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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A PEAK-READING VOLTMETER FOR THE U-H-F RANGES

Also

IN THIS ISSUE

● **PROGRESS IN AN** engineering field depends to a considerable degree upon the development of measuring instruments. As the field is extended through laboratory research, instruments are "tailor-made" for each project, but later commercial development usually brings with it simple, general-purpose direct-reading instruments. Initially of only moderate accuracy, they eventually are developed to an accuracy comparable with that achieved in older fields.

In the electrical-communication industry, the voltmeter affords an excellent example of this type of development. The frequency range of accurate measurements with voltmeters has been progressively extended from the audio-frequency limits of 20 years ago to the present figure of several hundred megacycles[1] approaching the limit to which currently available diodes can be pushed.

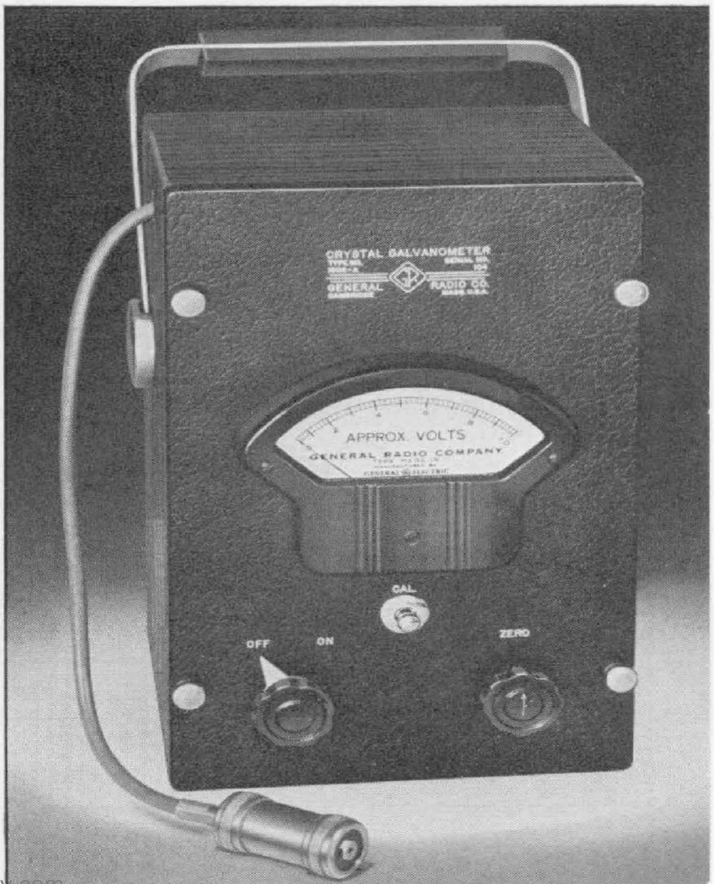

Figure 1. Panel view of the Type 1802-A Crystal Galvanometer.

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[1] C. A. Woodward, Jr., "A New Vacuum-Tube Voltmeter," *General Radio Experimenter*, September, 1946, pp. 1-10.

For still higher frequencies, there is an obvious need for a direct-reading voltmeter. Such an instrument must necessarily be of the pioneering type, in which accuracy is sacrificed for convenience and extended frequency range. The new TYPE 1802-A Crystal Galvanometer is exactly this type of instrument. Its range of direct measurement is 0.1 to 1 volt with an accuracy of ±5%, and two multipliers are furnished to extend the range to 10 volts and 100 volts. It can be used as a direct-reading instrument at frequencies up to 1000 megacycles and for the measurement of voltage ratios, the frequency limit is well above 1000 megacycles.

Functionally, this new voltmeter is a peak-reading instrument, consisting of a rectifier and a d-c amplifier. The extended frequency range is obtained through the use of a crystal rectifier in place of the thermionic diode used in vacuum-tube voltmeters. Crystal rectifiers, however, cannot yet be produced to a degree of uniformity comparable with that of the thermionic diode, and this fact explains the difference in accuracy between the crystal instrument and the vacuum-tube voltmeter. The scale is calibrated directly in volts, but the instrument has been named a crystal galvanometer to indicate that its accuracy is not as good as the 2% we have come to expect from the vacuum-tube voltmeter.

