MEASUREMENT OF CONDENSER AND COIL RESISTANCES BY THE DIFFERENTIAL THERMOMETER METHOD.

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The method of measuring the high frequency resistance of wire by means of the differential thermometer is due to J. A. Fleming (Proc. Phys. Soc. London, 23, p. 103. 1911).

In this method the heat developed in a wire by a known radio frequency current is compared to the heat developed in a similar wire by a direct current. The accuracy of the method is not very great but it is the only method by which an experimental comparison can be made. The high frequency resistance of a given wire is usually calculated by a theoretical formula which has been found to give results agreeing with the experimental method. Radio frequency resistance boxes are constructed of small wire, the resistance of which according to the formula is the same as the D. C. resistance of the wire. It is usual to measure the resistance of a circuit by means of the radio frequency resistance boxes.

A radio frequency circuit consists of a coil and a condenser. It is comparatively easy to measure the resistance of the circuit but to separate the resistance of the coil from the resistance of the condenser is a difficult matter. It has been customary to assume the resistance of the condenser to be zero and to ascribe all the resistance of the circuit to the coil. The basis for this assumption is the fact that dielectric losses as measured at frequencies up to two or three thousand cycles are found to diminish with frequency. When calculated for a frequency of a million cycles the losses are estimated to be almost zero.

Weyl and Harris (Inst. of Radio Eng., Proc. 13. 109, Feb. 1925) and Callis (Phil. Mag. 1, 428, Feb. 1926) have made measurements of the resistance (losses) in radio condensers at radio frequency and have found the losses to be considerable, the measured resistance being about one ohm at full capacity and as high as 20 ohms at small capacity.

Because these results were so large compared to the accepted values, I tried to find a check method. After considering various methods such as condensers in series and condensers in multiple and finding experimentally as well as theoretically that it was impossible to get a check, I finally resorted to the heat method. After the condenser was shown to have small resistance, the resistance of the coil was measured by the heat method. The coil resistance was found to be somewhat smaller than the values obtained by the usual method.

The condenser or coil was placed in one bulb of a differential air thermometer while a known D. C. resistance was placed in the second bulb. The thermometer was made of two pyrex glass beakers inverted

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and sealed to glass plates. Through each glass plate three holes were drilled. In two of these holes electrical connections were sealed, and in the third a glass tube was sealed. By connecting the glass tubes to a U-tube which contained a small amount of water, the relative pressure of the air in the beakers could be determined. Two T-tubes were placed above the U-tube, one under each beaker. By opening these T-tubes the pressure of the air in the beaker could be made equal to the pressure of the atmosphere.

The beakers were sealed to the glass plates with beeswax. At times there was some difficulty in getting the connection air tight. This was tested by noting whether the pressure became equal after a run. If there was evidence that one of the beakers leaked the result was discarded. The apparatus is shown in the diagram (fig. 1).

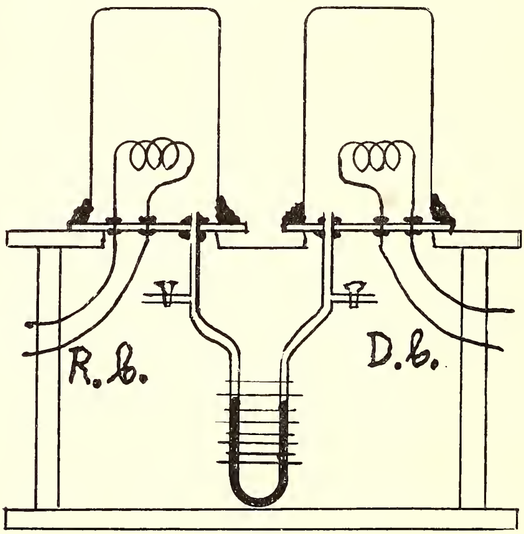

Fig. 1. Drawing showing the differential thermometer. The heat developed in the coil in the left hand beaker by the radio frequency current is balanced by the heat developed in the coil in the right hand beaker by the direct current. The equality of the height of the water in the U-tube indicates when equilibrium is established.

The coil or condenser under investigation was placed in one of the beakers and electrical connections were made with solder. In the second beaker a known D. C. resistance was placed and soldered to the electrical connections. It was found that when a coil was under investigation the best D. C. resistance to use was a coil which was an exact duplicate of the first coil. When the resistance of a condenser was being measured a short piece of "cromel" resistance wire, 3.4 ohms, was connected to the terminals in the D. C. beaker.

When making a measurement the procedure was as follows: The coil or condenser was placed in the beaker and connected in a high frequency circuit which was inductively connected to an oscillating circuit driven by a five-watt tube. The high frequency circuit was adjusted to the proper current value. The approximate value of the D. C. current was found and then the apparatus was left for some time to cool down to the temperature of the room, the two side T-tubes being open. In an hour or more the run proper was made. The side T-tubes were closed and the high frequency generator was started. The D. C. current was turned on and adjusted so as to keep the pressure in the two beakers equal, as indicated by the water in the U-tube. After some minutes when final equilibrium was obtained the two ammeters were read. The high frequency ammeter was a Westen 1.5 ampere thermo-ammeter which was correct for D. C. current and guaranteed by the maker to be accurate for 1500 kilocycle current. For small values of radio frequency current a General Radio 250 milliampere hot wire milli-ammeter was used. To measure D. C. current a Westen ammeter was placed in the circuit.

