THE General Radio EXPERIMENTER

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also

IN THIS ISSUE

A FREQUENCY-LIMIT MONITOR FOR THE HIGH-FREQUENCY BANDS

● **THE INCREASING USE** of frequencies between 1500 kc and 30,000 kc for special services, such as police, maritime, and aircraft communication and international broadcasting, in recent years has resulted in sufficient congestion to warrant frequency assignments within fairly close accuracy tolerances.

In order to maintain transmitter frequencies within the accuracy limits required by law, it is essential that each station maintain either a frequency monitor or rather elaborate frequency-measuring equipment.

Since the total investment in plant for stations in the high-frequency spectrum is often very small in comparison with that for most standard broadcast stations, it is difficult to justify the relatively large outlay involved in the purchase of a highly precise direct-reading monitor such as is required in the broadcast band. On the other hand, since operating personnel must often be kept at a minimum, it is desirable to have available an instrument which tells at a glance whether the transmitter frequency is within its legal accuracy limits.

The Type 775-A Frequency-Limit Monitor is designed to meet the

Figure 1. Panel view of the Type 775-A Frequency-Limit Monitor

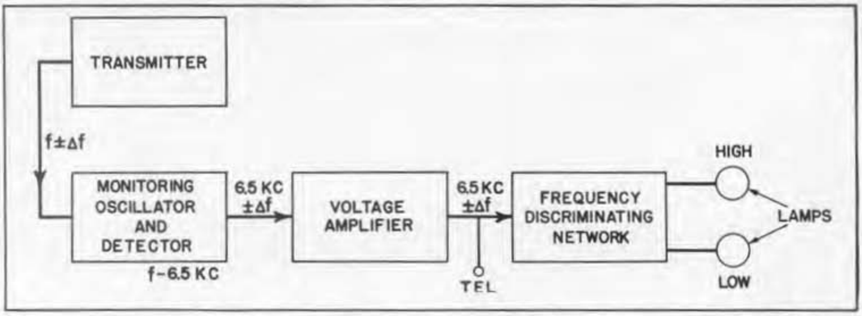

FIGURE 2. Functional diagram showing the operation of the frequency-limit monitor

need for a simple, compact, self-contained, and moderately priced frequency monitor to cover the frequency range from 1500 kc to 30,000 kc.

The requirements to be met by a frequency monitor for the high-frequency spectrum are quite different from those for the standard broadcast band.

In the broadcast band, sufficient congestion exists so that in many cases several different stations are assigned to the same channel. Under such conditions, when interference conditions arise, the interference is of the close heterodyne or "flutter" type. This type of interference becomes most annoying when the interfering signals differ sufficiently in frequency to produce an audible beat note. While nominally the accuracy tolerance on broadcast station frequencies is ±50 cycles, the Federal Communications Commission, therefore, actually requires much closer adherence to the true assigned frequency.

In order to check broadcast station frequencies to a sufficient degree of accuracy, it is required by law that each station shall maintain a continuously indicating, direct-reading frequency monitor of very high accuracy. The General Radio TYPE 475-A Frequency Monitor, used in conjunction with the TYPE 681-A Frequency-Deviation Meter, has long been approved for this class of service and is now in use in hundreds of stations the world over.

At frequencies above the standard broadcast band, conditions are radically different. Because of the larger number of channels available, the greater relative importance of "sky waves" in comparison with "ground waves," and the negligible amount of "chain" operation, sharing of common channels by continuous services is much less.

Such interference as occurs in the high-frequency range is consequently more often of the adjacent channel heterodyne type than of the close heterodyne type common to the broadcast band.

The frequency tolerances in the high-frequency bands have been set up to minimize such interference. Since adjacent channel heterodyne interference is not sensitive to small frequency changes within these tolerances, literal compliance with the accuracy limits set up is consequently sufficient to insure maintenance of reliable service. A monitor which tells at a glance whether the transmitter frequency is, or is not, within its legal accuracy limits is a convenient type to use for the high-frequency range.

The Type 775-A Frequency-Limit Monitor is designed for such a function. Mounted on the panel are two warning lamps and a dial, which is set to the frequency limit assigned to the station to be monitored. So long as the transmitter frequency remains within the assigned limits, both lamps remain dark. If the transmitter frequency increases beyond the assigned accuracy limit, one warning lamp lights. If the transmitter frequency decreases beyond the assigned accuracy limit, the other lamp lights.

