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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A NEW BRIDGE FOR THE MEASUREMENT OF IMPEDANCE BETWEEN 10 AND 165 MC

Also IN THIS ISSUE

● **WITH** the increasing use of higher and higher frequencies in radio and electronics has come a demand for a bridge for the measurement of impedances of antennas, lines, networks, and components with the accuracy and ease of operation that characterize the TYPE 916-A R-F Bridge[1], so widely used at lower frequencies. To meet this demand a new instrument, the TYPE 1601-A V-H-F Bridge, has been developed, which extends the range of conventional bridge techniques up to about 165 Mc. It can be used at frequencies at least as low as 10 Mc. This bridge is particularly well adapted to the measurement of coaxial-line circuits as well as lumped parameter circuits.

THE TYPE 1601-A V-H-F Bridge is designed for the direct measurement of relatively low impedances, but will measure high impedances indirectly. The resistive and reactive components of the unknown im-

[1]Sinclair, D. B., "A New R-F Bridge for Use at Frequencies up to 60 Mc," *General Radio Experimenter*, Vol. XVII, No. 3, August, 1942.

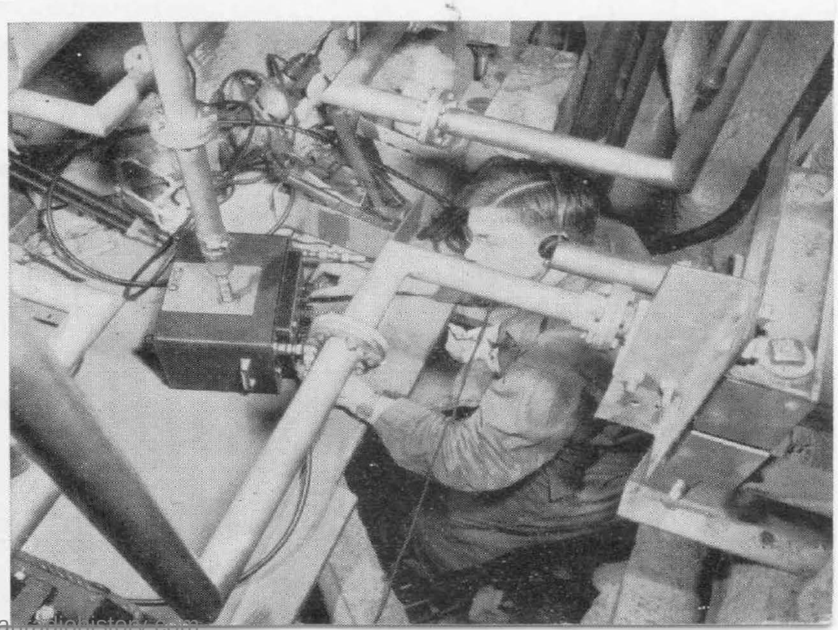


Figure 1. Ogden Prestholdt, CBS engineer, using the V-H-F Bridge to measure the new antenna of WCBS-TV, on the Chrysler Building. Some of the results of the measurement are shown in Figures 7 and 8, page 5.

pedance are measured in terms of incremental capacitances and are indicated on separate dials. The direct-reading resistance range is from 0 to 200 ohms and is independent of frequency except for small corrections. The direct-reading reactance range is from 0 to 230 ohms at 100 Mc and is inversely proportional to frequency. To insure a high accuracy of measurement on coaxial line circuits, a coaxial connector can be mounted directly on the bridge terminals so that errors due to connections between the bridge and line are kept small. For measurements on other types of circuits, a pair of terminals (one grounded) or a single terminal and a ground plane are provided.

BRIDGE CIRCUIT

The basic bridge circuit is shown in Figure 2 and is the same as that of the lower frequency TYPE 916-A Bridge. A complete analysis of this circuit has been published in previous articles[2] and it will suffice to indicate here only the basic balance equations.

