seen that in this case the maximum amplitude instead of being twice as great as that of the component waves is only 1.41 ($=\sqrt{2}$) times as large. The frequencies and original amplitudes have remained as in Figure 1. The reason for the change of the amplitude of the resultant wave is, of course, that for Figure 1 the maxima of the resultant waves occurred at the same time, whereas in this case they do not. The graphical result may be confirmed mathematically by a process similar to that for Figure 1. The following expression:

$$i=I_1 \sin \omega_1 t+I_1 \sin (\omega_1 t-\theta) \qquad (4)$$

shows the addition of two terms, the first representing curve A, and the second, curve B. By a simple trigonometric and algebraic transformation, equation (4) becomes

$$i=I_1 [\sin \omega_1 t (1+\cos \theta)-\cos \omega_1 t \sin \theta] \qquad (5)$$

For the case of Figure 2 we have assumed the phase displacement 90°, therefore $\sin \theta = 1$ and $\cos \theta = 0$. So that equation (5) becomes

$$i=I_1 (\sin \omega_1 t-\cos \omega_1 t) \qquad (6)$$

$$=I_1 [2 \cos 45° \sin (\omega_1 t-45°)] \qquad (7)$$

$$=1.41\ I_1 \sin (\omega_1 t-45°) \qquad (8)$$

Expression (8) exactly agrees with the graphical results of Figure 2.

It is seen that as the phase displacement is increased, the two component waves oppose each other for larger portions of the total time. From this it would be expected that for some value of θ the two waves might completely neutralise, and there would be no resultant action. That this may occur is shown in Figure 3, where two waves of the same frequency and amplitude as in Figures 1 and 2, but having a phase difference of π radians or 180° are shown. The sum of these two waves is zero at all points. Indeed, if we substitute for θ in equation

(5), the value 180°, we obtain immediately for the resultant:

$$i = 0.$$

Evidently the addition of two sine waves of the same frequency, but of different phases, will produce a new sine wave having an amplitude lying between the difference and the sum of the component amplitudes as the phase difference varies from 180° to 0°.

However, if the frequencies of the A and B waves are not equal, the amplitude of the resultant wave will not be constant, but will be affected by the constantly varying difference of phase of the component waves. The complete mathematical solution of this case is somewhat complicated, but a clear idea of the phenomena involved can be obtained by the graphical method. It will be found that in general, the result of the addition (which includes subtraction or negative addition) of two waves of different frequencies is to produce a third wave having a fundamental frequency of the same order, but varying in amplitude from the difference of the component amplitudes to their sum. This variation in the size of the resultant wave is periodic, and occurs at a frequency equal to the difference of the frequencies of the component waves.

This regular, periodic variation of amplitude forms the basis of the entire science of harmony in music. The waxing and waning of a wave resulting from the addition of two notes of slightly different pitches form what are called "beats." Figure 4 represents two waves of different frequencies, together with the resultant wave found by adding them point by point. The A wave, shown on the top axis, is taken to have a frequency of 250 per second, while the B wave is of frequency 200. The amplitudes are seen to be the same, say 10; and the difference in frequencies is 50 per second. On the three diagrams, the axes extend for a distance representing one-tenth of a second, so that 25 of the higher frequency and 20 of the lower frequency waves are shown. Examination of the C axis shows that, as was to be expected, there are 5 complete beats or periodic variations, which correspond to a beat frequency of 50 in one second.

In every case so far considered, the component waves have had the same amplitude. Figure 5 shows the addition of two waves having the same frequencies, as in Figure 4, but with amplitudes of 10 and 2 respectively. It should be noted that the variation of amplitude is from $I_1 - I_2 = 8$ to $I_1 + I_2 = 12$, and that the beat frequency is the same as in Figure 4. It should also be noted that whereas the smaller component wave B has an effective amplitude of only 2, the variation in the resultant wave is twice that. These theoretical considerations of the addition of wave motions may be verified experimentally.

We may take two organ pipes and connect them to a tank of compressed air thru separate valves, so that they may be blown individually or together. One of the pipes is of variable pitch, its frequency being alterable thru a considerable range. If both pipes adjusted to equality of pitch are blown simultaneously, a note of this pitch and of a volume twice as great is secured. If it were possible to blow both pipes so that they vibrated in opposite phase, it would be possible to secure complete neutralization of sound, that is, silence. This cannot be done experimentally with organ pipes. However, a somewhat similar effect may be secured by moving one of the pipes back and forth, and so changing the loudness of the resultant sound (due to direct transmission and indirect reflection from the wall) in some parts of the room. This indicates a change in the degree of addition or neutralization due to a variation in phase difference. These beats are also shown even more perfectly by the use of the clear tones produced by ordinary singing flames.*

If the two organ pipes have slightly different frequencies, the conditions of Figure 4 will hold. One pipe has been adjusted to 500 vibrations per second, corresponding roughly to the note C' and to a wave length in air of 0.6 meter (2.2 feet). If the other has a slightly different pitch, when both are blown together, there will be produced a tone which shows a slow increase and diminution of volume, the number of beats per second being determined by the difference of the frequencies of the organ pipes. If the difference of pitch is slightly increased, the beats increase in frequency, and if the difference of frequency of the pipes is still further increased, the beat frequency increases till finally the fluctuations can no longer be heard. When both organ pipes produce sounds of the same intensity, the beats are very marked. But even when the tone from one pipe is made very weak by shutting off part of the air supply, the beats are still very distinct, as would be expected from inspection of Figure 5. As a rule, the beats are more prominent than the weaker of the two component

*(The experiments herein described were performed at the original presentation of this paper before the INSTITUTE. Editor.)

