THE General Radio EXPERIMENTER

VOLUME XXIII No. 10 MARCH, 1949

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A NEW BRIDGE FOR IMPEDANCE MEASUREMENTS AT FREQUENCIES BETWEEN 50 KILOCYCLES AND 5 MEGACYCLES

Also

IN THIS ISSUE

In recent years there has been a steadily increasing amount of activity in the frequency range from 50 kc to the lower end of the standard broadcast band. In particular the widespread use of frequencies in this band for various short- and long-range navigation systems for both ships and aircraft has led to a demand for impedance measuring devices to allow simple, accurate measurements to be made of antennas, circuit components, and various networks. The TYPE 916-A R-F Bridge has proven to be a very useful instrument for making this type of measurement in the broadcast band and up to about 60 Mc, but it is not very satisfactory for use at frequencies below about 400 kc. In order to cover this range satisfactorily, a modification of the TYPE 916-A R-F Bridge has been developed which is called the TYPE 916-AL R-F Bridge. This new bridge has a nominal frequency

Figure 1. Panel view of the Type 916-AL Radio-Frequency Bridge.

range of 50 kc to 5 Mc, but it can be used at frequencies as low as 15 kc with some sacrifice in accuracy and sensitivity. Besides being useful at lower frequencies, it also has several advantages over the Type 916-A Bridge in the broadcast band, the most important of which is an increased sensitivity.

The basic circuit and method of operation of the new bridge are similar to those of the Type 916-A R-F Bridge[1,2]. A modified Schering bridge circuit is used in which the resistive and reactive components of the unknown impedance are measured in terms of incremental capacitances. The resistance of the unknown is indicated on a dial calibrated from 0 to 1000 ohms, and the reactance of the unknown is indicated on a main reactance dial calibrated from 0 to 11,000 ohms at 100 kc and an incremental reactance dial calibrated from 0 to 100 ohms at 100 kc. The resistance range is independent of frequency, and the reactance range is inversely proportional to frequency.

---

[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.

[2] Sinclair, D. B., "A Radio-Frequency Bridge for Impedance Measurements from 400 Kilocycles to 60 Megacycles," *Proceedings of the I.R.E.*, Vol. 28, No. 11, pp. 497-503, November, 1940.

Bridge Circuit

The basic bridge circuit is shown in Figure 2 and is the same as that of the Type 916-A. A complete analysis of this circuit has been published in previous articles,[1,2] 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 terminals short-circuited are given by the expressions:

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

$$C_{p1} = \frac{C_N}{R_B} R_A \qquad (2)$$

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:

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

$$X_X = \frac{1}{\omega}\left(\frac{1}{C_{p2}} - \frac{1}{C_{p1}}\right) \qquad (4)$$

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

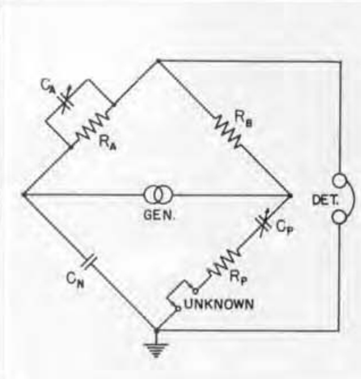


Figure 2. Basic circuit of the Type 916-A and Type 916-AL R-F Bridges.

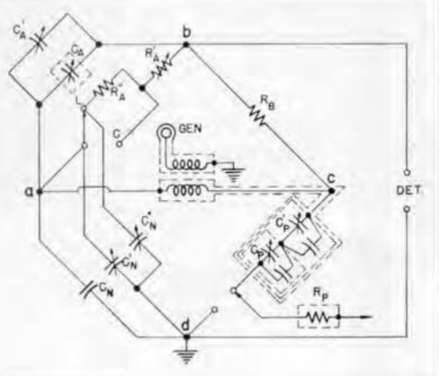


Figure 3. Complete circuit diagram of the Type 916-AL R-F Bridge.

C_p and has the opposite sign. This is the series-substitution method of measuring reactance. As a result of these relationships, 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.

