The Engineering Measurements of Radio Telegraphy

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ARTICLE IV

In the article published in this issue the principles of distributed capacity are discussed in detail. Its effects are told of and a table is published for the purpose of calculation. The author takes up the subject of measurement of distributed capacity at radio frequencies and low voltage, and describes the theory of the practice.

II.—MEASUREMENTS OF DISTRIBUTED CAPACITY

12. *General Considerations.*—We have shown various methods of measuring capacities at radio or audio frequencies, and at high or low voltages. In all the cases treated, the device, the capacity of which was determined, was a condenser; that is, a device specially arranged to have electrostatic capacity and consisting essentially of (nearly) inductance-free conducting surfaces, insulated from each other. The capacity under these conditions is *localized* in the circuit, and the circuit has been assumed to contain no capacity such as was concentrated in condensers. This assumption is, in general, only approximately true, for the inductances used in these experiments contain what is known as *distributed capacity*. Since the notion of distributed capacity in some ways is less simple to grasp than that of ordinary or localized capacity, we shall discuss it in detail. Its effects, particularly in incorrectly designed receiving sets, are very marked, and may lead to greatly diminished efficiency of the set as a whole.

In Figure 17 a number of turns of an inductance is shown. If a varying current is passing through this coil, there will be a difference of potential between the ends, A and B, of the coil, quite independent of its ohmic resistance. Between turn 1 and each of the other turns a difference of potential will exist, and consequently *electrostatic* lines of force will pass from each point of turn 1 to every point of the coil which is at a different potential. It is to be noted that we are not referring to the *magnetic* lines of force which are interlinked with the entire coil. Some of the electrostatic lines of force between turns 1 and 2 are shown in Figure 17. We have then the interesting conditions that turns 1 and 2 are, in effect, plates of a condenser. Electrostatic energy is stored in the space between each portion of a turn and every part of every other turn; and, since such energy can be stored only in capacities, we have distributed capacity along the entire coil.

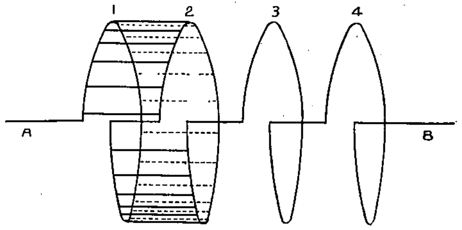

Fig. 17

It is evident, therefore, that the coil can no longer be considered as a simple inductance, but must be treated as an inductance across the terminals of which a capacity (equal to the total distributed

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capacity) has been shunted. It might, at first sight, seem that this assumption that the distributed capacity may be regarded as equivalent to a single concentrated capacity across the terminals of the coil, is of doubtful validity; but it can be demonstrated that in circuits where the resistance is so small as not to affect the natural period of the circuit appreciably, the assumption referred to is justified. We may, therefore, consider the coil L (Figure 18), which has a distributed capacity C_d, as equivalent to a simple inductance L, across which is connected the localized capacity C_d, as shown in dotted lines.

The effects of this distributed capacity are as follows: To begin with, if the inductance of the coil be calculated by the usual formulae, and the coil be placed in an oscillating circuit with a known capacity, C, the period, instead of being, as usual

$$T = 2\pi\sqrt{LC} \qquad (30)$$

is given by

$$T = 2\pi\sqrt{L(C + C_d)} \qquad (31)$$

The distributed capacity of a coil may therefore be very objectionable, particularly if work is being done at short wave lengths where the permissible external (and adjustable) capacity, C, is already quite small.

Another point of difference between a coil having distributed capacity and a simple inductance is of importance. Even if no capacity be connected across its terminals, such a coil may vibrate electrically. It is, in fact, a so-called open oscillator, and behaves in this respect quite like the usual antenna of a radio station. If, in Figure 19, G is a generator of radio frequency alternating current, and L_1 an inductance which couples it electrically to the coil, L, having a distributed capacity C_d, it will be found that for some particular frequency of excitation the coil, L, will vibrate powerfully electrically. The particular frequency in question will be (if the coupling between L_1 and L is very loose), the natural frequency of L. The second circuit, L_3 C_3, will then indicate this frequency by means of a maximum reading of the indicator, I, provided that its capacity and inductance are properly adjusted. This last circuit will therefore serve as a "wave meter," or more strictly, a frequency meter.