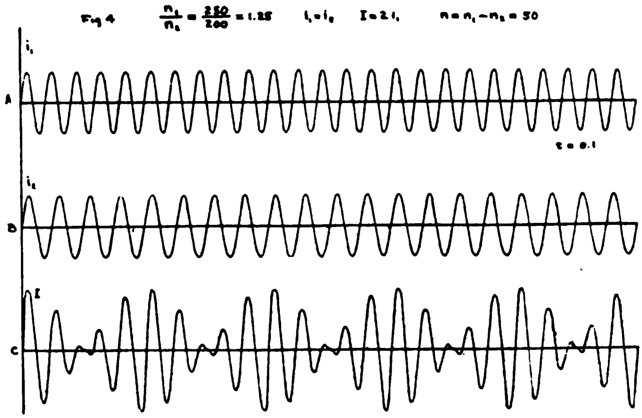

Figure 4

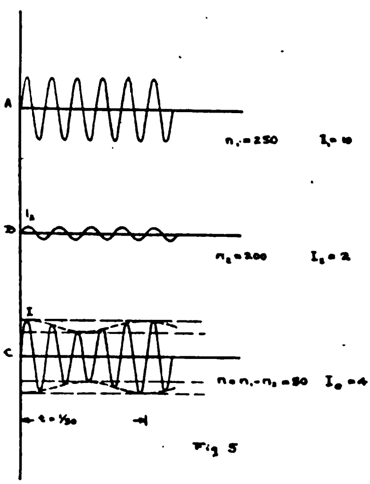

Figure 5

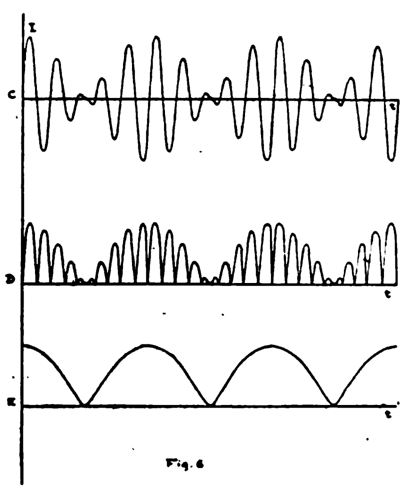

Figure 6

tones, and this fact is often made use of by engineers working in acoustic problems to determine the presence of a weak tone which cannot itself be heard because of other noises.

The acoustic effects described have their exact analogues in electricty. If we had two small alternators independently driven and with separate controlling resistances (so that their frequencies, phases, and amplitudes might be changed at will), it would be possible by varying the several resistances to secure all the effects shown in the preceding figures.

Changing the frequency of the interesting waves does not affect the production of beats so long as the difference between the frequencies is kept constant, except as the component or fundamental frequencies affect the responding mechanism. Responders or indicators are of two broad classes, polarized and non-polarized. A polarized indicator is one in which a displacement in one direction will produce a motion in a certain directon, and a dsplacement in the other direction will produce a motion in the opposite direction. Examples of this class are the ear and the ordinary magnetic telephone. In non-polarized indicators a motion is produced in a certain direction regardless of the polarity of excitation. That is to say, a positive displacement will produce the same motion as an equal negative displacement. Examples of this type of indicator are the static telephone and the magnetic telephone having no permanent magnet. Referring to Figure 4, and considering a wave motion in air represented by the C wave affecting a polarized indicator such as the ear, it is evident that the ear drum follows exactly the curve of excitation. It is also evident that as the frequency is increased indefinitely a point will be reached at which the ear drum cannot follow in its movements the rapid fundamental vibrations, tho it could move at a frequency corresponding to the beats. Air vibrations which approach and even pass this upper limit of audible vibration frequency may be produced by the use of a Galton whistle, and by moving this instrument back and forth in front of a reflector, beats in the high frequency note can be produced because of the interference between the direct and reflected waves. It is found that beats of sound can be heard up to the limit of audibility, but so soon as the whistle produces an air wave which cannot itself be heard, the beats become inaudible.

The reason for this can be seen from Figure 4 C. When the note frequency is so high that the inertia of the ear mechanism prevents any response to individual half waves, the applied wave energy alternates so rapidly that its effects are alternately equal and opposite, and there is no tendency toward motion of the drum. When the fundamental wave itself produces no motion regardless of its intensity, it is quite evident that variations in this intensity will produce no effect, and therefore that beats are inaudible under these conditions. The beats really exist none the less, and this may be proved by noting that even tho they are inaudible to some persons, others whose ears have a higher limit of audibility can still hear the variations in amplitude of the fundamental whistling tone.

