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AND ITS APPLICATIONS IN ALLIED FIELDS

IMPROVEMENTS IN RADIO-FREQUENCY BRIDGE METHODS FOR MEASURING ANTENNAS AND OTHER IMPEDANCES

SINCE the announcement of the TYPE 516-A Radio-Frequency Bridge some months ago,* this bridge has been in use continuously in the General Radio laboratories. Its applications have included the measurement of both lumped and distributed impedances at radio frequencies and the results obtained not only show the practicability of the method but also point the way to improvement in the design of the bridge itself.

The range of usefulness of the original model was greatly limited by the inductance of the resistance decade and by its change with dial setting. Although this inductance is less than one microhenry, it has an appreciable reactance at radio frequencies. Both this total reactance and its change as the decade dial setting is changed produce an error in capacitance measurement.

The effective capacitance of a condenser in series with an inductance is given by the expression,

$$\hat{C} = \frac{C}{1 - \omega^2 LC}$$

where $\hat{C}$ = effective capacitance in farads,

C = capacitance of the condenser in farads,

L = inductance in henrys, and

$\omega = 2\pi$ in radians per second,

and the effective capacitance is always larger than the nominal capacitance by the factor $\frac{1}{1 - \omega^2 LC}$. If an inductance of one microhenry is placed in series with a condenser of 500 $\mu\mu$f capacitance, the effective capacitance will be 510 $\mu\mu$f (an error of 2%), at a frequency of one megacycle. Since the error depends upon the square of the frequency, however, it is between 8% and 9% at 2 megacycles. With smaller capacitances, the error is less; with larger ones it is greater.

The inductance of the resistance decade varies from a few tenths to one

*"Bridge Methods for Measurements at Radio Frequencies," Charles T. Burke, General Radio *Experimenter*, July, 1932.

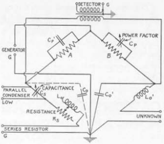


FIGURE 1. Careful elimination or compensation of parasitic capacitance and inductance makes the new radio-frequency bridge direct reading over a wide range

microhenry, depending upon the decade setting, and it presents a serious barrier to the use of the bridge as a direct-reading instrument.

In the design of a new model, therefore, considerable attention has been given to making the inductance of the decade constant with dial setting and to providing in the unknown arm of the bridge an equal amount of inductance to compensate. When this is done, the bridge can be made direct reading in capacitance and the case of making measurements is greatly improved.

This new bridge is shown schematically in Figure 1. Ratio arms A and B are equal as in previous models.

The inductance-compensated decade is shown in the lower left-hand arm of the bridge. This decade is so arranged that, when the resistance setting is increased, an amount of inductance equal to the inductance of the added resistance cards is removed from the circuit. When the dial setting is decreased, a like amount of inductance is added. Thus an inductance equal to the total inductance of the decade is in circuit at all times. In order that its total value shall not cause an error in capacitance readings, an approximately equal amount of inductance L_0' is placed in series with the unknown arm of the bridge. The magnitude of L_0' is adjusted to make the total inductance in the X arm (including leads to terminals) equal to L_0 plus the stray lead inductance in the standard arm.

It will be seen from Figure 1 that neither side of the standard condenser C_s is at ground potential, and therefore each side has a definite capacitance to ground. The capacitance of the rotor to ground is shunted across the standard resistance R_s and its effect on the resistance standard is entirely negligible over the useful range of the bridge. The capacitance of the stator to ground (C_0 in Figure 1) is in shunt with the entire standard arm of the bridge and can cause a serious error* in the setting of the resistance decade R_s.

In order to eliminate this error, an equal capacitance C_0' is connected across the unknown arm as shown in Figure 1. This makes the bridge direct reading in resistance.

The standard resistance R_s of the new bridge uses a decade of tenth-ohm steps instead of the slide wire used in previous models. The condenser C_P

*The effective resistance is given by the expression

$$\hat{R} = \frac{R}{\left[1 - \frac{C_0}{C}(1 - \omega^2 LC)\right]^2}$$

where $\hat{R}$ = effective resistance in ohms
R = decade dial setting (ohms)
C_0 = ground capacitance (about 30 $\mu\mu f$) in farads
C = capacitance setting of C_s in farads.

across ratio arm B in Figure 1 serves two purposes. It allows a finer adjustment of resistive component than is given by the tenth-ohm decade and it also permits power factor measurements to be made without calculation. The dial is calibrated directly in power factor at 1 megacycle. At other frequencies the dial reading is multiplied by the frequency in megacycles. In order that the bridge read correctly at the zero power factor setting of C_p, a condenser C_p' equal to the zero capacitance of C_p is placed across arm A.