For more accurate monitoring, the LIMIT dial may be set to closer tolerances than those required by law. The warning lamps simply indicate when the deviation in transmitter frequency exceeds the limits set on the dial.

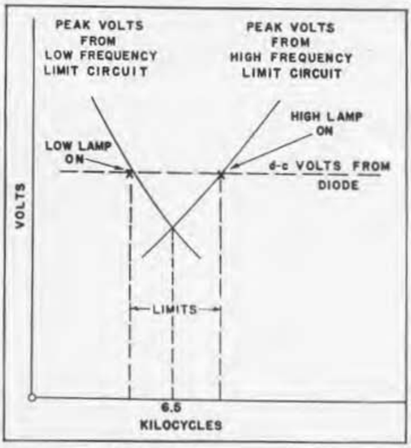

Figure 3. Voltage-frequency characteristics of the frequency-discriminating circuit

A functional diagram of the Type 775-A Frequency-Limit Monitor is shown in Figure 2. The instrument consists of a highly stable quartz-controlled monitoring oscillator which produces a voltage rich in harmonics, a detector which mixes the transmitter frequency and a harmonic of the local monitoring frequency to produce a low-frequency beat note, and a frequency-discriminating circuit which lights a warning lamp when the beat frequency departs from a value of 6.5 kc by more than a predetermined amount.

Provision is made for the use of four

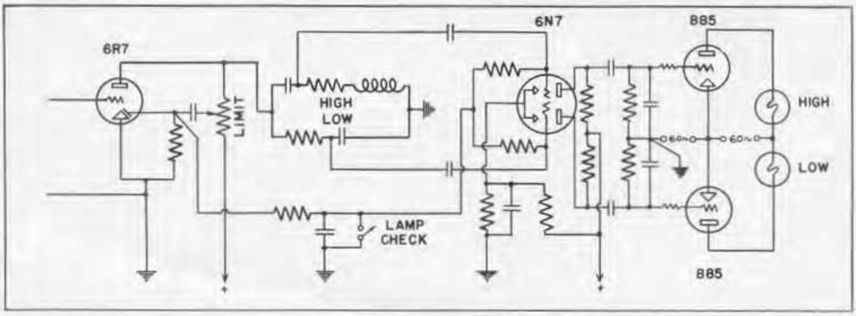

Figure 4. Schematic wiring diagram of the limit-indicating section of the frequency-limit monitor. The beat-frequency voltage obtained from the detector is impressed upon the grid of the 6R7 duplex-diode-triode. The a-c plate voltage of the 6R7 is developed across the frequency-discriminating circuit, the characteristics of which are shown in Figure 3. The voltage obtained from each branch of this circuit is fed to a grid of the 6N7 dual triode, which is biased to cut-off. Each plate of the 6N7 feeds a gas triode which has a warning lamp in its plate circuit. In shunt with the frequency-discriminating circuit is a potentiometer which is used to obtain a fraction of the total a-c plate voltage. This fraction is rectified by one of the 6R7 diodes and used to bias the grids of the 6N7 beyond their normal cut-off voltage. The d-c bias, controlled by the setting of the LIMIT dial, determines the frequency at which the lamps will light. When an a-c voltage on either grid exceeds this bias, plate current flows, tripping one of the 885's and lighting a warning lamp

separate crystals to monitor four different frequencies. The quartz plates are of the low-temperature-coefficient type and are protected against large changes in ambient temperature by a simple temperature-control system which maintains the compartment temperature at 50° C. ±3° C. An individual tuning condenser for each crystal is mounted on the panel and a selector switch on the panel simultaneously switches the quartz plate, tuning condenser, and input circuit when different transmitter frequencies are to be monitored.

An electron-ray tube is used to indicate when the local monitoring oscillator is correctly adjusted. By means of a switch mounted on the panel, it may also be connected to indicate when the correct input from the transmitter is obtained. The accuracy of the instrument is not critically affected by either local oscillator adjustment or input voltage.