The conditions are completely changed, however, if, instead of a polarized device, there is used one which is non-polarized, or one in which there is given an effect proportional to the integrated applied energy, regardless of the polarity or direction of displacement. Figure 6 applies to an instance of the second sort. In this diagram, the curve along the C axis is exactly like that of Figure 4. If motion in the same direction is produced for either positive or negative displacements, such motion will be shown by the curve D of Figure 6, which is the curve C rectified. A little consideration will make it clear that in this case, as the frequency of the component tones is increased (provided their difference is kept the same), there will still be a motion corresponding to the frequency of the beats even tho the responding mechanism can no longer follow the indivdual waves. The motion which will result is shown along the E axis.

The possibility of building a radio receiver based on the beats principle should now be evident. If two radio frequency currents of slightly different periods are allowed to interact, there will be a periodic variation of amplitude of the resultant radio frequency current, and this variation or beat frequency will be equal to the difference of the two fundamental frequencies. As is well known, it is not possible to indicate the existence of a radio frequency current by means of a polarized indicator such as the magnetic telephone of the usual type, since the wave frequency is beyond the upper mechanical limit of response of such indicators. An air core telephone, or one without a permanent magnet, would give an indication when such currents passed thru it, since it belongs to the non-polarized class and operates in a manner analogous to that shown in curves D and E.

The development of the heterodyne receiver by Professor

Fessenden and the engineers of the National Electric Signaling Company may now be considered. Figure 7 shows the first device in which the heterodyne principle was employed. Here A and A′ are separate receiving antennae, B and B′ loading coils, and C and C′ additional coils so arranged that their resultant field will act upon the diaphragm D. If, at a transmitting station two sustained waves of slightly different frequencies are sent out, and at the receiving station one antenna is tuned to each, their conjoint action will result in a motion of the telephone diaphragm corresponding to the difference of their frequencies. Signaling may be effected by sending short or long groups of both waves simultaneously, or one wave may be generated continuously and the signals sent by starting and stopping the other one. It is evident that an economy may be brought about by transmitting only one wave, and generating the second frequency at the receiving station. Figure 8 shows the apparatus arranged for this method of operation, and in this sketch G represents a radio frequency generator, and F and H tuning inductance and condenser respectively. The local generator G is under the control of the receiving operator, and therefore the difference between its frequency and that of the waves received from the transmitting station may be varied so as to give vibrations of the diaphragm D corresponding to any musical note which the operator may prefer.

The form of telephone shown in Figures 7 and 8 was found not to be a very efficient receiver, so that the sensitiveness of the entire system was improved by the use of a thin insulating diaphragm carrying one coil, this being placed in the field of the second fixed coil C, Figure 9. With this arrangement the effect is the same as in Figure 8, except that the repulsion between the coils as well as attraction is used. A still further increase in sensitiveness was attained by substituting for the dynamometer type a delicate static telephone as shown in Figure 10. This arrangement, together with one equivalent to it (in which the static telephone was placed in a coupled circuit) has been used by the Company for some time, and is effective. The arrangement gives a sensitiveness equal to that of the usual detector for persistent waves, yet the selective power is much higher and the response to static far less. With the arrangement shown in Figure 10, I have personally received signals over distances of approximately 3,000 miles (4,800 km.), altho the static telephone

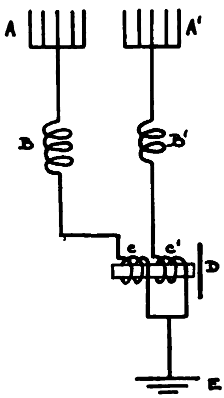

Fig. 7.

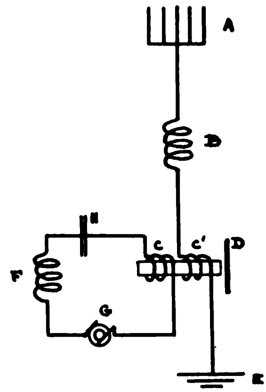

Fig. 8.

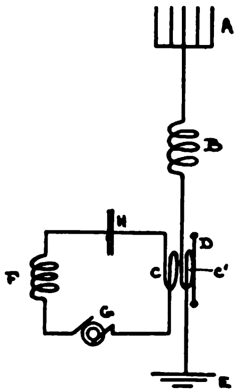

Fig. 9.

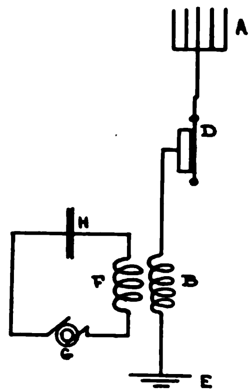

Fig. 10.

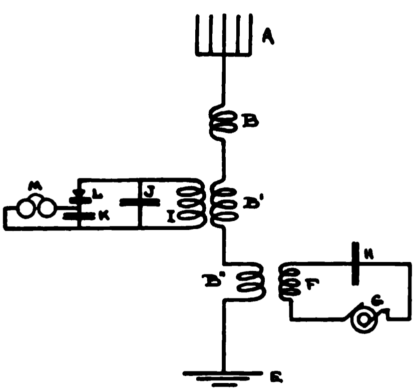

Fig. 11.

is notoriously insensitive, and such results might appear incredible.

