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DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
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LC 77

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41

THE COMPARISON OF CONDENSERS AT RADIO FREQUENCIES

(This Circular is not complete without Letter Circular No. 75, "The Secondary Standardization of Radio Wavemeters," referred to herein as LC 75).

The purpose of this circular is to describe in some detail the comparison of the capacity and effective resistance or phase difference of two condensers, one of which has already been standardized. This process is therefore a secondary standardization.

The primary standardization requires a condenser whose metal parts and contacts are such that the conductor resistance is negligible, and whose insulating parts are so chosen and placed that the (effective) dielectric resistance is also negligible. Such a condenser may be standardized at a low frequency by a fundamental method[1] and subsequently used at radio frequencies with confidence that the capacity is independent of frequency and that the effective resistance is negligible. In the absence of such a primary standard, recourse may be had to a condenser which has been compared with a primary standard.

The method here described is that of comparison by substitution, that is, the tested and untested condensers are compared by inserting them in turn in a circuit which is brought to resonance with a source of undamped waves. The apparatus required is, then, a standard condenser, an inductor to form a resonant circuit with the standard condenser or the condenser under test, a current-square meter or radio-frequency ammeter, and an electron tube generator. If only capacity comparisons are to be made and not resistance measurements, the current-square meter or ammeter may be replaced by any device capable of indicating resonance, and the electron tube generator may be replaced by a generator of damped waves if the latter is more available than the former, and is constant in frequency and power.

If comparisons are to be made frequently, it will be found useful to have a special set allowing quick and easy interchange of the two condensers in the tuned circuit. An example

[1] Rosa and Grover Scientific Paper of the Bureau of Standards, No. 10, "The Absolute Measurement of Capacity," 1904.

of such a set is the condenser comparison set, type R 507 B of the Bureau of Standards, a diagram of which is shown in Fig. 1. At the center of the device is a double-pole, double-throw switch, whose poles, aa', bb', cc', are mercury wells mounted on Pyrex glass tubes on the three sides of a 45° right triangle. The poles cc' are joined to the terminals of the inductor L, and either one of them may be grounded by a link joining it to the symmetrically situated mercury well d. The poles aa', bb', are equipped with exactly similar pairs of leads joining them to the terminals of the two condensers. The latter rest on insulating platforms of adjustable height. A single conducting turn, M, with a thermogalvanometer in series with it is coupled to the inductor to indicate resonance. This is used only for capacity comparison. In making comparisons of effective resistance, it is necessary to actually compare the values of current in the circuit corresponding to different values of inserted resistance. For this purpose a thermoelement with leads to a wall galvanometer is introduced directly in the circuit. This combination forms a current-square meter, the deflection of the galvanometer being, to within the accuracy of most measurements, proportional to the square of the alternating current through the thermoelement. (As explained in LC 75, readings proportional to the current squared can be used as satisfactorily as values of the current squared itself). The whole set is mounted on a travelling table.

The use of this set will be assumed in the following description of the method. The reader will have no difficulty in transferring the description to any device which he may wish to use. The procedure is as follows: the test condenser is put on one of the adjustable platforms, the platform is brought to the proper height, and the condenser terminals are joined to the extensions from the mercury wells on that side of the circuit. The standard condenser is similarly connected on the other side of the circuit. The choice of a coil to furnish the inductance for the circuit is determined by the frequency at which standardization is desired. This will be referred to later. The test condenser, if it be variable, is set at one of the points at which standardization is desired. The points on the scale already cited [2] as suitable for the calibration of a wavemeter are equally suitable for the calibration of a condenser. The links are set so as to throw the test condenser in the circuit with either or neither terminal grounded as may be required. The generator is tuned to circuit just formed and the resonant circuit is retuned to the generator, as explained in the description of the calibration of wavemeters. [3] If the test condenser is fixed, this step will have to be dispensed with. There need be no danger of an error introduced by failure to take this precaution, however,

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for several capacity comparisons may be made at different frequencies. Any serious discrepancy among the values obtained caused by a change in the output of the generator will at once be evident, and minor variations so caused will be likely to compensate for one another.