The dial on the panel used to set the accuracy limits is engraved for frequency deviations from ±500 cycles to ±3000 cycles. With this span of adjustment the frequency range of the instrument is as indicated in the specifications below.

A simple push-button switch on the panel is provided for routine checking of the instrument under operating conditions. Once installed and put in proper operation, no further adjustments are necessary except for changing the LIMIT dial when switching from one frequency to another.

The instrument is entirely self-contained. It may be operated from any 110-120 volt, 40-60 cycle line.

— D. B. Sinclair

SPECIFICATIONS

Frequency Range:

For limits of ±0.10%: 1500– 3000 kc
For limits of ±0.05%: 1500– 6000 kc
For limits of ±0.04%: 1500– 7500 kc
For limits of ±0.03%: 1700–10,000 kc
For limits of ±0.02%: 2500–15,000 kc
For limits of ±0.01%: 5000–30,000 kc

Accuracy of Monitoring Frequency: The absolute accuracy is 0.003% when using Type 376-M Quartz Plate.

Stability of Monitoring Frequency: The frequency stability is 0.001% over long periods of time.

Quartz Plate: Type 376-M Quartz Plates are to be used with this instrument and must be ordered separately.

Accuracy of Frequency Discriminating Network: When operated at proper input voltage, the warning lamps will light at frequencies which are within ±200 cycles ±10% of the LIMIT dial reading.

Tubes: Supplied with instrument —

1 — Type 6A8 Pentagrid Converter
1 — Type 6J7 Pentode
1 — Type 6R7 Duplex-Diode Triode
1 — Type 6N7 Dual Triode
2 — Type 885 Gas Triodes
1 — Type 6X5 Rectifier

Mounting: Standard 19-inch relay-rack mounting or table mounting.

Accessories Required: Type 376-M Quartz Plate.

Dimensions: Panel (width) 19 inches x (height) 7 inches x (depth) 10⅝ inches, overall.

Net Weight: 29⅝ pounds.

Power Supply: 110-120 volts, 40-60 cycles.

Power Input: Approximately 72 watts with heater ON and approximately 45 watts with heater OFF, with 115-volt line.

Type		*Code Word*	*Price*
775-A	(Including tubes, but less quartz plate)	DOUGH	$240.00
376-M	Quartz Plate (for use with Type 775-A)	LABOR	50.00 each

This instrument is manufactured under the following U. S. Patents and license agreements:

Patents of the American Telephone and Telegraph Company, solely for utilization in research, investigation, measurement, testing, instruction and development work in pure and applied science.

Patents and patent applications of Dr. G. W. Pierce pertaining to piezo-electric crystals and their associated circuits.

BROADCAST ANTENNA MEASUREMENTS WITH THE R-F BRIDGE

● IN THE PAST FEW YEARS the TYPE 516-C Radio-Frequency Bridge has been widely used by broadcast engineers for measuring the impedance of antennas and their associated coupling and feeding systems. The bridge method of measurement is rapid, convenient, and accurate. Radiating systems can be lined up quickly and, once adjusted, can be maintained at top performance through routine checks.

The application of the bridge to measurements of this sort is best illustrated by discussing a typical broadcast installation recently measured. A functional diagram of the radiating system at Station WEEI* is illustrated in Figure 2. This radiating system is designed to reduce the radiation in the east-west direction in order to avoid possible interference with Station WTAG in Worcester, Mass., which is operating on the adjacent channel. It consists of two vertical antennas, *W* and *E*, which are fed through a bridging transformer *T*, phasing networks ϕ_W and ϕ_E, concentric transmission lines L_W and L_E and impedance matching networks Z_W and Z_E.

By adjusting the bridging transformer *T*, and the phasing networks ϕ_W and ϕ_E, the ratio of magnitudes and the phases of the currents in the two antennas may be varied to give the desired field-strength pattern.