A further reference to Figure 10 will serve to show how the effective receiving power of the static telephone is increased by the application of the heterodyne principle. From the sketch it is clear that any current flowing in the antenna by way of the static telephone D will cause a motion of the diaphragm. The sound energy produced by this action will be proportional to the electrical energy, that is, to the square of the antenna current. If we consider the received wave as setting up the antenna current, it is seen that if the former is of audible frequency and sufficiently powerful, the diaphragm will give an audible indication of frequency twice that of the received wave. If the frequency is increased beyond that to which the diaphragm can respond, motion will be produced only at the beginning and ending of the trains of waves, and during all the time radio frequency current is passing, the diaphragm will remain in a state of steady strain. If such radio frequency waves are received in groups, there will be a pull on the diaphragm for each group, and the group tone will be produced with a strength proportional to the square of the antenna current. If we assume that no waves are being received, but that the generator G is in operation, the effects produced will be the same as outlined above. So long as the generator produces a stream of sustained radio frequency current, the diaphragm will remain strained toward the fixed plate, and motion will be produced only when the generator current is altered in value. If a stream of waves is received by way of the antenna, and at the same time the local generator is operated to produce currents of a slightly different frequency, the effects in the antenna may be considered to be those shown in Figure 4, where A represents the locally generated current, and B shows that from the received wave. These two series of alternating impulses acting simultaneously on the static telephone produce effects corresponding to the rectified form shown in Figure 4 C. Since attraction of the telephone diaphragm results from any increase of the electromotive force, regardless of the polarity, the tendency toward movement is shown by Figure 6 D. Inasmuch as the inertia of the diaphragm prevents the indication of the individual waves, its actual motion is shown in Figure 6 E. If the incoming wave has a frequency of 100,000 cycles per second (corresponding to a wave length of 3,000 meters) and that of the generator is 101,000, a musical beat tone of frequency 1,000 will be produced by the static telephone and the intensity of this sound will be *proportional to the square of the beat variation.*

What value this action has in increasing the strength of signals may be determined from a brief consideration of a mathematical explantion which has been proposed. Assuming a receiving current of i_1 milliamperes, it is clear that if the train be started and stopped by some form of interrupter the signal will be measured by $(i_1)^2$ audibility units since the response is proportional to the square of the antenna current. If, instead of interrupting the incoming wave, there is induced in the antenna a second locally generated radio frequency current of i_2 milliamperes, the resulting instantaneous valve will be

$$i = i_1 + i_2 \qquad (10)$$

The component of the antenna current measured by i_1 varies from zero to its full value as the signals are started and stopped, but the value of i_2, which is generated at the receiving station, remains constant. If the audible response were proportional to the current, there would be no increase in it due to adding i_2. But since this response is proportional to the energy, or current squared, it is proportional to

$$i^2 = (i_1)^2 + 2\, i_1\, i_2 + (i_2)^2 \qquad (11)$$

Considering now the various components of this antenna energy factor, the part represented by $(i_1)^2$ starts and stops with the signal dots and dashes, but is of inaudible frequency, and therefore does not add to the tone signal in the static telephone. The component $(i_2)^2$ is constant, and therefore forms no part of the signal. The remaining component, $2\, i_1\, i_2$ measures the signal, since it represents the beat itself. The response is proportional to the energy of the beat variation, that is, to

$$(i_1 + i_2)^2 - (i_1 - i_2)^2 = 4\, i_1\, i_2 \qquad (12)$$

The effective amplitude is one-half of this. It is therefore clear that with the heterodyne receiver it is possible to get a signal y times as loud as with the plain static telephone, where y is defined by

$$y = \frac{2\, i_1\, i_2}{(i_1)^2} = \frac{2\ i_2}{i_1} \qquad (13)$$

From (13) it is seen that if the current drawn from generator G, (Figure 10) is less than one-half that received, there will be no improvement in the signal, but as soon as more is taken from the local circuit an increase in effective sensitiveness is had. Values of current for an actual case may be taken as $i_1=1$ milliampere and $i_2=100$ milliamperes, which gives a value of $y=200$. In other words, under these conditions the signals received by the heterodyne will be 200 times as loud as tho the plain static telephone were employed with no local excitation. Since such a ratio of i_2 to i_1 is not at all out of the ordinary, the increase of sensitiveness which makes possible reception over distances of 3,000 miles (4,800 km.) may easily be understood.

It should be noted that the theoretical amplification factor expressed by y in equation (13) holds only for the interaction of two sustained sine waves. If damped waves are used, the beats will still be generated, but they will become weaker as the decrement of the received wave is increased, since as the beats tend to build up, the decreasing amplitude of one of the component waves will tend to reduce them. With highly damped discharges such as those produced by atmospheric disturbances, only a portion of a beat is produced, and therefore the response to static is small. But with the waves of a well-adjusted spark station of the synchronous rotary or fixed quenching gap types the amplitude ratio may reach comparatively large values. This obviously provides a means for selecting persistent signals and eliminating undesired atmospheric disturbances.

