THE General Radio EXPERIMENTER

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

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A BOLOMETER BRIDGE FOR THE MEASUREMENT OF POWER AT HIGH FREQUENCIES

I. Introduction

● In the u-h-f region, power measurements are of fundamental importance. While, at lower frequencies, current or voltage is generally measured in preference to power, at ultra-high-frequencies most practical devices for the measurement of these quantities are relatively large with respect to a wavelength, and their accuracy is impaired by the effects of resonance and standing waves. Power measurements, however, can be made with good accuracy at high frequencies by dissipating the power in a bolometer, which is a resistive element with a large temperature coefficient of resistance. The magnitude of the r-f power can be determined either from the measured change in resistance or from the change in bias power required to bring the bolometer resistance back to its original value with no r-f power applied.

The two most generally used types of bolometer elements are the thermistor and the fuse or barretter. A thermistor has a large negative temperature coefficient and consists of a small bead of semi-conducting material in which are embedded two fine wires. The fuse

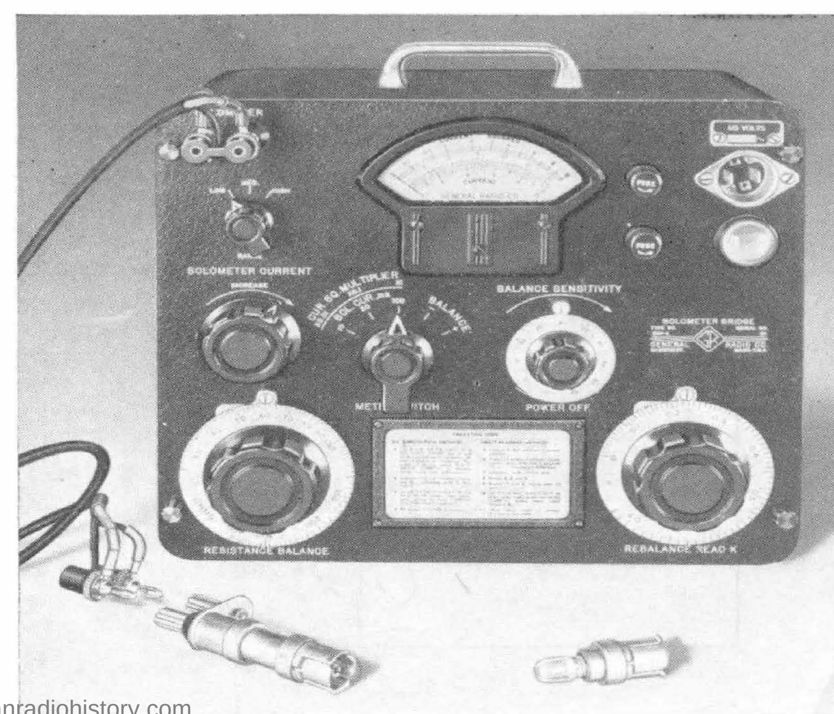


Figure 1. Panel view of the Type 1651-A Bolometer Bridge, with Type 874-H25 Thermistor Unit in left foreground.

or barretter is usually a short length of very fine platinum wire connected between two electrodes.

The change in bolometer resistance resulting from power dissipation is usually measured with a low-frequency or d-c bridge. The TYPE 1651-A Bolometer Bridge is designed for this measurement. It is a general-purpose bridge, flexible and adaptable in operation so that it can be used not only with General Radio bolometers,[1] but with those of other manufacturers as well. A wide range of bolometer resistances can be accommodated, and measurements can be made by either a substitution or a direct-reading method.

In the substitution method, d-c power is substituted directly for r-f power. All readings are made after the final balance, and the measured power is a simple product of dial and meter readings. The direct-reading method depends upon the change in bolometer resistance with power, and in this method the meter is calibrated at one point by substitution, after which other power levels can be read directly from the meter.

II. Circuit

The heart of the TYPE 1651-A Bolometer Bridge is the Wheatstone Bridge of Figure 2, in which the bolometer element forms one arm. To measure power with this circuit by the substitution method, the bridge is first balanced with the r-f power applied to the bolometer element. The balance is obtained by adjusting the applied d-c voltage until the bolometer element is heated to a temperature at which its resistance is the value required for a balance. At balance, the total power, P_1, dissipated in the bolometer element is

$$P_1 = I_1^2 R_B + P_{r\text{-}f} \qquad (1)$$

where I_1 is the d-c current flowing through the bolometer element, R_B is the bolometer resistance at balance, and $P_{r\text{-}f}$ is the r-f power being dissipated in the element.

