RESISTANCE OF RADIO CONDENSERS

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The resistance of air condensers has been measured by Weyl and Harris, Inst. Rad. Eng. 13, 109, (1925); by Callis, Phil. Mag. 1, 428, (1926); and Phys. Rev. 27, 113, (1926); by Brown, Weisbusch, and Colby, Phys. Rev. 29, 887, (1927); by Ramsey, Phil. Mag. 2, 1213, (1926); Phys. Rev. 27, 151, (1926); Proc. Ind. Acad. Sci. 36, 135, (1926); by Dye, Proc. Phys. Soc. London 40, 285, (1928); by Wilmotte, Jour. Sci. Instruments, 12, 369, (1928); by Morris, Phys. Rev. 33, 1076, (1929); and by Fletcher, Phil. Mag. 9, 464, (1930).

Before 1925 all measurements of condenser resistances at radio frequency were made by a comparison method in which a good condenser whose resistance was assumed to be zero was compared with the condenser in question. Certain measurements of condenser resistance made at frequencies of 3,000 cycles or less indicated that the resistance of a good condenser diminished as frequency increased and became practically zero at frequencies in the neighborhood of a million cycles if the same law held.

The method which Callis carried to completion in this laboratory was started in 1924. Although Weyl and Harris published their results early in 1925 Callis was not aware of it until late in the year after his paper had been sent for publication. These two sets of independent results with different methods gave results which agreed in that the values were very large compared to the usually accepted values which were supposed to be near zero. The results were of the order of one to ten ohms depending on capacity and frequency. These methods were alike in that they used a form of resistance-variation method with coils of relatively large inductance. Brown, Weibusch, and Colby used a resistance-variation method in which the coils used had very small inductance and obtained results much smaller than the observer mentioned above. One hundreth of an ohm being the order. Ramsey used Fleming's thermal method and obtained results in the neighborhood of a tenth ohm. Dye's method is an involved substitution method in which a specially constructed air condenser is used and the results are the values of the excess of the ordinary air condenser over that of the special air condenser. Detailed calculations show that the resistance of the special air condenser could be neglected. His results range from .011 ohm to .6 ohm.

The method used by B. D. Morris is much the same as that used by Ramsey except that instead of using the themal expansion of air as a means of indicating thermal equality in the two bulbs iron-advance thermocouples were used.

When thermal equilibrium is obtained we have $i^2R = I^2r$ where R is the resistance of a short piece of resistance wire; i, is the direct current flowing through the resistance, R; I, is the radio frequency current flowing in the condenser whose resistance is r.

The change in the method was made because there seemed to be a lag in temperature in the bulb containing the radio frequency circuit. The thermal junctions were used and they indicated the same lag while heating but also showed the condenser in the radio frequency side apparently evolved heat for some time after the current had been shut off.

The results given here were all taken after the two bulbs had come to thermal equilibrium and had remained in equilibrium for some time. Measurements were made at frequencies ranging from that corresponding to 410 to 125 meters wave length, and with capacities ranging from .00001 microfarads to .00024 microfarads. The resistance obtained varied from .07 ohms for relatively short wave and large capacity to 11. ohms for relatively long wave and small capacity.

A comparison of these results indicate that the resistance of a radio frequency air condenser, to a fairly close approximation, is directly proportional to wave length and inversely proportional to the three halves power of the ratio of capacities. Using these imperical assumptions the resistance was calculated for standard conditions by the equation,

$$R_s = R(300/\lambda)(C/.001)^{3/2}.$$

The standard condition was taken as 300 meters wave length and .001 microfarad capacity. R_s is the resistance of a .001 microfarad air condenser when the current has a frequency corresponding to 300 meters wave length or one million cycles. The measured values and calculated results are shown in Table I. In this table it will be seen that R_s is nearly the same (the value being near .01 ohm) although there is a small systematic variation of the values indicating the assumed law is not exact.

TABLE I. MORRIS'S RESULTS FOR THE RESISTANCE OF AIR CONDENSERS

$$R_s = R(300/\lambda)(C/.001)^{3/2}.$$

λ	C	R	R_s
125	.00001	5.5	.0132
280	.00001	11.0	.0122
190	.000054	.68	.0092
280	.000054	.79	.0106
320	.000054	.96	.011
280	.00013	.170	.0086
306	.00013	.195	.009
410	.00013	.275	.0095
290	.00024	.0706	.0086
325	.00024	.076	.0083
360	.00024	.079	.0078
400	.00024	.096	.0085
		Mean	.0098

In Table II the same law has been applied to the results of other observers. It will be noted that the first three sets of results, all of which are resistance-variation methods, agree much better than is apparent from the original data. Weyl and Harris, and Callis's results were obtained with relatively large inductance while Brown, Weibusch, and Colby used very small inductance. The latter necessarily used short waves and large capacity making their results low compared to the first two observes. Ramsey's results were made with the thermal method. They are seen to agree with the results in Table I.