The new low-frequency bridge differs slightly from the higher frequency model in the method of setting the initial reactance balance, and in the type of standard resistor used. The capacitor C_p', used only for the initial reactance in the older bridge, is calibrated in incremental reactance in the new bridge, and has a range of 0 to 100 ohms, with one ohm as the smallest division. The initial balance is made with an Ayrton-Perry, wire-wound rheostat, R_A', for the coarse adjustment, with the incremental reactance dial furnishing the fine adjustment. The incremental reactance calibration greatly increases the accuracy of measurement of small reactances.

The standard resistor, R_A, in the low-frequency bridge is 2250 ohms as compared to 330 ohms in the high-frequency model. To increase bridge sensitivity, the reactances of the *a-d-c* arms, shown in Figure 3, have been lowered, and so C_N and C_p are larger than in the high-frequency model. Hence, for a resistance range of 1000 ohms, R_B must be made larger to get the same value of $\frac{R_B}{C_N}$ which is the multiplying factor for the resistance capacitor in Equation (3). It is difficult to manufacture a TYPE 663 Resistor of the required size, and so a unifilar construction on a mica card is used, similar to those used in the TYPE 510 Decade Resistors. At these lower frequencies the performance of this type of resistor is entirely satisfactory. A very small adjustable capacitance connected in parallel with the resistor compensates for small differences in the reactance of different resistors resulting from variations in the number of turns of wire.

As can be seen from Figure 4, the circuit changes just mentioned make the open-circuit sensitivity, that is, with an infinite impedance detector, considerably greater than that of the TYPE 916-A Bridge. The input impedance to the generator terminals also is higher, which increases the sensitivity obtained when a high impedance generator is used to drive the bridge, and the detector terminal output impedance is lower, which also tends to increase the actual signal input to the detector.

Operation

The operating techniques for the TYPE 916-A and 916-AL Bridges are very similar. The main differences are that on the TYPE 916-AL Bridge coarse and fine initial reactance-balance controls are provided and that the measured reactance is the algebraic sum of the dif-

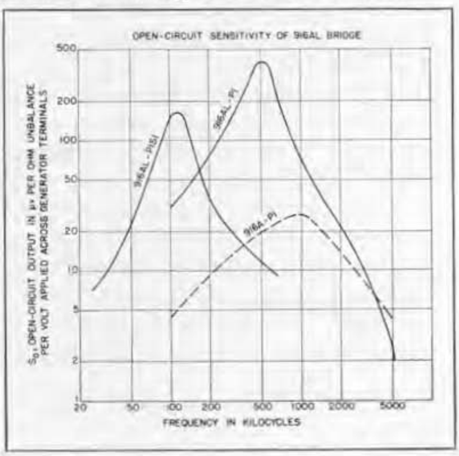


Figure 4. Sensitivity vs. frequency for the Type 916-A and Type 916-AL Bridges. Both the P1 and the P1S1 Transformers are supplied with the Type 916-AL. The P1 Transformer is used at low frequencies with the Type 916-A.

ferences between the final and initial settings of both the main and incremental reactance dials. The incremental reactance dial is mainly useful when the measured reactance is small; however, it also has been found to be very helpful when a series of measurements are to be made at the same frequency, as the main reactance dial can be initially set up scale at 1000 or so and a wide range of reactances of both positive and negative signs measured accurately without changing the initial balance.

As in the TYPE 916-A Bridge, the dielectric loss in the main reactance capacitor causes an error in the measured resistance of a circuit having a large reactive component of impedance. In most cases the error is negligible, as it amounts to about 0.03% of the measured reactance for large reactances and is somewhat less for smaller reactances. A chart is provided to correct for these errors when they are of importance.