The relationships between the various bridge parameters necessary to obtain an initial balance with the unknown short-circuited are given by the expressions:

$$R_P = \frac{R_B}{C_N} C_{A_1} \qquad (1)$$

$$C_{P_1} = \frac{C_N}{R_B} R_A \qquad (2)$$

After the final balance has been made with the circuit under test connected to the unknown terminals, the expressions for the unknown impedance in terms of the bridge parameters are:

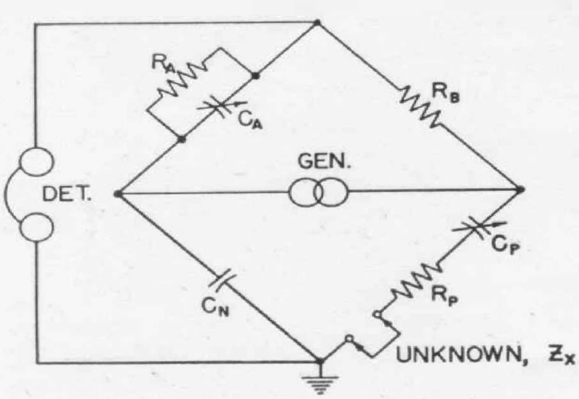
$$R_X = \frac{R_B}{C_N} (C_{A_2} - C_{A_1}) \qquad (3)$$

$$X_X = \frac{1}{\omega} \left(\frac{1}{C_{P_2}} - \frac{1}{C_{P_1}} \right) \qquad (4)$$

As can be seen from Equations (3) and (4), the unknown resistance, R_X, is proportional to the change in capacitance of C_A, and the unknown reactance, X_X, is equal to the change in reactance of C_P and has the opposite sign. In this series-substitution bridge, the C_A dial can be calibrated directly in resistive ohms, with the calibration independent of frequency, and the C_P dial can be calibrated in reactive ohms at one frequency, with the calibration inversely proportional to frequency.

[2] Sinclair, D. B., "A Radio Frequency Bridge for Impedance Measurements from 400 kc to 60 Mc," Proc. I.R.E., Vol. 28, No. 11, pp. 497-503, November, 1940.

(*Below*) Figure 2. Basic bridge circuit.
(*Right*) Figure 3. Complete schematic circuit.



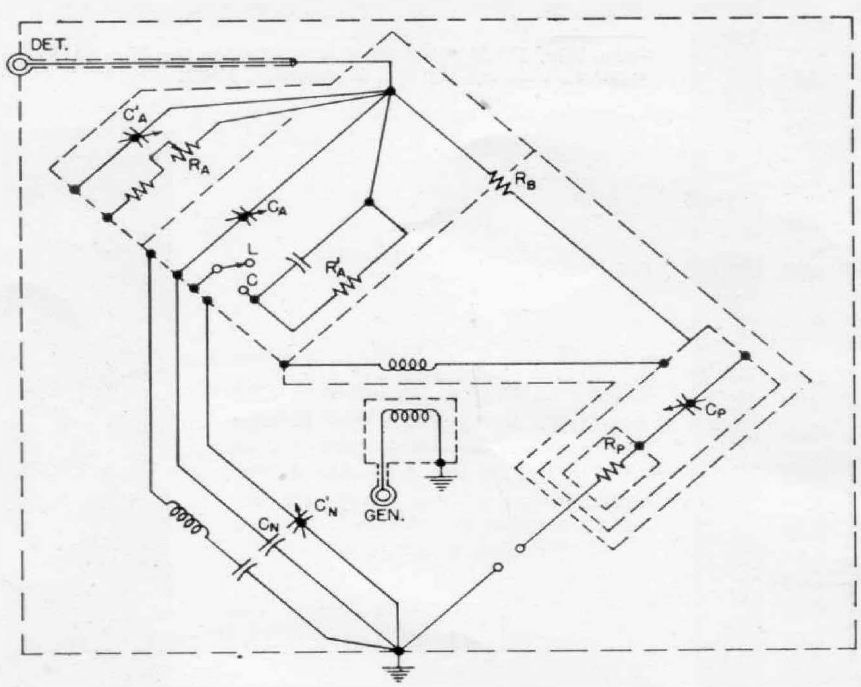


Figure 4. View of the engineering model of the V-H-F Bridge with coaxial adapter installed on the unknown terminal at the top of the cabinet. Panel size is approximately 11 x 9 inches. Production model has a larger ground plate around the unknown terminal and is equipped with carrying handles.

Although the basic circuit is similar, the method of obtaining the initial reactance balance in the V-H-F bridge differs from that of the TYPE 916-A Bridge. As shown in the complete circuit diagram in Figure 3, the initial reactance balance is made by means of the carbon rheostat R_A. The resistor R_A controls the reactance balance as can be seen from Equation (2), but has no effect on the dial calibrations as long as the value of R_A is not changed between the initial and final balances. The *L-C* switch indicated in the schematic is used to provide maximum fineness of control over a very wide range of resistance values by allowing a small resistor to be shunted across the variable resistor. The initial resistance balance is made by means of a small variable capacitor connected in parallel with C_A.