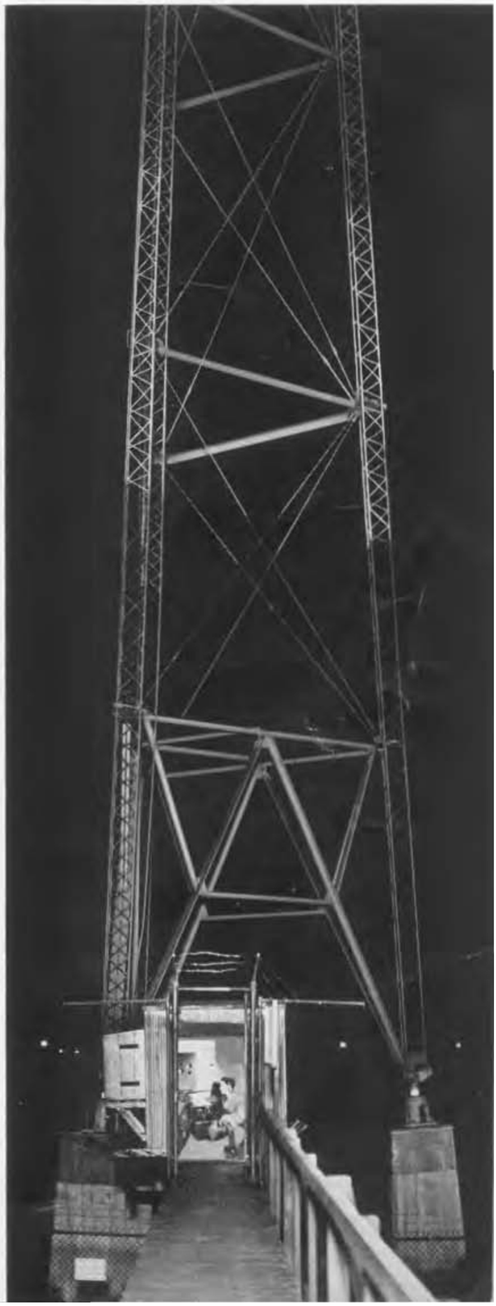

FIGURE 1. One of the antenna towers at WEEI. The structure at the base of the antenna houses the impedance matching network and meters for reading antenna current

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*C.B.S., Boston, Mass., 590 kc. We are indebted to the management and staff of WEEI for permission to carry out measurements on the radiating system of this station, which was chosen as a representative example of modern broadcast installation.

In lining up this radiating system the most important measurements are:

(1) Resistance and reactance of antenna at operating frequency.

(2) Characteristic impedance of lines.

(3) Impedance in which each line is terminated (input impedance of impedance-matching network).

(4) Input impedance of line when terminated with impedance-matching network.

(5) Characteristic impedance of phasing networks.

(6) Input impedance of phasing networks with system connected.

Each of these measurements is discussed briefly below.

1. Antenna

The antenna impedance is determined by breaking the system at the section *A–A* and measuring the impedance at the antenna and ground leads where they connect to the impedance-matching network *Z*.

A single measurement at the operating frequency is usually sufficient, but a frequency characteristic of the antenna is sometimes valuable in determining whether there is any disturbing effect caused by resonant sections of guy wires or any undesirable resonances at harmonics of the assigned station frequency. The measured resistance and reactance of the east antenna are shown plotted as a function of frequency in Figure 3.

For this installation, quarter-wave resonance is seen to occur at 685 kc, half-wave resonance at 1070 kc, and three-quarter-wave resonance at 1715 kc. At the operating frequency the antenna resistance is 20 Ω and the reactance 41 Ω capacitive. Expressed in complex notation, this impedance is: $Z_A = 20 - j41$.

When measuring directive systems of this sort an error may occur because of the mutual impedance between the two antennas.* For the system tested, this error was small at the operating fre-

