The GENERAL RADIO EXPERIMENTER

VOL. VIII. No. 11   APRIL, 1934

ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

THE GENERAL RADIO-HAZELTINE REACTANCE METER

THE Hazeltine Corporation and associated companies have built up a completely successful testing routine for broadcast-receiver research and production involving the use of the "reactance meter." This instrument allows quick measurement of coils and condensers and quick adjustment of the "ganging" or "tracking" of receiver circuits. Many an engineer has told us that in his laboratory the reactance meter is one of his most-used instruments.

The great number of uses for the reactance meter in the radio industry has prompted the General Radio Company to manufacture this instrument under Hazeltine designs and patents. The original designs have been modified slightly, in order to incorporate improvements that have become possible since the original designs were drawn up.

The General Radio TYPE 421-A Reactance Meter consists essentially of two radio-frequency oscillators. In operation, both are set to the radio frequency at which the measurement is to be made and the unknown reactance is then connected across the tuning circuit of one of them. This oscillator is then retuned to zero beat with the first one by means of a variable condenser, the dial of which is calibrated directly in micromicrofarads. The reading of the dial, if negative, indicates directly the capacitance of the unit being measured. If the reading is positive, an inductance is indicated.

For the rapid matching of coils, etc., it is not necessary to convert this inductance reading to millihenrys or microhenrys since the micromicrofarad units may be used directly as a basis of comparison. Where a definite measure of inductance is required, it may be obtained by the simple formula

$$L = \frac{1}{\omega^2 \, \Delta C}$$ in which L is the inductance in henrys, ω is 2π times the frequency at which the measurement is made, and ΔC is the capacitance difference read directly from the reactance-meter dials.

The reactance meter differs from the usual bridges used for measuring inductance and capacitance in that the
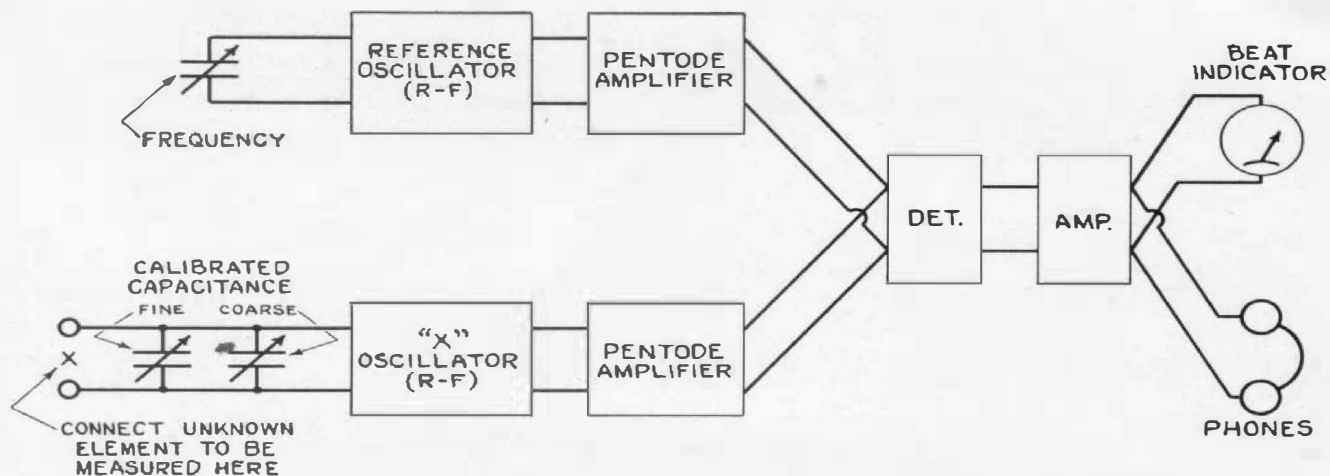
FIGURE 1. The reactance meter contains two oscillators, a calibrated condenser, and a means for indicating zero beat between the two oscillator systems

measurements are actually made at radio frequencies, thus closely approximating actual operating conditions. Furthermore, no power-factor balance is required and the indications are practically independent of power factor for most purposes. The instrument is simple to operate and direct reading for small values of capacitance. It also provides a very quick check when matching coils, condensers, etc., without the use of any computations.

What the instrument actually measures is the shunt susceptance connected to its terminals. Normal values of conductance have only small effect upon the reading. At some frequencies the reactance meter will actually function with conductances as large as 400 micromhos connected across its terminals.

