Volume I Part 1

PROCEEDINGS
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INSTITUTE OF RADIO ENGINEERS

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EDITED BY
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A DISCUSSION ON EXPERIMENTAL TESTS OF THE RADIATION LAW FOR RADIO OSCILLATORS.*

Opened by PROFESSOR MICHAEL I. PUPIN, PH.D., *Professor of Electro-Mechanics, Columbia University.*

I have been requested to speak before your Institute and I replied that, altho I am much interested in radio-telegraphy, and have done some work in that field, yet at the present time my chief interest lies in another direction. However, my work during the last three or four years has suggested a method which might prove useful in determining the law of radiation from antennae.

I number among my friends many workers in the radio field, among them such men as Professor Braun, Marconi, Hewitt, de Forest, Fessenden and Max Wien; the last being a colleague of mine, a fellow-student, and one with whom I have corresponded in regard to the matter of the determination of the radiation law. It struck me that there was one thing which perhaps these men have not done as thoroly as it might be done, and that is the determination of the relation between the frequency of the alternating current in the radiator and the capacity of the radiator to throw off energy. Of course you all know that the higher the frequency, other things being equal, the faster the energy is radiated. But what is the exact law, and what its theoretical foundation? I have always been interested in that. I have, for instance, asked Mr. Fessenden whether forty thousand cycles is sufficiently high for efficient radiation, and he replied that even lower frequencies might be employed. Marconi at that time said that he preferred a half million cycles per second, and thus we encountered a difference of opinion.

The extremely high frequency of these currents viewed from the standpoint of ordinary electrical engineering technique makes it difficult to produce trustworthy generators, and the higher the

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* Lecture delivered before The Wireless Institute, one of the component societies which combined to form the Institute of Radio Engineers.

frequency, the more difficult it becomes to produce a high power generator of continuous oscillations. Of course, if we are satisfied with currents which die away as rapidly as the sound from the crack of a whip, there is no difficulty in producing machinery of that kind. But if we wish to produce sustained electrical oscillations the problem becomes much more difficult. I regard the one hundred thousand cycle alternators which the General Electric Company produced for Mr. Fessenden, to deliver two kilowatts, as a triumph of mechanical knowledge and engineering skill. If frequencies higher than this are required, it becomes almost impossible to produce the machine, if a considerable output is required.*

If frequencies of between twenty and forty thousand cycles could be used, the conditions would be much more favorable, as it is quite within reach to make alternators of considerable output, say ten kilowatts, or more, for these frequencies. If radiotelegraphy is ever to become an important branch of electrical engineering, its advance will be brought about when we have very powerful generators capable of producing continuous radiation, and the simplest way of obtaining such a generator is by means of the high power alternator. Even at the present time the most nearly ideal way of producing such undamped radiation is by the use of the high frequency alternator.

As I have said, if we could get along with forty thousand cycles a second it would not be difficult to build an alternator of the requisite power. But how can we tell if forty thousand cycles would be satisfactory? We can tell only when we know the law of radiation, the relation between the frequency and the energy radiated at that frequency. At the present time this cannot be said to have been completely done.

There are two ways of arriving at the law of radiation. There is a purely mathematical way. Thus we may consider the case of a high vertical wire connected to the ground, which we may take to be a good conductor. It may also for purposes of approximate calculation be assumed to be an infinite plane. We know how the rate of radiation in this case varies with the frequency, but even this simple case has not been completely solved.

When we come to the complicated forms of antennae which we use in practice to-day, it becomes excessively difficult to work out the theory mathematically. But even if we could work it

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* See Editorial Notes at the end of this Discussion.

out completely mathematically, a simple experimental method would be preferable for many purposes. When Maxwell first worked out the formula for the inductance of a cylindrical coil, he produced an elaborately beautiful formula for calculating the inductance in terms of the length of the coil, the size of the wire, and various other quantities. But at the end of his calculations he says that even in this simple case the experimental method would determine the desired quantity much more satisfactorily than the mathematical method. In the case of the antennae employed in radio-telegraphy this is even more so. Even if we had the formula for the energy radiated from the antenna at various frequencies, it would be so complicated that it would be better to determine the desired relations experimentally after all. Various investigators have attempted to obtain the law experimentally with more or less success, but the work has not yet been brought to a definite close. My remarks this evening concern a method which I have used in other fields not directly related to radio-communication, and in these it has worked very well. I see no reason why it should not work equally well in determining the radiation factor. I have not seen this method mentioned, and while it may be known to those working in the art no harm will be done by repeating a description of it.

We start from very simple premises. We consider a conductor or part of a system of electrical conductors between the points R and S. If we impress an electro-motive force between these two points, we throw energy into the system by this means. We assume that the E. M. F. is of the sinusoidal alternating type and therefore of the form

$$e = E \cos pt.$$

That is, it is a simple harmonic E. M. F. and it will give rise to a simple harmonic current of definite amplitude and phase. Calling this current i we have

$$i = I \cos (pt - u).$$

The energy, or rather the rate at which energy is being thrown into the system is, of course, e i. If we wish to know the energy poured into the system in a unit of time, the mean value of e i is taken, according to the well known rule; that is, it is the mean value of the product of the instantaneous values of current and E. M. F. The E. M. F. does work on the system by overcoming certain reactions between the points R and S.

In every case of this kind there are two reactions, and this is

Figure 1

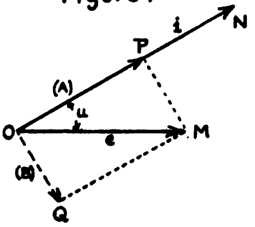


Figure 4

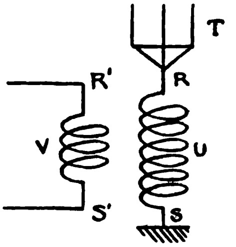


Figure 2

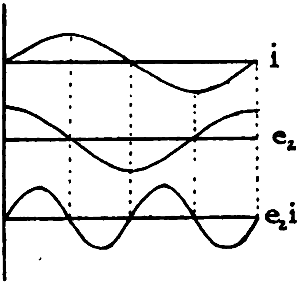


Figure 5

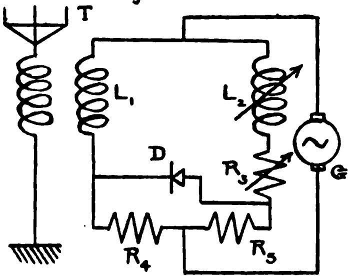


Figure 3

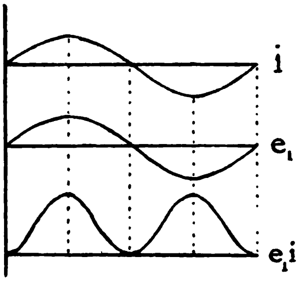
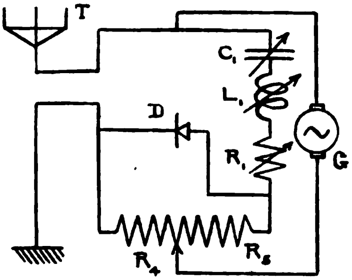


Figure 6



so without exception. For want of better names, we call these two classes the conservative and the non-conservative classes or reactions, respectively. There is, of course, an excellent reason for dividing the reactions into these two classes, as will be shortly seen.

Let us consider the difference between these two classes of reactions more closely. Every E. M. F. can be divided into two components in an infinite number of ways. We will divide the E. M. F. between A and B into components, as follows:

$$E \cos pt = A \cos(pt - u) - B \sin(pt - u).$$

These components are at right angles to each other. One of these components is exactly in phase with the current and the other is at right angles to the current. This resolution is shown graphically in Figure 1. Let OM represent the E. M. F. and ON the resulting current. The angle of phase displacement between these is angle NOM. Then OP is the component of the E. M. F. in phase with the current, and OQ the component at right angles to it. The lengths of OP and OQ are the A and B of the above equation.

It is perfectly well known that it does not make any difference how many reactions of an electrical kind there are between the two points; they could all be summed up in two components. The system may have any number of parts, but if the reactions are simple harmonic, they may be summed up into two.

By what may be termed an extension of Newton's third Law of Motion, the sum of the impressed forces and of the reactions of the system is always zero. So that altho the instantaneous value of the work done by the E. M. F. e_2 is not zero, its mean value is zero. Representing the mean value of the work done by M(ei), we have

$$M(ei) = O.$$

For if we write equation (1) above in the form,

$$e = e_1 + e_2, \text{ we obtain}$$

$$M(ei) = M(e_1i) + M(e_2i).$$

Let us consider the reaction $e_2 = B \sin(pt - u)$. It is what may be called the conservative reaction. During one-half of the cycle it does work which is positive, and during one-half it does work which is negative, and the sum is zero.

What is the meaning of positive and negative work? Speaking in an elementary way, if positive work means that energy is being supplied to the system between the two points, negative work means that the system is giving off energy between these points. So that negative work is done when the system does work against the E. M. F., and it does this by giving up its stored energy. The energy is stored in either an electrical or a magnetic field. During one-half the cycle the impressed forces do work which is stored up in the fields, and during the other half the energy in returning helps the generator to produce an E. M. F. This is the reason e_2 is called the conservative reaction. The energy it supplies is stored in the fields and can be gotten back. The other reaction does work which has a mean value greater than zero, and cannot be gotten back. Hence e_1 may be called the non-conservative reaction.

In Figures 2 and 3 are shown the E. M. Forces, e_2 and e_1, the current i; and the corresponding rates at which energy is being delivered at each instant, that is e_2i and e_1i. It will be seen that in Figure 2, the total work done upon the system is zero, whereas in the case shown in Figure 3, the total work done upon the system is positive. This work never comes back at all. Where is it? One cannot tell without more careful scrutiny of the physical system considered. We must then differentiate between work which returns and that which does not.

As a special case, (and the one of primary interest to us), let us consider that shown in Figure 4. Here T is the antenna or radiating system, U the secondary of an inductive coupler of which V is the primary. Thus there is impressed between the points R and S an E. M. F. The non-conservative E. M. F. will produce work of a kind that is dissipated. This will include heat generated in the coil U, heat generated in the conductors of the antenna T, heat generated at the ground connection and in the ground, and energy which has been radiated to unknown points. All of the energy which disappears as heat in the conductors or elsewhere, or which is radiated will manifest itself by a non-conservative reaction between the points R and S (or R′ and S′). So that if we had a method of measuring that non-conservative reaction, we should be able to measure the rate at which energy is being radiated after making proper allowance for the energy lost as heat. Fortunately we have a very simple method of doing this.

We shall examine somewhat more closely the reactions and the currents. In the first place it is clearly evident that the amplitude, I, of the current i is proportional to the amplitude of the impressed E. M. F. Obviously both are zero or infinity simultaneously. Symbolically expressed,

$$I = k E, \text{ where k is a constant.}$$

It can be seen from Figure 1 that both I and e are proportional to E. So that A and B are also proportional I. Thus we get

$$A = R_1 I \text{ and } B = R_2 I.$$

We must study R_1 and R_2, the two constants. We shall show that they have all the characteristics of a resistance and a reactance respectively. This gives us a clue to a simple method of measuring them.

Consider the expression M(ei) = W, where W is the total work done on the system per second (Mean Value). It can be shown to be equal to ½ A I.

For M(ei)
$= M[A\ I \cos^2(pt - u)] - M[B\ I \sin(pt - u)\cos(pt - u)]$
$= \frac{1}{2}$ A I, since the mean value of the square of the cosine thruout a period is one-half, and the mean value of the square of the sine times the cosine thruout a period is zero. Thus

$$M(ei) = W = \tfrac{1}{2} A I.$$

Substitute for A, its value given above. Then

$$W = \tfrac{1}{2} R_1 I^2.$$

So that R_1 is the quantity which when multiplied by $\frac{1}{2} I^2$ gives the energy which leaves the system permanently in the form of heat or something else. In ordinary circuits, this is the Joulean resistance. But a resistance due to the dissipation of any other form of energy may be similarly treated.