The r-f power is then removed and the bridge rebalanced by increasing the applied d-c voltage, V. The total power dissipated in the bolometer after this balance is

$$P_2 = I_2^2 R_B \qquad (2)$$

Since the same bolometer resistance is required for both balances, the total power dissipated in the bolometer must be the same, therefore

$$P_1 = P_2 \qquad (3)$$

Consequently the r-f power is equal to the difference in d-c power between the final and initial balances, or

$$P_{r\text{-}f} = I_2^2 R_B - I_1^2 R_B = I_2^2 R_B \left[1 - \left(\frac{I_1}{I_2}\right)^2\right] \qquad (4)$$

With this basic circuit the r-f power can be determined from a knowledge of the d-c current flowing through the bolometer during the initial and final balances and the bolometer resistance at balance.

[1] TYPE 874-HF Fuse Bolometer and TYPES 874-H25 and -H100 Thermistor Units were designed for use with this bridge.

Figure 2. Basic bridge circuit for power measurement.

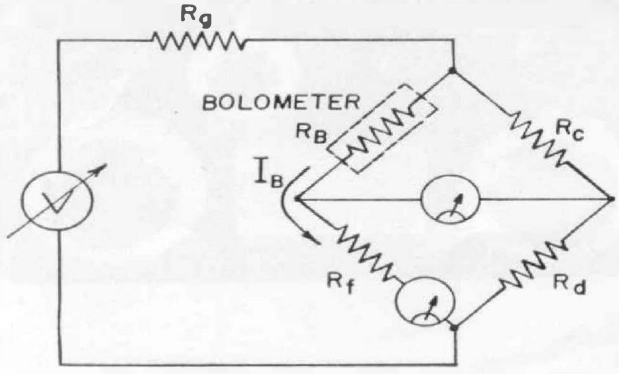
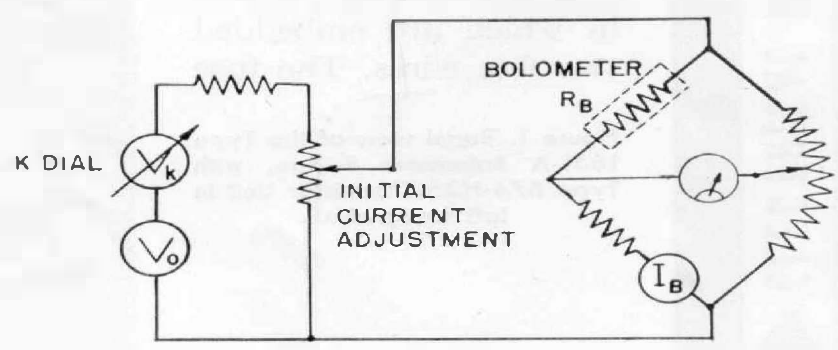


Figure 3. Modified basic circuit.



In order to simplify the measurement and make the bridge more flexible, the actual circuit used in the Type 1651-A Bolometer Bridge is the modified circuit shown in Figure 3. Here the bolometer resistance required for balance can be varied over an appreciable range by means of the potentiometer that replaces the fixed resistors R_c' and R_d in the simple circuit. The potentiometer is calibrated in terms of the bolometer resistance required for balance, and the bridge is thus adaptable to use with bolometer elements having widely varying characteristics. The supply voltage for the initial balance is fixed at V_o, V_k being set to zero, and the initial current adjustment is made by means of the potentiometer indicated. The final balance is made by means of V_k. Since the total circuit resistance is the same for the initial and final balances, the ratio of the initial and final bolometer currents is

$$\frac{I_1}{I_2} = \frac{V_o}{V_o + V_k} \qquad (5)$$

independent of the setting of the initial current adjustment. The V_k control can therefore be calibrated in terms of $1 - \left(\frac{I_1}{I_2}\right)^2$, which is called the K factor, and, from Equation (4),

$$P_{r\text{-}f} = K I_2^{\,2} R_B \qquad (6)$$

The voltage control, V_k, is a Variac connected ahead of the rectifier that supplies the bridge with d-c, as shown in Figure 4. The Variac dial is calibrated in terms of the factor K. A voltage stabilizer is used ahead of the Variac to minimize the effects of line voltage variations.

