the GENERAL RADIO Experimenter

INDEX

TO

GENERAL RADIO EXPERIMENTER

VOLUMES 30 and 31

JUNE, 1955 through MAY, 1957

GENERAL RADIO COMPANY

275 MASSACHUSETTS AVENUE

CAMBRIDGE 39 MASSACHUSETTS

Printed in U.S.A.

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the GENERAL RADIO Experimenter

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Since 1915 - Manufacturers of Electronic Apparatus for Science and Industry

VOLUME 31 No. 8 JANUARY, 1957

Photo Courtesy Interchemical Corporation

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Laboratory Amplifier

THE

GENERAL RADIO EXPERIMENTER

Published Monthly by the General Radio Company

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The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in electronic techniques in measurement. When sending requests for subscriptions and address-change notices, please supply the following information: name, company address, type of business company is engaged in, and title or position of individual.

COVER

The electrical properties of resins are being used more and more as indicators of other physical properties. This photograph shows the General Radio Type 1610 Capacitance Measuring Assembly with the Type 1691-A Dielectric Sample Holder in use at the Interchemical Corporation for measurements of dielectric constant and power factor as functions of frequency. Photograph reprinted from the *Interchemical Review,* Volume 15, Number 1, Spring, 1956 (Copyright 1956 by Interchemical Corporation).

GENERAL RADIO COMPANY

275 Massachusetts Avenue

Cambridge 39 Massachusetts

Telephone: TRowbridge 6-4400

BRANCH ENGINEERING OFFICES

NEW YORK: Broad Avenue at Linden, Ridgefield, New Jersey
Telephone—N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: 920 South Michigan Ave., Chicago 5, Illinois
Telephone—WAbash 2-3820

PHILADELPHIA: 1150 York Road, Abington, Pennsylvania
Telephone—HAncock 4-7419

WASHINGTON: 8055 13th St., Silver Springs, Maryland
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Telephone—VIctoria 9-3013

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Telephone—Toronto EMpire 8-6866

THE SOUND-LEVEL METER AS AN AUDIO-FREQUENCY VOLTMETER AND AMPLIFIER

The Type 1551-A Sound-Level Meter [1] is widely used as the basic instrument for sound measurements, but its capabilities as a general-purpose laboratory instrument are usually overlooked. The heart of the instrument is a stabilized, wide-range, high-gain amplifier which drives an indicating meter, and these are the essential elements for a high-sensitivity audio-frequency voltmeter. Thus, it can be used for gain or loss measurements, for hum and noise measurements, for monitoring, and as a bridge amplifier and null detector.

For these uses the microphone is removed as shown in Figure 1, and the voltage to be measured is applied to the microphone input connector.[2] The range of the instrument is from 5 microvolts to 3 volts. The actual indications are in decibels, which can be used directly for gain or loss. The corresponding voltages can be obtained through the use of decibel conversion tables. In fact, the gain of the instrument can be set so that full-scale meter readings follow the 1–3–10 series commonly found on audio frequency voltmeters.

The other important characteristics of the instrument are summarized in the following table:

Figure 1. View of the Sound-Level Meter with microphone replaced by connector.

Input Impedance: 7.3 MΩ shunted by 50 μμf

Output Impedance: 10 KΩ

Attenuator: 10 steps of 10 db (30 db to 130 db); overall transmission can be adjusted from 90 db gain to 10 db loss

Meter: Linear 16 db scale (−6 to +10 db)

Range: 116 db (24 to 140 db)

631,000:1 or 5 μv to 3.16 volts

	Open Circuit	*20 KΩ Load*
Full Scale Output Voltage:	1.4 volts	1.0 volts
Maximum Undistorted Output Voltage:	4.4 volts	3.0 volts
Maximum Gain:	97 db	94 db

[1] E. E. Gross, "The Type 1551-A Sound-Level Meter" *General Radio Experimenter*, March 1952, Vol. 26, No. 10, pps. 1–7.

[2] The proper mating connector is the Amphenol 91 MC3M male cable connector, which should have the orientation of the insert specified as position No. 2. (See Figure 2 for connection diagram.)

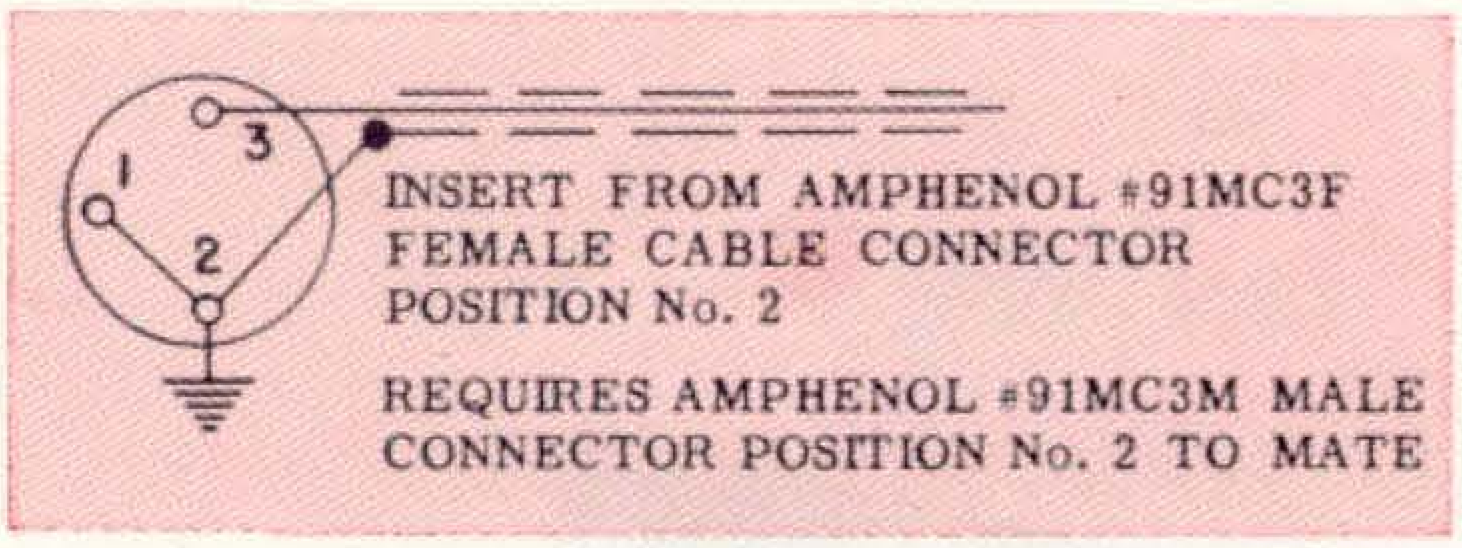


Figure 2. Connection diagram for input connector.

USES

Bridge Detector

The high sensitivity of this amplifier makes it a very satisfactory null detector. Either the panel meter or earphones can be used to indicate the bridge balance. Tuned filters can be inserted to discriminate against harmonics in the bridge source. The 1231-P2, P3, and P5 filters plug into the FILTER OUT jack [3] of the Sound-Level Meter. The Type 1951-A Filter, which gives greater harmonic rejection can be connected at the input to the amplifier.

Low-frequency hum, such as pickup from power lines, can be reduced by a factor of 10 if the weighting-network switch is set at A rather than at 20 kc. This setting reduces the response to low-frequency signals.

Gain-Loss Measurements

This voltmeter is particularly useful for measuring the transmission characteristic of audio-frequency amplifiers, filters, and transformers. The decibel scale can be used directly, since it is usually the ratio of input to output voltage that is wanted and not the absolute value. The input impedance (7.32 MΩ) is high enough so that the meter will ordinarily not upset the circuit being tested.

At frequencies between 15 Kc and 20 Kc errors in the meter scale can approach +15% when the meter is used to measure changes in the order of 10 db. At these frequencies it is desirable to use the attenuator to keep changes in meter reading as small as possible.

[3] The plug should be inserted just far enough to contact the terminal of the jack but not far enough to cause the jack to open and disconnect the preceding stages in the amplifier.

Noise and Hum Measurement

The high sensitivity of the sound-level meter makes it very useful for measuring directly the hum and noise level at the output of audio devices.

Although an a-c power supply is available, the instrument is normally battery operated, so it does not introduce hum into the system being measured. In the measurement of the noise level of magnetic tape recorders, the weighted (A or B) response of the sound-level meter is often used since this gives a better representation of audibility of the noise. If measurements are desired in terms of dbm, the gain can be set so that 0 dbm will be at a reading of 130 db and the total range will be from −106 to +10 dbm.

The upper limit of voltage measurement is increased by a factor of ten if the Type 1551-P11 20 db pad is inserted in the filter jacks. The voltage range then becomes 58 microvolts to 30 volts, and the dbm range −86 to +30 dbm.

Monitoring and Recording

The low-distortion output circuit of the sound-level meter can be used to operate an oscillograph to monitor visually the signal being measured, or earphones can be used for aural monitoring. The output system can also be used to operate analyzers, or graphic level recorders. Since separate amplifier stages drive the meter circuit and the output circuit, the nature of the load placed across the output terminals will not affect the voltmeter readings. For best operation of the output amplifier, however, the load should be 20 kΩ or higher.

Calibration Procedure for Voltage Measurements

When it is desirable to convert the decibel readings of the meter to the corresponding voltages, the following procedure is used to adjust the gain of the instrument for full scale readings of 1, 3, 10, etc.:

1. Calibrate the sound-level meter in the normal fashion using the 60-cycle internal calibration system.

2. From Table I below, determine Δdb, the correction factor dictated by the microphone sensitivity posted in the microphone well of the sound-level meter.

3. Adjust CAL control until meter reading with the weighting switch on 20 kc is different from the reading when the weighting switch is on CAL by the amount determined in 2 above.

4. Use the chart in Figure 3 to convert the decibel readings of the sound-level meter to the voltage appearing at its input terminals.

Example

1. When the instrument is calibrated in the normal fashion, the meter reads +3.2 db when the DECIBELS switch (attenuator) is at CAL and the weighting switch is at 20 kc or CAL.

2. The microphone sensitivity is −57.5 db and Δdb from Table I is −1.7.

3. The CAL control is readjusted until the meter reads 3.2 −1.7 or +1.5 db with the weighting switch at 20 kc; the meter still reads +3.2 db when the weighting switch is rotated to CAL.

4. The voltage being measured causes the meter to read +2 db with the attenuator set at 60, i.e., 62 db. To convert db to volts, enter the horizontal scale of the chart (Figure 3) at the

TABLE I

Microphone Sensitivity db re 1 volt/μbar. From 1551-A Microphone Well	Δdb Value to Use in Setting CAL Control Step 3 Above
−60	−4.2
−59	−3.2
−58	−2.2
−57	−1.2
−56	−0.2
−55	+0.8

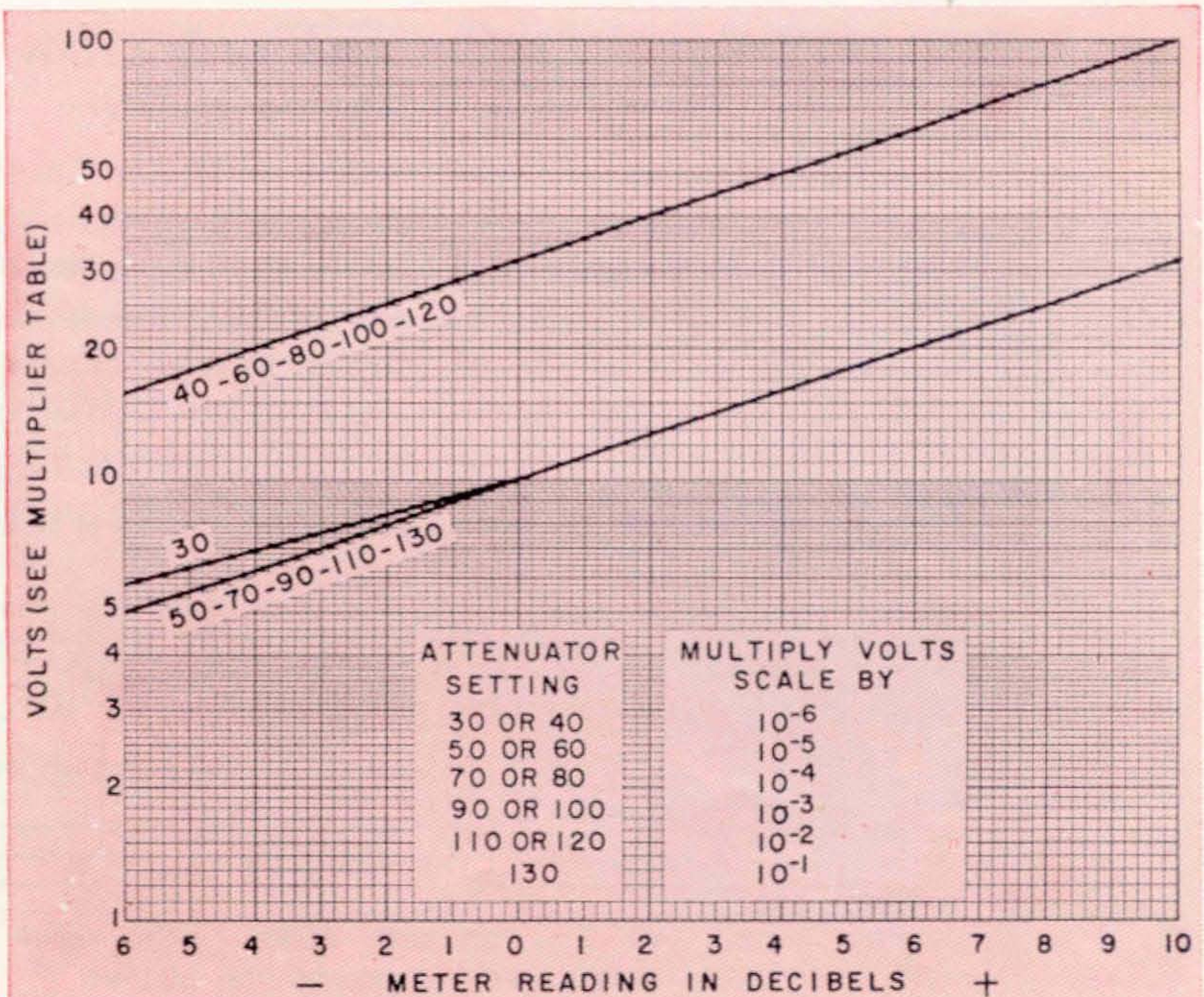


Figure 3. Chart for converting db readings to volts, after instrument has been standardized for full-scale values of 1, 3, 10, etc.

meter reading (+2 db) and then go up to curve for the attenuator setting (60 db); at this point read the voltage input to the instrument (400 microvolts) by going horizontally either to the left or right and multiplying by the factor indicated in the table.

The lowest full-scale reading is 31.6 microvolts when the attenuator is at 30. The maximum full-scale reading (with the attenuator at 130) is 3.16 volts.

Frequency Response

The over-all frequency characteristic with the weighting switch in the 20-kc position is shown in Figure 4. The amplifier has a very flat response from 40 cps to 15 kc, with the half-power points (−3 db) occurring below 20 cps and above 20 kc, and the response is useful down to 10 cycles and up to 35 kc. Weighting networks are included in a sound-level meter to modify its response to approximate the response of the human ear to pure tones. The response of the ear is essentially uniform at high sound levels, but at very low sound levels the ear is much less sensitive to low frequency sounds than it is to high frequency sounds. The curves in Figure 5 show the frequency response characteristics chosen for the sound-level meter for low level sounds (A Network) moderate level sounds (B Network) and high level sounds (C Network). The C Network response differs from the 20 kc response because the amplifiers are adjusted to give the flattest response with the microphone that is used with the sound-level meter. As indicated above, the weighted response of the sound-level meter is useful when hum is present in the signal from a bridge or when the effective noise level in the output of audio amplifier is being measured.

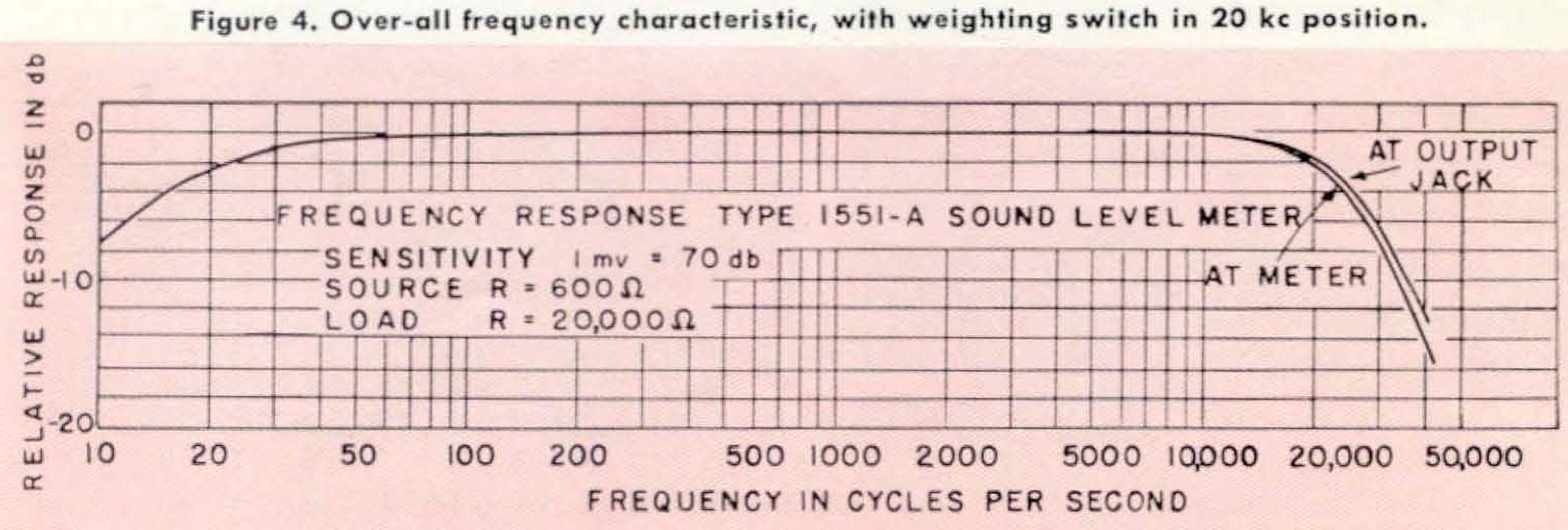
Input Noise

The inherent electrical noise voltage in the source resistance and in the instrument can cause an error in the meter reading at the lowest levels. This effect has been taken into account, and the curve for the 30-db attenuator position in Figure 3 has been corrected for source resistances of 0 to 20,000 ohms. Hence, the minimum voltage measurement is 5.8 microvolts and not 5.0 microvolts as it would be without the noise voltage. With a 1-megohm source resistance, the noise voltage causes a meter reading of −2 db (8 microvolts) with the attenuator at 30 db. For practical purposes, the noise voltage of the source can be neglected if it remains 10 db (3.16 to 1) below the signal voltage being measured.

Effects of Waveform

The indicator on the Sound-Level Meter is a copper-oxide-rectifier type, in which the rectifiers are operated at low current density. The meter is calibrated to read the r-m-s value of a sine wave and will pass the test for r-m-s addition specified in Appendix B of the

Figure 4. Over-all frequency characteristic, with weighting switch in 20 kc position.



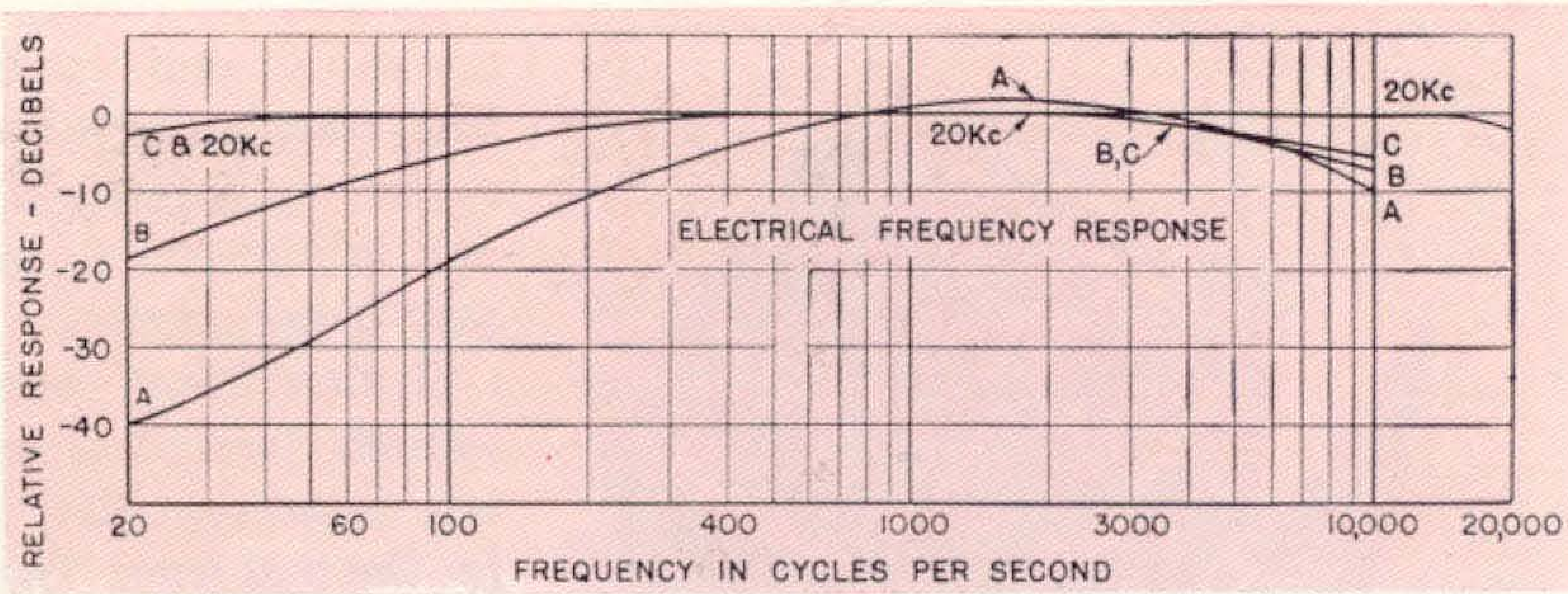


Figure 5. Frequency response for all positions of the weighting switch.

"American Standard for Sound-Level Meters for the Measurement of Noise and Other Sounds."[4] On complex waves the meter indication approaches the full-wave rectified average, rather than the r-m-s value. This type of indication closely approximates an r-m-s indication for many common waveforms. On square waves, where peak, r-m-s, and average values are identical, the meter reading is high by approximately 10% because it is calibrated for sine waves. On triangular waves its reading is below rms by about 3%, while on random noise the reading is low by approximately 10%.

[4] Z24.3 — 1944, American Standards Association.

Summary

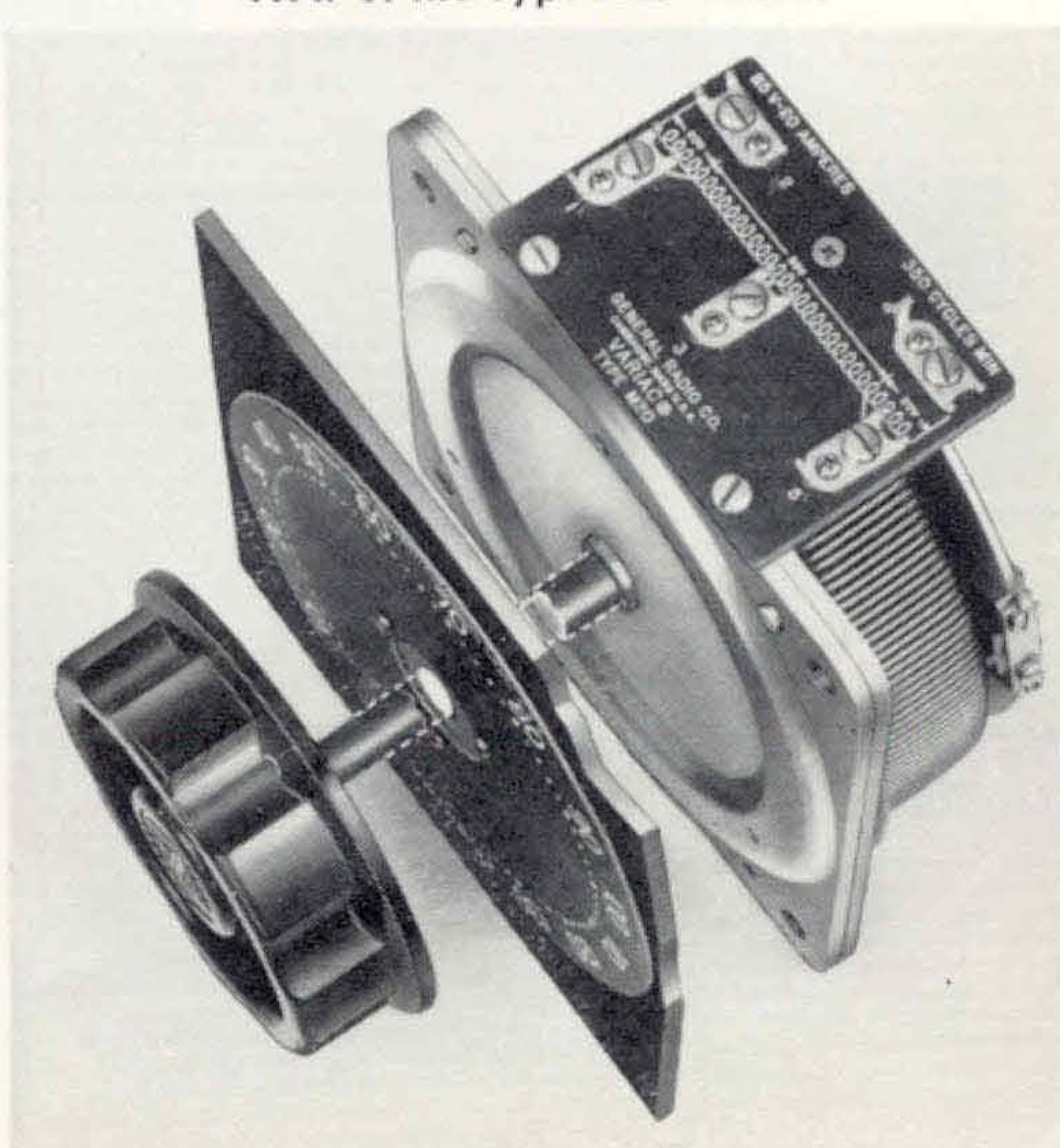
The Type 1551-A Sound-Level Meter has many characteristics that make it a useful general-purpose laboratory instrument. It is essentially a battery-operated, high-sensitivity, audio-frequency voltmeter, specifically designed to meter the output of a microphone. The characteristics needed to make the instrument satisfactory for its intended purpose are those required in a number of other laboratory measurements. High sensitivity and high gain are useful for bridge amplifiers and null detectors as well as for hum and noise measurements. The decibel scale is useful when measuring transmission characteristics of audio circuits while the decibel reading can readily be converted to corresponding voltage.

— E. E. GROSS

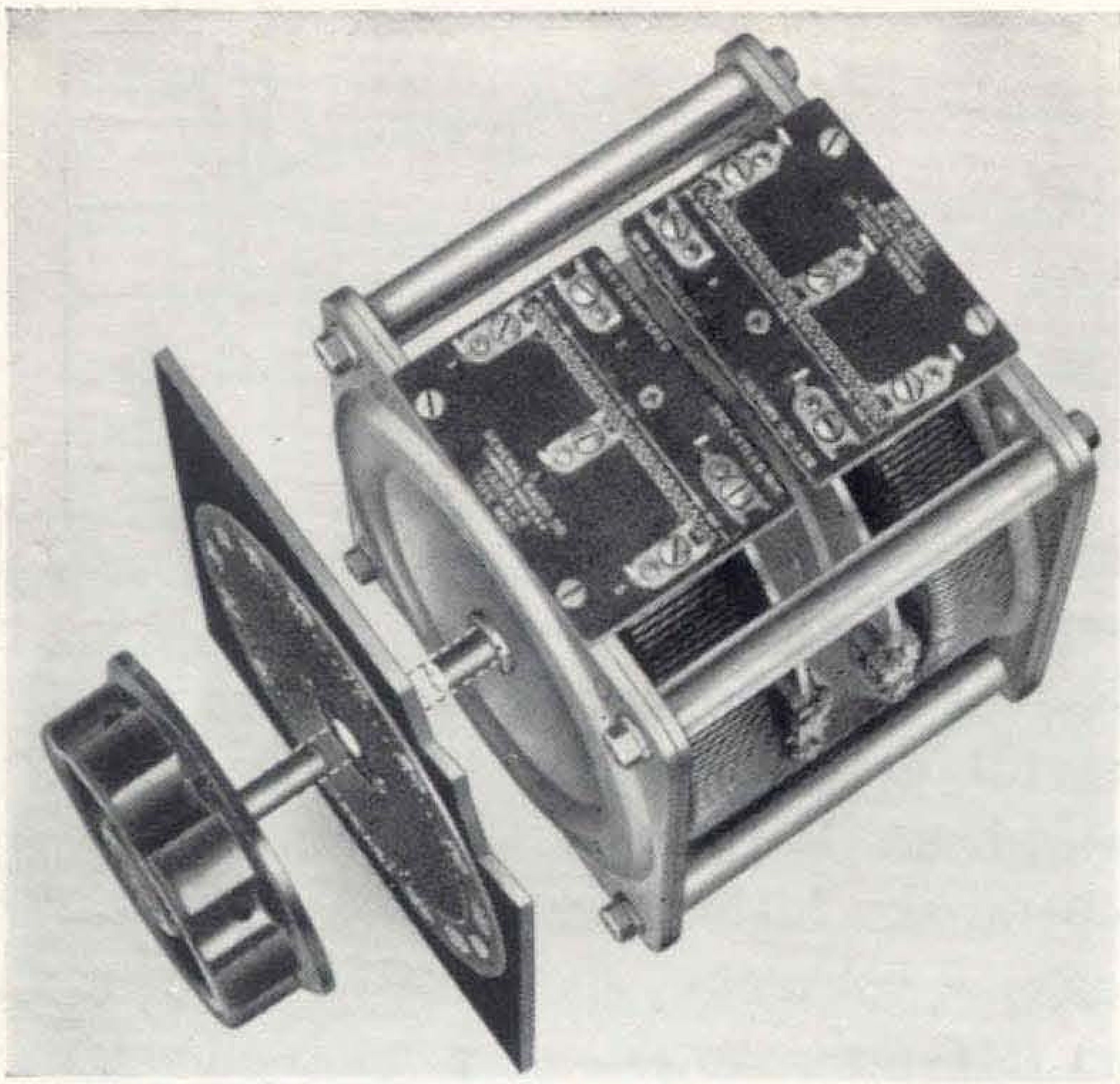
A 400-CYCLE VARIAC® WITH 20-AMPERE RATING

The new General Radio 20-ampere, militarized, high-frequency Variac follows the pattern established in the smaller ratings previously announced.[1] The Type M20 Variac, like its companion types, the M2, M5 and M10, is ruggedized, tropicalized, and designed to withstand successfully the usual environmental, operational shock and vibration tests normally required for military operation. It can be operated at any supply frequency between 350

View of the Type M20 Variac.



[1] "New Variac® Autotransformers for 350-to-1200 cycles Service," *General Radio Experimenter*, 29, 2; July, 1954, pp. 6–8.
"The Type M10, a 10-ampere Variac® Autotransformer for 350-to-1200 cycle Service," *General Radio Experimenter*, 29, 6; November, 1954, pp. 6–7.



View of 2-gang unit, Type M20G2.

and 1200 cycles. Other features of the "M" line Variacs include stamped base and radiator for improved shock resistance and protection; improved heat transfer between coil and base for cooler operation; finishes, materials, and lubrication to meet rigorous military requirements.

A new brush assembly, removable radially instead of axially, for greater service accessibility, is here introduced for the first time. The new brushes preserve the valuable attributes of the former GR unit brushes, low unsprung weight, coil springing, limited travel; but offer improved heat transfer to the radiator and greater convenience in examination or replacement.

The M20 Variac extends the range of controllable 400 cycle power into the multi-kva region required by today's aircraft, missiles, vessels and vehicles.

SPECIFICATIONS

Input Voltage: 115 volts, 380–1200 cycles per second
Output Volts: 0–115 or 0–135.
KVA Load Rating: 3.0
Rated Current: 20.0 amperes
Maximum Current: 26.0 amperes
No Load Loss at 400 Cycles: 27 watts
Dial Calibration: 0–115, 0–135
Angle of Rotation: 319 degrees
No. of Turns on Winding: 169
D-C Resistance, 20° C: 0.153 ohms
Driving Torque: 30–60 oz. inches
Replacement Brushes: Type VBT-8, $2.00 per set
Dimensions: Base, 7½ x 7½ inches (add ⅛ inch for adequate clearance); four mounting holes, 0.390 inches, in corners of base, 6¼ inches on centers; three alternate mounting holes, spaced 120° on 3-inch radius, tapped ¼-28; depth behind panel, 3 9/16 inches. Maximum panel thickness, ½ inch.
Net Weight (with knob and dial): 12 pounds, 13 ounces

Type		*Code Word*	*Price*
M20	Variac	CAVIL	$48.00
M20BB	Variac (with ball bearings)	CAVILBALLY	56.00

GANGED UNITS

	2-gang Type No. M20G2 (uncased)	3-gang Type No. M20G3 (uncased)
Dial Calibration	0–10	0–10
Driving Torque, inch-ounces	60–120	90–180
Code Word	CAVILGANDU	CAVILGANTY
Price	$107.00	$155.00
Price with Ball Bearings*	117.00	167.00

* Add suffix BB to type number

the GENERAL RADIO Experimenter

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Since 1915 — Manufacturers of Electronic Apparatus for Science and Industry

VOLUME 31 No. 9 FEBRUARY, 1957

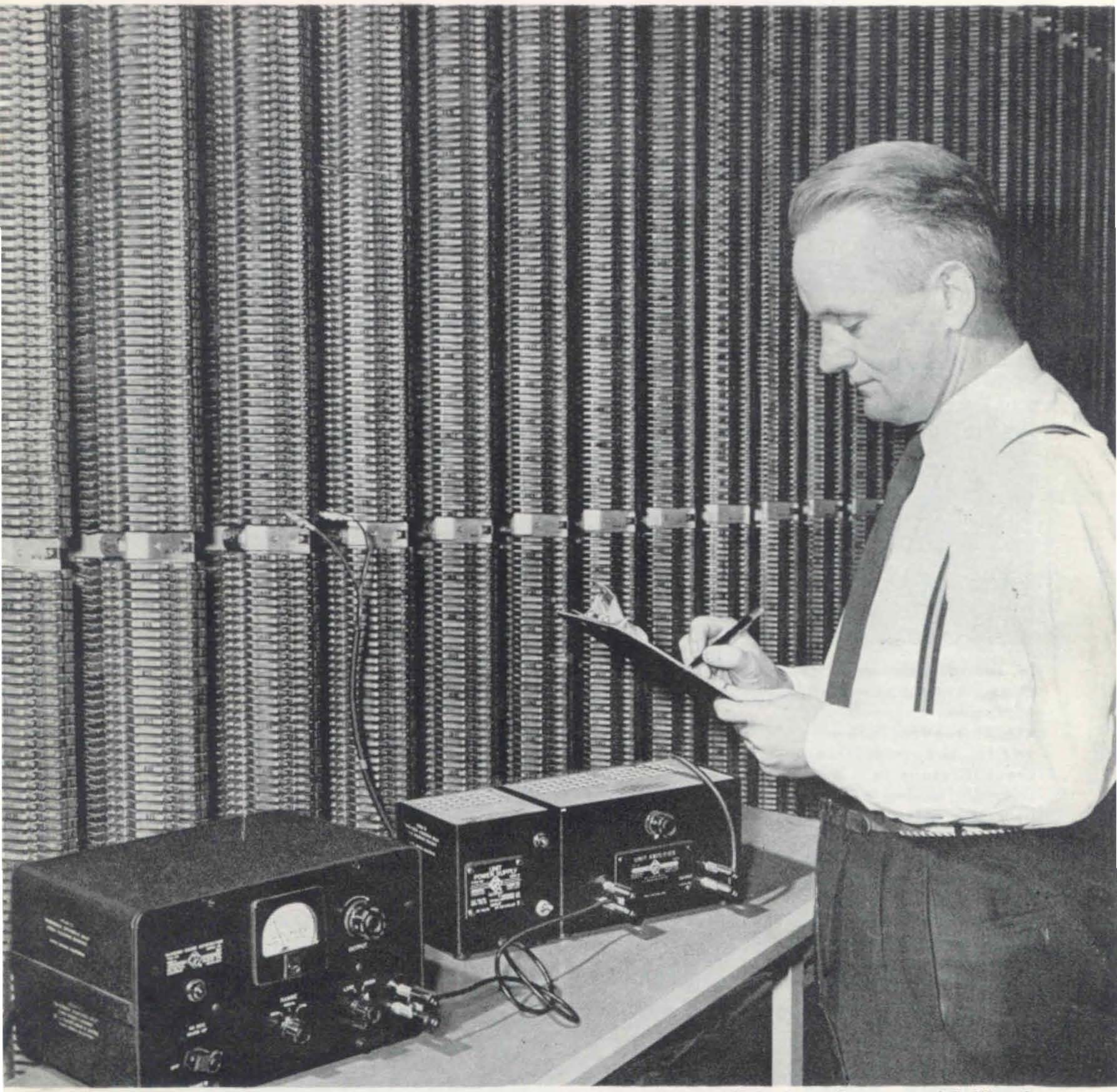

Photo Courtesy General Telephone Company of California

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3-Wire Power Cord — Armstrong Medal

THE

General Radio EXPERIMENTER

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COVER

In the measurement of crosstalk between communication channels, the use of random noise to excite the interfering channel results in a considerable saving of time over the point by point methods formerly used. Since random noise has constant energy per cycle, the interchannel crosstalk can be evaluated by a single measurement. The photograph shows Frederick D. Dahl, Transmission Engineering Department, General Telephone Company of California, using the General Radio Type 1390-A Random Noise Generator and the Type 1206-B Unit Amplifier in this type of measurement.

GENERAL RADIO COMPANY

275 Massachusetts Avenue

Cambridge 39 Massachusetts

Telephone: TRowbridge 6-4400

BRANCH ENGINEERING OFFICES

NEW YORK: **Broad Avenue at Linden, Ridgefield, New Jersey**
Telephone—N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: **920 South Michigan Ave., Chicago 5, Illinois**
Telephone—WAbash 2-3820

PHILADELPHIA: **1150 York Road, Abington, Pennsylvania**
Telephone—HAncock 4-7419

WASHINGTON: **8055 13th St., Silver Spring, Maryland**
Telephone—JUniper 5-1088

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WEST COAST: **Western Instrument Co., 826 North Victory Boulevard, Burbank, Calif.**
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TWO SHOWS EVERY DAY

SEE US ON THE SECOND AND THIRD FLOORS

FOR THAT NEW IDEA VISIT THE IRE

GENERAL RADIO COMPANY

Booths
3302, 3304, 3306,
2319

MARCH 18-21
NEW YORK COLISEUM
RADIO ENGINEERING SHOW
IRE NATIONAL CONVENTION

You'll see two General Radio exhibits at the 1957 Radio Engineering Shows at the New York Coliseum:

(1) A DISPLAY OF NEW AND UP-TO-DATE TEST INSTRUMENTS ON THE THIRD FLOOR;

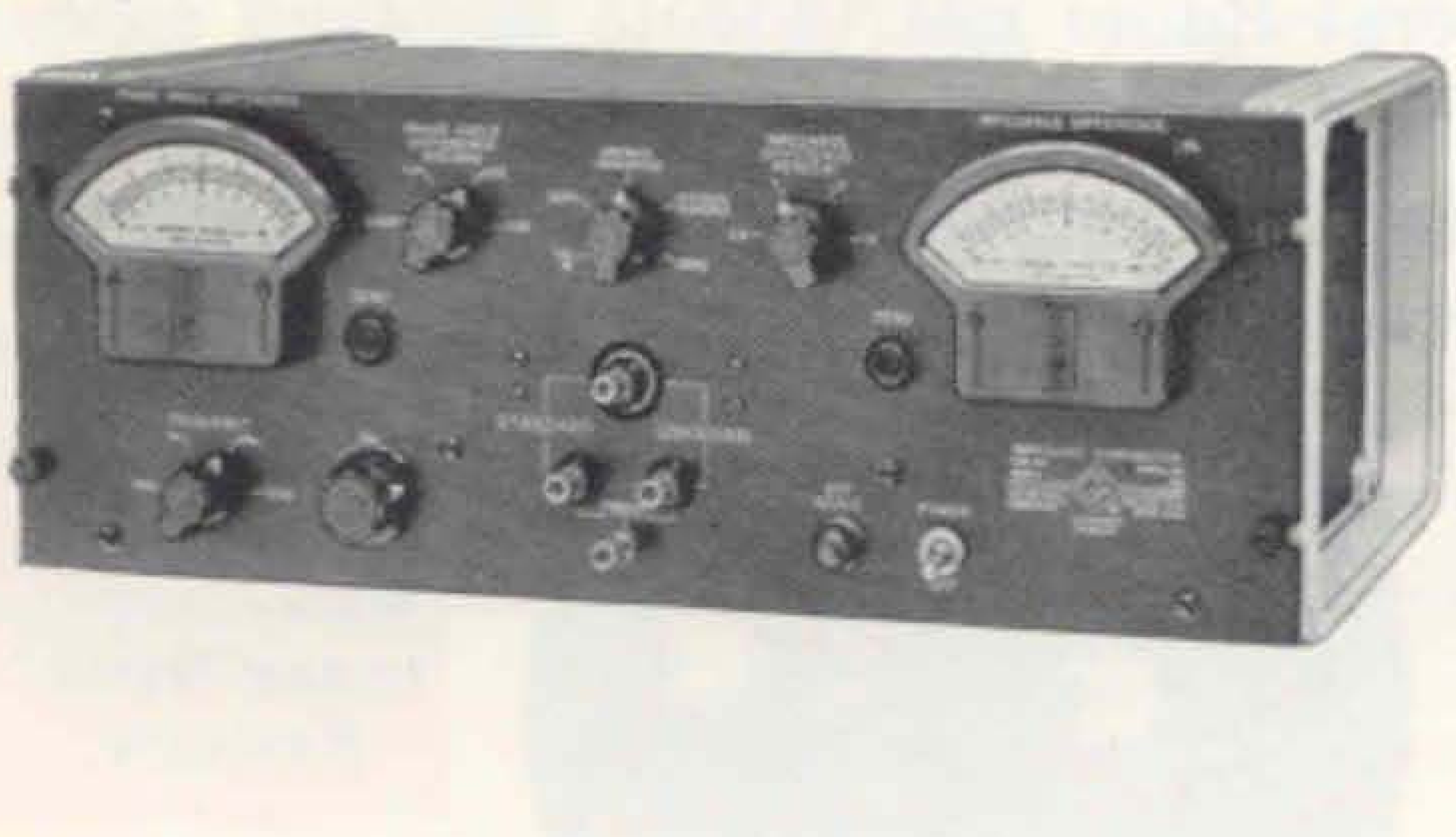
(2) A DISPLAY OF PRECISION PARTS AND COMPONENTS ON THE SECOND FLOOR.