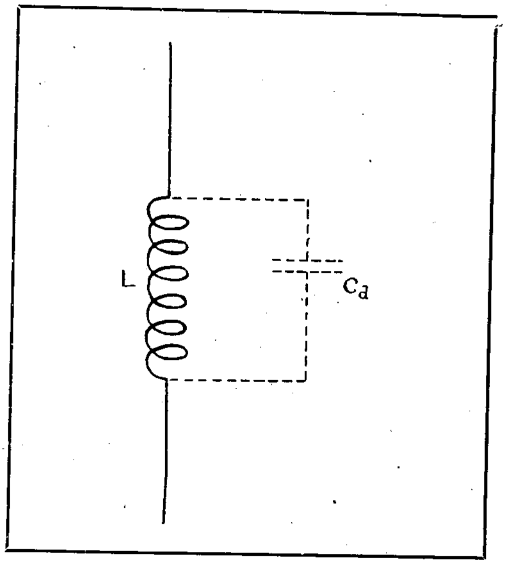

Fig. 18

If we consider more carefully the mode of electrical vibration of the inductance L, which possesses distributed capacity, we find it differs considerably from that in ordinary audio frequency alternating current circuits. In the latter, the value of current is the same at every point of the circuit at a given time. This is not the case for the open oscillator, L. At the left of Figure 19 is shown the curve of current distribution along L, the length of the short horizontal lines being proportional to the current at that particular level of the coil to which they correspond. The voltage or potential distribution along the coil is similarly shown in the second curve, to the right of the first. It will be seen that the potential is highest at the ends of the coil, but that the current is greatest at the middle. Remembering that the ordinary antenna corresponds roughly to one-half of such a coil, the ground connection being the analogue of the middle of the coil, it is immediately evident why the current in an antenna is greatest at the bottom, but the potential highest at the top. And a coil having distributed capacity resembles an antenna in another respect; it serves as a radiator of electromagnetic waves, and the greater the distributed capacity

n proportion to the inductance, the more rominent does the radiation become.

It is possible to calculate the distributed capacity of an inductance from its imensions. A convenient formula for ractical purposes, and a quite accurate ne, is given by Drude. It is the following:

$$C_d = 2\alpha r \frac{2 + \frac{h^2}{r^2} + \frac{r^2}{h^2}}{10 + 4\frac{h^2}{r^2} + 3\frac{r^2}{h^2}} \qquad (32)$$

where h = length of the coil, 2r = diameter of the coil to the middle of the wire.

α = a factor dependent on value of h/2r, and given in the following table. The top headings are core material. In the case of the tubes, the ratio of thickness of tube to radius was 0.05. In all cases, the ratio of diameter of wire with insulation to diameter of wire alone was taken as 1.09. The following table has been specially calculated from Drude's data to adapt it to ready use in calculating distributed capacity:

h/2r	Ebonite	Air	Ebonite Tube	Glass Tube	Ash
6.	2.10	1.81	1.83	1.86	2.24
5.	1.92	1.64	1.64	1.76	2.05
4.	1.74	1.47	1.48	1.54	1.89
3.	1.66	1.37	1.40	1.46	1.82
2.	1.62	1.26	1.34	1.43	1.82
1.	1.54	1.12	1.28	1.37	1.81
0.8	1.54	1.10	1.26	1.37	1.81
0.6	1.52	1.07	1.22	1.34	1.79
0.4	1.36	0.943	1.10	1.24	1.62
0.2	1.00	0.69	0.855	1.06	1.19
0.1	0.72	0.498	0.615	0.828	0.91
0.05	0.41	0.282	0.383	0.50	0.50

To facilitate interpolation of values, the curves of Figure 20 have been drawn. In order to find the value of α for any coil, we calculate h/2r, that is, the ratio of the length of the coil to its diameter, and find the value of α corresponding to the ratio, and to the type of core employed. Formula (32) can then be directly employed.

