Thus if the capacity of a condenser varies inversely as the capacity the resistance of any number of condensers in series is a constant provided the effective capacity is constant.

I might add that this will be true also if the resistance of a condenser is small enough to be neglected.

ON THE RESISTANCE OF RADIO CIRCUITS.

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In a radio circuit we have resistance, inductance and capacity. The current, I, is given by the well known formula for alternating current

$$I = \frac{E}{\sqrt{R_2 + \left(\frac{1}{Cw} - Lw\right)}}$$

where E is the electro-motive force, R, L, and C are the resistance, inductance, and capacity, respectively. When

$$\frac{1}{Cw} = Lw,$$

the impedance will be a minimum and the current rent will be a maximum, or I=E/R.

In alternating current of low frequency we have voltmeters by means of which the E. M. F. and difference of potential between various points can be measured. In high frequency work we have no voltmeters. The only measuring instrument we have is a thermal ammeter which depends upon the heat developed in the circuit.

In measuring the resistance of a radio frequency circuit there are two general methods—the impedance variation method and the resistance variation method. In the first the resistance is calculated from the change of the square of the current produced by a certain change of the capacity of the circuit. The second depends upon the change of the current produced by inserting known resistance in the circuit. In the resistance variation method the circuit is tuned until the current is a maximum, or I=E/R. Then resistance is inserted and the value of I is noted. As a particular case resistance is inserted until the current is one-half of the original current, then

$$I_2 = \frac{E}{2R}$$

and the resistance inserted is equal to the resistance of the circuit. The resistance thus formed is that of the coil, condenser and of other devices which may absorb energy from the circuit. It is comparatively easy to measure the total resistance of the circuit but is very hard to measure the resistance of any part of the circuit. Thus, to measure the resistance of a coil it is necessary to know the resistance of the condenser and other parts of the circuit. It will be necessary to define the term resistance. Resistance as used here means anything which absorbs energy. Thus the heating effect of a current through a resistance is I^2R, the square of the current times the resistance. In a condenser, energy may be absorbed and appear as heat, due to resistance of the connections, to dielectric absorption, to eddy currents set up in the plates, and to other causes. When we speak of the resistance of a condenser we mean that resistance which when placed in series with a perfect condenser the I^2R losses or heating effect of which will be the same as that produced by the condenser in question.

Fig. 1—At left, diagram showing a perfect condenser in series with a resistance; at right, showing how the actual resistance of a condenser may be in series or in parallel with a condenser.

It has been customary to assume that the resistance of the condenser is very small or zero for practical purposes.[1] This assumption is due to the fact that measurements at low frequency, 1000 to 3000 cycles, show that these losses are all due to the dielectric and that these losses diminish as the frequency increases, and that if the losses obey the same law at high frequency, 1,000,000 cycles, that they do at 1,000 cycles then the losses are negligibly small. This does not take in account any loss due to eddy current or other effects which do not appear at low frequency.

It has been shown by Weyl and Harris[2] and by Callis[3] that the resistance of a variable condenser varies from about 1 ohm to 15 or 20 ohms. The approximate law is that the resistance of an air condenser varies inversely with the capacity. These values are quite different from those usually assumed. If these results are true, all the measurements of the resistance of coils are too large, since it has been assumed that all the resistance of the circuit was in the coil.

These results can be checked by heat determinations. The coil or condenser can be placed in a calorimeter of some sort and the losses, heat developed, can be measured. Knowing the heat which is proportional to I^2R and the current, I, the resistance, R, can be determined. Heat measurements are not as accurate as a general thing as electrical measurements but an approximate value can be made.

I have made some preliminary measurements by placing the coil in an inverted pyrex beaker cemented to a glass plate through which electrical connection and a glass tube are cemented. A second pyrex beaker contains a wire of known resistance. These two beakers are connected together by a U tube in which a small amount of water is placed. Thus we have a sort of differential thermometer. When the coil is heated the air expands and changes the level of the water in the tube. This level is again restored by passing current through the resistance wire. If the two beakers are alike in every respect then the heat developed in one is the same as that developed in the other, and

[1] Phys. Rev., Vol. 21, p. 53, 1923.

[2] Inst. Radio Engineers. Proc. 13, 109, Feb., 1925.

[3] Phil. Mag., 1926.

$I^2R=i^2r$, when I and R are the high frequency current and resistance and i and r are the D. C. current and resistance. The results indicate that the coil resistance is considerably less than the resistance of the circuit as measured by the usual method. This indicates that the condenser resistance is greater than zero. Measurement of the heat developed in the condenser by the same thermometric method indicates that the resistance is measurable but is somewhat less than that obtained by Weyl and Harris and by Callis. The sum of the resistance of the condenser and of the coil is less than that of the circuit. Since these measurements are energy measurements it indicates that there is more energy developed in the circuit than that which appears as heat in the coil and the condenser. If we were to put the condenser and coil in a differential thermometer as described above, then there will be a certain amount of energy escape through the walls of the pyrex beaker. Energy is radiated into space. The extra amount of resistance is radiation resistance. It is known that a circuit containing an aerial has radiation resistance, but it has been assumed that an ordinary circuit does not have a measurable radiation resistance. Thus it is desirable to make more refined measurements on radio circuits in order to be able to separate the resistance of the coil from that of the condenser and determine the radiation resistance.