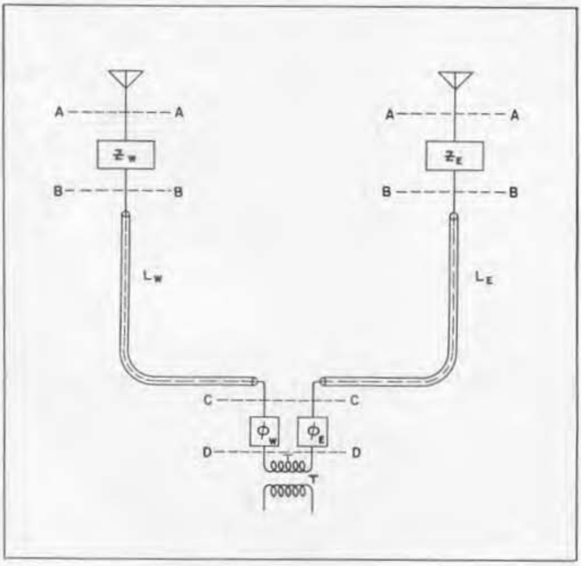

FIGURE 2. A diagram of the antenna system at WEEI. Z_E and Z_W are the impedance matching networks, L_E and L_W the concentric lines and ϕ_E and ϕ_W the phasing networks. The bridging transformer, *T*, is a coupling unit between the phasing networks and the transmitter

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*John F. Morrison, "Simple Method for Observing Current Amplitude and Phase Relations in Antenna Arrays," *Proc. I. R. E.*, October, 1937.

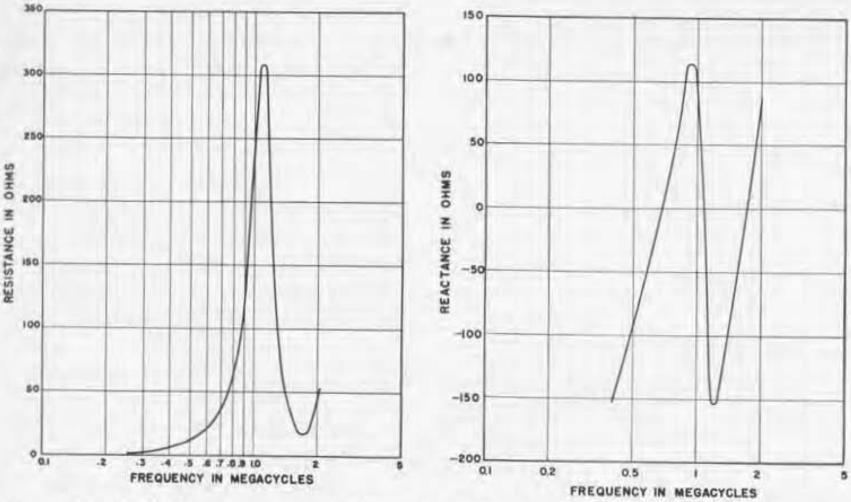

FIGURE 3. (*Left*) Resistance characteristic of the east antenna at WEEI. (*Right*) Reactance characteristic of the same antenna

quency, both resistive and reactive components looking into the east antenna changing about 1 Ω when the west antenna was opened and grounded at the base. All measurements on one antenna and its feeding system were made with the other antenna connected back through its feeding system to the transmitter.

2. Concentric Lines

To determine the characteristic impedance of the concentric lines, the system is broken at *B–B* and *C–C*. Measurements of the imput impedance of the line are then made from one end with the other end open and shorted. The characteristic impedance of the line is computed from the expression

$$Z_o = \sqrt{Z_{o/c} Z_{s/c}} \quad .$$

The lines used in the system tested are nitrogen-filled and approximately 1000 feet long. They are designed for a characteristic impedance of 65 Ω. A typical check on this figure is the measured value for the west line, L_W, of 65.4 − j0.56.

3. Impedance-Matching Networks

The impedance-matching networks Z_W and Z_E are designed to work between impedances of 65 + j0 and 20 − j41. They are of the so-called impedance-inverting type illustrated in Figure 4.*

In adjusting such networks the TYPE 516-C Radio-Frequency Bridge can be used to measure the impedances of the individual elements composing them and their input impedances when they are connected to the antennas. For perfect matching, when the system is broken at section *B–B*, the impedance at the input terminals of the impedance-matching networks with the antennas connected should be equal to the characteristic im-

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*For a discussion of impedance-matching networks see, for instance, Carl G. Dietsch, "Antenna Terminations," *Electronics*, Sept., 1935, and "Terminating Concentric Lines," *Electronics*, December, 1936.

pedance of the line, namely, $65 + j0$.

The degree of matching to be achieved is governed by practical considerations rather than theoretical. Too great a mismatch will cause serious standing waves to form on the concentric lines. The standing current waves may result in excessive power loss in the line and the standing voltage waves may cause the line insulation to break down.

