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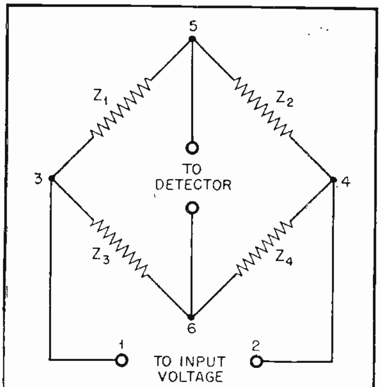
A. C. BRIDGES

Bridges of various sorts are employed widely for the accurate measurement of resistance, capacitance, and inductance and also of other quantities such as power factor, dissipation factor, and Q which are associated with impedances. An unknown quantity may be determined by means of a bridge circuit in terms of an accurately-known standard quantity. Thus, the bridge method of measurement is a comparison method.

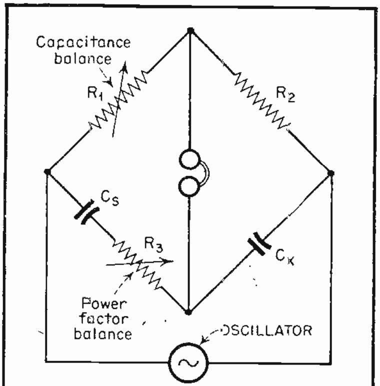
Figure 1 shows the basic arrangement of a 4-arm bridge circuit. The input voltage is applied to points 3 and 4 of the network, and a suitable current or voltage indicating instrument (sensitive voltmeter or galvanometer), termed the **detector,** is connected between points 5 and 6. If one or more of the impedance legs are adjusted so that $Z_1/Z_2 = Z_3/Z_4$, no current will flow through the detector because points 5 and 6, under these conditions, will be at the same potential. This is the condition referred to as **null.** At null, as evidenced by zero deflection of the detector, the unknown value of any one of the impedances may be determined in terms of the other three known values from the foregoing equation. Thus, $Z_2 = (Z_1Z_4)/Z_3$.



$$\frac{Z_1}{Z_2} = \frac{Z_3}{Z_4}$$

BASIC BRIDGE ARRANGEMENT

Fig. 1.



$C_X = C_S\,(R_1/R_2)$

p.f. = $0.000628\, f R_3 C_X$

p.f. is in %

f in cycles per second

R in ohms

C_X in mfd.

RUDIMENTARY CAPACITANCE BRIDGE

Fig. 2.

A bridge intended only for resistance measurements will contain four pure resistance arms (the symbols R_1, R_2, R_3, and R_4 will replace the Z-designations in Figure 1); the input voltage will be pure d.c., supplied by a battery: and the detector will be a d.c. galvanometer. Inductance and capacitance measurements, however, require that one or more legs of the bridge be suitable reactances or impedances. The input signal then must be an alternating voltage of appropriate frequency and the detector must be a sensitive a.c. instrument, such as a v. t. voltmeter, cathode ray oscilloscope, electron-ray tube, or high-resistance headphones.

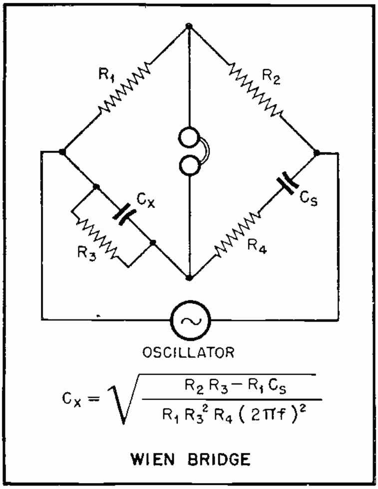


Fig. 3.

In this article, we will describe a.c. bridge circuits and will give their balance equations. These are the circuits which are employed in instruments designed both for laboratory and maintenance applications. Please bear in mind that the a.c.-type bridge may be used for resistance measurements, as well as for the determination of capacitance and inductance. Many combination bridges take care of resistance in addition to capacitance. The well-known **impedance bridge** measures resistance as well as capacitance and inductance. Resistance measurement, however, is an added feature of these bridges and unless a multi-purpose bridge is needed for reasons of convenience or economy, it is more satisfactory to confine resistance measurements to the d.c. bridge.

Capacitance is measured with the rudimentary 4-arm, Schering, and Wien bridges. Inductance is checked with the Maxwell, Owen, Hay, and resonance bridges. Among other miscellaneous applications, distortion may be checked by means of the Wien and resonance bridge circuits, and frequency in the audio spectrum may be checked with the Wien bridge.

