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THE General Radio EXPERIMENTER

VOLUME XXII No. 8 JANUARY, 1948

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

SENSITIVITY OF THE TYPE 916-A RADIO-FREQUENCY BRIDGE

Also

IN THIS ISSUE

ALTHOUGH IN MOST APPLICATIONS satisfactory performance is obtained from the Type 916-A Radio-Frequency Bridge when commercial signal generators and receivers are used, in some cases difficulty is encountered from apparently low bridge sensitivity or from noise and other extraneous signals picked up by the circuit under test. To those who have experienced this difficulty, the following analysis may be helpful in suggesting a solution.

In order to discuss bridge sensitivity, the term first must be defined. The definition used in this article is based on the following reasoning. With both the resistance and reactance dials set at the true balance positions, the voltage developed across the detector terminals is, of course, zero. However, if one dial is displaced from its true balance position while the other remains at its true balance position, the output voltage produced across the detector terminals is directly proportional to the deviation from the balance setting for small

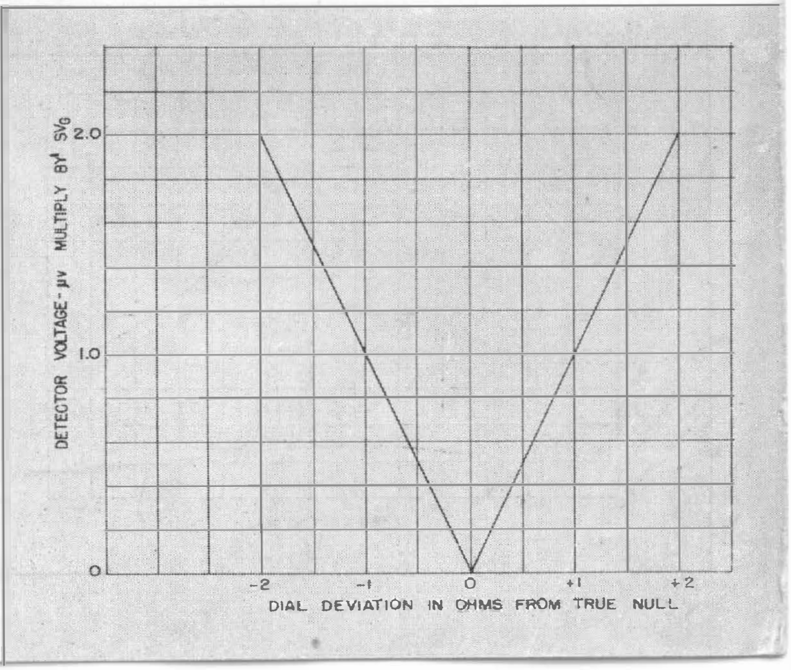


Figure 1. Voltage across the detector terminals of the r-f bridge as a function of the deviation of either dial from the true null position.

deviations. Therefore, a bridge sensitivity factor, S, can be defined as:

$$S = \frac{\frac{V_d}{V_g}}{\Delta}$$

where V_g is the generator voltage in volts, and V_d is the voltage in microvolts developed across the detector terminals when either dial is displaced from its true balance position by the amount Δ, in ohms, and the other dial is set at its true balance point.

The relationship between the output voltage produced across the detector terminals, in terms of the sensitivity factor and applied voltage, and the deviation from the true balance position in ohms is plotted in Figure 1. If the sensitivity factor, the applied voltage, and the detector sensitivity are known, the limitation on the bridge accuracy due to sensitivity can be determined from the graph.

The bridge sensitivity factor for an infinite detector impedance, S_o, is plotted as a function of frequency in Figure 2 for both the L and C positions of the L-C switch on the bridge. Of course, in the practical case, the detector impedance is not infinite, and in order to obtain the true sensitivity factor, S, the open circuit sensitivity factor, S_o, must be multiplied by $\left|\frac{Z_d}{Z_d + Z_o}\right|$ where Z_d is the detector impedance, and Z_o is the output impedance of the bridge. The resistive and reactive components of the output impedance are plotted as a function of frequency in Figure 3.