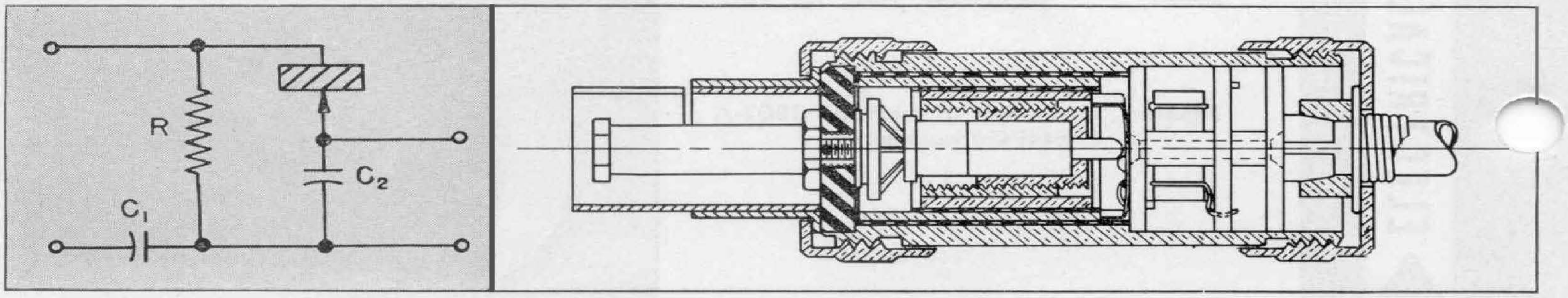
The crystal rectifier used in this voltmeter is one of the new units developed during the war[2,3], which were widely used as mixers and as uncalibrated voltage indicators. In a previous article[3] the characteristics of these crystals as voltmeter rectifiers were discussed, and it was pointed out that their excellent high-frequency characteristics considerably outweighed their lack of uniformity.

These crystals are commonly used as simple rectifiers in series with a meter. The use of a peak-reading circuit, however, has two important advantages: the input resistance is higher; and the variation in response between different crystals is less. The resistance of the 1N21B-type crystal is of the order of a few hundred ohms in the "forward" direction and from 15,000 to 100,000 ohms in the "reverse" direction. In the simple crystal-meter circuit the input resistance is approximately twice the forward resistance, while in the peak-reading circuit it is approximately one-third the back resistance, or from 5,000 to 30,000 ohms. Variations in crystal forward resistance affect the calibration directly in the series circuit, but in the peak-reading circuit, only the small difference between the peak applied voltage and the developed d-c voltage depends upon the crystal characteristics.

PROBE

The design of the probe in which the crystal rectifier is mounted is one of the most important factors in determining

Figure 2. Schematic (*left*) and cross section (*right*) of the probe.



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[2] W. E. Stephens, "Crystal Rectifiers," *Electronics*, 19, 7, July, 1946, pp. 112-119.

[3] Arnold Peterson, "Vacuum-Tube and Crystal Rectifiers as Galvanometers and Voltmeters at Ultra-High Frequencies," *General Radio Experimenter*, 19, 12, May, 1945, pp. 1-7.

the high-frequency performance. A cross-section of the probe and the schematic of the crystal and its associated circuit elements are shown in Figure 2.

The r-f voltage is applied to the crystal through the series combination of C_1 and C_2. The impedance of this combination at frequencies above about 10 Mc is so low compared with that of the crystal that the a-c voltage is effectively applied across the crystal. The rectified current charges up the capacitance C_2 with the discharge path through the high resistance, R, and the crystal back resistance. The resulting d-c voltage developed across this capacitance is then applied to the amplifier through the probe cable.

To obtain the highest possible natural frequency, the blocking condenser is in the ground lead, thus avoiding the inductance and capacitance to ground of a blocking condenser in the high potential lead. The use of a battery-operated amplifier avoids the hum problem that occurs with this connection in an a-c operated diode voltmeter.