DESIGN CONSIDERATIONS

The actual bridge circuit is more complex than is indicated in either Figure 2 or 3, owing to the presence of various stray inductances and capacitances. In general, these residual parameters cause errors in the bridge readings, and the most difficult problem in the design of the bridge was to keep these errors within acceptable limits by minimizing the residual parameters or placing them in parts of the circuit where they cannot cause errors.

A complete discussion of the bridge design is too lengthy to incorporate in this article, but a few of the more important considerations will be mentioned.

Standard Resistor

The standard resistor, R_B, must be so designed that it inserts a practically pure resistance between the top and right bridge junctions in Figure 3. Any reactance present causes an error in reactance which is proportional to the magnitude of the measured resistance. Of course, every resistor has some capacitance and inductance which cannot be eliminated, but if the inductance and capacitance are so proportioned that the square root of their ratio is equal to the resistance, the resistor will have a very small effective reactance at frequencies up to an appreciable fraction of the resonant frequency. For best compensation, therefore, the inductance and capacitance should have this relationship, and they should both be as small as possible in order to keep the resonant frequency high. In the V-H-F bridge the standard resistor is a cylindrical palladium-palladium oxide film resistor fitted with threaded end caps to eliminate the need for high inductance wire leads. In the circuit the total capacitance across the resistor is 0.31 $\mu\mu f$, and the inductance is about 0.019 μh which gives a very low reactance over the operating frequency range of the bridge when the resistance is 250 ohms.

Resistance Capacitor

Another serious residual parameter is the series inductance in the capacitor C_A used to measure resistance.

Equation (3) indicates that the measured resistance is proportional to the change in the effective capacitance of this capacitor. At high frequencies, the effective capacitance differs from the low frequency capacitance due to inductance in the capacitor, and the bridge tends to read low in resistance at high frequencies. In a conventional capacitor it is impossible to reduce the inductance to a negligible value; therefore, in order to minimize the magnitude of this effect, a compensating circuit consisting of an inductance and capacitance in series is connected across the capacitor C_N. The compensation is not perfect, but the magnitude of the corrections is appreciably reduced.