Another point which can be seen from the questions giving the values of A and B is that the angle of phase displacement is given by

$$\tan u = \frac{B}{A} = \frac{R_1 I}{R_2 I} = \frac{R_1}{R_2}.$$

This gives the tangent of the angle of lag. Since R_1 and R_2 fulfill all these conditions they have all the characteristics of ordinary resistances and reactances. Therefore we can determine them by the *WHEATSTONE BRIDGE.*

Energy is thrown into the antenna thru an electromagnetic coupling. We wish to know the values of the quantities we have just called the resistance and the reactance. With the high frequencies used in radio-telegraphy there should be no difficulty in determining them within one-tenth of one per cent. It takes some skill, but not very much to handle the bridge. As first used by Wheatstone, it was employed only with direct current, but in 1886 Rayleigh applied it to alternating currents as well. By this latter addition it can be used for the comparison of inductances and capacities as well as resistances.

In Figure 5 is shown one way of determining R_1. The inductances L_2 and the non-inductive resistance R_3 can be varied, as can also the non-inductive resistances R_4 and R_5. G is a generator of alterating current of radio-frequencies. D is some device which makes perceptible the presence of such alternating currents.

From the balance conditions of the bridge, that is, with no current through D, it is easy to calculate the quantity R_1 of the antenna and primary.

We can decompose R_1 into three parts, namely the ohmic resistances in the primary and secondary and the "radiation resistance." If these parts are R_1', R_1'' and R_1''', where R''' is the "radiation resistance" we have

$$\tfrac{1}{2}R_1\, I^2 = \tfrac{1}{2}R_1'\, I^2 + \tfrac{1}{2}R_1''\, I^2 + \tfrac{1}{2}R_1'''\, I^2$$

so that

$$R_1 = R_1' + R_1'' + R_1'''.$$

The last of these quantities is the one desired most. As a matter of fact we keep the quantities R_1' and R_1'' down by using wire of such dimensions that they are negligibly small in comparison with R_1'''.

From the value of R'''_1 it is not difficult to determine the law of radiation, and it is this method which I desired to lay before you.

EDITORIAL NOTES.

Since the above article was written, a 200,000 cycle alternator delivering 1 kilovolt-ampere has been built by the General Electric Company, and the research mentioned above will be carried out with it. Special means for separating true radiation energy from ohmic losses in the antenna, ohmic losses in ground connection, and from losses due to eddy currents induced in nearby conductors have been devised. And R. Goldschmidt has developed a "reflector type" alternator of comparatively slow speed with which frequencies up to 120,000 cycles per second have been obtained and with considerable power.

In Figure 6 is shown an alternative method of carrying out this experiment. Here L_1, C_1, R_1 constitute an artificial antenna having the same inductance, capacity and dissipative resistance as the actual antenna The equality of these quantities is tested in a manner similar to that given above.

The three principal methods in use at the present time for determining "radiation resistance," arranged in order of increasing precision, are the following:

(a) Inserting in the ground connection of the antenna a non-inductive resistance of such value that the current in the antenna is diminished in the ratio of one to the square root of two The additional resistance is then taken as equal to the non-conservative "radiation resistance." Austin has given a correction which must be made for the damping of the primary or exciting circuit.

(b) Determining from the resonance curve of the antenna by the Bjerknes method the damping factor and calculating therefrom the apparent "radiation resistance."

(c) Replacing the antenna by an artificial antenna of identical effective inductance and capacity, and ascertaining what non-inductive resistance must be inserted in the artificial antenna to secure in it the same current as formerly flowed in the actual antenna.

We have appended for the convenience of the reader the following list of important articles and references dealing with this matter.

H. Hertz, Electric Waves, Page 150, or.
Wiedemann's Annalen, Vol. 36, 1889, Page 81.
M. Abraham, Die Theorie der Elektrizität, Vol. 2, Page 70.
R. Rüdenberg, Annalen der Physik, Vol. 25, 1908, Page 446.
P. Barrecca, Jahrbuch der drahtlosen Telegraphic, Vol. 4, 1910, Page 31.
C. Fischer, Annalen der Physik, Vol. 4, 1910, Page 979.
J. A. Fleming, Proceedings Phys. Society, Vol. 23, 1911, Page 117.

M. K. Grober, Physikalische Zeitschrift, Vol. 12, 1911, Page 121.
C. Fischer, Physikalische Zeitschrift, Vol. 12, 1911, Page 295.
L. W. Austin, Physikalische Zeitschrift, Vol. 12, 1911, Page 924.
L. W. Austin, Jahrbuch, etc., Vol. 5, 1911, Page 419.
L. W. Austin, Journal Washington Academy, Vol. 1, 1911, Page 9.
P. Barrecca, Jahrbuch, etc., Vol. 5, 1911, Page 285.
J. Erskine-Murray, Jahrbuch, etc., Vol. 5, 1911, Page 499.

ALFRED N. GOLDSMITH, Ph. D.

DISCUSSION.

PROF. PUPIN. It will be noticed that this method does not require much power, for the radiation law is independent of the E. M. F. impressed. To avoid the evil effects of high inductance the electro-static telephone might be used as a detecting device.

DR. GOLDSMITH. This method is an excellent illustration of the courage needed to transfer ideas from one field of research to allied fields. It is evident that for the higher frequencies the alternator cannot be used. For this purpose the Poulsen arc converter without magnetic field and supplying but little energy and that of sinusoidal wave form can be employed. In order so far as possible to avoid the presence of resistance in the inductances in the bridge and antenna, they should be wound with "litzendraht," that is multiply stranded separately insulated wires of many strands of small individual diameter.

L. ESPENSCHIED. A properly adjusted buzzer used by the method of "Stosseregung," that is, impulse excitation, might be employed to produce the necessary feebly decaying alternating currents.

R. H. MARRIOTT. They are frequently so employed in testing detectors of various types. I wish also to call attention to the fact that in practical radio work there are other losses than those due to actual radiation and to heat. We get direct losses to ground and leakage losses.

PROF. PUPIN. They will appear either in R_1' or in R_1'', but not in R_1'''. Are they not very small in proportion to the radiation?

R. H. MARRIOTT. There are cases where I am not sure about that.

PROF. PUPIN. The reason they must be so is this. Suppose we take the length of wire which formerly made up the antenna and wind it into a coil. Determine the decrement of the current then obtained in this wire. You will have the same wire and the same leakage and an approach to equality in the other conditions. But it will not radiate.

If a free alternating current is started in this coil it will last a long time and be very persistent, that is, the damping will be very small. The open antenna has very much larger damping because of the radiation resistance and unless it leaks very badly, I could not imagine the resistance due to leakage being more than a very small fraction of the radiation losses.

R. H. MARRIOTT. The leakage losses from brush discharge in a powerful station must be considerable.

J. MARTIN. I should like to ask Prof. Pupin the value of an apparently simpler method of which I have recently read. It consists in placing in the aerial a sufficiently large non-inductive resistance to reduce the square of the reading of the hot-wire ammeter to one-half its previous value. The value of the resistance is then equal to that of the radiation resistance.

As to the values found by actual measurements, eight ohms or less is not uncommon. In the case of the Fessenden 25 K. W. transmitter recently installed on the battleship Connecticut, I had to prepare for a current of 50 amperes.

As to the question suggested by one of the members relative to the value of radiation efficiency, I can refer to an article by Kiebitz, translated in the London Electrician of April 30th, 1909, page 99:

Supply current; watts	1000
Secondary resistance, watts	200
Secondary discharge and heating in coil, watts	750
Spark, watts	20
Condenser and secondary heating, and brush discharges, watts	20
Aerial, earth, ozone	9
Leaving for radiation	1

PROF. PUPIN. Provided the current in the antenna is sinusoidal and that the extra non-inductive resistance is inserted at an antinode of current, the method outlined above should be a good first approximation.

HIGH TENSION INSULATORS FOR RADIO-COMMUNICATION.

By STANLEY M. HILLS.

There is hardly a piece of electrical apparatus in which some form of insulation is not to be found, and yet until very recently one might say that but a very small amount of consideration had been given to insulation problems.

The demand for compactness and consequent reduction of space factor, and the use of high voltages, together with the introduction of radio-telegraphy were perhaps the chief factors which led to the further development of insulation and insulators.

The most usual high insulators met with in radio work are glass, porcelain, mica, micanite, air, oil and patent compositions such as electrose.*

A substance insulates by the possession of three distinct properties:

I. The ability to stand mechanical and electrical stresses due to or caused by the potential or voltages stress applied.

II. Small conductivity, so that a negligibly small current can flow through it, and leak away.

III. The power to resist any chemical action that may be caused by the application of the voltage stress.

The first property is termed by Maxwell the dielectric strength of the insulator, the second property being termed the ohmic resistance. There is no direct relation between these two properties; for a low ohmic resistance does not necessarily imply a low dielectric strength, neither does a low dielectric strength indicate a low ohmic resistance. The chief value of the ohmic resistance test is the indication it gives of the moisture-resistant qualities of the insulator under consideration. In spite of the importance of the subject, but little information has been published, comparatively speaking, and that which has been published is widely scattered among the proceedings of many scientific societies and in the columns of the technical journals.

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* See Editorial Notes for more recent materials.

This paper has been written with a view to presenting in as concise a form as possible information regarding the properties of insulators which the members of the Institute of Radio Engineers are likely to employ.

A good insulator must possess the following properties:

1. High Disruptive Strength.

2. High Insulation Resistance.

3. Physical properties which are permanent over a wide range of temperature.

4. Non-volatility.

5. Should be non-hygroscopic.

6. Must be able to resist the action of water, acids, alkalies, and oils, and particularly for radio work, the action of sea spray.

7. Should be fireproof.

In addition, in certain cases, other requirements have to be met, such as mechanical strength for strain insulators, pliability for cables, etc. For radio work the insulation required may be divided into two main headings, namely:

(a) Antenna Insulation.

(b) Condenser Insulation.

(Transformer and generator insulation, falling under the consideration of the firm making these machines, are usually not of prime importance to the radio-engineer.)

The insulators in common use for antenna and condenser work are:

(a) Antenna Insulation.

1. Glass. 2. Porcelain. 3. Sulphur. 4. Patent Compositions.

(b) Condenser Insulation.

1. Air. 2. Compressed air. 3. Hard rubber. 4. Glass. 5. Hard Vulcanized Fibre. 6. Mica. 7. Oil. 8. Paraffin Wax.

It is the purpose of the author to discuss the physical and electrical properties of these insulators, to make a comparison between these properties, and to give the requirements of the work for which the insulators are usually used.

A considerable amount of confusion and argument has been caused by the misuse of the terms "dielectric strength," "electric strength" and "Specific Inductive Capacity," and we shall therefore define what meaning we wish to convey when using these terms.

In this paper the term dielectric strength is used when referring to the voltage which must be applied to a definite sample of the material in order to cause its rupture; and the term specific inductive capacity is used to define the energy storage capacity of a sample of insulation as compared to air or the ether.

The breakdown voltage of an insulator depends upon many conditions. The principal ones are:

a. The shape of the electrodes with which the voltage stress is applied.

b. The temperature, and facilities for heat radiation.

c. The thickness of the sample under test.

d. The length of time during which the stress is applied.

e. The wave form of the source of voltage supply.

f. The time rate of application of the stress; that is, whether the stress is applied suddenly, or gradually.

g. The condition of the sample as to dryness.