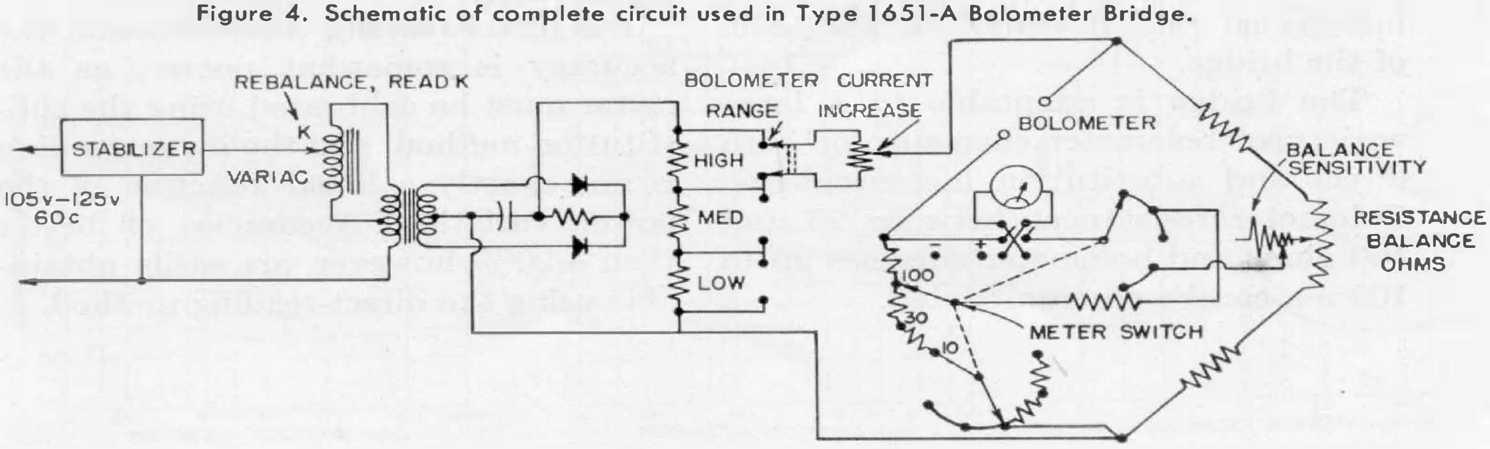
The same meter used to measure the degree of bridge unbalance is also used to measure the bolometer current. In order to minimize the effects of the temperature coefficient of the meter winding on the accuracy of the current measurement, a large resistor is connected in series with the meter, and the current is measured by measuring the voltage drop across taps on the fixed resistance arm of the bridge. The meter has a current-squared scale and a multiplier to permit direct accurate measurements of $I_2^{\,2}$ over a wide range of current. The current-squared scale is labeled A and the multiplier M; therefore, $I_2^{\,2} = MA$ and the magnitude of the r-f power is

$$P_{r\text{-}f} = MARK \text{ milliwatts} \qquad (7)$$

In this type of bridge all quantities are measured after the final balance has been made and after the r-f power has been removed, which eliminates errors due to changes in the r-f power level while readings are being taken and, by permitting the dial and meter measurements to be made slowly and carefully, tends to improve the accuracy of these readings.

The actual operating procedure is simple. The resistance dial is set to the desired bolometer resistance, the K dial

Figure 4. Schematic of complete circuit used in Type 1651-A Bolometer Bridge.



to zero, r-f power is applied to the bolometer, and the bolometer current adjusted for balance. The r-f power is then removed and the bridge rebalanced by means of the K dial. The r-f power is then the simple product $MARK$ as read from the bridge dials and meter.

