By McMURDO SILVER *

A PRECISION INSTRUMENT

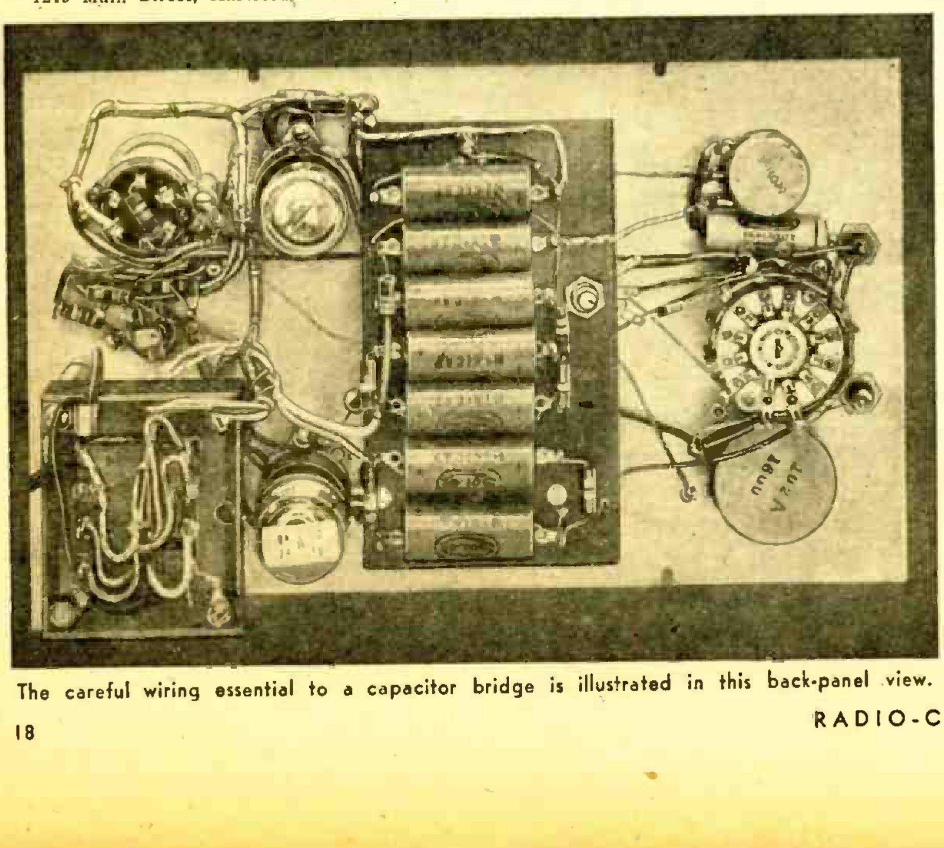
Laboratory Accuracy in a Serviceman's C/R Bridge

IN the early days of one- to five-tube battery receivers with usually but a single function per tube and circuit, location and correction of troubles was simple indeed. The exact reverse is true today, for even the simplest type of five-tube broadcast receiver has several multiple-function tubes, each function having its own separate circuit and set of component parts. Most important is that each one of these circuits—and there can be many indeed in a complex modern receiver—employs a large number of individual capacitors and resistors. Even partial failure or alteration in value of but one of the many unimportant-appearing little capacitors or resistors can—and usually does—cause the poor performance which the technician is employed to correct.

Drawing upon his thirty-five-odd years of experience in the design of high-quality radio receivers as a guide to the precise types and forms of measuring equipment which can most effectively serve the serious maintenance technician, the writer has recently completed a piece of measuring equipment going far beyond the rough approximations heretofore available at low cost. It has been his goal to bring to the maintenance profession those orders of accuracy heretofore available only in laboratory instruments costing several hundred dollars or more, and hence beyond reach of most service organizations.