The links are now changed so as to throw the standard condenser in the circuit and to ground the proper terminal. This circuit is now tuned to resonance and the condenser setting is recorded. The capacity of the standard at this setting is found from its calibration, and since the symmetrical construction of the set makes the circuits formed by the different positions of the links practically identical except as to condensers, this capacity will be the capacity of the test condenser at the chosen setting.

After one complete run, that is, one capacity determination at each chosen point of the calibration, the test and standard condensers are interchanged and a second run is made. It is well to use more than one standard if more than one is available, getting values at part or all of the chosen settings of the test condenser in terms of the calibrations of two different standards. This is in compliance with the general principle that, so far as possible, no standardization should depend wholly on any one standard. Corresponding readings of the two runs should, in testing a good condenser, agree within one or two tenths of one per cent. of maximum capacity. Condensers not so good will show greater discrepancies, and it will be found that some condensers will not retain their calibrations to any valuable degree of accuracy whatever. Some of the more common causes of such changeableness are: bad contact at the bearings, vertical play of the movable plates, looseness of the movable plates so that in turning they are carried out of alignment by inertia, stops against which the movable plates strike and are jarred out of alignment, a loose scale or index which slips on the rotating shaft.

Since the capacity of any but the best condensers varies with frequency, it is necessary to know at least approximately at what frequency the comparison is made. This may be determined by a wavemeter if one is available, or, if the value of inductance used is known, it may be calculated from the relation

$$f = \frac{159.15 \times 10^3}{\sqrt{LC}}$$

where f is the frequency in kilocycles per second, L is the inductance in microhenries, and C is the capacity in micromicrofarads. The corresponding relation for the wave length is

$$\lambda = 1.884 \sqrt{LC},$$

where λ is the wave length in meters.

The choice of a value of inductance for the circuit is determined by the frequency at which it is desired to know the capacity of the condenser. If measurement is desired at a specific frequency, a variable inductor may be used. But a variable inductor is not a satisfactory element of a measuring circuit as compared with a well designed fixed inductor. A better way, at least in testing a condenser whose capacity does not change greatly with frequency, is to choose two fixed inductors having inductances of such values that the circuits which they form with the condenser under test have natural frequencies respectively a little greater than and a little less than the frequency at which the capacity is to be determined. Capacity measurements made with these two inductors in the circuit will generally agree within the error of measurement, or, failing in this, will agree so closely that linear interpolation between the two values obtained will be justified.

To measure the effective resistance of a condenser, a thermoelement with leads to a wall galvanometer is introduced in the circuit, as already mentioned. The resistance of the circuit with the condenser under test inserted is measured by the resistance-variation method described in LC 75. If one side of the circuit is grounded, the resistors used are inserted on the grounded side. The switch is then thrown to insert the standard condenser in the circuit, and the resistance is again measured. If the standard condenser is of the type described at the beginning of this Circular having negligible resistance, the difference between the resistance of the circuit with the condenser under test inserted and the resistance with the standard inserted is the resistance of the condenser under test at the frequency at which the measurement is made. If the resistance of the standard is not negligible but is known for that frequency, the resistance of the condenser under test will be the difference mentioned, with the proper algebraic sign, plus the resistance of the standard at that frequency.

The resistance of a well designed condenser is apt to be so small in comparison with that of the circuit that an accurate determination will not be possible.

The use of Pyrex glass as insulator and mercury at the contacts in the switch is chiefly for the purpose of keeping negligible the resistance of that small part of the circuit outside the condensers which is changed by shifting the links, and thus avoiding the introduction at one position of the switch, of any resistance, other than that of the condensers,

which is not present at the other position. In addition to precautions of this kind, however, the measurements should be repeated with the two condensers interchanged on the two platforms.