From this wide range of conditions it can be seen that in making comparisons between samples of insulation, considerable care must be taken to ensure that all samples are tested under precisely similar conditions

The nearer the shape of the electrodes approaches that of the needle point, the lower will be the breakdown voltage; and, generally speaking, the higher the temperature the lower the breakdown voltage.

The breakdown voltage per unit of thickness decreases as the thickness of the sample increases; for example, a sample of mica 1/100 cm. thick will breakdown at about 200,000 volts per millimeter, whilst a sample one cm. thick will perhaps rupture at a pressure of 65,000 volts per mm. All insulators do not vary so much as this, but the safest way to obtain results for design work is to test several samples of various thicknesses, and plot a curve showing the relation between thickness and breakdown voltage.

When a dielectric or insulator is under electric stress the temperature rises rapidly at first, the amount of rise depending on the facility for heat radiation. Then the rate of change of temperature slowly decreases until finally the temperature becomes constant. When a direct current stress is applied, this increase of temperature is due to ohmic resistance losses, while if an alternating current stress be applied, the rapid alternations of the field cause dielectric hysteresis, an effect comparable to the hysteresis met with in iron. Such hystersisis always causes a rise of temperature.

As the stress applied is increased, the temperature of the insulator increases. Often heat is generated at a greater speed than it can be radiated thereby causing the material to burn or char, and rupture or breakdown occurs. A rupture is more frequently caused by this phenomenon than by the voltaic stress which is applied.

For this reason it is generally unwise to subject finished pieces of apparatus to unnecessarily severe or prolonged tests, as these may cause slight charring, which, altho it does not cause a breakdown at the time of the test, will do so sooner or later.

Owing to the fact that the temperature increases with the stress, the losses in a dielectric are not strictly proportional to the square of the voltage, but increase at a slightly greater rate than the square of the voltage.* Since the temperature enters into this question, the initial temperature of the dielectric and surrounding media and the facilities for heat radition also have considerable influence in determining the values of the losses which take place.

The specific inductive capacity or dielectric constant has a considerable effect on the insulation strength of any insulating material which consists of a mixture of various substances The voltaic stress divides itself in the inverse proportion to the specific inductive capacities of the materials. In 1898 Professor R. A. Fessenden performed an experiment which clearly illustrated this phenomenon. He took two electrodes, A and B, Figure 1, and placed them one centimetre apart, applying an alternating current at a pressure of 10,000 volts. This gave a fall of potential of 10,000 volts per cm., which was the maximum the air could withstand without brush discharge. Next he introduced between the electrodes two plates of glass, C and D, Figure 2, of specific inductive capacity 8, each plate having a thickness of .25 cm. As stated, the stress was divided in the inverse proportion to the specific inductive capacities of the air and of the glass. That is the air has now to withstand $\frac{8 \times 10{,}000}{9} = 8890$ volts across a thickness of 0.5 cm.

At every reversal of the voltage a spark passed. This quickly raised the temperature of the glass, and, by lessening its insulating

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* See Editorial Notes.

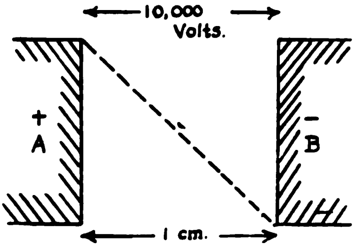


Figure 1.

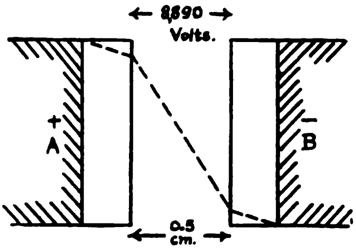


Figure 2.

Figure 3.

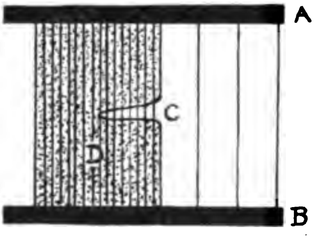
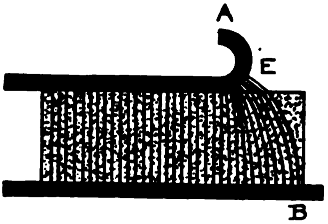


Figure 4.



quality, finally caused an arc to form between A and B. Thus where the layer air had previously withstood 10,000 volts to the cm., it now broke down, owing to the introduction of a material of much higher specific inductive capacity. The experiment shows that it is highly important that insulating materials which are made up of a number of substances should consist of either a thoroughly homogeneous mixture or that when applied in the form of layers, the specific inductive capacities should be so arranged that no sudden changes in the stress gradient are caused.

We shall now consider various dielectrics in detail.

AIR AND COMPRESSED AIR. Air is used as an insulator in transformers and condensers, more generally in the latter. An air condenser is the most simple form which can be obtained. It is efficient, the only loss which takes place being the energy which is spent in brush discharges which take place between the edges of the conductors. The dielectric strength of dry air is high, being in the neighbourhood of 3,700 to 4,000 volts per millimeter. The main objection to air condensers is their size, which must be large if any appreciable amount of energy is to be stored. Professor R. A. Fessenden has for some time used compressed air condensers, and by this means has been able to retain the advantages of the air condenser and yet largely eliminate their chief disadvantage. This is due to the fact that the dielectric strength of compressed air is much greater than that of air at atmospheric pressure. Thus he reduced the size for a given voltage and capacity. For ordinary practical purposes, it may be taken that the dielectric strength of compressed air is directly proportional to the pressure. This is not quite true theoretically, except where needle point electrodes are used.

In practice it is a difficult task to avoid having a point somewhere, and for practical work the author prefers to rely on the needle point test in preference to a test between two spheres. The sphere test usually gives higher values to an extent which depends upon the diameter of the spheres.

In March, 1909, Mr. E. A. Watson read a paper on "The Dielectric Strength of Compressed Air" before the English Institute of Electrical Engineers, and from a long series of experiments he deduced the following empirical formula connecting the dielectric strength and air pressure:

Dielectric strength in Kilovolts per cm.
at a temperature of 17 degrees C. = 20 + (25.6 times Air Pressure in Atmospheres).

From this the author has obtained the figures given in Table 2. So far as has been determined by experiment, this formula holds only up to a pressure of 15 atmospheres, though there is but little doubt that the formula would hold at least approximately for higher pressures.

When very high voltages are used considerable trouble is met with because of brush discharge. This is largely caused by the accumulation of dust which settles on the plates and forms points from which the brush discharge takes place. When using compressed air condensers it is advisable to be very careful to keep the plates clean and to ensure the use of dry air by the employment of suitable filters. One great advantage of air as a dielectric is that if a puncture occurs an automatic self-healing process takes place (oil being the only other dielectric which possesses this valuable property). Another advantage is that air does not deteriorate from aging effects.

INSULATING OILS. With the advent of high voltage work came the introduction of various oils for use as insulators. As a general rule, pure mineral, vegetable, and animal oils form good insulators, but their insulating properties depend largely on their purity.

To the eye, clear and almost colorless oils are likely to give the impression of purity; but a dark colored oil is often the purer because the clarifying process may entail the use of chemicals, small quantities of which may be left behind and thus reduce the insulating quality of the oil. Dust, especially metallic dust, moisture and sulphur are the three most destructive impurities. Altho sulphur by itself is an insulator, its presence in insulating oil is often the cause of a breakdown; particles of dust are likely to become "electrically charged," and when in that state will line up between points where there is a difference of potential, thus forming a conducting path and causing a spark to pass.

The oils obtained from the Western States are particularly likely to contain sulphur. The insulating strength of oil usually increases with the frequency of the applied voltaic stress; a property which is valuable in radio work, and one which is not met with in solid insulators.

Great care must be taken to eliminate moisture in any insulating oil, as it has a most deleterious effect on the insulation strength. The presence of 5 per cent. of moisture will often reduce the breakdown voltage by 50 per cent. A very good test for the presence of moisture in oil is to mix a small quantity of the oil with a little powdered anhydrous copper sulphate. The presence of even a small quantity of moisture will be indicated by a blue coloration of the oil.

Mr. Skinner, in a paper read before the American Institute of Electrical Engineers, gave the following specifications for a good transformer oil:

1. The oil should be a pure mineral oil obtained by the fractional distillation of petroleum and unmixed with any other substances and without subsequent chemical treatment.
2. The flash test of the oil should not be less than 180° C, and the burning test not less than 200° C.
3. The oil should not show an evaporation of more than 2 per cent. when heated at 100° C for eight hours.
4. The oil must not contain moisture, acid, alkali, or sulphur compounds.
5. It is desirable that the oil be as fluid as possible, and that the color be as light as can be obtained in a pure untreated oil.

Mineral oils usually evaporate slightly at temperatures a little below the flash point, and rapidly at temperatures above flash point.

One great advantage possessed by oil is that if a spark passes the puncture is self-healing, the only detriment being the particles of carbon which are left and which, if they become too plentiful, may cause the same trouble that dust does.

Insulating oils have a somewhat peculiar effect on mica. They tend to reduce its insulating value, but apart from that they are not harmful to insulators.

The dielectric strength of insulating oils increases with a rise of temperature, a property which is very valuable. On the other hand, the specific resistance decreases with temperature rise.

MICA. In many ways mica is a good insulator. It possesses a high dielectric strength, is unaffected by heat; but it suffers from mechanical disadvantages, owing to the fact that it is not flexible and is very easily split and broken. Mica is an anhydrous silicate of aluminum and potassium or sodium, the transparent samples being composed largely of aluminum and potassium and the less transparent ones contain magnesia and iron. The transparent varieties are usually the better insulators, but the black spots often noticeable in mica are not a source of weakness, as might be assumed at first thought. The chief disadvantages of mica are its lack of uniformity in dielectric strength and its great tendency toward surface leakage. The green shades of mica are usually the softest, whilst the Canadian "White Amber" is the most flexible. Insulating oil reduces the surface leakage, but also reduces the dielectric strength.

MICANITE. Micanite consists of layers of mica held together by an insulating cement. This cement is usually of secret composition, as it is the key to the quality of the ultimate product. At one time pure shellac was often used as a cement, but this is not advisable, as shellac has a low, softening temperature, is hygroscopic, and likely to deteriorate rapidly with age.

When heated, micanite can be readily moulded into various shapes, and thus the disadvantage of inflexibility of pure mica is overcome. Micanite is usually made up with cloth or paper as a backing, in addition to the cement, and the dielectric strength varies with the form of backing used. Reference to Table 1 will illustrate this point.

PARAFFIN WAX. This substance can be used both in the solid form and, when impregnated, in various forms of paper. It has a low, softening point, and is mechanically weak, being readily scratched with the finger-nail. It has a moderately high dielectric strength, and paper impregnated with it is often used in condensers. Paraffin waxed paper frequently cracks when bent in a cold state.

HARD RUBBER. This material has a high dielectric strength and is much used for bushings, terminal blocks, and small parts of apparatus. It is somewhat susceptible to surface leakage, especially when highly polished. It can be machined, but it is somewhat treacherous and is easily split and cracked.

Hard rubber deteriorates with age and exposure to the atmosphere. Though the polish does to a certain extent increase surface leakage, the oil used in the polishing process tends to form a preserving film over the surface of the sample. Hard rubber will not withstand high temperatures.

VULCANIZED FIBER. This is another material often used for bushings and terminal blocks. It has not a very high dielectric strength. It is brittle and may split and warp when exposed to changes in temperature, and is also very hygroscopic.