PRECISION INSTRUMENTS

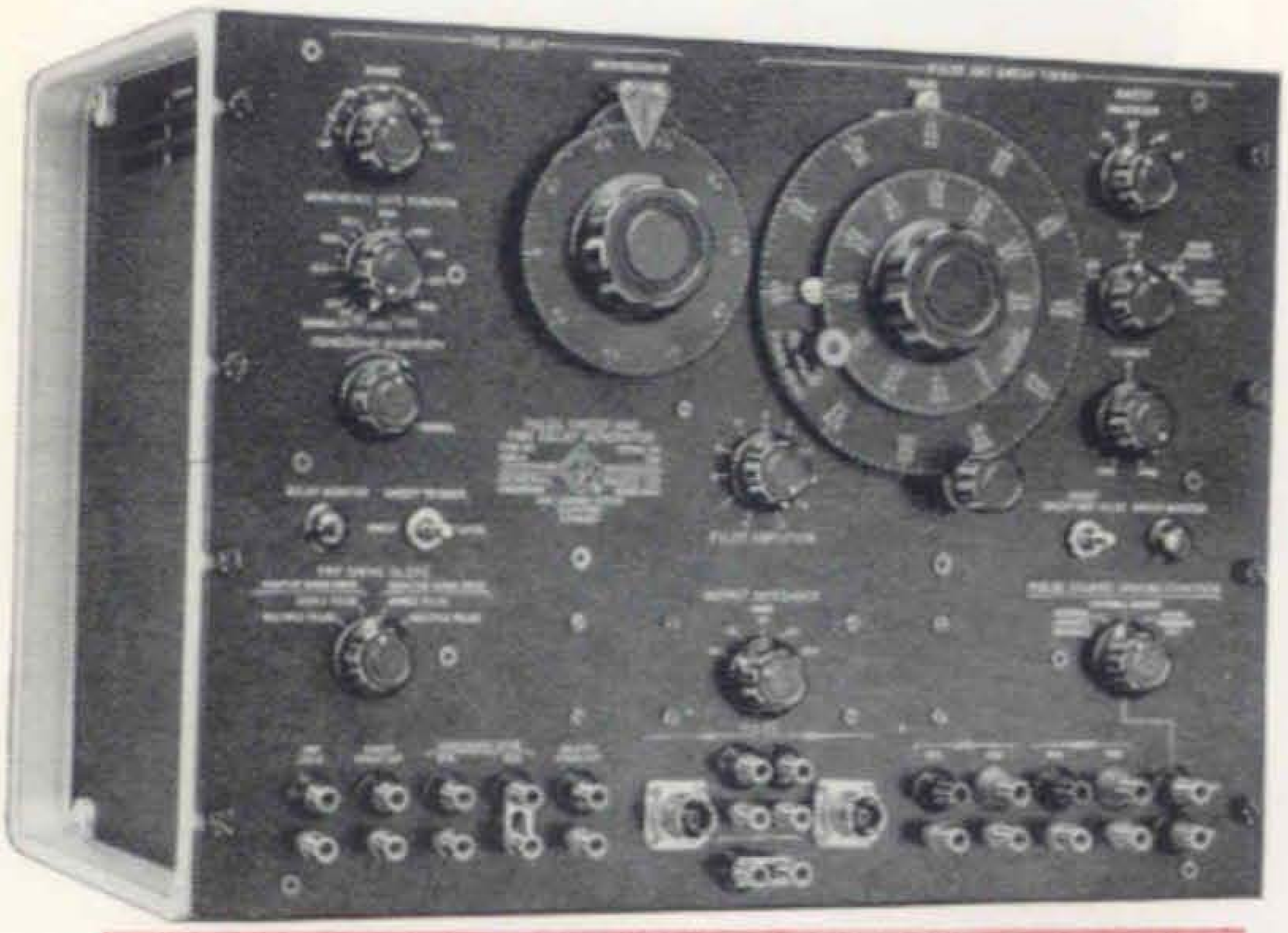
Booths 3302—3304—3306

Many of the instruments that you have read about in the *Experimenter* during the past year will be on display.

Impedance Comparator — Compares two impedances to 0.01% — For production testing, it can be used for inspection and acceptance tests, on inductors, capacitors and resistors; for the inspection and adjustment of ganged units for proper tracking; for materials inspection, such as silvered-mica sheets; for acceptance tests on balanced windings, and for selecting resistors to minimum phase-shift specifications. In the laboratory, it speeds up such measurements as that of drift in resistors, and of temperature and humidity characteristics; for these latter, built-in guard circuits provide for measurements in conditioning chambers, and output circuits for recorder operation are provided. The precision and speed of this comparator bring laboratory accuracy to production line testing; conversely, they bring production-test speed to laboratory measurements.



Type 1605-A Impedance Comparator



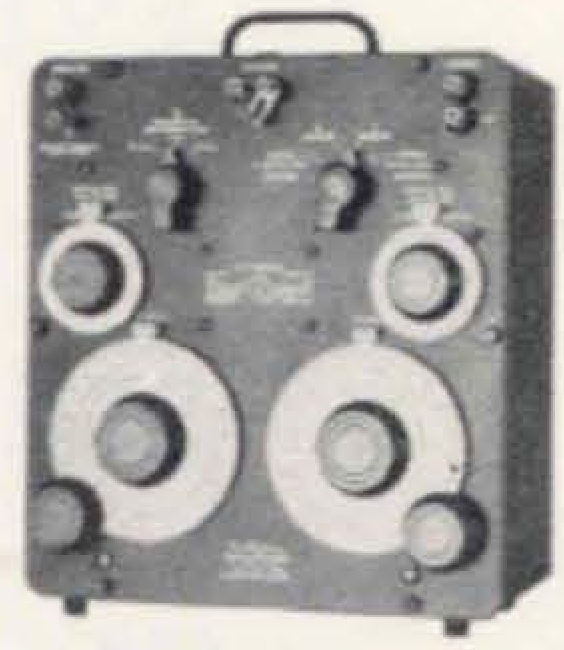
Type 1391-A Pulse, Sweep, and Time-Delay Generator

Electrometer—Basically an ultra-high-resistance millivoltmeter, this instrument measures voltages as low as 0.5 millivolt, currents as low as 5×10^{-15} amperes, and resistances up to 5×10^{14} ohms. Direct-reading, with high sensitivity and excellent stability, it has met immediate acceptance in engineering, science, and industry. Such features as guard terminal, recorder output, careful shielding make it adaptable to a wide variety of measurements.

Impact Noise Analyzer—This unusual instrument was specifically designed to evaluate the impact-type noises encountered in all types of modern industry; noises produced by such operations as stamping, punching, and riveting. It simplifies the measurement of such noises, which formerly required an extensive array of equipment. Also in this display are other instruments, comprising a complete sound-measuring system.

Pulse, Sweep, and Time-Delay Generator—This generator produces push-pull pulses, saw-tooth sweep voltages, and time delays to meet the requirements of laboratories engaged in time-domain measurements. High accuracy, excellent stability, and complete flexibility are combined in this generator with very wide ranges of operation.

Type 1230-A D-C Amplifier and Electrometer



Type 1603-A Z-Y Bridge

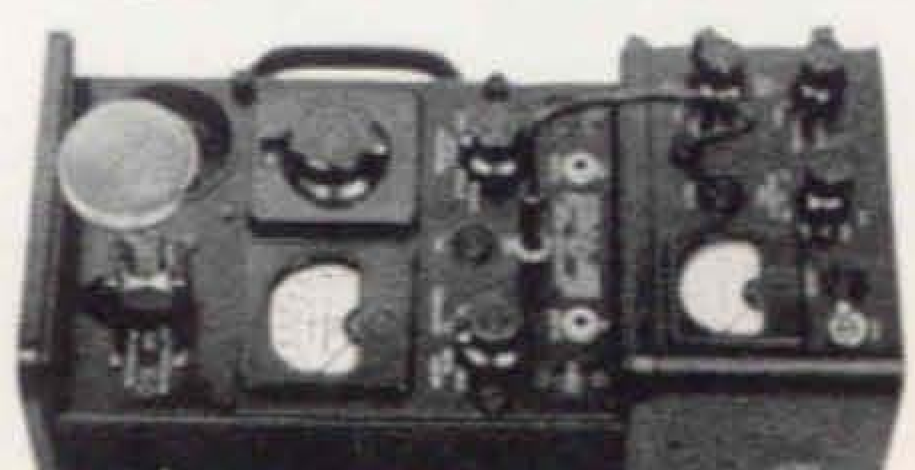
Universal Audio-Frequency Bridge—The Z-Y Bridge possesses the unusual property that it can be balanced for any impedance connected to its terminals, from short to open circuit, real or imaginary, positive or negative. Covering the frequency range from 20 cycles to 20 kilocycles, it has, in addition to the routine measurement of R, L, and C, many applications in determining the characteristics of magnetic circuits, transformers, electro-acoustic transducers, and electrolytes.

Unit Instruments—Oscillator, Time/Frequency Calibrator, Pulse Generator, Pulse Amplifier.

This group, representative of recent additions to GR's line of widely used Unit Instruments, offers the electronics engineer outstanding performance and quality at minimum price. Small in size, versatile in application, and reliable in operation, they are practically indispensable laboratory items.

Military Electronics—A group of General Radio instruments designed especially for military use will be shown, including a fuel-gauge calibrator, an r-f bridge, and a voltage regulator.

Type 1213-A Time/Frequency Calibrator



Sound-Level Meter with Impact-Noise Analyzer

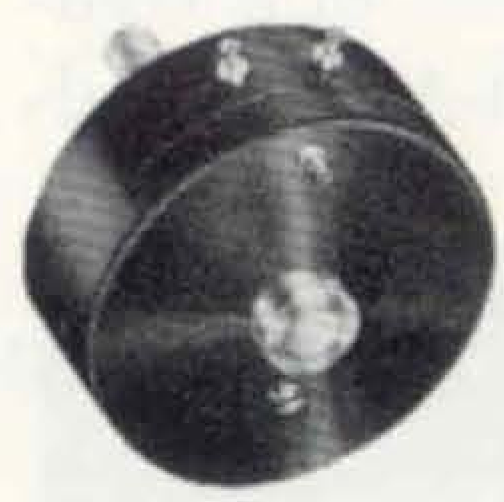
PRECISION COMPONENTS

Booth 2319

This exhibit on the second floor gives us a long-awaited opportunity to present to you our line of high-quality, precision instrument parts and accessories. Although designed orginally for use in General Radio instruments, these parts are widely used by other manufacturers both in their own products and in special-purpose laboratory instruments built for use in their own plants. Each item is built to definite and carefully controlled electrical and mechanical specifications to meet the exacting requirements of instrument makers.

In this group of items are decade assemblies of R, L, and C; variable air capacitors; transformers; knobs; dials; dial drives; coaxial connectors; plugs and jacks; patch cords; potentiometers; and binding posts. Also included is an extensive display of the world-famous Variac continuously variable autotransformer.






THERE IS NO SUBSTITUTE FOR QUALITY

General Radio products are designed for long life and reliable operation. A background of 41 years of experience in the design and manufacture of electronic instruments and components is represented in each GR product.

A cordial welcome awaits you at both General Radio Exhibits. Come in and talk over your measurement problems.

THREE-WIRE POWER CORD

A three-wire power cord, Type CAP-15, is now available from stock. Like the popular Type CAP-35 two-wire cord, the new three-wire model is 7 feet long with male connector at one end, female at the other. Both connectors are molded integrally with the rubber-covered cord and conform to the American Standard for Grounding-Type Attachment Plug Caps and Receptacles C73a-1953.

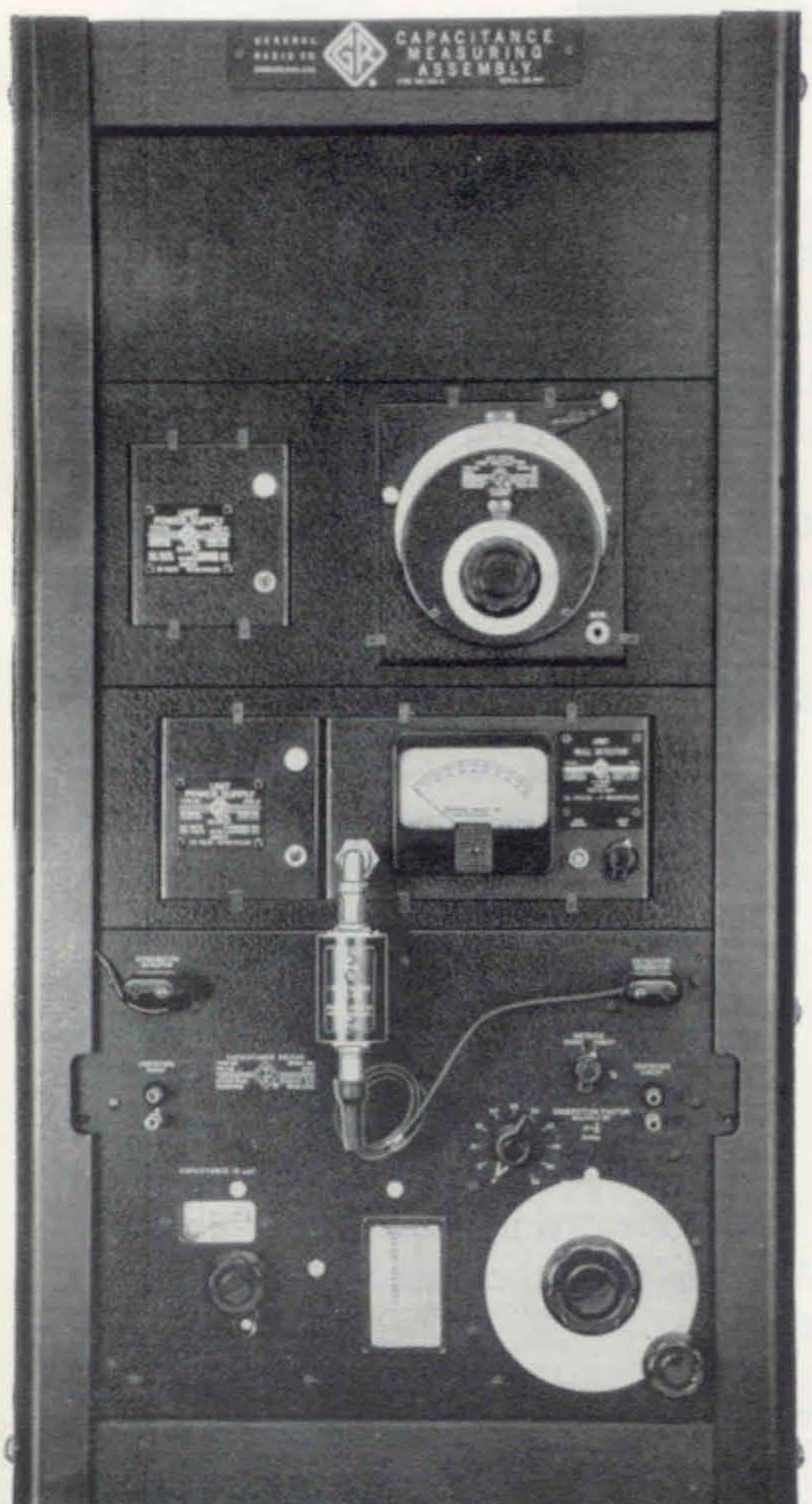
All three conductors are No. 18 AWG; electrical ratings are 7 amperes 125 volts.

Type		*Code Word*	*Price*
CAP-15	**3-Wire Power Cord**	TRICO	**$2.25**

CAPACITANCE BRIDGE ASSEMBLY FOR MEASUREMENTS AT ONE MEGACYCLE

Both commercial and military specifications for capacitors of 1000 $\mu\mu$f and less call for measurement of capacitance and dissipation factor at a frequency of one megacycle. The TYPE 716-CS1 Capacitance Bridge[1] has been designed specifically for these measurements. In conjunction with a suitable sample holder, it can be used equally well for 2-terminal measurements of dielectric constant and dissipation factor of dielectrics.

This bridge is now offered in a complete assembly, Type 1610-AK, including generator and detector, and consisting of the following items:



TYPE 716-CS1 Capacitance Bridge
TYPE 1211-B Unit Oscillator
TYPE 1212-A Unit Null Detector
TYPE 1212-P2 One-Megacycle Filter
Two TYPE 1203-A Unit Power Supplies
TYPE 480-P5UC1 and TYPE 480-P4U3 Adaptor Panels
Relay Rack Cabinet
Connection Cables and Power Cord

Although calibrated for a frequency of one megacycle, the bridge can be used at any frequency between 0.1 and 5 megacycles (see *Accuracy*, below). Accessories are available which enhance the usefulness and convenience of the assembly for specific measurements. For the measurement of small capacitors, particularly disc-ceramic types, the TYPE 1691-A Capacitor Test Fixture[2] is recommended. With the TYPE 1690-A Dielectric Sample Holder,[3] specimens of dielectric materials in the form of standard ASTM 2-inch discs can be measured.

[1] Ivan G. Easton, "A One-Megacycle Schering Bridge," *General Radio Experimenter*, 26, 9; February, 1952; pp. 4–7.

[2] "A Convenient Test Fixture for Small Capacitors," *General Radio Experimenter*, 30, 5; October, 1955; pp. 4–6.

[3] "A Sample Holder for Solid Dielectric Materials," *General Radio Experimenter*, 26, 3; August, 1951; pp. 1–5.

SPECIFICATIONS

Capacitance Range: Direct Method, 100 to 1150 $\mu\mu$f; Substitution Method, 0.1 to 1050 $\mu\mu$f.

Dissipation Factor Range: Direct Method, 0.00002 to 0.56; Substitution Method, 0.00002 $\times \frac{C'}{C_x}$ to 0.56 $\times \frac{C'}{C_x}$, where C' is the capacitance setting of the internal standard capacitor and C_x the capacitance of the unknown.

Frequency Range: Calibrated for one megacycle, the bridge operates satisfactorily at frequencies between 0.1 and 5 megacycles.

Accuracy (at one megacycle):
Direct Reading: Capacitance, $\pm 0.1\% \pm 1$ $\mu\mu$f when the dissipation factor of the unknown is less than 0.01; Dissipation Factor, ± 0.0005

or ± 2% of dial reading, whichever is larger, for values of D below 0.1.

Substitution Method: Capacitance, ± 0.2% or ± 2 μμf, whichever is larger; Dissipation Factor, ± 0.00005 or ± 2% of the change in D observed, when the change is less than 0.06.

When the dissipation factor of the unknown exceeds the limits given above, additional errors occur in both capacitance and dissipation-factor readings. Correction formulae are supplied, by means of which the accuracy given above can be maintained.

A correction chart for the precision capacitor is supplied, giving scale corrections to 0.1 μμf at multiples of 100 μμf. By using these data substitution measurements can be made to ± 0.1% or ± 0.8 μμf, whichever is the larger. For capacitance less than 25 μμf, the error will decrease linearly to ± 0.1 μμf. It is also possible to obtain, at an extra charge, a worm-correction calibration with which substitution measurements can be made to an accuracy of 0.1% or ± 0.2 μμf, whichever is the larger.

This same accuracy can be obtained at other frequencies between 0.1 Mc and 3 Mc, if corrections are made for the effects of residual impedance, and if adequate filtering is provided for the null detector. The filter furnished with the assembly operates at 1 Mc only.

Accessories Available: For measurements on unguarded dielectric specimens, the TYPE 1690-A Dielectric Sample Holder is recommended. For measurements of small capacitors having parallel, side-by-side leads, the TYPE 1691-A Capacitor Test Fixture is recommended.

Dimensions: (Height) 43 × (width) 22½ × (depth) 20 inches, over-all.

Net Weight: 150 pounds, approximately.

Type		*Code Word*	*Price*
1610-AK	**Capacitance Measuring Assembly**	SIREN	**$1290.00**
	Worm-Correction Calibration for Internal Precision Capacitor	WORMY	**50.00**
1690-A	**Dielectric Sample Holder**	LOYAL	**435.00**
1691-A	**Capacitor Test Fixture**	EDICT	**22.50**

CORRECTIONS—December Issue

In the table on page 9 of our December issue, the General Radio Slotted Line should be listed as TYPE 874-LBA. The older TYPE 874-LB is not adaptable to motor drive.

The first entry in the table, TYPE 1302-A Oscillator, indicates that the TYPE 1750-A Sweep Drive can be used with a graphic recorder or an X-Y plotter. The drive is designed primarily for use in CRO displays and its minimum speed is (0.5 sweep per second) somewhat high for recorder work. It is possible to operate the drive manually, however, to obtain an X-Y plot.

The TYPE 1750-A Sweep Drive can also be used with the TYPES 1001-A, 805-C, and 1021-A Standard-Signal Generators and the TYPE 1330-A Bridge Oscillator, although the sweep range is restricted to that covered by 300° of the slow-motion drive.

NEW GR OFFICE AT LOS ALTOS FOR SAN FRANCISCO BAY AREA

The General Radio Company announces the opening of a sales and engineering office at

1182 Los Altos Avenue
Los Altos, California
Telephone: WHitecliff 8-8233

This office will enable us to give better service to our customers in the rapidly growing industrial San Francisco Bay area.

Manager of the new office will be James G. Hussey, formerly of the staff of the General Radio Los Angeles Office.

James G. Hussey

ARMSTRONG MEDAL TO MELVILLE EASTHAM

Melville Eastham (right) receives medal from Frank Gunther, Vice President of Radio Engineering Laboratories

The Armstrong Medal of the Radio Club of America was awarded to Melville Eastham at the Club's 47th Anniversary Banquet held at the Columbia University Club, New York, on December 14, 1956. The award was made "in recognition of his outstanding contributions to the art of precision measurements in the radio and electronic field.

"For fifty years a design engineer, Mr. Eastham's effort made available to many workers in the electronic art reliable test equipment of a standardized nature which previously did not exist or had to be specially assembled as a laboratory setup.

"Beside his many technical contributions, Mr. Eastham was a leader in recognizing the importance of good employee relations, and assisted and encouraged his associates in continuing their technical education and in making contributions to technical literature. His thorough, practical approach to design problems and his enlightened management practices should be an inspiration to younger men."

Melville Eastham founded the General Radio Company in 1915 and was its president from 1915 to 1944. Upon his retirement in 1950, the Directors of the Company voted him the title of Honorary President.

A Member of the Radio Club, Mr. Eastham is also a Fellow of the Institute of Radio Engineers and of the American Association for the Advancement of Science. He is a Member of the American Institute of Electrical Engineers, the Acoustical Society of America, the American Physical Society, and the American Meteorological Society.

The Armstrong Medal

General Radio Company

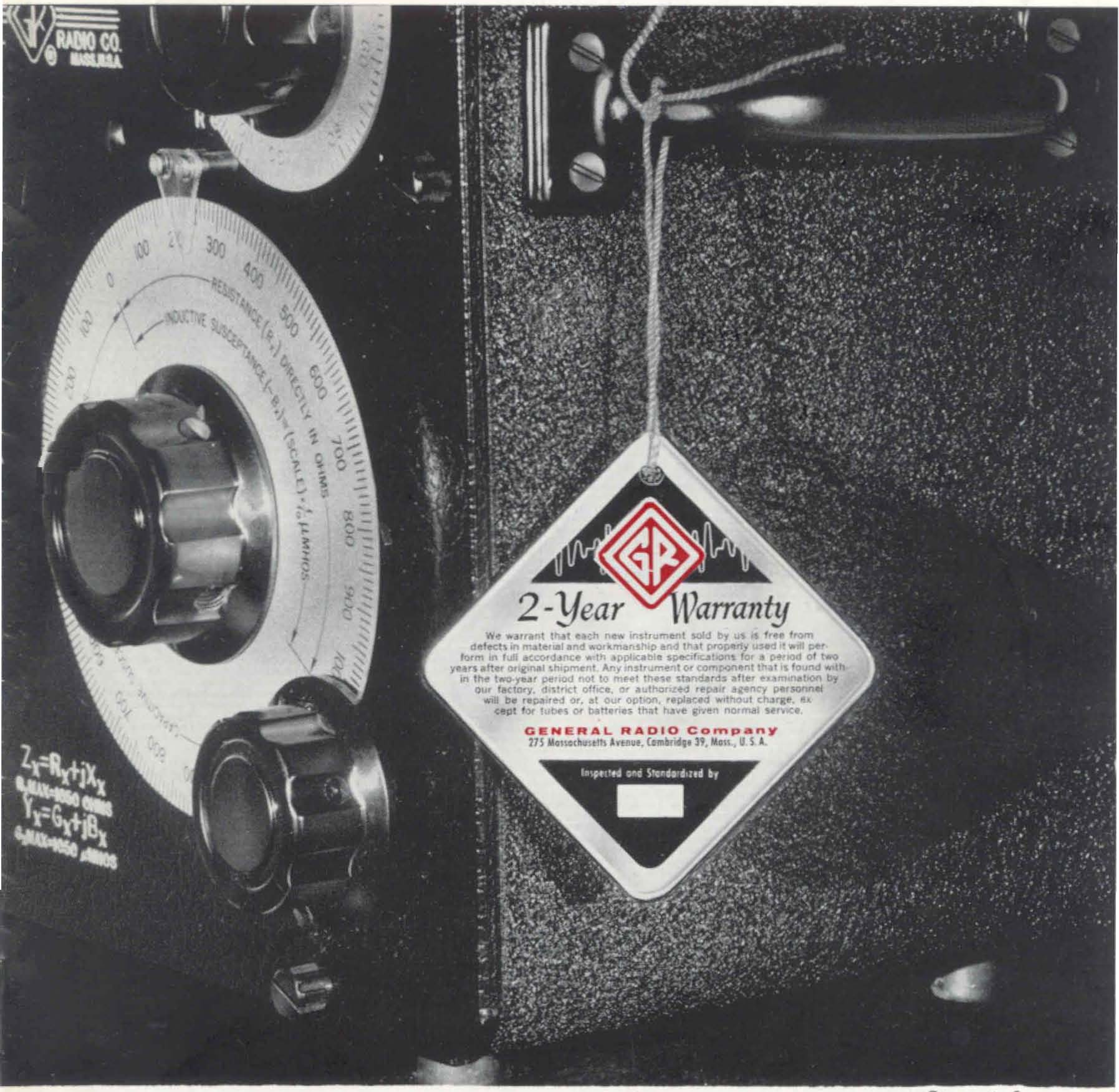
PRINTED IN U.S.A.

the GENERAL RADIO

Experimenter

Since 1915 · Manufacturers of Electronic Apparatus for Science and Industry

VOLUME 31 No. 10 MARCH, 1957



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THE GENERAL RADIO EXPERIMENTER

Published Monthly by the General Radio Company

VOLUME 31 • NUMBER 10 MARCH, 1957

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GENERAL RADIO COMPANY

275 Massachusetts Avenue

Cambridge 39 Massachusetts

Telephone: TRowbridge 6-4400

BRANCH ENGINEERING OFFICES

NEW YORK: Broad Avenue at Linden, Ridgefield, New Jersey
Telephone—N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: 920 South Michigan Ave., Chicago 5, Illinois
Telephone—WAbash 2-3820

PHILADELPHIA: 1150 York Road, Abington, Pennsylvania
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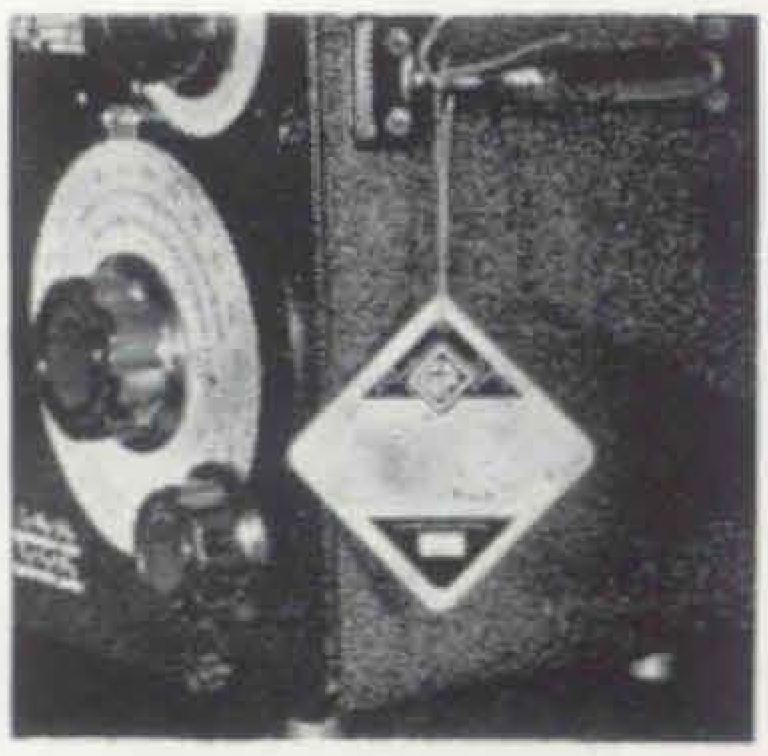


COVER

Look for this warranty tag on your electronic test equipment.

G-R INSTRUMENTS ARE BUILT TO LAST

New Two-Year Warranty Backs Up Well-Established Fact

A full two-year warranty — the first in the electronic instrument industry — now applies to *all* General Radio products shipped after March 1, 1957. This warranty is made possible by the ingredients of high quality that have always characterized GR equipment — circuit design that doesn't cut corners and which provides the extra refinements that assure stable and reliable performance; the use of high-quality components, which cost more but return several times their cost in calibration accuracy and stability; ruggedness of mechanical construction, which assures long life; care in manufacture, through the use of skilled workmen and modern machines; and thorough testing, to better-than-catalog specifications.

To the engineer using this equipment, G-R quality means added assurance that his measurements are correct, because he knows the G-R reputation for calibrations that *hold* their accuracy over the years. To the firm buying G-R equipment, high quality in basic measuring tools means lower costs in the long run: less time lost for repairs and *longer life with full performance* before replacement is required.

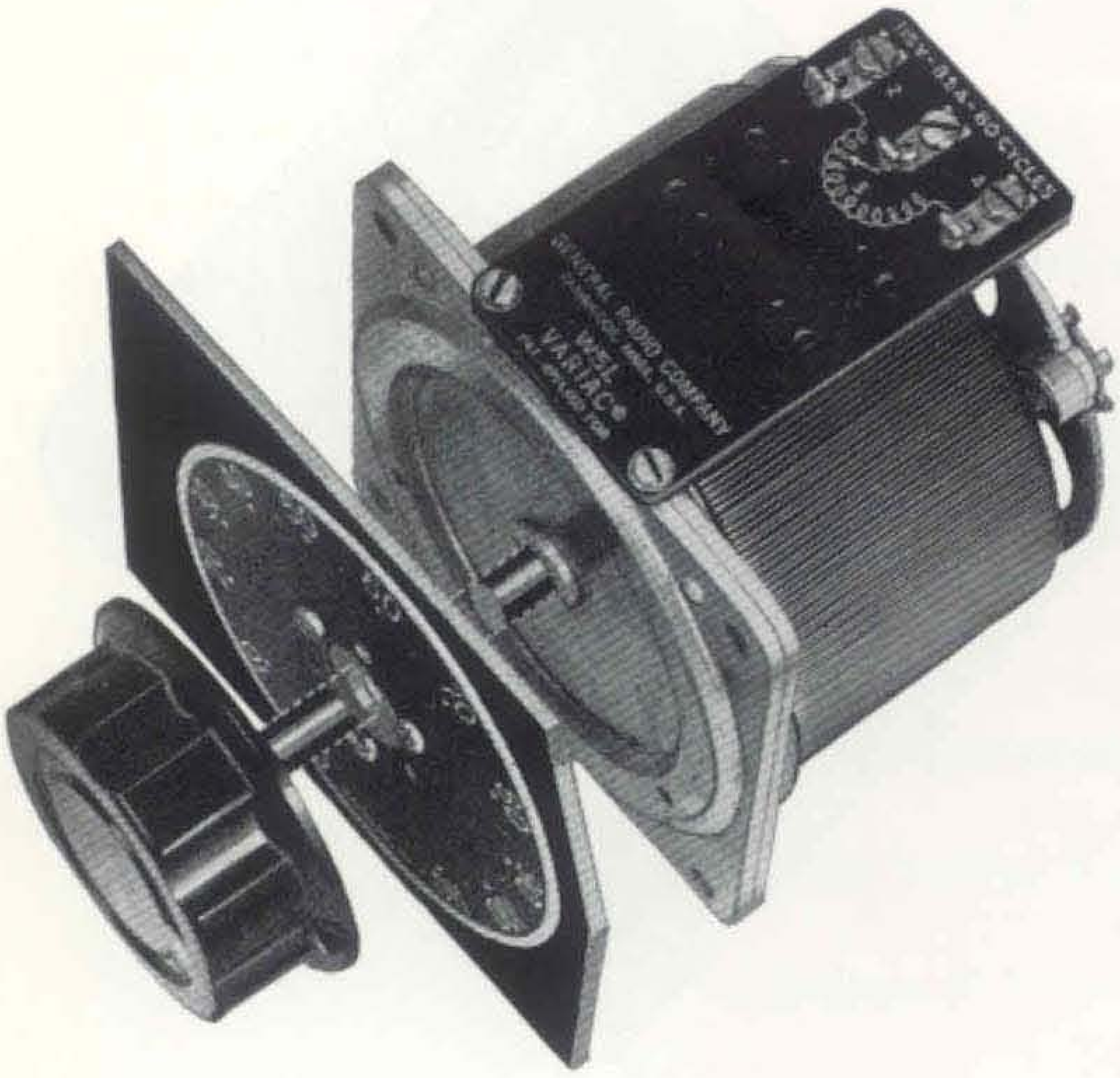
When you buy a G-R product you make an investment in lasting value. Our new warranty tag on all newly purchased instruments shipped after March 1, 1957, will serve as a reminder of this quality.

THE G-R 2-YEAR WARRANTY

We warrant that each new instrument sold by us is free from defects in material and workmanship and that properly used it will perform in full accordance with applicable specifications for a period of two years after original shipment. Any instrument or component that is found within the two-year period not to meet these standards after examination by our factory, district office, or authorized repair agency personnel will be repaired or, at our option, replaced without charge, except for tubes or batteries that have given normal service.

NEW VARIAC® HANDLES OVER 1¼ KVA

Type W5L Gives More Watts Per Pound, More Watts Per Dollar



For use in the "line-voltage connection," where the usual overvoltage feature is not needed, the new Type W5L Variac® offers outstanding performance and outstanding economy.

* See *Experimenter* for December, 1955.

Output voltage of the Type W5L is equal to input line voltage, that is, with 115 volts input, the output can be adjusted from 0 to 115 volts. Loads drawing up to 11 amperes at line voltage can be handled at any output setting, giving an output rating of 1.265 kva.

This increased rating is made possible by the elimination of both the overvoltage feature and 50-cycle operation, which permits the use of a larger wire size for the transformer winding. Size, weight, and mounting dimensions are identical with those of the Type W5.*

For the many uses where output voltages higher than input line voltage are not required, the Type W5L is an outstanding buy. It offers more watts per pound of weight and more watts per dollar than any other variable autotransformer on the market today.

SPECIFICATIONS

Input Voltage: 115 volts, 60 cycles; can be used on lines from 105 to 125 volts, 60 cycles.

Output Voltage: 0 to input line voltage; dial calibration, 0 to 115 volts, correct at 115 volts input.

Load Rating: 1.265 kva.

Rated Current: 8.5 amperes; may be drawn at any output setting.

Maximum Current: 11.0 amperes; may be drawn at or near input line voltage.

No-Load Loss at 60 cycles: 12 watts

Angle of Rotation: 325 degrees

No. of Turns on Winding: 235

D-C Resistance of Winding: 0.926 ohms at 20° C

Driving Torque: 10 to 20 ounce-inches.

Mounting: Without case, for panel mounting.

Net Weight: 6½ pounds.

Type		*Code Word*	*Price*
W5L	Variac ® Autotransformer..................	COTUG	$17.50
VB2	Replacement Brush..........................		0.75
W5LBB	Variac with Ball Bearings..................	COTUGBALLY	24.50

THE DESIGN OF IRON-CORED CHOKES CARRYING DIRECT CURRENT

The optimum design of inductors with ferro-magnetic cores, having dc superposed on the a-c signal, has never been very satisfactorily systematized. Such chokes are used, for example, as filter chokes in rectifier-type power supplies or as plate chokes in constant-current modulators. In the past, the usual procedure was for each user to make empirical measurements on sample coils, displaying the results as a family of curves of inductance versus d-c bias for a succession of different air gaps. These measurements were usually repeated for each different lamination used. There was no facile method by which normalized data could be presented for a given grade of ferro-magnetic material so that it could be simply used for as many different sizes and shapes of laminations as desired.

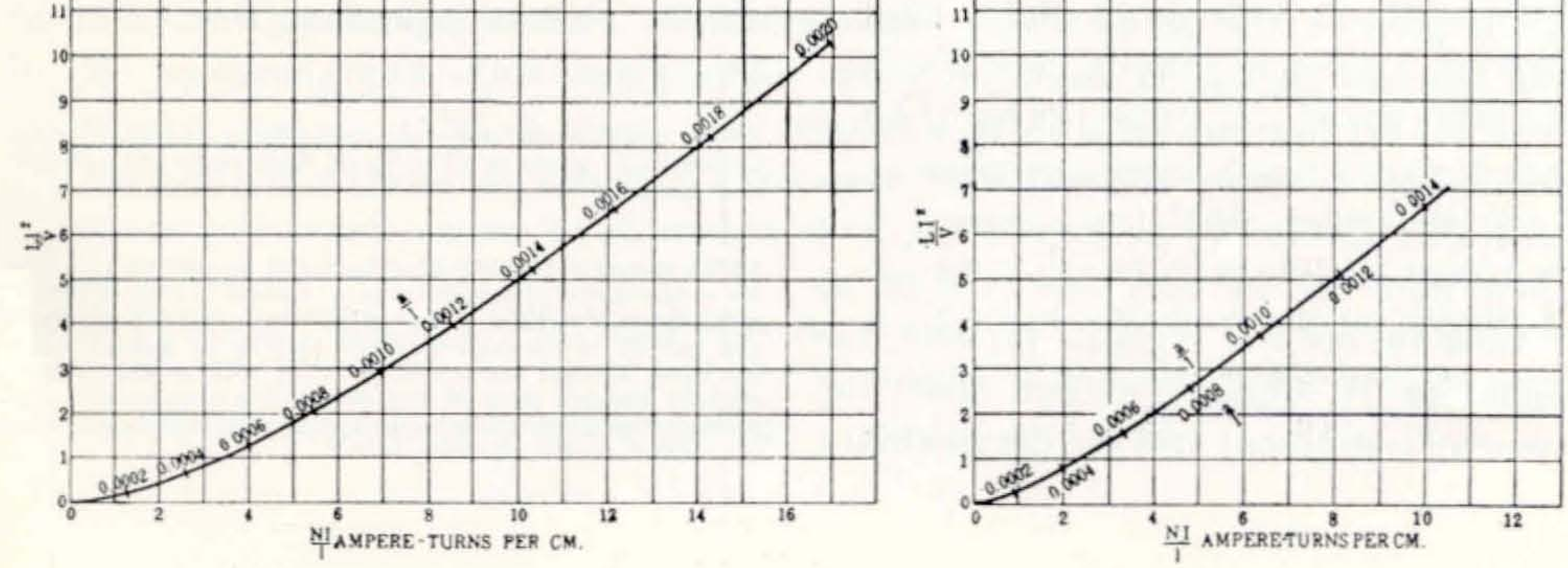
This situation was recognized in the early twenties by Mr. C. R. Hanna of the East Pittsburgh works of Westinghouse Electric and Manufacturing Company, and he presented a paper entitled "Design of Reactances and Transformers Which Carry Direct Current" at the Winter Convention of the AIEE in New York City in February of 1927.[1] This paper provided the methods for deriving and presenting succinctly normalized data of the type being considered here. Some Hanna-type curves are published in Federal Telephone and Radio's *Reference Data for Engineers*, but this is the exception rather than the rule. Hanna's contribution has never received the wide usage to which its advantages entitle it.

For complete understanding of the matter, reference should be made to Hanna's paper. However, it can be stated that Hanna's information enables one to calculate quickly the airgap which will yield the maximum inductance for a given number of turns on a given magnetic structure with a stated amount of superposed dc at a particular flux density. It may thus be seen that the curves are useful only to give the optimum design for a specific steady-state purpose. They do not contain the information needed, for instance, to design a "swinging" choke in which the inductance at 10 per cent of full-rated direct current is typically about five times what it is at full-rated direct current. For this purpose one would use a family of curves as described in the first paragraph.

Hanna's information (*cf* Figure 3 and Figure 6 of his paper, reproduced here as Figure 1) is presented as a single curve (for each flux density) of stored direct-current energy per unit volume $(\frac{LI^2}{V})$ versus d-c magnetizing force $(\frac{NI}{l})$. Hanna indicated that airgap per unit length for optimum performance by labeled "transverse marks" on the curve. While this conveys the information faithfully, we find that we can read and interpolate with appreciably more ease if a separate curve is provided for

[1] See *Journal of the AIEE*, February, 1927.

Figure 1. Curves of $\frac{LI^2}{V}$ vs. $\frac{NI}{l}$ from Hanna's paper.[1] *(left)* 4% silicon steel; *(right)* Hypernik.



airgap per unit length ($\frac{g}{l}$) versus d-c magnetizing force ($\frac{NI}{l}$).

Behavior of any shape and size of core, with some limitations, can be derived from such data by the use of nothing more than the proper constants pertaining to the core. These constants are the volume of iron and the length of the magnetic path. The latter is necessary to determine the value of the abscissa $\frac{NI}{l}$. The former is necessary when interpreting the value of the ordinate $\frac{LI^2}{V}$.

We have found it advantageous to amplify the information given in the single curve on Figure 3 of Hanna's paper. While he specified in 1927 that his Figure 3 applied to 4 per cent silicon steel, this is not now very specific since a number of the better grades of electrical silicon steels contain around 4 per cent of silicon, and so we are not sure whether it applies to the grade of silicon steel often employed for chokes. Further, we do not know the flux density, B, at which Hanna's curves were taken. Even if we did, it would be necessary to have similar curves at several flux densities to take care of all design problems encountered.

This comes about from the fact that the permeability is highly dependent upon the alternating flux density. With no dc present, the permeability follows the familiar course. It starts on a plateau at very low flux densities at a value somewhere between 400 and 500 [3], rises with flux density to perhaps 6000, and then falls off to very low values as saturation occurs. With dc present, the behavior is similar, except that the plateau is different and the permeability begins to drop off sooner, because of the d-c polarizing flux. The greater the dc, the sooner the falling off occurs.

THE ATTACHED CHARTS

The large curves herewith represent, respectively, the empirically obtained plots of $\frac{LI^2}{V}$ and $\frac{g}{l}$ against $\frac{NI}{l}$. The measurements were made using coils having cores of U. S. S. Radio Transformer "72" grade silicon steel, No. 26 U. S. gauge (approximately 0.019″), which is an AISI M-19 grade material. Over the past ten years these curves have been used with good results for coils having 26-gauge laminations of AISI M-19 material of other manufacturers also, and 29-gauge (0.014″) AISI M-15 (58 grade) material.

In the expressions used throughout:

A = effective cross-sectional area of core in square inches.

B = max. a-c flux density in lines/in.^{2}.

E = applied a-c voltage in volts, rms.

I = direct current in amperes.

L = inductance in henrys.

N = number of turns.

V = geometric volume of iron in cubic inches (no reduction for stacking factor).[4]

f = frequency in cps.

g = length of airgap, or airgaps, in inches. (Hanna calls this a).

l = length of magnetic path in inches.

For preparing both of these curve sheets, Hanna-type data was taken at 60 cycles with flux densities, B, of

[3] For a material which is variously known as Radio Transformer "72" grade or AISI M-19; Radio signifies a punchable grade rather than one that must be sheared.

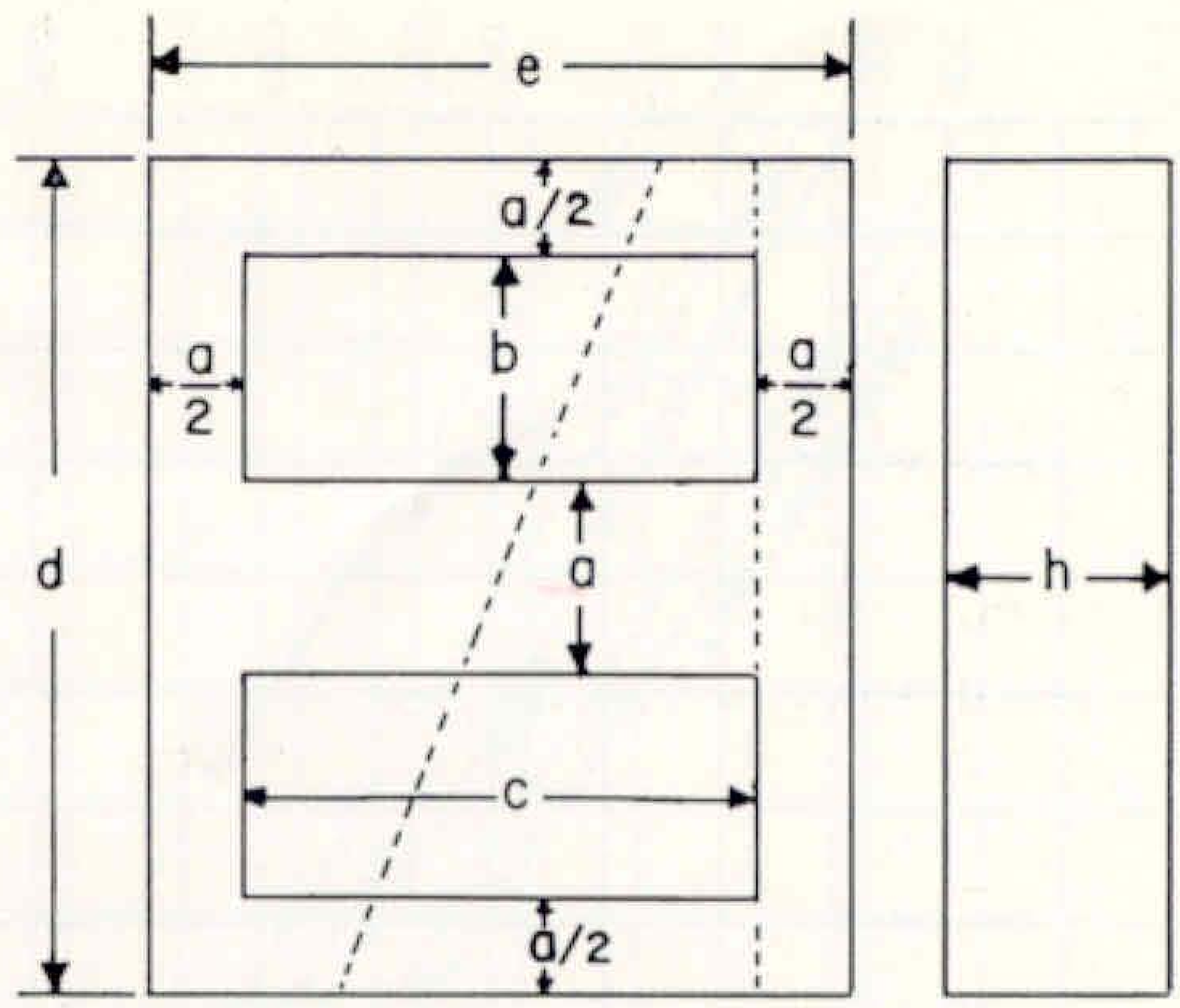
[4] This means that a stacking factor of around 96 per cent for noninterleaved laminations is implicit in the curves for inductance. Stacking factor should have no effect on airgap curves. If laminations much thinner or much thicker are used, so that the stacking factor will be less than or slightly greater than 96 per cent, then appropriate correction should be made to the inductance curves in direct proportion to the stacking factor.