The advantage of a well designed fixed inductor over a variable inductor is particularly marked in the comparison of two condensers as to resistance, since the resistance of the fixed inductor will generally be much lower than that of the variable, and the condenser resistance much more appreciable as a consequence. On the other hand there is much less likelihood than in the capacity measurements that linear interpolation will be justified between determinations at frequencies near to that at which it is desired to know the resistance.

The phase difference is derived from the resistance by means of the relation:

$$\psi = 130 \times 10^{-5} f R C$$

or the equivalent relation:

$$\psi = 388 \frac{RC}{\lambda}$$

where ψ is the phase difference in seconds, R the resistance in ohms, C the capacity in micromicrofarads, f the frequency in kilocycles per second, and λ the wave length in meters.

The same method and instrument can be used to measure the phase difference and dielectric constant of insulating materials. A condenser having the insulating material under test as its sole dielectric is made as follows. The insulating material in the form of a wide slab is floated in a tray of clean mercury. A loop of square rod slightly smaller in area than the slab is laid on the slab, forming a rim around its edge. The space so enclosed is filled with clean mercury. The condenser formed by the mercury surfaces and the insulating material between them is compared with a standard as to capacity and resistance. The phase difference is obtained from the formula already given and the dielectric constant from the equation:

$$K = \frac{11.3\ Cd}{S}$$

where K is the dielectric constant, C the capacity in micromicrofarads, d the thickness of the dielectric in centimeters, and S the area of one side of a condenser plate in square centimeters.

Department of Commerce,
Washington, D.C.

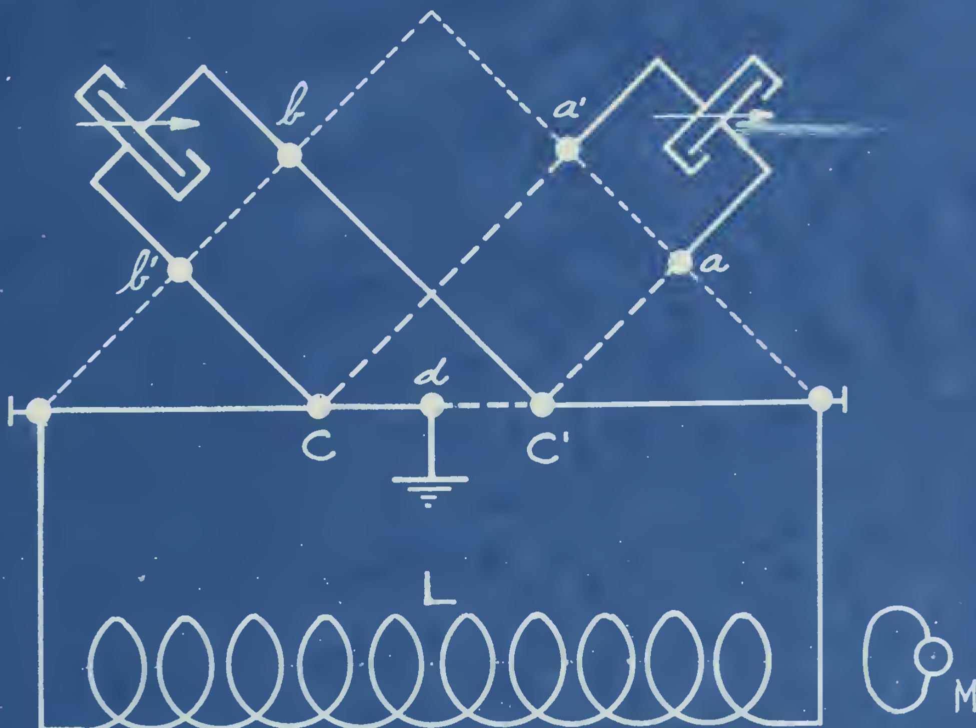

FIG. I. CONDENSER COMPARISON SET.

BUREAU OF STANDARDS WASHINGTON, D. C.	DRAWN	SCALE	
	TRACED	DATE	
	CHECKED	DRAWING NO. 930.	
DIVISION 1 SECTION 6	APPROVED		NO. SHEETS SHEET NO.