The circuit is also adaptable to direct-reading measurements of r-f power, but with somewhat less accuracy than is obtainable using the substitution method. It is convenient when a large number of measurements are to be made at power levels not too greatly different from one another. The direct-reading method depends upon the variation in resistance of the bolometer element with r-f power causing an unbalance indication on the meter. The meter indication is closely proportional to the r-f power from zero up to a power level which depends on the type of bolometer element used and the initial bolometer resistance setting. In general, the linear range extends up to power levels of from 10 to 100 milliwatts with less than 10% deviation from linearity. In the direct-reading method, the meter sensitivity is adjusted to read directly in milliwatts after calibration by the substitution method. The initial calibration procedure is more complicated than a single measurement by the substitution method, and in some cases the change in bolometer resistance with r-f power level may have an appreciable effect on the impedance match. Operating procedures for both methods are summarized on an instruction card mounted on the panel of the bridge.

The bridge is adaptable to a large variety of bolometer elements for both direct and substitution measurements. Bolometer resistances between 25 and 400 ohms and bolometer currents up to 100 ma can be accommodated.

III. Accuracy

The accuracy with which the bolometer bridge can measure the change in power dissipated in a bolometer element is controlled by the accuracy of the determination of the various factors involved in the calculation of the power. The accuracy of the meter is the most important factor, because the square of the current is used in the calculations, which means the error in power determination is twice the meter error. The accuracy of the meter on the linear scales is $\pm$(1½% of the reading + ½% of full scale). At full scale this means the meter may contribute as much as $\pm$4% error in the power measured. At one-third of full scale the maximum possible error due to the meter may be as great as $\pm$6%. A range switch is provided to keep the meter readings above ⅓ of full scale for currents above 3 milliamperes. The K dial calibration is accurate to $\pm$(1% of the reading + .005) and the bolometer resistance can be determined with an accuracy of better than $\pm$1%. The over-all accuracy obtainable in a particular measurement depends on the magnitude of the bolometer current and the magnitude of the K dial reading. However, accuracies of better than $\pm$10% can easily be obtained using the substitution method if the measured power is not too small. This compares favorably with the over-all accuracy obtainable with a self-balancing bridge, whose accuracy is usually expressed as a percentage of full-scale reading.

For direct-reading measurements the accuracy is somewhat poorer, as the meter must be calibrated using the substitution method, and the meter reading is not exactly a linear function of the power variation. Accuracies of better than $\pm$20%, however, are easily obtainable using the direct-reading method.

IV. Bolometer Elements

In addition to the TYPE 874-HF Fuse Bolometer Holder and the TYPE 874-H25 and H100 Thermistor Units, which were designed for use with the bolometer bridge, any other unit which is capable of operating within the resistance and current ranges of the bolometer bridge can be used. The power measurement ranges of the fuse bolometer and thermistor overlap one another. The thermistor units have a lower standing-wave ratio, are more rugged, and will measure somewhat lower powers than will the fuse elements, while the fuse elements are cheap and will measure higher powers than will the thermistor units. The fuse elements are limited in their frequency range by errors caused by standing waves on the fuse wire. Above about 1000 Mc these errors become significant. Thermistors can be used up to frequencies beyond the usable range of the coaxial connectors and components as they are physically very small. Both the fuse elements and the thermistor units can be used at frequencies as low as 5 Mc.

The TYPE 874-HF Fuse Bolometer Holder is designed to mount ¼ x 1-inch instrument fuses. Two types of fuses, the type MJR 1/32-ampere and type MJR 1/12-ampere, are supplied which are capable of measuring a wide range of power at the 50-ohm level; however, practically any fuse of the AGX type can be used if desired, although with some sizes it is not possible to obtain a balance at the 50-ohm level.

The TYPE 874-H25 and H100 Thermistor Units are similar to one another except for a difference in the power handling capacity of the thermistor. The maximum ratings of the TYPE 874-H25 and TYPE 874-H100 are 25 and 100 milliwatts, respectively.

The actual power measurement ranges of the fuse and thermistor elements as a function of their initial resistance for measurements by the substitution method are shown in Figure 5. Figures 6 and 7 show the power required for full-scale meter deflection with maximum meter sensitivity and the maximum measurable power for less than 10% deviation from linearity as a function of bolometer resistance, for measurements by the direct-reading method.