100, 500, 1000, 5000, 10,000, 20,000, and 30,000 lines/in.^{2}.

The $\frac{LI^2}{V}$ curves show the wide spread of inductance values as a function of B. The spread would be still wider if data had been taken for initial a-c permeability. It will be noted, in general, that the curves for higher B lie above those for lower B. For a large part of the distance, the 10- and 20-kiloline curves coincide. The 30-kiloline curve lies above these two near the origin, but shortly goes below them and continues to cross other curves of still lower B's.

The upward-inclined lines crossing the others connect points having the same $\frac{g}{l}$ ratios. These lines are practically straight until saturation sets in. They show that, in general, a given $\frac{g}{l}$ ratio is optimum even when the d-c polarizing flux is increased, provided that the a-c superposed flux is also increased.

The second set of curves (page 9) shows the optimum airgap (in terms of $\frac{g}{l}$, which is specific) as a function of the magnetizing force (in terms of $\frac{NI}{l}$). These curves are derived from those on the prior sheet through the original data. They are supplied in this different form, rather than the way this information appears on Hanna's curves, for two reasons. First, a great deal of confusion is eliminated. Second, these curves are much easier to interpolate for $\frac{g}{l}$ than are Hanna's. The same effects described concerning relative permeabilities and the effects on optimum airgap of higher B's and of saturation can be seen also on these curves.

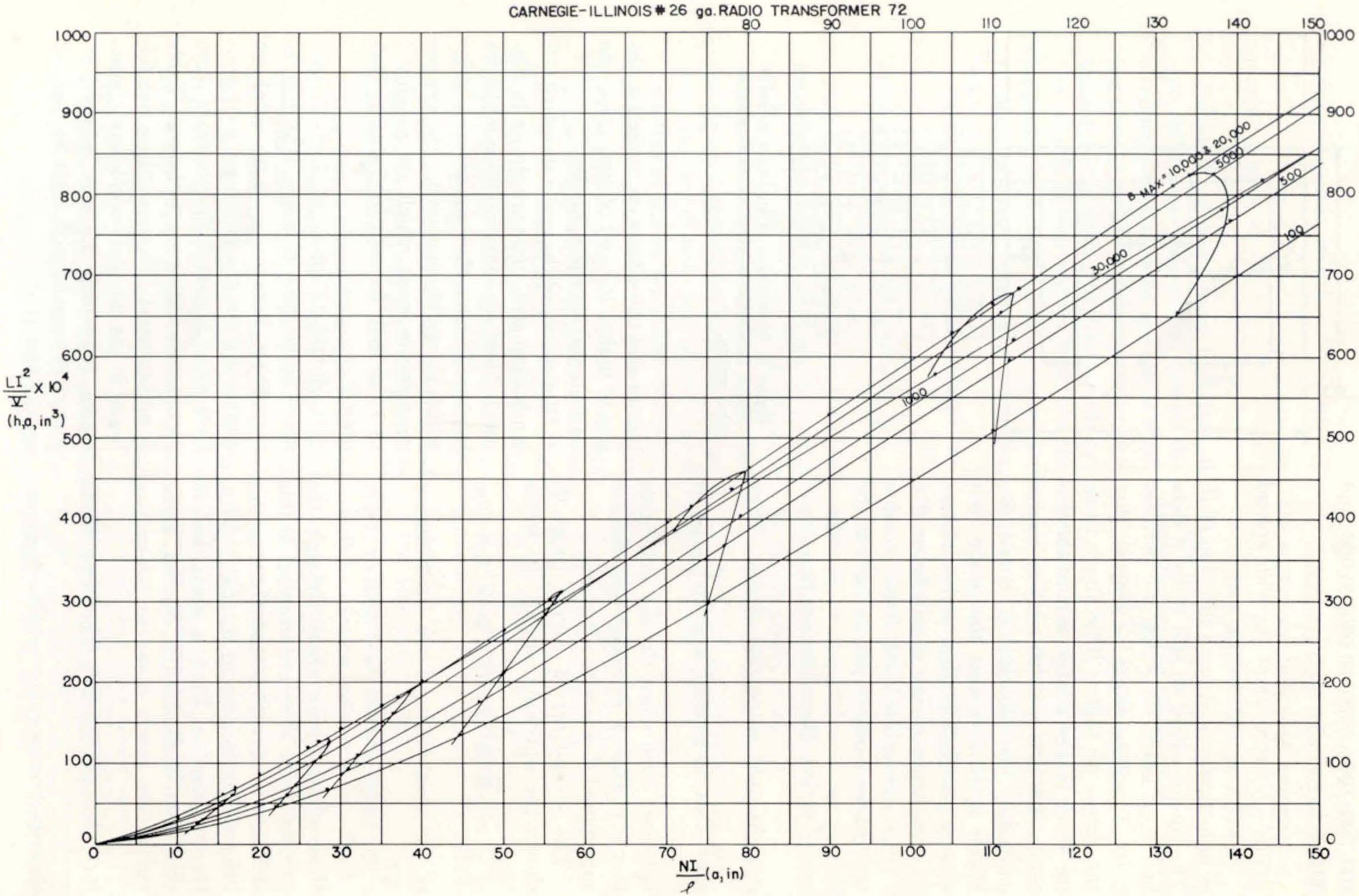


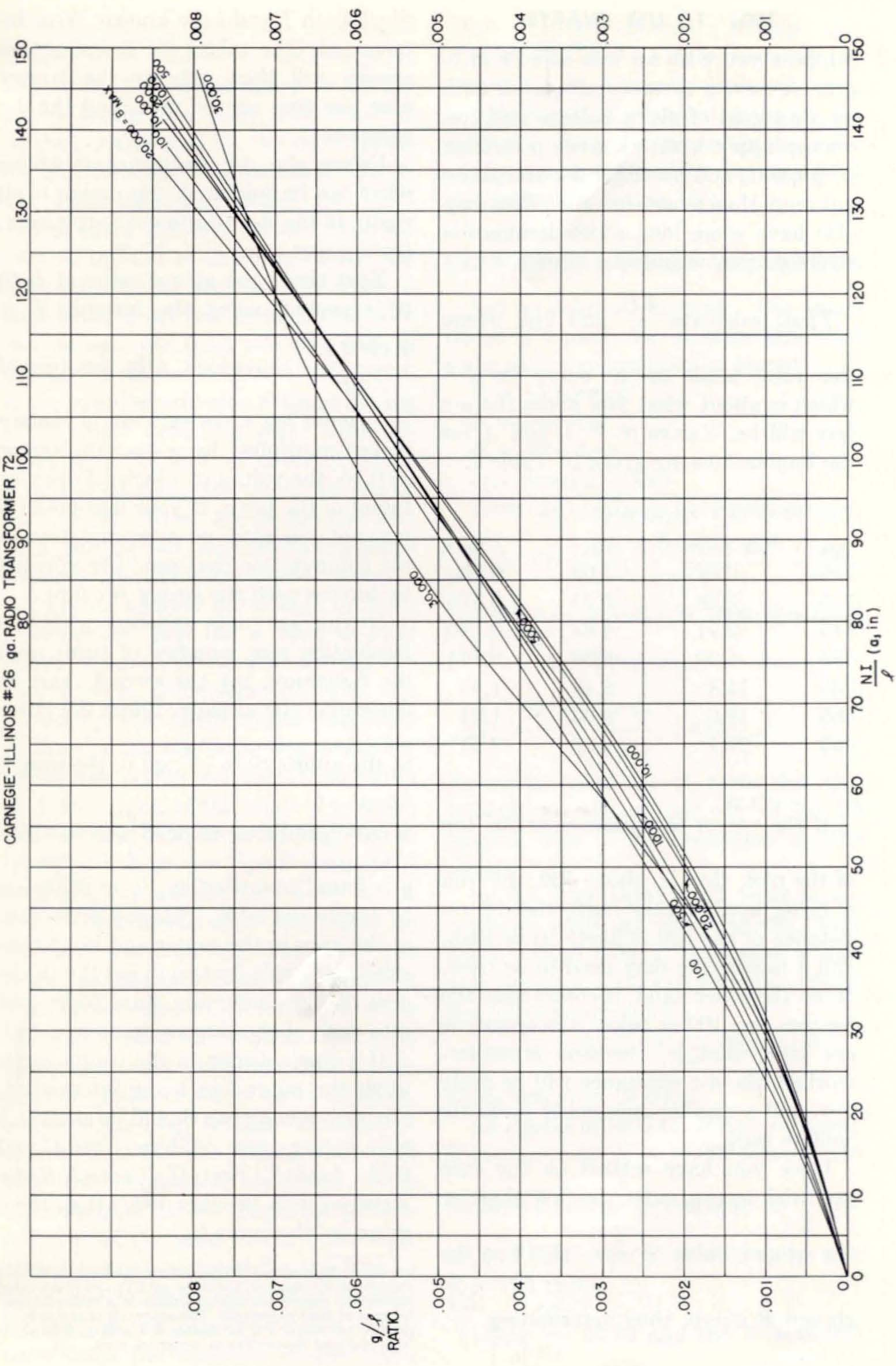
Type	a	h	b	c	e	d
746	11/32	23/32	1/4	3/4	13/32	1 3/16
745	5/8	5/8	5/16	15/16	1 9/16	1 7/8
345	3/4	3/4	17/32	1 1/8	1 7/8	2 9/16
485	15/16	15/16	21/32	1 19/32	2 17/32	3 3/16
365	1 3/16	1 3/16	25/32	2 1/8	3 5/16	3 15/16
685	1 3/8	1 3/8	1 1/16	2 3/8	3 3/4	4 7/8
565	1 5/8	1 5/8	1 1/4	2 5/8	4 1/4	5 3/4

Figure 2. Dimensions of standard General Radio laminations used as examples in this article.

Dimensions of the seven standard GR lamination structures are shown in Figure 2. They are convenient examples for use here because they constitute a series which is roughly geometric, the volume changing in steps which are roughly 2 to 1, as may be seen in Table 1, Column 2.

It should be obvious that all that needs to be done to apply this data to any other lamination is to establish dimensions for the structure analogous to those of Figure 2, deduce from them parameters analogous to those of Table I, and proceed. This procedure was followed in the calculation of a modulation choke, for which the core weighed almost 100 pounds, with complete success on the first trial.


CARNEGIE-ILLINOIS # 26 ga. RADIO TRANSFORMER 72
$\frac{LI^2}{V} \times 10^4$ (h,a, in³)
$\frac{NI}{\ell}$ (a, in)
B MAX = 10,000 & 20,000
5000
500
30,000
100
1000
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
100
200
300
400
500
600
700
800
900
1000


CARNEGIE-ILLINOIS #26 ga. RADIO TRANSFORMER 72
g/ℓ RATIO
NI/ℓ (a, in)
.008
.007
.006
.005
.004
.003
.002
.001
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
20,000 = B MAX
10,000
30,000
10,000
1000
100
500
20,000

HOW TO USE CHARTS

Suppose you wish an iron-cored coil to give at least a certain inductance with an a-c signal of given voltage and frequency applied, with a given polarizing dc present, and having a d-c resistance not more than a certain value. You may also have some idea which lamination structure you would like to use.

First, calculate $\frac{LI^2}{V}$ and find where this value lands on the curve for a B which is about what you guess the a-c flux will be. Values of V, l, and A for the laminations are given in Table I.

TABLE I

Core	V (*in.*^{3})	l (*in.*)	A (*in.*^{2})
746	0.67	2.69	0.238
745	1.46	3.75	0.375
345	2.71	4.81	0.540
485	5.49	6.38	0.844
365	11.4	8.19	1.35
685	18.0	9.63	1.81
565	29.1	11.00	2.53

If the $\frac{LI^2}{V} \times 10^4$ comes near the top of the plot, that is, above 700, the iron is being worked very hard, the d-c resistance of the coil is likely to be high, and a larger core may need to be used. If, on the other hand, it comes near the bottom, say 100 or below, the opposites are true; that is, the iron is underworked, the d-c resistance will be quite low, and a smaller core could perfectly well be used.

Once you have settled on the core you wish to use, enter the first chart at the proper value of $\frac{LI^2}{V} \times 10^4$ on the chosen B curve, thus determining $\frac{NI}{l}$. Since both I and l are known, N is determined. The tables for the structure chosen will then indicate the largest wire size that can be used, and the d-c resistance.

Unless the d-c resistance is above what can be tolerated, the design is all right. If the d-c resistance is too high, try a larger core.

Next check the actual value of B to be expected, using the formula $E = \frac{4.44\ BANf}{10^8}$, in which A is the area of the center-leg cross section in square inches multiplied by a stacking factor of 0.96, the values of which (A) can be found in the table. If your first-guess B was not too good, go over any steps in the computation that would be affected by having used the wrong B curve.

If you are now satisfied with the lamination size, number of turns, and d-c resistance, use the second chart to determine the airgaps. Enter the chart at the appropriate $\frac{NI}{l}$, go to the proper B curve, and read value of $\frac{g}{l}$, from which g is found immediately by multiplying by l from the table. This gap is the sum of the gaps in the center and in an outside leg. Divide by two to get the thickness of nonconducting shim to be put into each of the three airgaps in a coil.

If a single airgap in the center leg is used, the outer legs being interleaved, the optimum airgap should be about 1.5 mils larger (see "Those Iron-Cored Coils Again", Part II, *General Radio Experimenter*, January 1947) than the g given by the curve.[5]

[5] A center-leg airgap is not possible in the 745 or 565 cores (which are EI-shaped). Likewise, all EI's and many other lamination shapes are not adaptable to a center-leg gap because of their geometries. The other GR standard laminations are either F's, or double E's with slanted shear line, and lend themselves to center-leg gaps.

In this case, however, the inductance is likely to be reduced by something like 20% from the values indicated by the curves on the first chart. This seems to be the penalty paid for the extra stability and freedom from external field of the center-leg airgap design.

The extra stability results from the mutual friction of the interleaved outside legs of the laminations. This is sufficiently great that some laminations can be removed from one side only of the coil in order to adjust the inductance to a desired value without having to clamp or bind into place those remaining. Freedom from external field is a matter of geometry, with the airgap only in the center leg of the coil and with the outside legs providing some magnetic shielding to outside space.

There is another advantage to using a center-leg gap for a rectifier-filter choke which is encased in a magnetic can. A very bothersome problem was solved by this fairly simple expedient of substituting one center-leg airgap for three gaps, one in each leg. It was found that this choke, at the input of a choke-fed rectifier filter and having, consequently, a high a-c ripple component across it, was aurally very noisy in the 1/32″-thick cold-rolled steel case in which it was mounted. The noise was found to emanate from the vibrating sides of the case, which are close to the lamination structure adjacent the ends of the center leg. All other curative expedients failed, such as tight wedging, resilient padding, or high-temperature treatment to flow the potting compound into the lamination structure. With three airgaps the a-c magnetizing force required at the gaps in the outer legs, added to that required for the iron in the U-portion from one end of the center leg out and around to the other, constitutes the majority of the total. With a single center-leg airgap, this magnetizing force at the ends of the center leg is markedly reduced (say, around 3 to 1 in a typical instance). Its attractive force for the magnetic sides of the case is reduced by the square of this figure (or almost 10 to 1).

EXAMPLE OF A DESIGN CALCULATION

Let us take an example. The input choke of a particular rectifier filter had some such requirements as these:

$L = 15$ henrys

$I = 140$ ma

$R = 200$ ohms

core desired — 485

First calculation is for stored energy.

$$\frac{LI^2}{V} \times 10^4 = \frac{15 \times 0.14^2 \times 10^4}{5.49} = 535$$

Using the curve for $B = 1000$, this gives a $\frac{NI}{l} = 97.5$. From this:

$$N = \frac{97.5 \times 6.38}{0.14} = 4440$$

Referring to tables of turns for this lamination, this is a full core of No. 29 enamel wire. D-C resistance is 180 ohms.

So far, everything is all right in accordance with the specifications. Now check actual B-Max., assuming a 200-volt signal of 120-cycle frequency from the full-wave rectifier.

$$200 = \frac{4.44B \times 0.844 \times 4440 \times 120}{10^8}$$

From this $B = 10{,}000$.

The guess of 1000 for B was not good. If the curve for $B = 10{,}000$ is used, 525 for stored energy corresponds to $\frac{NI}{l} = 90$. For this value $N = 4100$ turns and $R = 166$ ohms.

Using $\frac{NI}{l}$ of 90 and the $B = 10{,}000$

curve on Chart 2, $\frac{g}{l} = 0.00455$. This means that $g = 29$ mils. Each gap should be half of this, or 14.5 mils. A figure of 15 will be near enough.

The specifications for the coil, therefore, will be these:

4100 turns of No. 29 enameled wire wound on a 485 core with three gaps of 15 mils each.

Actually, in this instance, it was necessary, to prevent noisy steel cans as a result of the external field of the coils, to make this input choke with a single center-leg airgap. To get the data for this coil, an inductance 20 to 25% larger must be used in the calculations and 1.5 mils added to the g given by the curves.

— P. K. McElroy

This method and data for coil design have been in use at General Radio for several years. The author is indebted to James K. Clapp, Charles E. Rice, and the late Hammond H. Hollis for the original measurements on which the charts are based.

SHOW BUSINESS

RADIO ENGINEERING SHOW

New York Coliseum **March 18–21, 1957**

General Radio Company exhibits are in Booths 3302-3306 and 2319. See the *Experimenter* for February for complete details.

1957 NARTB CONVENTION

The Conrad Hilton **Chicago** **April 7–11, 1957**

Again this year, at the convention of the National Association of Radio and Television Broadcasters, General Radio will be in Booth No. 1 with a display of station monitors (including the new TV monitor), modulation and distortion meters, line-voltage control devices, instruments for the measurement of antennas and lines, harmonic measuring equipment, sound-level meters, and other items of interest to broadcast engineers.

These engineers will be on hand to discuss your measurement problems.

William R. Thurston Charles A. Cady Joseph E. Belcher

SOUTHWESTERN IRE CONFERENCE AND ELECTRONIC SHOW

The Shamrock Hilton **Houston** **April 11–13, 1957**

At the Ninth Annual Southwestern IRE Conference, with which is combined the Second Annual Simulation Conference, General Radio products will be shown in Booth Nos. 63, 64, and 65. Engineers in attendance will be:

John C. Gray Frank J. Thoma William M. Ihde

General Radio Company ®

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the GENERAL RADIO Experimenter

Since 1915 — Manufacturers of Electronic Apparatus for Science and Industry

VOLUME 31 No. 11 APRIL, 1957

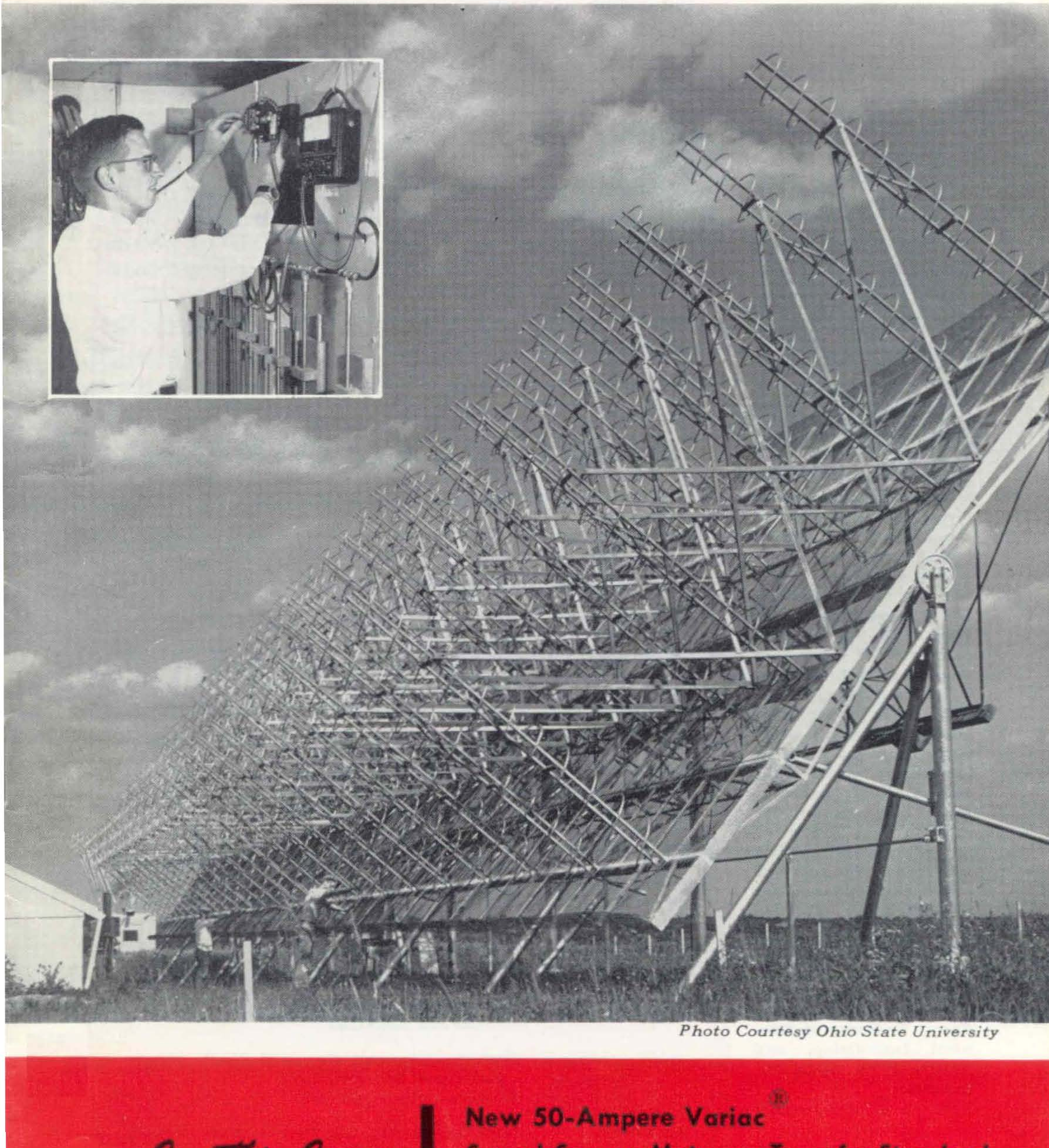

Photo Courtesy Ohio State University

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THE

GENERAL RADIO EXPERIMENTER

Published Monthly by the General Radio Company

VOLUME 31 • NUMBER 11 APRIL, 1957

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COVER

Radio astronomy is rapidly opening up new vistas of the universe which are not visible with optical instruments. The cover photograph shows the 96-element helical antenna of the radio telescope at Ohio State University. It operates 24 hours per day, mapping the sky on a moving paper chart.

The inset shows Donn Van Stoutenburg, a graduate student at OSU, using the General Radio Type 1602-B UHF Admittance Meter for matching the antenna input circuits of the radio telescope at 242 megacycles. The speed of measurement provided by the Admittance Meter is an important factor in design and maintenance.

These photographs are reproduced through the courtesy of Dr. John D. Kraus, Professor of Electrical Engineering, and Director of the Radio Observatory.

GENERAL RADIO COMPANY

275 Massachusetts Avenue

Cambridge 39 Massachusetts

Telephone: TRowbridge 6-4400

BRANCH ENGINEERING OFFICES

NEW YORK: Broad Avenue at Linden, Ridgefield, New Jersey
Telephone—N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: 920 South Michigan Ave., Chicago 5, Illinois
Telephone—WAbash 2-3820

PHILADELPHIA: 1150 York Road, Abington, Pennsylvania
Telephone—HAncock 4-7419

WASHINGTON: 8055 13th St., Silver Spring, Maryland
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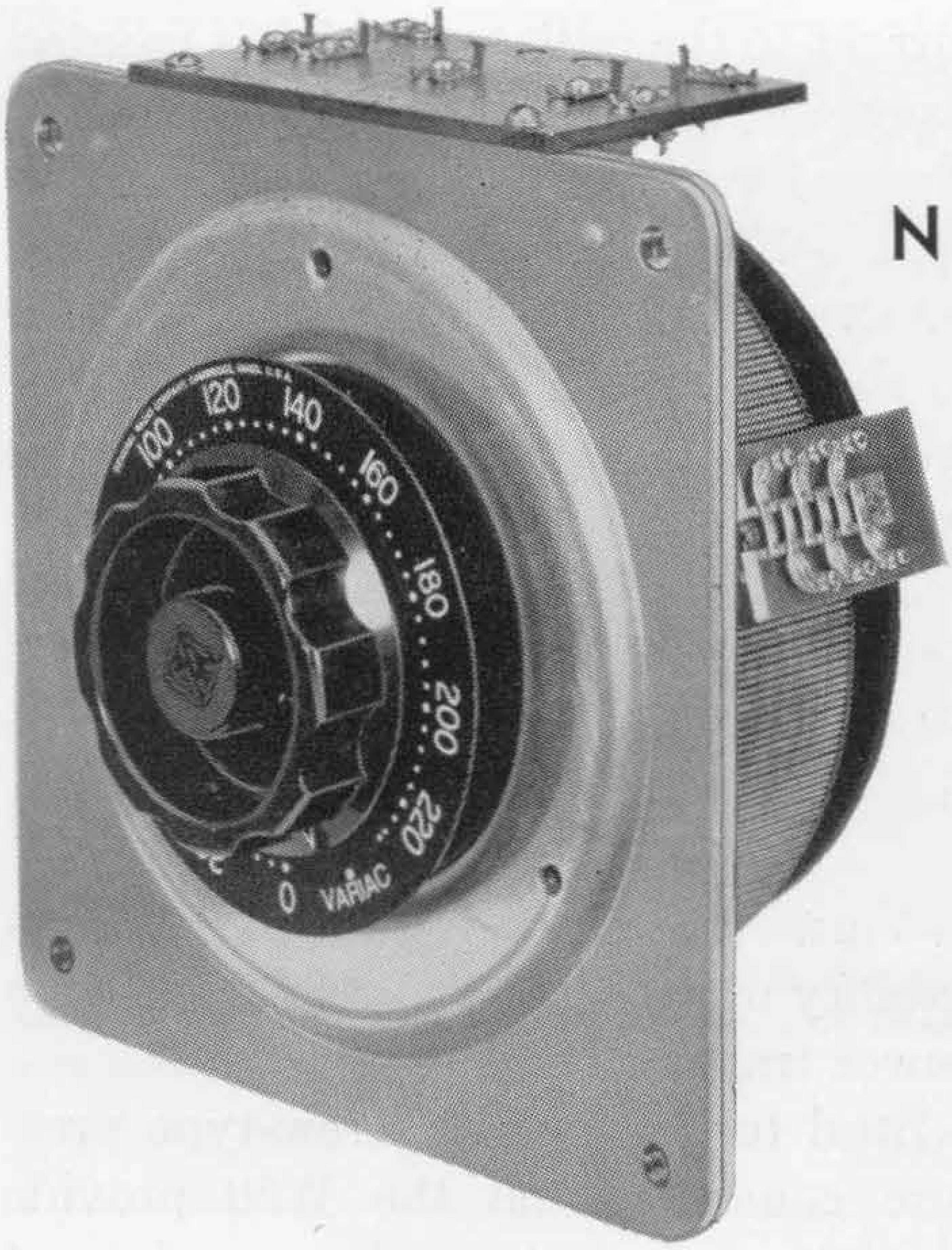


NEW "50" SIZE VARIACS® –TYPES W50 AND W50H

Figure 1. The new Type W50, largest of the Variacs, shown with the smallest standard unit, Type W2.

The old, reliable work horses of the continuously adjustable, high-power autotransformer field, TYPES 50A and 50B Variacs®, are being retired to a well-earned rest after many years of faithful and satisfactory service. To supplant these deservedly popular models, General Radio now introduces the new TYPES W50 and W50H. Embodying the many advantages inherent in the "W" design [1], these new "50's" deliver more watts per dollar, with smaller size, less weight, and lower losses than their predecessors. Mounting hole dimensions and arrangement are unchanged, for maximum interchangeability.

Current ratings are increased. The rated currents for the new 115-volt and 230-volt models are, respectively, 50 and 25 amperes, as contrasted to 40 and 20 amperes for the old models. TYPES W50 and W50H are UL-approved; cased models are undergoing examination and test for listing.

The general scheme of construction follows that of the W-type Variacs previously announced.[1] The radiator is captive, so that shaft adjustments do not upset radiator and brush setting. The base is stamped from plate stock, thus possessing superior physical properties to cast or die-cast construction. The assembly is secured by a hollow bolt, which serves as a shaft sleeve or ball-bearing housing as requirements dictate.

Because of the massive core and winding structure, the base insulator is molded and serves to lock the coil relative to the base under severe shock conditions. The coil is cemented to this molded insulator with a thermo-setting plastic to improve mechanical stability and thermal transfer from coil to base. Coil forms are the angel-cake-pan type previously described, which completely enclose the core.

Unique with these units is the use of a banked winding for such heavy wire; the process might be more properly described as "rod-bending" rather than

---

[1] "The Type W5 Variac — A New and Better Variable Autotransformer," *General Radio Experimenter*, December, 1955, XXX, 7, pp. 1–11.
"More New Variacs," *General Radio Experimenter*, May, 1956, XXX, 12, pp. 13–15.

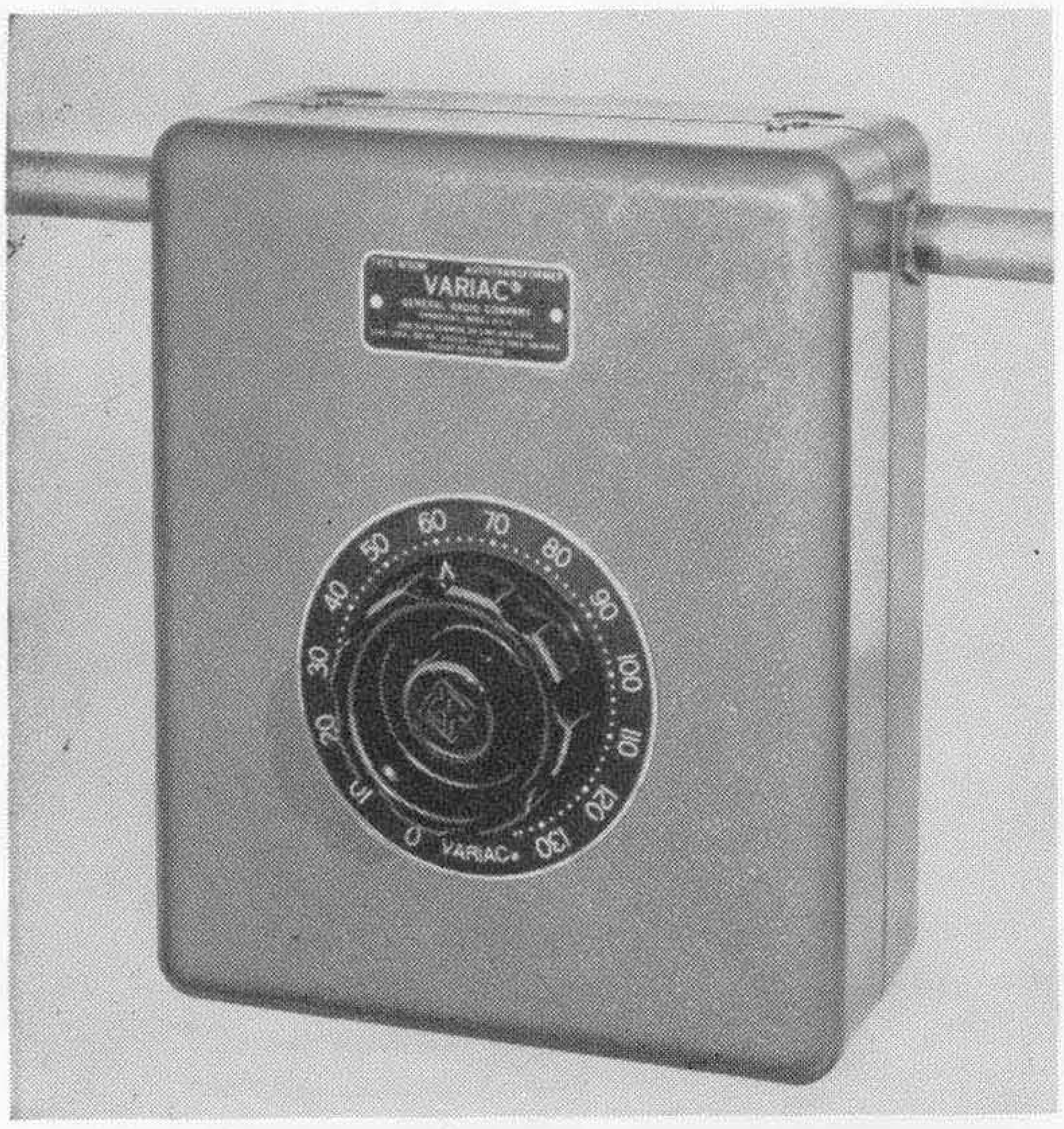


Figure 2. The Type W50M, cased model, shown in a typical wall installation with conduit wiring.

as "winding!" The winding machine was designed and built by General Radio. It actually oscillates the core during winding to force banking of the heavy conductors, and an ingenious servo-mechanism keeps the core rotation in step with the winding gear regardless of slippage in the belt drive.

The use of multiple brushes, consequent upon the high current rating, posed a dimensional problem — how to accommodate the wide, single-layer brush track, without an excessive core diameter, on a bank wound unit. This was solved by placing the brush track on the outer face of the toroid. (Figure 3). This brush location allows the closest approach to an ideal core aspect ratio for a given number of turns of the required wire size in a banked winding, for a minimum required panel space. A copper radiator "nose" serves to conduct both brush heat and brush current to the radiator, which is painted black on the surface away from the Variac for maximum radiant heat dissipation. The new unit brush, first introduced on the TYPE M20 Variac,[2] is used on the W50's, the better to carry away the heat generated by these higher powered units.

The *Duratrak* brush track is, of course, used on the new Type W50 and TYPE W50H. This has not been available on the older 50A and 50B types, and it brings a new degree of reliability to Variacs in the high-power field, a reliability approaching that of fixed-ratio power transformers.

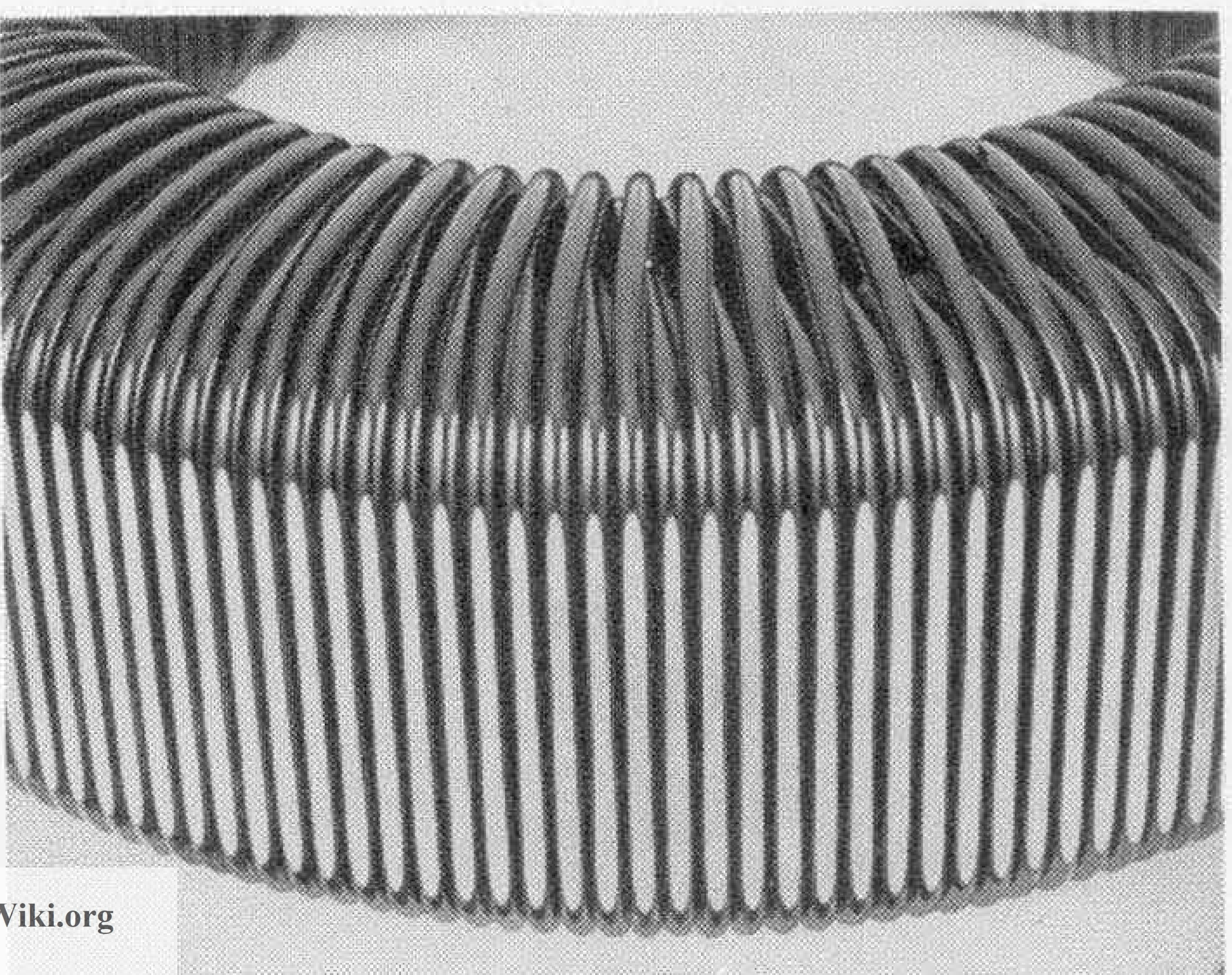
Stud terminals and screw-type pressure connectors on the W50 provide maximum convenience for a variety of conductor sizes and circuits. Screw terminals similar to those used on the M20 [2] are provided on the W50H. The terminal arrangement is the same as that on the standard W-model Variacs.

A built-in protector prevents damage to the costly winding from *sustained* overloads exceeding 160% of rating.

Adequate fuse or breaker protection should be provided in any installation of these Variacs to open the brush circuit on currents appreciably in excess of the rating. The added margin of safety afforded by the built-in protector

[2] "A 400-Cycle Variac with 20-Ampere Rating," *General Radio Experimenter*, 31, 8; January, 1957; pp. 7–8.

Figure 3. Close-up of the banked winding and Duratrak commutator surface.



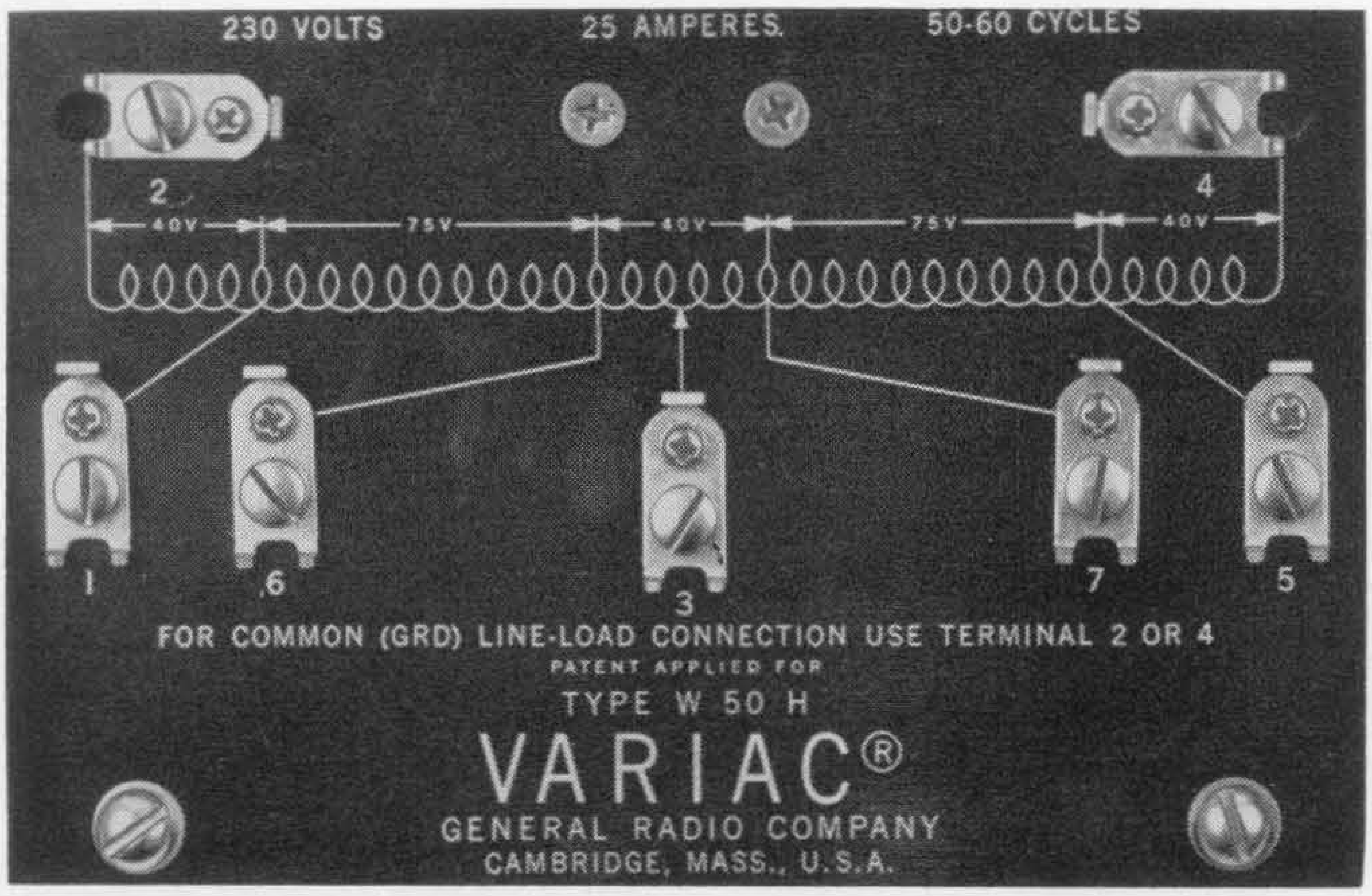


Figure 4. Terminal plate for the Type W50H, 230-volt model. The 115-volt model with higher current rating uses stud terminals and screw-type pressure connectors.