GLASS. Glass has a high dielectric strength, but possesses other disadvantageous properties which reduce its value as an insulator. It has a very large surface leakage, and is very hygroscopic. Being slightly soluble in rain water, there tends to be produced a roughened surface on which dirt can collect and form a conducting path, thereby increasing the already large amount of surface leakage. Glass will crack and shatter when violently struck and is not mechanically strong. Being transparent any flaws that are present are readily discernible. Lead is often present in glass, and the insulating value is thereby reduced. Plate, annealed and crown glass are the best for insulating properties. Glass is acid-proof and will withstand normal temperatures.

PORCELAIN. Porcelain has a higher dielectric strength than glass and less surface leakage. Cheap porcelain is often extremely hygroscopic and only the very best quality should be used for insulating purposes; this caution being particularly important for radio work. The author has found some samples of porcelain to absorb 1 to 2 per cent. of their weight of water. Porcelain for insulating work should not absorb moisture and should give a brilliant vitreous fracture when broken. Two tests may be performed to demonstrate this quality. A good porcelain when fractured will not give a flowing stain when ink is applied to the fracture. If the tongue be applied to the fracture, a vitreous porcelain will feel cold and glassy, while a poor porcelain will give a rough absorptive feeling like chalk or blotting paper. Porcelain essentially consists of English clay and china clay, with a small percentage of Tennessee clay, felspar and quartz. The clays form the body, giving mechanical strength, the felspar and quartz act as a flux and help to make the mass thoroly homogeneous. The most critical operation in the manufacture of porcelain is the baking process, the temperature required being about 2,700° F. If made too hot, the porcelain becomes porous, while if not sufficiently heated the clay does not become properly vitrified. For use as an insulator the porcelain must be thoroughly homogeneous, vitrified and solid. Unfortunately porcelain is opaque and flaws cannot be visually detected. If the porcelain is not homogeneous and vitrified it depends on the glaze for its insulating value, and once the glaze is fractured the insulating value is practically reduced to zero. Porcelain in comparison with glass is strong and tough, the surface does not weather badly, and, barring breakage, the insulating value is practically permanent. Generally speaking, good porcelain is comparatively non-hygroscopic. Porcelain varies greatly in quality. The German Hermsdorff porcelain is a particularly good variety.

SULPHUR. Sulphur has a moderately high dielectric strength, is soft and brittle, has a low melting point, and when hot is very volatile. Owing to its low melting point, it is often used as an insulating cement, and when mixed with finely powdered glass it is very suitable for that purpose, especially with porcelain insulators. Sulphur has a bad effect on insulating oils, and should not be used in places where it is likely to come into contact with them.

LAVA. This substance is not, as often supposed, of purely volcanic origin. It is a form of magnesium silicate bearing the chemical formula $H_2 Mg_2 Si_4 O_2$. It can be machined when in its natural state. When it is to be used for insulating purposes, it is first machined into the desired shape, and then baked at a temperature of 2000° F. The baking process makes the lava very hard and capable of withstanding a high crushing or compressive stress. It is free from metallic salts, and does not change in shape with changes in the surrounding atmosphere. Lava is slowly soluble in strong hydrochloric acid, but is otherwise acid and alkali-proof. It will stand a high voltaic stress without breaking down.

AETNA. Aetna is a patent composition used in the form of strain insulators. It has a fair dielectric strength, a tensile strength of 2.46 tons per square inch, and withstands the action of heat, but Mr. H. D. Symons reports that he has sometimes found it to be brittle, and an absorption test shows that Aetna absorbs 3.17 per cent. of its own weight of water at a temperature of 120° F.* The surface resists weathering well, and it forms a satisfactory strain insulator.

LAVITE. This is a patent material, of light color, and has a high dielectric strength. It is hard, in fact so hard that it can be used to scratch glass. It is unaffected by temperatures up to 1000° C. It is acid and alkali-proof, but a mixture of strong hydrochloric and nitric acids in the proportion of one to three will, when the solution is warmed, attack this material. It can be machined and turned, and will withstand a very high compressive strain. Lavite is suitable for the manufacture of tubes, bushings, and other small parts, the only disadvantage being that it cannot be made into large pieces of apparatus.

MARBLE. The use of marble as an insulator is practically confined to switchboards. It is liable to be hygroscopic and the condensed moisture on its surface produces and aids surface leakage. For good insulation, it should be free from metallic

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* H. D. Symons, Insulation and Insulators, Technics, Vol. 3.

veins. Usually the softer qualities of marble have the highest dielectric strength. It is liable to crack with a knock or a jar and is somewhat treacherous in behavior when being machined.* The specific gravity of marble often gives considerable indication of its insulating properties. Generally speaking:

1. The greater the specific gravity the lower the absorption of moisture.

2. Mechanical properties are good in the inverse ratio to the electrical properties.

3. The higher the specific gravity the lower the breakdown voltage.

4. The specific gravity increases as the crushing stress increases.

Marble, which will absorb more than 0.5 per cent. of its own weight of moisture after 24 hours' immersion in cold water, is not of much use for electrical work where high voltages are employed.

ANTENNA SUSPENSION INSULATORS. Suspension insulators, whether of some patent composition, glass or porcelain, should be designed to fulfil the following conditions: They must afford an efficient means of insulation in all weathers, which require them to be unaffected by fogs, dusty deposits that may be in the atmosphere, rain, acids or alkalies and salt water spray. The design and choice of the overall dimensions should be arranged so that a compromise is effected between the leakage distance and surface area, such that a maximum leakage distance is obtained with a minimum surface area.

The potential gradient from the antenna to the ground should be made as gradual as possible in order to reduce the risk of "arcing over" and "brush discharge" to a minimum.

All cemented joints must be so arranged that they are under a compressive strain, in fact, whenever possible, it is best to have the whole insulator under compressive strain, as insulators of this type are capable of standing a greater stress when so arranged.

With regard to insulators made of patent compositions it is important to ascertain whether they are affected by salt water and whether their surface roughens on exposure to the atmosphere. If they are to be used in tropical regions the effect which temperature has upon them should be investigated, as such com-

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* Hills and German, paper on "Dielectrics and Dielectric Testing," read before Junior Institute of Engineers, England, March, 1909.

positions are liable to contain shellac or other gum as a form of binding cement, and may soften in tropical temperatures.

CONCLUSION. The tendency of the age is to cheapen production and reduce the cost of both labor and material, but it is extremely unwise to be sparing of expense where insulation is concerned. In a way insulation may be said to be a keystone to the whole, i. e., if the insulation breaks down the remainder of the parts is useless. At the present time it is impossible to give standard values for the strength of insulating materials; they cannot be depended upon like the stress and strain values of iron and steel. Insulation is so greatly affected by changed conditions, and different batches of the same material are liable to be considerably different in insulating value, so that a high safety factor should always be used. Further, age invariably causes deterioration of insulation, especially in exposed positions. In high voltage, radio-frequency work very large static strains and stresses are liable to be produced. Often the possibility of these stresses arising is entirely overlooked and when the safety factor has been reduced to a minimum, a breakdown inevitably occurs. In this class of work it is advisable to allow a safety factor of ten, in order to be certain of safety. The perfect insulator, so far as our knowledge guides us, "Non-Est," therefore it is necessary to sum up the most important conditions to be fulfilled and select the insulator which most nearly satisfies those conditions.

Insulation is a complex subject, and when the field is narrowed down to high insulators there is much that might be written. A short bibliography has been appended with a view to assisting those who wish to study this subject more fully.

TABLE NUMBER 1

DIELECTRIC STRENGTH OF VARIOUS INSULATING MATERIALS

Material.	Dielectric Strength per 0.001 of an Inch in R.M.S. Volts A.C.
AETNA	35
ASBESTOS	125
BRISTOL BOARD	180
CELLULOID	90
FIBRE (Vulcanized)	175
LAVA (Talc.)	125
LAVITE	200
LEATHEROID	150
LINSEED OIL (Boiled and impregnated on Bond Paper)	600
MICA (Pure White)	3000
MICANITE (Cloth)	300
(Flexible Cloth)	190
(Paper)	420
(Flexible Paper)	300
MICA (Plate)	1000
(Flexible Plate)	700
OILED CAMBRIC	650
OILED PAPER	800
PARAFFINED BOND PAPER	900
PRESSBOARD	125
PRESSPAHN	300
SHELLACKED CAMBRIC	35
VULCANITE	840
HARD RUBBER	900
GLASS (Common)	203
(Head)	140
(White Alabaster)	290
(Plate)	280
PORCELAIN	1800
HERMSDORF HARD PORCELAIN	2500
LINSEED OIL	1200
" (Boiled)	1600
OLIVE OIL	1650
SPERM OIL	1300
"TRANSIL" OIL	2000
VASELINE OIL	1500

Values compiled from various sources—

Hobart & Turner on "Insulation of Electrical Machines."

H. D. Symons on "Insulation and Insulators."

J. A. Fleming on "Electric Wave Telegraphy."

S. P. Thompson on "Dynamo Electric Machinery."

S. M. Hills and T. Germann on "Dielectrics and Dielectric Testing."

N. B.—No hard and fast figures can be given for the dielectric strength, because samples and conditions of test vary considerably. Considerable care has been taken in compiling the above table, and the values given are on the "safe side," higher values often being obtainable.

TABLE NUMBER II.

Dielectric Strength of Compressed Air, at Temperature of 17 C.

Air Pressure in Atmospheres.	Dielectric Strength in Kilovolt Per C. M.
2	71.2
4	122.4
6	173.6
8	224.8
10	276.0
12	327.2
14	378.4

Figures calculated from formula given by A. E. Watson, proceedings, English Institute of Electrical Engineers, Vol. 43, page 132.

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EDITORIAL NOTES.

Since the above lecture was written a number of new insulators have appeared. As typical of this new class may be taken BAKELITE and CONDENSITE. They are resinous or amorphous products resulting from the action of phenolic bodies upon formaldehyde or other methylene compounds. They are usually light brown in color and even translucent, but may be produced in opaque forms of various colors. The property rights in the American patents have not as yet been judicially determined, but the principal claimants in America are Aylsworth and Baekeland. The materials can be produced in soluble forms, fusible or infusible. Frequently fibrous organic materials are impregnated with these compounds at high temperatures in the hydraulic press and then molded. The fibrous materials used are generally wood pulp or finely divided sawdust. Contrary to expectation, asbestos is not a suitable substance for impregnation because of its mechanical weakness and lack of elasticity. (The main object of adding the fibrous materials is to give flexibility and elasticity to the insulator. The phenolformaldehyde products are exceedingly hard and resistant, have a high crushing strength, but are very brittle.)

The insulation strength of these products is remarkable. Baekeland states that paper impregnated with them and submitted to hardening under heat and pressure has shown an astonishingly high disruptive (puncture) test, averaging 77,000 volts alternating current on sheets one-sixteenth inch thick. This is 1,230 volts per mil, 1,232 kilovolts per inch, or 485 kilovolts per cm. The production of these substances is very considerable, more than one ton of Bakelite being made per day at present.

In treating dielectric hysteresis in the preceding article, it was stated that the dielectric losses depended on the *n*-th power of the voltage, where *n* was greater than 2. A detailed discussion of this matter will be found in a paper by Fleming and Dyke (Electrician, Feb. 3rd, 1911, page 658). The values of *n* there given are 2.15 and 2.61 for two different samples of vaseline oil, 3.5 for air (tho, of course, with a much smaller constant of proportionality in this case), and 2.42 to 4.24 for glass jars and plates.

