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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

MEASUREMENTS ON I-F TRANSFORMERS WITH THE TYPE 916-A R-F BRIDGE

Also IN THIS ISSUE

INTRODUCTION

In the present standard design specifications for I-F transformers, some of the quantities specified are not directly related to the actual performance of the transformer in a radio receiver, and some cannot be measured without disassembly of the unit. Mr. C. A. Hultberg, Mr. T. Vanacore, and other members of the engineering department of the Colonial Radio Corporation have proposed a new set of design specifications based on three quantities, directly related to performance, which can be measured without disassembly of the transformer. They are:

1. Coil inductances.
2. Resonant impedance or conductance of each winding with the other winding short-circuited.
3. Coupling factor.

The resonant conductances and the coupling factor in this design specification can be measured accurately and directly by the Type 916-A R-F Bridge using the methods described in this article. The coil inductances can be measured

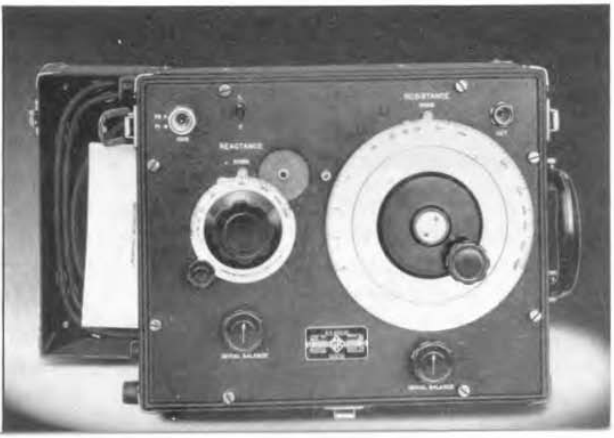


Figure 1. Panel view of the Type 916-A Radio-Frequency Bridge.

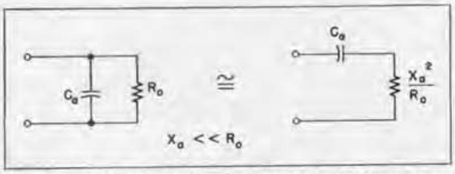


Figure 2. Equivalent series circuit of a high resistance in parallel with a capacitor.

with high accuracy on the TYPE 821-A Twin-T Impedance Measuring Circuit by the two-frequency method without disconnecting the trimmer capacitors. Equally good results can be obtained with the Radio-Frequency Bridge and an external TYPE 722-N Precision Condenser, connected for parallel substitution measurements.

CONDUCTANCE MEASUREMENTS

Although the TYPE 916-A R-F Bridge was designed for the measurement of the series components of relatively low impedances, it can easily be adapted to measure high impedances by shunting the unknown with a reactance so chosen as to bring the impedance of the combination within the range of the bridge. For the measurement of a high resistance, i.e., the resonant impedance of a parallel tuned circuit, it is possible to make the bridge direct reading in circuit conductance and to eliminate most of the calculations that usually make this method of measurement so tedious.

As shown in Figure 2, the capacitor, C_a, connected across a resistor, R_0, has an equivalent series circuit consisting of the same capacitor in series with a resistor approximately equal to $\frac{X_a^2}{R_0}$, when X_a is very small in comparison to R_0. This series resistance can be measured on the bridge and the value of G_0 determined from the expression

$$G_0 = \frac{1}{R_0} = \frac{R_m}{X_a^2} \qquad (1)$$

where R_m is the reading of the bridge resistance dial. The bridge can be made direct reading by so choosing the capacitor C_a to make X_a^2 a decimal value, thus eliminating all calculations.

In an actual measurement, the shunting capacitor alone is first connected across the bridge terminals and an initial balance made. The tuned circuit to be measured is then connected in parallel with the capacitor and a final balance made by adjusting the resistance dial on the bridge and the tuning capacitor on the circuit under test.

Since the method of measurement is based on an approximation, the accuracy and limitations of the method must be known before it can be used effectively. In the following paragraphs, the method will be analyzed and the magnitude of the errors determined.

Under the conditions outlined above, the impedance Z_1 connected across the bridge terminals during the initial balance is

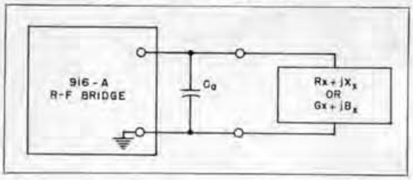
$$Z_1 = jX_1 = jX_a \qquad (2)$$

where X_a is the reactance of the shunt capacitor C_a shown in Figure 3.