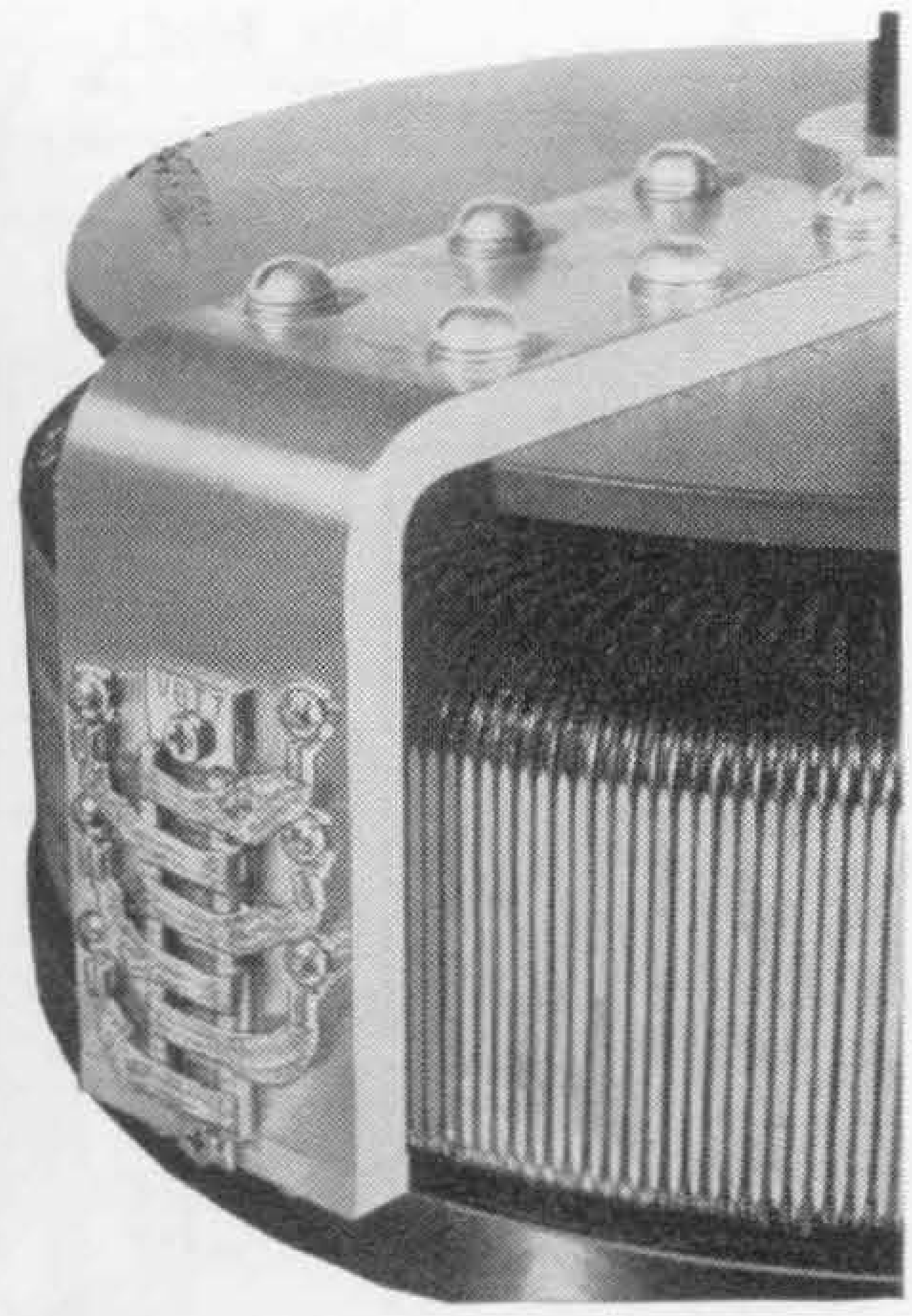


Figure 5. Close-up of the brush assembly and connectors.

SINGLE UNITS

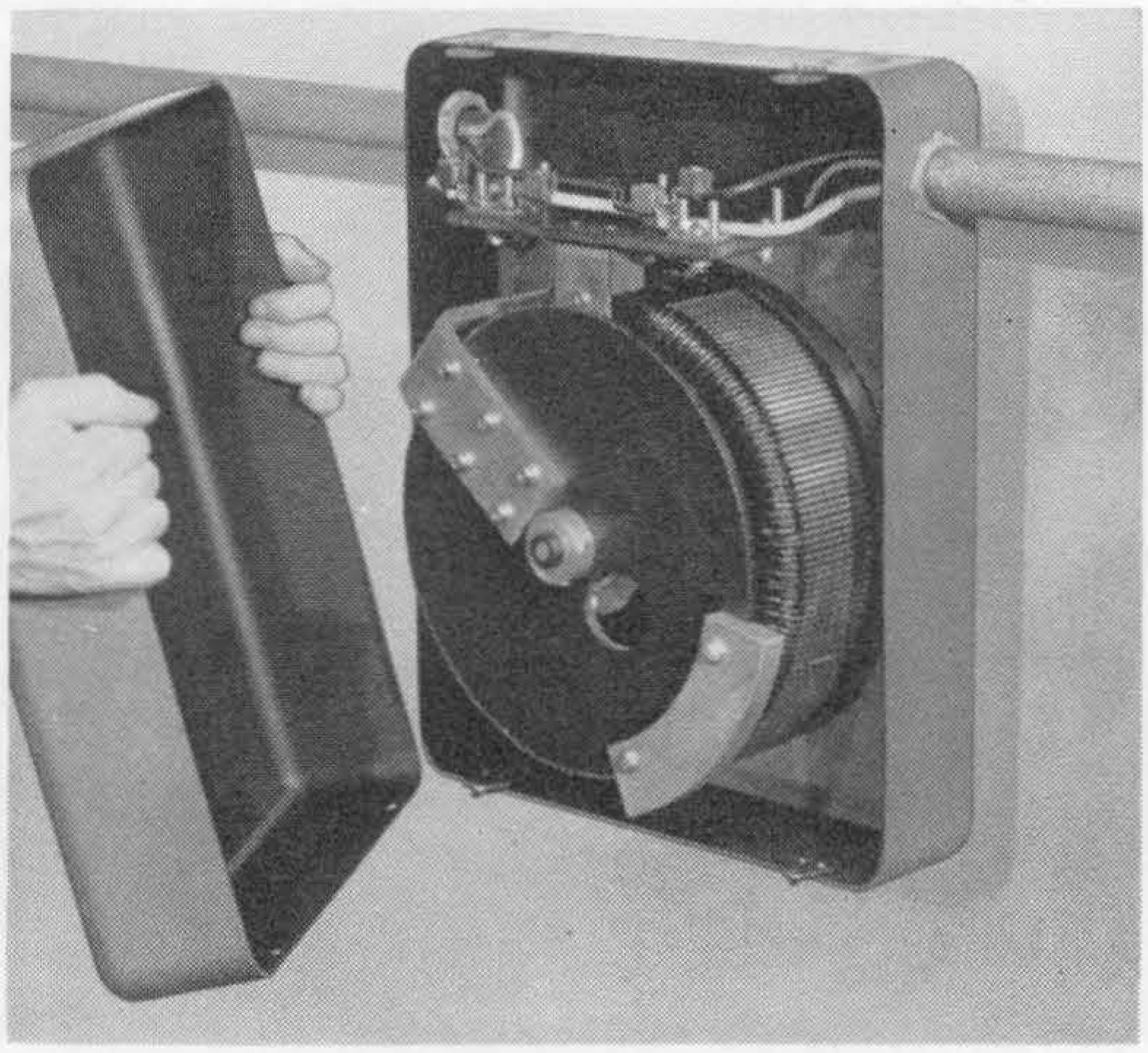
Type	Mounting	Input Volts (50-60 cycles)	*Line-Voltage Connection* Rated Output Amperes	Output Volts	Max. Output Amperes	Output KVA	*Overvoltage Connection* Output Volts	Rated Output Amperes	Net Weight — Pounds	Code Word	Price
W50	Without case	115	50	0–115	50	5.75	0–135	50	50	GATAL	**$120.00**
W50M	Cased	115	40	0–115	45	5.18	0–135	40	57	GATER	**145.00**
W50H	Without case	230	25	0–230	32.5	7.5	0–270	25	53	NITAL	**120.00**
W50HM	Cased	230 115	20	0–230	31	7.13	0–270 0–270	20 10	60	NITER	**145.00**
VBT-6	Replacement brush set for W50, W50M								¼		**5.00**
VBT-7	Replacement brush set for W50H, W50HM								¼		**5.00**

is available when, through negligence or accident, normal protective devices are not operating.

The Type W50 and Type W50H, as with other W-model Variacs, are available singly or in gangs, for manual or motor-driven operation, open or cased, with or without ball bearings.

We feel that the Type W50 and Type W50H Variacs with their increased output, lowered cost, weight, size, and losses will prove to be worthy successors to the Types 50A and 50B that they replace.

Figure 6. Cover of the M-type unit is easily removable.



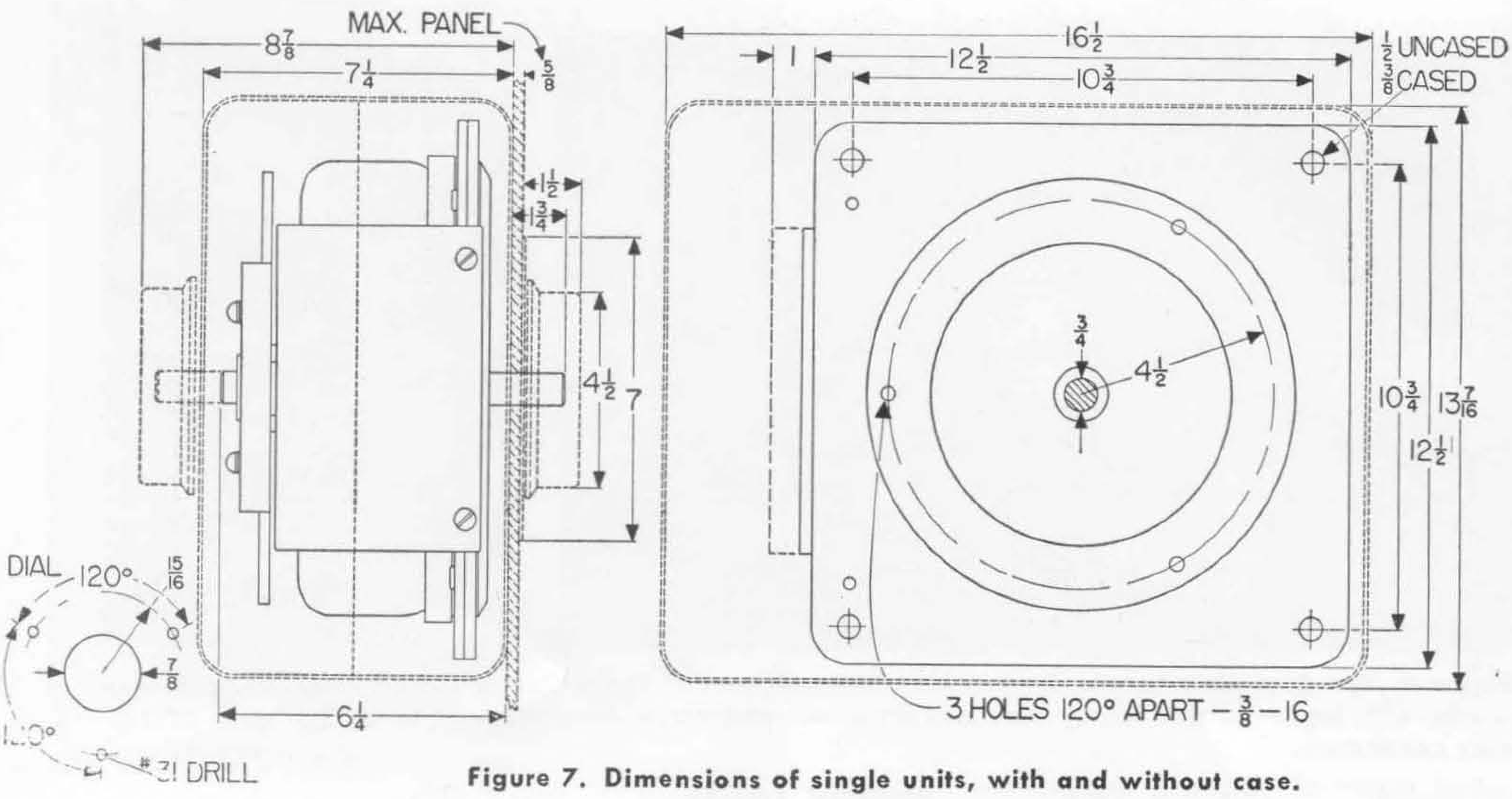


Figure 7. Dimensions of single units, with and without case.

SPECIFICATIONS

Core Loss at 60 cycles, all models: 50 watts

Driving Torque, all models: 200–400 oz.-in.

Turns on Winding:

W50, W50M	190
W50H, W50HM	298

Angle of Rotation: 320°

D–C Resistance of Winding:

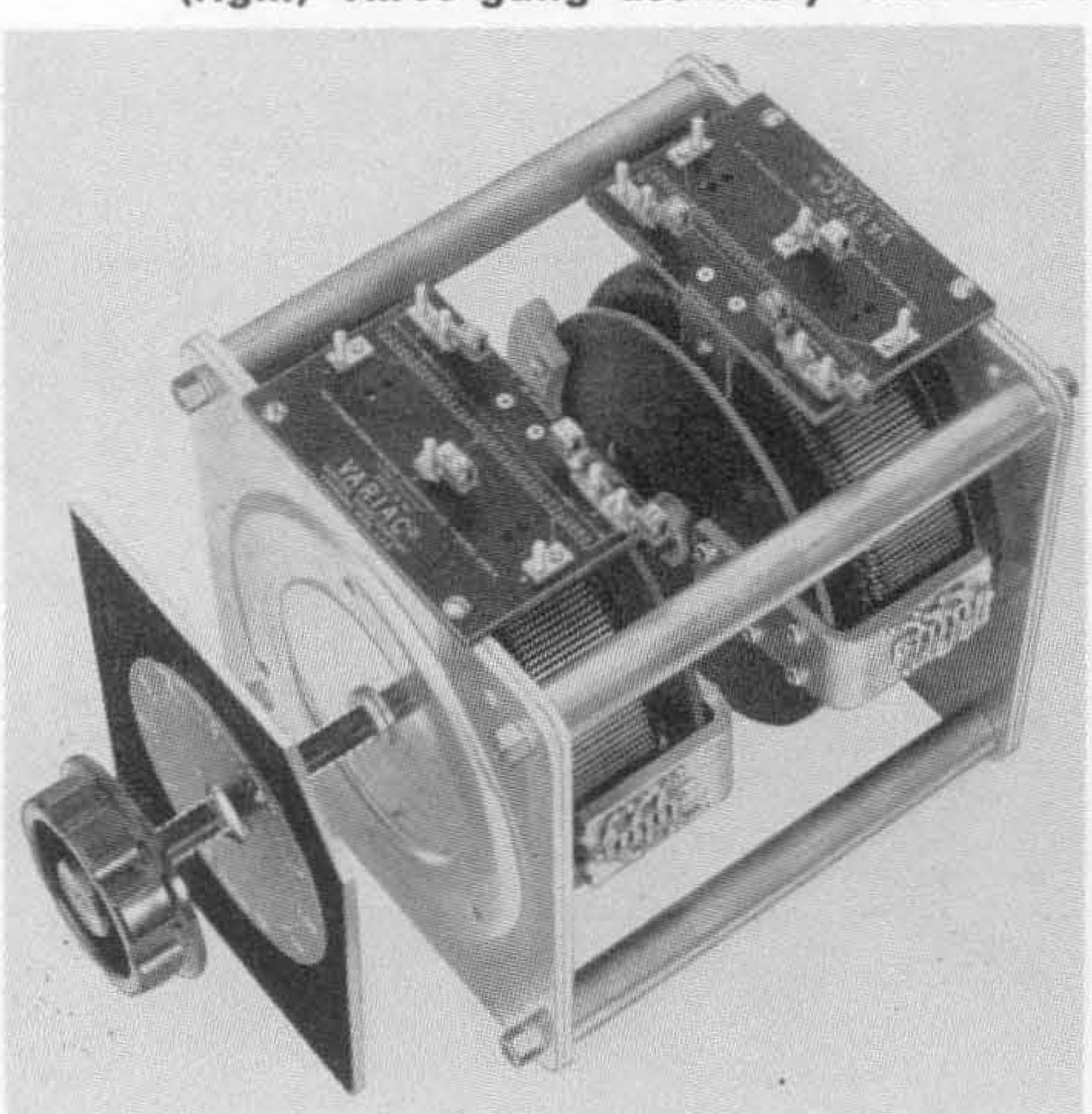
W50, W50M	0.075 ohm
W50H, W50HM	0.3 ohm

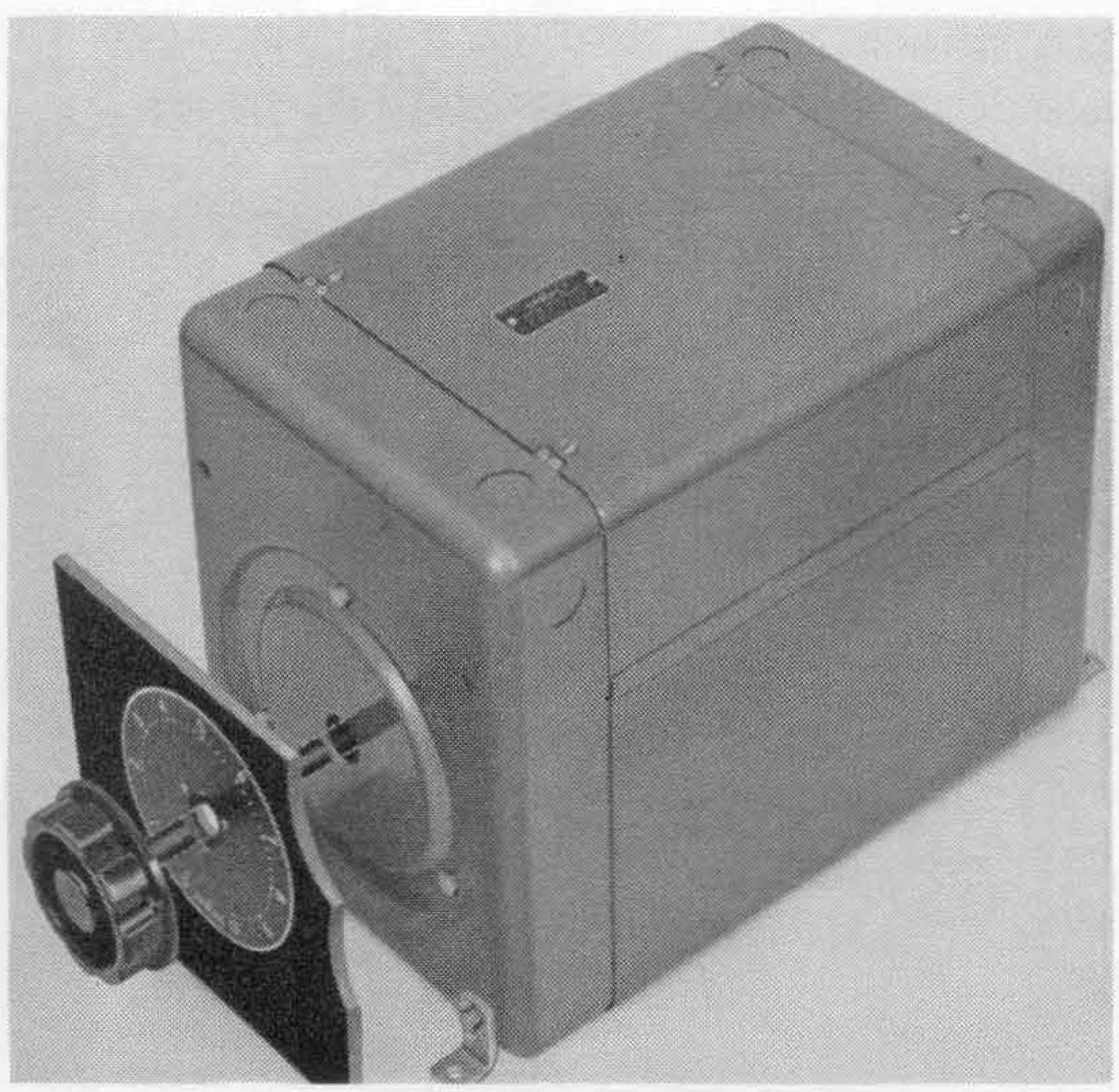
Dial Calibration: Reversible dial, line-voltage scale on one side, overvoltage on reverse side; accurate with rated input voltage applied.

GANGED UNITS

Ganged assemblies of Type W50 Variacs are used in parallel or in series on single-phase lines and in open delta or wye configurations on three-phase lines. The table on page 7 indicates the ratings of the various combinations. Dial plates for gangs have scales marked 0–10. Types 50P1 and 50P2 chokes to limit circulating currents are recommended for parallel operation.

Figure 8. (below) Two-gang assembly. (right) Three-gang assembly with case.





RATINGS FOR GANGED UNITS

SINGLE PHASE CIRCUITS

Type	*Input Volts*	*Output Volts*	*Max. Output Amperes*	*Rated Output Amperes*	*Output KVA†*	*Connection*	*Chokes Required*
W50G2	115	0–115 0–135	100	100 100	11.5	Parallel	One Type 50-P1
W50G2M	115	0–115 0–135	90	80 80	10.4	Parallel	One Type 50-P1
W50G3	115	0–115 0–135	150	150 150	17.25	Parallel	One Type 50-P1 One Type 50-P2
W50G3M	115	0–115 0–135	135	120 120	15.5	Parallel	One Type 50-P1 One Type 50-P2
W50HG2	230	0–230 0–270	65	50 50	15	Parallel	One Type 50-P1
W50HG2M	230	0–230 0–270	62	40 40	14.3	Parallel	One Type 50-P1
W50HG3	230	0–230 0–270	97.5	75 75	22.5	Parallel	One Type 50-P1 One Type 50-P2
W50HG3M	230	0–230 0–270	93	60 60	21.4	Parallel	One Type 50-P1 One Type 50-P2
W50HG2	460	0–460 0–540	32.5	25 25	15	Series *	
W50HG2M	460	0–460 0–540	31	20 20	14.3	Series *	
			THREE-PHASE CIRCUITS				
W50G2 **W50G2M**	115 115	0–115 0–115	50 45	50 40	10 9	Open Delta	
W50G3 **W50G3M**	230 230	0–230 0–230	50 45	50 40	20 18	Wye	
W50HG2 **W50HG2M**	230 230	0–230 0–230	32.5 31	25 20	13 12.3	Open Delta	
W50HG3 **W50HG3M**	460 460	0–460 0–460	32.5 31	25 20	26 24.6	Wye	

* Does not permit common connection between line and load. Load must not be grounded.
† No KVA rating is given for overvoltage connection. Output KVA is determined by the product of line voltage and maximum current for the line-voltage connection.

Type		*Description*	*Net Weight Pounds*	*Code Word*	*Price*
W50G2		**Two-Gang W50, without case**	103	GATALGANDU	**$260.00**
W50G2M		**Two-Gang W50, with case**	115½	GATALBONDU	**310.00**
W50G3		**Three-Gang W50 without case**	158	GATALGANTY	**385.00**
W50G3M		**Three-Gang W50 with case**	173½	GATALBONTY	**440.00**
W50HG2		**Two-Gang W50H, without case**	109	NITALGANDU	**260.00**
W50HG2M		**Two-Gang W50H, with case**	121½	NITALBONDU	**310.00**
W50HG3		**Three-Gang W50H, without case**	167	NITALGANTY	**385.00**
W50HG3M		**Three-Gang W50H, with case**	182½	NITALBONTY	**440.00**

Dial plates on ganged units read 0 to 10
Driving torque: Two-gang, 400–800 oz.-in.
Three-gang, 600–1200 oz. in.

CHOKES

Type		*Code Word*	*Price*
50-P1	**For operation of two units in parallel**	PARALLCHOK	**$14.00**
50-P2	**Used with 50-Pl for operation of three units in parallel**	TRIPLECHOK	**14.00**

BALL BEARINGS

Every Type W50 Variac assembly (single or ganged) can be furnished with ball bearings, which reduce the required driving torque. Surcharge for ball bearings:

Single Unit	**$15.00**
2-Gang	**20.00**
3-Gang	**25.00**

When ordering, add suffix BB to type number.

MOTOR DRIVE

Motor drives are available for Type W50 Variacs, as shown in the table on page 9. All models include motor capacitor and adjustable-position microswitches to limit the arc of traverse to any desired portion of the winding. All

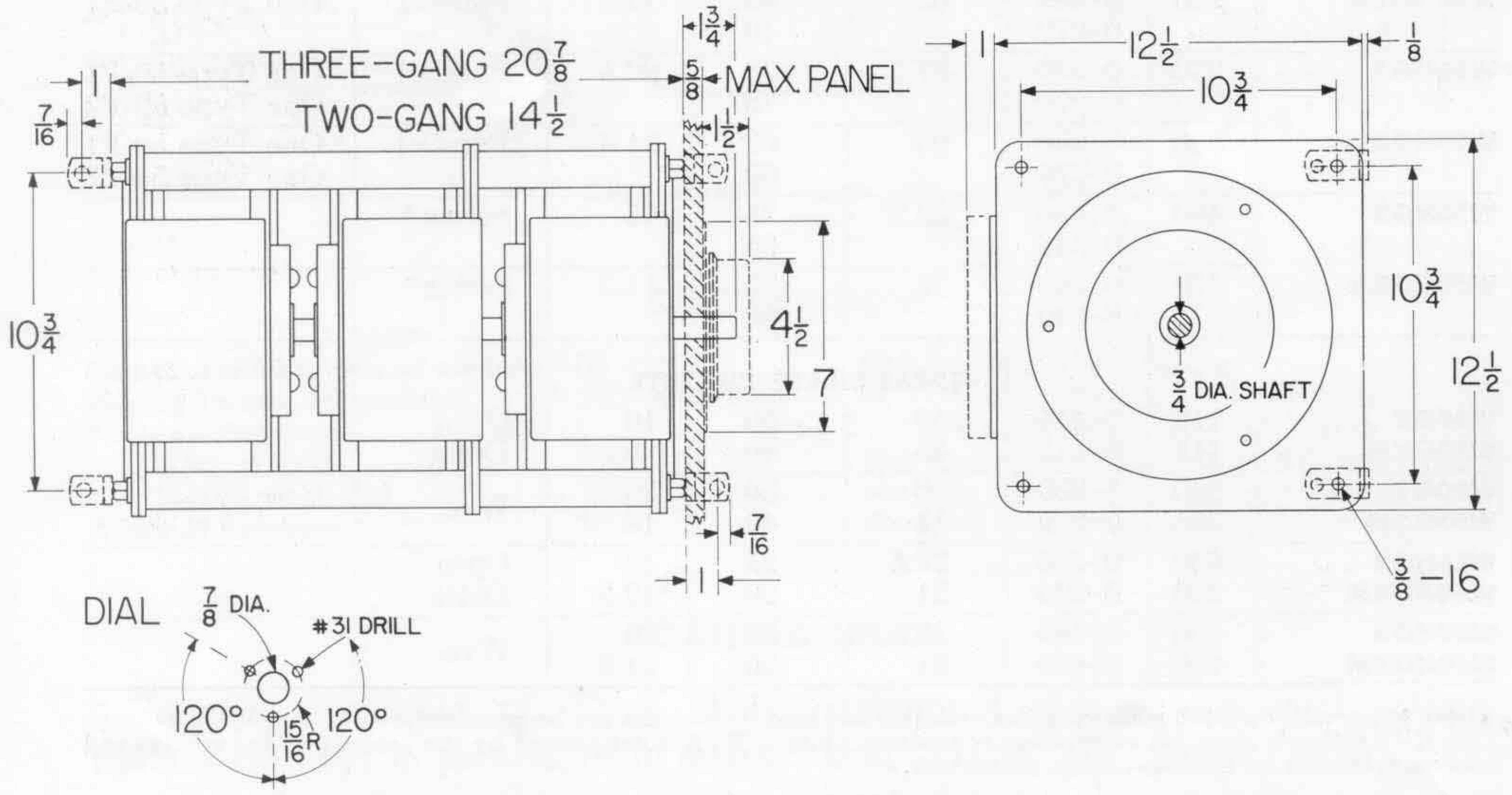


Figure 9. Dimensions of ganged assemblies, without case.

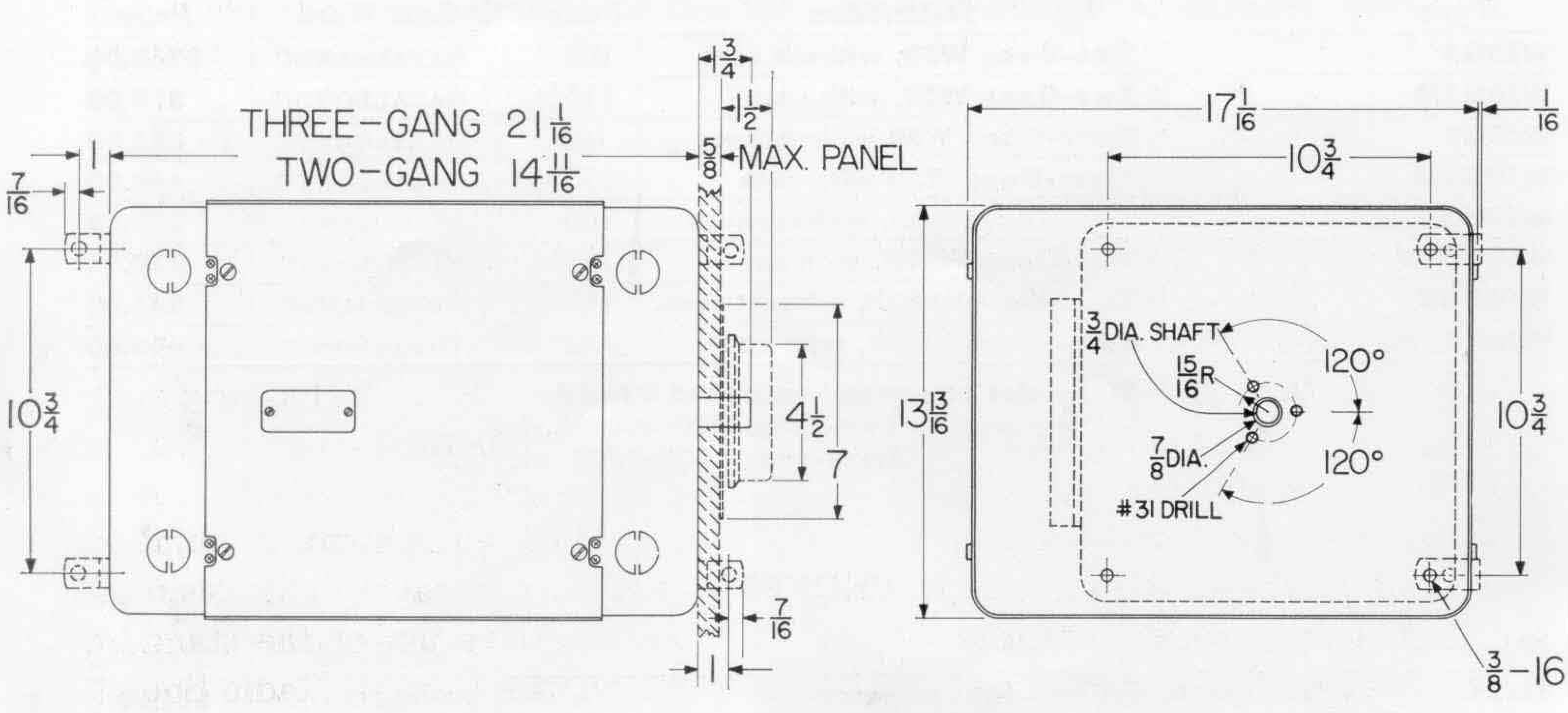
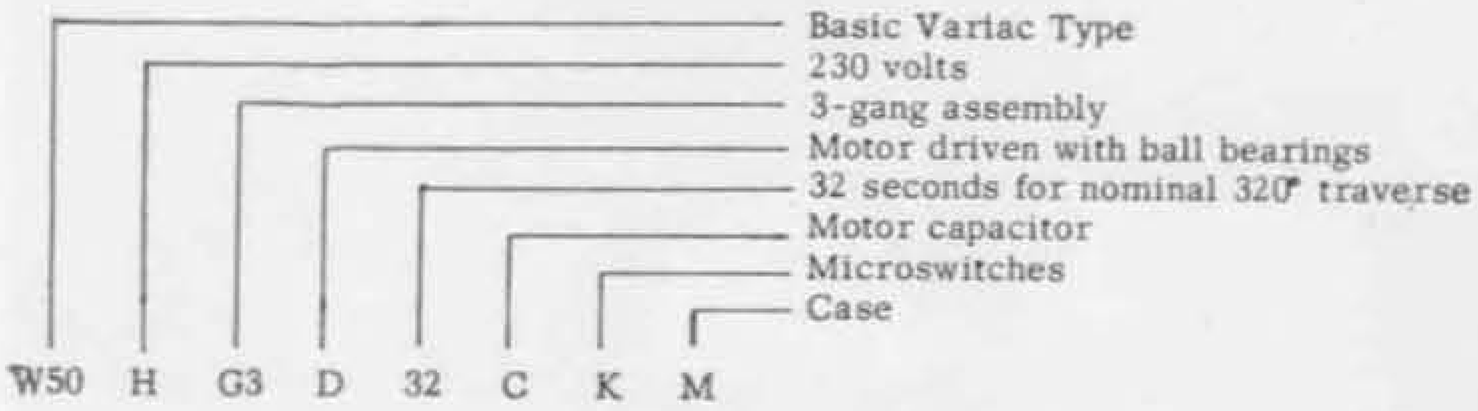
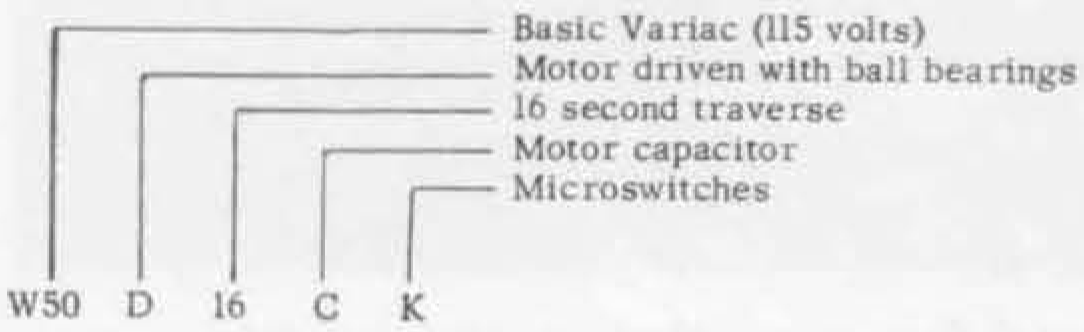


Figure 10. Dimensions of ganged assemblies, with case.

motor-driven models are equipped with ball bearings.[3] Type numbers are made up on the following basis, as explained in a previous article.[4]

—Gilbert Smiley





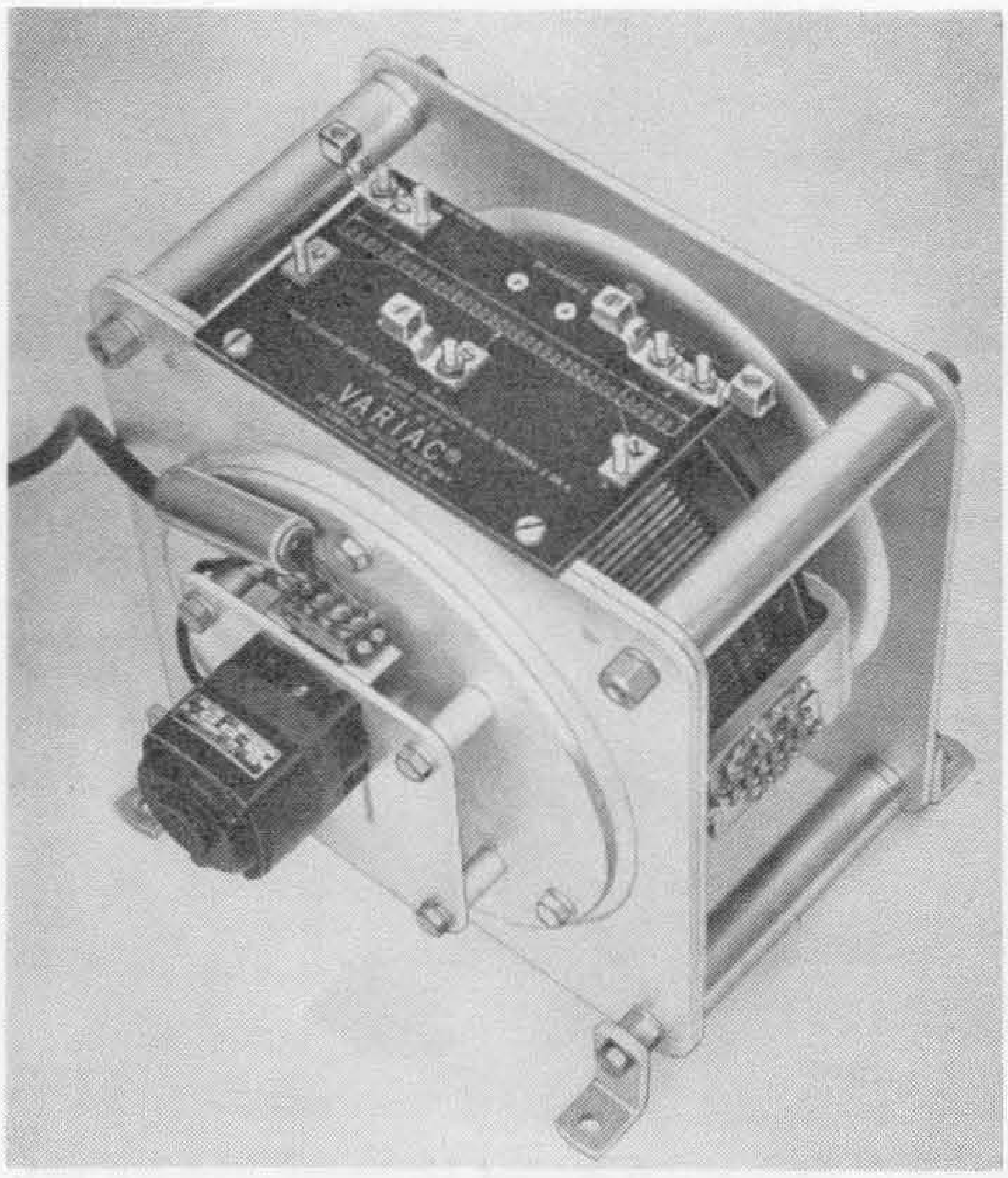


Figure 11. View of motor-driven unit, without case; Type W50D16CK.

PRICES *

VARIAC Type	TRAVERSE TIME IN SECONDS 16	32	64	128	Add for case
W50	$260.00	260.00	260.00	260.00	$55.00
W50G2		390.00	390.00	390.00	60.00
W50G3		520.00	520.00	520.00	65.00
W50H	260.00	260.00	260.00	260.00	55.00
W50HG2		390.00	390.00	390.00	60.00
W50HG3		520.00	520.00	520.00	65.00

* In lots of 5 or more. For quantities less than 5, there is a setup charge of $12.00, prorated over the number of units. (1–4).

[3] It is not necessary to add BB to the type number when the Variac is ordered with motor drive.

[4] "Motor Drives for W-Series Variacs", *General Radio Experimenter*, 31, 3; August, 1956, pp. 1–4.

THE SOUND-SURVEY METER AS A TRANSFER STANDARD

To assure uniformity and compliance with sensitivity specifications, hearing aids are given an over-all acoustical check. At Otarion, Inc., of Dobbs Ferry, New York, manufacturers of hearing aids, these devices are tested by standard methods using an artificial voice and an artificial ear.

The test stand shown in Figure 1 is an example of this technique as used to test the Listener® hearing aid, which is an eyeglass type and the first such unit to be produced commercially. The artificial voice, which consists of a small speaker in a box lined with sound-absorbing material, is shown at the top, with the bow containing the microphone of the hearing aid inserted through the opening and resting in the test position. The receiver, which is in the other eyeglass bow, is coupled acoustically by means of a small transparent tube, to a standard 2-cc cavity.

In this apparatus, the sound-pressure in the box is calibrated originally against the laboratory standard, a Kellog condenser microphone. Since the calibration equipment is cumbersome, and also because it is desirable to avoid excessive use of the standard microphone, the General Radio Sound-Survey Meter is used as a transfer

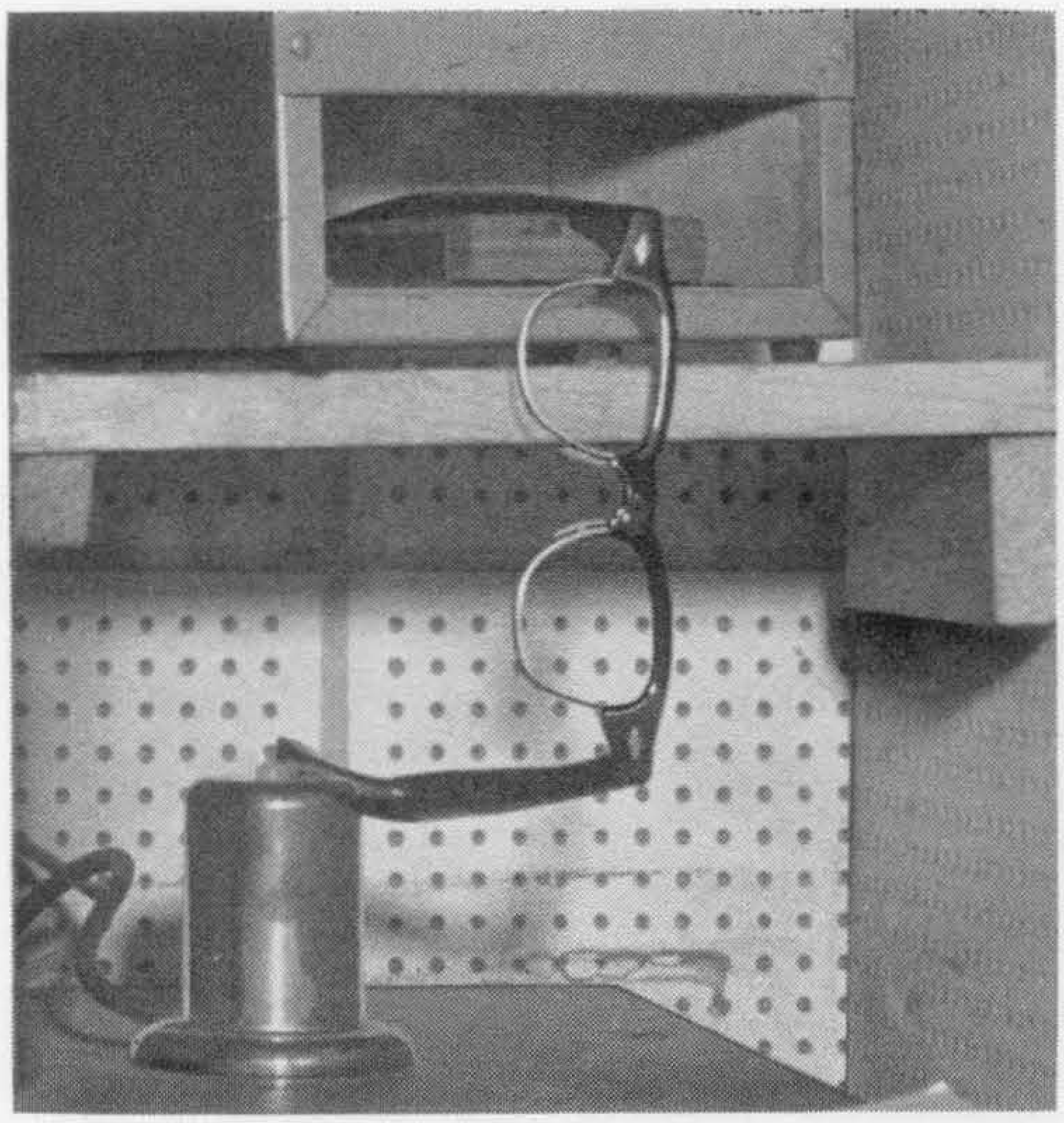


Figure 1. Test stand for the Listener® hearing aid.