A valuable discussion of the properties of compressed air condensers is given by Max Wien (Annalen der Physik, 1909, "On the Damping of Condenser Oscillations"). A type of compressed air coaxial cylinder condenser is there described, which is 100 cm. long, 6.5 cm. diameter, weighs 6 kilograms, has a capacity of 0.0017 mmf., and at normal working pressure of 15 to 20 atmospheres will withstand 40,000 volts across its terminals. The separation between the cylinders is about 3 mm. These values agree well with those given by R. A. Fessenden, namely, at 10 to 14 atmospheres pressure, the sparking voltage between plates 2 mm. apart was 28,500 volts. Such air condensers are found to produce no perceptible increase in the damping of a circuit in which they are placed, as compared with ordinary air condensers. It was found that Leyden jars added about 0.010 to the decrement, paraffin oil condensers about 0.001, and compressed air condensers less than 0.0002.

Methods of removing moisture from insulating oil without chemically changing the oil are given by S. M. Kintner (Electrical Journal, Vol. III, 1906). Filtration thru substances capable of combining with water and free acids is preferred to heating processes which may easily start an injurious decomposition of the oil.

There has been a marked tendency recently to standardize the rating of insulators and the proper factors of safety under various conditions. Thus, the Allgemeine Elektrizitäts Gesellschaft of Berlin, following the designs of their engineer, C. Kuhlman, has placed on the market a series of insulators of standard specifications. The insulators used on 4,400 volts spark over at 22,000 volts (factor of safety = 5), those for 17,000 volts spark over at 50,000 volts (factor of safety = 3), and those for 77,000 volts spark over at 170,000 volts (factor of safety = 2.2). The reason for the diminution of the safety factor with increasing voltage is that excess voltages depend upon current surges, and the currents on extremely high tension installations are generally limited to small values. Complete details of such a series of standardized insulators for 750 to 200,000 volts are given by W. Fellenberg (Elektrotechnische Zeitschrift, 1912, pages 640 and 684).

The use of insulated steel towers for antenna supports has given rise to a new insulation problem, namely the obtaining in insulators of the necessary mechanical strength under great compressive stress. One method which has so far worked well in practice is used at the Bush Terminal station of the National Electric Signaling Company. There the massive steel towers, 150 feet high, are supported each by 25 glazed porcelain conical insulators, approximately 8 inches long. These rest on a heavy concrete base. There are also two anchoring blocks, each mounted on 10 such insulators. Another method is to be employed at the Transatlantic Station of the Hochfrequenz-Machinen Aktiengesellschaft of Berlin (Goldschmidt alternator system) at Tuckerton, New Jersey. The tower, of steel 820 feet high, will rest on three spheres of a glass-like composition, the diameter of each sphere being about 3 feet.

Following somewhat different methods from those given in the present paper, W. Petersen in an article on High Tension Insulation in Archiv für Elektrotechnik, 1912, Vol. I, Page 28, draws certain conclusions which are of interest in radio-transmission.

In Figure 3, D, is a piece of porcelain placed between the metal plates A and B. The difference of potential between A and B is taken as not far from that value which would cause a brush discharge across AB. The lines of electric force are of course relatively crowded in the porcelain which has a higher dielectric constant than air. But its strength enables it to stand the strain. If now there be at C a crack or pore in the porcelain, the number of lines of force passing through it will not be very different from the previous value, hence the strain on the air in this cavity will be far greater than on that outside. Consequently the air in the crack will be ionised and a spark discharge across the gap will speedily follow. To avoid this "crater" action, care must be taken to use only perfectly smooth and flat pieces of insulating material, free from cracks and pores, in such situations.

If plate A is curved at its end as shown in Figure 4, and between the plates A and B is placed a sheet of insulator, it is most likely to be cracked at B. The reason will be seen when the distribution of the lines of electric force near B is examined. Those which are refracted as they pass from the insulator to air near E are so closely crowded together in the air that ionisation begins, with brush discharges, roughening of the surface at E, and eventual breakdown. The greater the dielectric constant of the insulator, the worse it behaves in this matter of the excessive crowding of the lines of force and consequent strain produced by the refraction at the boundary surface of the material.

ALFRED N. GOLDSMITH, Ph. D.

DISCUSSION.

Robert H. Marriott.—The problem of insulation in wireless is, as Mr. Hills says, a very important one. Probably every radio-engineer or operator present can cite a case or cases wherein a wireless transmitter or receiver had its efficiency materially lessened by poor insulation, and those of us actively engaged in wireless should be able to profit by this paper, which covers a considerable scope in few words.

Mr. Hills does not mention hard rubber as a material for antenna insulation. However, it is and has been used for this purpose in the form of rods about 1″ in diameter and 1 to 2 feet in length, with screw eyes in the ends for fastening ropes or wires. These rods have given considerable trouble, due to their absorption of moisture and their surface becoming wet from rain, snow, fog or local precipitation when they are colder than the surrounding air. And the eyes in the ends of the rods frequently straighten out.

I have improved these insulators on some occasions by substituting welded eyes, varnishing the hard rubber (which tends to keep it from absorbing moisture), and by fastening a copper cone or cup to the upper end of the insulator in such a way that it protects the hard rubber from rain, snow and fog, and to some extent from local deposition of moisture.

Wood is frequently used for strain insulators in the guys, and even rope has been used. Both of these materials in the form commonly used have been bad, at least mechanically, because when the weather caused them to rot or split they pulled apart.

A wooden strain insulator at Manhattan Beach, composed of two parallel 2″ x 4″ oak timbers that apparently had been boiled in asphaltum, and which was subjected to a tension strain in the direction of the grain of the wood, pulled in two in the middle and dropped the "sky-line," thus crippling the station for several days. Other insulators of this form broke at Manhattan Beach, but usually through splitting out at the ends. These insulators had been subjected to the weather for probably four years. Furthermore the breaking of a rope strain insulator is said to have caused the tower to fall at Cape Hatteras.

In place of these wooden and rope insulators I have used insulation in the form of dead-eyes, such as the R. Thomas & Co. porcelain strain insulators, and where porcelain insulators with a large enough groove could not be obtained, ship-rigging dead-eyes of lignum-vitae or Indian-hedge were used. With these the strain becomes a crushing strain; and even if the dead-eyes ever did crush, the two loops in the guy would simply come together and the guy would remain strong mechanically.

In addition wood has been and is used for insulating radio transmitting and receiving instruments.

For example.—In a certain condenser jar rack containing two banks of jars, the outside coatings of the jars are connected by strips of copper tacked to the bottom of the wooden jar rack; the inside coating of one bank connects to one transformer terminal and a spark gap, while the inside coating of the other bank connects to the other transformer terminal and to ground through the helix. If the potential of the transformer is 20,000 volts, then the potential of the copper strips tacked to the bottom of the wooden rack may be high, say 10,000 volts to ground. The wooden rack and the floor become damp, both sides of one bank of jars are then grounded, and the other bank takes approximately the potential load of 20,000 volts with only one thickness of glass, instead of two thicknesses to withstand this pressure. At the same time the capacity of the local circuit is doubled and therefore the local circuit is thrown out of tune with the antenna circuit.

Usually a jar will break in the bank that is doing the work. What happens then depends upon the experience of the operator. He will probably put in a new jar, losing considerable time and possibly some messages in doing it; then he breaks another jar. He may keep on breaking jars until he gets disgusted and gives up working the set.

Or, he may close down the spark gap until he gets a spark that does not break jars. He may be using the same amount of power, but his transmitter circuit is certainly out of tune with his antenna circuit, and little or no current will be transferred between the circuits with the general result that probably he will not send very far.

In the meantime, the jar rack may or may not show indications of burning where he will notice them. If he does see the burning he will probably do the right thing, i. e., scrape off the blackened part of the jar rack, set the rack legs on porcelain, glass or some other good insulator, put in a new jar and go ahead without more trouble.

I have obviated the grounding of the jar rack by fastening inverted Western Union insulators to the bottom of the legs, screwing the insulator pins to the inside of the legs.

Insulators frequently give trouble because they are colder than the surrounding air, causing the air to deposit moisture on the insulator. This can be stopped sometimes by simply warming up the insulator. For example, the muffler is short circuited and the operator should hold down the key until the muffler becomes warmer than the surrounding air, and the moisture evaporates. He no longer has a short circuit unless the muffler is dirty or is made of some material that will carbonize.

In radio-telegraphy we deal with high frequency alternating currents, so that when we want to keep rapidly alternating current from escaping, the insulator used for that purpose must not only be of proper ohmic resistance and dielectric strength, but it must be of low electrostatic capacity. An example of bad insulation with regard to the electrostatic capacity of the insulator is to be found in the twin wires used frequently for connecting the two leads of a loop antenna from the anchor spark gap to the antenna switch.

These twin wires may or may not have sufficient highly resistant material between them, but their electrostatic capacity is comparatively high and as one of them is connected directly to ground, considerable current will flow from the other wire to it instead of passing through the tuner, so that the signals are weakened.

RECENT DEVELOPMENTS IN THE WORK OF THE FEDERAL TELEGRAPH COMPANY.*

By LEE DE FOREST, Ph. D.
Engineer of the Federal Telegraph Co.

The Federal Telegraph Company is unique in several respects. Among these, it enjoys the distinction of employing no press agents. Consequently in the East almost nothing is known of what is being done in the West. This is, of course, regrettable from a technical standpoint.

The present chain of stations of the company comprises those at Seattle, Portland, Medford, Central Point, Sacramento, Phoenix, San Diego, El Paso, Fort Worth, Chicago and others. Tho messages have been sent from San Francisco to Chicago, the service is not of the same character as that maintained on the Pacific Coast, which latter is strictly commercial. The largest of all these stations are those at San Francisco and Honolulu. Each of these has a power of 40 kilowatts, which is to be increased to 60 kilowatts.

We operate under the Poulsen patents. But the apparatus imported from Denmark in 1910, showed many commercial defects and lack of reliability. The cooling appliances were inadequate, and the insulation faulty.

The system, as now in use, is the simplest imaginable, particularly at the transmitter end. Referring to Figure 1, E is a direct current generator of 500 to 1,000 volts or even more, D are choke coils intended to prevent the alternating current from the arc flowing back to the generator and also intended to keep the generator direct current constant, A is the arc itself, B a tuning or loading inductance, and T the antenna. The arc itself plays between a copper positive electrode and a carbon negative electrode. It is always water cooled. It is in an intense magnetic field, and the atmosphere surrounding it is usually illuminating gas. Where this cannot be obtained, denatured alcohol is used instead. If desired, ether can be added to the denatured alcohol.

In this system the transmitting key is used, not as in most

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* Lecture delivered before The Institute of Radio Engineers, November 6th, 1912, at Fayerweather Hall, Columbia University.

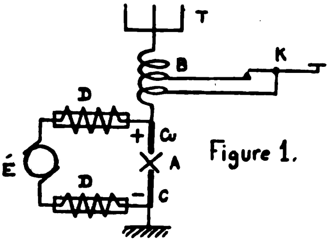
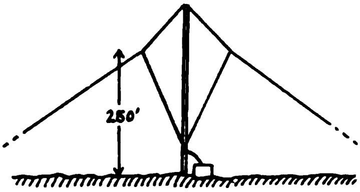


Figure 1.

Figure 5.



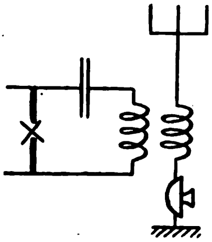


Figure 2.

Figure 6.

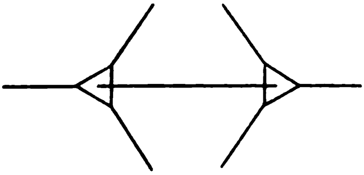


Figure 3

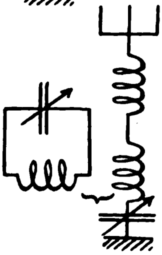


Figure 7.

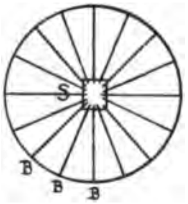


Figure 4.