4. Phasing Networks

The networks ϕ_W and ϕ_E are used, in the example of Figure 2, to produce a phase relation between the currents in the two towers which results in the desired radiation pattern. These are symmetrical T-networks of the type illustrated in Figure 5. They are designed to have an image impedance of $65 + j0$ at the operating frequency and consequently match the line.

The design and adjustment of such networks is beyond the scope of this article, but the application of the TYPE 516-C Radio-Frequency Bridge to their measurement is similar to the application to the impedance-matching networks. The individual elements may first be measured, the characteristic impedance may be determined from open- and short-circuit measurements, and the final measurement of the input impedance made when terminated in the complete radiating system. This last measurement at *D–D* for perfect matching should, of course, be $65 + j0$.

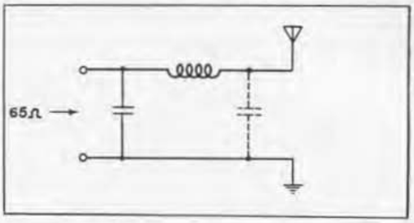


FIGURE 4. The impedance-matching network used to couple the transmission line to the antenna. This is an artificial quarter-wave line in which the condenser shown by dotted lines is replaced by the effective parallel reactance of the antenna

5. Maintenance

Once adjusted, the system should be checked periodically, particularly when current readings indicate that something may have changed. A measurement with the system broken at the section *D–D*, looking into the phasing network ϕ, which results in a resistive value of the proper magnitude, is usually sufficient indication that the impedances throughout the system are properly matched.

6. Measurement Technique

The panel of the TYPE 516-C Radio-Frequency Bridge is shown in Figure 7 and the circuit diagram in Figure 8.

The bridge is designed for measuring unknown impedances either in terms of a standard condenser and power factor condenser, as a Schering bridge, or in terms of a standard condenser and an inductance-compensated decade resistor, as a direct-reading impedance bridge.

For the type of measurement to be

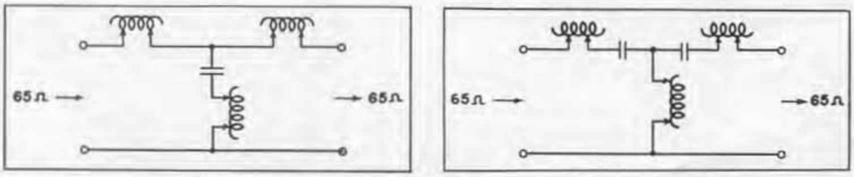


FIGURE 5. Circuit diagrams of the phasing networks used at WEEI

made on broadcast radiating systems, data are most conveniently taken with the bridge used as a direct-reading impedance bridge. For such measurements the bridge method has a considerable advantage over other methods in convenience and speed of operation. Users of the bridge in the field have stated that it is possible to make, in a few hours, measurements which might consume several days' time with resonance methods.

The full advantage of the bridge's direct-reading feature is obtained for the measurement of impedances having a resistive component between 0 and 100 Ω and a reactive component corresponding to a series capacitance between 40 and 1150 $\mu\mu$f. For the measurement of impedances which have an inductive reactance, or a capacitive reactance falling outside this range, a condenser in series with the unknown impedance must be used. For the measurement of impedances which have a resistive component between 100 and 600 Ω, an external resistor may be connected in series with the internal inductance-compensated decade resistor in the bridge. Type 500 Resistors are well adapted for such service and are recommended for values up to 500 Ω.

For accuracy and flexibility of operation in making antenna measurements, the use of a series condenser is recommended in practically all cases. It is seldom possible in a broadcast installation to connect the bridge to the points between which impedance is to be measured without the use of relatively long leads. Leads which are three or four feet long may well have inductive reactances of from 1 to 10 Ω at broadcast frequencies and such a reactance, measured as part of the unknown impedance,

Figure 6. This photograph shows the radio-frequency bridge, the modulated oscillator, and radio receiver set up in the "dog house" at the base of the antenna. The equipment at the extreme left of the picture includes the impedance-matching networks and meters for reading antenna current

may lead to serious errors in low-impedance measurements. With a series condenser, the effect of long leads may be eliminated by making two balances, one with unknown impedance shorted at its terminals and one with short removed.

