The GENERAL RADIO EXPERIMENTER

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ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

A NEW PRECISION WAVEMETER

FOR the rapid and convenient measurement of frequency with a minimum of equipment, the tuned-circuit absorption-type wavemeter has enjoyed a long and useful career. While for precise measurements it has long since been displaced by the more modern heterodyne instruments and the quartz-crystal standard of reference, its usefulness remains unchallenged in that wide field of measurement where only a moderate accuracy is demanded and where simplicity is an important requirement.

The absorption-type wavemeter consists fundamentally of a condenser, one or more coils, and a resonance indicator. Improvements in the design of these components make possible considerably improved performance in the wavemeter.

FIGURE 1. TYPE 724-A Precision Wavemeter

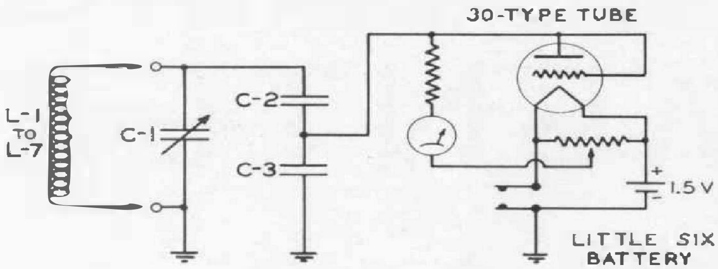

FIGURE 2. Circuit of TYPE 724-A Precision Wavemeter

The TYPE 724–A Wavemeter is a new instrument replacing the older TYPE 224. As a result of the re-design of coils, condensers, and resonance indicator, the new wavemeter has a wider frequency range and a greater sensitivity than its predecessor. The condenser is similar in constructional details to the TYPE 722 Precision Condenser recently described.* This condenser is built around an integrally cast frame of an aluminum alloy, with the rotor shaft, stator rods, and spacers of the same material. Ball bearings support the main shaft. The drive is of the worm-gear micrometer type with the worm cut directly on its shaft. In the wavemeter design, the effective angular rotation is about 270°.

The condenser setting is indicated on the dial and drum and is controlled from the front of the panel. There are 7500 divisions for the entire effective angular rotation of the condenser rotor. The precision of condenser setting is better than one part in 25,000. The plates are shaped to give an approximately linear variation in frequency with scale setting. This makes it possible to use calibration charts in tabular form and to interpolate between points in the table.

Seven coils are used to cover a frequency range between 16 kilocycles and 50 megacycles. The coils are wound on isolantite forms to give low losses and a high degree of stability. Each coil is enclosed in a moulded bakelite case. The plug-in mounting allows the coil to be rotated to obtain different degrees of coupling.

The resonance indicator is a rectifier-type vacuum-tube voltmeter, a distinct advantage over the thermocouple formerly used, since the danger of overloads burning out the indicator is eliminated. The rectifier is coupled to the tuned circuit through a capacitive voltage divider as shown in the circuit diagram, Figure 2.

— ARTHUR G. BOUSQUET

*"A New Precision Condenser," General Radio *Experimenter*, Vol. X, No. 8, January, 1936.

SPECIFICATIONS

Frequency Range: 16 kc to 50 Mc.

Accuracy: 0.25%.

Condenser: Precision worm-drive type.

Coils: Wound on isolantite forms.

Indicator: Rectifier-type vacuum-tube voltmeter.

Net Weight: With carrying case, 35¼ pounds; without carrying case, 18¾ pounds.

Dimensions: Carrying case, 17⅞ x 13 x 12½ inches over-all.

Code Word: WOMAN.

Price: $190.00.

MEASUREMENTS AT LOW FREQUENCIES WITH THE RADIO FREQUENCY BRIDGE

THE TYPE 516-C Radio Frequency Bridge,[1] although designed to operate throughout the broadcast band of frequencies and up to 5 megacycles, can be used at all lower frequencies: carrier frequencies and audio frequencies, and even the power frequency of 60 cycles. The only important changes that must be made are the replacement of the ratio arms and output transformers. This may be readily accomplished because both units are easily detachable and are mounted on the subpanel just below the removable cover. The accuracy of measurement obtainable at the lower frequencies is for all cases superior to that for 1 megacycle. At a frequency of 1 kilocycle the accuracy of substitution measurements is limited only by that of the capacitance and resistance standards used.