The heterodyne receivers described above are limited in practise by the low sensitiveness of the indicator, but this handicap has been removed by the adoption of the type now in use. This last arrangement is shown in Figure 11, where A and E represent antenna and ground, and where B′ and B″ are coils forming the antenna-to-ground circuit. I is a secondary coil and J a tuning condenser, K and L are respectively rectifier and telephone condenser, and M represents a magnetic telephone of the usual type. F G H shows the ordinary local generating circuit, coupled to the antenna thru the coils B″ F. In this apparatus the action is exactly as described above, the rectifier-telephone combination taking the place of the other non-polarized receivers. Referring to Figure 6 the action may be explained by considering that the C curve represents the currents in the radio frequency circuits, while rectified currents pass thru the telephone windings and produce a motion of the diaphragm corresponding to E. It is clear that in this arrangement of apparatus the amplifying power of the heterodyne system may be combined with the sensitiveness of the normal rectifier and telephone. The difficulty due to the delicacy of the usual detector has been overcome, and it is possible to get tremendous amplifications of sustained waves and very valuable increase of signal intensity even when receiving from spark transmitters.

NOTES ON THE RECENT ARLINGTON-SALEM TESTS

Heterodynes of the type last described were installed at Arlington and aboard the Salem for the recent tests between those stations, and were used as the extreme distances were approached. During these trials the greatest amplification factor measured was 12 times, and the average thruout the test was about 5. That is to say, spark signals from Arlington or from the Salem were received on the heterodyne an average of 5 times louder (as measured by the audibility factor) than upon the electrolytic detector operating alone. This increase in effective senstitiveness, together with auxiliary apparatus of especially efficient design, made possible the great communication distances attained, altho even without the heterodyne new records for consistent communication between ship and shore would have been established. In connection with reports of this test which have appeared in various newspapers and scientific periodicals, it should be noted that the spark transmitter and Fessenden receiver were used for all official communication trials, but that a number of other receivers, including a ticker, were placed aboard the Salem by the Navy Department for some special tests. In some of these experiments an arc transmitter which had been temporarily installed at Arlington was used. A statement has been made to the effect that signals from the arc were received further than those from the spark transmitter, and this in itself is true, altho it leads to an erroneous idea as to the reasons for the occurrence. The explanation is simply that the heterodyne was used for receiving all signals at long distances, whether from the arc or from the spark transmitter, the ticker receiver having been abandoned by the Navy engineers within the first few days of the cruise, since results from it were not to be compared with those obtained with the heterodyne.* The heterodyne amplifies sustained waves such

* Dr. Austin is of the opinion that the rotary ticker used on the "Salem" was probably in some way defective, as it did not appear more sensitive than the electrolytic even, altho ordinarily it shows a sensitiveness of from three to ten times greater.—Editor.

as those from the arc more than waves occurring in groups (such as produced by the spark transmitter) and it is this fact, rather than anything else, which explains the larger transmission distances quoted. In this connection it is also interesting that while "D's" were received from the arc transmitter further than from the spark apparatus, no daylight message test was made with the sustained waves, and hence no communication data such as that upon which the main test was based could be obtained for arc sending.

The heterodyne of Figure 11 is seen to consist of a standard receiving set associated with a local generating circuit by means of an inductive coupler. The generator G may be an alternator such as that shown in Figure 12, which is a 2 K.W. machine capable of generating frequencies up to 100,000 cycles per second, or it may be an arc or other form of oscillation producer. Figure 13 shows a unit containing variable inductance and capacity for all wave lengths from 600 to 11,000 meters, such as was used at Arlington and aboard the Salem. Figure 14 shows the sound-proof receiving room at Arlington with the apparatus used in the scout cruiser test, the heterodyne generator standing at the right hand and the usual receiving apparatus at the left side.

A further example of the amplifying power of the heterodyne receiver is found in a test between Boston and New York some time ago in which the antenna current of the spark transmitter at Boston was cut down, and the intensity of the signals received at Brooklyn measured by the shunted telephone method both on the regular receiver and on the heterodyne. The results are given in the following table:

BOSTON TO NEW YORK.

TRANSMITTING ANTENNA CURRENT	AUDIBILITY FACTOR		RATIO
	ELECTROLYTIC	HETERODYNE	
20 amp.	108	600	5.5
10	22	130	5.9
7	19	124	6.5
4	6	100	16.6
1	0	10	Infinite

From this it is seen that even with spark signals it is possible to read on the heterodyne messages which could not be heard at all on the regular receivers, and this of course greatly increases the distances over which radio communication is possible.

The quantitative results secured on the scout cruiser test permit an experimental verification of the Austin-Cohen transmission

Figure 12
2 KW-20,000 RPM-110 Volt Generator
100,000 Cycles, Single-Phase, Gear-Connected to 2000 RPM-120 Volt Direct Current Motor.

Figure 13

Figure 14

equation. In Figures 15, 16, 17, and 18, the curves give the values of the audibility factor calculated in terms of the distance between the stations. The crosses show the actual observations, and it will be seen that the agreement is quite satisfactory. Having determined the relations between the audibility factors, antenna currents, heights of antennae, wave lengths, and distance for ordinary receivers, and also for the heterodyne receiver, it is possible to compute the latter's communication ranges under any set of assumed conditions. Thus, by selecting constants which would apply to two stations of the Arlington type, it is possible to find suitable communication distances for various wave lengths and desired intensities of received signals, and so to arrive at feasible separations for a chain of similar plants. The results of such a series of calculations are shown in Figures 19, 20, and 21. These figures are the result of a graphical method of solving the Austin-Cohen equation. In them A_f represents the audibility factor, I_s the transmitter current, h_1 and h_2 the heights of the transmitting and receiving antennae respectively, and A and B are given the following expressions:

$$A = s$$

$$B = \frac{392\, I_s\, h_1\, h_2}{\lambda\, s\, \varepsilon^{\frac{0.0474\, s}{\sqrt{\lambda}}}}$$

where s is the distance between the stations. The reason for the adoption of these particular expressions is as follows. The Austin-Cohen equation then takes the form

$$A - B = O.$$

Consequently if we plot A against s (giving us the straight lines which pass thru the origin at 45°), and on the same sheet plot B against s (which gives us the curves concave to the axes as shown), the intersection of the A straight line with the B curve determines that value of s which satisfies the Austin-Cohen equation. We are forced to use the graphical method just described because of the transcendental nature of the original equation, which does not permit of a simple algebraic solution.