The free period of a coil of inductance, L, and distributed capacity, C_d, can be directly calculated from the formula

$$T = 2\pi\sqrt{L\,C_d} \qquad (33)$$

and its free wave length from

$$\lambda = 18.85\,(10)^8\sqrt{L\,C_d} \qquad (34)$$

with L expressed in henrys and C_d in farads.

Once the distributed capacity of a coil has been determined, and its natural wave length calculated, it is well never to use it in receiving sets intended to cover a range of wave lengths including the natural wave length of the coil. If this precaution is not observed, considerable energy will be absorbed in the free electrical vibration of the coil, and this energy is useless so far as receiving efficiency is concerned.

13. *Measurement of Distributed Capacity at Radio Frequencies and Low Voltage (by the Impulse-Excitation of Free-Period Method.)*

(*a*) *Theory.*—We shall suppose that the inductance of the coil in question is known for audio frequencies, either by direct measurement with an inductance bridge (as hereafter described), or by calculation, using the formulas given in Bulletin of the Bureau of Standards, Volume 8, Number 1. (Formulas and Tables for the Calculation of Mutual and Self-Induction, Revised.) We shall then determine the free period of the coil by exciting it impulsively, and calculate its distributed capacity by a simple formula derived from Formula (33).

It is assumed that the reader is aware that impulse excitation as used, for example, in the usual quenched spark sets, is a simple means of exciting a secondary circuit to vibrate in its own period and damping regardless (or nearly so) of the

