to the equation

$$\text{Change in capacity} = \frac{0.613}{\log_{10}\dfrac{b}{a}}\ \mu\mu\text{f per inch} \qquad (21)$$

End effects and capacities to ground do not affect this result, since they are constant at all times.

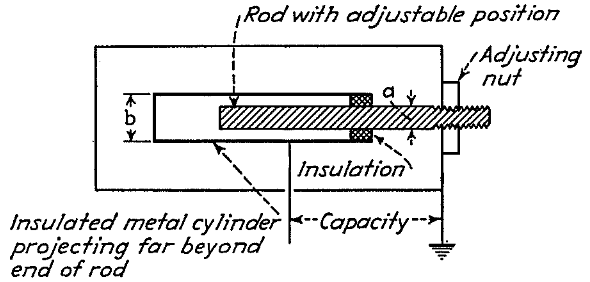

FIG. 27.—Schematic diagram of method of obtaining accurately known small increments of capacity.

The usual resistance standard employed in radio-frequency measurements is a resistance wire of such small diameter that skin effect is negligible at the frequency employed. In this way, the radio-frequency resistance will equal the low-frequency or direct-current resistance. It is not necessary for many purposes that the resistance standard be noninductive, since its reactance can be resonated out without affecting the resistance. It is, however, important that any shunting capacity present have a reactance considerably greater than the resistance. Resistance standards of this type are satisfactory for low and moderate values, *i.e.*, up to the order of one hundred ohms. When standards of higher resistance are desired, it is customary to employ metallized or other similar types of resistors that maintain a substantially constant resistance from direct current up to very high frequencies. When precision is important, it is desirable to check such resistances against low resistance standards composed of fine wire. Resistances of different orders of magnitude can readily be compared by such expedients as (1) measuring a resistance shunted across a resonant circuit in terms of the series of resistance of the circuit;[1] (2) the use of a transmission line; (3) by means of a bridged-T network, as in Fig. 24.

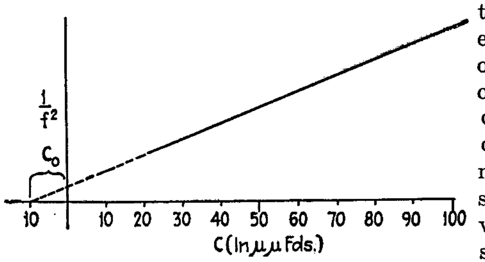

FIG. 28.—Plot of $1/f^2$, where f is the resonant frequency, as a function of external tuning capacity. The value of negative capacity C_0 at which the extrapolated line intercepts the capacity axis is the distributed capacity of the coil, and the slope of the line is a measure of the coil inductance.

Resistance standards are preferably fixed because of the complications introduced if an attempt is made to provide continuous adjustment.

10. Miscellaneous. *Measurement of True Coil Inductance and Distributed Capacity.*—The true inductance and distributed capacity of a coil can be obtained by observing the capacity that must be added to tune the coil to resonance at several

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[1] Paul B. Taylor, Method for Measurement of High Resistance at High Frequency, *Proc. I.R.E.*, Vol. 20, p. 1802, November, 1932.

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frequencies, and then p
Fig. 28. This will resu
negative value C_0 that
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where m is the slope of
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The distributed cap
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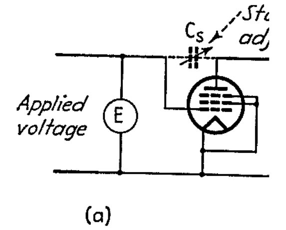

FIG. 2

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capacity is then determi
frequency or by substitut
maintain the current con
the method of Fig. 29b,[4]
capacity in series with a
latter is applied to the gri
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and the signal generator
capacity is

where E_1 and E_2 are the si
and C is the capacity acro

[1] Distributed capacity is so
resonance with the distributed
practical conditions, however, s
[2] Ralph R. Batcher, Rapid
p. 300, August, 1921.
[3] A. V. Loughren and H. W
Vacuum Tubes, *Proc. I.R.E.*, V
[4] Measuring Small Capacitie
1939.

frequencies, and then plotting the added capacity as a function of $1/f^2$, as shown in Fig. 28. This will result in a straight line that will intercept the capacity axis at a negative value C_0 that equals the distributed capacity. The slope of the line gives the true inductance according to the equation

$$\text{Coil inductance in henrys} = 0.0253m \tag{22}$$

where m is the slope of the curve of added capacity plotted against $1/f^2$, where f is in megacycles and capacity is in micromicrofarads.

The distributed capacity can be determined without plotting a curve by adjusting the coil successively to resonance with the fundamental frequency and then the second harmonic of an oscillator.[1] If C_1 and C_2 are the respective tuning capacities, then[2]

$$\text{Distributed capacity} = \frac{C_1 - 4C_2}{3} \tag{23}$$

Measurement of Very Small Capacities.—Very small capacities must sometimes be determined with very high precision. This can be done in several ways. One method that has been used in measuring the direct capacity between the control grid and plate of a pentode tube consists in applying a known large radio-frequency voltage to the capacity and measuring the resulting current that flows (see Fig. 29*a*).[3] The unknown capacity is then determined either by calculation from known voltage, current, and frequency or by substitution of a known adjustable capacity C_s that is readjusted to maintain the current constant when the plate lead of the tube is disconnected. In the method of Fig. 29*b*,[4] the output of a signal generator is applied to the unknown capacity in series with a very much larger known capacity. The voltage across the latter is applied to the grid of the first tube of a radio receiver, and the signal generator adjusted to give a reasonable receiver output. The unknown capacity is then shorted and the signal generator readjusted to give the same receiver output. The unknown capacity is