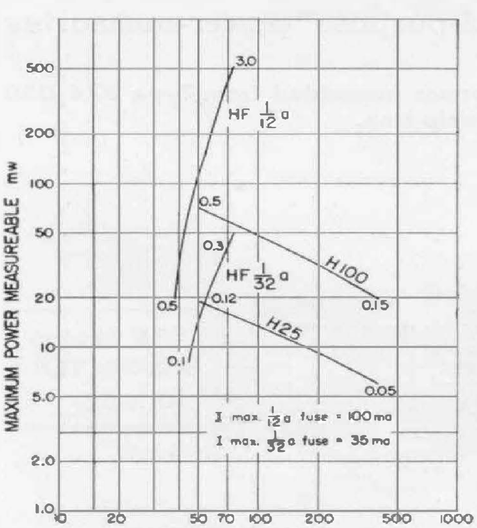


Figure 5. Power-measurement ranges of Fuse and Thermistor Bolometers and the Bolometer Bridge, by substitution method, as a function of bolometer resistance. Minimum detectable power in milliwatts is indicated by the numbers at the ends of each curve.

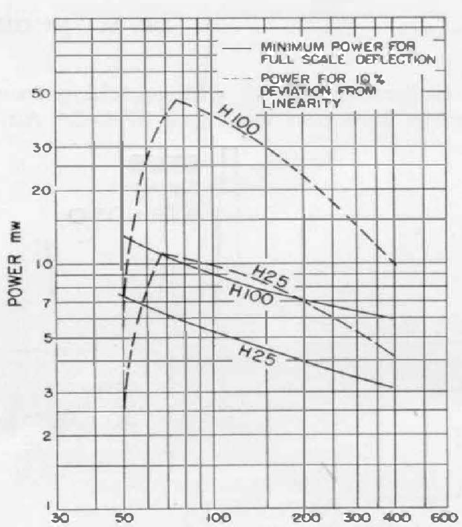


Figure 6. Sensitivity and power-measurement ranges of the Thermistor Units and Bolometer Bridge, for the direct-reading method.

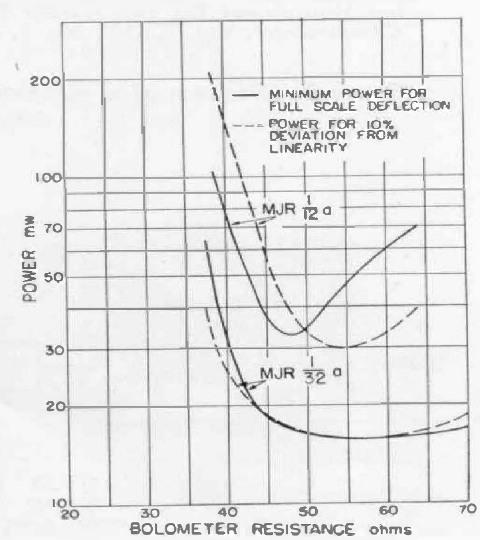


Figure 7. Sensitivity and power-measurement ranges of the Fuse Bolometer and fuses as indicated, for the direct-reading method.

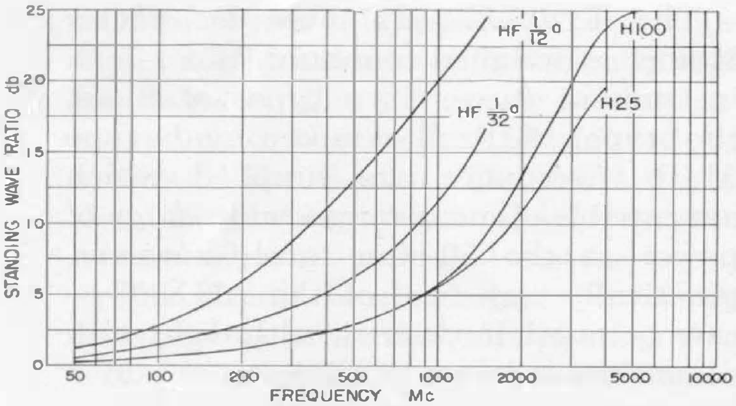


Figure 8. Standing-wave ratio as a function of frequency of the Fuse Bolometer and Thermistor Units.