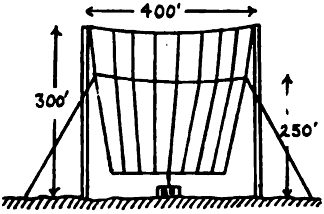
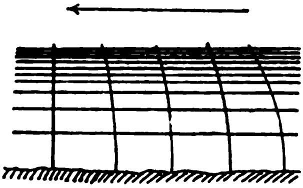


Figure 8.



stations to change the amount of energy emitted, but only to alter slightly the wave length. This is accomplished by connecting the key K as shown across one or two turns of the inductance B. When the key is pressed, the wave emitted is lengthened by say five per cent. So that all the time transmission is going on the antenna is radiating. This makes matters interesting but unsatisfactory for the amateur interloper who naturally fails to separate the two waves and interpret the messages. The wave not used for receiving, which is usually the shorter one, is termed the "compensation" wave, and the tuning at the receiving station must be sufficiently sharp to ensure that the compensation wave shall not be heard. It has been found that smaller amateur stations even in the neighborhood of the twelve kilowatt station cannot tune up to the longer wave, and this fact ensures their reception of what may be called reversed, and of course unreadable messages. We feel responsible for a state of thorough disgust on the part of said amateurs.

Furthermore, when in the immediate neighborhood of a powerful station of the Poulsen type, the received signals from other stations are considerably fainter when transmission is going on from the arc station. This may be due to either a surplus of energy passing thru the detector and rendering it insensitive; or to rendering partially opaque the transmitting medium by the undamped radiations.* I must admit that I cannot see just how this latter alternative can be the case tho it is difficult otherwise to explain the fact that even with the Audion detector the smothering effect is shown. For the effect mentioned, the arc may be as much as five miles distant, from the detector affected, and yet the signals from spark stations will drop to a marked degree.

It is of interest that the arc length or changes in it have practically no effect on the radiation, at least for telegraphy. For telephony, the constant conditions required are naturally more severe. For telephony, the double circuit arrangement shown in Figure 2 is used. The conditions being more critical in this case, the operator is required to watch the arc and keep it steady by occasional manipulation. The skill required is not great.

The receiving circuit ordinarily employed is shown in Figure 3. The coupling between the antenna circuit and the closed circuit is usually very loose. Thus with pancake shaped coupling coils such values of the angle between the coils as 88° are usual.

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* See Editorial Notes at the end of this Lecture.

This is exceptionally loose coupling and ensures sharp tuning of a quality unattainable in spark systems. The tuning is remarkably sharp and we have done much work in the direction of eliminating damping in the receiving circuits. In particular we have found it necessary to avoid leaky condensers. And because of the undamped nature of the radiation we can get all the advantages of loose coupling.

The detector used is the ticker. The old-style ticker is an intermittent contact operated by an electric buzzer. The contacts themselves are between two gold wires, one of them fixed and the other attached thru an insulating piece to a diaphragm which is maintained in continual vibration by the buzzer armature. The contact wires are connected to the terminals of the tuning condenser in the closed tuning circuit and also to a considerably larger fixed condenser (value about 0.02 mfd.), which latter condenser is also connected to the low resistance receiving telephones. The action of the ticker is to permit alternating currents of large amplitude to build up in the secondary tuning circuit, and at more or less regular intervals to discharge the variable condenser thru the telephones producing at each discharge a click. The telephones are the ordinary 75 ohm double head band type. The note produced is not a pure musical one because the ticker cannot be arranged so as to interrupt the alternating current which charges the condenser at the same point of the cycle at successive interruptions. In consequence some clicks are louder than others and the note is not clear. It may be characterized as a hissing sound not altogether agreeable to the ear. If a rectifier is placed in the ticker circuit the note becomes much purer. But the signals are weakened.

The difference between the two waves emitted from the transmitter is small. Thus when the sending key is up the wave may be 3000 meters and it may be 3150 meters when the key is depressed.

An efficiency of twenty per cent. is considered good for the Poulsen transmitter. Tho this is only about one-third what is obtained by the use of the quenched spark, yet it is found that in practice we can work far greater distances than with the latter. This may be because the ticker telephone combination is by far the most sensitive and efficient detector in existence.

As examples of what is done as regular service, we work from Los Angeles to San Francisco, a distance of 350 miles with 12 kilowatts direct current. San Diego, with 5 kilowatts D. C.

is in communication with San Francisco at night. In the winter, the conditions are naturally much better. With 12 kilowatts D. C. we even work from San Francisco to El Paso in the daytime, a distance of 900 miles; not sufficiently continuously for commercial service but still very frequently; it being practically a daily performance.

The power utilized is limited by two considerations. One of these is the capacity of the antenna and the other is the voltage at the arc. We have worked up to 1200 volts but higher voltages than this are not excluded. As to the antennae, we have adopted as standard the double harp, twin-mast system. Its construction is clearly shown in Figures 4 and 5 which are those of a typical antenna of 0.005 mfd. capacity. The new antenna for the large South San Francisco station is supported by twin towers 440 feet high, 600 feet apart. The antenna capacity is here 0.012 mfd. Because of the low voltages employed, insulation difficulties are minimized. The type of tower now used is triangular in cross section and does not taper. For it special timbers have to be sawed. The plan of the guying system is shown in Figure 6. It will be seen that the construction lends itself to great rigidity. As the results of our tests with the 12 Kilowatt stations we have reached the conclusion that this type of masts and antenna is the best for our system. In some of our stations, we employ the flat top aerial of less height for receiving. But we regard the flat top aerial as inferior to the harp type. The harp type also has the mechanical advantage that by its use the danger of twisting of the spreaders disappears.

The ground employed is the radial type with connection to earth at outer points. It is shown in Figure 7, where S is the station house. The ground wires, which are buried two or three feet below the surface radiate in all directions, and are heavily bonded together at their outer extremeties, B.

At the South San Francisco station, the antenna current is about 40 amperes when 35 kilowatts is drawn from the direct current generator at 600 volts. The Honolulu Station is exactly like the South San Francisco one. The system as now improved is simple in operation and installation. As evidence of this, Mr. Elwell, Chief Engineer of the company, went to Honolulu on two days notice, and within sixty days the Honolulu station was in operation. And yet in this case there were considerable difficulties to be overcome. All the apparatus and supplies had to be shipped from San Francisco, and the Chinese workmen, who were the only ones available, would not work at heights above one hundred feet. The distance covered by this station is 2300 miles. Since August, not less than 1500 to 2500 words of press have been transmitted daily. There are in addition a considerable number of paid messages. The rate is 25 cents a word against 35 cents of the cable companies. At the present time, we can operate up to 8 in the morning. When the new 60 kilowatt sets are installed, we expect to operate thruout the day.*

Between Los Angeles and San Francisco two to three hundred messages are sent every day, and this is strictly paid business, of a kind where accurate service is required. Of course, a certain type of customers is specifically catered to. Thus the California Fruit Growers Association do much business between Los Angeles and San Francisco. They demand a thirty minute service, that is, between sending the message and receiving the answer, and we have kept up that service for over a year now. This is a very strict test because these messages are all in an unpronounceable code. The Publishers' Press Association has also used our service from five to nine in the evening for a period of ten months or more.

There is another chain of stations at the following points: Chicago, Kansas City, El Paso, and Fort Worth. But these stations were equipped with too little power. The static in Texas is terrific and prevents service except in the daytime. At Chicago there are two 80 foot towers, 250 feet apart, placed at the top of a high building. They each carry 40 foot spreaders. The limit of power capacity here is 7.5 kilowatts, the limit in this case, being determined by the dimensions of the antenna. If greater power is desired, it will be necessary to use higher voltage.

An extremely interesting phenomenon has been observed in this work with undamped radiations of slightly different wave lengths. It is that at certain times daily, practically thruout the year, and under certain meteorological conditions, very surprising variations in the strength of the received signals occur when definite wave lengths are used, and only when these wave lengths are used. For example, the Los Angeles station works with a wave of 3260 meters and a compensation wave of 3100 meters, and the shorter wave is radiated continuously with the exception of the time during which the dashes or dots are being sent.

Now it will suddenly happen that the longer wave will become

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* Since this paper was prepared 24-hour service, both ways, has been instituted and is daily successfully maintained.

very weak or even be entirely lost at the San Francisco station, distant 350 miles north, whereas it will be received with normal strength at the Phoenix, Arizona station, distant 300 miles to the east. Nevertheless the shorter compensation wave, which differs in wave length by only about 5 per cent., will be received in San Francisco with full strength, or even with greater intensity at times.

This phenomenon of the extinction of the waves occurs frequently, particularly at our stations near the Pacific Ocean; for weeks it was observed every evening and at other times was entirely absent. In consequence the operators have arranged to send on either of the two waves used.

The duration of this fading effect is often several hours after nightfall; then it suddenly vanishes and thereafter both waves have their normal intensity. This alteration of intensity is sometimes for one wave, and sometimes for the other, and rarely for both; and in the last mentioned case the operator can find a third wave on which he can receive clearly. Usually, however, one of the wave remains of normal intensity; in other words, waves which differ in length by several hundred meters do not vanish simultaneously.

This selective absorption does not seem to be limited to specific localities, appears mostly at sunset, lasts far into the night, but is seldom observed near noon.

At first I thought that the effect could be explained by altered conditions at the transmitter or receiving station, as, for example, thru alteration of antenna capacity because of the presence of fog, etc. But the persistency with which it occurred, and the fact that no amount of tuning at the receiving station remedied matters altho simultaneously other stations were receiving this wave perfectly, prevents the acceptance of an explanation on the grounds of atmospheric absorption, that is, such an explanation as is employed to clear up the daylight absorption at long ranges.

Clearly it is impossible that a wave of 3260 meters previously of satisfactory intensity can be absorbed completely at a distance of 350 miles while at the same time a wave of 3100 meters remains of full strength. And there is not much to be said in favor of the assumption that alterations of the refractive power of low-hanging cloud banks or of layers of clouds produce a bending of the wave trains which causes them to pass over the receiving station, while at the same time waves of only 5 per cent. differ-

Figure 9.

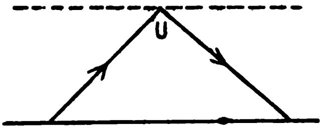


Figure 13.

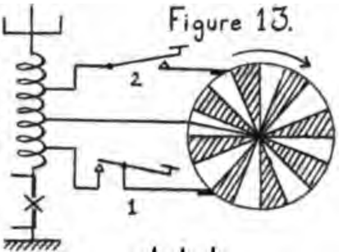


Figure 10.

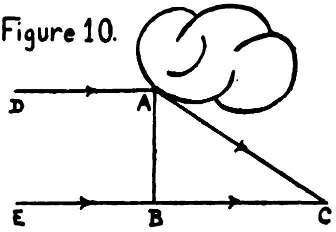


Figure 14.

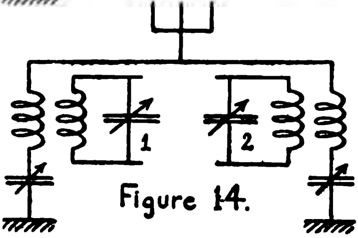


Figure 11.

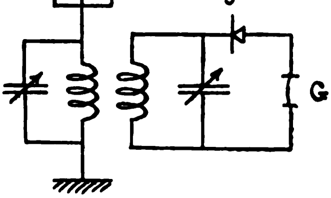


Figure 15.