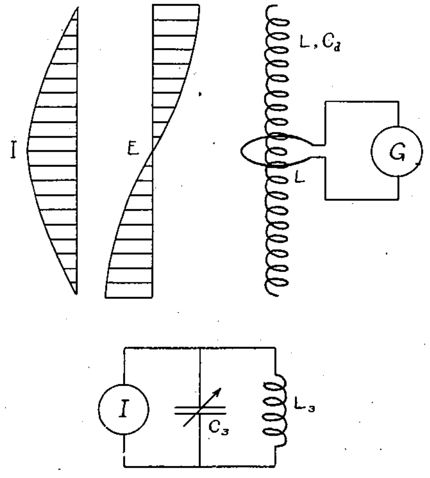

Fig. 19

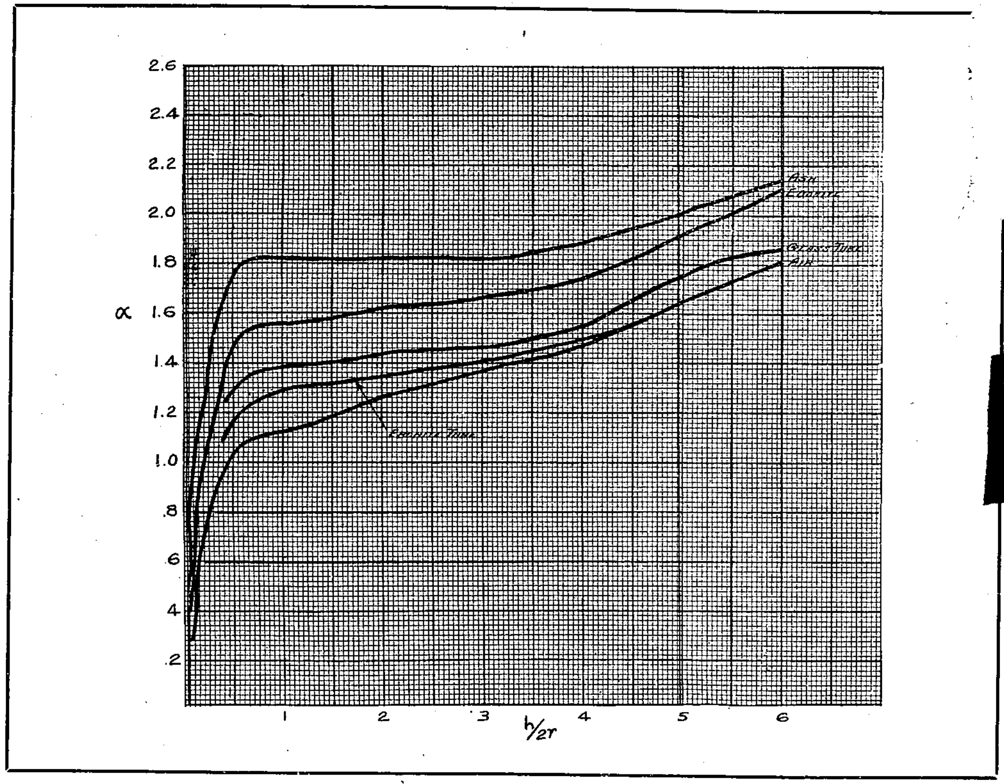

Fig. 20

period of the primary. In order that impulse excitation should be secured, the primary circuit should be highly damped and its coupling to the secondary not too close. We shall meet these requirements by making the primary circuit actually aperiodic, so that no free alternating currents can occur in it at all, but only individual highly damped pulses of current. We shall then couple it loosely to the secondary circuit, which is the inductance having distributed capacity, thus causing that coil to vibrate in its natural period. Suppose that the indicator I which is shunted across the capacity C_3 is of so high a resistance that its influence on the period of the circuit L_3C_3 is negligible. This is the case if its resistance is much larger than the quantity

$$\sqrt{(L_3/4C_3)}.$$

We may then take the period of this last circuit as

$$T_3 = 2\sqrt{L_3 C_3}$$

and the period of the inductance itself as

$$T_2 = 2\sqrt{L C_d}$$

If the condenser C_3 is varied while L is in vibration till a maximum indication is obtained, $T_1 = T_3$, and therefore

$$C_d = \frac{L_3 C_3}{L} \qquad (35)$$

which enables us immediately to calculate C_d.

It was mentioned that the primary circuit was to be made aperiodic. The condition for this is that, if R_1 is the resistance of the primary exciting circuit, C_1 its capacity, and L_1 its inductance, the resistance must be at least as great as the value of R_1 given by the equation

$$R_1 = 2\sqrt{\frac{L_1}{C_1}} \qquad (36)$$

R_1 may be made larger than this, but nothing is gained by so doing.

(*b*) *Arrangement and Description of Apparatus.*—A wiring diagram of the apparatus is given in Figure 21. A, B,

d H are the terminals of a high pitch zzer, F if the battery which operates e buzzer, and E is a regulating resistce for controlling the buzzer current. nnected across the gap of the contact int of the buzzer are L_1, R_1, and C_1, all series. As indicated, L_1 is loosely coupled to the coil, L, which is the inductance having distributed capacity under measurement. L_3 and C_3 are the inductance and capacity (both known) of the wave meter circuit, D is a detector, and T a telephone receiver. With the apparatus as actually used, F was a 10-volt storage battery, E was from 10 to 20 ohms, C_1 was a 2-microfarad No. 21-D Western Electric Condenser, L_1 a single turn or two turns of No. 18 lamp cord wound around L, and R_1 was between 10 and 100 ohms. L (in one case) was a coil of 157 turns of multiply stranded wire (so-called "litzendraht"), consisting of 7 sets of wire, each set made up of 7 strands of No. 32 enamel covered copper wire, the sets being all twisted together and the whole triple silk insulated, radius 8.045 cm., length of winding 31.7 cm. The wave meter circuit L_3 C_3 consisted of the inductance L_3, which was made up of 16.8 turns of No. 18 lamp cord wound on a core 8.7 cm. in diameter. Its inductance was 18,980 cm. The capacity C_3 was a small variable air condenser, maximum value being 0.00074 μf. The detector, D, was a usual crystal rectifier, and the telephone a 2,000-ohm double head band receiver.