The circuit used in the bridge is shown in Figure 2. When an unknown condenser is connected to the terminals in the P arm, the bridge is balanced for capacitance by adjustment of condenser C_N, and for resistance either by the decade resistor N or by the power factor condenser C_A. The calibration of these three controls is such as to make the bridge direct reading in capacitance, resistance, and power factor.

The features of this bridge which make possible its use as a direct reading bridge at 1 Mc are the equality of the ratio arms A and B, the use of a decade resistor[2] N compensated to maintain a constant inductance at all settings and the equalizing of the capacitance arms for series inductance and parallel capacitance by the addition of the inductor L_P and the condenser C_{PO}.

The ratio arms furnished with the bridge have resistances of 100Ω. The power factor condenser C_A has a maximum capacitance of 50 μμf, giving a power factor range at 1 Mc of 3%. The condenser C_B placed across the arm B serves merely to balance out the zero capacitance of C_A. The calibration of the power factor dial is proportional to both the resistance of the ratio arm and to frequency. Hence, when the bridge is used at frequencies below 1 Mc, the range of the power factor condenser C_A can be restored by increasing the ratio arms. This is conveniently done in multiples of ten, that is, 1000-ohm arms for 100 kc,

[1]C. E. Worthen, "Improvements in Radio Frequency Bridge Methods for Measuring Antennas and Other Impedances," General Radio *Experimenter*, Vol. VIII, No. 7, December, 1933.

[2]R. F. Field, "Constant Inductance Resistors," General Radio *Experimenter*, Vol. VIII, No. 10, March, 1934.

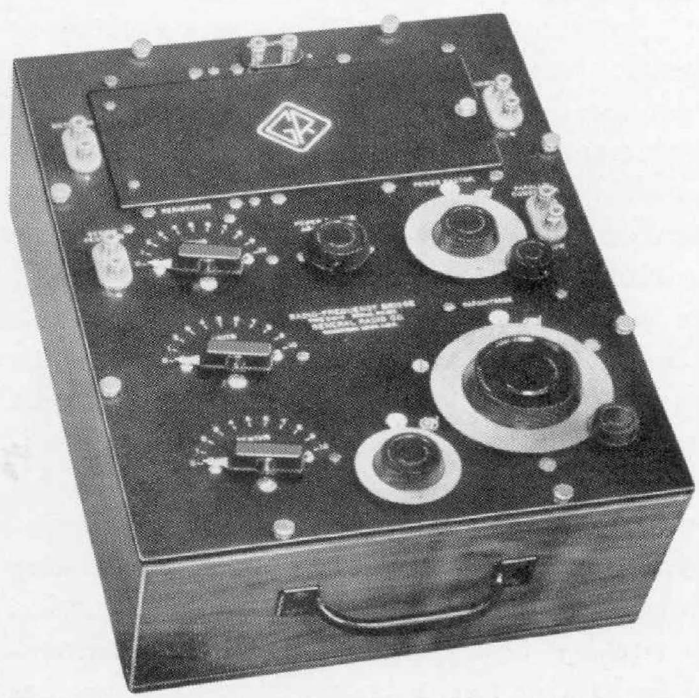

FIGURE 1. TYPE 516-C Radio-Frequency Bridge

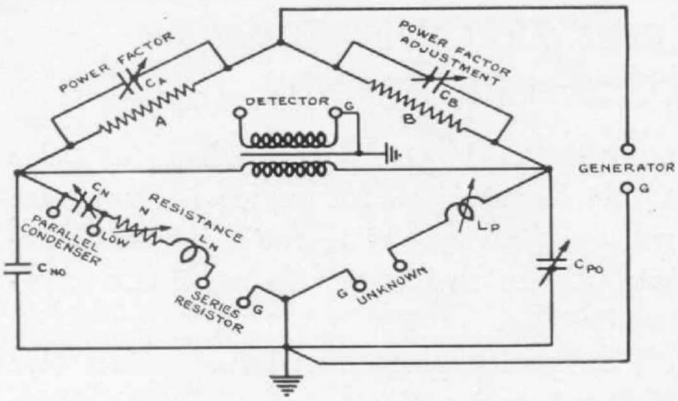

FIGURE 2. Circuit of the radio-frequency bridge. Circuit constants are as follows:

$A, B = 100\ \Omega$
$C_A = 0\text{–}50\ \mu\mu f$
$C_B = 15\ \mu\mu f$, adjustable
$C_N = 1000\ \mu\mu f$, maximum
$N = 0\text{–}111\ \Omega$
$C_{NO}, C_{PO} = 35\ \mu\mu f$
$L_P = 1.2\ \mu h$, approximately

10,000-ohm arms for 10 kc, and 100,000-ohm arms for 1 kc. For the power frequency of 60 cycles the arms should be 1.667 megohms. Ratio arms of these sizes are now available.