Accuracy

The TYPE 916-AL R-F Bridge is particularly well suited to the accurate measurement of relatively low-impedance circuits over the frequency range from 50 kc to 5 Mc. The accuracy for resistance measurements is $\pm(1\% + 0.1\Omega)$, after correcting for the dielectric loss in the reactance capacitor at low frequencies. The accuracy of the reactance measurement at the higher frequencies is appreciably affected by residual parameters in the bridge circuit, that is, stray capacitances and inductances, particularly when the resistive component of the measured impedance is large. In fact, these residual parameters largely determine the upper frequency limit of the bridge. For frequencies up to 3 Mc, the accuracy is

$$\pm\left(2\% + 0.2 \times \frac{100}{f_{kc}}\Omega + 3.5 f_{kc}^2 R \times 10^{-10}\Omega\right)$$

where R is the measured resistance and f_{kc} is the frequency in kilocycles. The errors in reactance when circuits having large resistive components of impedance are measured increase rapidly at frequencies above 3 Mc, and at 5 Mc the accuracy is $\pm(2\% + 0.01\Omega + 2.3R^{1.4} \times 10^{-3}\Omega)$.

COMPARISON OF THE TYPES 916-A AND 916-AL BRIDGES FOR OPERATION IN THE BROADCAST BAND

The TYPE 916-AL Bridge has some advantages over the TYPE 916-A for many types of measurements, even in the broadcast band. They are:

1. The sensitivity is higher. Increased sensitivity is, of course, helpful if the generator output or detector sensitivity is low, and in some cases it reduces the effect of leakage. In antenna measurements the relative effect of extraneous signals and noise picked up by the antenna under test, which tend to obscure the null, on the accuracy of setting to the null is proportional to the product of the sensitivity and the attenuation of the bridge between the circuit under test and the detector. In the normal connection of the generator and detector the TYPE 916-AL Bridge is much superior to the TYPE 916-A in this respect; however, a great improvement in the attenuation of undesired signals can be made in some cases with the TYPE 916-A Bridge by interchanging the generator and detector connections.[3] When this is done, in many cases the product

[3] Soderman, R. A., "Sensitivity of the TYPE 916-A R-F Bridge," *General Radio Experimenter*, Vol. XXII, No. 8, pp. 3, 4, January, 1948.

of sensitivity and attenuation may not be greatly different for the two bridges.

2. Small reactances can be measured accurately and conveniently and often much time can be saved by eliminating the need for frequent changes of the initial balance to obtain high accuracy when a series of measurements are made at one frequency. Even in applications in which the increased accuracy of the reactance measurement is unnecessary, the incremental reactance dial may be helpful as the expanded scale makes it much easier to read than the reactance dial on the Type 916-A.

The Type 916-AL Bridge has at least one disadvantage compared to the Type 916-A, which is that the maximum direct reading reactance range is smaller. At 1 Mc, the reactance range on the Type 916-AL is ± 1100 ohms, while it is ± 5000 ohms on the Type 916-A. However, the reactance range of the Type 916-AL is satisfactory for most measure-