Inspection of the curves shows how markedly the signaling range of the stations increase as the required audibility factor is diminshed and as the wave length is increased.

In Figure 22, the full line gives the strength of signals from Arlington at night, as plotted from actual observation on the audibility factor at various distances. The dashed curve gives

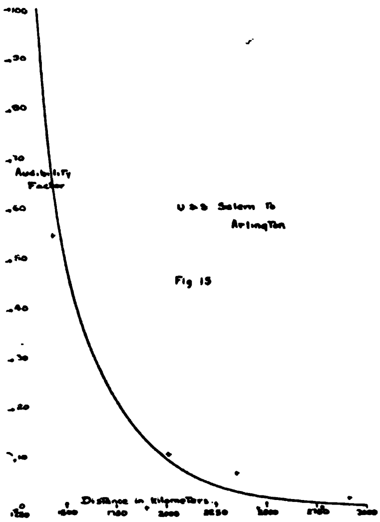

Figure 15

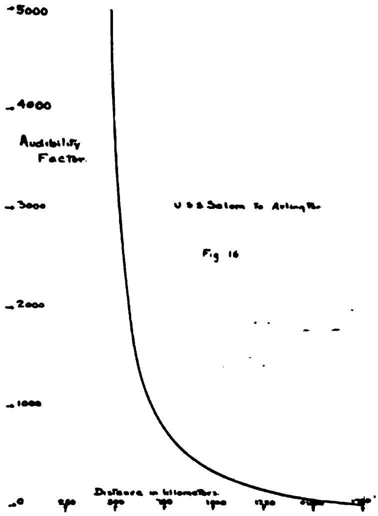

Figure 16

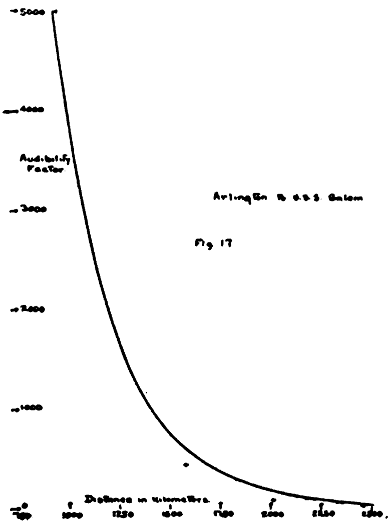

Figure 17

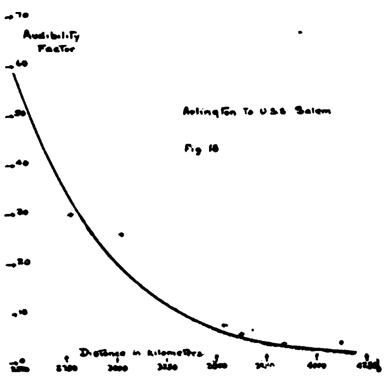

Figure 18

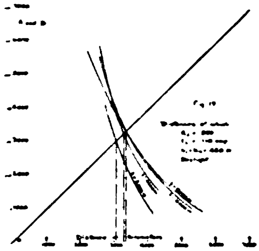

Figure 19

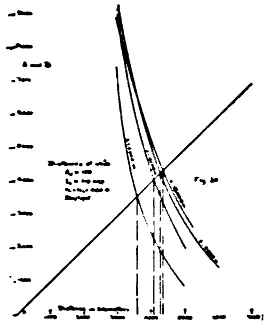

Figure 20

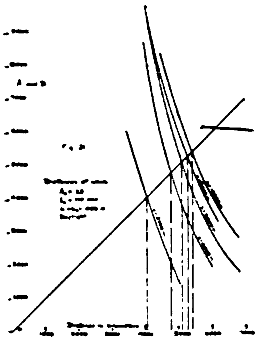

Figure 21

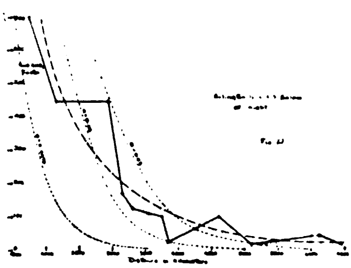

Figure 22

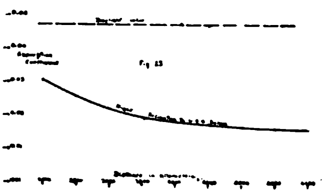

Figure 23

the smoothed average of these observations. The three dotted curves are calculated from the Austin-Cohen equation for *daylight* transmission and for three different values of the absorption coefficient. It is evident that night absorption follows a different law from daylight absorption because the dashed curve crosses two of the dotted curves. This is further verified by Figure 23, wherein the absorption coefficient is plotted against distance for day and night observations. It will be seen that the night values follow a different law from the constant daylight values.