The power factor range may be extended by adding a condenser across the arm *A* with its shield connected to the junction of the ratio arms, so as not to increase the parallel capacitance C_{PO}. At a frequency of 1 kc with 100,000-ohm ratio arms, a total capacitance of 1600 $\mu\mu$f will give a dissipation factor of unity.

Increasing the resistance of the ratio arms as the frequency is lowered serves also to keep their resistance comparable to the reactance of the capacitance arms. In general, this condition gives to a bridge its maximum sensitivity of balance. Bridge sensitivity also depends on the relative position of generator and detector with respect to the various bridge arms, usually being greatest for that connection which allows the greatest current input to the bridge. With ratio arms much lower in impedance than the capacitance arms, the generator should be connected across the ratio arms, provided the input impedance of the detector is high. A limit to this practice is set by the power dissipation allowable in the ratio arms. For this reason low voltage bridges have the generator connected across the ratio arms and high voltage bridges between the junctions of ratio arms and capacitance arms. The terminals of this bridge are marked for the latter connection, but generator and detector may be transposed as occasion demands.

The lower limit of frequency of the air core transformer furnished with the bridge is about 500 kc. For the lower frequencies TYPE 578 Shielded Transformers[3] are available in two models, having the two frequency ranges 2 kc to 500 kc and 20 cycles to 5 kc. These transformers have nearly complete shields around both windings with an air space between the shields. This construction makes the effective terminal capacitance to be placed across the capacitance arms about 40 $\mu\mu$f. Adding this to the 35 $\mu\mu$f already in the bridge increases the value of C_{PO} to about 70 $\mu\mu$f. This may differ by ± 10 $\mu\mu$f between transformers, and the two terminal capacitances in any one transformer may differ by 3 $\mu\mu$f. Because of this latter difference in capacitance the parallel condenser C_{PO} should be reset for each transformer, as must also the zero adjustment condenser C_B. The exact value of this capacitance may be measured by a direct capacitance measurement on a

[3]"Shielded Transformers for Impedance Bridges," General Radio *Experimenter*, Vol. X, No. 5, October, 1935.

TYPE 650-A Impedance Bridge.[4] It may also be measured on the bridge in which it exists by changing one of the ratio arms a known amount, such as by shunting it with a ratio arm of ten times its resistance.

The capacitance and resistance ranges of the bridge are set by the inductance and resulting natural frequency of the capacitance arms, and by the impossibility of compensating a decade resistor much above 100Ω. As the frequency is lowered these limits can be extended. Terminals are provided for the addition of parallel capacitance and series resistance. Since natural frequency varies as the square root of the total capacitance, it ceases to be an important limitation in capacitance below 100 kc. For the same reason, resistors need no longer be compensated for inductance below that frequency; but the capacitance to ground of the rotor of the standard condenser and of the three decade resistors, amounting to about 100 $\mu\mu$f, will be placed across this added resistance. This shunt capacitance sets limits of perhaps 1000 ohms at 100 kc and 100,000 ohms at 1 kc.

The accuracy of the bridge for direct reading at the lower frequencies is essentially the same as for radio frequencies. At a frequency of 1 kc the errors are, for capacitance, 5 $\mu\mu$f or 1%, whichever is the greater, and for resistance 0.1 ohm or 2%, provided the proper preliminary adjustments of the bridge have been made. For power factor the error is 0.0002 or 5% if the error caused by the parallel capacitance C_{PO} is taken into account.[5]

Substitution measurements in which the unknown condenser is connected in parallel with the standard condenser are more accurate than direct measurements across the bridge. The preliminary adjustments of the bridge are replaced by an initial balance with the unknown disconnected. Losses in the standard condenser are eliminated except at high frequencies where the ohmic resistance of the condenser is significant.[6]

When the calibrated condensers mounted in the bridge are used as standards, any fixed condenser of

FIGURE 3. TYPE 578 Transformers are available on plug-in bases for use with the radio-frequency bridge. The model shown in the photograph can be used between the bridge and the a-c line for 60-cycle measurements

[4]R. F. Field, "Direct Capacitance and Its Measurement," General Radio *Experimenter*, Vol. VIII, No. 6, November, 1933.