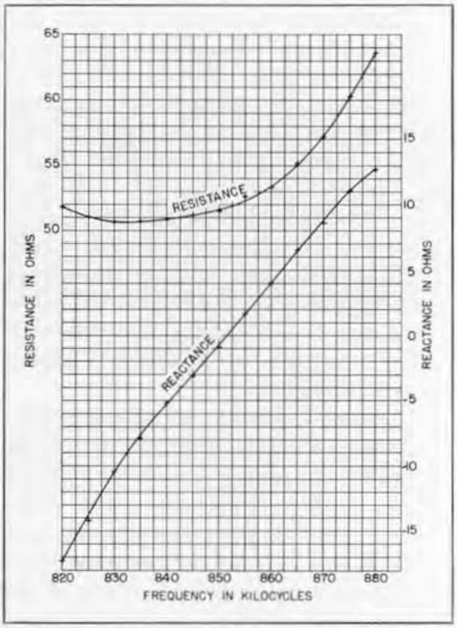
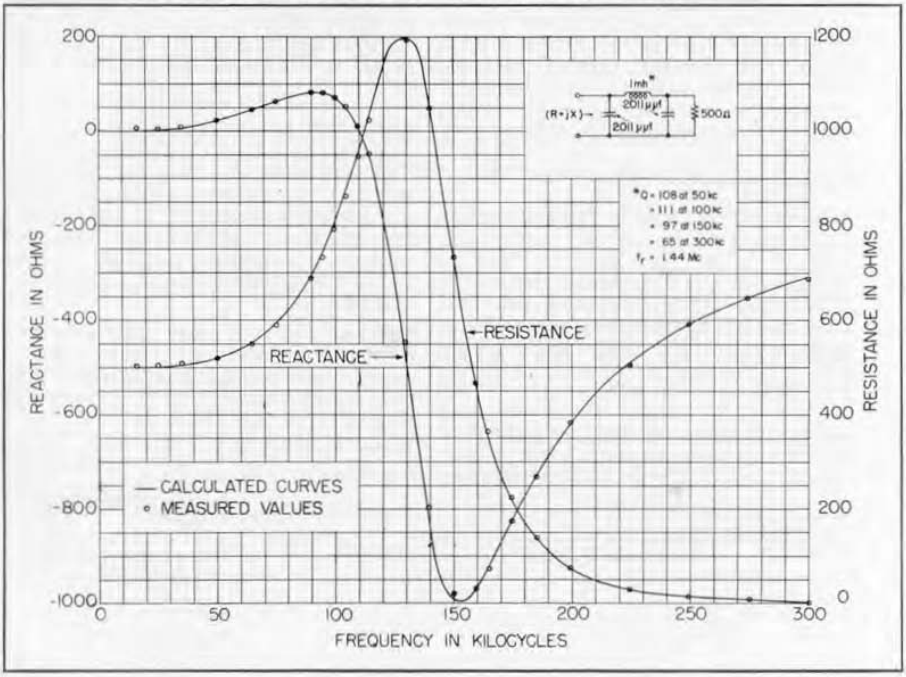


Figure 5. Measured input impedance of a coaxial transmission line feeding a 3-element antenna array.

Figure 6. Measured and calculated input impedance of a constant-K-type filter.



ments made on broadcast antennas and matching and phasing networks, and, if necessary, circuits having larger reactances can be measured indirectly by connecting a shunt capacitance across the unknown terminals of the bridge.

Typical Measurements

Some of the applications of the bridge are the measurement of resistors, capacitors, inductors, conventional and transmission line networks, and antennas. Following are two examples of typical measurements:

Figure 5 shows the results of a series of measurements made on the transmitter end of a coaxial line feeding a three-element antenna array with its associated matching and phasing networks. The probable accuracy of the generator frequency is about ± 1 kc, which explains some of the spread in the points from a smooth curve due to inaccuracies in the measurement of frequency.

The results of a series of measurements of the input impedance of a constant-K type, low-pass, π-type filter over the frequency range from 16 kc to 300 kc are indicated by the circles in Figure 6. The solid lines drawn on the graph are the theoretical values of the resistance and reactance calculated from the circuit constants.

—R. A. Soderman

SPECIFICATIONS

Frequency Range: 50 kc to 5 Mc.

Reactance Range: 11,000 Ω at 100 kc. This range varies inversely as the frequency, and at other frequencies the dial readings must be divided by the frequency in hundreds of kilocycles. To facilitate the measurement of small reactances, the instrument is provided with an incremental reactance dial which has a range of 100 ohms at 100 kc.

Resistance Range: 0 to 1000 Ω.

Accuracy: For reactance at frequencies up to 3 Mc, $\pm(2\% + 0.2 \times \frac{100}{f_{kc}}\Omega + 3.5 f_{kc}^2 R \times 10^{-10}\Omega)$ where R is the measured resistance in ohms and f_{kc} is the frequency in kilocycles. The errors in reactance increase relatively rapidly at frequencies above 3 Mc; and at 5 Mc the accuracy is $\pm(2\% + 0.01\,\Omega + 2.3\ R^{1.4} \times 10^{-3}\Omega)$. For resistance, at frequencies up to 5 Mc, $\pm(1\% + 0.1\,\Omega)$, subject to correction for residual parameters at low frequencies. The correction depends upon the frequency and upon the magnitude of the unknown reactance component. A plot of this correction is given in the instruction book supplied with the bridge.

Accessories Supplied: Two input transformers, one covering the range from 50 to 400 kc, the other from 400 kc to 5 Mc; two leads of different lengths (for connecting the unknown impedance); two Type 774 coaxial cables for connecting generator and detector.