The TYPE 516-C Radio-Frequency Bridge is direct reading up to 111 ohms and 1150 $\mu\mu$f. For the measurement of inductance or of higher values of capacitance, a small fixed condenser may be placed in series with the unknown as shown in Figure 3a. When the resistance of the unknown is above 111 ohms a parallel condenser or a combination of series and parallel units (see Figures 3b and 3c) can be selected to produce a balance. While in each of these cases the bridge is not direct reading, the necessary calculations are not difficult.

The terminals marked PARALLEL CONDENSER in Figure 1 are provided in order that capacitances may be measured by the substitution method. A parallel condenser can also be connected here to extend the range of the standard condenser. An additional pair of terminals engraved SERIES RESISTOR is provided. The direct-reading range of the bridge may be extended by adding a plug-in resistor or an unknown resistor may be connected to these terminals and measured by direct substitution.

The substitution method* for capacitance and resistance measurements is recommended where precise results are

*"An Equal-Arm Capacitance Bridge," R. F. Field, General Radio *Experimenter*, January, 1930.

FIGURE 2. Panel layout of the TYPE 516-C Radio-Frequency Bridge. The circuit details are shown in Figure 1

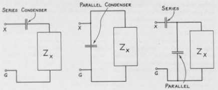


FIGURE 3. Because of the very high values of resistance and reactance encountered in impedance measurements near resonance, the impedance can be modified by series, parallel, or series-parallel condensers to bring it within range of the bridge: (*a*) series connection for all inductive and for large capacitive reactances; (*b*) parallel connection for resistances greater than 111 ohms; and (*c*) series-parallel connection where both (*a*) and (*b*) are required

desired. When the bridge is used as a direct-reading instrument, some accuracy is sacrificed. The over-all accuracy obtainable is, however, extremely good in the range where the bridge is direct reading. Even at frequencies in the vicinity of 5 megacycles, the accuracy of comparison is about 5%. At broadcast frequencies it is about 1%.

The standards themselves are, of course, subject to some variation with frequency, due to skin effect in the resistors and inductance in the condenser frame. The resistance decade is adjusted at direct current to well within 0.1%, and at one megacycle comparison with straight-wire standards shows a discrepancy of only about 0.1%. At high capacitance settings, the frequency error in the condenser is detectable, but below 500 $\mu\mu$f no serious error occurs up to 4 or 5 megacycles.

One particularly important application of the bridge is in the measurement of antenna characteristics. The bridge method has several advantages over resistance substitution or resistance variation methods.

First among these is low power. The

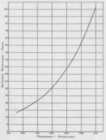


FIGURE 4. Resistance of a broadcast transmitter antenna operated considerably above its fundamental

bridge may be operated from a small, portable, battery-operated oscillator, whose output is one watt or less. This has other advantages than merely convenience. A low power oscillator can be completely shielded and direct pickup between the oscillator and the antenna can be eliminated. This, together with the avoidance of stray impedance errors, gives a decided advantage to the bridge method.

Resistance measurements on a broadcast antenna made with the radio-frequency bridge are shown in Figure 4. This antenna is operated considerably above its fundamental (frequency) and consequently all measurements were taken with a series condenser (Figure 3a). Since an antenna is entirely resistive at its fundamental, this point can be identified as the frequency where the capacitance read on the bridge is equal to the capacitance of the series condenser used.

Figure 5 shows the resistance of an antenna from below its fundamental to

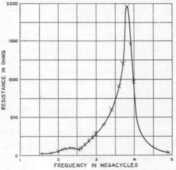


FIGURE 5. Resistance of a receiving antenna from below its fundamental to above its half-wave point

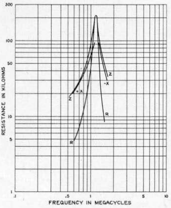


FIGURE 6. Resistance and reactance characteristic of a multi-section choke in the vicinity of resonance. Note that both inductive $(+X)$ and capacitive $(-X)$ are, for convenience, plotted as positive to the same scale as the resistance

above its half-wave point (parallel resonance). In this measurement it was necessary to use a series condenser up to 2600 kilocycles and the parallel condenser connection above 2600 kilocycles when the resistance exceeded 111 ohms. The hump at the low end of the curve is due to energy absorption by another antenna nearby.

Other types of measurements conveniently made with the bridge include the frequency characteristics of radio-frequency coils and chokes.

The results of one set of measurements are shown in Figure 6, which represents the impedance characteristics of a radio-frequency choke for use at broadcast frequencies. These measurements were made with the parallel condenser shown in Figure 3b and the results calculated from the parallel circuit equations. Resistance, reactance and impedance, as well as inductance and self-capacitance, can be calculated from the data obtained by means of the bridge.