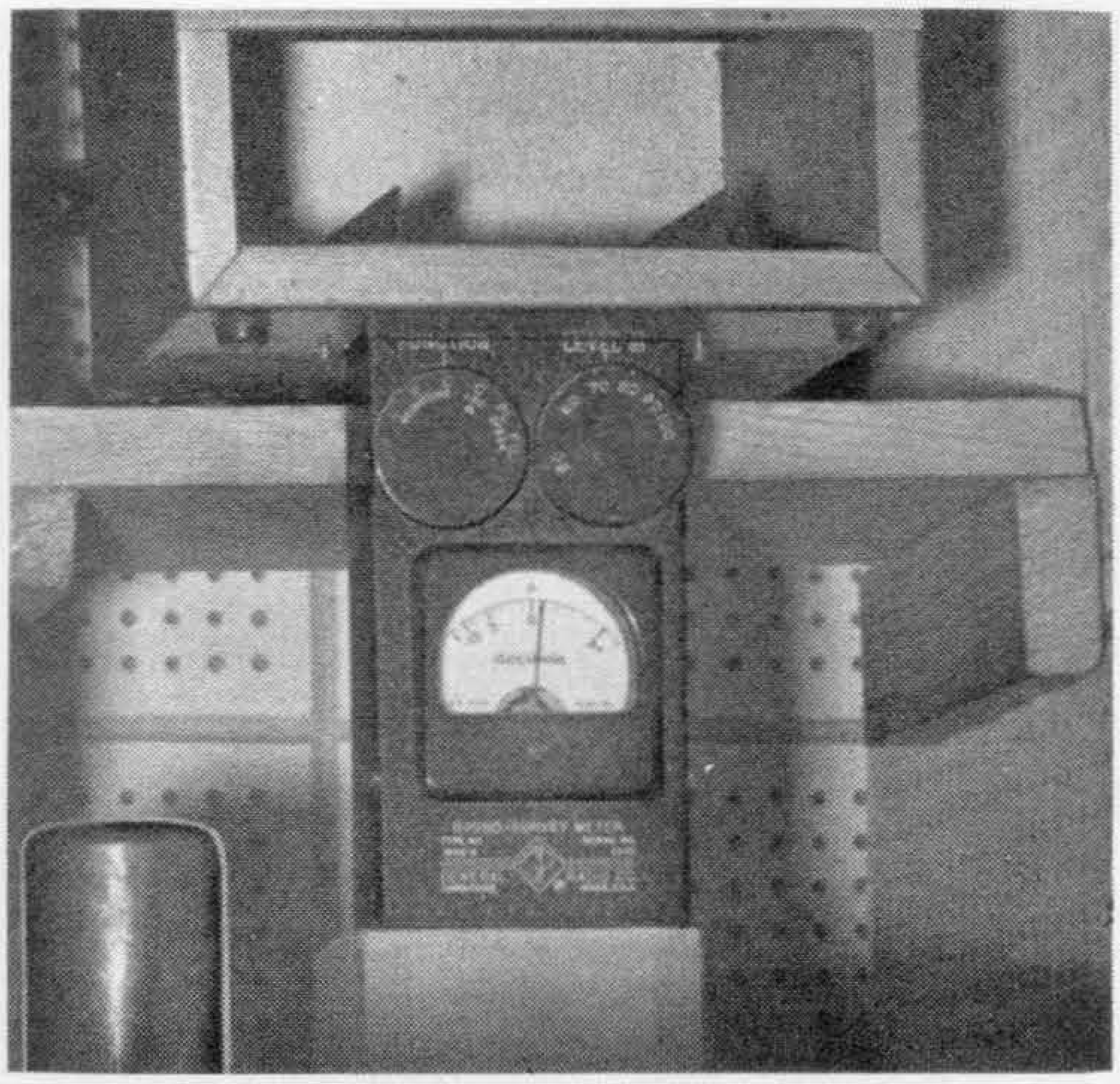


Figure 2. Sound-Survey Meter in position to measure sound level.

standard. An opening at the base of the artificial voice makes possible the insertion of either the Sound-Survey Meter or the standard condenser microphone to measure the sound-pressure level. As shown in Figure 2, this procedure involves no cumbersome equipment and can be accomplished quickly and easily. Thus periodic checks with this simple and convenient device will indicate immediately any change in level that has occurred in the interval between calibrations with the laboratory standard and also any differences that may exist between various test positions.

Otarion, Inc., also finds the Sound-Survey Meter useful for routine checks of audiometer calibration.

We are indebted to Mr. William H. Greenbaum, Vice President and Director of Engineering at Otarion, Inc., for the information in the above article.

DOUBLE PULSES WITH THE TYPE 1391-A PULSE, SWEEP, AND TIME DELAY GENERATOR

Many inquiries have prompted investigation of methods of producing double pulses with the Type 1391-A Pulse, Sweep, and Time-Delay Generator. This article will present two possible methods. In the first method, each pulse of the pair has the same duration, and the interval between pulses is set by the delay controls. In the second method, durations of the first and second pulses and the inter-pulse interval are all independently variable.

In the first method, two sweeps and their associated pulses are produced, the first timed by the direct synchronizing pulse, and the second by the delayed synchronizing pulse. Thus, basically, the inter-pulse interval is the DELAY setting (1 μsec to 1 sec), and the duration of each pulse of the pair is that indicated by the setting of the PULSE

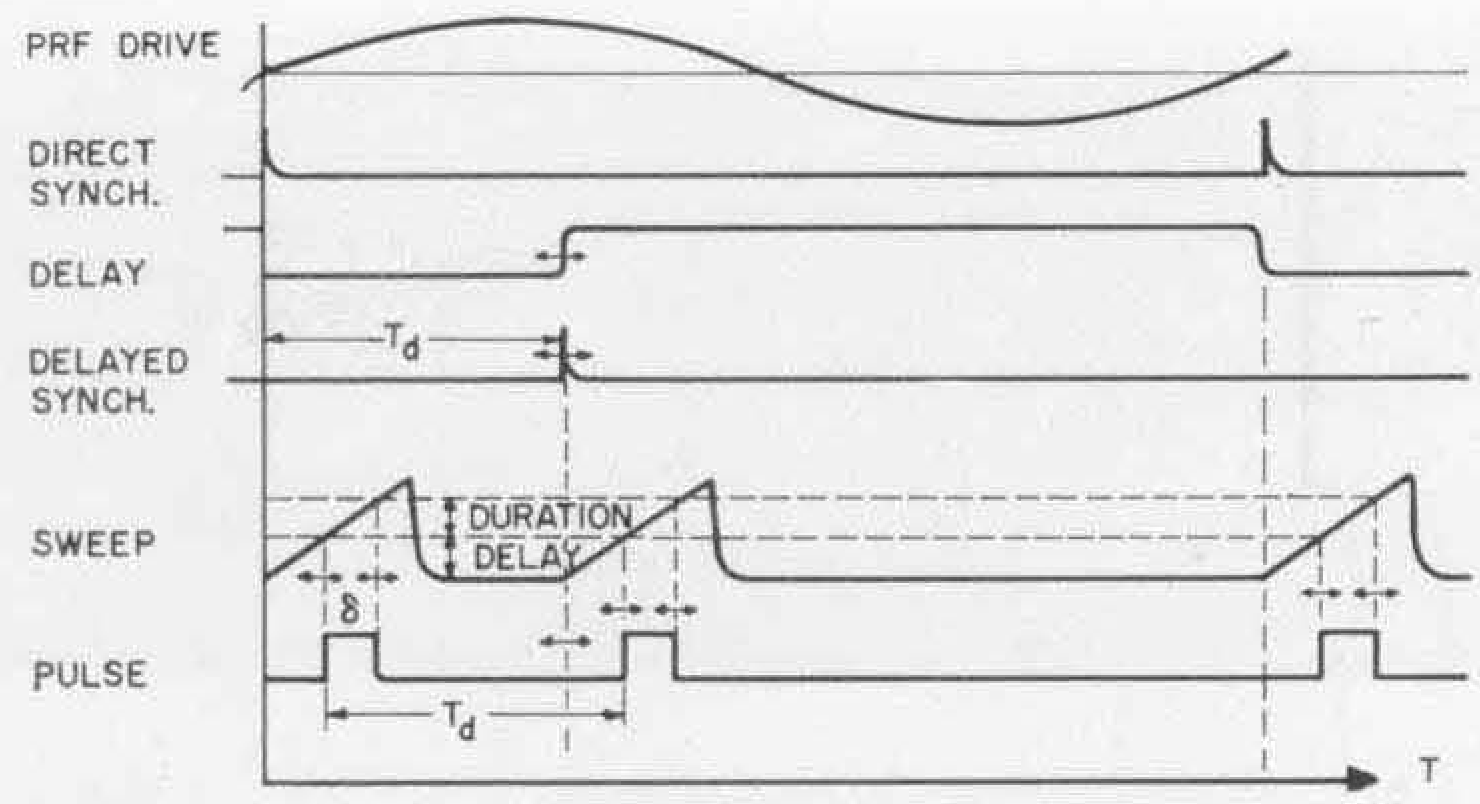


Figure 1. First Method. Equal pulse duration, adjustable time interval.

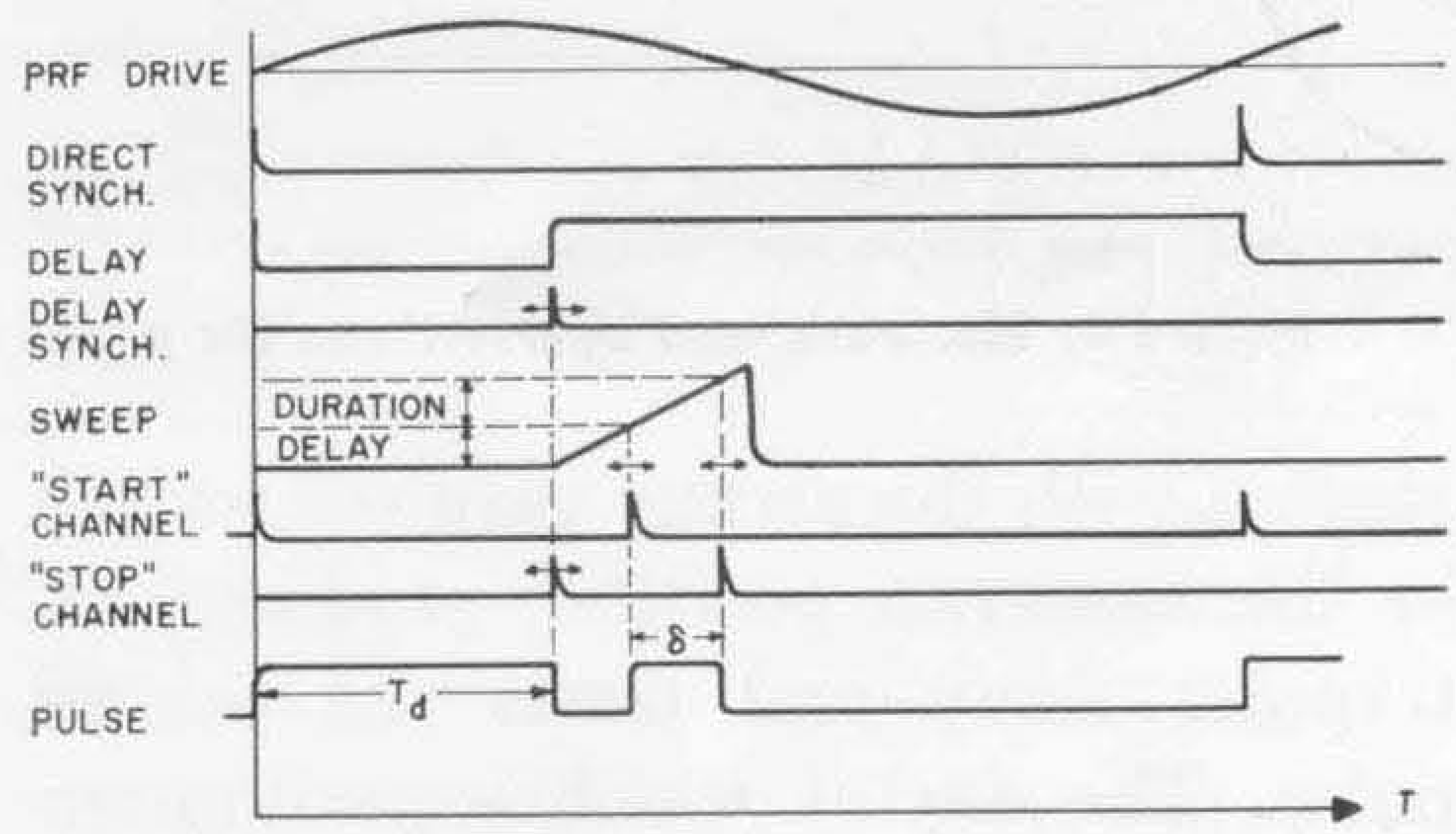


Figure 2. Second Method. Delay circuits set first pulse duration; sweep sets inter-pulse delay and second pulse duration.

DURATION control (see Figure 1). Since the minimum sweep duration is 3 μsec, and 1-to-2 μsec recovery time should be allowed, the actual minimum pulse delay is 4 to 5 microseconds. Note also that the pulse-delay interval produces and registers a delay between the direct synchronizing pulse and the first pulse of the pair. This procedure, according to the instrument specifications and the comments of this paragraph, yield the following possible ranges: duration of each pulse of pair, 0.05 μsec to 0.1 sec; interpulse interval, 5 μsec to 1 sec; delay from direct synchronizing pulse to first pulse of pair, 0.25 μsec to 0.1 sec.

This double pulse is obtained by connection of the DIRECT SYNC post to the POS. COINCIDENCE DRIVE post through a 3.3 kilohm resistor. The direct synchronizing pulse is large enough to produce an output from the delay synchronizing circuits under these circumstances, and, with the SWEEP TRIGGER switch in DELAYED position, the two sweeps of Figure 1 are produced.

The second method will produce a pulse pair of completely independent duration and interpulse interval. The time relationships are shown in Figure 2. The duration of the first pulse is that set by the DELAY control. The interval between pulses is that set by the PULSE DELAY control, and the duration of the second pulse is that set by the PULSE DURATION control. Thus we have, from the catalog specifications for the instrument the following figures:

(1) First pulse duration, 1 μsec to 1 sec.

(2) Interpulse delay, 0.25 μsec to 0.1 sec.

(3) Second pulse duration, 0.05 μsec to 0.1 sec.

(Note that at maximum sweep duration, interpulse delay and pulse duration must be traded. If a 0.05-sec. pulse is desired, only 0.05 second delay is available, etc.)

No internal modification of the instrument is needed to produce this double pulse. The direct and delayed synchronizing pulses are used to start and stop the first pulse, while the sweep,

Figure 3a.
Double Pulse
First Method
12-μsec sweep
25-μsec delay
8-μsec pulse
PRF—10 kc

Double Pulse
Second Method
12-μsec sweep
1st pulse 10 μsec
Delay 5 μsec
2nd pulse 2.5 μsec

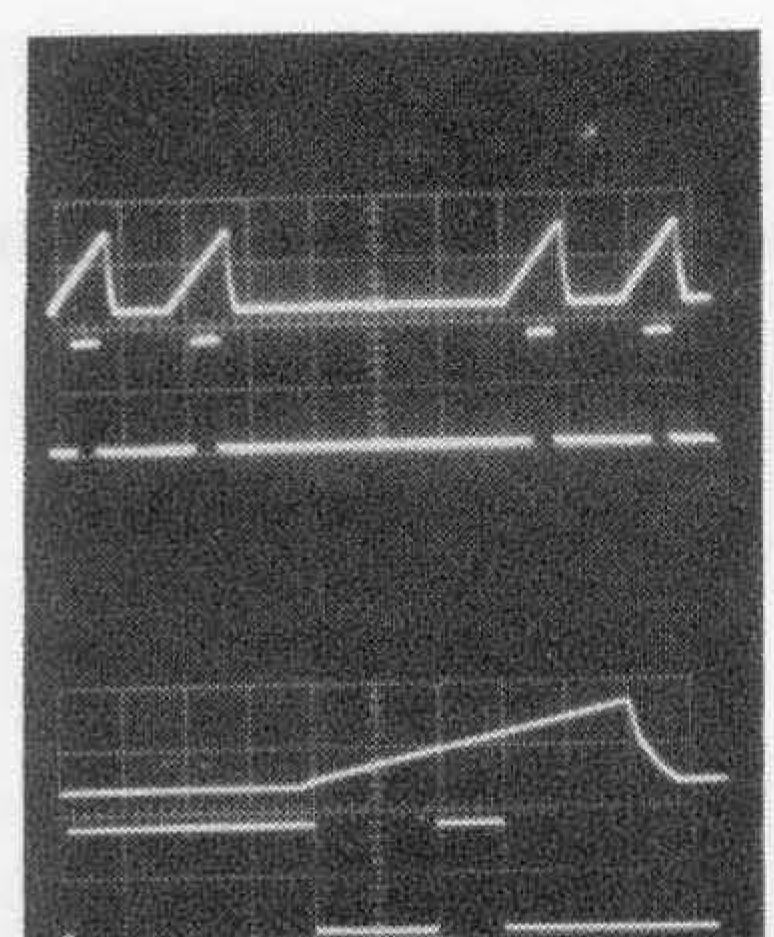
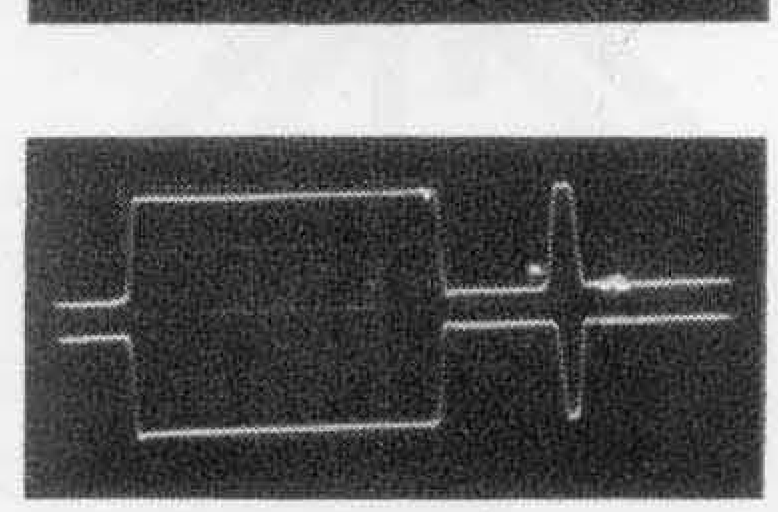


Figure 3b.
Showing minimum duration of push-pull output pulses and interpulse delay; method 2.



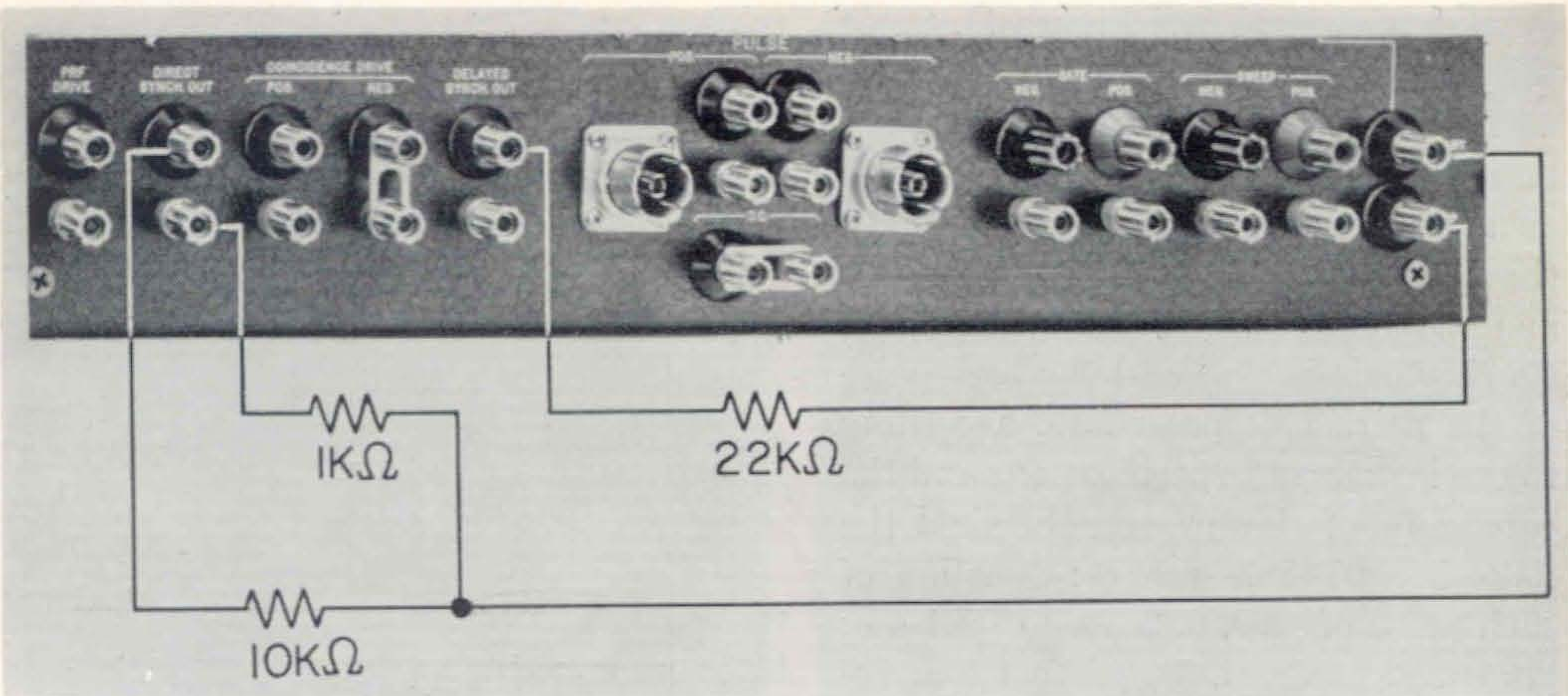


Figure 4. Network and connections for producing a double pulse by the second method.

started with the SWEEP TRIGGER switch in the DELAYED position, produces interpulse delay and times the second pulse. The circuit which superimposes the direct and delayed synchronizing pulses on the internally produced start and stop pulses is shown in Figure 4. These networks are connected between the DIRECT SYNC and START, and the DELAYED SYNC and STOP, binding posts. Then the SWEEP START toggle switch is set to DELAYED and the PULSE SOURCE DRIVING FUNCTION switch is set *midway between* the INTERNAL and EXTERNAL positions. This switch will permit the internally produced timing pulses and the externally produced pulses to be added together.

— R. W. FRANK

COMING SHOWS

In the month of May, General Radio equipment will be on display at three technical apparatus shows. We hope to see you at the General Radio booth.

SEVENTH ANNUAL RESEARCH EQUIPMENT EXHIBIT AND APPARATUS SYMPOSIUM

National Institutes of Health — **Bethesda, Maryland** — **Booth 80** — **May 13–16, 1957**

NATIONAL CONFERENCE ON AERONAUTICAL ELECTRONICS

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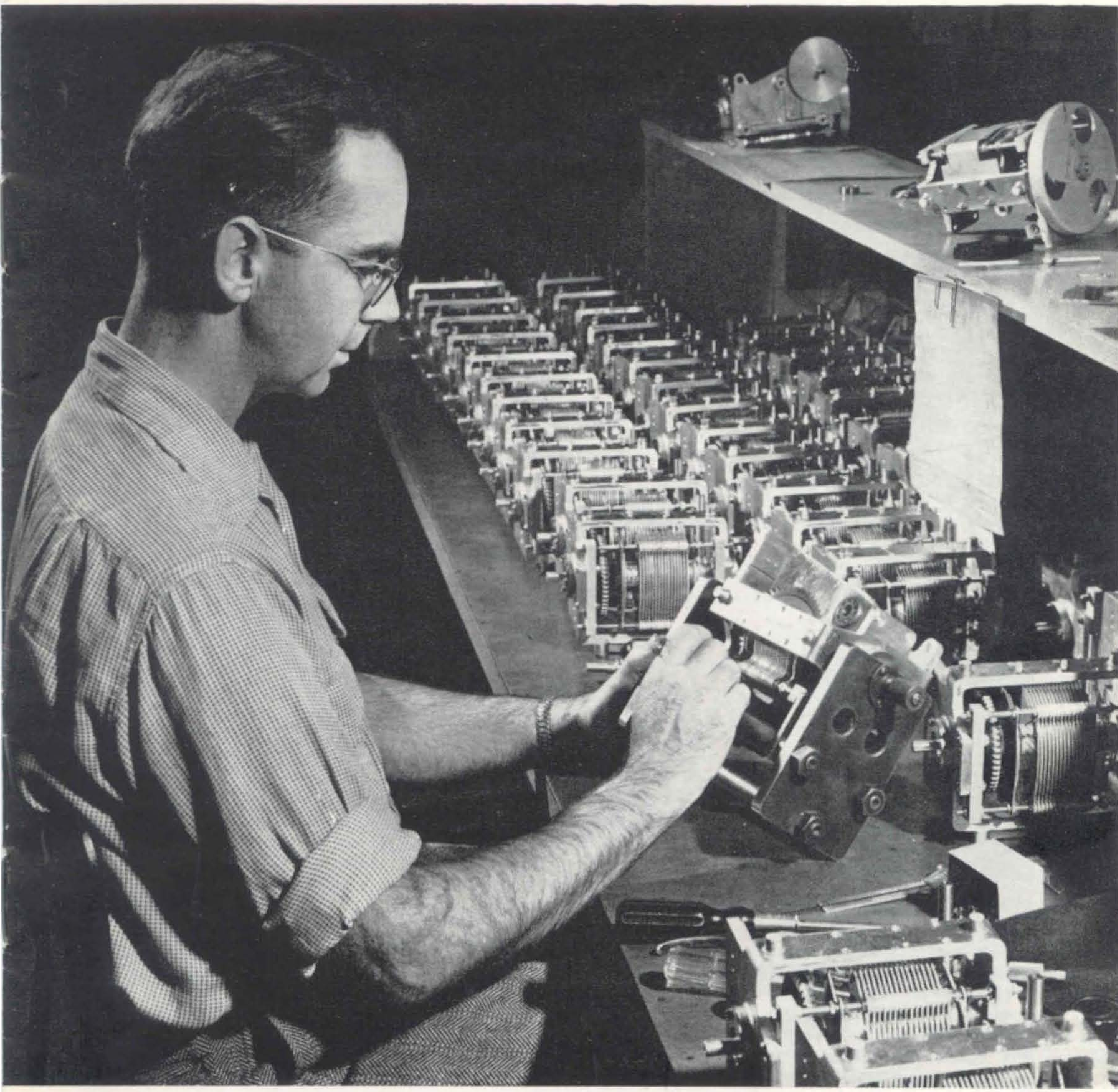

In This Issue

THE GENERAL RADIO EXPERIMENTER

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Contents

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GENERAL RADIO COMPANY

275 Massachusetts Avenue

Cambridge 39 Massachusetts

Telephone: TRowbridge 6-4400

BRANCH ENGINEERING OFFICES

NEW YORK: Broad Avenue at Linden, Ridgefield, New Jersey
Telephone—N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: 920 South Michigan Ave., Chicago 5, Illinois
Telephone—WAbash 2-3820

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Cover

The accuracy of a precision variable air capacitor depends upon the maintenance of close mechanical tolerances—from the fabrication of each part to the final assembly. This photograph shows Type 722 Precision Capacitors undergoing adjustment and alignment in a jig to assure linearity of the capacitance characteristic.

THE MEASUREMENT OF CABLE CHARACTERISTICS

Coaxial cables play an important role in today's electronic world. They are vital elements in television, radio communication, radar, blind landing devices, and practically every other electronic device employing high frequencies. The electrical characteristics of the cables used in these applications must meet very rigid specifications,[1] and the problem of accurately measuring the characteristics is important to the cable designer to enable him to check his designs, to the cable manufacturer to inspect the cable being produced, and to the cable user to make it possible for him to determine accurately the properties of the cables with which he is working.

In addition to coaxial cables there are several dual-coaxial and shielded twin-conductor types in fairly common use, and the television industry uses large amounts of unshielded twin-conductor cables. The problem is to select test equipment that will do the job simply, with good accuracy, and at reasonable cost. General Radio Company manufactures equipment which meets all these requirements, and this series of articles will discuss how it can be used to measure attenuation, characteristic impedance, velocity of propagation, capacitance, and other characteristics.

BASIC CABLE CHARACTERISTICS

Conventional transmission line theory starts with the line parameters of shunt capacitance (C) and conductance (G) *between* the conductors, and series inductance (L) and resistance (R) *of* the conductors. Wave equations derived from the theory and worked into a convenient form contain three coefficients that are combinations of these four parameters, namely: characteristic

impedance: $Z_o = 10^3 \sqrt{\frac{L}{C}}$ ohms,

velocity of propagation: $v = \frac{101.6}{\sqrt{LC}}$ per-cent of velocity of light in free space,

attenuation: $\alpha = 434.3 \left(GZ_o + \frac{R}{Z_o}\right)$ decibels per hundred feet[2].

These three coefficients, Z_o, v, and α, are most directly useful for calculations in transmission-line applications, and capacitance (C) is also useful in low-frequency applications and is often needed for the determination of Z_o, which is not always convenient to measure directly. Consequently, the cable characteristics most frequently used are Z_o, α, and C, with v seldom listed,

[1] Joint Army-Navy Specifications, MIL-C-17B, dated Sept. 7, 1955, "Cables, Coaxial and Twin-Conductor for Radio Frequency."

[2] In these equations the units are as follows: C in $\mu\mu$f/ft.; G in mhos/ft.; L in μh/ft.; and R in ohms/ft. Also, it is assumed that the cable losses are small.

• This paper, which will be published in several parts, is a revision of an earlier paper by Mr. Thurston that has been available in pamphlet form. Later installments will cover the equipment and procedures used in measuring the significant cable characteristics. When the series is complete, reprints will be available. —Editor probably because it is less frequently used and can, if needed, be found from its simple relation to Z_o and C.[3] It is important to consider the frequency behavior of these characteristics, since this factor greatly influences the choice of measurement methods.

Frequency Behavior of C, G, L, and R

In cables intended for high-frequency use, the insulating material is generally polyethylene, Teflon, or a combination of one of these materials and air. In any case, the dielectric constant and dissipation factor are essentially constant from audio frequencies to microwave frequencies, a great convenience. Thus, the capacitance (C) is constant, and the conductance (G) is directly proportional to frequency.[4] (Other types of cables, in particular those with rubber-type insulation used at lower frequencies or for high attenuation at high frequencies, are not considered in the simplified presentation of this section. Their capacitance is not constant, so their frequency behavior is more complicated.)

The behavior of inductance (L), shown in Figure 1, is influenced by skin effect, whereby current penetration into a conductor is effectively limited to a depth that decreases as the frequency is raised. At very low frequencies the effective depth of current

[3] v in per cent $= \frac{101{,}600}{(Z_o \text{ in ohms})\ (C \text{ in } \mu\mu f/\text{ft.})}$

[4] $G = 2\pi f C D$, in which f is the frequency and D is the dissipation factor.

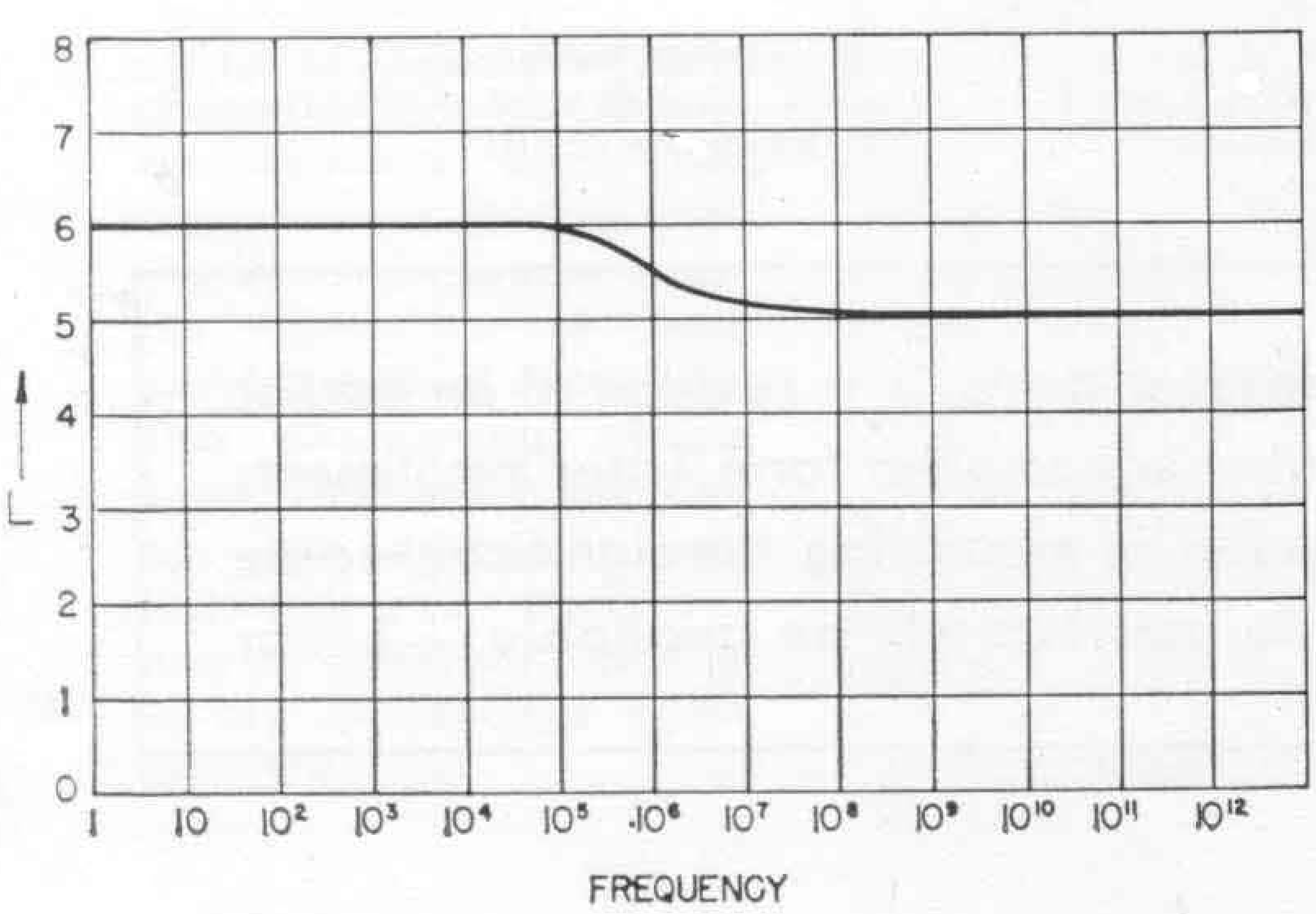


Figure 1. Variation of inductance with frequency (arbitrary units).

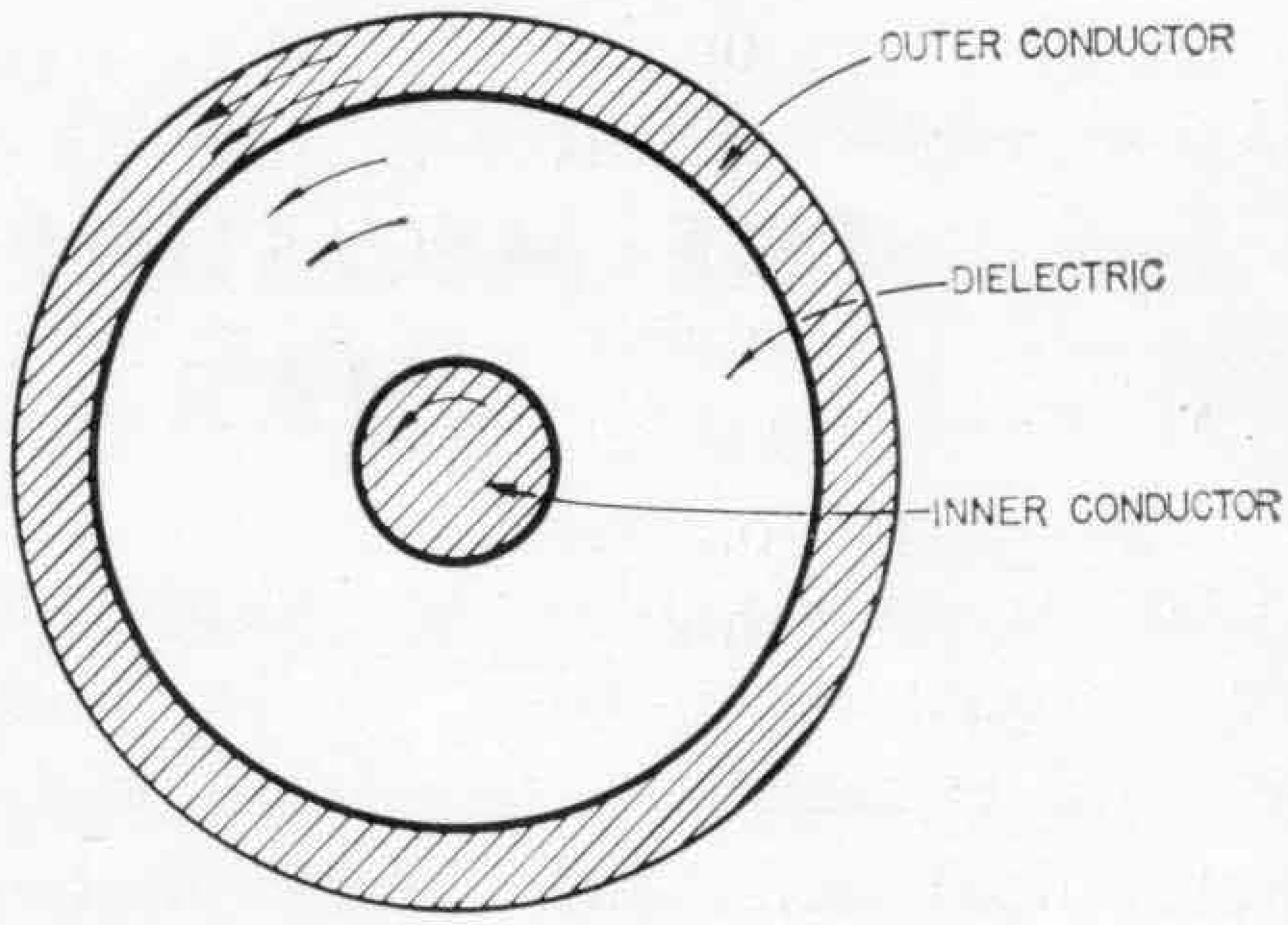


Figure 2. Current distribution in coaxial transmission line.

penetration in metal is large compared to the conductor dimensions, and the current is practically uniformly distributed over the conductor cross sections, as shown by the shaded areas of Figure 2. Magnetic flux, the amount of which per unit current determines the inductance, exists around the current, as indicated by the arrows, and some of this flux is within the conductors, making inductance a maximum.

At very high frequencies, the depth of penetration is negligibly small compared to the cable dimensions, so the current is crowded into the very shallow paths indicated by the black circles in Figure 2. With the same current flowing, the amount of flux *within* the conductors themselves is negligible, yet the flux *between* the conductors (in the dielectric) is unchanged; so the inductance is less than at low frequencies. No further appreciable reduction in flux can occur; thus the inductance is again practically constant and remains so.

The total change of inductance in non-magnetic conductors is readily calculated from conductor dimenions, and, for example, is about 20 per cent for 50-ohm polyethylene-dielectric cables. The frequency range in which the change occurs and the shape of the curve in this region are dependent upon the size of the cable (the change starts at lower frequencies in larger cables) and upon the way the conductors are made. Skin effect is retarded in stranded conductors as compared to solid conductors, even though the individual strands are not supposed to be insulated from one another, and this fact makes it extremely difficult to calculate the practical frequency limits of the region of inductance change. Furthermore, normal mechanical variations, and possibly electrical inter-strand contact variations, in the cable limit the accuracy with which the inductance curve can be measured. Clearly, the curves of Figures 1 and 3 are idealized. For example, if TYPE RG-8/U cable had solid conductors, the upper limit [5] of the inductance change region would be about 9 Mc. Because of the stranding of the conductors, the upper limit is higher, possibly 15 or 20 Mc.

The behavior of resistance (R) is determined by skin effect. As the depth of current penetration is reduced, R increases and becomes approximately proportional to the square root of frequency when skin depth becomes very small compared to conductor dimensions. The type, thickness, and quality of plating used on the conductors also influences the high-frequency resistance, and, at extremely high frequencies, a phenomenon called "braid effect" can make attenuation abnormally high.

Variation in Z_0, v, and α with Frequency

The characteristic impedance, Z_o, varies as $\sqrt{\frac{L}{C}}$; since C is independent of frequency, Z_o varies as $\sqrt{L}$. Therefore, the frequency characteristic of Z_o, shown in Figure 3a, is very similar to that of L (Figure 1) except that the total percentage change of Z_o between low frequencies and high frequencies is about half the percentage change of L. The change in Z_o is nor-

[5] Frequency at which the inductance is within 1% of the final, high-frequency value.

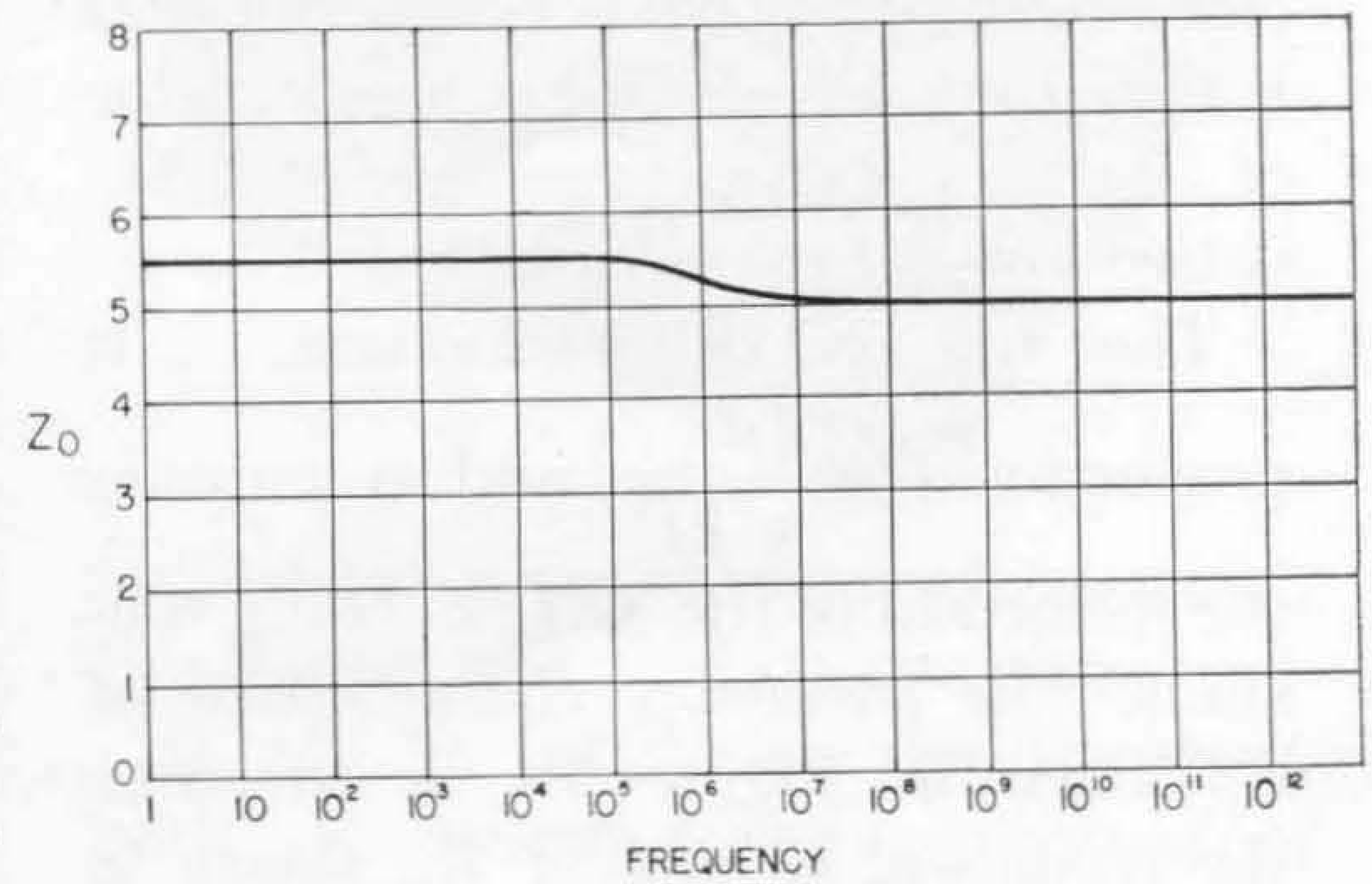


Figure 3a. (above) Variation of characteristic impedance with frequency (arbitrary units).