The probe assembly has been designed to minimize inductance throughout by using cylindrical blocking and by-pass condensers, as illustrated in the sectional view, Figure 2. The outer shell forms the ground connection, and, with the first inner cylinder, forms the capacitance C_1. The first inner cylinder, in turn, forms the capacitance C_2 with the center assembly. The resistor R is formed by a resistive coating on the surface of the mycalex insulating disc that carries the center terminal of the probe.

HIGH-FREQUENCY ERROR

This design together with the high resonant frequency of the crystal cartridge itself yields a probe with a resonant frequency of about 1800 Mc. The actual value for any unit depends on the particular crystal cartridge used. The resonant frequency varies with different units from 1650 to 2000 Mc. This value is sufficiently high that the resonance correction is only about 30 per cent at 1000 Mc. No transit-time or other frequency corrections need be applied. The correction factor for resonance is shown in Figure 3.

Frequently, the voltmeter is used only as an indicator of the existence of voltage. Then the resonant frequency is not a limiting factor on the useful frequency range of the instrument, and it can be used at frequencies up to and beyond

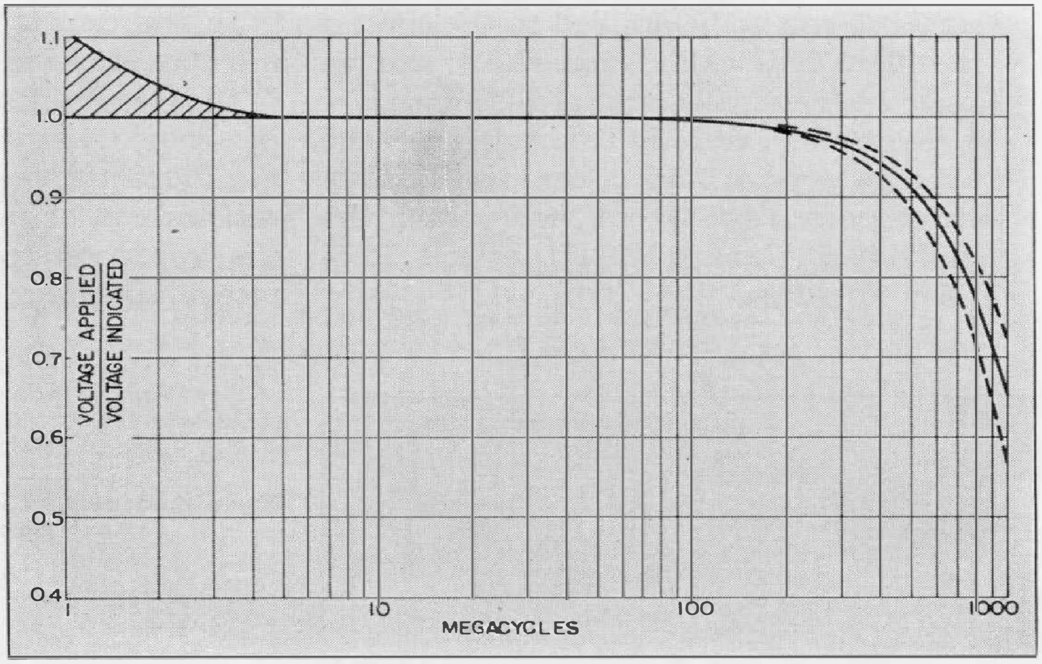


Figure 3. Frequency correction for resonance in the probe. The dash lines show the range of variation among normal crystals. Additional correction curves for use with the multipliers are supplied in the instruction book.

3000 Mc. Since there is no appreciable frequency correction that depends upon voltage level, measurements of voltage ratios can also be made at frequencies well above 1000 megacycles.

LOW-FREQUENCY ERROR

At frequencies below a nominal value between 10 and 30 Mc, the indication falls off as a result of the small series capacitance in the probe. The frequency at which this effect becomes noticeable depends on the characteristics of the individual crystal, particularly the back resistance. The voltmeter is not intended for use at frequencies below 10 Mc.

CALIBRATION

The crystal develops across the blocking condenser about 75 per cent of the peak voltage applied. Variations between crystals, therefore, will affect the calibration and show up as differences in absolute level and changes in the shape of the calibration curve.