The direct-reading dial on the instrument provides a range of 40 $\mu\mu$f and may be read to within 0.2 $\mu\mu$f or better. This dial controls the small condenser which is used in making most measurements. For measuring relatively large capacitances and inductances a larger condenser is provided on the meter. This condenser is supplied with a calibration curve and has a total capacitance of 2000 $\mu\mu$f. The actual range which may be covered on this large condenser depends upon the frequency at which the measurement is made, since this condenser is also used for setting to zero beat. Under the worst conditions, however, the range on this dial is equal to approximately 500 $\mu\mu$f. If desired, an external precision condenser can be used to extend the range where necessary. Extremely large capacitances or small inductances can be measured when placed in series with larger reactances, as will be described presently.

In designing the circuit for the reactance meter every effort was made to provide maximum convenience and accuracy. Aside from the direct-reading capacitance dial, and the calibration curve for the large condenser, a frequency calibration curve is supplied for each set of coils. Important frequencies in the broadcast band are calibrated directly on the frequency dial.

The visual beat-indicator meter is provided to supplement the usual telephones in setting accurately to zero

beat. This meter is of the oxide-rectifier type and gives a definite indication allowing extremely accurate setting of the capacitance dials. Each of the oscillators is provided with a separate pentode amplifier, thus electrically isolating the oscillator circuits and, accordingly, minimizing any tendency for the two oscillators to pull into step as zero beat is approached. Oscillator and amplifier tubes and coils are individually shielded. The circuit has also been designed so that the operation is uniform over a wide range of frequencies and the readings of the instrument are independent of line voltage fluctuations.

It will readily be seen that the reactance meter may be used for a wide variety of measurements in the average receiver laboratory or production line. By means of this instrument, the differences between coils, condensers, etc., in the various stages of a multi-stage radio-frequency or intermediate-frequency amplifier can be immediately determined and suitable adjustments made if desired.

These measurements can generally be made without disconnecting any of the other equipment which may be connected in the circuit. For instance, let us consider a radio-frequency amplifier having four ganged condensers. Some frequency, say 1400 kilocycles, is selected for the test. With the first condenser in the gang connected across the "unknown" terminals of the reactance meter, and the receiver tuned for 1400 kilocycles, the COARSE CAPACITANCE dial is set for zero beat. The reactance meter is then disconnected from the first condenser in the gang and connected to the second condenser and retuned to zero beat by means of the FINE CAPACITANCE dial. The reading of this dial then indicates directly how much the second condenser is out of line with the first. This procedure may then be continued on each of the other condensers in the gang and with the condensers set to tune the receiver at various frequencies. For these tests the reactance meter frequency may remain unchanged. Typical results, as-main unchanged. Typical results, as-

FIGURE 2. Front-of-panel view of the TYPE 421-A R. F. Reactance Meter. The dial at the left adjusts the frequency of the reference oscillator, the two at the right the "X" oscillator

suming the set to be aligned at 1400 kc on the dial, are as follows:

Approx. Receiver Tuning	Condenser Corrections			
	No. 1	No. 2	No. 3	No. 4
1400 kc	0	0	0	0
1200 kc	0	+0.2 $\mu\mu$f	+0.4 $\mu\mu$f	−0.6 $\mu\mu$f
1000 kc	0	−1.4 $\mu\mu$f	−0.2 $\mu\mu$f	−0.2 $\mu\mu$f
800 kc	0	−3.4 $\mu\mu$f	+0.6 $\mu\mu$f	+0.6 $\mu\mu$f
600 kc	0	−3.0 $\mu\mu$f	+1.4 $\mu\mu$f	+1.0 $\mu\mu$f

A similar procedure may be used in checking the coils. For this purpose the tuning condensers are set at minimum capacity, thereby tuning all circuits out of the working range. In this case, however, the frequency of the reactance meter should be changed rather than the tuning condensers.

It will readily be seen that these types of measurements are invaluable in designing ganged receivers and also in checking gang condenser assemblies, matched sets of coils, etc. Charts like the above are extremely useful when made as a part of the sampling procedure to check alignment on sets taken from the production line. A similar but simplified procedure may be used for accurate alignment of completed receivers on the assembly line. In this case the trimmers are readjusted to produce zero beat.

The reactance meter is also useful in measuring the resonant frequency of choke coils, etc., since a coil measures zero reactance at its natural frequency, inductive below and capacitive above.

The capacitance of a large bypass condenser may be measured by connecting it in series with a known capacitance C within the normal range of the reactance meter. If ΔC is the difference between the readings of the reactance meter with and without the unknown in series with the condenser

C, the actual capacitance of the unknown will be equal to $\dfrac{C^2}{\Delta C} - C$.