Accessories Required: A radio-frequency generator and a detector are required. The Type 1001-A and the Type 805-C Signal Generators are satisfactory generators, as are the older Type 605-B and the Type 684-A Modulated Oscillator. A well-shielded radio receiver covering the desired frequency range is recommended as the detector.

Mounting: Airplane-luggage type case with carrying handles. Both input transformers are mounted inside the case. Coaxial cables, leads, and instruction book are stored in the cover of the instrument when not in use.

Dimensions: 17 × 13½ × 11⅛ inches overall.

Net Weight: 34¾ pounds.

Type		*Code Word*	*Price*
916-AL	**Radio-Frequency Bridge***	CLUCK	**$450.00**

*U.S. Patent 2,376,394

THE MICROFLASH LOOKS AT SHOTGUN COMPENSATORS

Game bird hunters and skeet shooters among our readers will be interested in the article entitled "Shotgun Compensators," which appeared in the October, 1948, number of *The American Rifleman.* Detailing the results of an investigation by National Rifle Association's Edwards Brown and Massachusetts Institute of Technology's Harold E. Edgerton, this article compares the performance of eight well-known types of chokes and compensators under a standardized set of conditions.

Figure 2.

Figure 1.

Photographs of the shot patterns, taken at one-millionth of a second with the General Radio Microflash, at the muzzle and at distances of 10 inches and 10 feet from the muzzle are shown, as is the percentage of total shot contained in a 20-inch circle at 20 yards. Measurement of percentage reduction in recoil were also made by means of a ballistic pendulum.

The set-up used for photography is shown in Figure 1, and Figure 2 is a typical shot-pattern photograph at 10 feet from the muzzle.

GEIGER-MUELLER COUNTER TUBES

For Use with Type 1500-A Counting-Rate Meter

Two counter tubes, as listed below, are now available for use with the General Radio Counting-Rate Meter. They differ mainly in the thickness of the mica window. TYPE 1500-P4 has a thick window (3 to 4 milligrams per square centimeter), while TYPE 1500-P5 has a window density of less than 2 milligrams per square centimeter. The thin-window tube, TYPE 1500-P5, is intended for detecting low-energy particles such as Beta radiation from Carbon 14 and Sulphur 35. In general, it should be used wherever the particles to be counted have energies below about 0.3 mev. For higher energies, the thick-window tube, TYPE 1500-P4, should be used.

These tubes supersede TYPES 1500-P2 and 1500-P3 previously listed.

Type	*Window*	*Code Word*	*Price*
1500-P4	Mica — 3 to 4 mg. per sq. cm.	WORRYLOBBY	$50.00*
1500-P5	Mica — less than 2 mg. per sq. cm.	WORRYLOCAL	75.00*

* For export, add 10% to these prices.

BACK AT THE OLD STAND

Frederick Ireland

General Radio at Los Angeles.

General Radio's Los Angeles office, after two and a half years at a different address, is now back at its original location, 1000 North Seward Street. Under the capable direction of Frederick Ireland, of the factory engineering staff, this office is equipped to supply to West Coast customers any desired information on the characteristics, price, and delivery of General Radio products and to recommend equipment to meet specific requirements.

Many orders for popular items and parts of our manufacture can be shipped from stock maintained at Los Angeles. For items not stocked, this office will forward your order to our factory and will have information on hand regarding the date of shipment.

Please note that the telephone number at our Los Angeles office is HOllywood 9-6201.

MISCELLANY

PAPERS — At the 1949 I.R.E. National Convention, "A Device for Admittance Measurements in the 50- to 500-Mc Range," by W. R. Thurston, Engineer; and "The Measurement of Non-Linear Distortion," by A. P. G. Peterson, Engineer.

RECENT VISITORS to our plant and laboratories include Mr. J. P. A. Lochner, South African Council for Scientific and Industrial Development, Pretoria, South Africa; and Mr. J. V. Foll, Managing Director, Muirhead and Co., Ltd., Beckenham, Kent, England.

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

PRINTED IN U.S.A.