In order to set the absolute level, provision is made for calibrating the crystal rectifier at the 0.7-volt level. The power cord in the upper compartment is used to connect to an a-c power line of 115 volts, and a voltage divider in the cabinet derives from this voltage the necessary 0.7 volt to be applied to the crystal rectifier. This calibration check can be used whenever the crystal is replaced.

The meter scale is calibrated for the average crystal and, when the level is standardized at 0.7 volt, will match the individual TYPE 1N21B Crystal Rectifier to ±5%.

AMPLIFIER

The d-c amplifier uses a degenerative cathode-follower circuit with a 1R5-type tube as a triode. The circuit is arranged as a bridge system, as shown in Figure 4. The reading of the indicating meter is set initially to zero by adjusting the bias resistor until balance is obtained. The resistor is connected so that, as the bias is varied, the degenerative resistance for voltages applied by the crystal is maintained nearly constant. This arrangement makes the sensitivity practically independent of the zero setting. The sensitivity of the amplifier is changed by the adjustable series resistance in the meter circuit, and this adjustment does not affect the zero setting.

PROBE FITTINGS

Since the inverse peak voltage rating of the high-frequency crystal rectifiers is only a few volts, the range of the voltmeter can be extended only slightly by reducing the sensitivity of the d-c amplifier. Voltages above one volt are measured by the use of capacitance voltage dividers placed ahead of the probe. Two of these multipliers are furnished to give a complete coverage to 100 volts in decade steps.

In addition to the multipliers, fittings are provided for two coaxial connectors of the General Radio 774 type. A 50-ohm disc-type resistor is also provided. These are illustrated in Figure 5. The 50-ohm resistor can be used in conjunction with the voltmeter for making approximate measurements of power up to 1000 Mc.

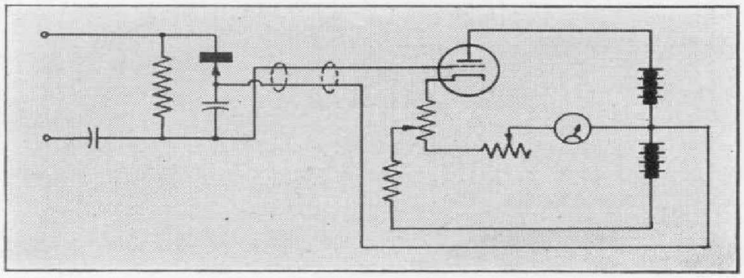


Figure 4. Elementary schematic circuit diagram of the complete voltmeter.

PANEL AND CABINET

As shown in Figure 1, the meter, mounted in the center of the panel, carries only the basic range of 0 to 1.0 volt. The two main controls, which are the on-off switch and the zero set, are operated by the knobs below and on either side of the meter.

The shielded walnut cabinet is of the same construction as that for the TYPE 1800-A Vacuum-Tube Voltmeter with the storage compartment at the top for the probe and the various fittings supplied. The handle can be locked in either the position parallel to the panel or perpendicular to it, thus permitting the instrument to be set in a vertical, a horizontal, or a 30-degree position.

The TYPE 1802-A Crystal Galvanometer brings to the u-h-f range of frequencies the convenience and flexibility of the vacuum-tube voltmeter. The variety of probe terminations including coaxial connectors facilitates its use with other laboratory instruments. Experimental models have already been used by a few laboratories engaged in microwave research. Their experience indicates that it is a most useful and convenient voltmeter for the u-h-f ranges.

— ARNOLD PETERSON

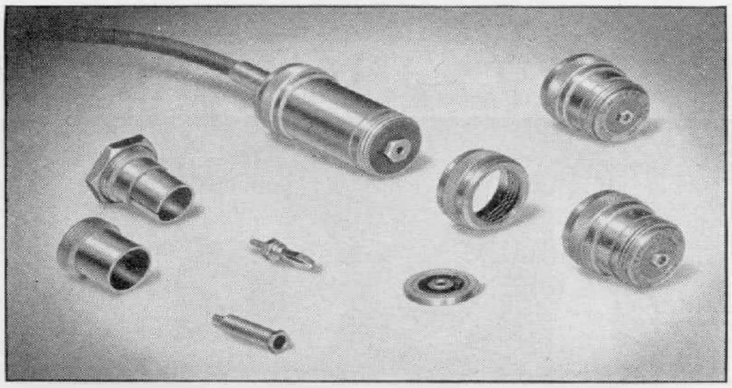


Figure 5. View of the probe and fittings. The capacitance-type voltage multipliers are shown at the right.