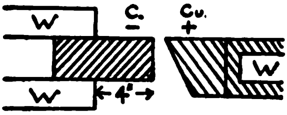


Figure 12

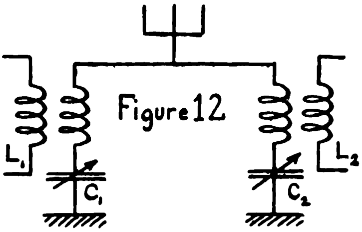
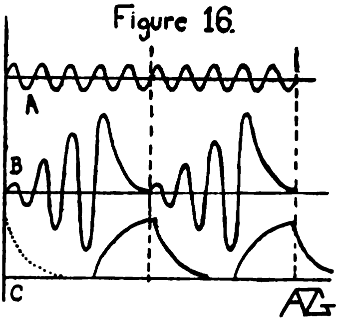


Figure 16.



ence in length are received as well, or even more strongly (as is frequently observed).

It is however possible, that under certain atmospheric conditions, which may be caused by clouds or masses of fog (which are found with great regularity at certain seasons on the Pacific coast), or by by partially ionized masses of air at greater heights. the energy of the upper part of the wave may be deflected or bent downward. Dr. Eccles at the Dundee meeting of the British Association pointed out that a bending of the wave as it travelled might be produced if the upper layers of air were even partly conducting. The appearance of the bending wave front as it travels from left to right is shown in Figure 8. Under such conditions there are acting at the receiving stations two trains of waves which have travelled over paths of unequal lengths or which have travelled with unequal velocities. Consequently there will be a phase displacement between them and interference at certain localities. These are the nodes at which total or partial extinction of the oscillations occurs.

The possibility of such an interference has already been mentioned by several authors in their speculations concerning the propagation of electric waves over the surface of the earth. For example, Professor Pierce, of Harvard University, states in his book: "Principles of Wireless Telegraphy," "The upper layers of the atmosphere which have been rendered conducting thru the action of sunlight, may act to a certain extent as reflectors of electric waves and thus limit their propagation over the surface of the earth; the transmission would then be superior in the day time, with the exception of the case where a possible interference occurred between the direct and reflected waves. This interference, if it exists, would strengthen waves of certain length and might annihilate waves of different length, so that this interference could be made of assistance by altering the wave length by an amount corresponding to half the period. No such effects however have been observed."

Dr. Pierce's conclusions regarding the superiority of daylight transmission are, as you know, contradicted by the experimental results. The ionization of the air at lower levels is able to counteract the influence of the reflection at the upper layers. On the other hand I believe that there is now ample evidence to concede the existence of such reflection as darkness approaches. In Figure 9, the conducting layer of air at U is shown and the path of the wave with its reflection at U is also shown.

How shall we account for the fact that the reflection effect was not observed till recently? In spark telegraphy two waves of nearly equal length were rarely used (with the exception of the case of those due to coupling of the open and closed oscillating circuits). Alterations in the wave length used in transmission are seldom attempted or else are of considerably greater magnitude than those used in our work with continuous oscillations, which latter therefore bring the desired effect into greater prominence. It would be interesting to observe whether similar observations have been recorded with sustained radiation in other climates, or whether these effects are limited to the particular atmospheric conditions and localities in which we have observed then.

Because of the great commercial demands on the stations up to the present time I have not been able to undertake a careful series of observations altering the transmitting wave by successive small steps in order to ascertain between what intervals of wave length these effects of interference or disappearance pass thru maxima and minima. Before an exact statement can be made theory and practice must work together for some time.

In Figure 10 is illustrated one set of conditions which would lead to the reflection and interference effects observed. Suppose we are working with two waves, λ_2, of length 3000 meters and λ_1 of 3150 meters. At A assume a reflecting surface (cloud bank or mass of ionized atmosphere). The distance BC is taken as $20\,\lambda_1$ which equals $21\,\lambda_2$. The distance AC is taken as $28.5\,\lambda_1$ which also equals $29.9\lambda_2$. So that the difference of the paths for the two waves λ_1 and λ_2 is $28.5 - 20 = 8.5\,\lambda_1$ for the first wave, and $29.9 - 21 = 9.0\,\lambda_2$ for the second wave. The height AB is found to be 37.5 miles in this case. Its height is found to depend on its distance from the sending and receiving station provided the differences of paths of the two waves are assumed known. It will be seen that in this case the longer wave will arrive at C by two paths which bring the two portions of the wave to C in directly opposite phases. In consequence the longer wave will be partially or totally annulled at C. On the other hand, the shorter wave travels to C by two paths which bring the two portions of the wave to C in phase. They therefore reinforce each other and may appear with increased intensity. Other values for AB, BC, and AC are 27.7 miles, $10\lambda_1$ or $10.5\lambda_2$, and 18 λ_1 and 18.9 λ_2 respectively. Yet another set of values is 17 miles, 3 λ_1 or $3.15\,\lambda_2$, and $10\,\lambda_1$ and $10.5\,\lambda_2$ respectively.

Figure 17

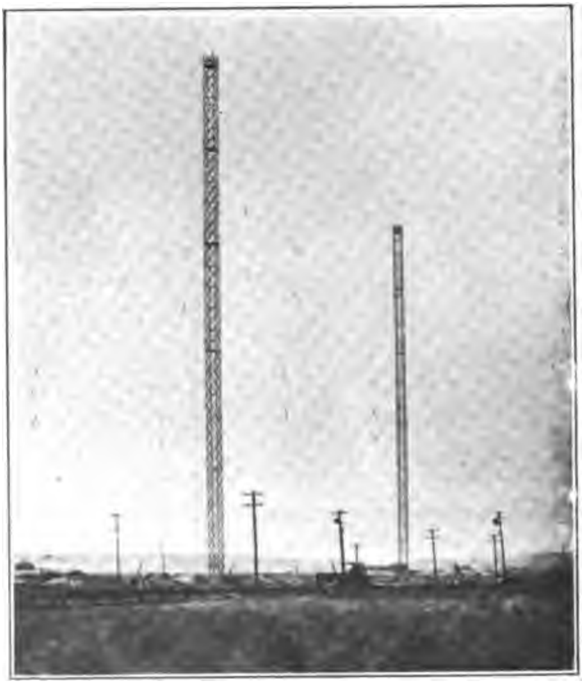


Figure 18

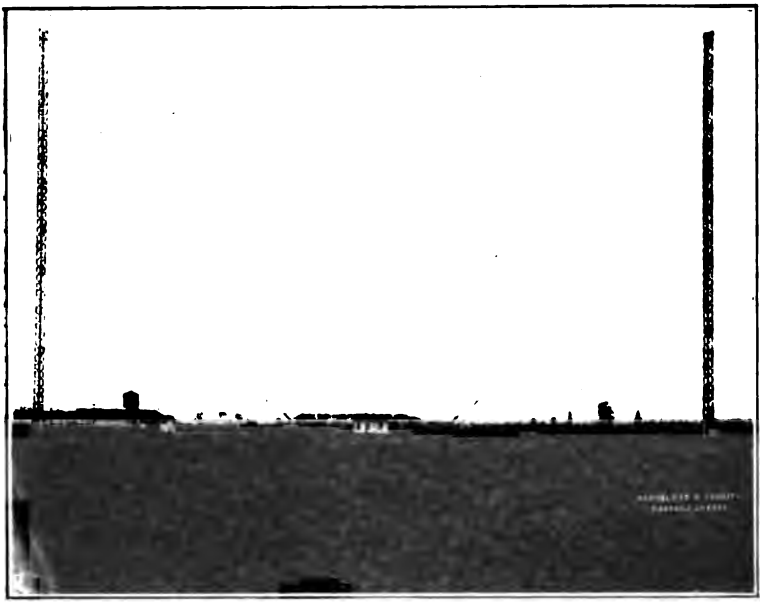


Figure 19

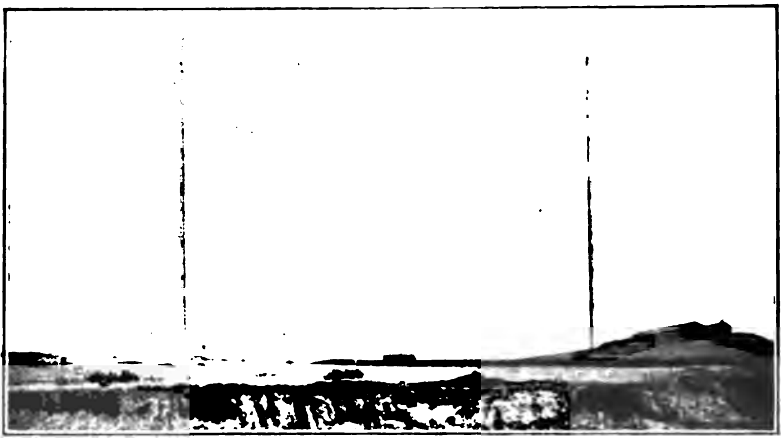


Figure 20

Figure 21

Figure 22

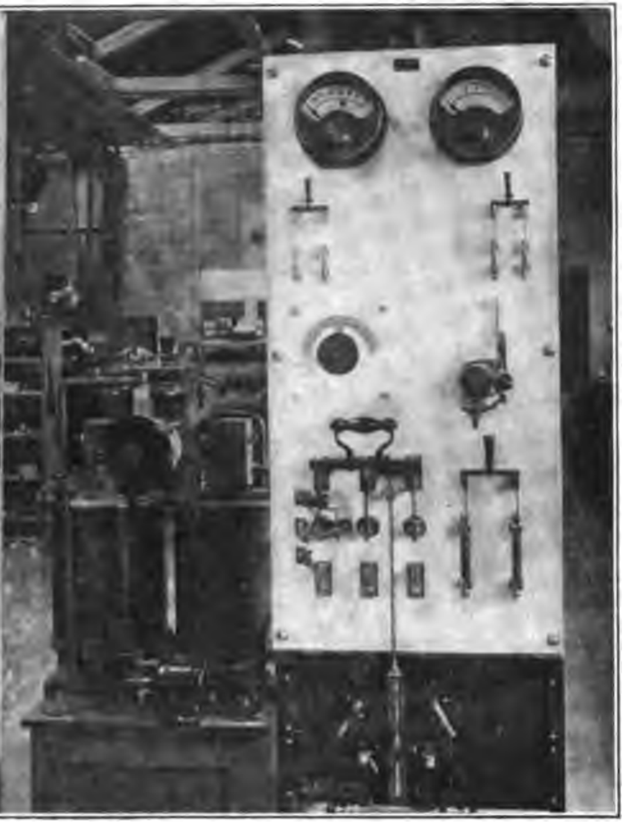


Figure 23

If the reflecting layer is half way between the stations, its height is 62 miles under the conditions here assumed. Five minutes is sometimes the interval during which the effect persists. For its disappearance the ionized layer need rise only one-half of one wave length. Almost never have both the waves faded at the same time. This shows that the reflecting stratum is at a great height. I believe that prolonged and tabulated observations will add considerably to our theoretical knowledge of this subject.

It is possible that the so-called "freak work" in wireless is due to this interference effect. It is impossible to say because we have had no simple way of changing the wave length suddenly in the quenched spark sets. But I believe that the extreme long distance work done by small sets must frequently be explained thus. Then too, it would account for the fact that the Marconi Transatlantic stations can operate sometimes with a few kilowatts and sometimes require 125 to 600 kilowatts.

And finally, to return to our commercial work, we now use a wave length of 5000 meters at our South San Francisco station. Thus we avoid interference with neighboring spark stations, altho properly tuned quenched sparks sets with a wave length differing 8 per cent. from our own do not interfere with us. It has been our aim to conduct our business with maximum certainty and minimum of interference, and we have succeeded so well in the first aim that we believe that any failure in the second is rather the fault of the other systems.

EDITORIAL NOTES.