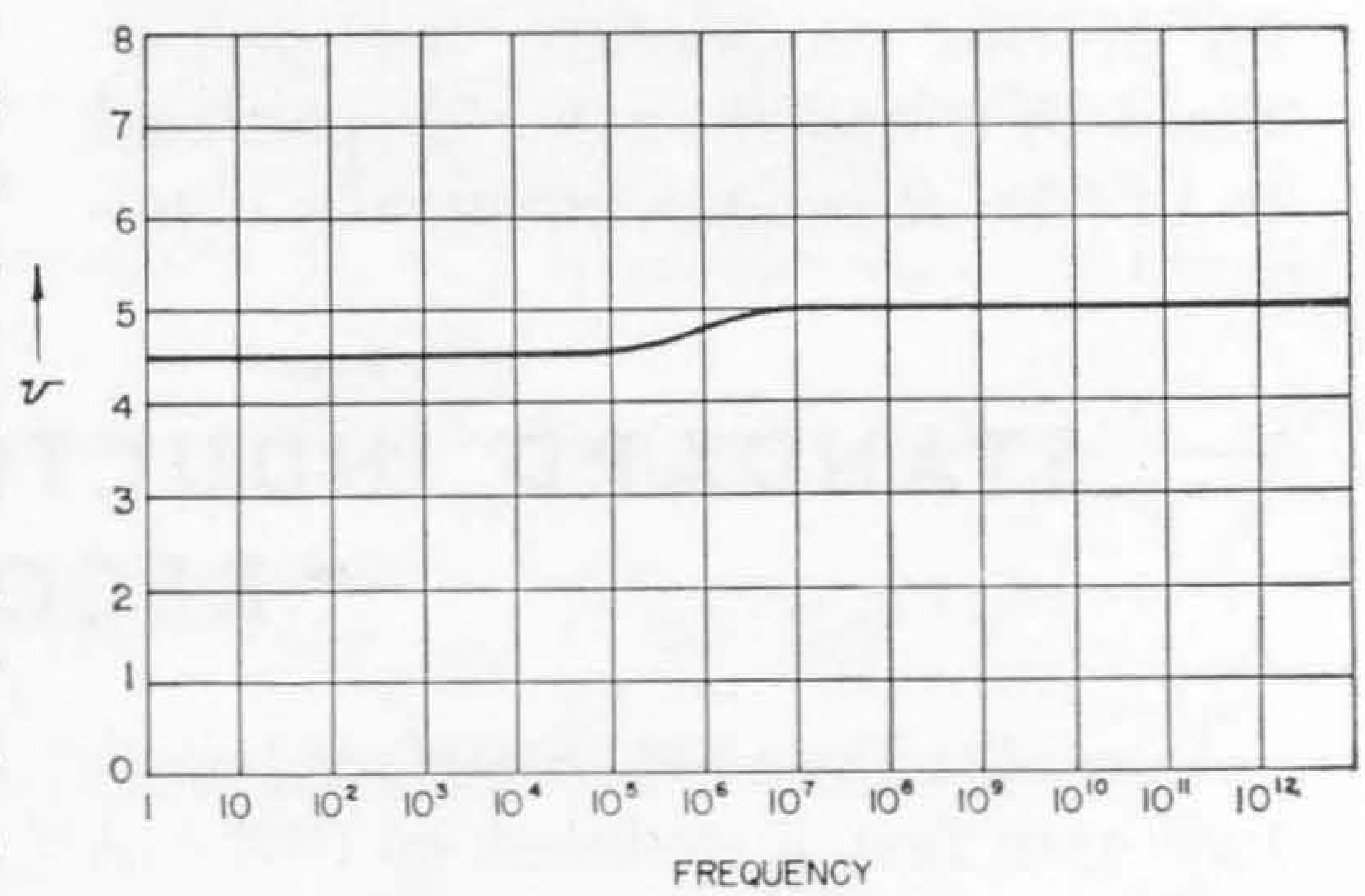


Figure 3b. (above) Variation of velocity of propagation with frequency (arbitrary units).

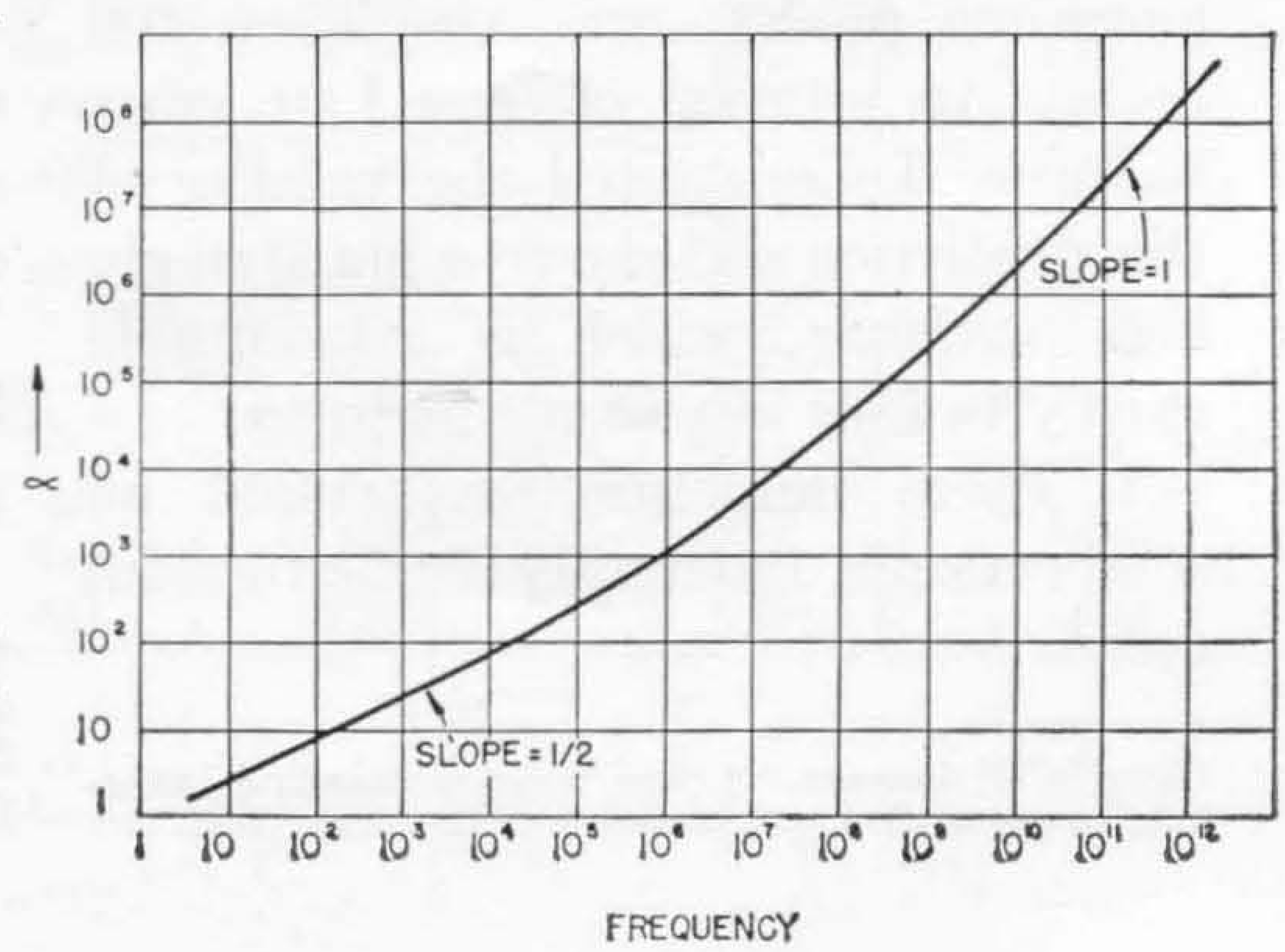


Figure 3c. (right) Simplified version of the variation of attenuation with frequency (arbitrary units).

mally complete at frequencies sufficiently low so that only the final, high-frequency value need be considered or listed. However, special situations arise in which it must be considered. As an example, it may be convenient for a cable manufacturer to make the test of characteristic impedance at a frequency of 1 Mc. In RG-8/U cable, at this frequency, the characteristic impedance is 4 per cent higher than the high-frequency value of 50 ohms. The target value at 1 Mc is therefore 52 ohms.

The velocity of propagation, v, is proportional to $\frac{1}{\sqrt{LC}}$, and so varies as the reciprocal of the $\sqrt{L}$, C being constant. The frequency characteristic of v, shown in Figure 3b, is therefore the reciprocal of that of Z_o, shown in Figure 3a.

The attenuation constant, α, is made up of two components, one proportional to R and the other proportional to G. The R component usually dominates at lower frequencies and varies as the square root of frequency when current penetration is small compared to conductor dimensions. The G component becomes relatively more important at higher frequencies and is directly proportional to frequency. The slope of α versus frequency when plotted on log-log graph paper is ½ if R dominates, 1 if G dominates, and between ½ and 1 if neither one is negligible. A greatly simplified high-frequency attenuation characteristic is shown in Figure 3c; more complicated curves would generally be obtained because of the effects of stranding, braiding, dielectric impurities, and other departures from idealized theory. Normally, for production testing purposes it is sufficient to measure α at a single frequency in the general range of normal use, but if an accurate value is required at some other frequency, it is necessary to make a measurement at that frequency. — W. R. Thurston

(to be continued)

STANDARD INDUCTORS – A STABILITY RECORD

When the Type 1482 Standard Inductors were first introduced in 1952,* it was expected that they would prove to be more stable and reliable than their long-time predecessors, the Type 106 Series. An interval of over four years has now demonstrated the validity of this prediction and shown a gratifyingly high stability, which is attributable chiefly to four important features:

1. These inductors are wound on solid ceramic, inherently stable toroidal cores.

2. They are subjected to an aging process to relieve winding strains and stabilize the winding prior to final calibration.

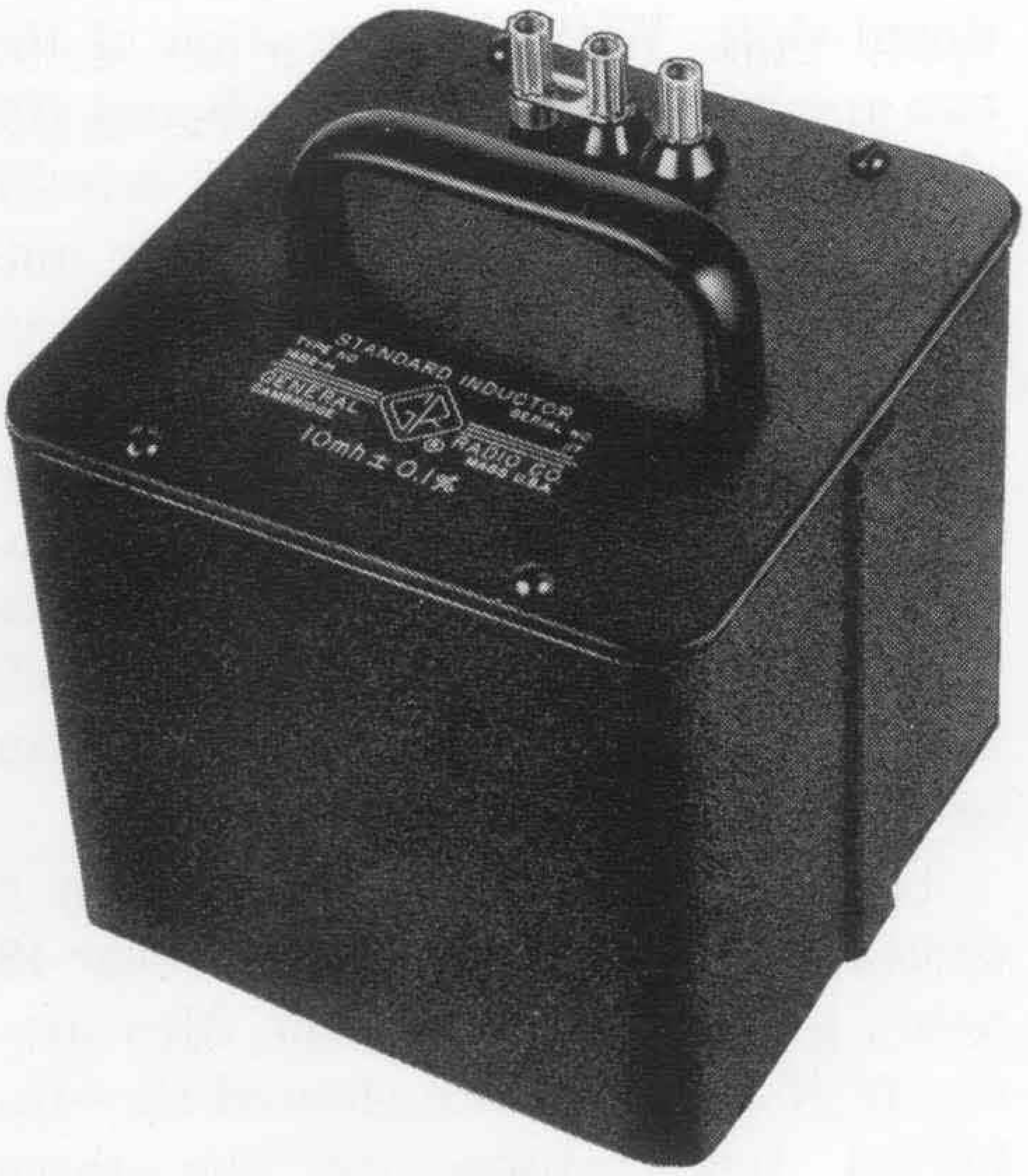
3. Packed in granulated cork, these toroidal units have essentially a floating support free from any localized points of strain.

4. An effective hermetic sealing eliminates variation in inductance due to ambient humidity.

Two complete sets of these inductors, constructed in the summer of 1952, are kept to serve as our primary standards of inductance, in terms of which all of

*Horatio W. Lamson, "A New Series of Standard Inductors," General Radio *Experimenter*, November, 1952.

our production units are given their final calibration for our certificate data. One of these sets has been sent to the National Bureau of Standards for calibration on three separate occasions, namely, in September, 1952, July, 1955, and January, 1957. This means that, in addition to 4½ years of extensive laboratory use, these inductors have endured three round trips between Cambridge and Washington.



The Bureau's certified values of self-inductance at 100 cycles offer convincing proof of the stability of these units. The following table shows the differences between certified values on the three measurement dates, as well as the net overall shift since the first measurement. These data are given with more significant figures than correspond to the tolerance limits, ± 0.03%, to which the Bureau certifies absolute inductance.

In the table, all increments are given in parts per million. The third column indicates the assumed precision of the Bureau's measurement, based on a tolerance of ± 1 in the last digit. The last column gives the accuracy to which the Bureau certification was given.

It will be noted that, for the most part, the indicated shifts are random in character and do not greatly exceed the resolution of the Bureau measurements. There is a moderate preponderance of positive shifts, increase of inductance. Only the 2h, 1h, and 200 μh units showed a progressive uni-direc-

Type	*Inductance*	*Precision of Bureau of Standards Measurements*	*Indicated Shifts in Inductance*			*Tolerance of Bureau of Standards Certification of Absolute Inductance*
			Sept. 1952 to July 1955	*July 1955 to Jan. 1957*	*Sept. 1952 to Jan. 1957*	
1482 T	10 h	± 10	− 10	0	− 10	± 300
1482 R	5 h	± 20	0	+ 40	+ 40	± 300
1482 Q	2 h	± 5	+ 50	+ 25	+ 75	± 300
1482 P	1 h	± 10	+ 20	+ 20	+ 40	± 300
1482 N	500 mh	± 20	0	+ 60	+ 60	± 300
1482 M	200 mh	± 5	− 50	+ 10	− 40	± 300
1482 L	100 mh	± 10	− 50	+ 50	0	± 300
1482 K	50 mh	± 20	− 20	+ 20	0	± 300
1482 J	20 mh	± 5	0	− 30	− 30	± 300
1482 H	10 mh	± 10	− 20	+ 40	+ 20	± 300
1482 G	5 mh	± 20	+ 100	0	+ 100	± 300
1482 F	2 mh	± 5	0	+ 20	+ 20	± 300
1482 E	1 mh	± 10	0	0	0	± 300
1482 D	500 μh	± 20	− 100	+ 180	+ 80	± 500
1482 C	200 μh	± 50	+ 200	+ 50	+ 250	± 500
1482 B	100 μh	± 100	+ 800	− 500	+ 300	± 1000
Arithmetic Average (Omitting 200 μh, 100 μh)					37	
Algebraic Mean (Omitting 200 μh, 100 μh)					+ 27	

tional shift. With the exception of the two smallest inductors (200 μh and 100 μh) the overall shifts averaged only 37 and never exceeded 100 parts per million, which is 0.01 per cent. It may or may not be significant that the unit-valued inductors averaged distinctly less in overall shift, 14 parts per million. In all cases, the over-all (4.3 year) shifts indicated by the Bureau data were well within the limits to which the Bureau certified the value of inductance.

The inductors were stabilized in a constant temperature room for over 48 hours prior to measurement. Measurements of d-c resistance showed the stabilized temperatures for the three occasions to be within one degree C. The temperature coefficient of inductance, about $+ 30/10^6$, is of the same order as the precision of the Bureau data.

The average shift, omitting the two smallest inductors, is of the same order as that which would be produced by a one-degree change in temperature.

We believe that the foregoing gives a convincing proof of the high degree of stability exhibited by this set of inductors. Our regular production Type 1482 units show a comparable degree of stability. This has been demonstrated on numerous occasions when some of our customers have returned their inductors to us for recalibration in accordance with their own periodic requirements.

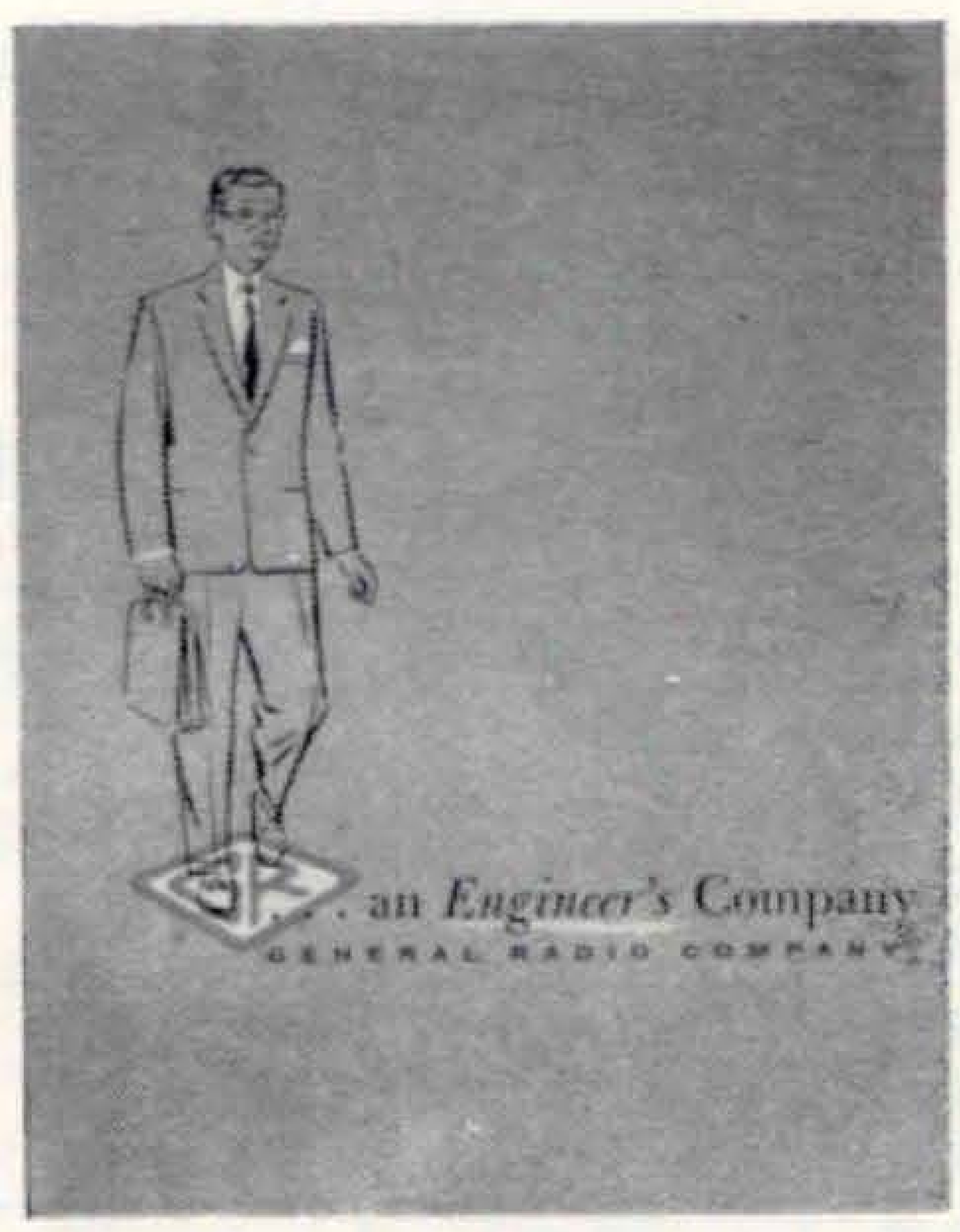
Such stable and accurately calibrated inductors can be used with complete confidence in all standardizing laboratories and for the calibration of all types of inductors and bridges, as is done in our own laboratories.

— Horatio W. Lamson

AN ENGINEER'S COMPANY

If you know an engineering student or recent graduate who might be interested in either development or sales engineering in the electronic instrumentation field, we'd like to send him a copy of our new booklet "An Engineer's Company." Just send your request, with the man's name and address, to:

Mr. John D. Quackenbos
at our Cambridge office



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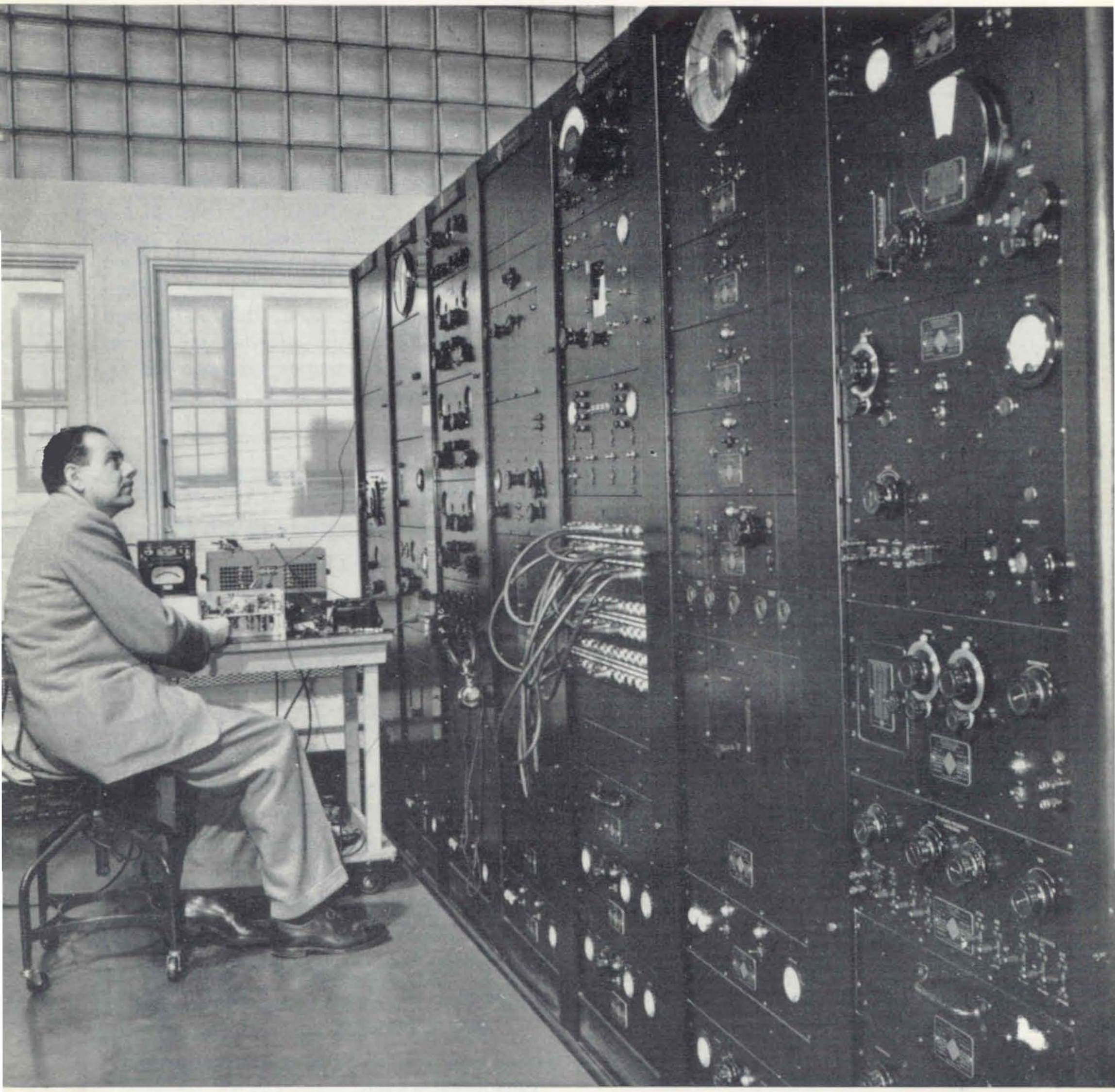

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275 Massachusetts Avenue, Cambridge 39, Mass.

Telephone: TRowbridge 6-4400

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COVER

At General Radio we have been manufacturing frequency standards for the electronics industry since 1916. The frequency standard shown here includes four piezo-electric oscillators, with means for intercomparing their frequencies. It supplies standard frequencies and standard time throughout our Cambridge plant. The frequency is constant within five parts in 10^8 per month and is known at all times to 2 parts in 10^8.

THE MEASUREMENT OF CABLE CHARACTERISTICS (Part II)

MEASUREMENT OF ATTENUATION (α) OF COAXIAL CABLES AT 400 MC AND 3000 MC

Military specifications (MIL-C-17B) require that for quality control the attenuation of all high-frequency cables be measured at 400 Mc and, in most cases, also at 3000 Mc. Low-frequency cables are usually measured at 1 Mc. For both the 400-Mc and 3000-Mc measurements the insertion-loss method is recommended. This method can be used for all cable types. The insertion-loss method and its practical application using commercially available equipment are described in detail below.

METHOD OF MEASUREMENT

The measuring setup consists of a constant-output signal source, a cable sample to be measured, and a heterodyne-type detector having a step attenuator and an indicating meter that are accurately calibrated in decibels. The signal source and the detector are made up of the components shown within the dashed boxes of Figure 4. Changes in signal level into the detector are directly measured in terms of the corresponding changes in attenuator setting and meter reading.

To make a measurement, the signal source is first connected to the detector, the detector (attenuator plus meter) reading is noted; then the cable sample is inserted between the signal source and the detector, and the new detector reading is noted. The insertion loss of the sample in decibels equals the difference between the two detector readings.

The insertion loss measured as above is made up of the attenuation loss of the cable sample (which is the quantity to be determined) plus any reflection losses that may occur at the junctions between the signal source, cable, and detector. Pads are used at the signal source output and detector input, and if the impedance of the cable sample matches the impedance of the pads, the reflection losses are zero, and measured insertion loss equals attenuation loss of the sample. If the impedance of the cable sample does not match the impedance of the pads, then at each junction a reflection loss occurs, and their combined value is subtracted from measured insertion loss to obtain attenuation loss of the sample. A discussion of the nature of reflection losses and how to determine them will be found later in this paper.

DETAILS OF EQUIPMENT[6]

Signal Source: The signal source consists of a Unit Oscillator (Type 1208-B for 400 Mc or Type 1220-A2 for 3000 Mc), a Type 1201-A Unit Regulated Power Supply, a Type 874-G10 10-db Pad next to the oscillator, and a second 10-db pad next to the cable sample (see paragraph after next). At 400 Mc the use of a Type 874-F500 500-Mc Low-Pass Filter is recommended.

Detector: The heterodyne-type detector consists of a 20-db input pad (see next paragraph), a crystal mixer (Type 874-MR Mixer Rectifier), a local oscillator (Type 1209-B Unit Oscillator), and a 30-Mc i-f amplifier with step attenuator and meter, both accurately calibrated (Type 1216-A Unit I-F Amplifier). The mixer combines the signal input and the

[6] General Radio equipment required is listed briefly at the end of this article. For detailed specifications, see G. R. catalog, or write for them.

local-oscillator output (set to the proper frequency) to produce a beat at 30 Mc, which is amplified and measured by the i-f amplifier. With adequate level supplied by the local oscillator to the mixer, the amplitude of the 30-Mc beat is proportional to the signal input level, so that attenuation measurements can be made very accurately by means of the calibrated attenuator and meter in the i-f amplifier.

Pads: The type of pad used at the signal source output and detector input depends on frequency and on cable impedance. At 400 Mc for all cables up to 100-ohm impedance and at 3000 Mc for 50-ohm cables, TYPE 874-G10 10-db Pads are most conveniently used. At 400 Mc for cables above 100-ohm impedance and at 3000 Mc for cable impedances other than 50 ohms, use appropriate lengths (so as to obtain approximately 10 db attenuation in each) of the same type cable as that being measured.

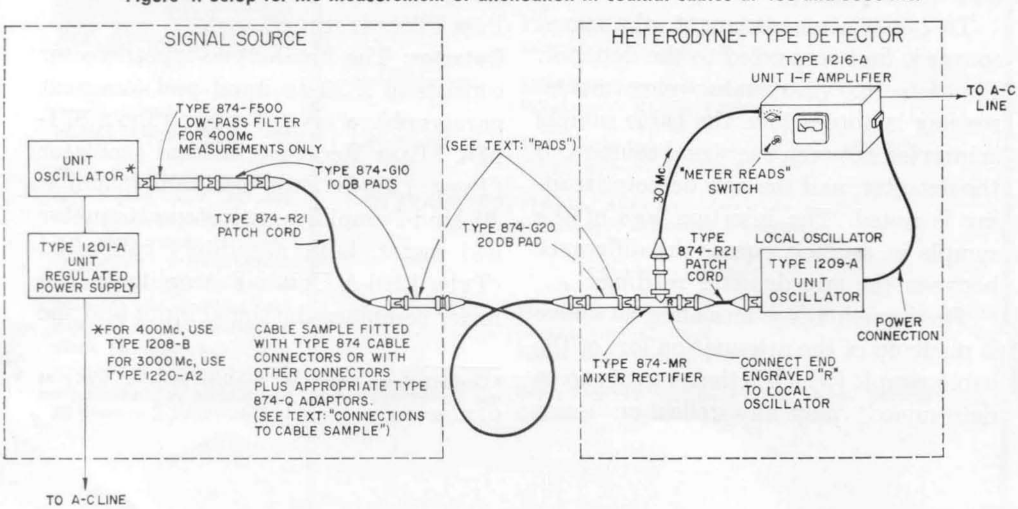
Connections to Cable Sample: The cable sample should be fitted with suitable connectors for making reliable connections to the measuring apparatus. Available TYPE 874 Cable Connectors can be used on many different standard cables,[7] or if standard military connectors are used, appropriate TYPE 874 Adaptors can be used to make the connections to the TYPE 874 Connectors at the signal source and detector. The use of TYPE 874 Connectors for attenuation measurement purposes is recommended where possible, because they can be installed on cables considerably more easily and quickly than other connectors and can be re-used many times.[8] Cables that cannot be fitted with TYPE 874 Connectors can be fitted with Type N, Type BNC, Type C, Type HN, Type LC, or Type UHF connectors, and adaptors

[7]For example, TYPE 874-C can be fitted to RG numbers 5, 6, 21, 126, and 143; TYPES 874-C8 and 874-C9 can interchangeably be fitted to RG numbers 8 through 13, 63, 79, 114, 115, 144, and 146; TYPE 874-C58 can be fitted to RG numbers 22, 55, 58, 111, 122, 141, and 142; and TYPE 874-C62 can be fitted to RG numbers 59, 62, and 140. Other combinations can probably be improvised. In many of these cases the fit to the cable will not be excellent mechanically, but it will be satisfactory as a temporary method of connection for measurement purposes. In installing these connectors, the rubber cable guard can be omitted, the armor of armored cables must be cut back, and the outer braid of double-shielded cables may not always fit under the braid-clamping ferrule, in which cases only the inner braid is used.

[8] The braid-clamping ferrules cannot usually be re-used, but they are available separately and inexpensively.

For cable connector type	*Ferrule type*	*Ferrule price*
874-C, C8	FEC-3	10 for $1.00
874-C58	FEC-2	10 for $1.00
874-C62	FEC-7	10 for $1.00
874-C9	FEC-9	10 for $1.00

Figure 4. Setup for the measurement of attenuation in coaxial cables at 400 and 3000 Mc.



from plug and jack versions of all of these to Type 874 are available.[9]

Length of Sample: The choice of sample length of a cable is usually a balance between measurement accuracy, which improves with longer samples, as will be discussed later, and practical considerations, which generally, though not always, make shorter lengths preferable. A maximum limit on the length is set by the sensitivity of the detector and power output of the oscillator. Expressed in terms of the attenuation of the sample, this limit is about 60 to 80 db.

The accuracy of the over-all measuring system can be checked at any time merely by measurements with the Type 874-G10 10-db signal source output pad in and out of the circuit. The change in reading when the pad is removed should equal the known attenuation of the pad.

ADJUSTING THE EQUIPMENT

Detector: The local-oscillator frequency is set to 370 Mc for a 400-Mc measurement or to 742.5 Mc for a 3000-Mc measurement. In the latter case, the 2970-Mc fourth harmonic of the local oscillator is generated by the mixer to produce a 30-Mc beat with the 3000-Mc signal frequency. In either case, tune the local oscillator for maximum i-f amplifier meter deflection after the signal source has been set to proper frequency of measurement as outlined below. The output coupling loop on the local oscillator should be adjusted to produce between 25% and 100% deflection of i-f amplifier meter when METER READS switch on amplifier is set to D-C MIXER CURRENT.

Signal Source: For 400-Mc measurements, the dial of the Type 1208-B Unit Oscillator is set to 400 and the output coupling loop adjusted to give a convenient level at the detector. For 3000-Mc measurements, the Type 1220-A2 Unit Klystron Oscillator must be set to 3000 Mc and its repeller voltage adjusted for maximum output.

When the oscillator is first turned on, allow a few minutes for warm-up. Since it does not have a frequency calibration, the klystron oscillator is set by using the local-oscillator frequency calibration as follows. (Once set, the frequency seldom needs to be readjusted.)

1. Connect detector to signal source, omitting the 20-db pad and the adjacent 10-db pad, disconnect local oscillator from mixer, set METER READS switch on i-f amplifier to D-C MIXER CURRENT, and adjust klystron oscillator REPELLER VOLTAGE control for maximum deflection of meter on i-f amplifier. This produces maximum output level from klystron oscillator for whatever frequency it happens to be set initially.

2. Set METER READS switch to I-F OUTPUT, reconnect local oscillator to mixer, and adjust local-oscillator frequency to produce two strong deflections of the i-f amplifier meter separated by 15 Mc on the local oscillator dial. If the klystron oscillator happens by luck to be set at 3000 Mc, then the two settings of the local oscillator dial will be at 742.5 Mc and 757.5 Mc respectively. If not, then use a screwdriver to readjust klystron-oscillator frequency, repeating steps 1 and 2 until these two frequency readings are obtained on local-oscillator dial. There also may be two very weak deflections in between the 15-Mc-spaced strong deflections, and these are beats

9

Military connector	*Adaptor Type* *with jack*	*with plug*
Type N	874-QNJ	874-QNP
Type BNC	874-QBJ	874-QBP
Type C	874-QCJ	874-QCP
Type HN	874-QHJ	874-QHP
Type UHF	874-QUJ	874-QUP
Type LC	874-QLJ	874-QLP

with harmonics of the klystron oscillator frequency, but they are so much lower in level that they cause no ambiguity.

ACCURACY

The accuracy of measurement is determined by the accuracy of the attenuator-meter combination in the i-f amplifier. The maximum error is 1 per cent of the attenuation value being measured plus a fixed error of 0.3 db. Since the measurement is always made at the intermediate frequency of 30 Mc, accuracy is independent of the measurement frequency. Because of the fixed error, the total error expressed in per cent of the attenuation value being measured is less for higher attenuation values; so it is desirable to use fairly long cable samples. For example, the maximum over-all error when measuring 6 db of attenuation is 6 per cent, while for 20 db it is 2.5 per cent, as shown in Figure 5.

The Type 1201-A Unit Regulated Power Supply prevents errors due to fluctuation of the signal source output during a measurement. The use of 50-ohm pads at the ends of the cable sample makes reflection losses at these junctions negligible for cables having characteristic impedance values near 50 ohms. When cables having other values of impedance are measured, the reflection losses are usually accurately known and can be subtracted from the measured insertion loss to obtain the true attenuation loss of the sample, as discussed in detail in the next section, or lengths of cable of the same type as being measured can be used as pads, thus eliminating reflection losses.

EFFECT OF IMPEDANCE MISMATCH

In general, the insertion loss of a network is made up of attenuation loss, representing essentially the power absorbed by the network, and reflection losses caused by impedance-level changes at the input and output junctions. Since, in the method previously described, the attenuation loss of a cable sample is for most cable types determined by measurement of its insertion loss in a 50-ohm measuring system, the reflection losses must be considered as possible sources of error when the cable characteristic impedance is not 50 ohms, and either their effects must be made negiligible or corrections must be made.

Reflection loss can be explained as follows. When energy traveling along a uniform system encounters an impedance discontinuity, a portion of the energy is reflected back to the source, so that the energy transmitted beyond the discontinuity is less than the incident energy by the amount of the reflected energy, thus resulting in a "reflection loss." The magnitude of this reflection loss for a single junction is:

$$10 \log_{10}\left(\frac{1}{1 - |\Gamma|^2}\right) \text{ decibels,}$$

in which $|\Gamma|$ is the absolute magnitude of the reflection coefficient of the junction and is directly related to the voltage-standing-wave ratio (VSWR)

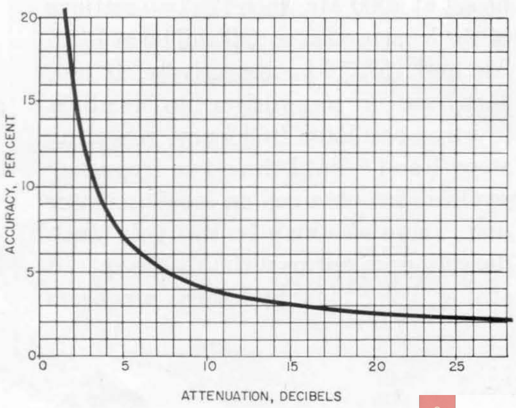


Figure 5. Variation of measurement accuracy with cable sample attenuation.

as follows:[10]

$$|\Gamma| = \frac{(\text{VSWR}) - 1}{(\text{VSWR}) + 1}$$

Fortunately, the VSWR must be fairly high before any significant amount of reflection loss is produced; for example, a VSWR of 1.25 corresponds to a reflection loss of only 0.05 db, while a VSWR of 2.00 corresponds to a loss of 0.5 db.

If the cable sample being measured in the 50-ohm system does not have a characteristic impedance of 50 ohms, two equal discontinuities exist, one at each end of the cable sample. As a result, there are two equal reflection losses, each of which can be calculated from the equations in the above paragraph. In addition, multiple reflections are set up in the cable sample between the junctions, and these can modify the reflection losses by an amount depending on the electrical length of the cable sample and on the frequency and thus cannot be corrected for by a simple calculation. The multiple reflections are rapidly attenuated in traveling through the cable sample and can be made negligible by the use of a long sample.

For example, to take an extreme case, suppose the VSWR of the junctions is 2.00, as it would be for a 100-ohm cable sample. Then, if the attenuation of the cable sample is about 10 db, the maximum possible error caused by multiple reflections is only ± 0.1 db. The normal calculated reflection loss at each junction is, as mentioned earlier, 0.5 db, so the total reflection loss for both junctions is 1.0 db. Suppose that the measured insertion loss of the 100-ohm cable sample in this example turns out to be 11.2 db. The desired attenuation loss is found by subtracting the calculated total reflection loss of 1.0 db from the measured insertion loss of 11.2 db, giving a final answer of 10.2 db with an uncertainty of ± 0.1 db, or ± 1%, owing to multiple reflections.

Figure 6 gives values of the total reflection loss of both junctions as a function of VSWR and also as a function of the characteristic impedance of the cable sample. (The references to twin-conductor cables and to the 200-ohm impedance level will be explained later.) It was pointed out in the previous paragraph that this loss is small, and the curve shows in addition that cable characteristic impedance need be known only approximately in order to obtain a sufficiently accurate value for the reflection-loss correction. For example, the correction is 0.36 db for 75-ohm cables and 0.28 db for 71-ohm cables; so it seems reasonable to use a rounded-off correction of 0.3 db for both types.

The maximum possible magnitude of the error caused by multiple reflections can be determined from Figure 6 and is equal to the number given for the reflection loss reduced by twice the cable attenuation; *e.g.*, if cable attenuation is 10 db, reduction is 20 db or 10 to 1.

[10] Γ is also related to the impedance levels on both sides of the junction as follows: $\Gamma = \frac{Z - Z_0}{Z + Z_0}$, in which Z_0 is the characteristic impedance of the uniform system up to the junction, and Z is the input impedance of the system beyond the junction. Also, the ratio of reflected power to incident power is equal to $|\Gamma|^2$. VSWR equals $\frac{Z}{Z_0}$ or $\frac{Z_0}{Z}$, whichever is greater than unity, if Z and Z_0 are both real.

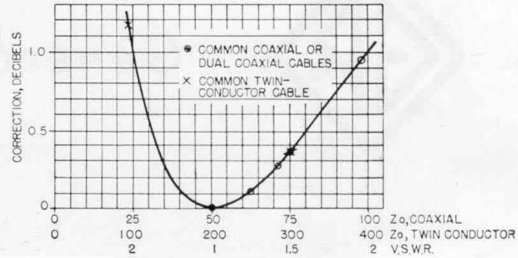


Figure 6. Reflection-loss correction (to be subtracted) vs. cable impedance and VSWR.

For a VSWR of 2.00, Figure 6 gives a reflection loss of 1.0 db, so the maximum possible error due to multiple reflections is one-tenth of this, or 0.1 db.

If the cable sample cannot be made long enough to attenuate the multiple reflections sufficiently when a high VSWR exists, steps should be taken to reduce the mismatch. Suitable resistance pads[11] can be used if available, or other means can be devised to fit the particular conditions.

If the impedance of the cable to be measured is greater than 100 ohms, the reflection-loss correction is too large to allow good accuracy; so for such cables the use of pads matching the cables is recommended.[11]

The military specification MIL-C-17B requires that at 3000 Mc the pads and connectors at the cable sample must match the sample impedance.[11]

In summary, the use of a Type 874-G10 10-db pad at each end of the cable sample provides a known impedance termination suitable for many types of cable. When cables having characteristic impedances in the vicinity of 50 ohms are measured, reflection losses are negligible, and the measured insertion loss is equal to the attenuation. When cables having impedances other than 50 ohms are measured, the reflection losses can, in most instances, be calculated, or determined directly from Figure 6, and subtracted from measured insertion loss to obtain the true attenuation. Thus a single measurement setup can be used for nearly all cable types.

For other cable types, appropriate lengths of the same type cable replace the 50-ohm pads.

— W. R. Thurston

(To be continued.)

[11] Lengths of cable having the same characteristic impedance as the cable under test can be used as pads.

LIST OF EQUIPMENT

Quantity	*Item*	*Price*
1	Type 1216-A Unit I-F Amplifier	$335.00
1	Type 1208-B Unit Oscillator	200.00
1	Type 1220-A2 Unit Klystron Oscillator	272.90
1	Type 1209-B Unit Oscillator	235.00
1	Type 874-F500 Low Pass Filter	16.00
2	Type 874-G10 10-db Pads	50.00
1	Type 874-G20 20-db Pad	25.00
1	Type 874-MR Mixer Rectifier	32.50
1	Type 1201-A Unit Regulated Power Supply	85.00
2	Type 874-R21 Patch Cords (one supplied with each Unit Oscillator)	
	Type 874 Adaptors and Cable Connectors as required	

Note: Much of this equipment is also used for other measurements to be described in later articles of this series.