SPECIFICATIONS

Voltage Range: 0.1 to 1 volt, direct-reading; 1 to 10 volts and 10 to 100 volts direct-reading with multipliers supplied.

Accuracy: ±5% of full scale on sinusoidal voltages, subject to frequency correction.

Waveform Error: The meter response approaches that of a peak voltmeter, but the scale is calibrated in r-m-s values for a sine-wave input. On distorted waveforms the percentage deviation of the reading from the r-m-s value may be as large as the percentage of harmonics present.

Frequency Error: High-frequency error is caused by resonance effects. The resonant frequency depends on the particular crystal used. With a 1N21B crystal in the probe, the resonant frequency is between 1650 and 2000 Mc; with the 10:1 multiplier attached, between 1700 and 2200 Mc; and with the 100:1 multiplier attached, between 1350 and 1650 Mc. For frequencies below resonance the applied voltage at the terminals is approximately equal to the indicated voltage multiplied by $1-\left(\frac{f}{f_o}\right)^2$, where f is the operating frequency and f_o is the resonant frequency. At frequencies below a nominal value between 10 and 30 Mc the output falls off as a result of the small capacitance in the probe. The frequency at which this effect becomes noticeable depends upon the characteristics of the individual crystal.

Input Impedance: The input capacitance is nearly independent of the standard crystal used, but the input conductance depends on the frequency, voltage level, and the crystal characteristics. For 1N21B crystals representative values are:

Probe: Capacitance — 5 μμf
Conductance — 100 μmhos
10:1 Multiplier: Capacitance — 2.5 μμf
Conductance — Less than 25 μmhos
100:1 Multiplier: Capacitance — 1.6 μμf
Conductance — Less than 10 μmhos

Power Supply: One Burgess Z30N and one Burgess 2F batteries are furnished.

Vacuum Tube: One 1R5-type vacuum tube is supplied.

Crystal: One 1N21B-type crystal is supplied.

Mounting: Walnut cabinet; cable and probe are stored in cabinet.

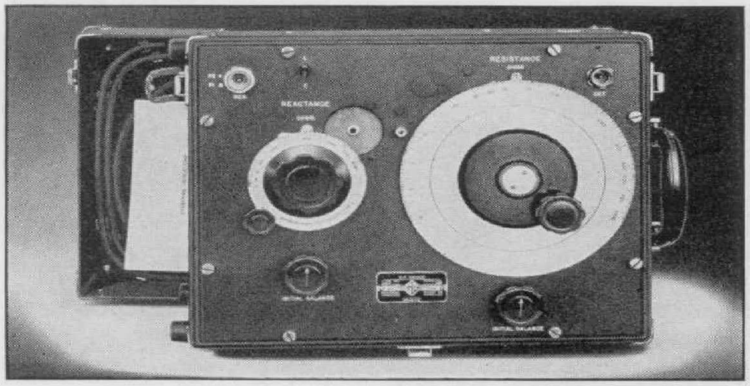
Accessories Supplied: One TYPE 1802-P1 10:1 Multiplier, one TYPE 1802-P2 100:1 Multiplier, one TYPE 1802-P3 Cable Termination, fittings for plugging into TYPE 774-G or 774-M coaxial connectors.

Dimensions: 7 x 7 x 10½ inches, overall.

Net Weight: 10¾ pounds.

Type		*Code Word*	*Price*
1802-A	**Crystal Galvanometer**	CONIC	**$175.00**

LEAD CORRECTIONS FOR THE RADIO-FREQUENCY BRIDGE



In the measurement of impedance with the TYPE 916-A Radio-Frequency Bridge, the bridge settings at balance indicate the magnitude of the unknown impedance as seen at the bridge terminals, which includes the impedance of the connecting leads. Standard leads of known reactance are supplied with the bridge to facilitate making the necessary connections for lead reactance to ground.