It is to be noted that the data based on the scout cruiser trials and the test between Boston and New York has reference only to receiving with heterodyne from spark transmitters. When sustained waves are used the sensitiveness of the receiving apparatus is further and greatly increased, and the signals have a perfect flutelike note of any frequency the operator may prefer, yet static is not amplified by the apparatus. A still more effective type of the receiver is being worked on, and shows great promise, but even in the form described, this invention of Professor Fessenden bids fair to work a revolution in radio communication.

SUMMARY: Detectors are classified as of the relay or of the transformer type. Relay detectors are arranged so that the energy for the indicator response comes from a local source of energy at the receiving station. Transformer detectors utilise the received energy for producing the indicator response. The need of an amplifying transformer type detector, which selectively neglects static, is mentioned. The basis of the heterodyne receiver, namely, the audible beats produced by the interference of two vibrations of inaudible (radio) frequency received on a non-polarized receiver, is then fully considered. The development of the heterodyne receiver, its circuit arrangements, and the apparatus employed are described in detail. The use of the heterodyne in the Arlington-Salem tests and the results obtained are given.

DISCUSSION.

ROBERT H. MARRIOTT: How can you arrange to receive radiotelephone messages with the heterodyne receiver?

JOHN L. HOGAN, Jr.: We bring the beats at the receiving station to a point above audibility.

EMIL J. SIMON: What form of sustained wave generator was used in the Boston and Arlington tests?

JOHN L. HOGAN, Jr.: The arc was used in both these tests.

JULIAN BARTH: What arrangements were made in the Arlington tests to permit rapidly following changes of wave length of the transmitting station?

JOHN L. HOGAN, Jr.: The heterodyne receiving set was directly calibrated in wave lengths, and was very easily manipulated for tuning.

GUY HILL: I regard the tests between Boston and Brooklyn as very remarkable, and have personally witnessed such results as Mr. Hogan describes. It is certainly notworthy that spark signals can be amplified to so marked an extent by the heterodyne receiver.

JULIUS WEINBERGER: Has the heterodyne receiver been used with damped wave trains at the receiving station, generated, for example, by the use of the usual buzzer circuit?

JOHN L. HOGAN, Jr.: It has been so employed, but the amplification is not large and the tone is impure.

DR. LOUIS COHEN (by letter): As a matter of record, and in the interests of historical accuracy, it is desirable to give a brief history of the development of the heterodyne receiver. About 1907 or 1908, Professor Fessenden conceived the splendid idea of utilizing the best phenomena for the amplification of radio signals, and also for the elimination of interference. Essentially the operation of the heterodyne is as follows: We superimpose on the incoming signal another current from a local source, of a slightly different frequency; and the operation of the detector is determined by the resultant of the two currents, which gives a current of variable amplitude. If I_1 is the incoming current, I_2 the local current, ω_1 and ω_2 their "angular velocities" (2 π times their frequencies), β the difference of their angular velocities, and φ_t a variable angle, the resultant current can be written in the form:

$$I = \sqrt{I_1^2 + I_2^2 + 2\, I_1 I_2 \cos \beta t \cos (\omega_1 t + \varphi_t)}. \qquad (1)$$

If the response of the indicating instrument is proportional to the square of the current, as in the case of an electrodynamometer, the response of the instrument is given by the product of a constant and the square of the value of I above. As a detecting instrument, Professor Fessenden used an electrodynamometer telephone or an electrostatic telephone. The latter was found to be far more sensitive, and is generally used now.

From equation (1) above, it can be readily seen that the variable part of the amplitude of the force is proportional to the products of the currents I_1 and I_2, hence the amplifications may be considerable. Furthermore, if the value of the beat frequency is above three thousand or so, that note will be above the limit of practical audibility; consequently signals differing in frequency by only a few per cent. from that of the local current will not be heard in the telephone.

Professor Fessenden in all his experiments used only persistent oscillations. In fact, he used radio frequency alternators giving slightly different frequencies, one at the transmitting and the other at the receiving station.

On taking charge of the research department of the National Electric Signaling Company, this work was turned over to me for further development. The idea suggested itself that it was possible to use the same principle for the reception of spark signals, and that, employing the arc as a local source of radio frequency currents, amplification could be obtained. This would give a more flexible and adaptable system. In carrying on this work on the heterodyne, I had the able assistance of Messrs. Forbes, Lee, and Van Dyck.

The principle utilized in the amplification of the damped oscillations is practically the same as in the case of sustained oscillations. Using the same symbols as before, with the addition of a, the damping factor of the incoming signal, we have

$$I = \sqrt{I_1^2 \varepsilon^{-2at} + 2 I_1 I_2 \varepsilon^{-at} \cos \beta t + I_2^2 \cos (\omega_1 t + \varphi_t)} \quad (2)$$

Since I_1 is generally small in comparison with I_2, we neglect the first term under the radical, and thus get a periodic force, acting on the receiver, of the beat frequency $n = \frac{\beta}{2\pi}$ and damping factor a. If the damping is not large we shall have partial beat formation. The beats are not so distinct, and the note is not so pure as in the case of the interaction of sustained oscillations, but we do get a note which is independent of the spark note and which can be varied at will by altering the frequency of the local source. The practical difficulty which arises is that slight variations in I_2, the current from the local source cause considerable disturbances in the telephones because the local current is large compared with the received current. A special arc giving a pure sine wave, and working quietly was therefore devised, and before I left the Company the heterodyne receiver working between Boston and Brooklyn was giving very good results.