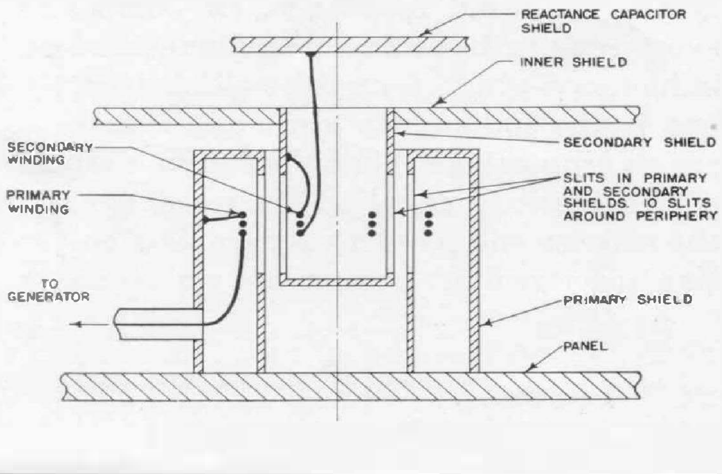
Transformer

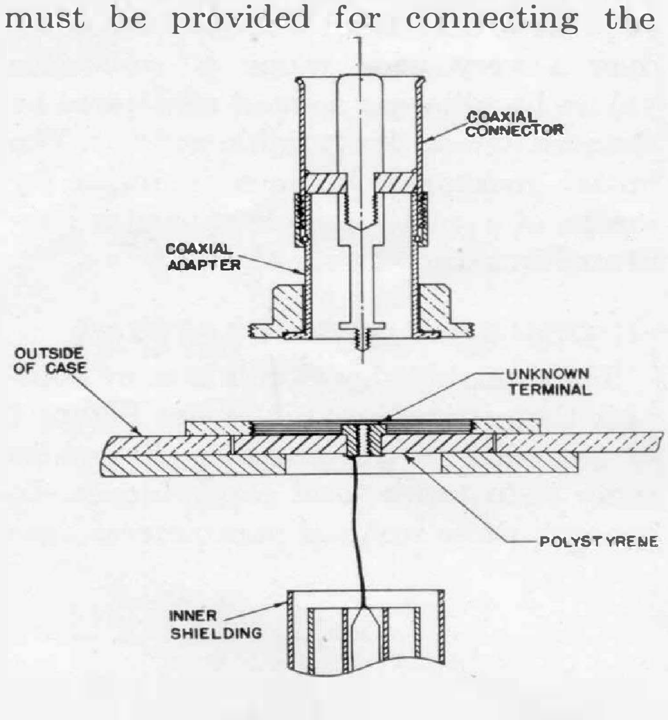
The heart of the bridge is the transformer. The coupling between the primary and secondary windings must be almost purely magnetic, since any electrostatic coupling between the windings effectively places a reactance in parallel with C_N and the unknown arm, which may cause serious errors. As shown in Figure 3, the primary and secondary windings are separately shielded, with the primary shield connected to the instrument case. Figure 5 is a cross-sectional view of the transformer used in the bridge. Magnetic coupling between the primary and secondary windings is obtained through a series of slots in the adjacent walls of the two shields. The direct capacitance between shields is part of C_N. Although the coefficient of coupling is small, adequate sensitivity is obtained and the electrostatic shielding is excellent.

Unknown Terminal

In any bridge, terminals of some type must be provided for connecting the

(Below) Figure 5. Cross section of bridge transformer.
(Right) Figure 6. Cross section of unknown terminal and coaxial adapter.





unknown circuit to be measured. At high frequencies the design of these terminals is important, because stray inductances and capacitances will seriously affect the measured impedance. The ultimate terminal design would be one in which the terminals produce no transformation of the unknown impedance. The terminal arrangement used in the V-H-F bridge, shown in Figure 6, has been designed to approach the ideal. One actual terminal is provided, and the instrument case acts as the other terminal.

For measurements using the terminals directly, a short-circuiting cap is provided for setting up the initial balance. The cap screws into the instrument case and contacts the high unknown terminal, thus providing a very low inductance short circuit. After the initial balance is made, the cap is removed, and the circuit to be measured is connected between the high unknown terminal and the instrument case. A small residual capacitance of 1 $\mu\mu$f between the unknown terminal and the instrument case appears in parallel with the unknown circuit. In some cases this capacitance has an appreciable effect on the measured impedance, and the impedance indicated by the bridge must be corrected for it in order to obtain the true impedance. A chart, provided in the instruction book, greatly simplifies the task of making this correction.

For measurements on coaxial systems, a coaxial adapter is supplied, which eliminates errors from connecting leads and from the residual terminal capacitance. This adapter, shown in Figure 6, is a short section of 50-ohm coaxial line, with a Type 874 Coaxial Connector on one end and fittings to mount it on the bridge at the other end.

Terminal capacitance compensation is provided by adding series inductance in the center lead, so that the terminal capacitance and the inductance form a 50-ohm artificial line whose only effect is to increase slightly the electrical length of the adapter. This series inductance is obtained by increasing the characteristic impedance of a short section of the adapter line. An important advantage of this coaxial adapter is that the standing-wave ratio of a coaxial system being measured is not affected by the terminal capacitance of the bridge.

For measurements on 50-ohm coaxial systems, the only effect of the adapter is to increase the electrical length of the 50-ohm coaxial line that would ordinarily be used to connect the unknown network to the bridge. The total electrical length can be determined from a reactance measurement with the far end shorted. Then, from an impedance measurement

Figure 7. Plot of the impedance of a single element in the WCBS-TV antenna. Numbers on curve indicate frequency in megacycles.