Figure 8 shows the standing-wave ratio as a function of frequency for the various elements. At the higher frequencies it is necessary to use a matching transformer between the source and the bolometer when the power into a line terminated in its characteristic impedance is desired. A matching transformer can be easily assembled using Type 874 Coaxial Elements[2] as indicated in the block diagram of Figure 9. To match the bolometer to the line, the matching transformer is adjusted until the slotted line indicates the absence of any reflected energy. When the power output of an oscillator into a matched load is to be measured, a transformer made up to Type 874 components can be used to transform the bolometer impedance into the conjugate of the oscillator output impedance. In this application a slotted line is not required, as the transformer is adjusted for the maximum indication on the bolometer bridge.

[2]W. R. Thurston, "Simple, Complete Coaxial Measuring Equipment for the U-H-F Range," *General Radio Experimenter*, Vol. XXIV, No. 8, January, 1950.

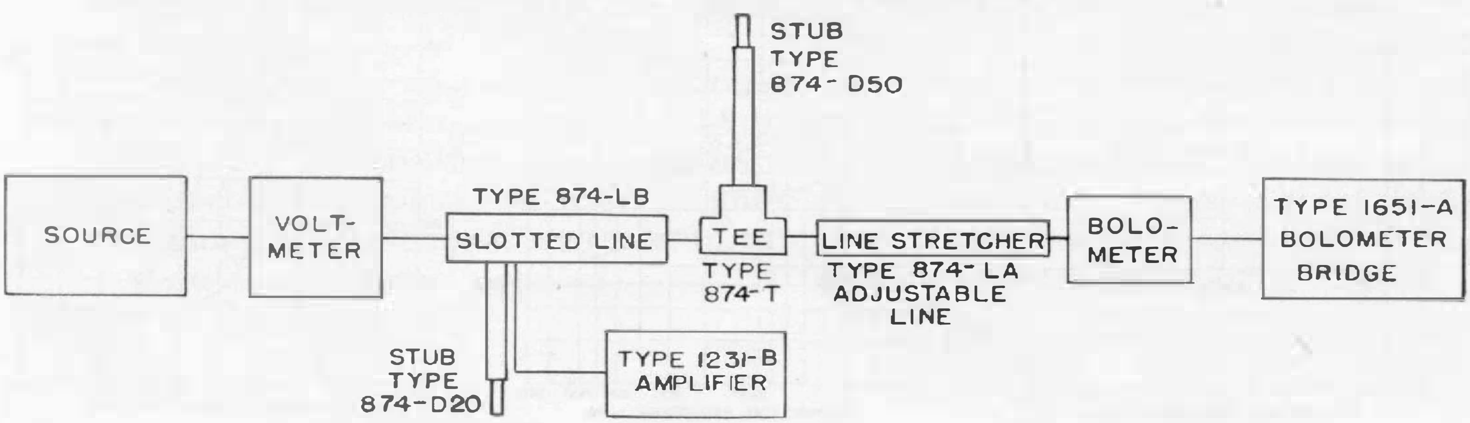
V. Applications

The Type 1651-A Bolometer Bridge can be used for all measurements of power in the medium power range over a frequency range dependent on the characteristics of the bolometer element used. High power measurement can be made by using dissipative attenuators or directional couplers to transmit only a known fraction of the r-f power to the bolometer element.

Typical measurements are the power output of oscillators, loss measurements, the static characteristic of bolometers, and the calibration of voltmeters. Voltmeters can be calibrated using the circuit of Figure 9 with the voltmeter connected between the slotted line and the source. When no standing waves are present, the voltage is constant all along the line and its magnitude can be calculated from the measured power and the characteristic impedance of the line. Figure 10 shows the results of a calibration made of the Type 874-VR Voltmeter Rectifier over a wide frequency range. The rise in indicated voltage is a result of resonance in the crystal and the theoretical slope is indicated by the solid line.

The Type 1651-A Bolometer Bridge is a general-purpose power-measuring

Figure 9. Diagram of a voltmeter calibration circuit with matching transformer assembled from Type 874-D50 Adjustable Stub and the Type 874-CA Adjustable Line.



instrument designed for maximum utility and adaptability in the u-h-f laboratory. Since tuning systems and transformers are easily assembled from the extensive line of Type 874 Coaxial Elements already available in many laboratories, expensive specialized accessories are not necessary. In the educational laboratory, in addition to demonstrating a variety of power measurement problems, the bridge can be used for calibrating bolometers and demonstrating their change in resistance with current. In commercial and industrial laboratories, its flexibility permits operation with many different types and makes of bolometers, and it can be adapted for use with existing equipment of different manufacturers.

