Radio Editors of magazines and newspapers are hereby given permission to reprint in whole or in part, with proper credit to the Aerovox Corporation, the contents of this issue of the Aerovox Research Worker.

The AEROVOX Research Worker

The Aerovox Research Worker is a monthly house organ of the Aerovox Corporation. It is published to bring to the Radio Experimenter and Engineer authoritative, first hand information on condensers and resistances for radio work.

VOL. 10, NO. 4 | APRIL, 1938 | 50c per year in U.S.A. 60c per year in Canada

Practical Methods of Testing Condensers

PART 4

By the Engineering Department, Aerovox Corporation

BRIDGES

ACCURATE measurements of capacity, power factor and equivalent series resistance can be made by means of bridges. Before treating specific types of bridges, it is necessary to consider bridge networks in general.

Let us start with the Wheatstone bridge, used to measure resistance and illustrated in Figure 1. The galvanometer, G, will not show any current when the points B and D are at the same potential. When this condition has been obtained by varying the resistance of one or more branches, the following relation holds:

$$\frac{R_1}{R_2} = \frac{R_4}{R_3}$$

OR,

$$R_1 = \frac{R_4}{R_3} R_2$$

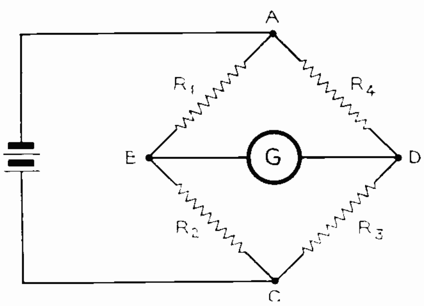

Fig. 1

Thus it is possible to find the resistance of any one branch if that of the other three is known.

This bridge can also be operated on a.c. if the source and the detector are changed accordingly; the same law then holds. Such a bridge can also be balanced with but one adjustment since there is only one equation which must be satisfied.

When one of the branches of an a.c. operated bridge contains a reactance as well as a resistance, however, there is a phase shift in that branch which must be matched with an equal phase shift in another branch if the bridge is to be balanced. Now there are two adjustments to be made—one for magnitude of potentials at B and D and one for the phase relation. When the bridge is balanced, two different equations express the relations between the components.

An example is shown in Figure 2, where a Wien bridge is illustrated. The condenser C_1 will usually have some losses which can be represented by the resistance R_1. It will now be found that the bridge cannot be completely balanced by the adjustment of R_2, R_3 and C_4 alone. When the nearest approach to balance has been obtained by adjusting one or more of the above quantities, losses in series with C_4 have to be introduced so as to produce the same phase angle in the branch C_4 as in C_1-R_1. Here it is assumed that C_4 is the standard condenser and has a lower power factor than the unknown condenser C_1. The additional losses are introduced by means of the variable series resistor R_4 which should be adjusted until complete balance is obtained. Then we have the following two identities:

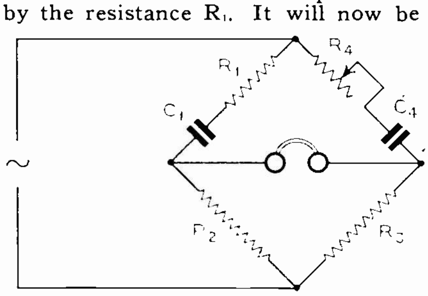

Fig. 2

$$\frac{R_1}{R_2} = \frac{R_4}{R_3}$$

$$\frac{C_1}{C_4} = \frac{R_3}{R_2}$$

Thus this bridge affords a method of measuring the equivalent series resistance as well as the capacity.

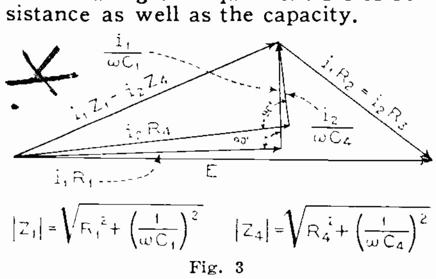

Fig. 3

For further clarification, Figure 3 shows the vector diagram of voltage drops across the 4 arms when the bridge is balanced. Obviously the vec-

Printed in U. S. A.

tors of branch 1 and 4 must coincide or else the bridge would not be balanced.

SENSITIVITY

The sensitivity of a bridge network depends on the magnitude of the e.m.f. at the source, the sensitivity of the detector and the relation between the impedances of the various branches. The first two factors are not due to the bridge network itself and we need only examine the third.