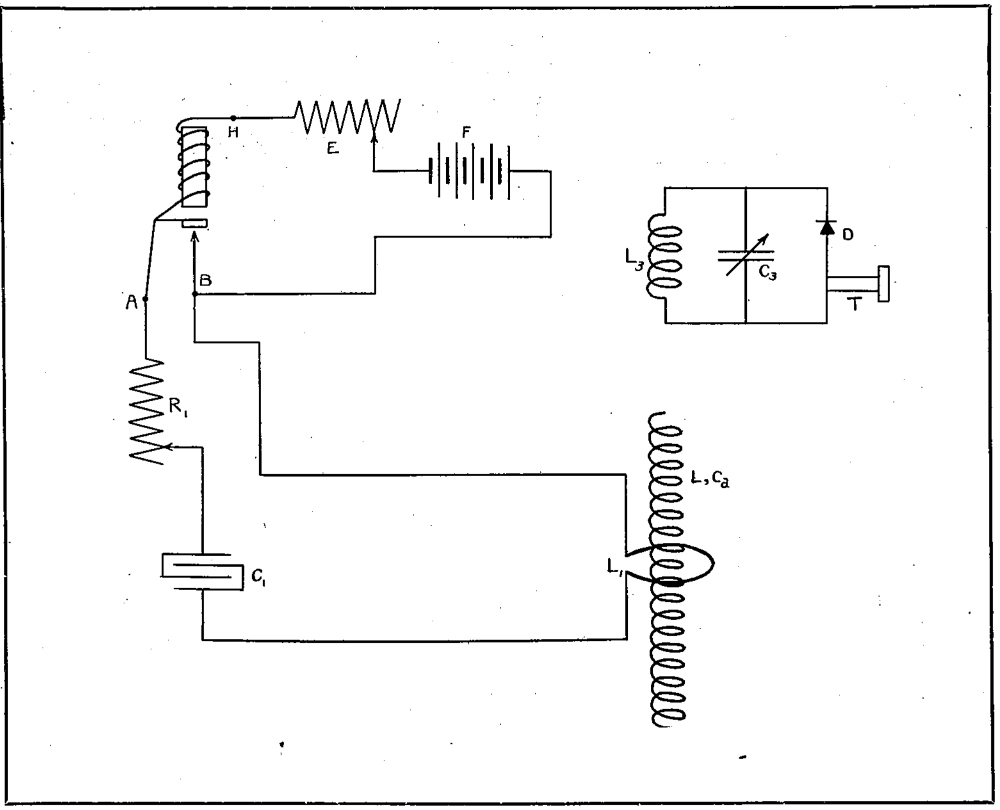

Fig. 21

The actual arrangement of the apparatus is shown in the photograph, Figure 22. To the left are seen the enclosed buzzer, and the resistances, E and R_1. The condenser, C_1, and a long coil, the distributed capacity of which is being measured, are in the middle. The two turns of the coupling inductance, L_1, are shown wound around L. To the right,

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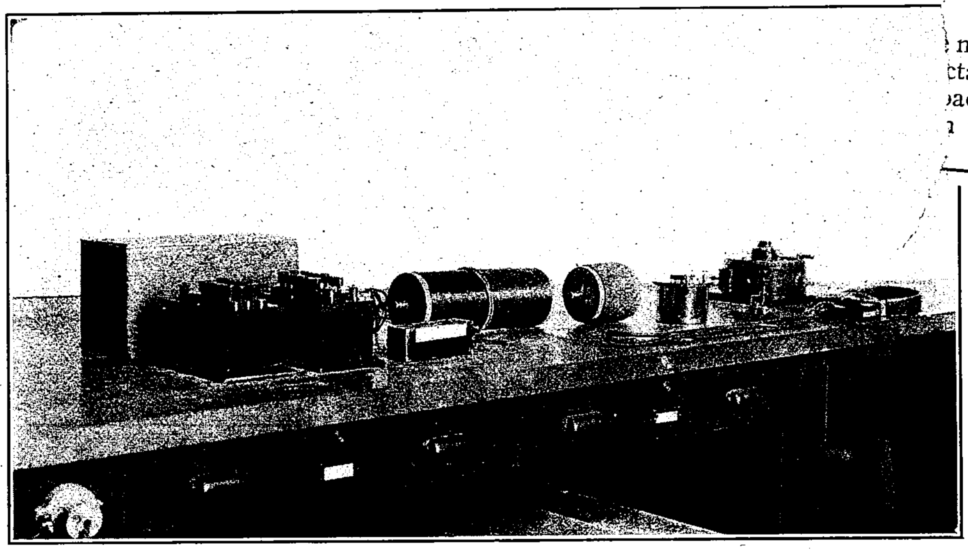


Fig. 22

L_3, C_3, D, and T are seen in order.