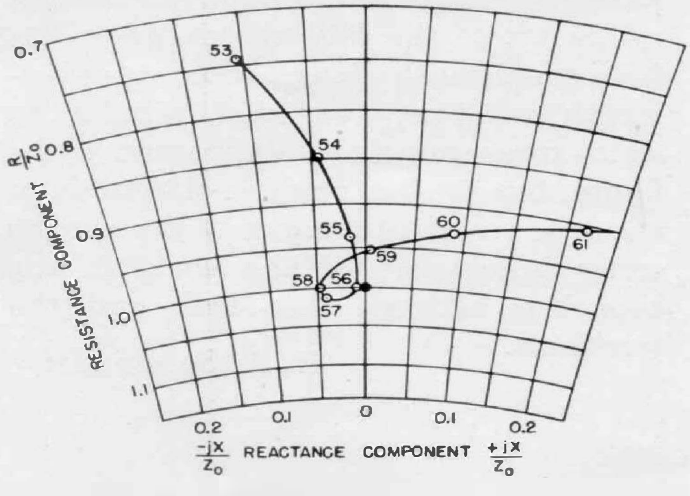
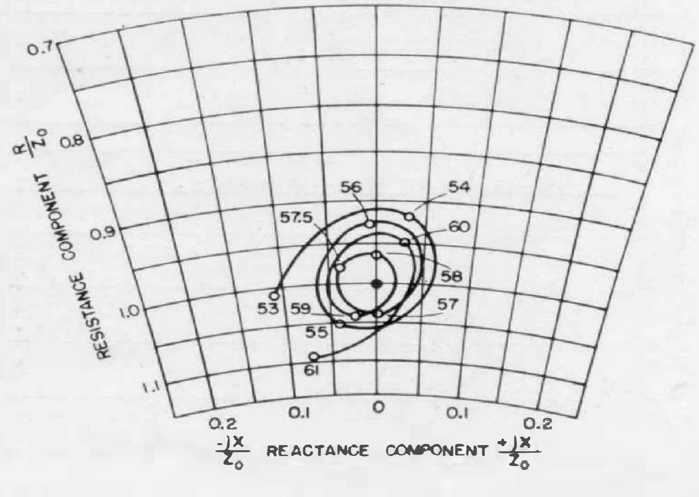


Figure 8. Plot of the impedance of the entire 16-element array, as seen from the transmitter.



with the line terminated in the unknown impedance, transmission line equations or charts can be used to determine the unknown impedance.

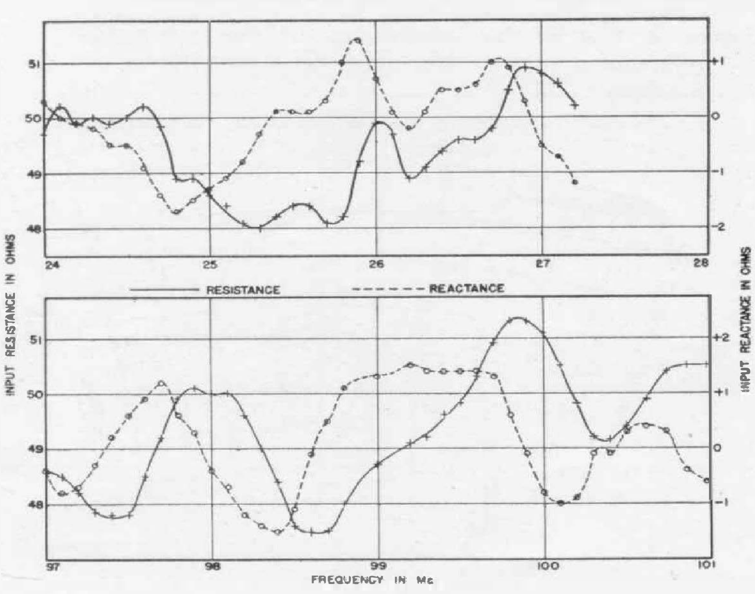
CORRECTIONS

As previously mentioned, residual parameters cause small errors in the bridge measurements. The most serious of these is the effect of inductance in the capacitor C_A used for measuring resistance. The error varies with frequency and with the magnitude of the resistance measured. A chart is provided to correct the bridge readings for this effect.

Residual parameters also cause a small error in resistance which is proportional to the magnitude of the reactance measured. This error is so small that it is important only when the resistive component of a high Q circuit is measured. When important, the error can be reduced appreciably through the use of the correction chart supplied.

At the highest frequencies, distributed inductance and capacitance in the reactance capacitor, C_P, cause a small error in reactance. A chart is provided for correction when this effect is important.

Figure 9. Input impedance of a 2400-foot length of General Radio Type 874-A2 Coaxial Cable.



TYPICAL MEASUREMENTS

Some of the applications of the bridge are the measurement of resistors, capacitors, inductors, transmission-line networks, and antennas. Following are a few typical examples.

Figures 7 and 8 show the results of measurements made by WCBS-TV on their new television antenna located near the top of the Chrysler Building in New York City. The antenna consists of 16 radiating elements, four on each of the four faces of the building. Figure 7 shows the impedance variation of an individual element over the operating frequency band, and Figure 8 shows the impedance of the whole array as seen by the transmitter.