* 1249 Main Street, Hartford, Connecticut

If, in the design laboratory, it has been necessary to measure resistors and capacitors to an accuracy of a few percent, then it is obviously desirable that the maintenance technician be able to do likewise. Excellent approximations of resistance values may be made by a well designed and built ohmmeter. Capacity may not be so measured accurately, for *two values* enter into capacitance measurements—actual capacitance in microfarads or micromicrofarads, *plus power factor*. Considering only resistance measurements for a start, the good ohmmeter cannot be particularly accurate over much of its range because of the characteristic slope of its meter scale. The usual ohmmeter scale is "open" over its lower half and its accuracy can be excellent over this portion of its scale. Over the upper half, however, the scale graduations become increasingly crowded, since they must reach practically infinity at full-scale. Allowing for the normal and usual ±2 percent accuracy of even the best meters, a glance at the upper half of the ohmmeter scale in terms of graduation crowding versus such meter variation shows why high accuracy cannot be anticipated. It is true that this condition can largely be set at nought by provision of such a multiplicity of resistance ranges that it is seldom necessary to use the crowded high end of the scale in practice. Nevertheless, the really accurate method of measuring resistance is by means of the Wheatstone Bridge—the ohmmeter serves an essential function but for truly accurate measurement the bridge is a "must".



The careful wiring essential to a capacitor bridge is illustrated in this back-panel view.

SUPERIORITY OF THE BRIDGE

It is true that an ordinary a.c. voltmeter or ammeter can be used to measure capacitance in the usual ohmmeter manner, but what actually happens is that the technician measures *capacitative reactance* which is then translated into capacity in terms of that capacitance which exhibits a given capacitative reactance at the particular a.c. frequency of measurement. Such attempts at measurement of capacitance cannot be more than approximately useful, since they ignore power factor. It is possible to find a capacitor apparently quite satisfactory so far as capacitance goes, yet have this capacitor exhibit such a high power factor as to be operatively useless. The fundamental Wheatstone Bridge method permits measurement of both capacitance and power factor, and so is a prime essential to the serious technician. Such a bridge may be so designed that it can provide resistance measurements with accuracy far exceeding the ohmmeter method, hence is most desirable.

One of the disadvantages of bridges so far available to the service technician is not alone that their accuracy left much to be desired because of low-cost components and the cursory test and calibration necessary to yield a low final selling price, but their lack of range as well. The equipment designer and the maintenance technician alike must be able to measure down to a fraction of an ohm, a fraction of a micromicrofarad—as well as up toward 1000 megohms and 1000 microfarads. Small compression mica trimmer capacitors—even air trimmers—of extremely low capacity can be causes of trouble and so must be capable of measurement in any well-equipped shop. Low values of resistance measurement are also necessary when "shooting trouble" in auto radio primary circuits, a.c. receiver heater circuits and the like. High ranges of resistance must be accurately determined in grid leaks and performance-impairing circuit leakage, while high values of capacitance appear in the filter capacitors of battery eliminators for portable battery sets as well as in "a.c., b.c. and d.c." sets themselves.

PRACTICAL PRECISION BRIDGE

The capacitance-resistance bridge illustrated and diagrammed covers the direct range of 10 ohms through 1000 megohms and 10 μμf through 1000 μf. This is not its real range, for in operation it reaches down to ¼ ohm and ¼ micromicrofarad—low enough to cover compression mica trimmers and high-resistance or faulty connections in auto radio heater and vibrator input circuits, where high current requirements necessitate low circuit resistance. Values of unknown capacitances and resistances below 10 μμf and 10 ohms are measured and indicated directly, as the increment such low values add on the bridge dial when they are shunted across some convenient small value of capacitance or resistance first connected to the bridge terminals and measured. With a 10 μμf capacitance (conveniently provided by a pair of wires twisted together just sufficiently to give a 10 μμf indication on the bridge) it becomes possible to measure accurately capacitances as low as ¼ μμf. The same is true for resistance, substituting a 10 ohm resistor for the 10 μμf test capacitor.

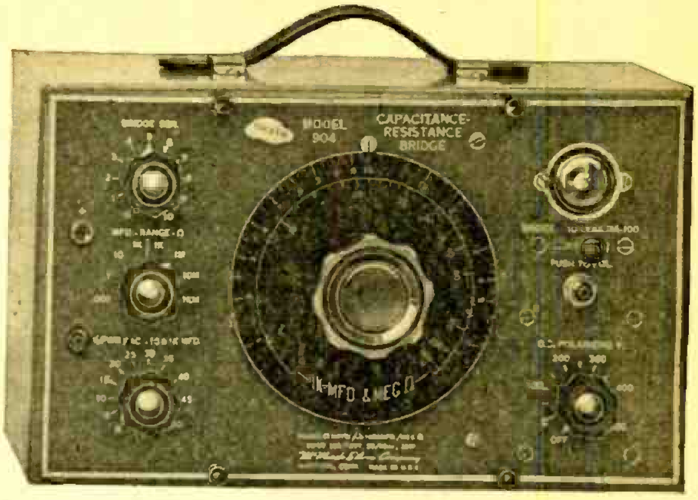
Power factor of capacitors in the ranges usually made up of paper, oil and electrolytic structures should be measurable up to 50 percent. Since paper capacitors seldom are made below .001 μf, and as mica, ceramic and air capacitors seldom exhibit poor power factor without complete failure, we may establish power factor measurement as essential in the range of .001 μf up through 1000 μf.