When the tuned circuit having a series resistance R_x and a reactance X_x is connected and the final balance made, the series resistive and reactive components of the impedance Z_2 then connected across the terminals are:

$$R_2 = R_m = \frac{X_a^2}{R_x} \cdot \frac{1}{1 + \left(\frac{X_a + X_x}{R_x}\right)^2} \qquad (3)$$

Figure 3. Bridge connections for the measurements discussed in this article.



$$X_2 = \frac{X_a + \dfrac{X_a X_x}{R_x^2}\left(X_a + X_x\right)}{1 + \left(\dfrac{X_a + X_x}{R_x}\right)^2} \tag{4}$$

In this case, R_m is the reading of the resistance dial, and, since the reactance dial is not moved when making the final balance,

$$X_2 = X_1 = X_a \tag{5}$$

If the expression for X_2 given in Equation (5) is substituted in Equation (4), and the resulting expression for X_x substituted in Equation (3), the result is

$$R_m = \frac{X_a^2}{R_x} \tag{6}$$

$$X_x = -X_a \tag{7}$$

Equation (7) shows that the resonant circuit must be detuned to produce a series reactance of magnitude $-X_a$ for balance. Detuning causes the effective series resistance, R_x, to decrease from its maximum value at resonance, R_0. The magnitude of this deviation is small if $\dfrac{X_a}{R_0}$ is small, and can be calculated in the following manner.

For small deviations, ΔC, from the capacitance at resonance, C_0, the effective series resistance and reactance of a parallel-tuned circuit are given quite accurately by the approximations

$$R_x \simeq R_0\left[1 + \left(\frac{\Delta C}{C_0}Q\right)^2\right] \tag{8}$$

$$X_x \simeq \frac{\Delta C}{C_0} Q R_0 \tag{9}$$

where Q is the storage factor of the resonant circuit. The amount of detuning necessary to produce the reactance indicated by Equation (7) can be determined from Equation (9). The actual deviation in R_x from its resonant value can then be determined from Equation (8). The resultant expression for the resonant conductance, G_0, is:

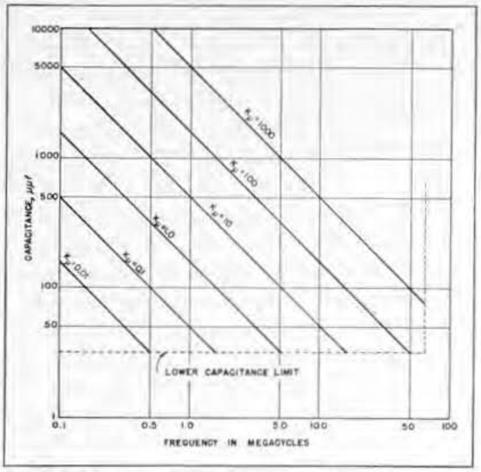


Figure 4. Shunt capacitance vs. frequency for various decimal multipliers.

$$G_0 = \frac{1}{R_0} \simeq \frac{R_m}{X_a^2}\left[1 - \left(\frac{X_a}{R_0}\right)^2\right] \text{ mhos} \tag{10}$$

If we let

$$K = \frac{1}{X_a^2} \tag{11}$$

and

$$\frac{X_a}{R_0} \ll 1,$$

then

$$G_0 \simeq KR_m \text{ mhos} = K_\mu R_m \text{ } \mu\text{mhos} \tag{12}$$

where K_μ is the factor which converts the indicated series resistance in ohms to the resonant conductance in micromhos.

$$K_\mu = 10^6 K = \frac{10^6}{X_a^2} \tag{13}$$

The error, E, in the indicated conductance expressed as a fraction of the indicated conductance is approximately:

$$E \cong \left(\frac{X_a}{R_0}\right)^2 = \frac{G_0^2}{K} = KR_m^2 = K_\mu R_m^2 \times 10^{-6} \quad (14)$$

Therefore, if the errors due to detuning are to be kept small, the reactance of the shunt capacitor should be very small compared to the resonant impedance.