The voltage developed across the bridge generator terminals, V_g, is not equal to the open circuit voltage produced by the signal generator used as a signal source unless the generator output impedance is zero as the input impedance to the bridge is not infinite. To obtain the magnitude of the applied voltage, the open circuit generator voltage must be multiplied by the factor $\left|\frac{Z_i}{Z_i + Z_g}\right|$ where Z_i is the input impedance to the bridge and Z_g is the output impedance of the generator. The input impedance to the bridge is plotted as a function of frequency in Figure 3.

The sensitivity factor is not independent of the magnitude of the resistive component of the unknown impedance but decreases slowly as the resistive component increases. The sensitivity factor plotted in Figure 2 is for relatively small resistances; however, the effect of the uncertainty of balance upon the measurement of the resistive component expressed as a percent of the unknown resistance decreases as the magnitude of the resistive component increases.

In some applications, and particularly in the measurement of broadcast antennas, extraneous signals and noise picked up by the circuit under test and introduced into the bridge tend to decrease the measurement accuracy by partially masking the null. This effect can be serious when the maximum voltage available for application to the generator terminals is low. The use of a

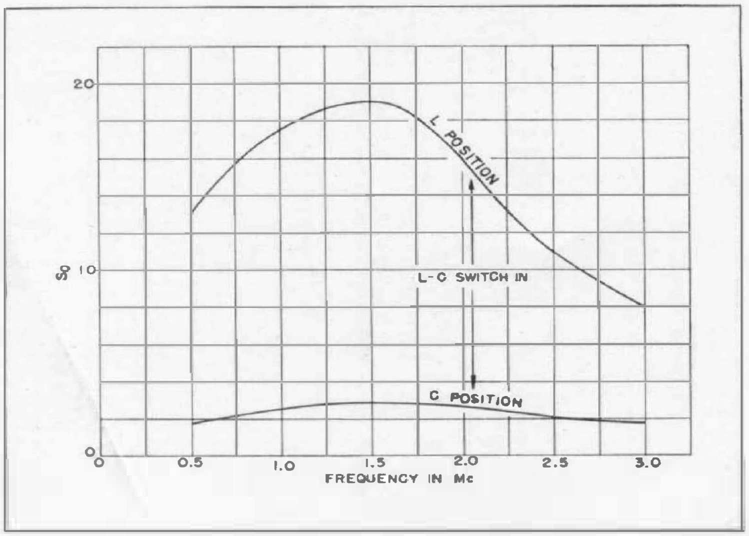


Figure 2. Open-circuit sensitivity factor, S_o, as a function of frequency.