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Experimenter

Since 1915 – Manufacturers of Electronic Apparatus for Science and Industry

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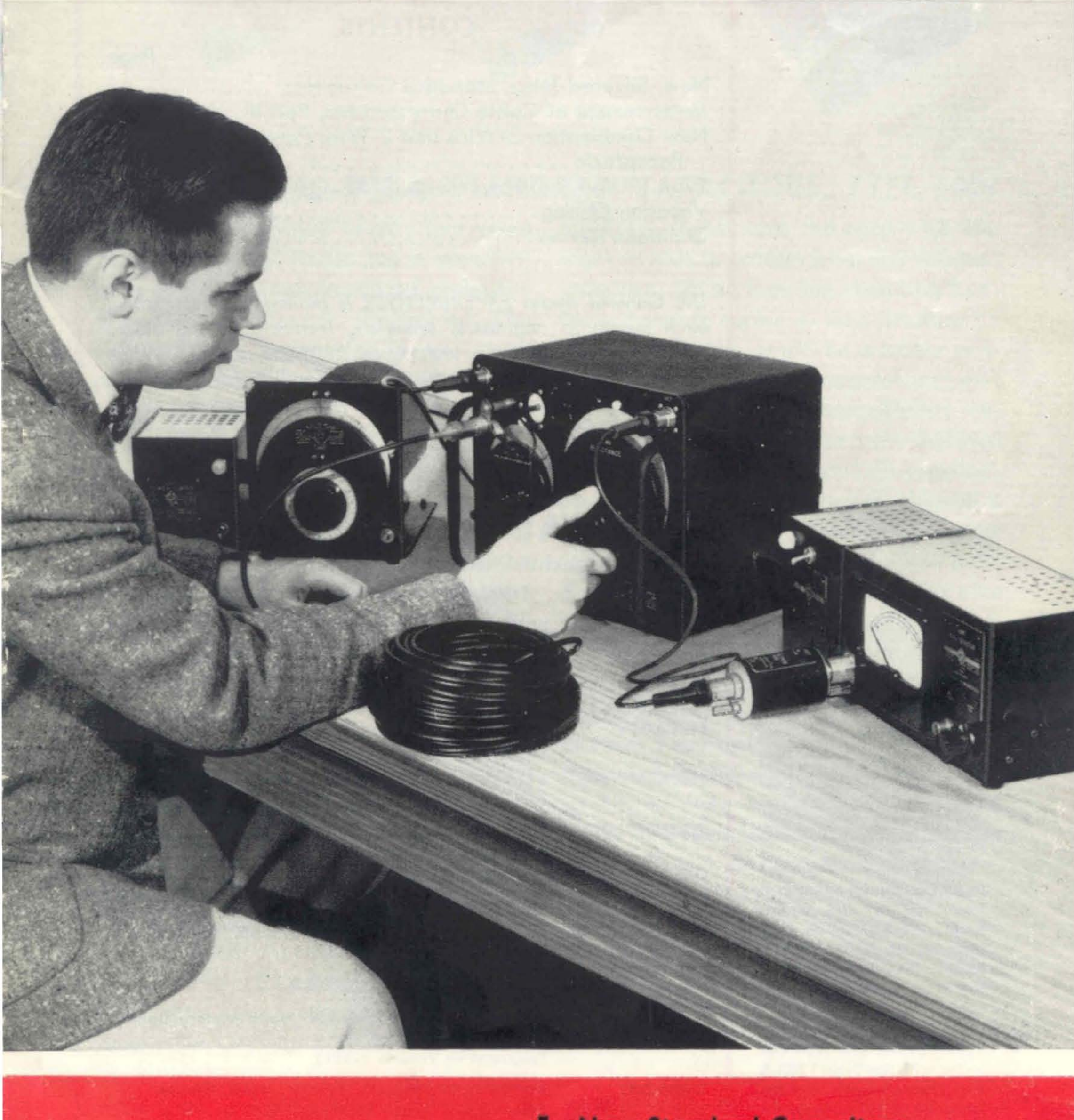

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GENERAL RADIO COMPANY

275 Massachusetts Avenue, Cambridge 39, Mass.

Telephone: TRowbridge 6-4400

BRANCH ENGINEERING OFFICES

NEW YORK: **Broad Avenue at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

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Telephone — VIllage 8-9400

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COVER

Measuring the attenuation of a coaxial cable at a frequency of one megacycle. The equipment consists of the Type 1606-A Radio Frequency Bridge, the Type 1211-A Unit Oscillator with Type 1203-B Unit Power Supply, the Type 1212-A Unit Null Detector with the Type 1203-B Unit Power Supply, and the Type 1212-P2 1-Mc Filter.

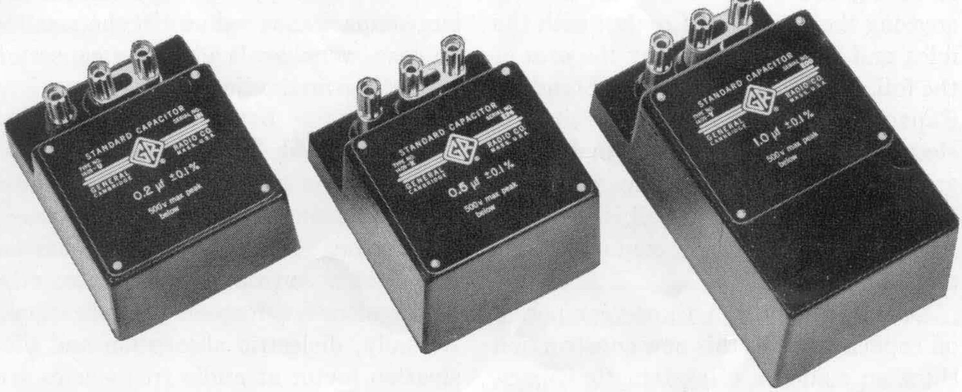


Figure 1.

NEW, SILVERED-MICA, STANDARD CAPACITORS, TYPE 1409

It has been almost twenty-five years since the General Radio line of standard mica capacitors was developed under the direction of the late G. W. Pickard. The characteristics sought for these capacitors were stability, accuracy, low losses, and convenience of use. These characteristics are still the objective in a laboratory standard capacitor, but today's criteria are necessarily somewhat more severe than were those of a quarter-century ago. It is, therefore, a tribute to the soundness of the original design that a great many of its details as well as its principles are included in the new TYPE 1409 Standard Capacitors, currently in production.

Primarily, the new capacitors take advantage of the improvements possible with properly processed silvered mica, but in the course of the development all phases of design and manufacture were reviewed and a considerable number of changes made.

STABILITY

Stability was secured in the original design by: (1) the omission of impregnants, such as wax, which could change with time and ambient conditions; (2) silica gel sealed into the case with the stacked unit to protect from any residual moisture; (3) a clamping structure having a low-rate spring so that pressure on the stacked unit would be sensibly constant with time and temperature; and (4) artificial aging by temperature cycling. These features, which are retained in the new units, produced an excellent capacitor, which, nonetheless, showed a tendency to increase in capacitance over the years at a slow but predictable rate. Figure 2, which is the record of our own working standards over a 22-year period, shows a linear increase after the first year, when percentage change in capacitance is plotted against the logarithm of time. The initial and normal first-year drift of these units was largely eliminated by the artificial aging; hence a drift of 0.1% in approximately ten years after shipment was the expected performance. It is interesting to speculate whether the units in question will continue at the indicated rate and drift another 0.1% in the next 100 years, but the matter is obviously of somewhat academic interest to most of us.

The mechanism of the drift in a capacitor with foil electrodes is believed to be a gradual flow of the soft foil, increasing the intimacy of *contact* with the mica and perhaps increasing the *area* of the foil. In the new TYPE 1409 Standard Capacitor each sheet of mica has silvered electrodes, assuring a much higher degree of contact between mica and electrode. Additionally, soft foil is still used to insure low-resistance contact to the electrodes.

Data taken over a three-year period on capacitors with this new construction show no evidence of systematic capacitance drift. Such changes as have been observed are random and less than .01% (100 ppm). An order-of-magnitude improvement over the previous design is indicated, with a distinct possibility that the improvement is even greater than this.

ADJUSTMENT ACCURACY

The older type capacitors were adjusted within 0.25% of nominal accuracy by trimming; large capacitance values were adjusted by a second, small unit in *parallel*, while small capacitance values were adjusted by a large unit in *series*. In the new construction the use of silvered-electrode mica permits adjustment within 0.1% in a single unit for the large capacitance values. In the smaller values a very small adjusting capacitor is used for final adjustment.

ELECTRICAL CHARACTERISTICS

In addition to low dissipation factor and high ultimate insulation resistance, interest has focused in recent years on dielectric absorption, of importance in d-c or ultra-low-frequency applications. Actually, dielectric absorption and dissipation factor at audio frequencies are aspects of the same phenomenon, both being chargeable to interfacial polarizations occurring at frequencies below one cycle per second. The typical rise in dissipation factor at low audio frequencies is shown in Figure 5.

The mica used in the TYPE 1409 is selected to have average dissipation factor of no more than 0.0002 at 1 kilocycle and insulation resistance of at least 5,000 megohm-microfarads. This usually means clear, or clear and fair-stained, ruby mica, but selection is ultimately on the basis of electrical performance rather than on arbitrary visual quality.

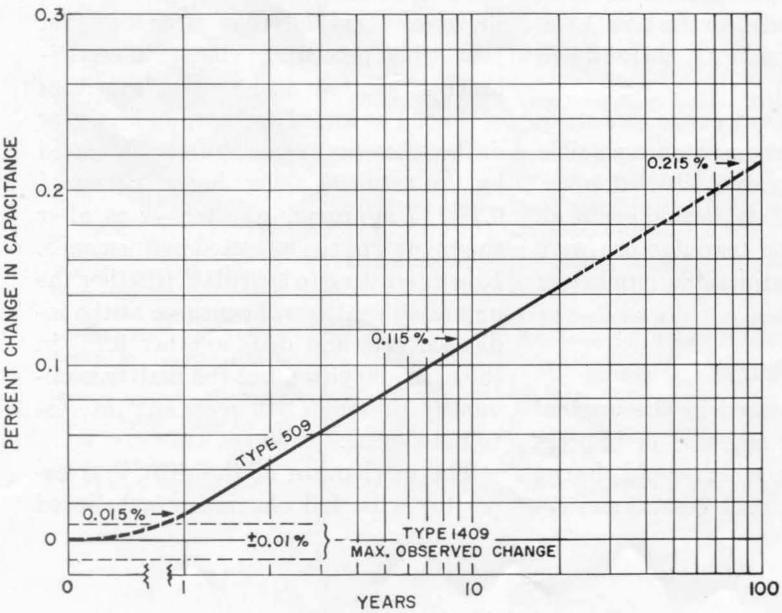


Figure 2. Record of change in capacitance of Type 509 Standard Capacitors in General Radio laboratories over a 22-year period. Range of observed changes in the new Type 1409 units for a 3-year period is shown by the dashed lines.

Moisture is the deadly enemy of good electrical performance in mica, and extreme care must be taken to exclude moisture during assembly of the capacitor. The mica is stored at an elevated temperature for an extended period before assembly. Actual assembly is done in an air-conditioned room with relative humidity maintained at 30% or lower. The assembled capacitor stacks are placed in desiccators until final assembly into their cases.

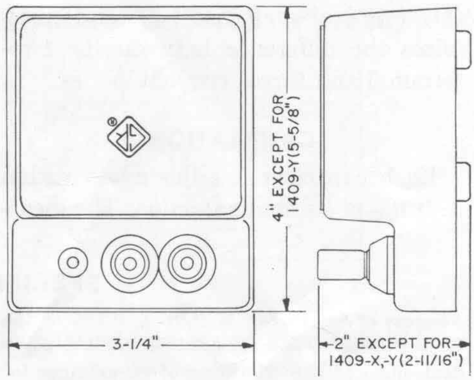


Figure 3. Dimensions of the Type 1409 Standard Capacitors.

HOUSING AND CALIBRATION

Like their predecessors, the new TYPE 1409 Standard Capacitors are encased in a cast-aluminum enclosure, but this also has been redesigned. Weight has been reduced, center of gravity moved nearer the binding posts, and four units have been substantially reduced in volume and weight. An independent ground binding post has been added so that these units may be used either as two-terminal or three-terminal capacitors. Indicated stability and uniformity of temperature coefficient are good enough so that an accurate knowledge of the temperature is useful. Hence, provision has been made for the insertion of a dial-type, bimetallic thermometer into a wall of the case.

To absorb any residual moisture that may remain in spite of all precautions, a quantity of silica gel is sealed into the unit. To insure a good seal and anchorage between the metal and the sealing compound, a groove is milled into the inside walls of the case. Finally, a metal plate is fastened to the bottom to complete the electrostatic shielding.

Mica and foil are so stacked that the two outside foils are connected to the low (L) terminal. This partial shield reduces the capacitance between the high

Figure 4. Mica for the Type 1409 Standard Capacitors is selected for low losses in this test setup using the Type 1605-A Impedance Comparator.

(H) terminal and case (G), and minimizes the difference between the two-terminal and three-terminal values.

CALIBRATION

Each capacitor is adjusted to within ± 0.1% of its nominal value. The measured capacitances for both the two-terminal and the three-terminal connections, at one kilocycle, are entered on the calibration certificate supplied with each capacitor.

— IVAN G. EASTON
P. K. MCELROY

SPECIFICATIONS

Accuracy of Adjustment: Within ± 0.1% of the nominal capacitance value engraved on the case.

Calibration: Measured values of capacitance for both the two-terminal and the three-terminal connections at a specified room temperature are entered in the calibration certificate. These values are obtained by direct comparison, to a precision of better than 0.01%, with a like standard periodically certified by the National Bureau of Standards to an accuracy of ± 0.03% in absolute capacitance.

The TYPE 1409 Standard Capacitors may be connected in parallel with no cumulative error, by plugging them together.

Temperature Coefficient of Capacitance: +35 ±10 ppm per degree Centigrade between 10° and 70° C.

Dissipation Factor: Less than 0.0003 at 1 kc and 23° C. See Figure 5.

Frequency Characteristics: See Figure 5. Values of series inductance and series resistance at 1 Mc are given in the table below. This resistance varies as the square root of the frequency for frequencies above 100 kc.

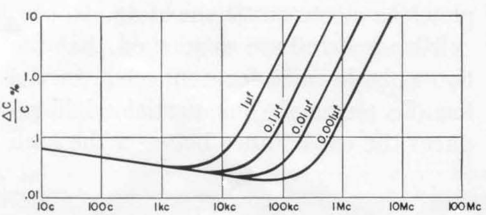
Leakage Resistance: 5,000 megohm-microfarads or 100,000 megohms, whichever is the lesser.

Maximum Voltage: 500 volts peak at frequencies below the limiting frequencies tabulated below. At higher frequencies the allowable voltage decreases and is inversely proportional to the frequency, approximately. These limits correspond to a temperature rise of 40° Centigrade for a power dissipation of 5, 6, and 7.5 watts respectively, for the three case sizes.

Mounting: Cast aluminum cases with rubber feet.

Terminals: Two insulated jack-top terminals, plus jack-top terminal and ground strap.

Dimensions: See Figure 3.



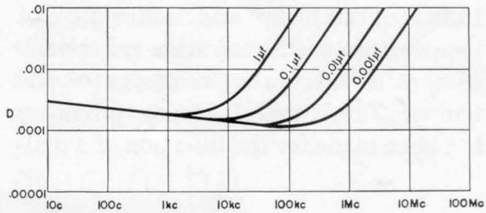


Figure 5. (*Left*) Fractional change in capacitance as a function of frequency. (*Right*) Dissipation factor as a function of frequency.

Type	*Capacitance in μf*	*Maximum Peak Volts*	*Frequency Limit for Max. Volts*	*Series Inductance in μh*	*Resistance in Ohms at 1 Mc*	*Weight in Pounds*	*Code Word*	*Price*
1409-F	**0.001**	500	4.0 Mc	0.050	0.02	1¼	GOODCONBOY	**$ 32.00**
1409-G	**0.002**	500	2.3 Mc	0.050	0.02	1¼	GOODCONBUG	**32.00**
1409-K	**0.005**	500	1.1 Mc	0.050	0.02	1¼	GOODCONCAT	**34.00**
1409-L	**0.01**	500	640 Kc	0.050	0.02	1¼	GOODCONDOG	**34.00**
1409-M	**0.02**	500	370 Kc	0.050	0.02	1¼	GOODCONEYE	**36.00**
1409-R	**0.05**	500	175 Kc	0.055	0.02	1¼	GOODCONPIG	**39.00**
1409-T	**0.1**	500	100 Kc	0.055	0.02	1¼	GOODCONROD	**42.00**
1409-U	**0.2**	500	50 Kc	0.055	0.02	1¼	GOODCONSIN	**50.00**
1409-X*	**0.5**	500	20 Kc	0.055	0.02	1¾	GOODCONSUM	**80.00**
1409-Y†	**1.0**	500	10 Kc	0.070	0.03	2½	GOODCONTOP	**130.00**

*Mounted in medium case.
†Mounted in large case.

MEASUREMENT OF CABLE CHARACTERISTICS (Part III)

ATTENUATION OF DUAL-COAXIAL CABLES

Dual-coaxial cables are made up of two, separate, individually shielded, coaxial cables encased in an additional common braided shield and a common jacket. Attenuation is measured for each individual coaxial core separately, and thus the method described above for coaxial cables can be used without modification. The impedance of these cables is usually 62.5 ohms for each coaxial core (125 ohms total for both cores), and the reflection-loss, as determined from Figure 6, is 0.1 db.

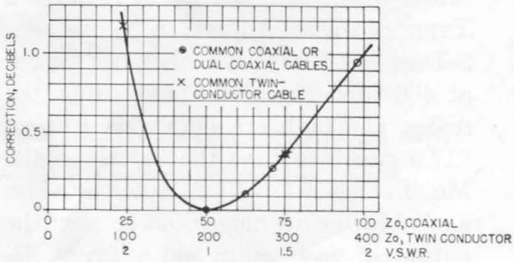


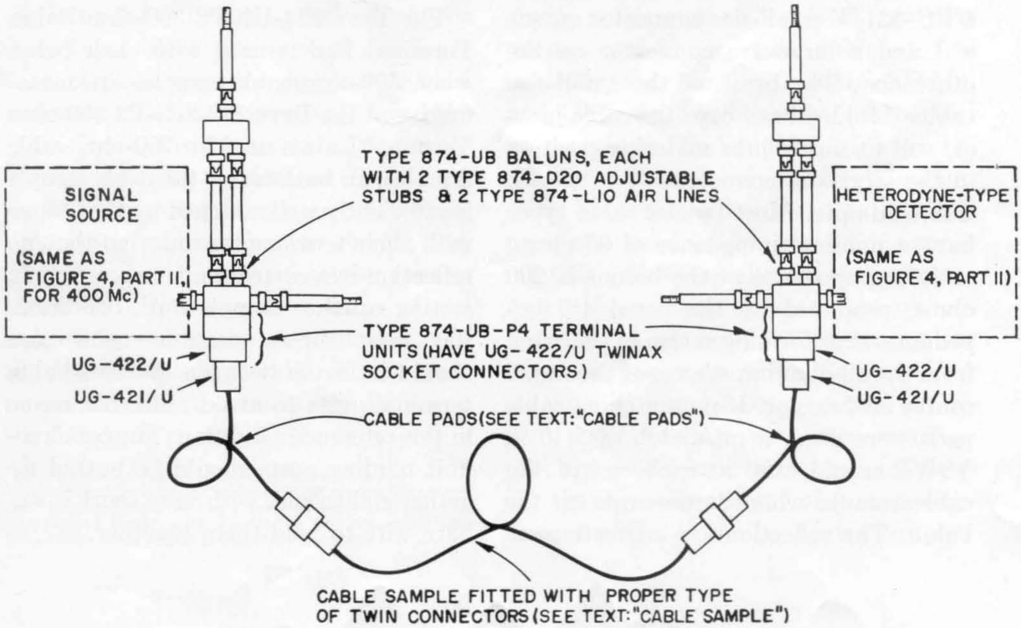
Figure 6. Reflection-loss correction (to be subtracted) vs. cable impedance and VSWR.

ATTENUATION OF SHIELDED TWIN-CONDUCTOR ("Twinax") CABLES

Shielded twin-conductor or "twinax" cables consist, as the name implies, of a pair of parallel, spaced wires surrounded by a shielding braid and must usually be measured only at 400 Mc. They can be measured using the same method with a slight modification of the setup already described for coaxial cables. All that is necessary is the addition of two Type 874-UB Baluns (balanced-to-unbalanced transformers) to the setup at the points where the cable connects to the measuring equipment, as shown in Figure 7.

In this figure the details of the signal source and heterodyne-type detector are not repeated, since they are the same as those shown in Figure 4 (Part II).

Figure 7. Setup for the measurement of attenuation in twinax cables at 400 Mc.



Baluns: The Type 874-UB Balun is a tuned type, and each balun requires 2 Type 874-D20 Adjustable Stubs and 2 Type 874-L10 10-cm Air Lines for use at 400 Mc. The stubs have calibrated scales, and both are simply set to read "17.5 cms." to tune the baluns to 400 Mc. Type 874-UB-P4 Adaptor provides a reliable shielded connection between the output of each balun and a Type UG-422/U twinax socket connector, which connects directly to Type UG-421/U twinax cable plugs on the cable pads.

Cable Pads: These can be made using a length (to give about 10 db attenuation each) of the same cable type as that under test. Small-size twinax cable used for sample and pads can be fitted directly to the UG-422/U series of twinax connectors used on the balun terminal units, using female-to-female adaptors as necessary to make connections. If large-size twinax cable is being used for the sample and for the pads, adaptors from the small-size connectors on the balun terminal units to the large-size series of connectors used on the sample and pads can be readily made from a few inches of RG-22B/U small-size twinax cable with a UG-421/U small-size connector on one end and a large-size connector on the other end. The braid of the small-size cable, if folded back over the cable jacket, will fit nicely into soldering position in the large-size connector.

Cable Sample: Most twinax cable types have a nominal impedance of 95 ohms, and the impedance at the baluns is 200 ohms, produced by the usual 4:1 impedance-transforming action in the balun from the 50-ohm impedance of the signal source or detector. If no matching cable pads were used, a mismatch of 2.10 in VSWR would exist at each end of the cable sample where it connects to the balun. The reflection-loss correction, as determined from Figure 6, would be 1.18 db. (In Figure 6, the impedance scale having 200 ohms opposite a VSWR value of 1 applies when the baluns are used in the measuring setup.) It is recommended, however, that pads be used to match the cable sample between it and the baluns so as to eliminate the need for any reflection-loss correction, partly because the correction is fairly large and partly because, as a result, an appreciable error could then be caused by a small misadjustment of the baluns.

Making the Measurement: The method of measurement is the same as that for coaxial cables, as described previously, and no reflection-loss correction need be made since matching pads are used.

ATTENUATION OF UNSHIELDED TWIN-CONDUCTOR CABLES

There are several 300-ohm cables and one 200-ohm cable in this category. They can be measured by use of the Type 874-UB Baluns in exactly the same way as for the twinax cables just discussed, except that different balun terminal units are used. The reflection-loss correction can always be eliminated.

The Type 874-UB-P3 300-ohm Balun Terminal Pad is used with each balun when 300-ohm cable samples are measured, and the Type 874-UB-P2 200-ohm Terminal Unit is used for 200-ohm cable samples. In both cases, the cable sample is sufficiently well matched by the baluns with their termination units so that no reflection-loss correction is necessary. In setting up the "sample out" condition, the most direct possible connection should be made between the two balun terminal units to avoid reflection errors in this reference condition. The terminal-unit binding posts should be butted together end to end, with very short U's of bare wire to hold them together.

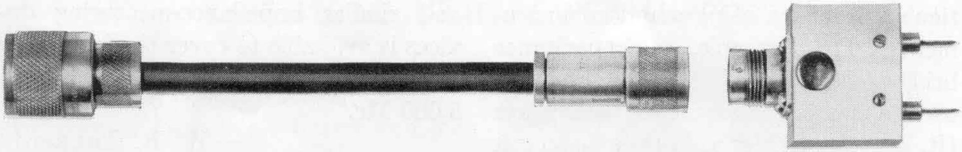


Figure 8. (*Left*) **Adaptor made up from RG-22B/U cable with large-size and small-size twinax connectors.** (*Right*) **Type 874-UB-P4 Adaptor to connect balun to small twinax connector.**

Care must be taken to keep the unshielded cable sample well away from interfering objects, including other parts of itself. This requirement rules out measuring a coiled sample and usually requires the sample to be strung around the room, or up and down the hall, on non-metallic hangers and spaced two or three feet from walls, pipes, and the like. This is admittedly a nuisance, but such precautions appear to be unavoidable.

MEASUREMENT OF ATTENUATION AT OTHER FREQUENCIES

There are several military cables that require a measurement of attenuation at 1 Mc. The attenuation values are generally so low that the accurate use of the insertion-loss method requires very long cable lengths. A better method is to use an impedance bridge, with which the open-circuit and short-circuit reactance of a cable sample having an electrical length of one-eighth wavelength and the open-circuit or short-circuit resistance of a cable having an electrical length of a quarter wavelength can be measured. (The electrical length equals the physical length multiplied by the square root of the effective dielectric constant of the insulating material.) Attenuation can then be accurately calculated from these resistance and reactance values, using the following equations.[12]

[12] For a detailed discussion of this bridge method, including a refined technique for getting maximum accuracy, see "Measurements of the Characteristics of Transmission Lines," by Ivan G. Easton, in the November and December, 1943, issues of the *Experimenter*.

$$\alpha = \frac{Z_O}{R_{SC}} \times \frac{868.6}{\text{length, ft.}} \text{ db/100 ft.}$$

or

$$\alpha = \frac{R_{OC}}{Z_O} \times \frac{868.6}{\text{length, ft.}} \text{ db/100 ft.}$$

where $Z_O = \sqrt{|X_{SC}| \cdot |X_{OC}|}$, X_{SC} and X_{OC} are the short- and open-circuit reactances, respectively, of the eighth wavelength section used to determine Z_o, and R_{SC} and R_{OC} are the resistances for the quarter wavelength section. Measurements at 5 Mc can be made in the same manner.

The Type 1606-A R-F Bridge is well suited for measurements at 1 Mc and 5 Mc.

Departing from military specifications for a moment, there are occasions when a cable designer or a development engineer making use of cable might want to measure a particular cable at frequencies other than 1 Mc, 5 Mc, 400 Mc, and 3,000 Mc. The insertion-loss method as described can be used at any frequency between about 20 Mc and 4,000 Mc, a range that includes the UHF television band (475 to 890 Mc), assuming that suitable oscillators are on hand. The bridge method mentioned above can be used at almost any frequency for which a bridge is available, provided that cable lengths can be selected to give resistance and reactance readings that are within, or can be brought within, the accurate range of the bridge. Special methods can be devised in particular problems using standard instruments. For example, a capacitance bridge (TYPE 716-C) can sometimes be used to measure all four cable parameters (R, L, G, and C) of a short cable length (25 ft.) at low frequencies (100 Kc), and attenuation can then be calculated. A large selection of General Radio bridges and similar impedance-measuring devices is available to cover the frequency range from low audio frequencies to 5,000 Mc.[13]

— W. R. THURSTON

(To be continued)

[13]Our Sales Engineering Department will be glad to make recommendations for any specific measurement problems.

LIST OF EQUIPMENT

In addition to the items listed in previous installments, the following units are used in measuring twin-conductor cables.

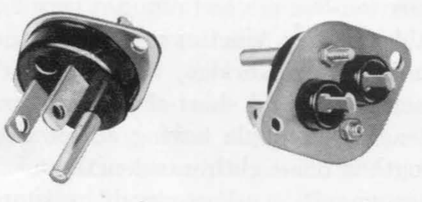
Quantity	*Item*		*Price*
2	Type 874-UB Balun	@ $75.00	$150.00
2	Type 874-UB-P2 200-ohm Terminal Unit	@ 6.50	13.00
2	Type 874-UB-P3 300-ohm Terminal Pad	@ 15.00	30.00
2	Type 874-UB-P4 Adaptor	@ 50.00	100.00
4	Type 874-L10 Air Lines	@ 5.50	22.00
4	Type 874-D20 Adjustable Stubs	@ 14.00	56.00

For measurements by the bridge method at 1 Mc, the following instruments are recommended:

Quantity	*Item*		*Price*
1	Type 1606-A Radio-Frequency Bridge		$620.00
1	Type 1212-A Unit Null Detector		145.00
1	Type 1211-B Unit Oscillator		275.00
1	Type 1212-P2 1-Mc Filter		30.00
2	Type 1203-B Power Supplies	@ $40.00	80.00

NEW COMBINATION 3-WIRE AND 2-WIRE POWER RECEPTACLE

As rapidly as production schedules will permit, General Radio ac-operated instruments are being equipped with 3-contact power-input receptacles that will accept either the standard 2-wire power cord, TYPE CAP-35, or the new 3-wire cord CAP-15.* The 2-wire cord will be supplied with instruments unless the 3-wire type is specified in the order.



Front and rear views of the Type 109-A 3-wire receptacle.

The new 3-wire receptacle is available for installation by our customers in instruments that now have the 2-wire receptacle. Designated TYPE 109-A, this receptacle, unlike the old 2-wire type, is not recessed, which would require an excessively large diameter. Instead, the new receptacle is interchangeable with the old 2-wire receptacle on existing instruments, without change in mounting holes.

Type		*Code Word*	*Price*
109-A	3-wire Receptacle	TRIPU	$1.25

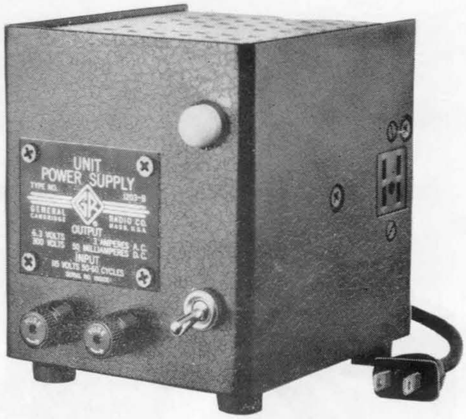
*"3-Wire Power Cord" *General Radio Experimenter*, 31, 9, February, 1957.

TYPE 1203-B UNIT POWER SUPPLY

The popular, general-purpose Unit Power Supply Type 1203-A, designed primarily to provide a-c heater and d-c plate power for General Radio Unit Instruments, has been replaced by an improved version Type 1203-B. The circuit of the new model has been revised to include additional filter capacitance, thereby reducing the output ripple. By a rearrangement of components, the fuses have been moved to the front panel for greater convenience of servicing.

The 230 v, 50-cycle model Type 1203-AQ11 has been replaced by the Type 1203-BQ18 for 230 v, 50- to 60-cycle service.

In both new models these changes have been accomplished at no increase in price.



View of the Type 1203-B Unit Power Supply.

SPECIFICATIONS

Output (at 115-v input): 300 v dc (±5%) at 50 ma; 6.3 v ac at 3 amp; (with a-c load at 1.5 amp or less, max d-c load is 65 ma, about 285 v dc).

Regulation: At no load, d-c output is 380 v.

Ripple: Less than 80 mv (120 cps) at full load.

Input: 105-125 v, 50-60 cps, 50 w full load at 115 v.

Connectors: Line cord permanently attached to instrument. Standard 4-point connector mounted on cabinet side for other Unit Instruments.

Rectifier: 6X4.

Accessories Supplied: Mating plug for equipment other than Unit Instruments; spare fuses.

Housing: Black-crackle-finish aluminum panel and sides. Aluminum cover finished in clear lacquer.

Dimensions: Width 5 in., height 5¾ in., depth 6¼ in. over-all, not including power cord.

Weight: 5 pounds.

Type		*Code Word*	*Price*
1203-B	**(115 volts, 50-60 cycles)**	ALIVE	**$40.00**
1203-BQ18	**(230 volts, 50-60 cycles)**	ALIVEREGAL	**50.00**

VACATION CLOSING

During the weeks of July 22 and July 29, our Manufacturing Departments will be closed for vacation.

There will be business as usual in the Sales Engineering and Commercial Departments. Inquiries, including requests for technical and commercial information, will receive our usual prompt attention.

Our Service Department requests that, because of absences in the manufacturing and repair groups, shipments of equipment to be repaired be scheduled to reach us after the vacation period.

CHAIRMAN RETIRES

Harold B. Richmond, for the past thirteen years Chairman of the Board of the General Radio Company, retired on June 30, 1957, having reached the Company's mandatory retirement age.

After his graduation from the Massachusetts Institute of Technology in 1914, he served with Stone & Webster and later was a member of the electrical engineering teaching staff at MIT. He was called to active duty as an officer in the Coast Artillery Corps in the first World War. He joined the General Radio Company as an engineer in 1919 and two years later was elected its Secretary. He became Treasurer in 1926, which position he held until his election as Chairman of the Board of Directors.

His principal interests have always been in the business and managerial affairs of the Company. In addition to carrying on this work with vigor and high ability, Mr. Richmond has found time for notable work in outside affairs. He has been director and president of the Radio Manufacturers Association (now RETMA); director, president and chairman of the Scientific Apparatus Makers Association; director of the Liberty Mutual Insurance Company and of the Boston Woven Hose and Rubber Company. In addition, because of a deep interest in education, he has served for many years as a member of the corporation of the Massachusetts Institute of Technology and as a trustee of Northeastern University and of Norwich University.

During the second World War, he was Chief of the Guided Missile Division of the National Defense Research Committee at a time when few had much faith in the future of guided missiles. For his energy and foresight in promoting continued research along these lines, he was awarded the Presidential Medal for Merit and was later Chairman of the National Academy of Science Ordnance Advisory Committee on Guided Missiles.

His wise leadership and counsel have contributed much to the establishment of many of the Company's basic policies and to its present position in the industry.

General Radio Company

PRINTED IN U.S.A.

the GENERAL RADIO Experimenter

Since 1915 – Manufacturers of Electronic Apparatus for Science and Industry

VOLUME 32 No. 3 AUGUST, 1957

Photograph courtesy of Hycon Eastern

In This Issue

the GENERAL RADIO Experimenter

Published Monthly by the General Radio Company

VOLUME 32 • NUMBER 3 AUGUST, 1957

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The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in electronic techniques in measurement. When sending requests for subscriptions and address-change notices, please supply the following information: name, company address, type of business company is engaged in, and title or position of individual.

GENERAL RADIO COMPANY

275 Massachusetts Avenue, Cambridge 39, Mass.

Telephone: TRowbridge 6-4400

NEW YORK: **Broad Avenue at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: **6605 West North Avenue, Oak Park, Illinois**
Telephone — VIllage 8-9400

PHILADELPHIA: **1150 York Road, Abington, Pennsylvania**
Telephone — HAncock 4-7419

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Telephone — JUniper 5-1088

LOS ANGELES: **1000 North Seward St., Los Angeles 38, Calif.**
Telephone — HOllywood 9-6201

SAN FRANCISCO: **1182 Los Altos Ave., Los Altos, Calif.**
Telephone — WHitecliff 8-8233

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COVER

Production testing the Hycon Eastern Model 13MA Crystal Filter for i-f shaping. The filter operates at 13 Mc and has a 30-kc bandwidth. The sweep frequency is supplied by the Type 805-C Standard-Signal Generator, whose slow-motion dial is driven by the Type 1750-A Sweep Drive.

THE MEASUREMENT OF CABLE CHARACTERISTICS (Part IV)

MEASUREMENT OF CHARACTERISTIC IMPEDANCE (Z_o)

In Part I it was shown that the characteristic impedance of polyethylene-dielectric and teflon-dielectric cables is constant at very low frequencies, decreases somewhat in a medium-frequency range, and is again constant at a lower value at very high frequencies. (See Figure 3a.) Characteristic impedance can easily be determined at any desired frequency if a suitable impedance bridge[13] is available with which to measure the open-circuit reactance, X_{oc}, and short-circuit reactance, X_{sc}, of a sample length of cable.[14] The characteristic impedance is then $Z_o = \sqrt{X_{oc}X_{sc}}$.

The bridge method is the most satisfactory method for measurements on cables at low frequencies, such as 1 Mc, where the inductance varies with respect to frequency, and for measurements on rubber-dielectric cables and other types of cables in which capacitance is not independent of frequency. Twin-conductor cables are more difficult but can be measured by use of the TYPE 874-UB Balun connected between the bridge and the cable sample and adapted to the desired frequency of measurement.

Since polyethylene-dielectric and teflon-dielectric cables have practically constant Z_o for all frequencies above about 20 to 40 Mc, and since it is this value of Z_o that enters into most applications and is usually listed, an indirect method of measuring Z_o can be used. This method is based upon the following simple relation to velocity of propagation (v) and capacitance (C):

$$Z_o = \frac{101{,}600}{(v \text{ in per cent}) \times (C \text{ in } \mu\mu f \text{ per ft.})}$$

ohms. Since C for polyethylene-dielectric or teflon-dielectric cables is independent of frequency, it can be measured at any convenient low frequency, such as 1,000 cycles. (MIL-C-17B Specification allows any frequency from 1,000 cycles to 1 Mc.) The relative velocity of propagation, v, can be determined, as outlined in the following section, at any convenient frequency above the region of changing characteristic impedance. Then Z_o can be calculated from the formula given. The advantages of this indirect method are that it is simple and requires less expensive equipment than the impedance-bridge method, and the high-frequency part of the measurement (measurement of v) can be made using some of the same equipment that is necessary for the measurement of attenuation. Thus we have reduced the measurement of Z_o to the easier measurements of v and C. Because of the small variations in characteristics that occur from point to point along a flexible cable, it is desirable to use the same piece of cable for both measurements.

[13] Our Sales Engineering Department will be glad to make recommendations for any specific measurement problems.

[14] Preferably near an electrical length of one-eighth wavelength.

MEASUREMENT OF VELOCITY OF PROPAGATION (v)

The usual reason for making this measurement is, as implied above, to determine characteristic impedance (Z_o), but the value of v is occasionally required for other reasons. Since v is constant at high frequencies (Figure 3b), the frequency of measurement is not at all critical provided that it is above 20 to 40 Mc. The measurement can be made with the equipment shown in Figure 9.

The TYPE 1208-B Unit Oscillator, amplitude-modulated, delivers power through a Type 874-G10 10-db Pad and a patch cord to a Type 874-Q2 Adaptor fitted with banana plugs. These plug into the jack-top binding posts of a second Type 874-Q2 Adaptor,[15] and one end of the cable sample is also connected across these binding posts. (Connectors are not used on the cable sample for this measurement.) The coaxial end of the second adaptor connects to one end of the Type 874-VQ Voltmeter Detector, whose other end is terminated in a Type 874-WM 50-ohm Termination. The demodulated audio envelope signal is connected by a patch cord to the Type 1212-A Unit Null Detector. The Type 720-A Heterodyne Frequency Meter is strongly recommended in order to improve the accuracy with which the frequency is known from 2% to 0.1% and to reduce very significantly the danger of miscalculating the number of quarter-wavelengths, k, in the cable sample, as described below.

It can be seen that this system can be described as consisting of a 50-ohm generator of variable frequency driving an untuned voltmeter in parallel with the cable sample input. If the other end of the cable sample is open-circuited, and if the oscillator frequency is varied, the cable-sample input impedance will vary between alternate maximum and minimum values, with the minima marked by minimum indications on the voltmeter. It is well known that the minima occur when the length of the cable sample is equal to an odd number of quarter-wavelengths.

The measurement is made by finding the frequencies for two adjacent voltmeter minimum readings. Before using the frequencies so found, it is desirable to find also the next several frequencies for minima and to check that the separations between any two adjacent frequencies are reasonably uniform, thus guarding against being misled by a possible spurious minimum. Call the lower of the two frequencies to be used f_1 and the next higher one f_2. The physical length, l, of the cable sample is also measured. To calculate per cent velocity from these data, first determine the number, k, of quarter-wavelengths contained in the sample length at the frequency of f_1 by means of the following approximate[16] relation:

[15]The Type 874-Q2 Adaptor is supplied with two banana plugs and two binding posts.

[16]This formula is approximate because of normal measurement errors in determining $f1$ and $f2$, and because k must be an exact, odd integer.

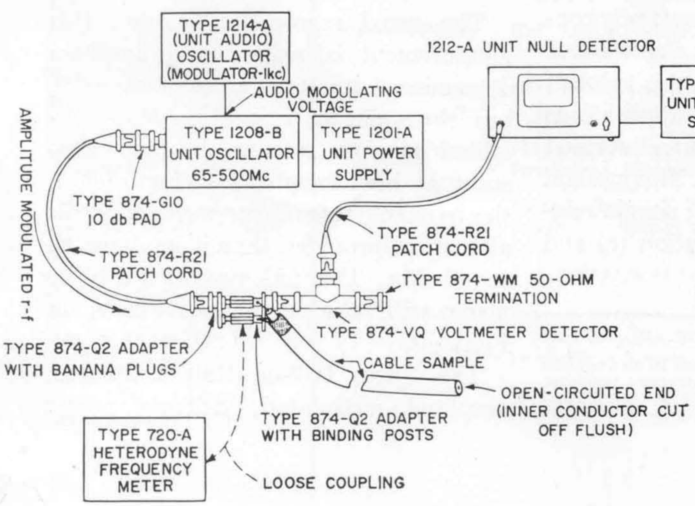


Figure 9. Arrangement of equipment for measurement of velocity of propagation in coaxial cables.

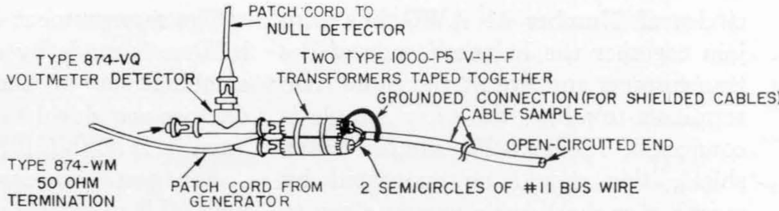


Figure 10. Method of connections to twin-conductor cables. The remainder of the measuring system is identical with that of Figure 9. Instead of copper foil and tape, Type 874-ZC Clamps can be used, if desired.

$$k \simeq \frac{2f_1}{f_2 - f_1},$$

using for the quantity $(f_2 - f_1)$ the average difference between successive frequencies. As calculated, k should be very close to an odd integer and should be rounded off to this integer, which is then used in the following formula to determine per cent velocity:

$$v = \frac{(l \text{ in ft.}) \text{ x } (f_1 \text{ in Mc})}{(2.46) \text{ x } (k, \text{ integer})} \text{ per cent.}$$

A convenient length for the cable sample is about 25 feet, which will result in values for $(f_2 - f_1)$ of around 12 Mc for polyethylene-dielectric cables and around 15 Mc for polyethylene-and-air-dielectric cables. It is convenient to choose f_1 in the 100- to 200-Mc range, since the heterodyne frequency meter is direct reading in this range. If much longer cable samples or higher frequencies are used, successive minima are more closely spaced percentage-wise, and there is the possibility that k will not be selected properly, an error that is not easy to detect. If the frequency meter is not used, it is recommended that lower frequencies and/or shorter cable samples be used to minimize this danger. The frequency range of the Type 1208-B Oscillator (65-500 Mc) is adequate for most applications.

The error of measurement equals the sum of the error in determining l and the error in determining f_1. The physical length of the cable sample can probably be measured with an accuracy of $\pm\frac{1}{2}$ inch or better, but end effects must also be considered. The equivalent electrical "length" (due to fringe capacitance) of the open circuit at the far end of the cable can be kept to less than ¼ inch, and the length of cable input connections to the binding posts kept to less than ½ inch with reasonable care and for all but the largest cable types. These end effects will be approximately compensated if ¼ inch (or more for larger cables) is added to the measured length of the cable proper. All things considered, in typical cases the error of measuring l is about $\pm 0.4\%$ for a 25-foot length. The error of measuring frequency is $\pm 2\%$ if the calibration of the Type 1208-B Oscillator is used directly, but the use of the Type 720-A Heterodyne Frequency Meter improves this to $\pm 0.1\%$. Therefore, the over-all accuracy of determining per cent velocity can be about $\pm 0.5\%$. Because of the variations in characteristic impedance along the cable, mentioned earlier, this accuracy is probably somewhat better than is significant.

The measurement of twin-conductor cables, shielded or unshielded, is made in exactly the same way as just described, except that two Type 1000-P5 V-H-F Transformers (untuned, balanced-to-unbalanced transformers for the 50-250-Mc range) are used to connect the generator and the voltmeter, respectively, to the input end of the cable sample, as shown in Figure 10. The two transformers are strapped together with copper foil (to provide a common ground) and tape, and two short semicircles of Number 11 AWG bus wire join together the balanced ends of the transformers and are at the same time terminals to which the cable sample is connected. If the cable sample has a shield, this should be connected by means of a short, wide copper strap to the common ground of the transformers.

MEASUREMENT OF CAPACITANCE (C) AND CAPACITANCE UNBALANCE[17]

The capacitance per foot (C) of cables, usually required for the determination of characteristic impedance (Z_o) and useful in its own right for inspection purposes and for circuit calculations at low frequencies, can be easily measured with very high accuracy. The high accuracy is desirable for two reasons: (1) The error in Z_o as determined from measured values of velocity of propagation (v) and capacitance (C) is the sum of the errors in both measurements, and minimizing the capacitance error helps to maintain reasonable accuracy for Zo. (2) In the measurement of capacitance unbalance of shielded twin-conductor cables, the final answer is directly proportional to the difference between two, nearly equal, measured capacitance values, and, if most of the allowed cable tolerance is to be utilized, accurate measurements are essential. We have already seen that for polyethylene-dielectric and teflon-dielectric cables the capacitance is independent of frequency and that MIL specifications allow the use of any frequency between 1,000 cycles and 1 Mc for the measurement. In the interests of accuracy it is best to select a low frequency, and 1,000 cycles is usually most convenient. The Type 716-C Capacitance Bridge is well suited for this measurement because of its wide capacitance range and its high accuracy.

The measurement of capacitance unbalance is made by connecting various combinations of the two inner conductors and shield to the bridge as outlined in MIL-C-17B Specification.[17]

For best accuracy the substitution method is recommended. Using the correction chart mounted on the panel of each instrument, one can obtain an accuracy of $\pm 0.1\%$ or ± 0.8 $\mu\mu$f, whichever is greater, for capacitance values up to 1,000 $\mu\mu$f. Twenty-five feet of 50-ohm polyethylene cable normally has a capacitance of about 750 $\mu\mu$f, to which the 0.8 $\mu\mu$f accuracy figure applies. If longer samples are used, making the capacitance greater than 1,000 $\mu\mu$f, the 0.1% accuracy can be maintained through the use of Type 1409 Standard Condensers. Type 505 Condensers are satisfactory for initial balancing. In the measurement of capacitance unbalance, capacitance differences of less than 800 $\mu\mu$f will be encountered, and the accuracy of ± 0.8 $\mu\mu$f can be improved to ± 0.2 $\mu\mu$f, if desired, by the use of worm correction data supplied with the Type 716-C Bridge on special order.