Another frequent use of the reactance meter is to determine the inherent capacitance of a radio-frequency coil which resonates somewhere above the broadcast band. For this purpose, two frequencies are used and measurements taken with the reactance meter. If C_1 is the reading of the reactance meter at frequency f_1, and C_2 is the reading at frequency f_2, when f_2 is greater than f_1, then the actual L and C of the coil are:

$$L = \frac{1/f_1^2 - 1/f_2^2}{4\pi^2(C_1 - C_2)}$$

$$C = \frac{f_1^2 C_1 - f_2^2 C_2}{f_2^2 - f_1^2}$$

A chart for easily obtaining L and C is provided in the instruction book.

The above illustrations do not in any way include the entire scope of the reactance meter, which can be applied to an almost unlimited number of problems. The illustrations are merely given as concrete examples of some of the more common types of measurements. Complete data for making these and many other types of measurements are supplied in the instruction book for the reactance meter.

The instrument is regularly supplied with three sets of coils, one covering the broadcast band, the others covering from 125 kc to 300 kc and from 1500 kc to 4000 kc. It is entirely operated from a source of 115-volts, 60-cycle power. All tubes are supplied.

—H. H. SCOTT

A SHIELDED TRANSFORMER FOR BRIDGE-CIRCUIT USE

THE best transformer for connecting a generator to a bridge would have no direct capacitance between its primary and secondary windings and no terminal capacitances associated with its secondary winding. The existence of direct capacitance between primary and secondary allows the reflection into the bridge circuit of the terminal capacitances of the primary winding, made up in large part of the terminal capacitances of the generator itself, and applies directly to the bridge a small part of the generator voltage proportional to this direct capacitance. The existence of terminal capacitance of the secondary winding places these capacitances across the two arms of the bridge whose junction is grounded.[1]

When a bridge is used for direct measurements, the error introduced by terminal capacitances becomes negligible only when the ratio between these capacitances is the same as that between the two ratio arms. Transformers for equal-arm bridges are usually constructed in such a manner that the secondary terminal capacitances are equal. While the same practice might be followed for bridges with unequal ratio arms, it is not usually adopted. For bridges with variable ratio arms it is, of course, impossible to cause the ratio between the terminal capacitances to vary as the ratio arms are changed.

While for substitution methods the values of the terminal capacitances generally cancel out from the bridge equations, it is usually desirable to make them as small as possible. In this way, the second order effects due to the terminal capacitances and the errors introduced by the power factors of these capacitances are minimized.

Equality of the terminal capacitances may be obtained in two ways. Both depend upon the fact that either terminal capacitance of a winding is almost entirely that between the shield and the adjacent layer of the winding. To make the terminal capacitances equal, it is only necessary that the first and last layers of the winding be symmetrical with reference to the shield.

This was accomplished in the shielded transformers used in the General Radio TYPE 216 Capacity Bridge by dividing each winding into two parts and placing one coil of each winding on each of the legs of the transformer with the shield in between them, as shown in
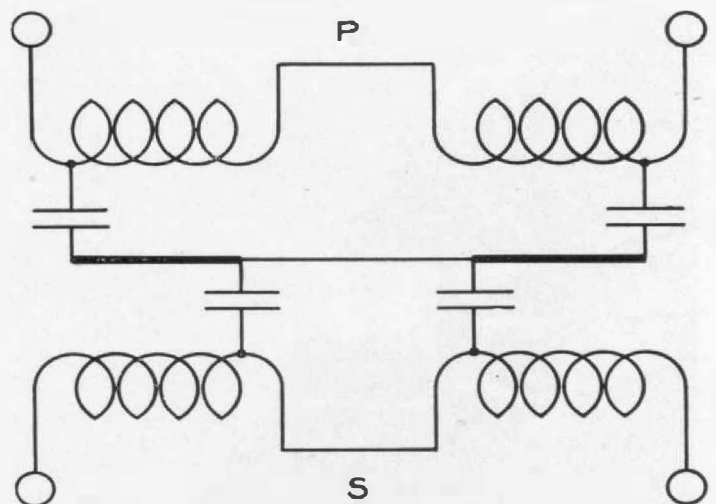

FIGURE 1. Two ways of connecting the "divided-winding" type of shielded transformer. The connection shown for the "S" winding is used on both windings of the TYPE 216 Capacity Bridge