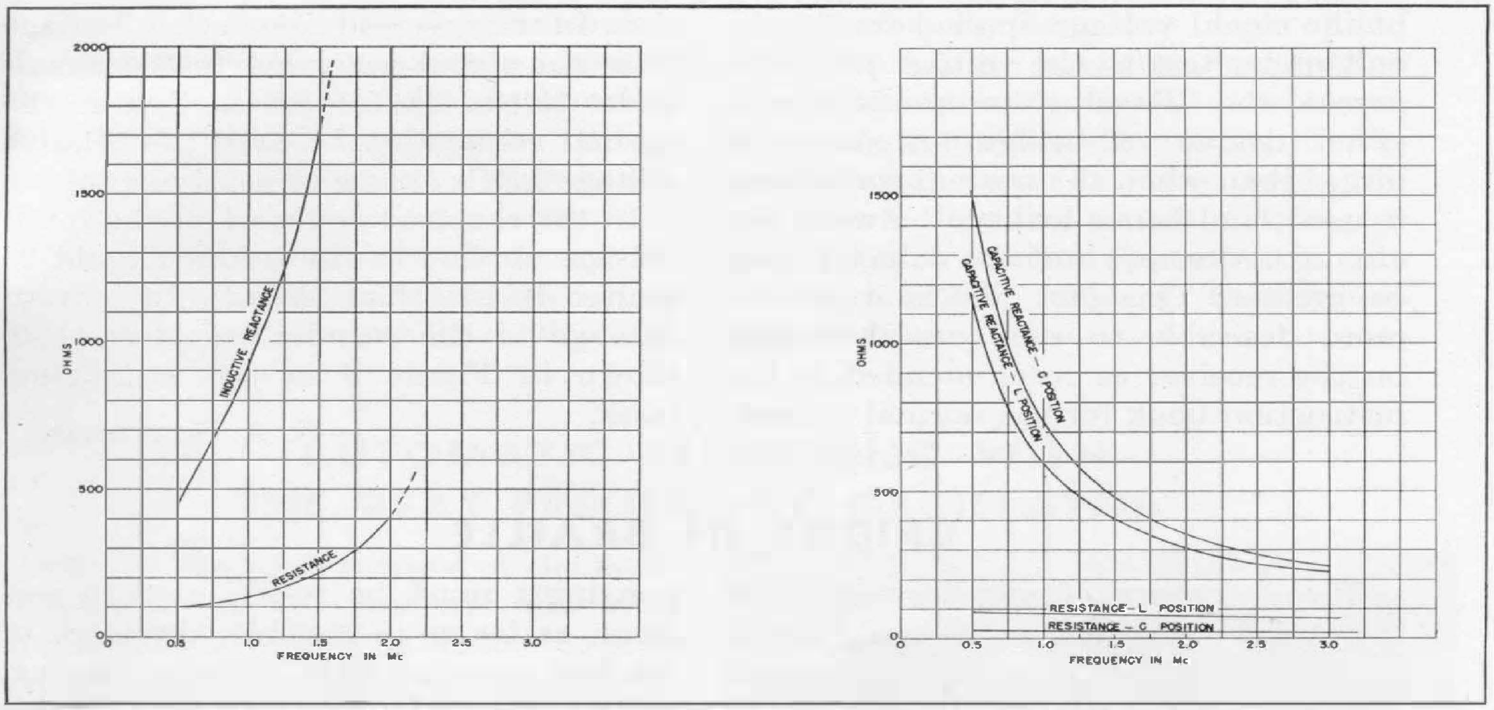
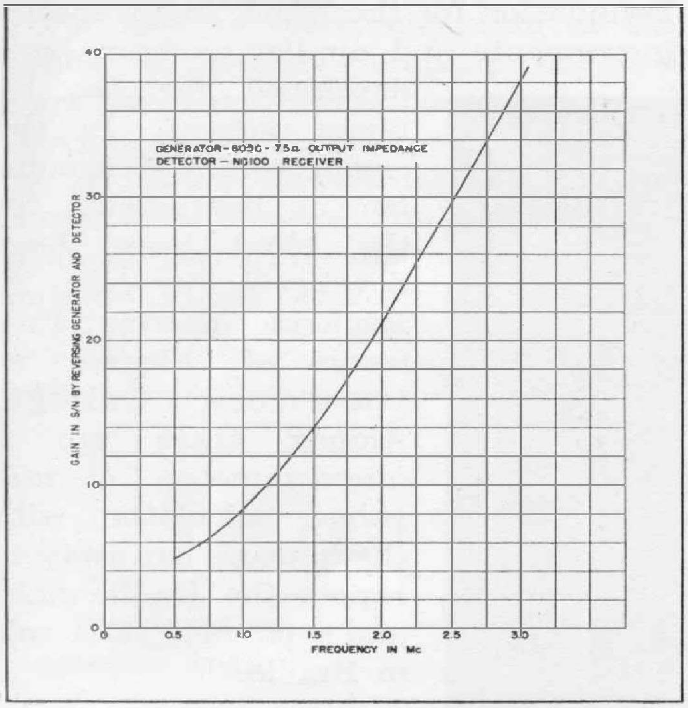


Figure 3. Resistive and reactive components of (*left*) input impedance and (*right*) output impedance of the bridge as a function of frequency.

highly selective receiver is helpful, since it amplifies a smaller amount of the undesired signal than does a receiver with poor selectivity. Ordinary communications receivers with crystal filters are desirable for this application.