The errors due to losses in the shunting capacitor are negligible as long as the dissipation factor of the capacitor is less than 0.01 and the resistance dial is set at zero when the initial balance is made with the capacitor alone connected.

The shunting capacitances required for various values of K_μ are indicated in Figure 4. Figure 5 shows the values of conductance measurable within various accuracies as a function of K_μ. The limits indicated by the dashed lines are determined by the accuracy of calibration of the resistance dial.

EXAMPLE

The intermediate-frequency transformer chosen for this illustration is a standard double-tuned inductively-coupled unit, operating at 455 kilocycles, which is completely assembled in its shield can with its trimmer capacitors connected. In the following paragraphs the general test procedure will be described; however, in most applications a number of short-cuts will be apparent to the user.

The first step is to estimate roughly the magnitude of the conductance to be measured so a value of K_μ can be selected which will permit the measurement to be made within the desired accuracy. In the example under consideration, the conductance is of the order of 30 μmhos, and the desired accuracy is ±5 per cent. From Figure 5 it can be seen that a K_μ of 0.1 meets these requirements. Figure 4 or Equation (13) shows that the shunting capacitance required for this value of K_μ at 455 kilocycles is 110.6 $\mu\mu$f.

The indicated value of shunting capacitance includes the terminal capacitance of the bridge and other stray capacitances. Hence, for greatest accuracy, the capacitor should be measured in place on the bridge. This can be done using the reactance-measuring property of the bridge itself; however, the accuracy of the determination of K_μ

Figure 5. Range of conductance measurable within given accuracy limits for various values of Kμ.

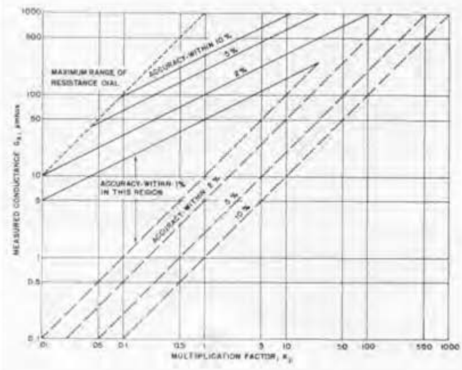
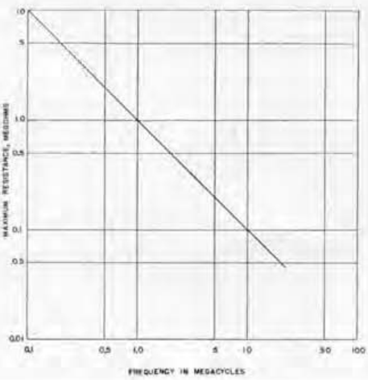


Figure 6. Resistance above which the "Boella Effect" starts to influence appreciably the parallel resistance of IRC Type F-1 Resistors vs. frequency.



under these conditions is only ±4 per cent, because the bridge accuracy for reactance measurement is ±2 per cent.

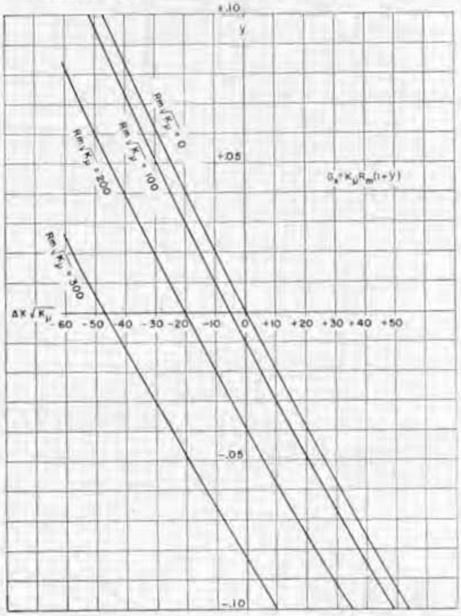
A more accurate method of determining the precise value of K_μ is to measure the conductance of a low-reactance resistor having a known conductance, using the bridge in the same manner as for transformer measurements. In this method of calibration the reactance dial is adjusted for the final balance in place of the tuning capacitor on the transformer, and K_μ is the ratio of the conductance of the standard resistor to the resistance dial reading.