Table III shows the results of Dye. The results of Dye are smaller than any of the others. It will be remembered that his method is a substitution method in which a condenser of practically zero resistance was used.

TABLE II. RESISTANCE OF RADIO FREQUENCY CONDENSERS

Comparison of results taken from various sources.

The resistance is calculated for standard capacity and wavelength, i.e., 0.001 microfarads and 300 meters, by the equation

$$R_s = R(300/\lambda)(C/.001)^{3/2}.$$

	λ	C	R	R_s
Weyle and Harris	96	.0005	1.2	1.33
	96	.0001	2.8	.286
	96	.00005	18.5	.65
	200	.0005	.71	.37
	230	.0005	.86	.39
	260	.0005	1.04	.41
			Mean	.57
Callis	300	.001	1.65	1.65
	300	.0005	2.8	.96
	300	.0001	10.65	.33
			Mean	.98
Brown, Weibusch and Colby	43.4	.00048	.113	.26
	63	.00048	.15	.24
	83	.0018	.042	.38
	119	.0018	.049	.30
	119	.00386	.0284	.58
	172	.0038	.0305	.40
			Mean	.35
Ramsey	27	.00008	.06	.015
	40	.00008	.04	.0068
	80	.00008	.06	.0051
	300	.00008	.098	.0022
			Mean	.0098

Miss Fletcher in investigating the supposed "gas effect" discovered by Morris finds that the apparent effect is not due to an evolution or absorption of gas but that it is due to the fact that the source of heat in the condenser in the radio frequency circuit is inside the condenser while the source of heat is a wire outside the condenser in the comparison circuit.

This being true the inside of the condenser in the radio frequency circuit is at a higher temperature than the outside when the two circuits are in thermal equilibrium. When allowed to cool to the temperature of the room the cooling curves of the two bulbs will be different. This effect makes it appear that the

TABLE III. DYE'S RESULTS FOR THE RESISTANCE OF AIR CONDENSERS

$R_s = R(300/\lambda)(C/.001)^{3/2}$.

λ	C	R	R_s
* 200	.000184	.045	.0021
215	.000314	.024	.0060
300	.000494	.011	.00382
600	.000494	.014	.0026
790	.000184	.11	.0033
1200	.000314	.06	.0025
1500	.000494	.035	.0026
2150	.000184	.25	.00276
2610	.000314	.12	.0024
3000	.000494	.07	.0026
4600	.000184	.6	.0031
5000	.000314	.3	.0032
6000	.000494	.3	.0028
15000	.000494	.35	.0028
		Mean	.0033

*Note. This set of data is taken from points plotted logarithmically on unruled paper and are approximately the original observations.

radio frequency condenser heats slower and cools slower than the identical condenser in the comparison circuit.

In this investigation Miss Fletcher finds that some condensers obey the imperial law proposed by Morris and used above while the results obtained with other condenser give a more constant value for R_s, if the square root of the ration of capacities is used instead of the direct ratio in the formula.

When one remembers that the resistance of a condenser is made up of dielectric resistance which diminishes with frequency and of the resistance of connections and plates which can be called metallic resistance which increases with frequency it can be seen that the formula which applies to one condenser will not apply to a second condenser of different construction.

These formula give results for R_s which are near enough to a constant value to show that the resistance variation methods in which the resistance of the coil is calculated or liminated give results which are very large. It seems that there is an extra resistance in the circuit which in these methods is added to the resistance of the condenser. It has been suggested that this might be radiation resistance. Calculation of the radiation resistance from a coil shows that the added resistance is much larger than any reasonable value of radiation resistance. The heat methods give the resistance of the condenser much smaller showing that the energy dissipated into heat in the Condenser is relatively small.

To sum up, the resistance of a good radio Condenser is in the neighborhood of a few hundredths ohm and usually can be neglected when connected to the usual coil which has a resistance near ten ohms. If extreme accuracy is wished it is necessary to know the resistance at the exact frequency and capacity at which the condenser is used.

The fact that a certain condenser is measured and a low resistance is obtained does not necessarily mean that the resistance of this condenser is lower than that of a second condenser which has been measured and a large resistance obtained. Both condensers must be measured under the same conditions, wave length and capacity setting, or the results must be reduced to standard conditions.

The published results of Brown, Weisbusch and Colby indicate that the resistance of the condenser which they measured is very small. When these results are reduced to standard conditions they are about the same as those of Weyl and Harris and of Callis which were thought to be out of all reason. It might be well to point out that Brown et al used a Bureau of Standards type of condenser while the other observers used commercial condensers. Thus the commercial condensers measured had a resistance two or three times that of the Bureau of Standards type.