Figure 4. Gain in signal-to-noise ratio as a function of frequency when generator and detector connections are interchanged.



Another method of reducing the effect of noise introduced into the bridge by the circuit under test is to reverse the generator and detector connections. In the normal connection, the bridge isolating transformer is connected between the generator and the bridge. In this position the insertion loss of the transformer attenuates only the signal applied to the bridge. In reversed connection, the transformer is between the bridge and the detector and both the desired signal and noise from the unknown are attenuated by it, resulting, in general, in an increase in the signal-to-noise ratio produced in the detector. The amount of increase is appreciably affected by the impedances of the signal generator and detector. In a typical arrangement, using a General Radio Type 805 Signal Generator and a National Type NC 100 Receiver, the increase in signal-to-noise ratio produced by reversing the connections is plotted as a function of frequency in Figure 4.

In the reversed connection, the ratio

of the signal voltage applied to the circuit under test to the voltage produced across the detector terminals for a given degree of bridge unbalance is larger than when the normal connection is used, and hence leakage between the circuit under test and the detector may be greater. This fact makes it all the more desirable to use coaxial fittings on the receiver as recommended in the instruction book for the normal connection. In the reversed connection, leakage from the signal generator to the circuit under test is less important than in the normal connection because the relative voltage levels are more nearly equal.

In the reversed connection, the input voltage applied to the bridge should be limited to less than 15 volts to prevent damage to the standard resistor, R-3, shown in Figure 8 in the instruction book.

—R. A. Soderman

BRIDGE IN BRAILLE

The casualties of war have focused increasing attention on the problems of aiding the physically handicapped to find a satisfactory niche in industry and in society. With most types of disability, the solution is not too difficult: artificial limbs are being perfected for the legless and armless; plastic surgery restores lost features; and only the restriction to a sedentary life is necessary for many of those whose handicap is functional.

With the blind, however, the solution is more difficult The loss of what is, for many purposes, the most used of the five senses means that others of the four remaining must be re-educated to perform, as far as is possible, the work of the lost sense of sight. Touch, hearing, and smell are all called into play for this purpose, and in the education of the blind are developed to an amazing degree.

For written communication, and for utilizing the various instruments and machines that implement contemporary existence, the sense of touch is the one most used.

Under the auspices of the American Foundation for the Blind, many special instruments and appliances have been developed for use by blind persons. In the engineering field, a number of instruments for the blind have been developed by T. A. Benham, Assistant Professor of Physics at Haverford College. Among these are a microammeter, a machine calculator with the housing cut away to expose the Braille dials, and a circular slide rule in Braille.

One of Professor Benham's developments that is of particular interest to the General Radio Company is the modified Type 650-A Impedance Bridge shown in the photograph. This bridge has been fitted with celluloid dials with Braille figures, and the dials are so mounted that they do not interfere with the normal operation of the bridge.

Professor Benham has been blind since the age of two and has devised this dial system for his own use. A more complete discussion of the work being done in this field will be found in his article "Aids for the Blind," which appeared in the February, 1947, issue of Electrical Engineering.

AUTOMATIC RECORDING WITH THE BEAT-FREQUENCY OSCILLATOR

Of the many advantages of the beat-frequency type of oscillator, the outstanding is probably its ability to scan rapidly a wide range of frequencies. This feature is particularly valuable in connection with automatic graphic recording arrangements where frequency-response data or other information is to be obtained in the form of a permanent and graphic record. The single-control, single-sweep arrangement of the beat-frequency oscillator is readily adapted to mechanical drive from, or in conjunction with, a recorder mechanism.