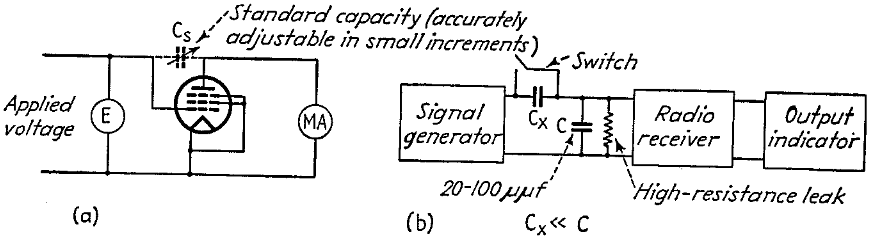

FIG. 29.—Methods of measuring very small capacities.

$$C_x = C\frac{E_1}{E_2} \tag{24a}$$

where E_1 and E_2 are the signal generator voltages with and without the switch shorted and C is the capacity across the receiver input.

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[1] Distributed capacity is sometimes calculated from the frequency at which the coil is in parallel resonance with the distributed capacity. This does not give the distributed capacity effective under practical conditions, however, since it corresponds to a different current distribution within the coil.

[2] Ralph R. Batcher, Rapid Determination of Distributed Capacity of Coils, *Proc. I.R.E.*, Vol. 9. p. 300, August, 1921.

[3] A. V. Loughren and H. W. Parker, The Measurement of Direct Interelectrode Capacitance of Vacuum Tubes, *Proc. I.R.E.*, Vol. 17, p. 957, June, 1929.

[4] Measuring Small Capacities with a Signal Generator, *Hygrade Sylvania News Letter* 56, October, 1939.

Extremely small changes in capacity can be determined by making the capacity involved part of the tuning capacity of an oscillator and then determining the effect upon the oscillator frequency. An auxiliary oscillator can be used as a fixed frequency standard and the frequency variations of the measuring oscillator obtained by observing changes in the beat note between the two oscillators. The relation between the frequency change and capacity is

$$\Delta C_x = C_0 \left[\left(\frac{f_0}{f_1} \right)^2 - 1 \right] \tag{24b}$$

where ΔC_x is the change in capacity, C_0 the original tuning capacity of the oscillator, f_0 the oscillator frequency when tuned only by C_0, and f_1 the oscillator frequency when tuned by C_0 and ΔC_x in parallel. The oscillator tuning capacity C_0 includes tube wire and stray capacities and must be determined experimentally by substituting a known capacity for ΔC_x and noting the resulting frequency change. Since this calibrating capacity can be large enough to be measured accurately by other methods, it is possible to evaluate C_0 very accurately.

Measurement of Dielectrics.[1]—The properties of dielectrics at radio frequencies are normally obtained by the substitution method. The procedure consists in placing a sample of the dielectric between the plates of a condenser that is in parallel with a resonant circuit tuned by a variable condenser. The change in capacity produced by the insertion of the dielectric is obtained by the readjustment of the variable condenser required to maintain resonance, while the shunt resistance resulting from the dielectric losses is determined by evaluating the parallel impedance of the circuit with and without the dielectric present. When solid dielectrics are involved, it is normally permissible to assume that the losses of the standard variable condenser are independent of the setting of this condenser. This approximation is permissible because the losses in solid dielectrics are very much greater than the losses in a good variable condenser.

VOLTAGE, CURRENT, AND POWER MEASUREMENTS

11. Direct-current Voltmeters and Ammeters.—Direct currents and d-c potentials are normally measured with portable instruments of the moving-coil (D'Arsonval) type. Such instruments are available in sensitivities corresponding to full-scale deflection with currents as small as twenty-five microamperes, corresponding to voltmeter sensitivities up to 40,000 ohms per volt. The voltage drop in the moving coil for full-scale deflection is normally under 100 mv.

A given voltmeter or ammeter can be used to cover a wide range of values by the use of suitable multipliers or shunts, respectively. Multirange instruments for measuring current can employ either individual shunts for each range, as in Fig. 30*a*, or a universal shunt, as in Fig. 30*b* and *c*. In the latter arrangement, relative multiplying factor is proportional to R/R_1, irrespective of the meter resistance. When a multirange current instrument is to be protected with fuses, a separate fuse must be provided for each range, with switching arrangements as shown in Fig. 30, in order that the fuse resistance will not affect the calibration.

Multirange voltmeters are obtained by varying the series resistance, using either of the circuits shown in Fig. 31.

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[1] For further discussions of dielectric-loss measurements, see J. G. Chaffee, The Determination of Dielectric Properties at Very High Frequencies, *Proc. I.R.E.*, Vol. 22, p. 1009, August, 1934; D. B Sinclair, Impedance Measurements at High Frequencies with Standard Parts, *Gen. Radio Exp.*, Vol. 14, No. 4, September, 1939; E. T. Hoch, Electrode Effects in the Measurement of Power Factor and Dielectric Constant of Sheet Insulating Materials, *Bell System Tech. Jour.*, Vol. 5, p. 555, October, 1926; Miller and Salzberg, *loc. cit.*; L. Hartshorn and W. H. Ward, The Measurement of the Permittivity and Power Factor of Dielectrics at Frequencies from 10^4 to 10^8 Cycles per Second, *Jour. I.E.E.*, Vol. 79, p. 597, 1936; also, Wireless Section, *I.E.E.*, Vol. 12, p. 6, March, 1937.

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RADIO ENGINEERS' HANDBOOK

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