(*c*) *Procedure.*—An estimate of the magnitude of the distributed capacity C_d is made, and L_3 and C_3 are so chosen that it is possible to make

$$L_3 \, C_3 = L \, C_d$$

L_3 is then loosely coupled to L, and a number of readings of the resonance point of C_3 are taken. It is necessary to know the values of L and L_3, either by calculation of measurement. The condenser C_3 must also be calibrated.

(*d*) *Errors of the Method, Their Elimination; and Probable Accuracy.*—Unless L and L_3 are loosely coupled, the readings of the wave meter circuit are not dependable. Furthermore, it is essential that the resistance of D and T shall be high, as mentioned under theory.

As an example of the measurement, we consider the following: Coil of which the distributed capacity was being measured; "Litzendraht" coil, described under *b*.

L (as calculated by Nagaoka's Formula) $= 16.55 \, (10)^{-4}$ hy.

L (as measured on special apparatus at approximately 2,500 meters) $= 16.7 \, (10)^{-4}$ hy.

C_d (as calculated by Drude's Formula, number (32) above, assuming air core) $= 5.85 \, (10)^{-12}$ farad.

L_3 (in wave meter circuit) $= 18.98 \, (10)^{-6}$ hy.

C_3 (in wave meter circuit, when resonance is secured = 20 divisions) $= 4.9 \, (10)^{-10}$ farad.

C_d (as calculated from Formula (35) above) $= 5.68 \, (10)^{-12}$ farad.

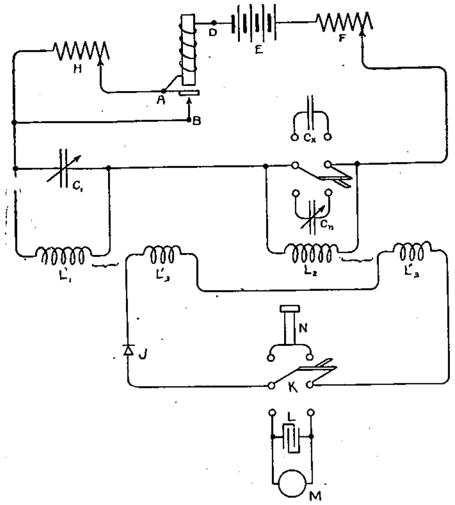
λ_f (fundamental free wave length of the coil as obtained from the calculated values of L and C_d) = 186. meters.

λ_f (fundamental free wave length of the coil as obtained from the measured values of L and C_d) = 183. meters.

It will be seen that the discrepancy in the value of $C_d = 2.9$ per cent, and that the discrepancy in the value of $\lambda_f = 1.6$ per cent.

The method which has been here outlined can readily be employed at high voltages. It becomes necessary to replace the buzzer excitation circuit by a quenched spark circuit, still further damped, if necessary, by insertion of the additional resistance R_1. Instead of the detector and telephone indicator, a hot wire ammeter in series with L_3 and C_3 may be employed instead. The theory is in no wise altered by these changes.

In the December issue of the WIRELESS AGE a connection was omitted from Figure 14, published to illustrate The Engineering Measurements of Radio Telegraphy. On the following page a corrected diagram of the figure is shown.



This is the fourth article by Dr. Goldsmith, in a series on the engineering measurements of radio telegraphy. The fifth will appear in an early issue.

DR. DeFOREST ON THE AUDION

At the November meeting of the Radio Institute at Fayweather Hall, Columbia University, an interesting lecture was delivered by Dr. Lee DeForest on the Audion—A Detector and Amplifier. The lecture was followed by a practical demonstration of the device.

The inventor gave a novel explanation of the operation of the audion, asserting that it did not obey the rectifying principle, but that the effect of the incoming oscillations from a transmitting station was to suddenly increase the resistance of the local circuit containing a high-voltage battery; this in turn, he said, caused a fluctuation of current that reproduced the radio signals in the head-phones.

After describing the steps preliminary to the discovery of the audion, Dr. De Forest showed in an elementary way the circuits of the audion as an amplifier. The instrument on exhibition consisted of four audions, each of which gave an increase of intensity of signals over the one preceding it; thus, amplications of 200 times the original strength of signals received in the first audion were obtained, according to the speaker.