Two adjustments usually must be made with practical a.c. bridges. The first is the reactive balance and is the one giving the information from which we determine the unknown capacitance or inductance value. The second is the resistance balance which shows the equivalent series resistance of the capacitor or inductor under test. The equivalent series resistance value subsequently is used in the computation of power factor, dissipation factor, or Q. Direct-reading bridges intended for

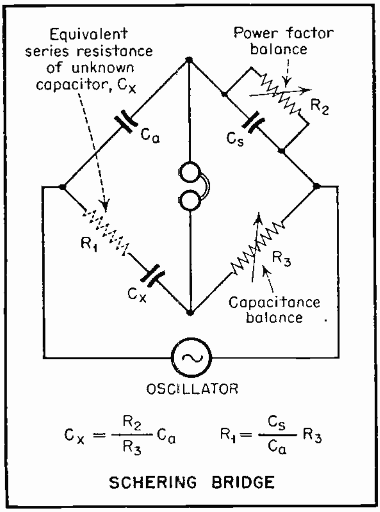


Fig. 4.

rapid manipulation, such as those designed for the radio service trade, show power factor values directly. Unless specified otherwise, a.c. bridge measurements ordinarily are made with an input signal of 1,000 cycles frequency.

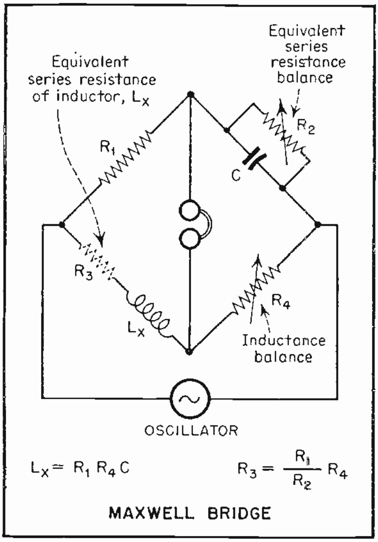


Fig. 5.

For simplicity, radio service bridges employ 60 or 120 cycles, since these frequencies are easily obtained without an oscillator.

The various circuits commonly found in a.c. bridges are described separately in the following paragraphs.

Rudimentary Capacitance Bridge

In this circuit shown in Figure 2, an unknown capacitance, C_x, is compared with a known standard capacitance C_s by means of the ratio arms R_1 and R_2. By means of a suitable calibration, the dial of R_1 may be made direct-reading in microfarads. The bridge is balanced for capacitance first by adjusting R_1 for null. Further adjustment of R_3 sharpens the null point on R_1. The resulting final setting of R_3 is used in calculating the power factor of the capacitor (C_x) under test. Equations for computing capacitance and power factor are given in Figure 2.

The rudimentary bridge has the advantage that it permits determination of capacitance without calculations involving the bridge signal frequency.

Wien Bridge

The circuit of the Wien bridge is given in Figure 3. This bridge, while requiring use of a much more complicated balance equation than the preceding type, permits determination of capacitance in terms of resistance and frequency, the standards of which can be known with considerable accuracy. The Wien bridge has other important applications, other than capacitance measurement, which are discussed later in this article under the heading **Miscellaneous Bridge Applications.**

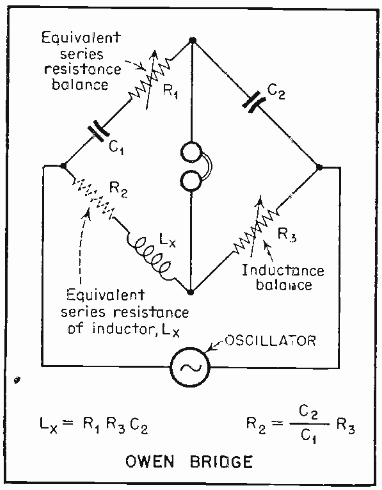


Fig. 6.

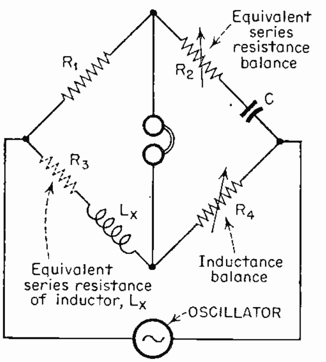
Schering Bridge

The Schering bridge (see Figure 4) is widely used in capacitor laboratories and in the testing of cable characteristics. Its balance equations are simple, since they do not contain complex frequency terms.

The Schering bridge has the special advantage that it allows a d.c. voltage to be applied to the capacitor under test (as in the checking of electrolytic capacitors at their rated d.c. working voltages) without the danger of having direct currents circulate through, and possibly damage the bridge.