The a-c conductances of IRC TYPE F-1 Resistors and other similar units are very close to their d-c conductances for resistances within the limits indicated in Figure 6; deviation at higher resistances is caused by the Boella effect. In some cases the shunt capacitance of the resistor will cause small errors; however, corrections for these errors can be made using Figure 7. In this case a 100,000 ohm resistor is used as a standard and the shunting capacitance adjusted until the resistance dial reads 100 ohms.

After the shunting capacitance has been adjusted or the value of K_μ accurately determined, the capacitor is connected across the bridge terminals and the initial balance made. This balance should be made with the resistance and reactance dials both set at zero and the *L-C* switch in the *L* position if the shunting capacitance is greater than 160 $\mu\mu$f. If the shunting capacitance is less than this value, the *L-C* switch should be set in the *C* position, the resistance dial at zero, and the reactance dial at about $5000 - \dfrac{10^3}{\sqrt{K_\mu}}\, f_{Mc}$. This procedure eliminates the necessity of making an additional initial balance with the bridge terminals shorted. In the case under consideration, the capacitance is 110.6 $\mu\mu$f so the *L-C* switch is set in the *C* position, the reactance dial at 3500, and the initial balance made.

The circuit is now set up to measure the unknown conductance. The resonant conductance of the primary alone should be measured first. This is done by short-circuiting the secondary winding leads and connecting the primary winding in parallel with the shunting capacitor on the bridge. Then a balance is obtained by adjusting the resistance dial on the bridge and the primary trimmer capacitor in the transformer. The reading of the resistance dial multiplied by K_μ gives the magnitude of the conductance. In this example the resistance dial reading is 134 ohms and, since $K_\mu = 0.1$, the measured conductance is 13.4 μmhos.

Figure 7. Correction in measured conductance for error caused by reactance in the circuit under test.



MEASUREMENT OF COUPLING FACTOR

The coupling factor, F_c, is defined as:

$$F_c = \frac{R_p}{R_{ps}} = \frac{G_{ps}}{G_p} = 1 + k^2 Q_p Q_s$$

$$= 1 + \left(\frac{k}{k_c}\right)^2 \qquad (15)$$

where R_p and G_p are the resonant primary resistance and conductance with the secondary short-circuited, R_{ps} and G_{ps} are the resonant primary resistance and conductance with the secondary resonated, Q_p is the storage factor of the primary circuit alone, Q_s is the storage factor of the secondary circuit alone, k is the actual coefficient of coupling, and k_c is the coefficient for critical coupling.

In order to determine the coupling factor, the resonant primary conductance must be measured with the transformer secondary resonated. This is accomplished by removing the short-circuit from the secondary and obtaining a new balance by adjusting the resistance dial and the secondary trimmer capacitor. The other bridge controls and the primary tuning should not be disturbed between the two measurements of the primary conductance. In this measurement the error will be approximately twice that indicated in Figure 5. The resistance dial reads 273 ohms when the secondary of the transformer under consideration is resonated, and hence its conductance is 27.3 μmhos. From Equation (15) the coupling factor is therefore

$$\frac{27.3}{13.4} = 2.04 \text{ and } \frac{k}{k_c} = 1.02.$$

The resonant secondary conductance can be measured in the same manner as outlined for the primary; and, if desirable, the coupling factor can be determined from measurements on the secondary instead of the primary. The same answer should be obtained in both cases.

The resonant conductance of other types of single and double-tuned circuits and the conductance of relatively low-reactance resistors can also be measured accurately on the TYPE 916-A R-F Bridge through the use of the method described, and, in applications in which a number of measurements are required at one or more specified frequencies, a fixture can be constructed which will mount directly on the bridge and have the required calibrated capacitors connected across the terminals by means of a switch. For tuned-circuit measurements, small external trimmer capacitors may also be provided to permit a finer tuning capacitance adjustment than can be obtained using the capacitors built in the transformer.

— R. A. SODERMAN

REPRINTS AVAILABLE

Reprints of the foregoing article are being prepared, with larger and more detailed charts of Figures 4 through 7. Copies will be available shortly and will be sent to any of our readers who request them.

— EDITOR

LABORATORY EXERCISES WITH THE VACUUM-TUBE BRIDGE

As is evident from a consideration of its circuit characteristics, the TYPE 561-D Vacuum-Tube Bridge is not limited in its applications strictly to the measurement of tubes, but is capable of measuring the voltage gain, output resistance, and effective transconductance of any three-terminal network appropriately connected to its terminals.