The TYPE 516-C Radio-Frequency Bridge is the result of several years of research and development work in radio-frequency measurements. Its accuracy, wide range, and ease of operation make it the most satisfactory instrument available for radio-frequency impedance measurement. It should be emphasized that the bridge is not intended to be completely a "fool-proof" instrument and, when improperly used, erroneous results can be obtained. In the hands of those possessing experience in the technique of high frequency measurements it will fill a long-recognized need and will give dependable and accurate results.

—C. E. WORTHEN

TYPE 516-C RADIO-FREQUENCY BRIDGE

SPECIFICATIONS

Capacitance Range: 0 to 1150 $\mu\mu$f, direct reading. Can be extended to infinity by using a series condenser as described in the foregoing article.

Resistance Range: 0 to 111 ohms, direct reading. Can be extended to several thousand ohms by using a condenser in parallel with the unknown.

Frequency Range: 500 kc to 5000 kc with output transformer furnished. With proper output transformer, range can be extended downward to audio frequencies.

Accuracy: As a direct-reading bridge, 1% to 5% up to 5 megacycles. With direct substitution methods, greater accuracy can be obtained.

Accessories: The bridge is supplied complete with output transformer but without a radio-frequency generator or detector. Operating instructions are also included.

Additional Accessories Required: As a radio-frequency generator a TYPE 484-A Modulated Oscillator is suggested. See the October, 1932, issue of the General Radio *Experimenter*.

Detector: A radio receiver covering desired frequency range. A TYPE 619-A or TYPE 619-B Heterodyne Detector may be used. Consult Catalog G or Bulletin 10.

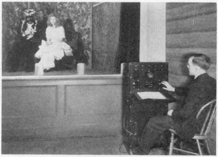
Condensers: If measurements outside the direct-reading range of the bridge are to be made, plug-in fixed condensers are required. TYPE 505 Condensers are recommended. A set of these, whose capacitances are 100 $\mu\mu$f, 200 $\mu\mu$f, 500 $\mu\mu$f, and 1000 $\mu\mu$f, is adequate for most purposes. See the *Experimenter* for January, 1933, and August-September, 1933.

Dimensions: 18 inches (long) x 12 inches (wide) x 8 inches (height) over-all.

Net Weight: 23 pounds.

Code Word: BATCH.

Price: $225.00.



THEATER NOTES

Little Eva Goes to Heaven on a Variac

COSTUMES can be rented and a cast, by many rehearsals, can be developed to give a creditable performance, but the mechanical auxiliaries such as lighting and scenery introduce difficulties that are extremely troublesome in amateur dramatics production. These difficulties are especially serious where funds are limited and the production must be given on a stage rented for the one performance.

It was such a problem that confronted the "Friends of the Drama," an experienced play-producing group of Arlington, Massachusetts, when they gave a melodrama based on Harriet Beecher Stowe's "Uncle Tom's Cabin." Simon Legree and his blood hounds could chase Eliza across the ice realistically enough, but how was heaven to open and take up little Eva when she died? The conventional method of pulling her to the bridge over the stage with a block and tackle was out of the question from the dramatic as well as the mechanical standpoint, for the audience would most certainly have seen humor instead of the pathos that was intended.

The "Friends of the Drama" were fortunate enough to have just com-

The control panel designed for "Friends of the Drama" by Stage-Manager Dawes. Dials for the two Variacs are in easy reach of the operator who works with his elbows on the cue-sheet desk pleted an unusual control system for its stage lights and this was pressed into service to produce the death scene by means of lighting effects. As little Eva died, the stage lights gradually dimmed and a golden shaft of light, behind the bed and pointing heavenward, grew gradually brighter as death came. The method was simple, yet extremely effective.

The control system was the panel shown in the accompanying photograph, an asbestos board fitted with wheels for portability on which were mounted dimming and power distribution circuits. The dimming controls were General Radio TYPE 200-CM Variacs.[1] These are small adjustable transformers that enable the operator to apply any voltage to his lights from a full 115 volts down to zero in steps of only ½ a volt. The operator sat in the first row with this small board and cue sheet before him and adjusted the brilliancy of the stage lights and the spot in steps so gradual as to be imperceptible.

This installation demonstrated several very real advantages of the Variac over conventional resistance-type controls in addition to the obvious ones of small mounting space and low price. The Variac dissipates a much smaller amount of heat, and although this may not make for comfort of the operator during rehearsals in an unheated hall, it should please the fire marshal. In addition, the voltage control on a Variac is essentially independent of the load current. Hence it can be used for any number of lamps up to the maximum permitted by its current rating[2] and the operator can control the brilliancy from maximum down to complete "black out."

— J. D. C.

[1]See General Radio *Experimenter* for June-July, 1933.

[2]The TYPE 200-C Variac is rated at 5 amperes, and, although overloading is not recommended, currents 50% greater can be safely handled for periods of as much as 3 minutes. Variacs having larger current ratings are under development.

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