Maxwell Bridge

The Maxwell bridge (see Figure 5) is extremely convenient for inductance measurement in that it permits an unknown inductance (L_x) to be compared with a known capacitance (C). This is advantageous since capacitance standards of sufficient accuracy usually are more readily available and are easier to handle than are inductance standards. The Maxwell bridge may be used to measure coils having a wide range of equivalent series resistance, or Q values. The balance equations are simple.



$$L_x = \frac{R_1 R_4 C}{1 + (R_2 2\pi f C)^2}$$

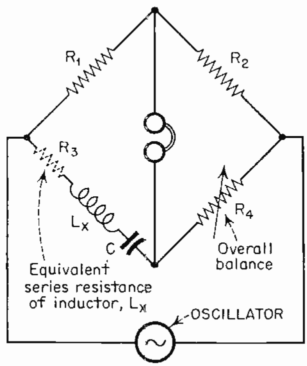
$$R_3 = \frac{R_1 R_2 R_4 (2\pi f C)^2}{1 + (R_2 2\pi f C)^2}$$

HAY BRIDGE

Fig. 7.

Owen Bridge

The Owen bridge (see Figure 6) is similar to the Maxwell in comparing an unknown inductance (L_x) to a known standard capacitance (C_2). Unlike the preceding circuit, however, the Owen bridge requires two capacitors. The simple balance equations of the Owen bridge resemble those of the Maxwell bridge.



$$L = \frac{1}{(2\pi f)^2 C} \qquad R_3 = \frac{R_1}{R_2} R_4$$

RESONANCE BRIDGE

Fig. 8.

Hay Bridge

The Hay bridge (see Figure 7) generally is used only for the measurement of inductors whose Q (ratio of inductive reactance X_L to resistance R) is greater than 10. From Figure 7, it will be noted that frequency terms enter to complicate the balance equations of the Hay bridge. The Hay bridge often is arranged for the measurement of incremental inductance; that is, inductance of a coil with a direct current flowing through it.

Resonance Bridge

In the resonance bridge (see Figure 8), the unknown inductance (L_x) forms a series resonant circuit with the capacitance C. The latter must so be chosen in value that resonance occurs at the frequency of the bridge signal voltage. At resonance, inductive and capacitive reactances, being equal in magnitude and opposite in sign, cancel. The bridge accordingly balances as if the reactive arm is pure resistance. The resonance bridge has the disadvantage that the range of the capacitor C must be rather large in order for the bridge to cover a wide inductance range at a given signal frequency. A further disadvantage is the fact that the equation for unknown inductance is not so simple as that for the Maxwell and Owen bridges.

Miscellaneous Bridge Applications

Aside from the purposes for which they originally were intended, several of the a.c. bridge circuits are useful in other applications. The most important of these are described briefly in the following paragraphs.

Frequency Measurement. Most of the bridges having balance equations containing frequency terms can be used for the measurement of frequency within the audio-frequency spectrum. This is possible because the bridge is balanced at only one frequency at a time. Consequently, a new null point must be found when the bridge signal frequency is changed to a different value. The variable arm of such a bridge accordingly may be calibrated to read directly in cycles per second. The result is a simple frequency meter of high utility.

The Wien bridge (Figure 3), because of its simplicity and the fact that it employs only resistors and capacitors, is readily adapted to use as an audio frequency meter. When R_2 is made twice R_1 and C_x made equal to C_s, and a dual ganged rheostat used for the two sections R_3 and R_4, the null conditions for both resistance and reactance will be satisfied at all times, and the frequency applied to the bridge may be determined (by means of the null settings of R_3, R_4) from the equation: $f=1/(6.28\ R_3\ C_s)$.

Distortion Measurement. When frequency-selective bridges, such as the Wien and resonance types, are adjusted for null, any voltage appearing at their output terminals is due to harmonics of the test signal, the fundamental having been suppressed by the circuit. A measurement of this residual voltage therefore would be expected to give an indication of the total harmonic content of the bridge signal. The accuracy of this simple method is not good, however, chiefly because the bridge circuit attenuates each of the harmonics unequally.

Frequency Rejection. For the same reason (namely, that the fundamental frequency of the bridge signal is suppressed by a frequency-selective bridge circuit), bridges of the Wien and resonance types often are employed as simple band elimination filters to remove the null frequency or a reasonably narrow band about that frequency. The sharpness of response of such a network in this application is improved by employing high-Q capacitors; and in the case of the resonance bridge, a high-Q coil as well.

Selective Networks. The Wien bridge is the basis of simple, selective resistance-capacitance networks employed to set the frequency of audio and supersonic oscillators, distortion meters, simplified wave analyzers, and peaked amplifiers. These circuits are connected into a degenerative amplifier in such a way that feedback occurs on all frequencies except the null frequency of the bridge circuit The amplifier gain accordingly is cancelled on all frequencies except the null frequency. Signals on the null frequency therefore are transmitted readily by the amplifier.

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