For electrolytic capacitor measurement and reforming after idle periods the ideal bridge must incorporate a source of continuously variable d.c. potential which may be applied to any capacitor under test. Provision must be made for determination of leakage currents through electrolytic capacitors as well.

If we can provide means for measuring condenser capacitance under conditions where actual d.c. operating voltages are applied at the same time that capacity is being measured, we may locate those intermittent condensers which are the bane of the service technician; condensers which test correctly out of circuit but which fail to function when restored to the equipment from which they were disconnected because a d.c. potential not present in outside measurement is reapplied to them.

Fig. 1 and the photos illustrate and diagram a capacitance-resistance bridge satisfying all of the requirements set forth above, a precision measuring instrument yielding an accuracy in measurement of capacitors and resistors of ±3 percent nominally over the range of ¼ μμf or ohm up through 100 μf or megohms; with such laboratory order of accuracy falling off slightly only between 100 and 1000 μf or megohms. Using it, power factor may be accurately determined, polarizing voltages may be applied to any and all types of capacitors during actual capacitance measurement, leakage currents in two ranges of 0-10 and 0-100 ma may be measured—even insulation resistance up to 1000 megohms with 0 to 500 volts d.c. applied may be accurately determined.

Operation is simple as it is accurate. The power cord plug inserted into any 105/125 volt, 50/60 cycle a.c. mains outlet, the bridge is turned on by moving the lower right knob from OFF to ON, and tubes allowed to warm up. Middle right lever switch set to BRIDGE, it is only necessary to connect an unknown resistor or capacitor to the two left panel jacks by means of the clip leads supplied and set RANGE knob to that position which allows the electron-ray tube to open to a maximum for some setting of the 5-inch dial, when the value of the unknown is read directly from the dial setting multiplied by the indicated RANGE knob figure. The upper left knob allows adjustment to the degree of "eye" opening which yields most accurate readability. The lower left knob reads power factor directly in percent at that setting which, after the bridge is balanced, yields greatest farther opening of the "eye." D.c. polarizing voltage is applied in accordance with the rating of the capacitor under test by appropriate setting of the lower right knob and depressing of the button-switch immediately above it. Capacitor leakage current is read on the "eye" as the percentage of closure it exhibits when the lever switch is thrown to the 10 or 100 ma leakage positions with polarizing voltage applied. No eye closure indicates no leakage current; full eye closure indicates 10 or 100 ma leakage current, depending upon lever switch position.



Front view of the Silver Model 904 Capacitance-Resistance Bridge.

Fig. 1 illustrates circuit-wise how all of these functions are incorporated in an instrument measuring only 12⅝ inches long, 7⅝ inches high and 6 inches deep over knobs, in a weight of but 10 pounds, and all with large and costly laboratory instrument accuracy. The actual bridge measuring circuit itself consists of a 4-arm Wheatstone Bridge circuit in Carey-Foster form. The main dial controls the ±2 percent precision potentiometer P1 which constitutes two simultaneously variable arms of the bridge. A third bridge "arm" is always the unknown, or X, connected to the INPUT terminals. The fourth, or "standard" arm consists of C1, C2 or C3 for three capacitance ranges, or of R1 R2 or R3 for three resistance ranges. To obtain the two special high ranges of 10 to 1000 μf or megohms, special "expanding" resistors R4, R4a are cut into circuit at one or the other end of P1 by the range switch S1, S1a, S1b. Standard resistors are held to ±1 percent accuracy; capacitor standards, of mica and special mineral oil construction, to ±2 percent.