— R. A. Soderman

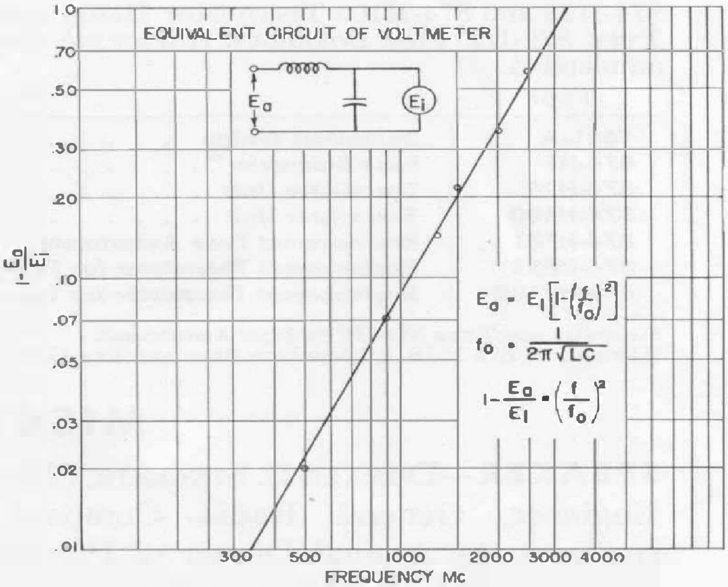


Figure 10. Departure from unity of the ratio of actual to indicated voltage as a function of frequency for Type 874-VR Voltmeter Rectifier, measured with the circuit of Figure 9. The solid line indicates the theoretical slope as determined by the equation.

SPECIFICATIONS

Range and Accuracy — Substitution Method

With Type 874-H25 Thermistor Unit		
Thermistor resistance set for max. sensitivity	0 to 6 mw	±(10% + 0.05 mw)
Thermistor resistance set at 50 ohms	0 to 18 mw	±(10% + 0.12 mw)
With Type 874-H100 Thermistor Unit		
Thermistor resistance set for max. sensitivity	0 to 20 mw	±(10% + 0.15 mw)
Thermistor resistance set at 50 ohms	0 to 70 mw	±(10% + 0.5 mw)
With Type 874-HF Fuse Bolometer Holder, MJR 1/32-ampere fuse		
Fuse resistance set for max. sensitivity	0 to 8 mw	±(10% + 0.1 mw)
Fuse resistance set at 50 ohms	0 to 14 mw	±(10% + 0.15 mw)
Fuse resistance set for max. power range	0 to 50 mw	±(10% + 0.3 mw)
With Type 874-HF Fuse Bolometer Holder, MJR 1/12-ampere fuse		
Fuse resistance set for max. sensitivity	0 to 20 mw	±(10% + 0.5 mw)
Fuse resistance set at 50 ohms	0 to 100 mw	±(10% + 0.75 mw)
Fuse resistance set for max. power range	0 to 500 mw	±(10% + 3 mw)

Bolometer Resistance Range: 25 to 400 ohms.