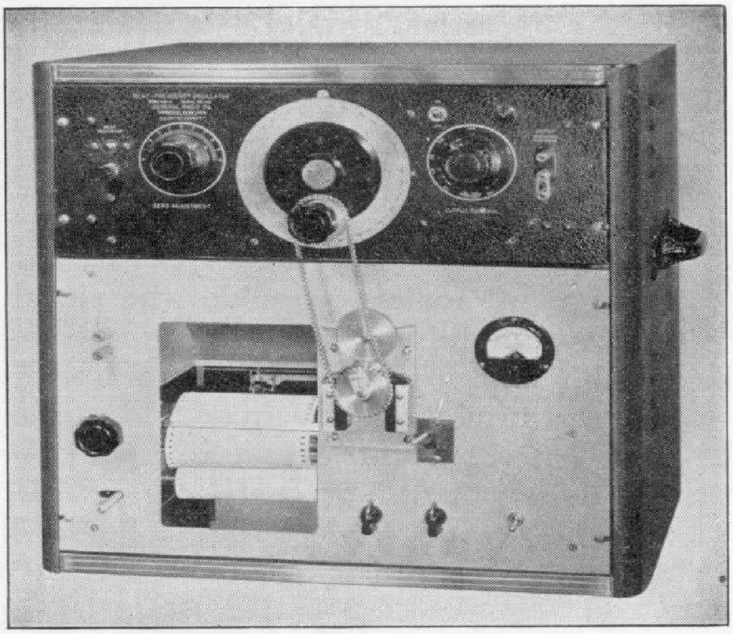
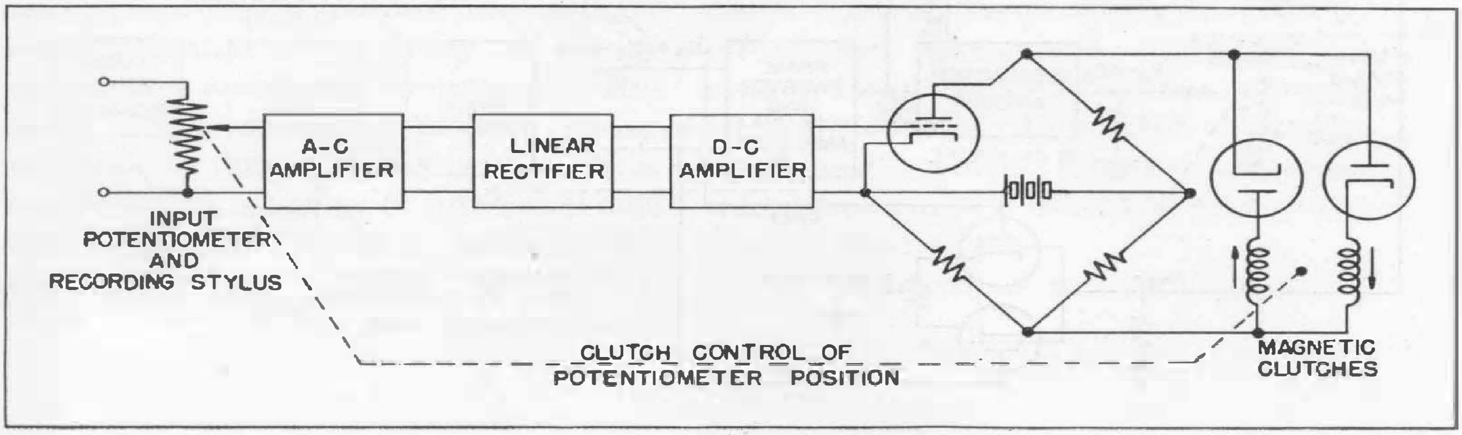


Figure 2. View of the Model FR-1 Graphic Recorder with the Type 913-C Beat-Frequency Oscillator.

For several years, engineers of the Sound Apparatus Company of New York have been engaged in a program of developing methods of graphic recording at audio frequencies. They have chosen the General Radio Type 913 Beat-Frequency Oscillator as the most suitable signal source, and a drive mechanism and chart are available for using this oscillator in conjunction with their recorders.