In the instruction book for this bridge, approximate expressions for the correction are given, i.e.

$$R_x = R_e \left[1 + 2\frac{X_e}{X_a} - \left(\frac{R_e}{X_a}\right)^2\right]$$

$$X_x = X_e + \frac{X_e^2 - R_e^2}{X_a}$$

where R_x = Resistance of unknown
X_x = Reactance of unknown
R_e = Resistance indicated by bridge setting.
X_e = Reactance indicated by bridge setting.
X_a = Lead reactance (obtained from chart in instruction book).

There are a number of cases where these approximate expressions are not adequate and where their use will lead to appreciable errors in the result. Because of this, the following more complete expressions have been derived:

$$R_x = R_e \left[1 + 2\frac{X_e}{X_a} + 3\left(\frac{X_e}{X_a}\right)^2 - \left(\frac{R_e}{X_a}\right)^2\right]$$

$$X_x = X_e + \left[\frac{X_e^2 - R_e^2}{X_a} + \frac{X_e}{X_a}\left(\frac{X_e^2 - 3R_e^2}{X_a}\right)\right]$$

These corrections and a corrected set of illustrative examples of their use have been printed in the form of an errata sheet to be inserted in the instruction book for TYPE 916-A Radio-Frequency Bridge. A copy of this sheet will be sent to any user of the bridge upon request.

When asking for the errata sheet, please give the serial number of the bridge with which it is to be used.

DELIVERIES

Every now and then in these pages we try to keep our readers posted on the operations of the General Radio Company. We have in recent years published several articles about our organization, how we try to operate, and what we are trying to do.

Just now the thing that probably concerns all of us most is the question of deliveries. As was to be expected, the war brought about an enormous demand for precision test equipment. Looking back, we are now rather proud of our record and the record of our industry in this all-out race for production. It is not easy to produce precise and frequently intricate technical equipment. It requires highly trained manpower, complicated production procedures, and frequently very scarce components. In spite of these factors, we were able to increase production to more than six times its prewar peak. We had thought that when the war was over we could expect a large decrease in demand which could easily be met by the now existing facilities. What we did not fully realize was the extent of the demands of the starved civilian industry nor the size of the requirements for the rehabilitation of the war-ruined industries and laboratories abroad.

These demands, coupled with a scarcity of component parts and materials, many of which are in acutely short supply, have resulted in delays in delivery of many of our products which must often seem to be unreasonable.

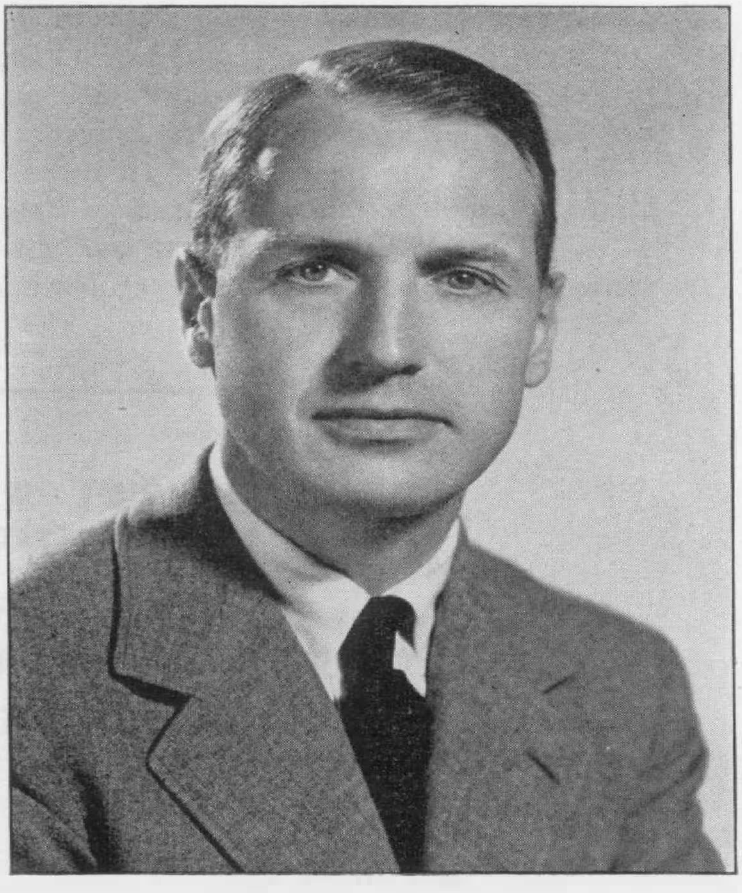
Those of our readers who are in the manufacturing business will know what we mean by the extreme delays involved in obtaining key components. Materials like copper wire and some classes of transformer steel are almost unobtainable anywhere on any delivery schedule or for any price.