While the arc was being developed, experiments were also carried on to determine the best sensitiveness of the herodyne, the most suitable detector, design of apparatus, and various other special details, which can not be adequately discussed here.

It may be noted here that, since the force acting on the electrostatic telephone is proportional to the square of the *voltage,* it must vary inversely with the (frequency) ^{2} for a given current thru the telephone (which is merely a capacity); hence the lower the frequency the greater the sensitiveness. For short wave lengths, the electrostatic telephone is therefore not suitable, but for wave lengths of 3,000 meters and more it compares favorably with the most sensitive receivers.

Finally, it may be mentioned that the heterodyne principle may be applied in connection with any of the common types of rectifying detectors, but in that case, while considerable amplification is obtained, no beat formations occurs. The reason is the following. In the case of the electrostatic telephone the response is proportional to the maximum force acting on it, while the rectifying detector depends for its action on the integrated effect of the square of the current. We shall have then for the force

$$F=\int_0^\infty I_1 I_2 \varepsilon^{-2at} \cos \beta t \, dt.$$

If we put $\beta=0$, which means equality of frequencies of incoming and local currents, the effect will be proportional to I_1I_2, and we shall have an amplification in the ratio of $\frac{I_2}{I_1}$.

Mr. Van Dyck carried on some experiments at Brant Rock at my suggestion, receiving signals from the New York Herald station on a crystal detector and amplifying them by means of an arc circuit in accordance with the heterodyne principle. He has found that under favorable conditions we may get an amplification of twenty to fifty times.

H. E. HALLBORG (by letter): Mr. Hogan has ably shown that the theory of beats is as important relative to the heterodyne receiver as the theory of resonance is to coupled circuits in general. The beat phenomena are well illustrated in the paralleling of two alternators. The synchronising lamps flicker rapidly when the frequencies of the machines are widely different, but the lamps may either glow with great brightness, be quite dark, or glow with any intermediate brilliancy (depending on the permanent phase relation between the currents produced by the two machines) when the frequencies are the same. Interesting permanent records of such beat phenomena could easily be obtained by the oscillograph.

During the first tests between the Scout Cruisers "Salem" and "Birmingham" in 1910, I was in charge of the transmitting apparatus at Brant Rock. When receiving from the ships on the 3,750 meter wave, Mr. G. W. Lee, the Chief Operator, always insisted on my starting the radio frequency alternator (100,000 cycles). It was run on open circuit, but with the field excited. A marked increase in audibility at this wave length was thus attained. The beats in this case were in the neighborhood of 20,000 per second, and therefore above audibility. It is interesting to note that the circuit conditions were those which the Company has now found to be the best, replacing the static telephone arrangement. Pressure of routine work at that time prevented further investigations, and it remained for the engineers of the Company to complete the development of the apparatus at a much later date.

The heterodyne, when worked with sustained oscillations, naturally gives considerable freedom from tapping of messages by the amateur. However, until a much simpler and more reliable method of generating radio frequency currents than the present arc or alternator is devised, the heterodyne system will be a shore station equipment, particularly adapted for working at fixed wave lengths. The elements of the circuits have to be so simplified that an experienced engineer is not an essential feature of each installation. For the present, at least, it seems to me that its sphere of usefulness is practically limited to large shore installations.

MR. JOHN L. HOGAN, Jr. (by letter): The discussions by Dr. Cohen and Mr. Hallborg are of distinct interest in connection with the commercial development of the heterodyne. I can confirm Mr. Hallborg's comments concerning reception from the U. S. S. Birmingham and Salem spark transmitters early in

1910, and remember very well an occasion on which the frequencies of the local alternator and the ship transmitter were so nearly alike that audible beats were produced in the telephones of the usual liquid rectifier receiver. The heterodyne is much more suitable for commercial radio signaling than when either Mr. Hallborg or Dr. Cohen were familiar with it, and is not limited in its use either to fixed wave lengths or to shore stations.

Inasmuch as some of the dates and conclusions given by Dr. Cohen cannot be considered in agreement with facts, I am taking the liberty of correcting his two most essential errors. Professor Fessenden's conception of the heterodyne principle dates back at least to 1902, since the receiver of Figure 7 in my paper is shown in his U. S. patent 706,740 issued on August 12th of that year. In the apparatus using a local oscillation generator in combination with a standard rectifier receiver electrical beats are produced and utilized. That this is a fact may be proved by noting that the apparatus is effective for aural reception of sustained waves and that the audio frequency produced is equal to the difference in the fundamental oscillation frequencies.

The heterodyne is still the subject of rigid research, and its progress has been based upon interpretation and understanding of physical facts observed under differing conditions, rather than on any isolated suggestions of a single investigator. The maximum of credit is due to Professor Fessenden, for he made the fundamental invention compared to which the improvements brought out by such of us as have continued the work are indeed small.