[5]All power factor readings must be increased by the factor $(1+\frac{CPO}{CP})$.

[6]"Residual Impedances in the Precision Condenser," General Radio *Experimenter*, Vol. X, No. 5, October, 1935.

suitable size may be connected in the P arm to complete the bridge circuit, together with sufficient resistance to make possible a resistance balance with the added resistor N or the power factor condenser C_A. The error for capacitance is that of the standard condenser, 5 $\mu\mu$f or 1%. Small capacitances of less than 20 $\mu\mu$f can be measured to an accuracy of .2 $\mu\mu$f or 2% by using the small condenser which is connected in parallel with the main condenser.

When an external precision condenser is used as a standard, it is connected in the P arm and the calibrated condenser in the bridge used merely as a balancing condenser. The unknown condenser is then connected across the precision condenser. The error for capacitance is that of the precision condenser, 1 $\mu\mu$f or .1% for a direct reading on the TYPE 222-M Precision Condenser or .1 $\mu\mu$f or .1% with the application of its worm correction.[7] The resistance balance can be made by means of the added resistor N, an external decade resistor connected in series with the precision condenser or the power factor condenser C_A.

The power supply for the bridge may be either a modulated or unmodulated vacuum-tube oscillator, depending on the type of detector used.

Above 150 kc an all-wave radio receiver makes a very satisfactory detector when used in conjunction with a modulated oscillator. A short-wave receiver arranged for the reception of c-w signals may be used with an unmodulated oscillator.

Below 100 kc a resistance coupled amplifier, having a gain of 80 db and using a copper-oxide rectifier or vacuum-tube voltmeter, forms the most convenient detector. It must, however, be tuned sufficiently to have a discrimination of at least 20 db against the second harmonic, both to remove the error resulting from harmonics and to sharpen the bridge balance.

In the narrow band of audio frequencies lying between 0.5 and 5 kc, head telephones may be used and the amplifier gain somewhat reduced. At the power frequency of 60 cycles certain precautions must be taken if power is taken from the a-c line. The 60-cycle static and magnetic fields in the average laboratory are often sufficiently intense to provide appreciable coupling between generator and detector. While the effect of the electrostatic field may be removed by shielding, the effect of magnetic fields at 60 cycles can be reduced only by removing their source to a sufficient distance or by using astatic transformers. At other frequencies it is also important that the generator have a negligible external magnetic field.

The TYPE 484-A Modulated Oscillator, which may be used either modulated or unmodulated, covers the frequency range down to 10 kc. TYPES 713-A and 613-B Beat-Frequency Oscillators extend the frequency range to 10 cycles. The TYPE 508-A Oscillator covers the audio-frequency range from 200 cycles to 4 kc in 10 discrete steps, while the TYPES 213 and 813 Audio Oscillators operate at the single frequencies, 400 cycles and 1 kc. TYPES 514-A and 714-A Amplifiers are resistance coupled amplifiers having

[7]R. F. Field, "Increased Accuracy with the Precision Condenser," General Radio *Experimenter*, Vol. X, No. 5, October, 1935.

gains of 45 and 80 db, respectively, up to 50 kc, the latter being a-c operated.

A TYPE 578-A Shielded Transformer may be used to connect the bridge to the 110-volt 60-cycle supply. It should be used step up when connected to the generator terminals and step down when connected to the detector terminals. In the former case about 400 volts will be applied across each condenser, in the latter 3 volts.

—R. F. FIELD

RATIO ARMS FOR TYPE 516-C RADIO FREQUENCY BRIDGE

Type	*Resistance*	*Frequency*	*Price*
516-P2	10 Ω	10 Mc	$6.00
*516-P3	100 Ω	1 Mc	6.00
516-P4	1 kΩ	100 kc	6.00
516-P5	10 kΩ	10 kc	6.00
516-P6	100 kΩ	1 kc	8.00
516-P7	1667 kΩ	60 c	10.00

SHIELDED TRANSFORMERS

Type	*Frequency Range*	*Price*
*516-P10	5Mc—10Mc	$8.00
578-A	60 c supply	15.00
578-AR	50 c—10 kc	20.00
578-BR	20 c— 5 kc	20.00
578-CR	2 kc—500 kc	20.00

*Furnished with the bridge.