We are glad that the great majority of our customers are well acquainted with these problems and are being patient when we often must quote delivery delays of many months. We wish to assure all of our customers who have been patiently waiting for delivery that we are doing everything we can to get the instruments produced; and that, in spite of acute spot shortages, our entire enlarged plant is operating at full capacity, and, finally, that we will not sacrifice quality and care in production just to speed deliveries.

MISCELLANY

The Medal of Freedom was presented to Dr. W. N. Tuttle of the General Radio Company on August 27 at an informal ceremony in the engineering library of the Company, witnessed by his colleagues on the engineering staff.

The presentation was made by Major General Harold M. McClelland, formerly Air Communications Officer of the Army Air Forces and now commanding Army Air Forces Air Communications Service. The award was made "for exceptionally meritorious achievement which aided the United States in the prosecution of the war against the enemy in Continental Europe as head, radar subsection, Operational Analysis Section, Headquarters, Eighth Air Force, from 16 October 1942 to 3 October 1944. During this period Dr. Tuttle distin-



guished himself by adapting blind bombing equipment and technique for introduction into the Eighth Air Force, making a very valuable contribution to the success of numerous close cooperation attacks. His vision and untiring efforts reflect high credit upon him and were of great importance to the operations of the armed forces of the United States."

Dr. Tuttle is a graduate of Harvard, Class of 1924, and received his S.M. in 1926 and his Ph.D. in 1929 from that University. He is a senior member of the Institute of Radio Engineers, a member of the Acoustical Society of America, of the American Physical Society, and of Sigma Xi.

VISITORS

A recent visitor to General Radio, returning after several weeks in Paris, was Mr. Paul Fabricant, of the Paris firm Radiophon, our representatives in France. Other visitors include Mr. Frederick S. Barton, of the British Air Commission; Dr. Lewis M. Hull, of Aircraft Radio Corporation; Mr. O. B. Ottesen, of Jan Wessels Radiofabrikk, Oslo, Norway; and Mr. Louis E. LeBel, of Marianno Soares & Cia., Ltda., Rio de Janeiro and São Paulo.

NOTICE OF PRICE CHANGE

Because of rapidly rising costs, all prices given in our current price lists are increased by 10% effective October 1, 1946, for shipments to be made after December 31, 1946.

This will, of course, not affect any firm orders that you may now have with us, but is applicable only to new orders.

We regret the necessity of this price change, which we have resisted as long as possible, but we know that our customers will understand the conditions that have made it necessary.

We also regret that, contrary to our long-established practice of quoting firm delivered prices, it is now necessary to limit to six months the period for which we will guarantee a price. For shipments which cannot be made within six months from our receipt of the order, customers will be advised prior to shipment if any price changes have been made, at which time the order may be canceled without obligation.

GENERAL RADIO COMPANY
275 MASSACHUSETTS AVENUE
CAMBRIDGE 39 MASSACHUSETTS
TELEPHONE: TROWBRIDGE 4400

BRANCH ENGINEERING OFFICES

NEW YORK 6, NEW YORK
90 WEST STREET
TEL.—WORTH 2-5837

LOS ANGELES 38, CALIFORNIA
950 NORTH HIGHLAND AVENUE
TEL.—HOLLYWOOD 6201

CHICAGO 5, ILLINOIS
920 SOUTH MICHIGAN AVENUE
TEL.—WABASH 3820

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