Figure 9 shows the input impedance variation with frequency of a 2400-foot length of 50-ohm coaxial cable. The cable is sufficiently long as to act as an infinite line, and the variations in impedance are caused by variations in the characteristic impedance of the cable along its length.

Figure 10 shows the impedance variation with frequency of a 2100 $\mu\mu$f Type 848 Variable Air Capacitor in the vicinity of anti-resonance. The resonance is actually a transmission-line resonance because the capacitor is electrically similar to a high-capacitance transmission line as shown in the equivalent circuit. The anti-resonance indicated is the half-wavelength resonance. Another resonance was measured at about 142 megacycles where the line was electrically a full wavelength long. The ¾-wavelength resonant condition, similar to series resonance, is also apparent in the figure, but its frequency is shifted from the true resonant frequency due to the series inductance of the leads in the capacitor between the stack and the terminals.

— R. A. Soderman

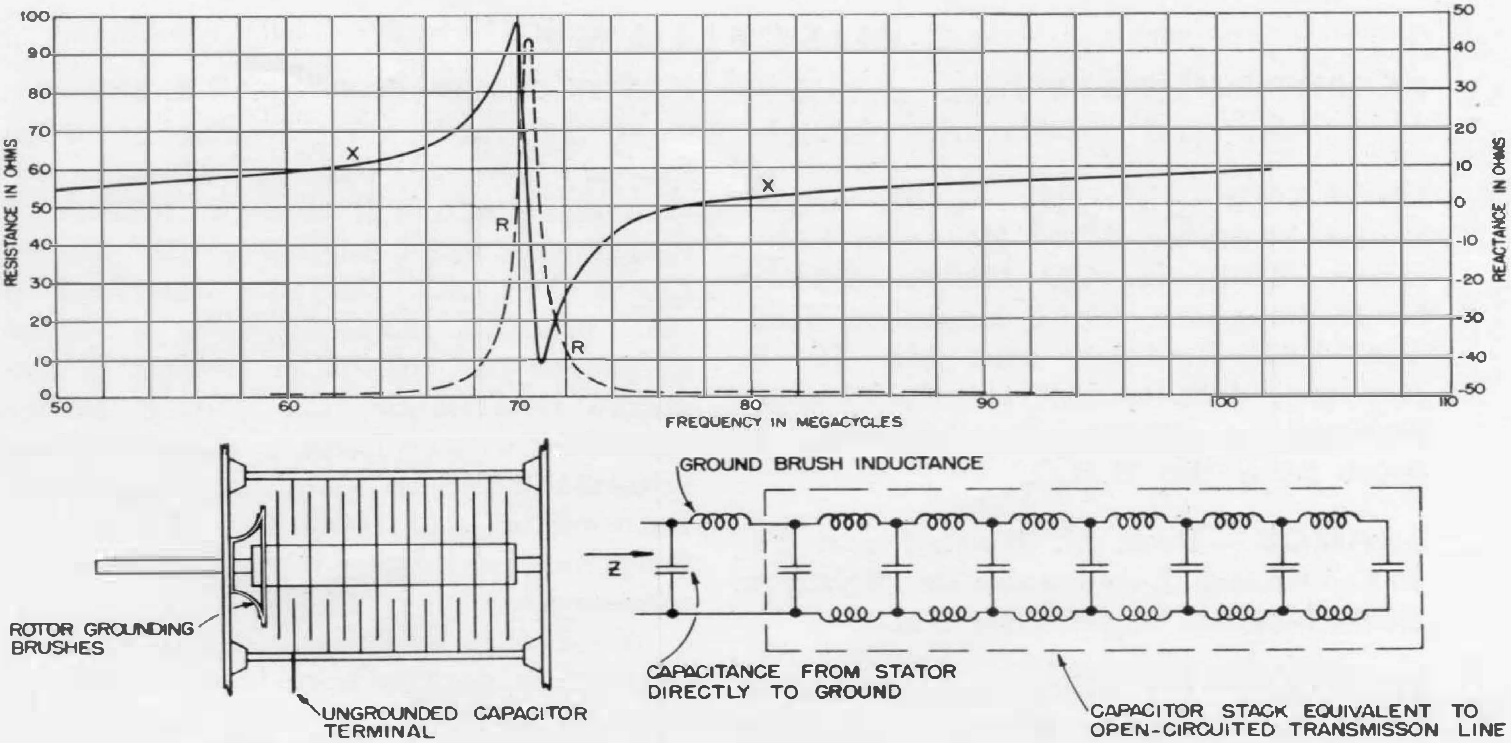


Figure 10. Resistance and reactance of a Type 848-C Variable Air Capacitor at frequencies above its normal operating range. Approximate equivalent circuit of the capacitor is shown below the plot.