Figure 1. Functional diagram of the recorder.



The basis of operation of the recorder is readily understood with reference to Figure 1. It will be seen that the system is a servo mechanism, which maintains at a predetermined level the signal input to the a-c amplifier. The position of the potentiometer arm and recording stylus is thus proportional to the signal level impressed on the input potentiometer.

Figure 2 shows the combination of the 913-C and the Sound Apparatus Company's Model FR-1 Graphic Recorder. The oscillator dial drive is chain coupled to the paper-drive mechanism of the recorder through the link unit shown.

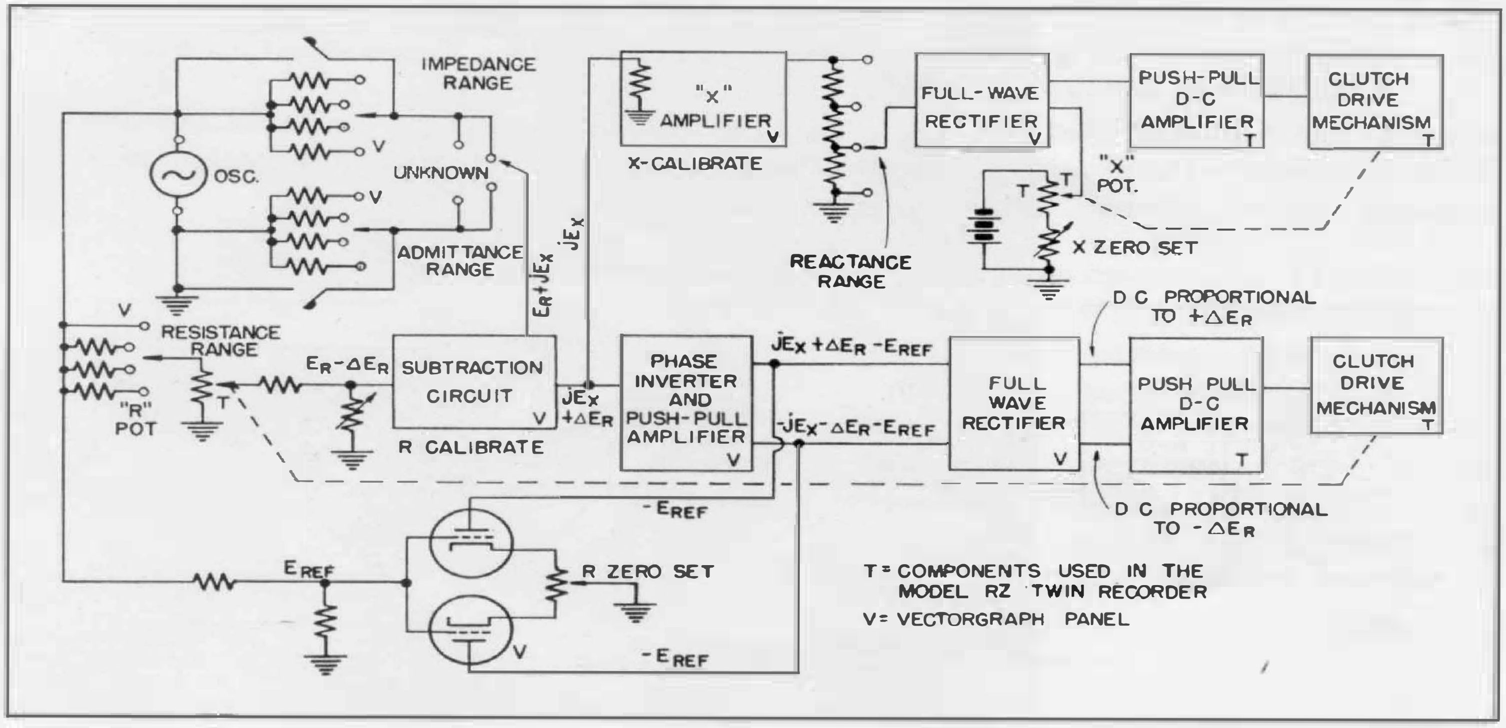
A recently announced development of particular interest is the "Impedance Vectorgraph." Incorporating a twin recorder, Model RX, and the beat-frequency oscillator, Model 913-C, this equipment makes possible the simultaneous and fully automatic recording of the separate components of impedance as a function of frequency. Equivalent series resistance and reactance or equivalent parallel conductance and susceptance of a two-terminal network or component can be plotted.