When thermal equilibrium is obtained the heat produced in one beaker is equal to the heat produced in the second beaker, assuming the thermal constants of the two beakers to be the same. Then $I^2R = i^2r$, where I and R refer to the current and resistance in the high frequency circuit, and i and r refer to the current and resistance in the D. C. circuit. Then we have the resistance of the radio frequency circuit is $R = (i^2r)/I^2$. Any dielectric losses, eddy current losses, or resistance losses will appear as heat. R, the resistance of the circuit, is the series resistance in the circuit which will produce the same heat as all these effects.

The accuracy of heat measurements is not as great as the accuracy of ordinary resistance measurements and the accuracy of these measurements is not as great as might be desired, but they are sufficiently accurate to indicate the approximate values and to settle the point in question.

When the coil was measured it was found that the resistance of the coil was less than the resistance of the circuit obtained by the resistance variation method. This result indicates that the condenser must have a resistance which can not be neglected. When the condenser was placed in the beaker the resistance was found to be very small—about 0.1 ohm—the capacity of the condenser being .00008 microfarads. This indicates that the heat generated in the circuit is less than the total energy of the circuit.

Table I gives the data taken using five different coils. A. C. resistance is the resistance of the coil measured by the resistance variation method, assuming the resistance of the condenser to be small. Resistance (Heat) is the resistance obtained by means of the calorimeter.

TABLE I. Resistance of Coils at 1,000 Kilocycles

Capacity of Condenser in Microfarads	D. C. Resistance	A. C. Resistance Resistance Variation Method	Resistance Heat Thermometer Method	Inductance in Microhenrys	Remarks
Coils of No. 20 Copper Wire, 30 Turns Each					
.00008	0.35	10.7	8.2	316	Two coils in series
.00028	0.35	8.3	7.3	91	Two coils series opposition
.00028	0.175	4.3	3.7	91	Single coil
Coil of No. 30 Copper Wire, 20 Turns					
.00020	9.6	19.4	11.5	127	Single coil
Coil of No. 40 Copper Wire, 14 Turns					
.00054	16.6	21.1	17.2	47	Single coil
Coil of No. 40 Copper Wire, 30 Turns					
.00009	34.3	52.5	36.6	282	Single coil

Each result given in the above table is the average of a number of separate determinations.

It will be noticed that in every case the resistance as measured by the heat method is less than that measured by the resistance variation method. The high frequency resistance of the coil was balanced against the D. C. resistance of a similar coil. As a check the connections were interchanged so as to test the equality of the thermal constants of the two bulbs. It was found that within the accuracy of the method there was no difference. Instead of a duplicate coil in some cases, the coil was checked against a short piece of resistance wire. These results agreed with the results obtained by using duplicate coils. Since the results obtained by the two methods check, it shows that the resistance of the condenser as given in the following table can be relied upon, as it was necessary to use unsymmetrical circuits when measuring the resistance of the condenser. To make the two circuits and bulbs as symmetrical as possible, a dummy condenser was placed in the D. C. side with the resistance wire in order to make the thermal capacity of the contents of the two bulbs equal.

In Table II given below, the average of a number of readings is given.

TABLE II. Resistance of a 11-Plate Condenser Set at .00008 m. f. (About one-third maximum)

	300 Meters	80 Meters	40 Meters	27 Meters
Highest	.15 ohm	....	....	....
Lowest	.05 ohm	....	....	....
Mean	.098 ohm	.06 ohm	.04 ohm	.06 ohm

At first it was thought that the results for 80, 40 and 27 meters were too low since the ammeter in all probability read too high. Since then the ammeter has been calibrated at high frequency and found to be correct for $6x10^7$ cycles (5 meters). In the work at 300 meters it was necessary to keep the current at or below .8 ampere, since the potential became so high that an arc started between the plates of the condenser when the current was .9 ampere.

After these results were taken the condenser was compared with three others made by different firms and it was found that there was no appreciable difference between this condenser and the average condenser.

These results show that the resistance of a good radio condenser is not excessive and that the results of Weyl and Harris, and Callis are entirely too large. Their results must be explained in some other manner. The probable explanation is as follows: The calorimeter method measures the energy that remains in the pyrex glass beaker. Any energy radiated through the glass will not cause heat. Therefore, there must be an appreciable amount of energy radiated from an ordinary circuit. In other words, there is a certain amount of resistance in the circuit which can not be ascribed to either the condenser or to the coil.

A STRAIGHT LINE FREQUENCY AUDIO OSCILLATOR.

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In a laboratory there is need of a source of alternating current of varying frequency. This need was formerly met by using alternating generators in which the speed of the rotor could be changed. Frequencies from a few cycles up to 3000 cycles were obtained in this manner. Since the three-electrode tube has come into general use, audio oscillators[1] having iron cores have been used. In order to get any considerable range of frequency it is necessary to substitute several coils and condensers from time to time. This is troublesome, and each coil or condenser calls for a new calibration.

If two oscillators which are oscillating at radio frequency are tuned so they are near the same frequency a continuous note is heard in a

[1] Ramsey, R. R. Experimental Radio (Revised), p. 59.