SPECIFICATIONS

Frequency Range: 10 Mc to 165 Mc. Satisfactory operation can, for some measurements, be obtained at frequencies as low as 2 Mc and as high as 175 Mc, but the bridge sensitivity decreases markedly at frequencies beyond the nominal range of 10 to 165 Mc. In addition, the accuracy of measurement of small reactances decreases as the frequency decreases, owing to lack of precision in reading the reactance dial, whose range is inversely proportional to frequency, and at frequencies above the nominal range the corrections become larger.

Reactance Range: ±230 ohms at 100 Mc. Dial range varies inversely with frequency and is calibrated at 100 Mc.

Resistance Range: 0 to 200 ohms, independent of frequency.

Accuracy: For resistance, ±(2% + 1Ω) subject to correction for inductance in the capacitor used to measure resistance. The correction increases with frequency and the magnitude of the resistive component. A correction chart is supplied with the instrument. The ohmic uncertainty indicated in the accuracy statement, namely 1 ohm, is roughly proportional to the magnitude of the reactive component of the unknown impedance. The indicated value is the maximum obtainable, and the minimum is 0.1 ohm.

For reactance, ±(5% + 2Ω). The ohmic uncertainty is roughly proportional to frequency and to the magnitude of the resistive component. The maximum value is indicated and the minimum value is 0.1 ohm at 100Mc.

Accessories Supplied: Two Type 874-R20 Cables; one Type 1601-204 Coaxial Extension Assembly; one Type 874-WN Short Circuit Termination; one Short-Circuiting Cap.

Other Accessories Required: R-F generator and receiver covering the desired frequency range; Type 1208-A Oscillator is recommended for frequencies above 65 Mc. Both oscillator and receiver should be reasonably well shielded.

Additional Accessories Recommended: A Type 874-WM 50-ohm Termination is useful in checking the bridge. The bridge is equipped with Type 874 Coaxial Connectors, and if connection is to be made to equipment using Type N Connectors, Type 874-Q1 Adapters will be needed. See price list below.

Dimensions: (Length) 13½ x (height) 9 x (depth) 10½ inches, overall.

Net Weight: 17½ pounds.

Type		*Code Word*	*Price*
1601-A	**V-H-F Bridge*†**	FLORA	**$385.00**
874-WM	**50-Ohm Termination***	COAXNUTTER	**8.00**
874-Q1	**Adapter to Type N Connectors***	COAXMEETER	**6.00**

*U. S. Patent No. 2,125,816; also patent applied for.
†U. S. Patent No. 2,376,394.

MISCELLANY

RECENT VISITORS from abroad to our plant and laboratories include:

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Visit Our Booth at the I.R.E. Show

At the Radio Engineering Show in Grand Central Palace, March 6-9, General Radio will show a number of new instruments, including the slotted line and coaxial elements described in last month's *Experimenter*, a signal generator for television testing, a dynamic polariscope, the V-H-F bridge described in this issue, a direct-reading admittance comparator for frequencies between 85 and 1000 Mc, and a two-frequency audio generator for distortion measurements.

We shall be at Booths 92 and 93, as in past years, and we hope that our friends who attend the I.R.E. Convention will drop in to see us. Representatives of the Sales Engineering, Development Engineering, and Service Departments will be on hand to answer questions and to discuss applications of our equipment.

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GENERAL RADIO COMPANY

275 MASSACHUSETTS AVENUE

CAMBRIDGE 39 MASSACHUSETTS

TELEPHONE: TRowbridge 6-4400

BRANCH ENGINEERING OFFICES

NEW YORK 6, NEW YORK
90 WEST STREET
TEL.—WOrth 2-5837

LOS ANGELES 38, CALIFORNIA
1000 NORTH SEWARD STREET
TEL.—HOllywood 9-6201

CHICAGO 5, ILLINOIS
920 SOUTH MICHIGAN AVENUE
TEL.—WAbash 2-3820

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