Essentially the method consists of maintaining a constant current through the unknown impedance and of recording the complex components of voltage developed across it. The real and imaginary components of this voltage are directly proportional to the resistance and reactance respectively of the unknown impedance. Referring to the functional diagram of Figure 3, the operation of the system is as follows: For impedance measurements, the Admittance Range Switch is short-circuited and current fed to the unknown through the Impedance Range Resistors. These are of such magnitude as to insure a current that is independent of the unknown impedance.

The "R" Potentiometer inserts into the subtraction circuit a signal which cancels the resistive component of voltage E_R with the exception of the error voltage ΔE_R. After phase inverting this error voltage ΔE_R and the reactive voltage jE_x, these voltages are added to the reference voltage E_{REF} and rectified.

The output of the rectifier yields a d-c voltage proportional to $+\Delta E_R$ and

Figure 3. Functional diagram of the Impedance Vectorgraph.



a d-c voltage proportional to $-\Delta E_R$. If the error voltage is reversed in phase, the voltages will be reversed, giving a push-pull error voltage output. This error voltage is amplified through a push-pull d-c amplifier, which operates a clutch mechanism to move the slider on the "R" Potentiometer to reduce the error voltage. Automatically, this "R" Potentiometer plots the resistive component of the impedance.

After the subtraction circuit there now remains only jE_x, the reactive voltage which is amplified and rectified. This rectified output is cancelled out by the "X" Potentiometer output. The error in cancellation is amplified through a d-c amplifier which operates a clutch mechanism to move the slider on the "X" Potentiometer to reduce the error. Automatically, then, this "X" Potentiometer plots the reactive component of the impedance.

The measurement of admittance is accomplished by shorting the impedance range resistors, A, and inserting the admittance range resistors into the circuit. Essentially constant voltage is now impressed across the unknown. The input to the subtraction circuit is now switched from the top of the unknown Z to the bottom of the unknown, placing the voltage across the small admittance range resistors into the subtraction circuit. This voltage is proportional to the current through the unknown both in magnitude and phase. These in-phase and out-of-phase components of voltage are then proportional to the conductance and susceptance respectively and are recorded similarly to the impedance components.