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[1] The "terminal capacitances" of a transformer winding are defined as the lumped equivalent capacitances between each of the two terminals and the shield of the distributed capacitance between the winding and the shield. They are $C_{P1h'}$, $C_{P2h'}$, $C_{S1h''}$, and $C_{S2h''}$ in Figure 2. — EDITOR.
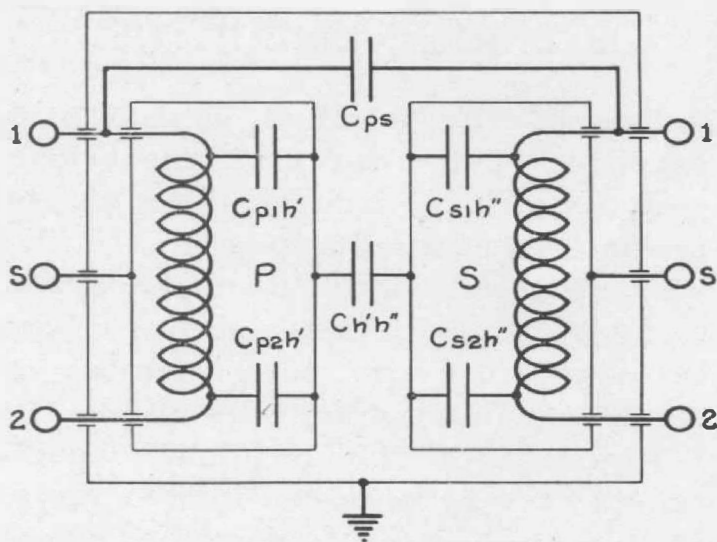
FIGURE 2. Capacitance network in the new Type 578-A Bridge Transformer

Figure 1. The two coils could be connected together so that the terminals of the winding nearest the shields are the terminals of the complete winding as shown for the primary winding, or they could be connected so that the terminals nearest the shields are at the junction of the two coils as shown for the secondary winding. In each case, the other terminal capacitance of each half of the winding is small. For the second case, in which the larger termi-
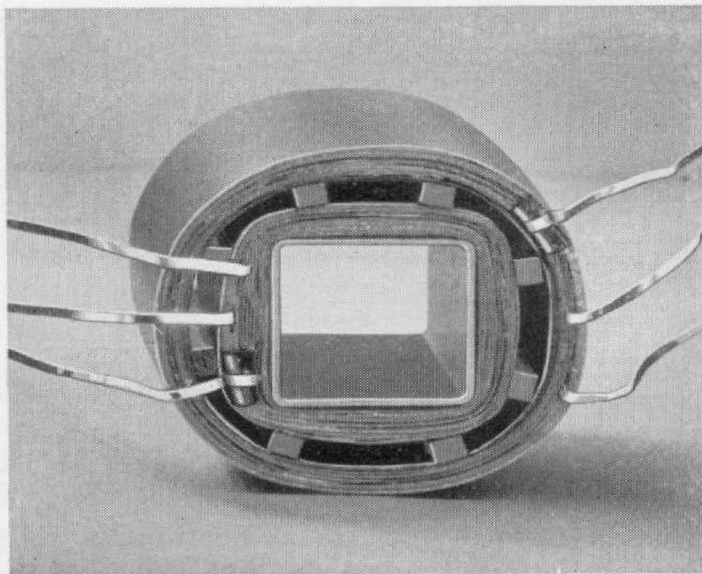

FIGURE 3. The TYPE 578-A Bridge Transformer has an air space between the two individually shielded windings

nal capacitances are concentrated at the junction of the windings, the effective terminal capacitances of the coil are divided between its terminals in proportion to the voltages appearing across the two halves.

A second method by which the terminal capacitances of a coil may be made equal is illustrated in Figure 3. Two shields are provided, one at the beginning and the other at the end of the winding. The terminal capacitances are then the capacitances between the first and last layers of the winding and the adjacent shield. By making the thickness of the paper insulation between the layer and the shield proportional to the diameter of that layer, these two capacitances may be equalized. The two shields are then connected together. This method is preferable to that in which windings are placed on both legs of the transformer because it simplifies the method of winding and increases the coefficient of coupling of the transformer.

With the amount of paper that is allowable between the winding and shield, the terminal capacitances are larger than is desirable, being of the order of 200 $\mu\mu$f. The power factors of these terminal capacitances are approximately that of paper, about 1%. Both the effective terminal capacitance and its power factor can be reduced materially by surrounding both primary and secondary windings with their own shields and separating the adjacent shields by insulating spacers so that most of the capacitance between the shields is that due to air. In this manner, half the capacitance between the two shields is placed in series with each terminal capacitance so that each ef-

fective terminal capacitance is less than one-half of the capacitance between the two shields, provided that shield next to the winding is allowed to float, while the other shield is grounded. In case the shield next to the winding is connected to one of its terminals, the capacitance associated with that terminal becomes equal to the capacitance between the two shields, the other terminal capacitance being somewhat greater than the direct capacitance between the windings.