This type of bridge circuit wherein two arms are varied simultaneously and oppositely in value yields the advantage of a 100 to 1 range for each rotation of P1, plus the desirable logarithmic scale calibration wherein accuracy is substantially constant percentage-wise at low, medium or high settings of the dial scale. It also lends it-

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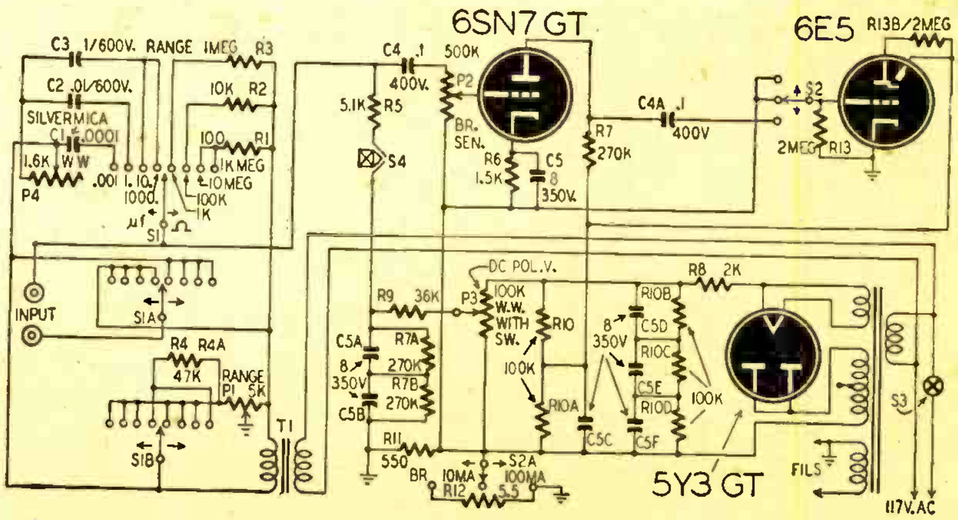

Fig. 1—Complete schematic of the bridge. Measurements are made with three main controls.

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self admirably to extension of its range through the "vernier" effect upon P1 of adding R4, R4a into circuit to cover from 10 to 1000 μf or megohms.

Voltage for operation of the bridge itself is supplied through special transformer T1 connected to the horizontal bridge arm junctures. Balance is indicated by the absence of voltage across the vertical bridge arm junctures (ground and arm of S1) indicated by the 6E5 electron-ray tube, with the null voltage amplified by the 6SN7GT triode to its left in Fig. 1. Indicator sensitivity is controlled by potentiometer P2.

The power transformer provides heater voltage to the three tubes, and has its high voltage secondary connected as a whole to the 5Y3GT rectifier tube used as a half-wave rectifier. Filtration is a simple problem in this type of instrument, while such use of an essentially standard power transformer and rectifier tube permits obtaining something over 500 volts d.c. output simply and easily. For operation of the amplifier and indicator tubes this is cut down to 200 volts by the voltage divider R10, R10a. The full 500 volt d.c. output of the power supply appears across extra-heavy potentiometer P3, with any panel-calibrated portion of this voltage from 0 to 500 volts obtainable from its arm for application to the capacitor—or resistor—under test through filter resistor R9, PUSH TO POLARIZE button switch S4, and isolating-current limiting resistor R5. C5 through C5f are all 8 μf, 350 working volt electrolytic capacitors. C5d, C5e and C5f in series are the filter input capacitor of 1050 volts rating for the 500 volt circuit voltage—ample safety indeed against line surges. Voltage distribution across them, as well as across C5a, C5b and C5c is held constant and capacitor life is prolonged by shunt resistors R7a, R7b and R10b, R10c and R10d.

Switches S2, S2a shift the function of the 6E5 indicator tube from that of a bridge balance (null) indicator over into a two-range milliammeter with resistor shunts R11 and R12 yielding 0-10 and 0-100 ma ranges. The 6E5 connected across one or both of these resistors in series with the internal d.c. polarizing voltage source and the specimen under test provides a milliammeter which may not be burned out like the ordinary meter movement if a short-circuited condenser is inadvertently tested.

"Where extremely precise measurement of the leakage current through capacitors under test may be required, a more accurate indicator than the 6E5 is preferred. The milliammeter in any conventional volt-ohm-milliammeter may be employed for such precise measurement. It is merely necessary to connect such milliammeter between the capacitor under test and the black jack of the bridge. The meter should be short circuited for all except leakage current measurements, for its resistance can upset power measurements."