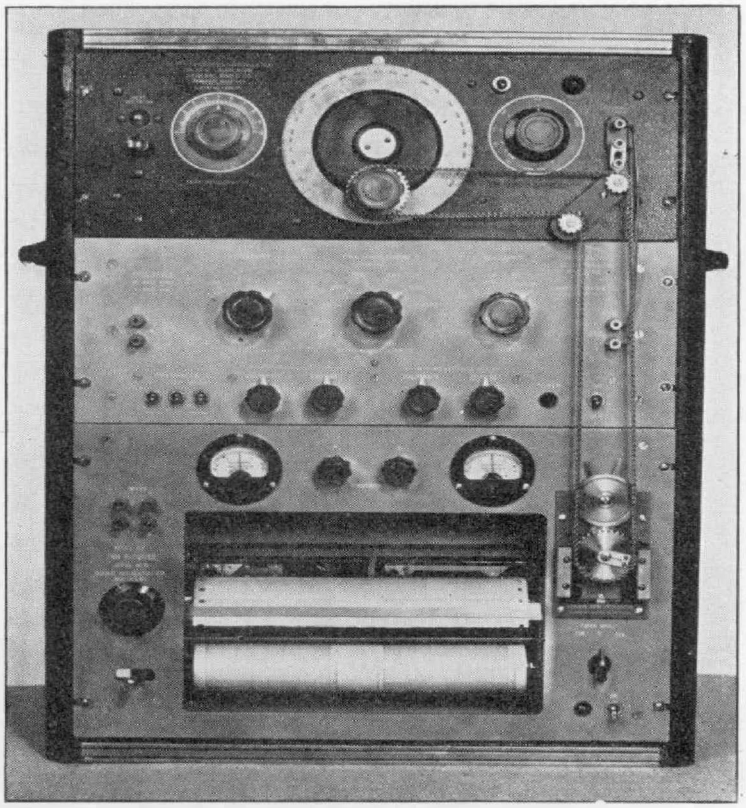


Figure 4. Panel view of the Impedance Vectorgraph.

—L. P. Reitz
I. G. Easton

ECCENTRICITY EFFECTS IN PRECISION ROTARY DEVICES

Technical advances embodied in modern communication, laboratory, and process equipment require increasingly high standards of accuracy in rotary control and indicating components. Residual inaccuracies result from many contributing factors. Large among these may be an eccentricity of rotational axis with respect to working parts. Small eccentricities, sometimes overlooked, may often offset much or all of the care lavished on the construction of a precision control. Even when eccentricity errors are recognized, they cannot always be eliminated, as, for example, on the General Radio 722 Precision Condenser, which requires a worm calibration curve if it is to be used to the limit of accuracy.

The presence of eccentricity causes

the indicated rotation to differ from true rotation by an angle the size of which is a function of the eccentricity. In a device with working parts of true radius, R, with a shaft center displacement, E, from the origin of R, the indicated angle of rotation, β, will differ from the true angle, α, as expressed by the equation:

$$\beta - \alpha = \sin^{-1}\left[\frac{E}{R}\sin\beta\right].$$

Put into words, this says that the angle of error is that angle the sine of which is the product of the eccentricity to radius ratio multiplied by the sine of the indicated angle of rotation.

Since, with small angles, the sine of the angle closely approximates the angle, it is possible to write an approximate form of the equation, thus:

$$\beta - \alpha \approx 57.3\,\frac{E}{R}\sin\beta.$$

For values of E/R less than 0.1, the error introduced by the approximation is negligible, and no good design, certainly, should exceed a ten per cent eccentricity ratio.

The importance of the eccentricity factor can best be shown by a typical example. Consider a precision voltage-divider ("potentiometer") of two-inch radius, with an eccentricity of but twenty one-thousandths of an inch, and a total electrical rotation of 320°. Maximum eccentricity error occurs at 90° or 180° indicated rotation, when sine β is plus or minus one. This maximum error is:

$$\beta - \alpha = 57.3 \times \frac{.020''}{2.000''} \times \pm 1 = \pm 0.573^\circ$$

which yields a percentage error of

$$\frac{\pm 0.573^\circ}{320^\circ} \times 100 = \pm 0.18\%$$

instead of the 0.05% that might have been expected from the two thousand carefully spaced turns of the winding. Thus, in effect, the eccentricity error has nullified the accuracy inherent in the precision winding and contact arrangement.

Sometimes it is possible to use eccentricity deliberately to offset other nonlinearities; if such other errors are sinusoidal or approximately sinusoidal with rotation. Under these circumstances, the introduction of a calculated eccentricity of the proper phase and magnitude can improve over-all linearity materially. For instance, the regulation characteristic of a Variac, while not sinusoidal, can be partially offset by the deliberate introduction of eccentricity that is a function of load current. During World War II, this principle solved an annoying problem in connection with alternating current supply of a magnetic deflection coil operated from a Variac used as an alternating-current potentiometer. The corrective eccentricity offset the regulation error sufficiently to meet the narrow resolution specification required.

—Gilbert Smiley

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PRINTED IN U.S.A.