In the practical demonstration of the apparatus the application of the devices to wire telephony was shown. A pair of ordinary wireless telegraph headphone receivers were connected to the audion amplifier. The first audion was then connected to a single magneto telephone receiver. The currents produced by the vibration of the single magneto receiver when near to the faintest sounds were sufficient to cause clear reproduction in the double headphone receivers. When a handkerchief was dropped on the single magneto telephone the feeble electric currents generated by the impingement of the sound waves upon the telephone diaphragm were sufficiently amplified by the audions to produce a considerable racket in the ear-pieces.

The single magneto telephone was then taken to a distant room and the audion amplifier connected to three loud-speaking telephones. Dr. DeForest's assistant in the distant room whispered into the magneto receiver and the electrical impulses thus produced were sufficiently amplified to be heard over the entire lecture hall.

It was stated that it is proposed to use the audion in connection with long distance wire telephony as an amplifier and that it might make transcontinental (New York to San Francisco) telephony possible.

A demonstration of the application of the audion in connection with wireless telegraphy was given. Radio signals coming from several wireless telegrah stations in the vicinity of New York had been recorded on the steel tape of the Poulsen telegraphone. The audion amplifier reproduced radio signals from the telegraphone records, which were so faint that they could not be heard on the telegraphone in the regular way. They were, however, sufficiently increased in intensity by the audion amplifier to make them audible. It was possible in this way to record the sound of the human breath on the telegraphone records and reproduce it quite distincly.

A new type of audion having double grids and double plates was shown. With this arrangement it is possible to light all three filaments from one storage cell, which, of course, is conducive to the simplicity of operation of the set.

How to Conduct a Radio Club

By E. E. BUTCHER

ARTICLE II

READERS of the series on How to Conduct a Radio Club will be interested to learn that the Bureau of Navigation, United States Department of Commerce, has concerned itself with the plan outlined relating to the formation of an organization, and suggested that the following be published:

"Radio station licenses can only be issued in the name of a club if it is incorporated in some State of the United States; otherwise the license must be in the name of some individual of the club who will be held responsible directly for its operation.

"Radio clubs having a club station should apply to the radio inspector of their district for the assignment of an official call signal which must be used for all radio communication."

In view of recent developments in radio telegraphic research the writer of these articles has decided to vary the practice generally employed relating to the order of publication; thus this article is written specifically for members of radio clubs already in existence, in the hope that it will spur them on to renewed efforts in investigating.

In it will be described two methods for the amplification of radio telegraph signals. As a rule, amateurs try to make the loudest noise possible when receiving signals from distant transmitting stations. At all radio stations, in fact, commercial or amateur, efforts are invariably made to obtain the greatest intensity of signals possible. Of the two methods presented for the amplification of signals, the second is not original with the writer, but was obtained as a result of his attendance at a lecture delivered recently at a meeting of the Institute of Radio Engineers. The first method was not brought out at the meeting, but suggested itself to the writer during the lecture.

Many amateurs are already familiar with the audion detector and the method of its application to wireless telegraphy, but there are some who are absolutely without knowledge relating to the device. For the benefit of the latter readers the audion will be explained in all of its details, accompanied by a diagram; a brief description of the construction and operation of the audion will also be given.

The audion detector is not a new apparatus, having been in use since about 1906. For some reason, however, it has not been employed generally in commercial service. This is probably due to the fact that, because of the battery current required, it is believed to be a device of considerable expense. The writer will show that this impression is erroneous.

In the equipment of every radio club should be included an audion detector. The apparatus, however, should be placed in charge of responsible members of the organization, for through careless usage it may easily be burned out.

The audion detector is shown in Fig. 1, and consists of a 4 to 6 volt lamp filament, F, a nickel-plated grid, G (which may also be a plate bored full of holes), and a plate, P, to which is connected one side of the local headphone circuit. The grid, G, is connected to one side of the closed oscillatory circuit of the receiving tuner and the filament, F, to the opposite side of the circuit. Either the B or A side of the filament may be connected to the lead D; the B side will generally give the best results.

The secondary of the receiving tuner is represented at L′, which is shunted by a variable condenser, VC. The variable condenser is of very small capacity; the maximum need not be more than .0001 mfds.—in fact, it may consist of two very small concentric brass tubes sliding over one another.

The members of radio clubs should