The current through the detector for any condition other than balance can be calculated by the customary mesh equations and determinants. A general expression is then obtained for the current in the galvanometer and further analysis shows that the maximum sensitivity is had when all branches are equal, or, in the Wheatstone bridge when

$$R_1 = R_2 = R_3 = R_4 = R_5 = R_6$$

where R_5 is the resistance of the galvanometer and R_6 is the resistance of the source. In the case of an a.c. bridge network the same law holds if we replace R in each instance by Z

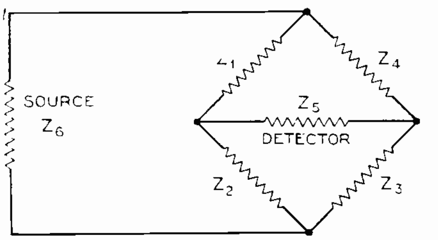

Fig. 4

where Z is a complex quantity of the form R+jX. Such a network is shown in Figure 4. Greatest sensitivity is obtained when

$$Z_1 = Z_2 = Z_3 = Z_4 = Z_5 = Z_6$$

It is not often possible to make all branches equal in impedance, therefore it is interesting to know how to obtain the best sensitivity in special cases. When Z_5 and Z_6 are given, the conditions for maximum sensitivity are:

$$Z_3 = \sqrt{Z_5 Z_6} \qquad Z_2 = \sqrt{\frac{Z_5 Z_1}{Z_5 + Z_1}(Z_5 + Z_6)}$$

$$Z_4 = \sqrt{\frac{Z_6 Z_1}{Z_6 + Z_1}(Z_5 + Z_1)}$$

If it is necessary to have the ratio Z_1/Z_4 or Z_1/Z_2 far from unity best sensitivity is obtained when Z_1 equals Z_2 while Z_1/Z_4 differs from unity rather than vice versa. This can be proved as follows: suppose $Z_1 = 999\ Z_2$ and the applied e.m.f. is e, then the table shows the voltages across Z_2, Z_3, and Z_5 for different degrees of unbalance, assuming for the moment that Z_5 is infinitely high and that the voltages across Z_2 and Z_3 are in phase.

ACCURACY

Errors may be introduced by: inaccurate bridge arms, resistance units which have residual reactance, reactances which have resistance, stray magnetic or electrostatic coupling between bridge units or between source and detector, stray capacitances between units and ground.

The remedy of the first three causes is obvious. Coupling between bridge arms can be minimized by separation of the units and by shielding. Separation serves to eliminate intercoupling but it does not reduce the stray capacity to ground.

Stray capacity to ground varies with the position of each unit and sometimes with the position of the observer's body. It is not possible to eliminate the unit-to-ground capacity, but it can be definitely fixed by the use of shields so that this effect reduces to known fixed capacitances across one or more bridge arms. The extra capacity can then be taken into account and corrected.

In many applications stray ground capacities introduce only a negligible effect due to the values of the bridge constants. Whenever the admittances introduced by such stray capacitance are small compared to the admittance of the bridge arm shunted by it, the error may be neglected. In many cases, when high-impedance arms or high frequencies are used, very careful consideration of stray capacities is required.

The effect of ground capacities can be remedied by the use of shielding or by employing a Wagner ground.

SHIELDING

The object of shielding is to eliminate the coupling between units and to make the stray capacitances (unit to shield) definite in magnitude so that they are independent of the position of the shielded units or the body of the observer.

When a shield is placed around an impedance element, there will be a definite capacity between the element and the shield. There is also a variable capacity between shield and ground. The best practice is to connect the shield to one terminal of the impedance element within it and to arrange the bridge in such a way that this terminal can be grounded or otherwise connected so as to keep shield-to-ground capacity from affecting the bridge balance.

	voltage across Z_2	voltage across Z_1	voltage across Z_5
balance	.001e	.999e	0
Z_2 50% too large	.0015e	.9985e	.0005e
Z_2 50% too small	.0005e	.9995e	.0005e
Z_1 50% too large	.00067e	.99933e	.00033e
Z_1 50% too small	.002e	.998e	.001e

Compare this with the following table of the values when Z_1 equals Z_2.

	voltage across Z_2	voltage across Z_1	voltage across Z_5
balance	.5e	.5e	0
Z_2 50% too large	.6e	.4e	.1e
Z_2 50% too small	.33e	.67e	.17e
Z_1 50% too large	.4e	.6e	.1e
Z_1 50% too small	.67e	.33e	.17e

Although this example was calculated for the special case when Z_5 is infinitely high, it shows the tendency when Z_5 is finite. The sensitivity is greatest when Z_1 equals Z_2 even if Z_1 and Z_4 are far different.

The effect of the shields is to place a capacitance of fixed value across each shielded element. This extra capacitance must be adjusted by means of small auxiliary condensers so as to be in the same ratio as the bridge arms or it can be a part of the bridge arm. Bridges which have been so adjusted are good for this one bridge ratio only.