Thru the kindness of the Federal Telegraph Company and Mr. Elwell a number of photographs illustrating the work of the company are here reproduced. Figure 17 is the antenna at San Diego. It is of the earlier double pole and spreader type. Figure 18 is the station at Portland, Oregon. The towers are square in cross section. A newer type of tower construction, namely the triangular cross-section type, is shown in Figure 19, the Central Point, Oregon, station. The Transpacific South San Francisco station is shown in Figure 20. In Figure 21 is shown the interior of the Central Point station. To the left is the 500 volt direct current control board with generator field rheostat, measuring instruments, and breaker. Next to it can be seen the arc converter with its powerful field magnets, arrangements for artificial cooling, and front button which, when pressed, makes contact and starts the arc. To the left of the operator's table is seen the receiving set with variable inductances and capacities controlled from the front knobs, various switches for altering wave length range, etc., and the telephone jacks. Standing on the top of the receiving set is a specially wound coil which is employed when extra long waves are to be received. Next to the receiving set is the operator's key, and then the board where the wave length of the radio-frequency currents is controlled. The antenna hot wire meter is visible at the top of this board, and below it a rotary switch which enables the operator to rapidly change the wave length, which procedure, from the foregoing article, will be seen to be strictly necessary at times. To the extreme right of the operator's table is the motor-driven ticker for receiving. It is supplied in duplicate. At the top of the room is seen the antenna helix with the various taps leading to it. Near its bottom and to its right is seen the lightning switch.

The details of the transmitting apparatus are shown in Figures 22 and 23. Figure 22 shows the new Poulsen generator with special anode. There is a quick detachable bottom plug for cleaning the arc chamber when necessary. The massive field coils are shown. They are wound with heavy square cross section copper wire. Figure 23 shows the arc and its control board. Under the switch-board panel are shown the water valve lever which controls the flow of water thru the arc chamber jacket, and the receiving contact device. Both of these are operated by the large triple pole switch. This switch controls the flow of water, the flow of gas, the motor for rotating the carbon electrode of the arc, the power current, the radio-frequency circuit, the receiver circuit, and the motor-driven tickers.

The hypothesis suggested tentatively by Dr. de Forest relative to the opacity of the ether for certain wave lengths has, up to the present time, met with no substantiation. We are forced to regard it as highly improbable. The view that the interference effects are the results of the joint action of the direct and reflected waves, as also suggested by Dr. de Forest, is very probably correct, and should lead to valuable and extended researches on the most favorable locations of stations and wave lengths to be employed.

In order to render the action of the ticker somewhat more clear Figure 16 is inserted. It is intended to show the currents in the various circuits. Curve A gives the antenna current. Curve

B gives the current in the secondary tuned circuit. Curve C gives the condenser discharge current thru the telephone receiver. It will be noted how the resonance effects which are obtainable with sustained alternating current in the antenna are utilized fully. This ingenious receiving device is due to Prof. P. O. Pederson of Copenhagen.

The circuit arrangements for which these diagrams apply are somewhat different from those now employed, but embody the same principle.

Dr. de Forest has formally notified the Editor of the results of the tests at the Arlington station. The 30 Kilowatt arc was first tested on December 8th. Two way communication with South San Francisco, and also with Honolulu, was almost immediately established, altho at the time Honolulu was still in daylight! Owing to the greater height (600 feet) of the Arlington antenna, its signals are received with greater intensity than those of the latter station at Arlington. The energy used at Arlington was from 35 to 40 K. W.

Alfred N. Goldsmith, Ph.D.

DISCUSSION.

E. J. Simon: I understand that using 35 kilowatts at the San Francisco station the antenna current is 40 amperes. What is the radiation resistance?

Dr. de Forest: We have not measured it because it cannot be accomplished in the usual way, namely by the insertion of resistance in the antenna. The arc is directly in that circuit, and any change alters the conditions markedly.

Dr. Goldsmith: It should be possible to accomplish the desired result thru the following means. Measure the arc voltage which is applied to the antenna (R. M. S. value of the alternating E. M. F.) by means of an electrostatic voltmeter. Then measure the effective inductance and capacity of the antenna at the desired wave length or frequency ω separately. Then if R is the radiation and ohmic resistance of the antenna, L and C its effective inductance and capacity, E and I the R. M. S. values of the voltage and amperage of the antenna, we have

$$R = \sqrt{\frac{E^2}{I^2} - \left(L\omega - \frac{1}{C\omega}\right)^2}.$$

E. J. Simon: We may determine the damping by measuring the decrement by the Bjerknes method.

Dr. Goldsmith: Before employing either of the above methods it would be well to calculate what effect the non-sinusoidal character of the arc current would have on the results.

E. J. Simon: An artificial antenna or substitution method might be employed.

R. A. Weagant: In this case air condensers should be used in the artificial antenna.

E. J. Simon: Does the ground extend beyond the horizontal projection of the antenna?

Dr. de Forest: Yes; the extreme spread of the antenna is 400 feet, but the radius of the ground is 350 feet.

E. J. Simon: The signals weaken in the morning. Is there any definite lag of the change of intensity of the signal as compared with the time of sunrise?

Dr. de Forest: We have as yet made no such quantitative measurements.

R. A. Weagant: How loose is the coupling used in receiving?

Dr. de Forest: Usually 10 to 15%. In cases of bad static it may be 5%.

E. J. Simon: Do you use the longer wave because of its greater energy?

Dr. de Forest: Yes, and to prevent interference, but the energy difference is small.

E. J. Simon: What is the fundamental of the South San Francisco aerial?

Dr. de Forest: About 2800 meters.

Dr. Goldsmith: Will you describe the automatic sender, the optical printing receiver, and the diplex transmission and reception methods?

Dr. de Forest: For high speed transmission we employ an automatic sender. For receiving at high speeds we use the Einthoven thread galvanometer, which consists of a fine thread of gold wire in an intense field of an electromagnet. It is placed in series with a rectifying detector and on receipt of incoming signals is slightly deflected. By suitable optical systems, a greatly enlarged shadow of the brilliantly illuminated wire is thrown on a moving strip of photographically sensitive paper, which is then rapidly developed and fixed. From the wavy line on the strip of paper the message can be read. We have spent over $12,000 in investigating this method, and have imported the best instruments we could get in Denmark and Germany. But the entire method is impractical commercially and a flat failure. And it always will be. The Pederson high speed transmitting key is a device which is operated by punched tape such as is used in the Wheatstone sender. It is a somewhat complicated device which acts on the principles that small rotating rods, released by mechanical means, close light contacts and thereby permit heavier rotating contacts, which are always in readiness to operate, to add aerial inductance and thereby increase the wave length. The arrangement of circuits used with the Einthoven galvanometer is shown in Figure 11. The galvanometer is shown at G. The wire in it is 0.00005 of an inch in diameter. Our experience with it has been unsatisfactory. Static is sufficient to throw the spot of light completely off the moving paper strip, and we sometimes had to run the paper thru three times, and even three times three times, before a good record was secured. Even the possibility of sending more than 100 words per minute does not compensate for such disadvantages. A possible method of diplex is shown in Figure 12, where L_1 and L_2 are the primaries from which energy at different wave lengths is transferred to the antenna. Marconi tried something of the sort, but omitted the condensers C_1 and C_2, hence it is very doubtful whether the device operates as then shown. An extremely successful method of diplex operation is shown in Figure 13. It will be noticed that the contacts on the rotating sector wheel are so arranged that contact for key 2 is broken just as contact for key 1 is made. When neither key is depressed a medium wave of length 3200 meters, for example, will be sent. If key 1 is depressed the wave length rises to 3400 meters, and if key 2 is depressed a wave length of 3000 meters is emitted. If both keys are depressed, waves of length 3000 and 3400 are alternately sent out for short intervals of time. The arrangement at the receiving station is shown in Figure 14, where 1 and 2 are the two receiving circuits tuned to 3400 and 3000 meters respectively. This system has worked perfectly between Los Angeles and San Francisco. It is very practical, and arcing at the brushes has been largely overcome. I use 450 interruptions per second.

JOHN L. HOGAN, JR.: Have you any data as to the decrement of your receiving antenna circuit? You speak of extremely sharp resonance.

Dr. de Forest: Stress of commercial business at the San Francisco station has prevented our making such measurements.

J. L. Hogan, Jr.: What is the comparative sensitiveness of the "Ticker" as compared with the solid rectifiers?

Dr. de Forest: Qualitatively I should say that the ticker was about three times more sensitive. We get louder signals with the ticker signals from the arc station than we can get when we employ a "chopper" at the transmitting station to break up the outgoing wave train, and a rectifier at the receiving station. To give you an idea of the actual intensity of the signals, at Los Angeles the operators invariably use the typewriter while receiving.

J. L. Hogan, Jr.: Is the ticker ever run at interrupter frequencies as high as 1000 or 1200 per second?

Dr. De Forest: No, the normal rate is about 200 per second. This gives a hissing note in the telephone receiver, a sound which is very characteristic, and easily read when one becomes accustomed to it.

J. L. Hogan, Jr.: You state that you use very loose couplings at the receiver, and that the tuning is much better than can be had with feebly damped oscillations of the type produced by quenched spark transmitters. Perhaps you will recollect that it has often been contended that if quite persistent waves were used one might secure all the resonance benefits of sustained wave transmission. If I recollect correctly, this was your own position formerly.

Dr. De Forest: It was, but my recent work has forced me to change my opinion in that respect. We are able to secure tuning conditions that I would have considered impossible with the best quenched spark senders. I feel certain that with the sustained oscillations you can secure better tuning.

J. L. Hogan, Jr.: Have you made any measurements which would indicate that the attenuation term in the Austin-Cohen transmission equation should have a different value for sustained than for damped waves, or that there should be a factor included which varies with the transmitter decrement?

Dr. De Forest: We have secured no data in that direction as yet. I expect to attack the reflection and interference problem more exhaustively first.

It may be of interest to those present to know that we have shipped a 30 kilowatt set to the Government station at Arlington, Virginia. For such sets we require an antenna capacity of 0.01 microfarad. This set should be installed within a few weeks. Personally I anticipate considerable absorption in the towers. They are too near together. By the first of the new year we will have a 60 kilowatt arc in operation. This type of arc brings with it new problems of cooling, etc. The general construction of our arcs is shown in Figure 15. Water cooling is accomplished by the water jackets and pipes at W. The diameter of the carbon in the 12 kilowatt arcs is 1 inch, and this may rise to 4 inches in the 60 kilowatt arcs.

MARCONI TRANSATLANTIC STATIONS.

At the request of President Marriott, Mr. Hallborg of the Marconi Company, who has lately returned from Europe, described the Transatlantic Marconi station at Clifden as follows:

The power used is 125 kilowatt, of which about 50 kilowatts is radiated from the aerial. Power is supplied by four 5000 volt direct current generators in series. These generators are of special type with slotted commutators and air blowing between the segments for cooling and prevention of destructive arcing. These machines charge a storage battery when it is desired to run the alternating current machinery which may be used to feed the high tension transformers. These last are of the American Transformer Company's manufacture with special means for avoiding high tension surges.

In receiving a static preventer is used wherein two balanced crystals are employed. Their current voltage characteristics are identical. The arrangement is similar to that employed by Eccles with the valves. The alternating current generators are each 500 kilowatt and 25 cycle.

The receiving aerial consists of 4 wires each 2000 feet longer than the sending antenna. The transmitting aerial is sometimes employed in a curious way to assist in tuning, by tuning it to the incoming wave and using the reradiated energy to assist the receiving aerial.

At this point Dr. de Forest remarked that he had noticed that large aerials tuned to the incoming wave assisted smaller ones in their vicinity thru the reradiated energy.