The procedure to be followed in making such measurements is as follows:

(1) A series fixed condenser is chosen, the capacitance of which lies between 40 and 1150 $\mu\mu$f. The value of condenser chosen should be such that when the unknown impedance is placed in series the effective capacitance will still be within those limits.

(2) The bridge is connected to the unknown impedance with the fixed condenser in series with the high lead, and the unknown impedance is then short-circuited at its terminals.

(3) The internal inductance-compensated decade resistor in the bridge is set to zero and the bridge balanced with the internal standard condenser and the power factor adjustment. The setting, C_1, of the standard condenser is recorded.

(4) The short-circuit is removed from the terminals of the unknown impedance and the bridge rebalanced with the internal decade resistor and the internal standard condenser. This gives the setting, R, of the resistor and a setting, C_2, of the standard condenser.

The change of resistance in the bridge, R, is then equal to the resistive component of the unknown and the change of reactance in the bridge,

$$\frac{1}{\omega}\left(\frac{1}{C_1}-\frac{1}{C_2}\right)=\frac{1}{\omega}\left(\frac{C_2-C_1}{C_1C_2}\right),$$ is equal to the reactive component of the unknown.

Since the leads to the unknown impedance are included in circuit in both measurements, their impedance drops out in taking impedance differences and no error is introduced. A small residual error is left, which is caused by the capacitance of the high lead and series condenser to ground, but this is usually negligible for low-impedance measurements.

The bridge is ordinarily used with a modulated oscillator as power source and a radio receiver as detector. It has been found that, if distortion occurs in the audio modulating voltage or in the modulation process, false readings may be obtained when the radio set is not accurately tuned to the carrier frequency. The error is most pronounced when the reactance to be measured varies with frequency in a manner markedly different from the reactance of the internal standard condenser. Conditions under which this error may be important are readily recognized by the presence of a