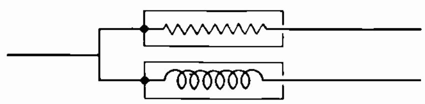

Fig. 5

When two impedances are in parallel they must be individually shielded and the grounded terminals must be joined as illustrated in Figure 5. When two impedances in series are in one bridge arm the only solution is to have one shield large so as to include its own impedance element and the other impedance element with shield and all. Then there cannot be any indefinite stray capacity. This is shown in Figure 6.

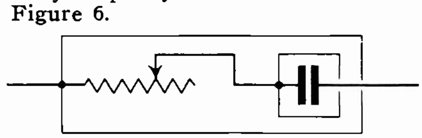

Fig. 6

Applying the above described principles to the Wien bridge of Figure 2 the circuit becomes as in Figure 7. The shielding of the four bridge arms is relatively simple because the shields can be arranged so as to connect to ground or to the point A which simply results in a capacity across the source.

The detector shielding is a more difficult problem since both terminals of the detector are above ground potential. If a single shield is placed around the detector the shield to

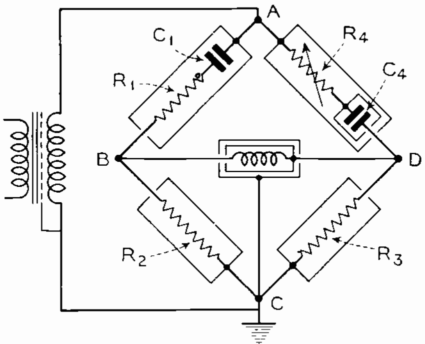

Fig. 7

ground capacity is across either R_2 or R_3 and the capacity varies with the position of the detector. This indefinite capacity can be made fixed by the addition of another shield around the first one, connecting this second shield to the point C which is grounded. The capacity between the two shields is across R_3 and becomes a part of this branch.

The double shield would be a good solution if it were always easy to apply. The detector is usually coupled to the bridge by a transformer which means that a double shield should be employed between primary and secondary.

WAGNER GROUND

Nearly all the effects of stray capacitances can be eliminated by means of a Wagner ground. Figure 8 shows the Wagner ground added to a bridge. It consists of two impedance arms across the source with their junction grounded. These impedances can be resistances or condensers depending

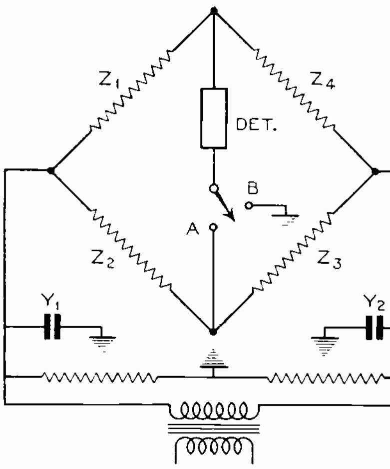

FIG. 8

on the characteristics of the bridge arms.

Adjust the bridge to balance as well as possible with the switch set at A. Then set the switch to B and adjust the Wagner ground impedances for balance. It will be necessary to go back and forth several times until an adjustment is found which provides balance in both positions of the switch.

When this adjustment is obtained, the detector is at ground potential so its capacity to ground cannot affect the bridge. The stray capacities across the bridge arms and across the power transformer can be represented by the lumped admittances Y_1 and Y_2. These are across the two arms of the Wagner ground, have become part of it and are adjusted in the same ratio Z_2/Z_3. Thus they are not affecting the bridge.

APPARATUS

The source usually consists of an oscillator or a microphone hummer which is coupled to the bridge by means of a transformer. If the source is not to be grounded a shield should be placed between primary and secondary.

In many cases it is necessary to apply a polarizing voltage to the condenser while it is being measured on the bridge. The polarizing voltage should be applied in a manner which will not react unfavorably on the bridge arms nor affect the detector.

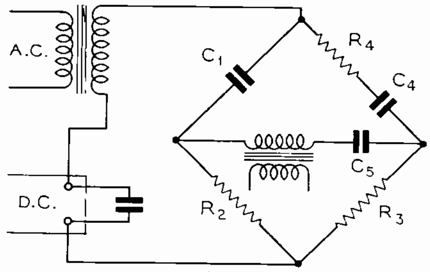

FIG. 9

Two methods are shown in Figures 9 and 10. In Figure 9 the d.c. is simply in series with the a.c. source while the condensers C_1, C_4 and C_5 protect the bridge arms and the detector. This circuit can sometimes be simplified by the use of a power supply with imperfect filter when the ripple serves as the a.c. signal.

Another method, shown in Figure 10, consists of placing the d.c. in series with the detector branch and arranging the bridge arms in such a way that no current can flow except the slight leakage which might occur in the condenser.