The new TYPE 578-A Bridge Transformer is made up of a primary and secondary winding shielded in the manner described above. This construction is shown in Figure 2. Representative values of its various terminal and direct capacitances are given in Table I. A copper shield placed between the iron core and the windings is grounded to the case. This effectively grounds the iron core and eliminates the necessity for grounding each separate lamination.

Aside from electrostatically isolating the generator and bridge which it connects, a transformer also serves to match the impedance of the bridge to the impedance of the generator and allow the maximum power transfer to the bridge. In the ideal transformer, the

FIGURE 4. A mounted TYPE 578-A Bridge Transformer showing the terminal plate on the 600-turn side

turns ratio of secondary to primary is the square root of the ratio of its load to the generator resistance. For this ideal case, the voltage appearing across the secondary load is one-half the generator voltage multiplied by the turns ratio. As the resistance ratio departs

TABLE I
CAPACITANCES OF TYPE 578-A BRIDGE TRANSFORMER

DIRECT CAPACITANCE	Ground		TERMINAL CAPACITANCE	Ground	
C_{PS}	h'	.2 $\mu\mu f$	$C_{P1h'}$	$h''S$	200 $\mu\mu f$
C_{PS}	h''	.2 $\mu\mu f$	$C_{P2h'}$	$h''S$	200 $\mu\mu f$
$C_{Ph'}$	h'', S	400 $\mu\mu f$	$C_{P1h''}$	S	13 $\mu\mu f$
$C_{Sh''}$	P, h'	400 $\mu\mu f$	$C_{P2h''}$	S	13 $\mu\mu f$
$C_{h'h''}$	P, S	30 $\mu\mu f$	$C_{S1h''}$	Ph'	200 $\mu\mu f$
$C_{Ph''}$	S	26 $\mu\mu f$	$C_{S2h''}$	Ph'	200 $\mu\mu f$
$C_{Sh'}$	P	26 $\mu\mu f$	$C_{S1h'}$	P	13 $\mu\mu f$
			$C_{S2h'}$	P	13 $\mu\mu f$

TABLE II

RESISTANCE RANGES OVER WHICH VOLTAGE RATIO OF A TYPE 548-A BRIDGE TRANSFORMER IS WITHIN 6DB

Connection	Generator Resistance	Load Resistance
Step-up	50 Ω to 5 kΩ	1 kΩ to 100 kΩ
Step-down	1 kΩ to 100 kΩ	50 Ω to 5 kΩ

from equality with the square of the turns ratio, the voltage ratio decreases slowly from its ideal maximum. For a departure of 4 to 1 in turns ratio or 16 to 1 in resistance ratio the voltage ratio is reduced to one-half the maximum, or 6 db. An allowable variation in voltage ratio of this magnitude is reasonable in the case of bridges for, by increasing the power of the oscillator or the amount of amplification in the detector, it is easy to make up for a 2 to 1 change in voltage. A transformer having a turns ratio of 4 to 1 which can be used either step-up or step-down is, therefore, suitable for all resistance ratios between 16 to 1 and 1 to 16. This is a sufficiently wide range to cover most of the impedances met with in generators and bridges.

The values chosen for the TYPE 578-A Bridge Transformer are such as to give a frequency range from 50 cycles to 10 kilocycles, over which the voltage ratio does not drop below one-half its maximum value, or 6 db. This variation in voltage ratio is allowable for bridge connections although it would be considered unsatisfactory for a high-quality voice circuit. For resistances varying from 50 ohms to 100 kilohms, this range may be divided as between step-up and step-down use according to Table II. For extremes in both resistance and frequency range, the effects of the two ranges are additive, so that the voltage ratio under these conditions may be ¼ the maximum value, or 12 db.

The transformer is mounted in a Model B case* with the copper shield inside the iron core grounded to the case. The terminals are brought out to six screw terminals, three on each side with the associated shield at the right, for permanent panel mounting. It may be mounted on one of the TYPE 274 Transformer-Mounting Bases for easy reversal of connections.

—ROBERT F. FIELD

*See pages 140 and 143 of Catalog G.

[The TYPE 578-A Bridge Transformer, recently developed by Mr. Field, is now available at $15.00. The code word is TABLE.
—EDITOR.]

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