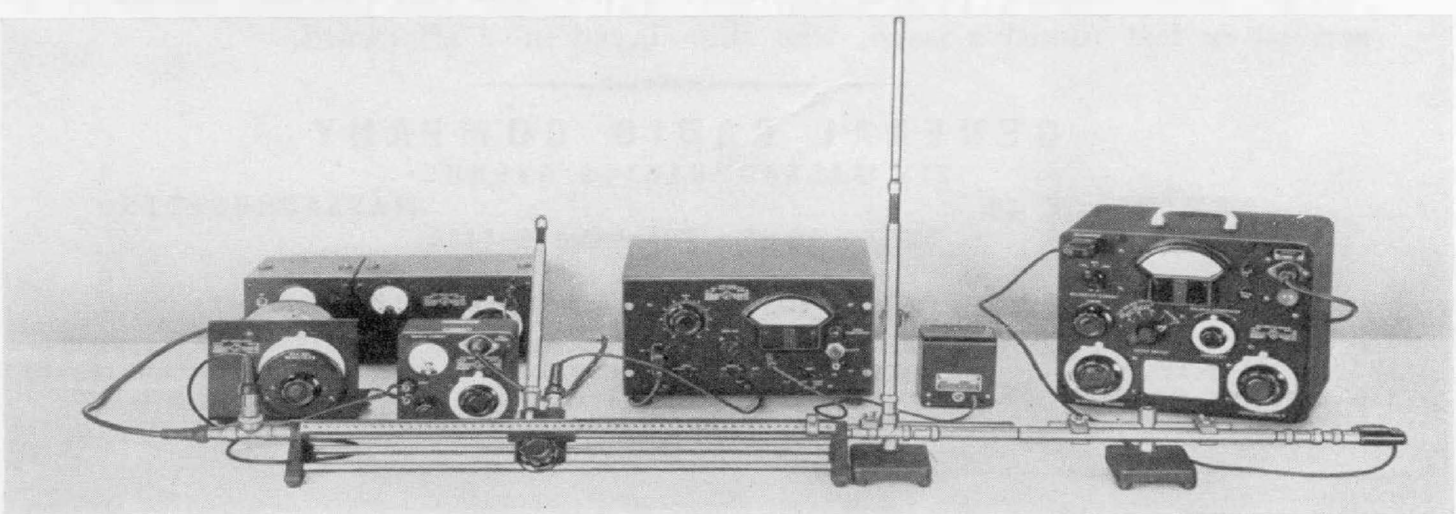
Current Range: 0 to 100 milliamperes.

Power Supply: 105 – 125 volts, 60 cycles.

Accessories Supplied: One CAP-35 Power Cord, one Type 274-NE Shielded Connector.

Accessories Required: Bolometer element. Types

Figure 11. View of the equipment shown in the diagram of Figure 9.



874-H25 and 874-H100 Thermistor Units, and Type 874-HF Fuse Bolometer Holder are recommended.

Dimensions: (Height) 12 x (width) 12 x (depth) 8¾ inches overall.
Net Weight: 21 pounds.

Type		*Code Word*	*Price*
1651-A	Bolometer Bridge	BEGIN	$325.00
874-HF	Fuse Bolometer*	COAXHOLDER	34.00
874-H25	Thermistor Unit	COAXWARMER	40.00
874-H100	Thermistor Unit	COAXHEATER	40.00
874-HFP1	Replacement Fuse Assortment†	FUSOR	2.50
874-HP25	Replacement Thermistor for Type 874-H25	THERM	9.00
874-HP100	Replacement Thermistor for Type 874-H100	CALDO	9.00

*Includes one Type 874-HFP1 Fuse Assortment.
†Consists of five MJR 1/12-ampere fuses and five MJR 1/32-ampere fuses.

MISCELLANY

SPEAKER—Donald B. Sinclair, Chief Engineer, General Radio Company, spoke at the Annual Dinner of Dayton Section, I.R.E., on May 18. His subject: "The Engineer and His Professional Society."

ELECTED — Kipling Adams, Manager of the General Radio Chicago Office, as Chairman of the Chicago Section, I.R.E., for 1950-51.

RECENT VISITORS to General Radio — J. M. Van Steeden, Hulsewe Ingenieursbureau, Amsterdam, Netherlands; Roger Goublin, Compagnie Française Thomson-Houston, Gennevilliers, France; and Björn Lundvall, Telefonaktiebolaget L. M. Ericsson, Stockholm, Sweden.

CREDITS—The Type 1651-A Bolometer Bridge, described in the article by R. A. Soderman, was developed by W. R. Thurston.

The Type 1534-A Polariscope, described in last month's issue, was the outgrowth of a Master's thesis by Jordan Baruch of M. I. T., at that time a cooperative student at our plant. Baruch's investigation and experimental model provided the basis for the final design, which was executed by Gilbert Smiley. Baruch's advisors in his thesis work were Professor H. E. Edgerton of the Electrical Engineering Department and Professor W. M. Murray of the Mechanical Engineering Department, M. I. T.

VACATION — During the weeks of July 24 and July 31 most of our employees will be vacationing. Manufacturing departments will be closed and other departments will be manned by a skeleton staff. Every effort will be made to take care of urgent business, but repairs cannot be made, except in hardship cases. Our Service Department requests that shipments of material to be repaired be either scheduled to reach us well before this vacation period or delayed until afterward.

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