DETECTORS

Phones are popular as detectors but they have several drawbacks. There is the "head effect" or capacity between the phones and the body of the observer. Then the sensitivity is unsatisfactory on lower frequencies such as 60 or 120 cycles. Amplifiers are

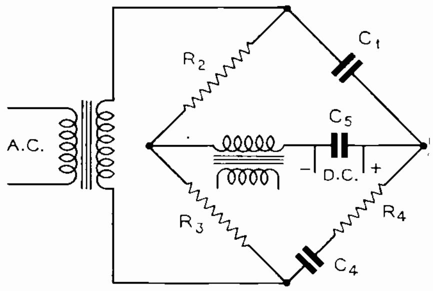

Fig. 10

commonly employed and the phones can still be used as detectors since they are now free from the head effect. For low frequencies however some indicating meter is preferred.

The coupling between bridge and amplifier is usually a transformer except in cases where one side of the detector can be grounded and the grid leak of the tube is directly across the bridge. The difficulties with the transformers have already been pointed out.

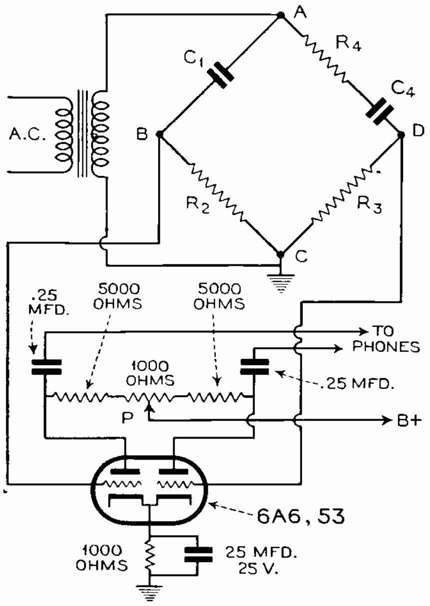

Fig. 11

There is still another possible system which reduces the stray capacity effect and yet permits both points B and D to be above ground potential. This is shown in Figure 11. A double tube, such as 6A6 or 53 is used as a detector, the grids being connected to the points B and D. When first setting up the circuit, B and D should be shorted and with the source functioning, the potentiometer P should be adjusted for silence in the phones. Then remove the short and balance as usual. This method works well as long as the signals applied to the grids do not overload either of the tube sections. The phones may be replaced by a transformer so that further amplification is possible.

to really know Condensers...

AEROVOX CAPACITY and RESISTANCE *Bridge*

WHAT IT DOES

CAPACITY BRIDGE

. . . measures capacity 100 mmfd. (.0001) —100 mfd. in 6 ranges; leakage; power factor to 50%, etc., of condensers UNDER ACTUAL WORKING CONDITIONS.

RESISTANCE BRIDGE

. . . measures resistance values of resistors and electrical equipment and circuits, 10 ohms—1 megohm in 5 ranges.

INSULATION RESISTANCE

. . . measures this important factor in condensers and other devices. Meter is calibrated directly in megohms. Reads up to 10,000 megohms.

VACUUM-TUBE VOLTMETER

. . . consists of amplifier stage and grid-leak detector. Measures minute values 0-2 volts.

VOLTMETER

. . . available for voltage readings. 0-60 v., 0-300 v., 0-600 v. at 1000 ohms per volt. *May be used externally.*

MILLIVOLTMETER

. . . meter terminals brought out directly. Range 60 mv. at 60 ohms or 1 ma. *Can be used with external shunts.*

MILLIAMMETER

. . . meter can be read in milliamperes. 0-6 ma., 0-60 ma. *May be used externally.*

VARIABLE POWER SUPPLY

. . . available directly at terminals, supplying between 15 and 600 volts *continuously variable over entire range.*

Better condensers of today call for more critical testing means. Above all, condensers must be tested under ACTUAL WORKING CONDITIONS. Otherwise, tests mean little or nothing.

As leading manufacturers of good condensers, AEROVOX has deemed it necessary to evolve superior testing means. Originally developed for our own laboratory use, the AEROVOX Capacity and Resistance Bridge has been re-designed into a simplified, portable instrument for the use of servicemen and other radio workers. A sufficiently large production schedule has brought the cost down to well within the reach of the serious radio man.

Regardless of what test equipment you may already have, this is one instrument you can not afford to be without, if you must really know condensers!

Condenser Testing Manual

24-page handy Manual. Replete with the theory of bridges and the functioning of such types as Wien, Schering, Maxwell, Hay, Owen, et al. Mathematical data, diagrams. Also provides necessary practical instructions; describes tests and measurements that can be made with the AEROVOX Bridge. Manual supplied free with each Bridge; others may obtain one or more copies, while the limited supply lasts, at \$.50 per copy.

See The Bridge . . .

See it! . . . Try it! . . . at your Jobber. Or address the Research Worker for more complete literature.

AEROVOX CORPORATION

70 WASHINGTON STREET, BROOKLYN, N. Y.

Sales Offices in All Principal Cities