A DIRECT-READING CONDENSER FOR SUBSTITUTION MEASUREMENTS

FOR capacitance measurements by the substitution method,[1] a variable air condenser reading negative increments of capacitance directly on its scale is a great convenience. The TYPE 222-M Precision Condenser, which has been widely used for this purpose, has now been discontinued and is replaced by the TYPE 722-M Precision Condenser. The new instrument is similar in details of construction to the TYPE 722-H and TYPE 722-F Precision Condensers recently described.[2]

The maximum capacitance of the condenser is in the vicinity of 1100 μμf, which provides a direct-reading range of 1000 μμf.

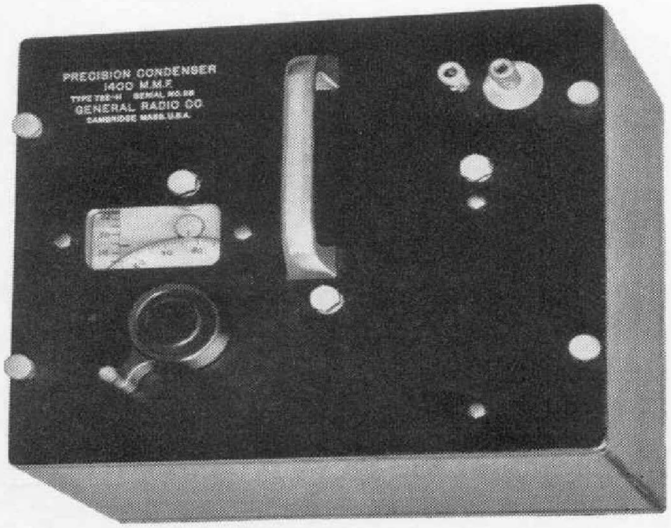

FIGURE 1. External view of a TYPE 722 Precision Condenser

[1] R. F. Field, "An Equal-Arm Capacitance Bridge," General Radio *Experimenter*, Vol. IV, No. 8, January, 1930.

[2] "A New Precision Condenser," General Radio *Experimenter*, Vol. X, No. 8, January, 1936.

SPECIFICATIONS

Capacitance Range: Direct reading in capacitance *removed* from circuit over a range of 1000 $\mu\mu$f.

Accuracy: 1 $\mu\mu$f or 0.1%, whichever is larger.

Dimensions: Panel, 8 x $9\frac{1}{8}$ inches; depth, $8\frac{1}{8}$ inches.

Net Weight: $11\frac{1}{8}$ pounds; $20\frac{1}{4}$ pounds with carrying case.

Type	*Code Word*	*Price*
722-M	COMIC	$100.00

TYPE 713-A BEAT-FREQUENCY OSCILLATOR

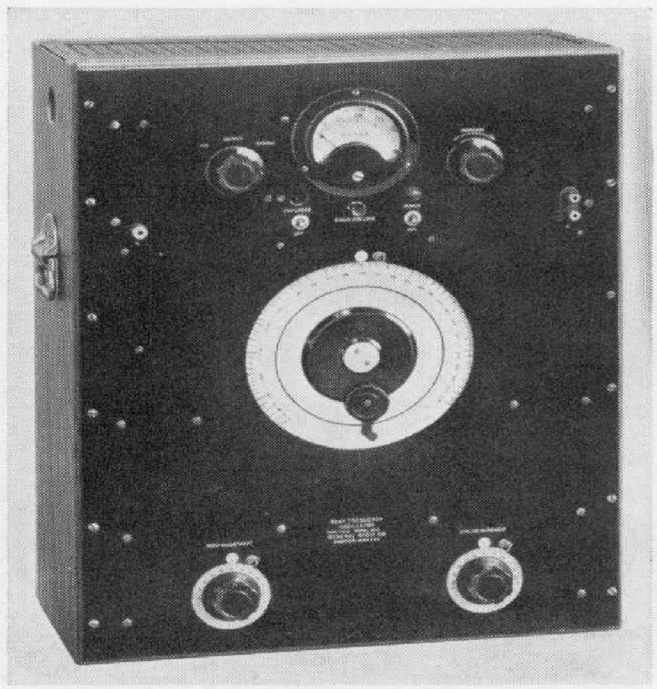

FIGURE 1. TYPE 713-A Beat-Frequency Oscillator

WHEN originally announced in the July, 1935, issue of the *Experimenter* the TYPE 713-A Beat-Frequency Oscillator was calibrated between 10 and 16,000 cycles per second. The actual frequency range covered is greater than this, and, in order to take full advantage of the capabilities of the instrument, the upper limit of calibration has been extended to 20,000 cycles. Units currently available are calibrated over this larger range.

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