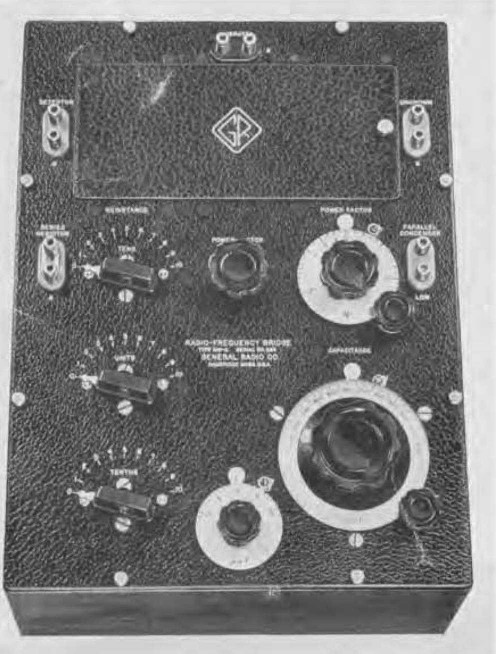


FIGURE 7. Panel photograph of the TYPE 516-C Radio-Frequency Bridge

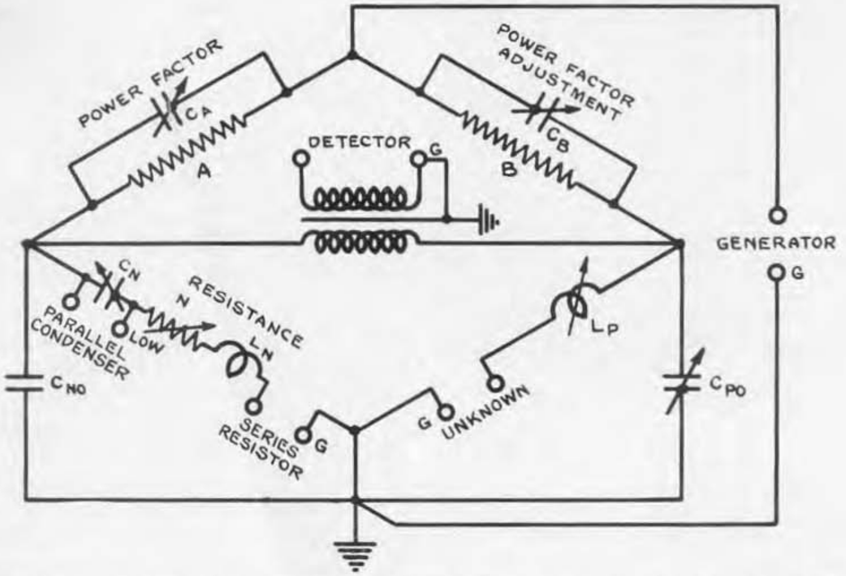


FIGURE 8. Circuit diagram of the TYPE 516-C Radio-Frequency Bridge. Careful adjustment in our laboratory of C_{PO} and L_P to compensate for residual impedances makes the bridge direct reading in capacitance and resistance

strong second harmonic of audio frequency at the bridge balance. The second harmonic is caused by the beating together of the first-order side-bands and does not of itself cause any error in the bridge balance.

By using an unmodulated oscillator for a power source and a radio set with a beat oscillator coupled to the *i-f* stages, this error is avoided since the bridge is then operated at a single frequency. A modulated source is considerably more convenient to use, however, and, in general, careful tuning to the carrier will yield a sufficiently accurate result.

The complete set-up of equipment recommended for antenna measurements consists of:

(1) TYPE 684-A Modulated Oscillator (can be used either modulated or unmodulated).

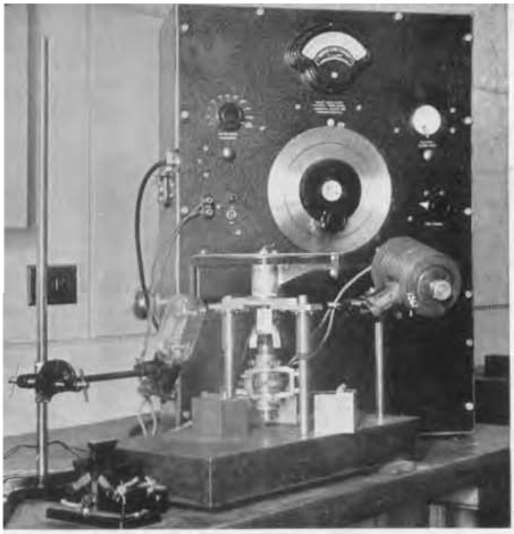
(2) TYPE 516-C Radio-Frequency Bridge.

(3) One 200 $\mu\mu$f, one 500 $\mu\mu$f, and one 1000 $\mu\mu$f TYPE 505 Condensers.

(4) One 100 Ω and two 200 Ω TYPE 500 Resistors.

(5) Radio receiver. If the receiver is used with a local beat oscillator in the *i-f* circuit to beat with an unmodulated wave from the bridge, it should be provided with a good sensitivity control. This is necessary because, for loud signals, a local beat oscillator will tend to maintain the audio output constant, irrespective of input signal, over a fairly wide range at high input levels. Under such conditions it is impossible to determine when a balance is approached and the balance point is "knife-edge" in width.

— D. B. SINCLAIR



MISCELLANY

• MANY GENERAL RADIO instruments designed primarily for the communications field find their way into industrial research laboratories, where the use of electrical methods of measurement in investigating mechanical phenomena is constantly increasing. One instrument which seems to be almost universal in its application is the TYPE 636-A Wave Analyzer. The photograph at left shows this instrument as used in the laboratories of the Sperry Gyroscope Company in connection with vibration studies. We are indebted to the authors and to *Electrical Engineering* for permission to reproduce this photograph which was used to illustrate an article by O. E. Esval and C. A. Frische entitled "Dynamic Balancing of Small Gyroscope Rotors," appearing in the June, 1937, issue.

• GENERAL RADIO engineers participate in technical conferences — at the 1938 Winter Convention of the A.I.E.E., H. H. Scott and L. E. Packard attended the conference on Sound and Vibration; W. N. Tuttle the conference on Network Analysis and Synthesis. A. E. Thiessen will lead the discussion on Modulation and Distortion Measurements at the Broadcast Engineering Conference sponsored by Ohio State University, February 14 and 15.

Mr. Scott, on February 15, will speak before the Engineers' Club of Philadelphia on the industrial applications of General Radio instruments.

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