The versatility and adaptability of the bridge for these measurements make it particularly useful in teaching and in laboratory experiments for students. In the March, 1948, issue of *American Journal of Physics*, Professor Edward H. Green, of Brooklyn College, under the title, "A Precise Laboratory Exercise Using a Vacuum-Tube Bridge," describes a student laboratory exercise based on the TYPE 561-D Vacuum-Tube Bridge. The article covers such measurements as the gain and output resistance of triode amplifiers with and without feedback, cathode followers, negative coefficients, and the determination of the criterion for oscillation of a negative-resistance oscillator. This comprehensive and very readable article should be of interest to teachers of electronics and of electrical communications. Reprints are available and we shall be glad to send copies to all who request them.

MISCELLANY

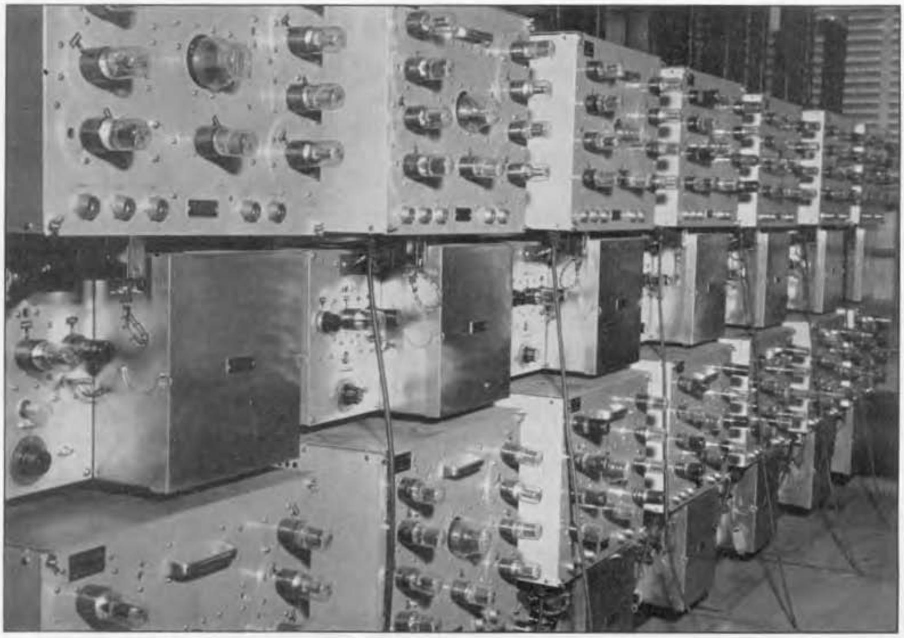
RECENT VISITORS to our plant and laboratories — Mr. John R. Pheazey, Works Director, Standard Telephones and Cables, Ltd., London; Mr. C. I. Snow and Mr. F. H. Andrews of Imperial Chemical Industries, London; Mr. K. Bogedam, Copenhagen; Dr. L. Rohde of Rohde and Schwartz, Munich; and Mr. H. S. Walker, RCA Victor Co., Ltd., Montreal.

1949 IRE CONVENTION — March 7-10 are the dates set for the 1949 Annual Convention of the Institute of Radio Engineers, which promises to be the biggest and best in the Institute's history. The Convention will open with the annual meeting of the Institute on Monday, March 7, at 10:30 A.M., when Ivan S. Coggeshall will speak on "Perpetual Youth and the IRE." On Tuesday, the President's Luncheon will honor the incoming president, Stuart L. Bailey, and on Wednesday evening, at the annual banquet, Frank Stanton, president of CBS, will speak on "Television Today."

Technical sessions will be held at both the Hotel Commodore and Grand Central Palace. A total of 170 papers will be presented during the 4-day period, covering a wide range of subjects in radio, electronics, and allied fields.

Some 200 firms will exhibit their products at the Radio Engineering Show, held at Grand Central Palace.

The General Radio exhibit will be in Booths 92 and 93, the same space that we have had for the past two years. Representatives of the Development Engineering, Sales Engineering, and Service Departments will be on hand to discuss applications of General Radio equipment and to answer questions. We hope that all our friends will drop in.



A group of Type 1100 Frequency Standards undergoing performance tests in our Standardizing Laboratory. Accuracy and stability must be well inside catalog specifications before the oscillators receive the Laboratory's O.K.

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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 6201

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

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