Twin-conductor cables can be measured using the three-measurement method.

The Type 1214-A Unit Oscillator (400 or 1,000 cycles), already required for the velocity-of-propagation measurements, is a very satisfactory generator for the bridge, and the Type 1212-A Unit Null Detector (also used in the other measurement), with the Type 1951-A Filter, is an excellent bridge detector. No other equipment is needed.

— W. R. Thurston

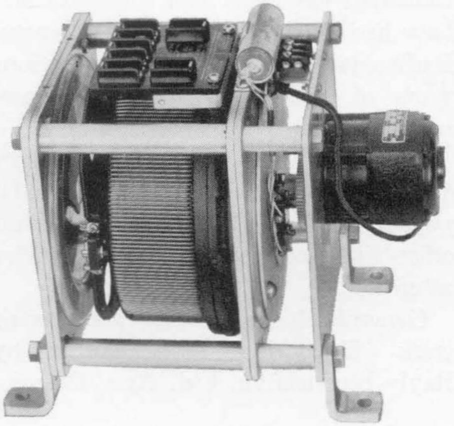
(To be concluded)

[17]Because the measurement of capacitance unbalance, a characteristic of shielded twin-conductor cables, is discussed in MIL-C-17B Specification, it will not be discussed in detail in this article.

The equipment for the measurements discussed in this article includes many items listed in previous installments. In addition, the following are needed:

Quantity	*Item*	*Price*
1	**Type 1214-A Unit Oscillator**	**$ 75.00**
2	**Type 874-Q2 Adaptor ... @ $ 4.25**	**8.50**
1	**Type 874-WM 50-ohm Termination**	**12.50**
1	**Type 874-VQ Voltmeter Detector**	**30.00**
1	**Type 1212-A Unit Null Detector**	**145.00**
1	**Type 1201-A Unit Power Supply**	**85.00**
2	**Type 1000-P5 V-H-F Transformer ... @ 27.50**	**55.00**

MOTOR DRIVE FOR V10, V20 VARIACS®



The popular V10 and V20 series of Variacs is now available in motor-driven models, as listed in the table below. These models do not have ball bearings and are supplied without cases.

Prices given in the table are per unit for a minimum quantity of 5 units. For less than 5 units, add the set-up charge.

Type numbers are made up as follows:

V10HG3 D 16 C K S

- V10HG3 — Variac Type No.
- D — Motor Drive
- 16 — Traverse Time
- C — Capacitor*
- K — Microswitches*
- S — **

* Capacitor and microswitches are supplied on all models.

**Add S to all type numbers for motor-driven V10 and V20 models.

Ounce-in. Torque	120	240	480	240	480	960	
Capacitor Included	Yes	Yes	Yes	Yes	Yes	Yes	
Microswitches Included	Yes	Yes	Yes	Yes	Yes	Yes	
Seconds for 320 Traverse	8	16	32	32	64	128	
Variac Type							*Set-Up Charge Prorated 1-4 Units*
V10	**$138.00**	**$138.00**	**$138.00**	**$138.00**	**$138.00**	**$138.00**	**$12.00**
V10G2	—	**184.00**	**184.00**	**184.00**	**184.00**	**184.00**	**12.00**
V10G3	—	**218.00**	**218.00**	**218.00**	**218.00**	**218.00**	**12.00**
V10H	**139.00**	**139.00**	**139.00**	**139.00**	**139.00**	**139.00**	**12.00**
V10HG2	—	**186.00**	**186.00**	**186.00**	**186.00**	**186.00**	**12.00**
V10HG3	—	**221.00**	**221.00**	**221.00**	**221.00**	**221.00**	**12.00**
V20	**162.00**	**162.00**	**162.00**	**162.00**	**162.00**	**162.00**	**12.00**
V20G2	—	**236.00**	**236.00**	**236.00**	**236.00**	**236.00**	**12.00**
V20G3	—	—	**292.00**	—	**292.00**	**292.00**	**12.00**
V20H	**162.00**	**162.00**	**162.00**	**162.00**	**162.00**	**162.00**	**12.00**
V20HG2	—	**236.00**	**236.00**	**236.00**	**236.00**	**236.00**	**12.00**
V20HG3	—	—	**292.00**	—	**292.00**	**292.00**	**12.00**

NEW CANADIAN OFFICE

Photo by William Notman

Arthur Kingsnorth

Photo by Ashley Crippen

Richard Provan

To provide the best service for our Canadian customers, a General Radio factory branch office for Canada was opened August 1.

The new office is located at 99 Floral Parkway, Toronto 15, Ontario, just south of Route 401 at the Keele Street turnoff. We cordially invite you to visit us there. There will be a substantial stock of instruments available, which we hope that many *Experimenter* readers will take the opportunity to inspect.

This extension of our domestic direct-sales policy has terminated a long and cordial association with the Canadian Marconi Company, our representatives for many years.

The new office is in charge of Arthur Kingsnorth, ably assisted by Richard J. Provan. Both are well known to Canadian engineers and scientists and have had much experience with General Radio equipment through their previous years of association with our representatives.

The telephone number is CHerry 4-6221. If you are a resident of Canada, your phone call or letter directly to that office will receive prompt and effective attention.

General Radio service and repair work will continue to be handled by Bayly Engineering, Ltd., Ajax, Ontario.

STORAGE BOX FOR TYPE 1021-P OSCILLATOR UNITS

The versatile Type 1021 Standard Signal Generators cover a frequency range from 40 Mc to 2000 Mc by means of three oscillator units and a common power supply cabinet.

Since the safe storage of oscillator units not in use has frequently been a problem, we are making available the Type 1021-P10 Storage Box, which will hold one oscillator unit. This box is made of treated, moisture-resistant white wood and is virtually dust tight.

Type		*Code Word*	*Price*
1021-P10	**Storage Box**	BOXEY	**$18.00**

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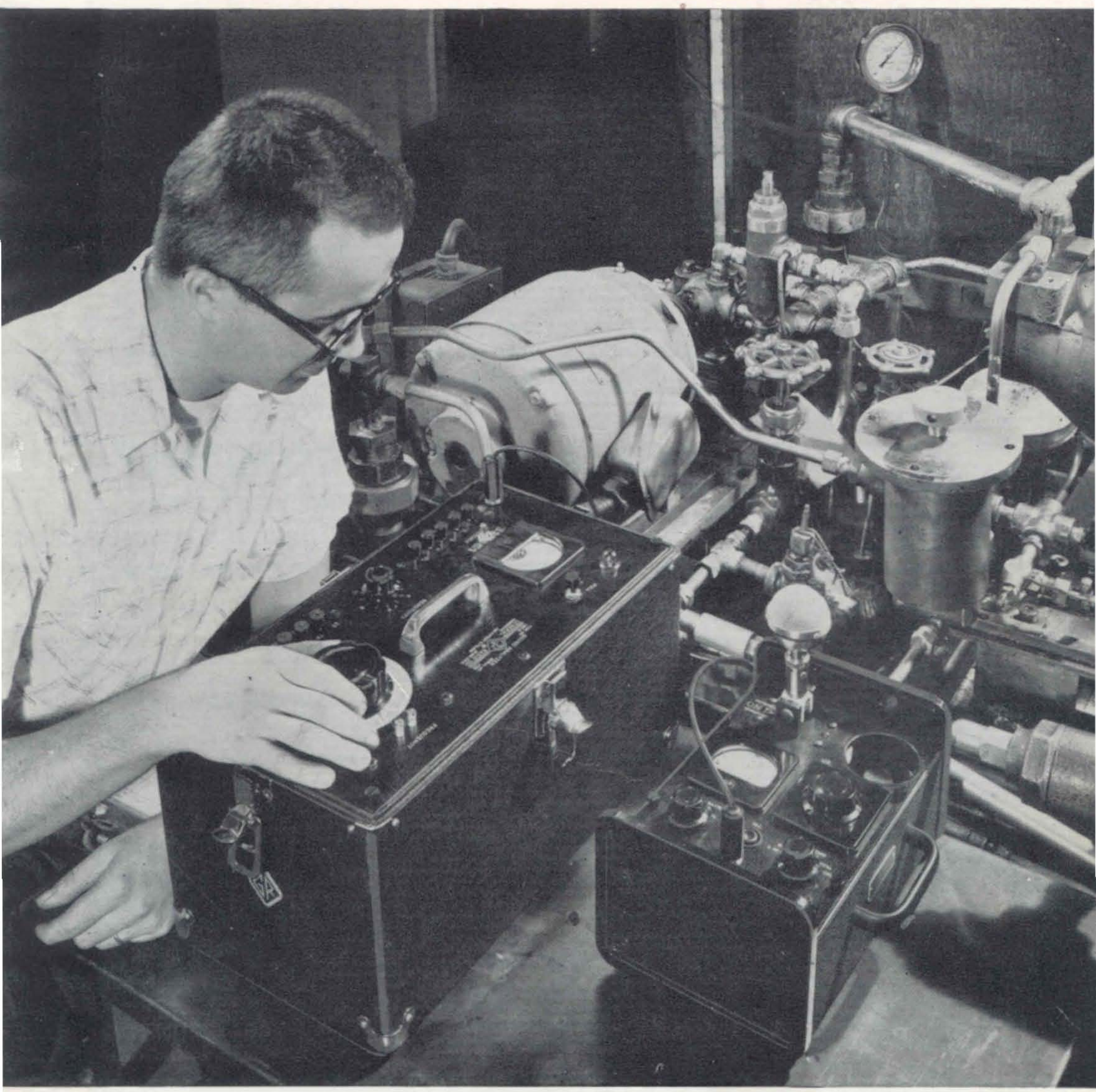

Photo Courtesy The Oilgear Company

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- Representative for Germany
- UL-Approved Variacs®

the GENERAL RADIO Experimenter

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275 Massachusetts Avenue, Cambridge 39, Mass.

Telephone: TRowbridge 6-4400

NEW YORK: **Broad Avenue at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: **6605 West North Avenue, Oak Park, Illinois**
Telephone — VIllage 8-9400

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COVER

At the Oilgear laboratories in Milwaukee, measurements on fluid-power pumps with the General Radio Sound-Level Meter and Sound Analyzer provide valuable information for setting performance standards, designing better products, and correcting faulty performance.

THE PHASE ANGLE OF POTENTIOMETERS USED AS RHEOSTATS

The phase angle of a variable resistor is nearly always a problem in precision a-c circuitry. It is now becoming increasingly important owing to the widespread use of this type of component in computing and control systems. Investigations of the voltage phase shift in potentiometers used as voltage dividers have been reported in the literature.[1,2] This article is primarily concerned with "pots" used as rheostats, and, therefore, the phase angle is that of an impedance.

We are interested here only in the small phase angle by which a rheostat differs from a pure resistance. This variation from the ideal, caused by inductance and stray capacitance, is often appreciable at audio frequencies. We are not concerned here with the large phase angles that occur at higher frequencies.

The precise measurement of the phase angle of a resistor at audio frequencies has hitherto been difficult,[3] largely because most audio-frequency bridges use rheostats whose phase angles may be comparable to those which are to be measured. The new General Radio Type 1605-A Impedance Comparator[4] makes possible precise yet rapid measurements by comparison with small fixed resistors of negligible phase angle. The desire to explain data taken with this instrument has led to the analyses and calculations which follow.

[1] M. H. Hayes and J. L. West, "Potentiometer Characteristics," *Tele-Tech and Electronic Industries*, February, 1955.

[2] "A-C Performance and Phase Compensation of Copper Mandrel Potentiometers," *Helipot Technical Paper*, 4.97.

[3] G. H. Raynor and L. H. Ford, "The A-C Properties of Resistors and Potential Dividers at Power and Audio Frequencies, and their Measurement," *Journal of Scientific Instruments*, 3, 4, 5, May, 1955.

[4] M. C. Holtje and H. P. Hall, "A High-Precision Impedance Comparator," *General Radio Experimenter*, 30, 11, April, 1956.

PHASE ANGLE CALCULATIONS ON RHEOSTATS

Fixed Resistors: Let us consider first the phase angle of a fixed resistor. The familiar equivalent circuit of Figure 2 is valid in all resistors if we consider only small phase angles.

The Q of this circuit is:

$$Q = \omega(L/R - RC) - (\omega^3 L^2 C/R) \quad (1)$$

We will limit ourselves to values of Q less than 0.1, so that we can set:

$$Q = X/R \cong \theta = tan^{-1}(X/R) \quad (2)$$

where θ is in radians (since tan (.1) = .1003, which is close enough for our calculations). To show that the ω^3 term is negligible, we can express $\omega^3 L^2 C/R$ as $(\omega L/R)^2 (\omega RC)$. If ωRC and $\omega L/R$ are each less than 0.1, the cubed term is less than 1/100 of the first-order terms

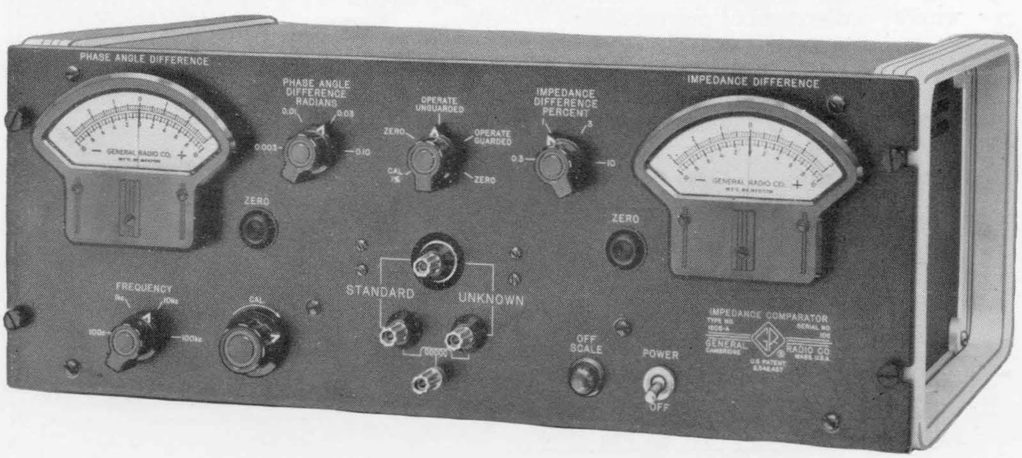


Figure 1. Panel view of the Type 1605-A Impedance Comparator, used for the measurements described in this article.

and is thus negligible. This would indicate that the effects of inductance can be added to those of capacitance, since the terms resulting from the interaction between the two are negligible for small phase angles. Therefore, we can use the simple expression

$$\theta = Q = \omega[L/R - RC] \qquad (3)$$

for our calculations. Note from this expression that:

(a) Q is proportional to ω, and therefore the frequency of measurement is unimportant, except that it must be chosen to give Q values that are measurable but less than 0.1.

(b) Low-valued resistors are inductive, and high-valued resistors are capacitive. The transition for wire-wound resistors occurs usually between 2000 and 20,000 ohms.

(c) For values of R where both terms are important, it is impossible to measure L and C separately.

Rheostat with Inductance Only

Figure 3 shows a measured curve of Q vs rotation for a 1000-ohm pot (Type 973K). This plot shows that, for most of the range of rotation, Q is constant. This means that the inductance is increasing linearly with rotation. If Q is assumed constant, the equivalent circuit is that of Figure 4, and the expression for Q is:

$$Q = \omega(\alpha L/\alpha R) = \omega L/R \qquad (4)$$

where α = normalized rotation
R = total resistance
L = total inductance

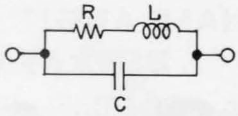


Figure 2.

Figure 4.

Although, in our calculations, the variation in Q is neglected when α is small, this effect should not be overlooked if the phase angle must be accurately known for small angles of rotation. This variation is caused by mutual inductance between the turns of the winding. If the coupling were perfect, the inductance would be proportional to n^2 and α^2, and Q would be proportional to α. However, the coupling extends over only a few neighboring turns, so that, as more and more turns are used, the variation approaches that of the uncoupled case where the inductance increases linearly with n and α.

Rheostat with Lumped Capacitance

If we assume that the stray capacitance is lumped across the terminals as shown in Figure 5, the circuit may be drawn, for convenience in analysis, as shown in Figure 6. The Q for this circuit is:

$$Q = -\omega\alpha R(C_1 + C_2) + \omega^3\alpha(1-\alpha)R^3C_2^2(\alpha C_1 + C_2) + \ldots \qquad (5)$$

The ω^3 term can be shown to be negligible if the first term is less than 0.1. Therefore, we can use the simple equivalent circuit of Figure 7 and the expression

$$Q = -\alpha\,\omega RC \qquad (6)$$

where $C = C_1 + C_2$, which is a straight line from the origin. When the inductance effect is added to this capacitance effect, the equation becomes

$$Q = \omega(L/R - \alpha RC) \qquad (7)$$

The second curve of Figure 3 shows the inductive pot with added lumped capacitance to illustrate equation (7).

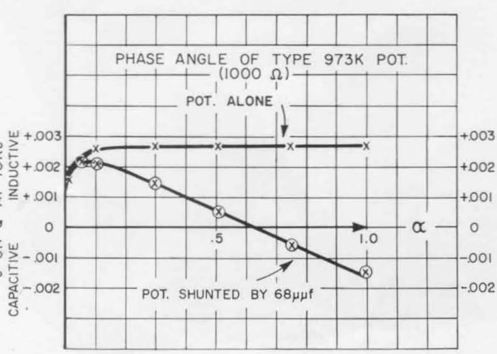


Figure 3.

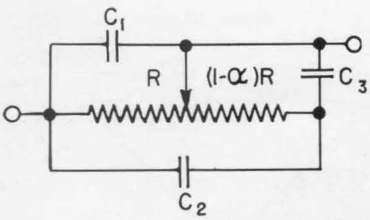


Figure 5.

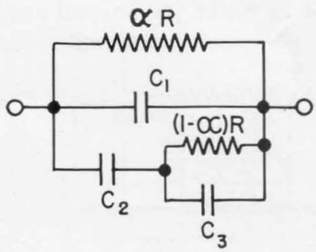


Figure 6.

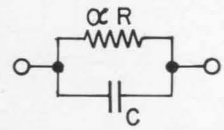


Figure 7.

Equivalent Circuits for Distributed Capacitance

For many rheostats the assumption that the stray capacitance is lumped across the unit is an oversimplification. Better results are obtained if it is also assumed that there is capacitance distributed along the winding to a conductor, which may be the housing, a supporting panel, a metal mandrel, or a shield. The total phase angle can then be calculated as the sum of these fixed and distributed capacitance effects. Because we are concerned with first-order effects only, we can use lumped-parameter equivalent circuits for the distributed circuit of Figure 8. The circuits of Figures 9 and 10 give the same results as the first-order terms of the hyperbolic functions of the well-known transmission-line equations. The circuit of Figure 9 is the more descriptive and uses an interesting division of the capacitance. The second circuit, Figure 10, is simpler to use, however, since it has fewer branches. The effective inductance of this circuit is the result of the capacitance.

An equivalent circuit for a rheostat is given in Figure 11. Here the resistance of the unused part of the winding, $(1-\alpha)R$, is assumed negligible compared to the impedance of the stray capacitance, and the actual inductance of the winding, αL, has been added.

Formulas for Distributed Capacitance Effects

The shape of the Q vs α curve for distributed capacitance effects depends on how the conductor is connected. The conductor could be tied to the rotor, tied to the end of the winding, left floating, or tied to a third terminal. These cases can all be quickly calculated by use of the circuit of Figure 11 and the simple expression of equation (3) above.

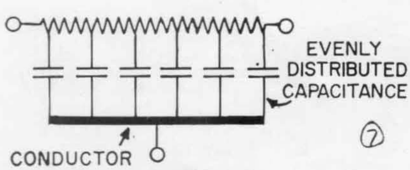


Figure 8.

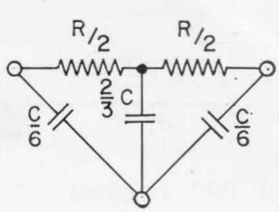


Figure 9.

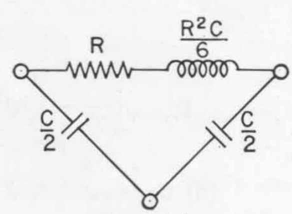
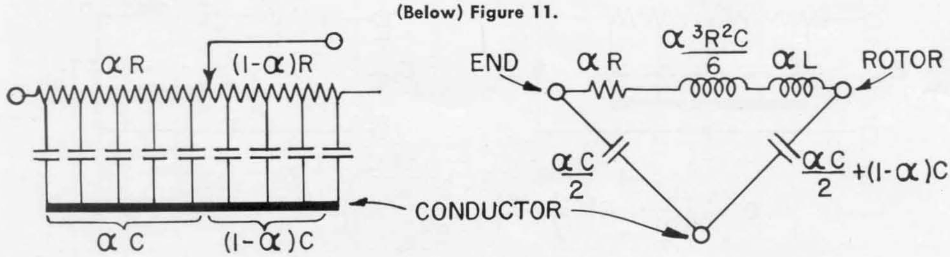


Figure 10.

(Below) Figure 11.



(a) Conductor tied to Rotor (or unused end)

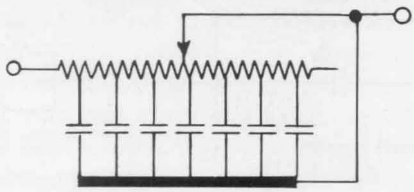
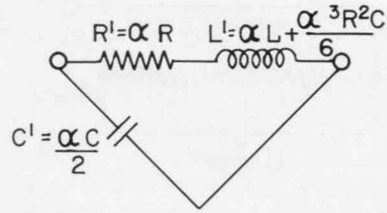


Figure 12.



$$Q = \omega\left(\frac{L'}{R'} - R'C'\right) = \omega\left(\frac{\alpha L + \frac{\alpha^3R^2C}{6}}{\alpha R} - \frac{\alpha R \alpha C}{2}\right) = \omega\left(\frac{L}{R} - \frac{\alpha^2 RC}{3}\right)$$

(b) Conductor tied to End

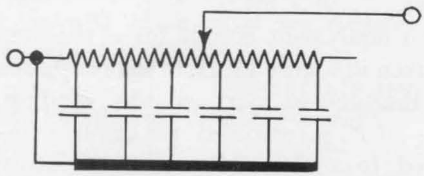
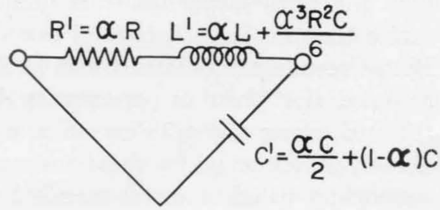


Figure 13.



$$Q = \omega\left(\frac{L'}{R'} - R'C'\right) = \omega\left(\frac{\alpha L + \frac{\alpha^3R^2C}{6}}{\alpha R} - \alpha R\left[\frac{\alpha C}{2} + (1-\alpha)C\right]\right) = \omega\left(\frac{L}{R} - RC\left[\alpha - \frac{2}{3}\alpha^2\right]\right)$$

(c) Conductor Floating

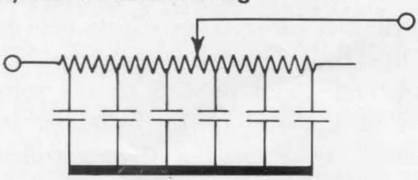
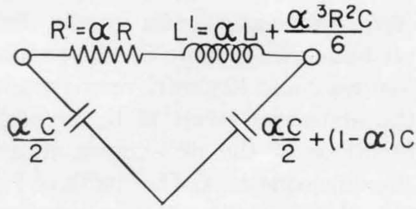


Figure 14.



$$C' = \frac{\frac{\alpha C}{2}\left[\frac{\alpha C}{2} + (1-\alpha)C\right]}{\frac{\alpha C}{2} + \frac{\alpha C}{2} + (1-\alpha)C} = \frac{\alpha C}{2} - \frac{\alpha^2 C}{4}$$

$$Q = \omega\left(\frac{L'}{R'} - R'C'\right) = \omega\left(\frac{\alpha L + \frac{\alpha^3R^2C}{6}}{\alpha R} - \alpha R\left[\frac{\alpha C}{2} - \frac{\alpha^2 C}{4}\right]\right) = \omega\left(\frac{L}{R} - RC\left[\frac{\alpha^2}{3} - \frac{\alpha^3}{4}\right]\right)$$

(d) Conductor tied to a Third Terminal

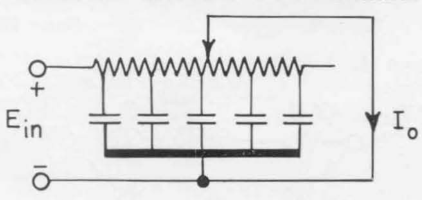
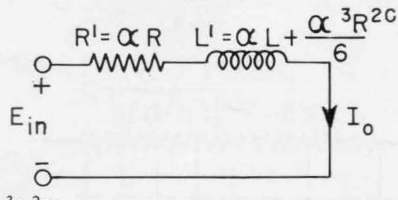


Figure 15.



$$Q = \omega\left(\frac{L'}{R'} - R'C'\right) = \omega\left(\frac{\alpha L + \frac{\alpha^3R^2C}{6}}{\alpha R}\right) = \omega\left(\frac{L}{R} + \frac{\alpha^2 RC}{6}\right)$$

In (d) the Q given is that of the direct impedance, E_{in}/I_o. Note that the capacitive arms of the network of Figure 11 have no effect.

Normalized plots of these functions are given in Figure 16 with the inductance assumed to be zero. Inductance would simply displace the curves upward by $\omega L/R$.

EXPERIMENTAL CHECKS OF CALCULATED CURVES

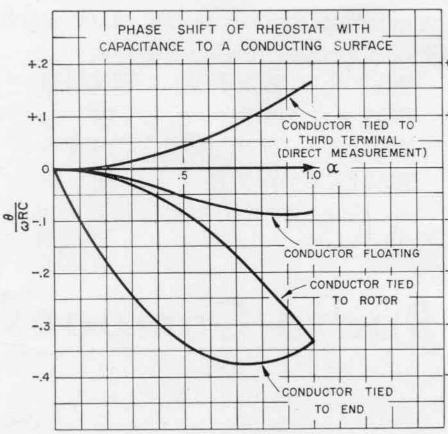
In order to check these equations, measurements were made on pots that had relatively large distributed capacitance to a conductor, so that the other stray capacitances would be negligible.

Figure 17 shows curves for a pot with a metal shield wrapped around the winding. Note that if the curves are displaced by $\omega L/R$, they are similar to the calculated curves. The small difference could be caused by other capacitances or irregularities in the distributed capacitance.

A good example of the floating conductor case is given in Figure 18, which shows the plot of a ten-turn pot. This unit has a metal mandrel which is left floating. The curve is calculated (the full-scale measurement is used to calculate C) and the measured points are shown.

— H. P. Hall

Figure 16.



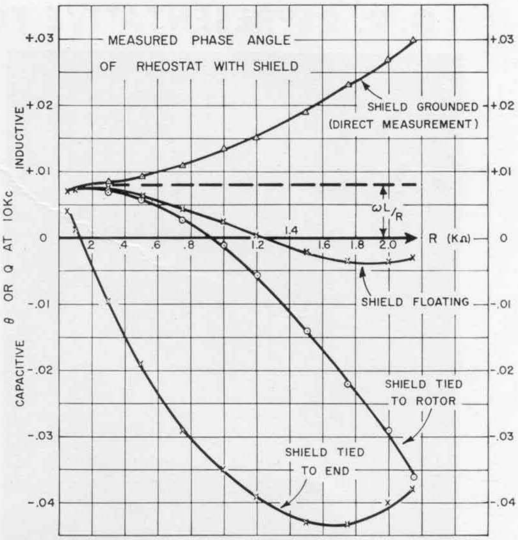
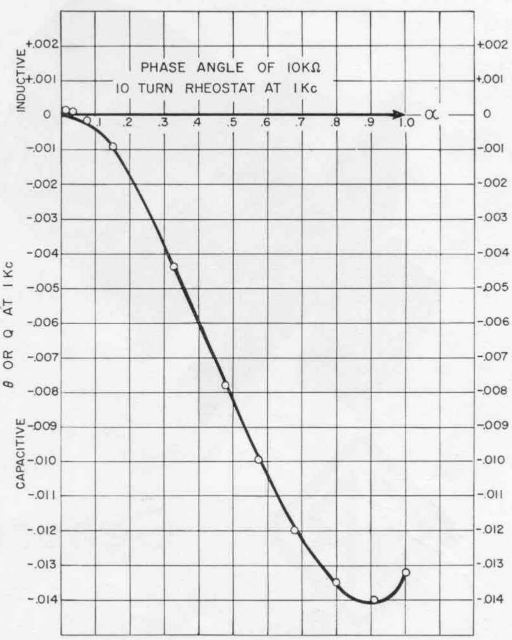


Figure 17.

Results of measurements on a number of standard types of potentiometers will be published in a subsequent issue.

Figure 18.



G. R. REPRESENTATIVE FOR GERMANY APPOINTED

We take pleasure in announcing the appointment of Dr.-Ing. Günter Nüsslein of Ettlingen/Karlsruhe as General Radio representative for Germany.

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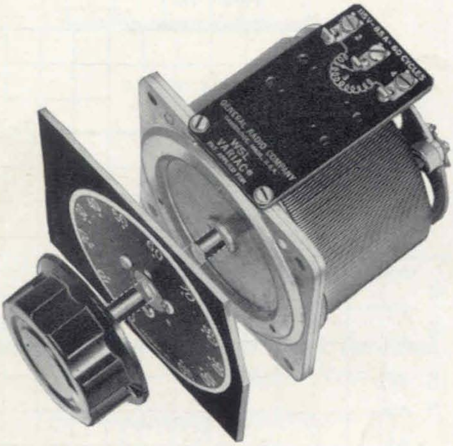
Dr.-Ing. Nüsslein is a well-known figure in electronic engineering circles. He received the Diploma Engineer degree in radio engineering and the degree of Doctor of Engineering from the Technical University of Berlin. Since his graduation, he has been associated with prominent research and manufacturing institutions in Germany and for some years was a consulting engineer in private practice. He is the author of many technical articles on electronic matters and has numerous patents and patent applications in the electronics field to his credit.

This appointment was effective July 1, 1957.



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We have received word from the Underwriters Laboratories that three additional Variacs are now listed under their Re-examination Service. This brings the number of UL-approved Variacs in the current models to 12. A complete list of approved models follows:

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W5L	W50	V10
W5M	W50M	V10M
W5MT	W50H	V20

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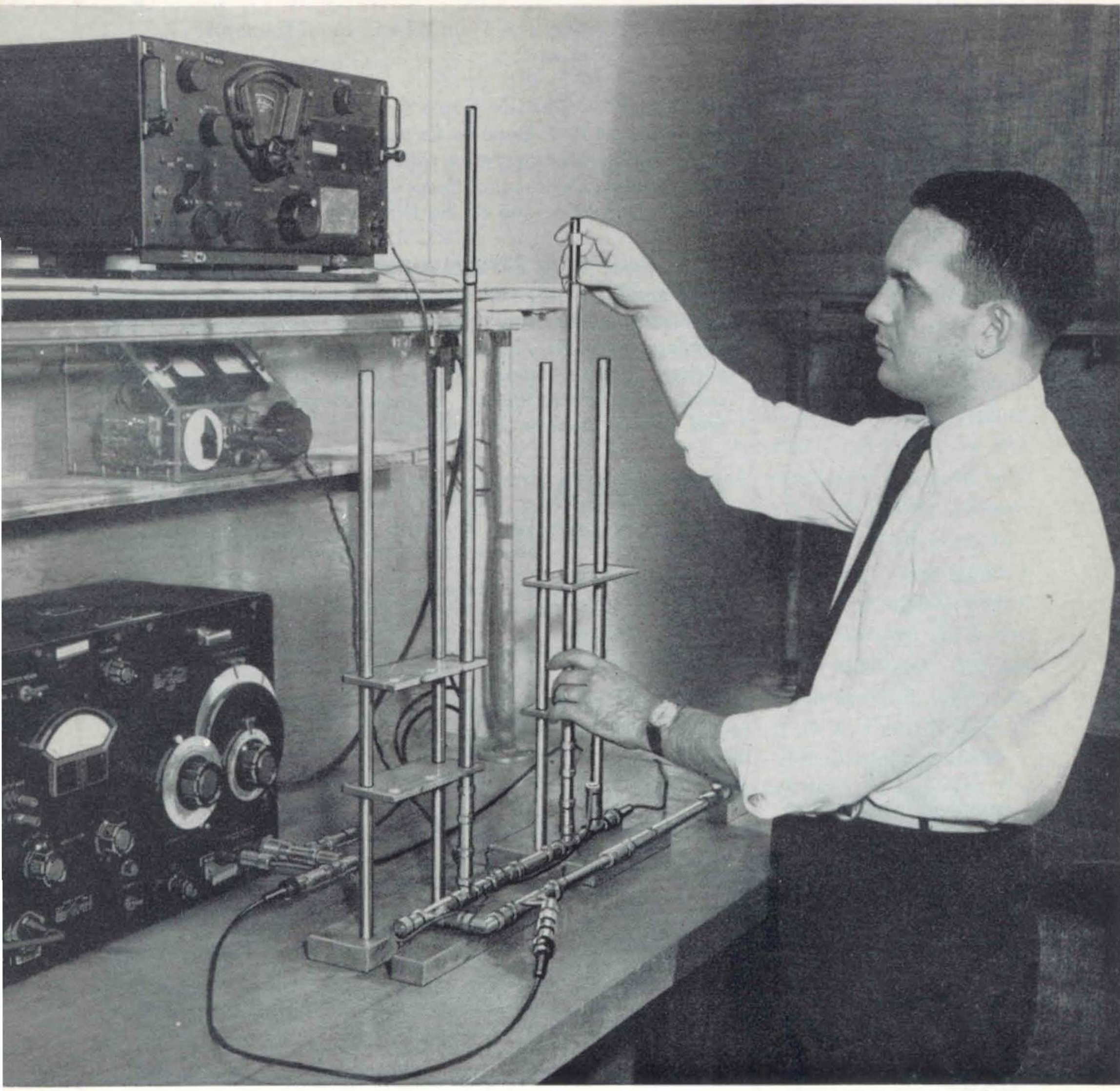

Photo Courtesy Philco Corporation

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More New Capacitors
Reducing Transformer Noise

the GENERAL RADIO **Experimenter**

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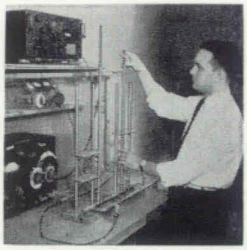


Mario Fortini of Philco Research Division measures transistor performance with Type 874 coaxial-line equipment.

TRANSISTOR TESTING WITH TYPE 874 COAXIAL ELEMENTS

The excellent electrical properties and ease of interconnection of General Radio Coaxial Elements have led to their use in many specialized testing systems at very-high and ultra-high frequencies. An interesting example is their use by engineers of the Philco Corporation in the evaluation of the high-frequency capabilities of SBDT-12 graded-base transistors.* With this coaxial-line equipment, the transistors have oscillated at frequencies as high as 1100 Mc, as contrasted with an upper-frequency limit of 700 Mc in circuits using conventional lumped-constant elements. Excellent agreement has been obtained between measured results with the coaxial circuits and predictions of transistor performance based on conventional measurements at frequencies below 300 Mc.

The Type 874 Coaxial Elements have been used in the measurement of both gain and impedance, and in the determination of oscillation capability. Standard elements were used for the most part, although a few were modified for specific purposes. These modifications are detailed later in this article.

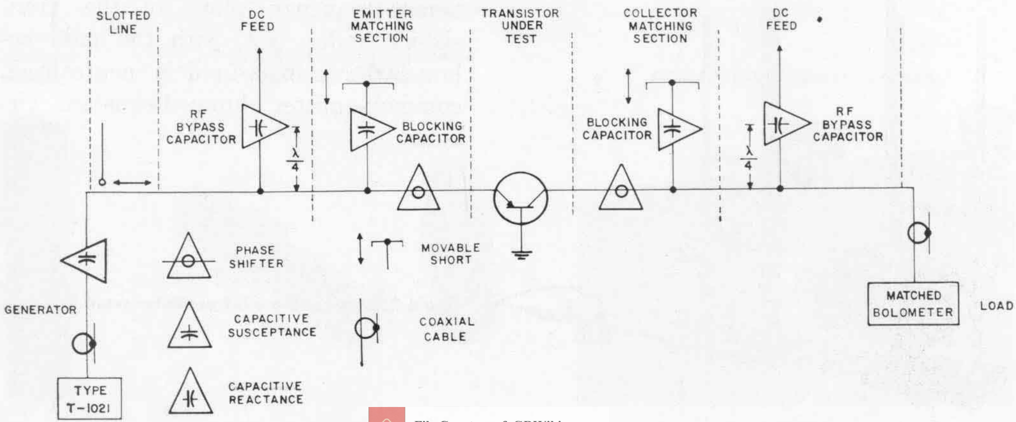
*This work was performed in the Philco Research Division, in a transistor applications group under the direction of James B. Angell, by Donald A. Zettel, a student of the cooperative program at the University of Detroit, working under the guidance of Mario M. Fortini. The work was supported in part by the Signal Corps under contract No. DA-36-039 SC-46640.

U-H-F AMPLIFICATION

The technique for measuring the unneutralized gain of a graded-base transistor in a common-base connection is shown in Figure 1. The coaxial-line equipment consists of a transistor mount, input and output matching sections, and d-c supply paths for powering the transistor. Each matching section consists of an adjustable-length line and an adjustable shunt stub. Type 874-K Coupling Capacitors in the stubs prevent the stubs from short-circuiting the bias currents to ground. D-C power is applied by means of a feed-through capacitor, which serves as the short-circuiting end of a quarter-wave stub.

Gain is measured with a bolometer and power meter after the input and output circuits to the transistor are matched to the characteristic impedance of the line. Because the transistor has a certain amount of internal feedback, caused chiefly by the collector capacitance and base spreading resistance, precautions are necessary to insure the simultaneous matching of input and output. First the input is matched by means of the input adjustable line and stub with the output terminated in a Type 874-WM 50-Ohm Termination. A signal generator and slotted line are used to indicate the

Figure 1. Functional diagram of the u-h-f amplifier.



matched condition at the frequency of interest. A 50-ohm termination is then connected to the input, and the output circuit is matched, again using the signal generator and slotted line to determine the match. This process is repeated on both input and output until a match is simultaneously achieved at each end of the amplifier section when the other end is terminated in 50 ohms. The gain is measured by first noting the power into a 50-ohm bolometer from a matched generator, and then noting the power output with the matched amplifier inserted between the generator and bolometer.

U-H-F OSCILLATION

Figure 2 is a photograph of the oscillator arrangement in which the Type 874 Coaxial-Line Elements are used. A diagram of the equipment in this setup is shown in Figure 3. The oscillator is in essence a tuned amplifier, as described above, in which the output is connected back to the input through an adjustable line. A Type 874-LK10 Adjustable Line is used to adjust the phase of the feedback. A high-pass filter section in the feedback path is necessary to prevent oscillation at some lower frequency.

In practice, the oscillator is adjusted as follows. First the input and output are tuned to some particular frequency, as described in the above section for the amplifier. If a gain greater than unity is observed at this frequency, the feedback path is closed from output to input. The presence of oscillation is detected by a change in the transistor collector current as the phase in the feedback path is adjusted. The frequency of oscillation is measured with a super-heterodyne receiver coupled loosely into a Type 874-LR Radiating Line in the feedback path.

In order to determine the maximum frequency of oscillation, the above procedure is repeated at progressively higher frequencies. Normally the process converges very rapidly, since the amplifier gain varies at a rate very close to —6db per octave of frequency in the range of interest.

Oscillation frequencies in excess of 1100 Mc have been obtained on developmental graded-base transistors of the SBDT-12 variety. In general, between 200 and 400 Mc can be added to the maximum frequency of oscillation when the coaxial-line techniques are employed in preference to pseudo-lumped-constant circuits. The maximum frequencies of oscillation determined with the coaxial-line equipment have agreed very closely with extrapolations of gain-versus-frequency plots of the transistors under test, with the gain below 300 Mc measured in neutralized, common-emitter, lumped-constant circuits.

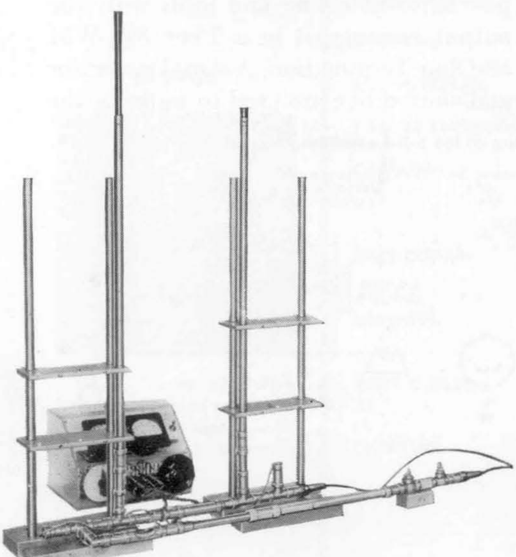


Figure 2. View of the u-h-f oscillator setup.

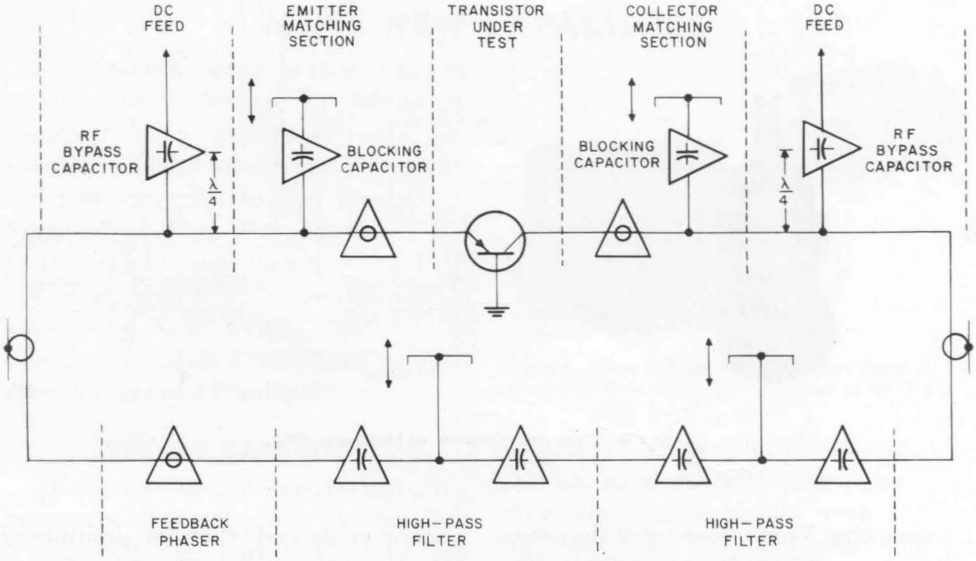


Figure 3. Functional diagram of the u-h-f oscillator.

SPECIAL COMPONENTS FOR U-H-F TESTS

Four special components were required in the above tests. All of these components were readily fabricated from various components of the Type 874 line of coaxial equipment.

The *Transistor Mount* is shown in Figure 4. It was assembled from a modified Type 874-WN3 Short-Circuit Termination and a Type 874-B Basic Connector. A shield at the middle of the mount isolates the input from the output circuit. The base lead of the transistor is grounded to this shield. The transistor can is grounded to the outer conductor of the mount. The emitter and collector leads are tied to the center conductors of the input and output connectors respectively.

Line Stretchers were required for both the input and output circuits. It is necessary that these lines be of the shortest length possible for the desired impedance transformation, in order to minimize the possibility of spurious low-frequency modes of operation. The input line stretcher is fortunately achieved, in the thousand-megacycle range, by a partial disengaging of the connectors between the transistor mount and the input matching stub. The output line stretcher

Figure 4. Transistor mount.

Figure 5. Modified adjustable line (Line Stretcher).

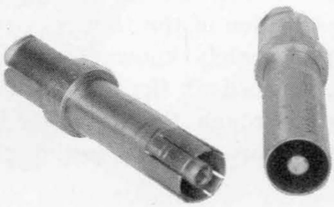
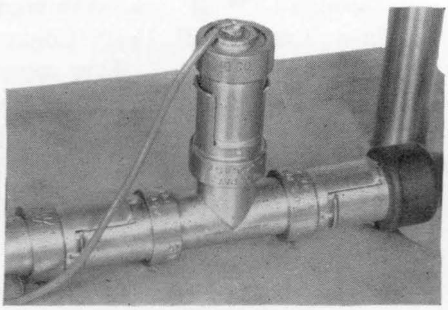


Figure 7. D-C supply termination.



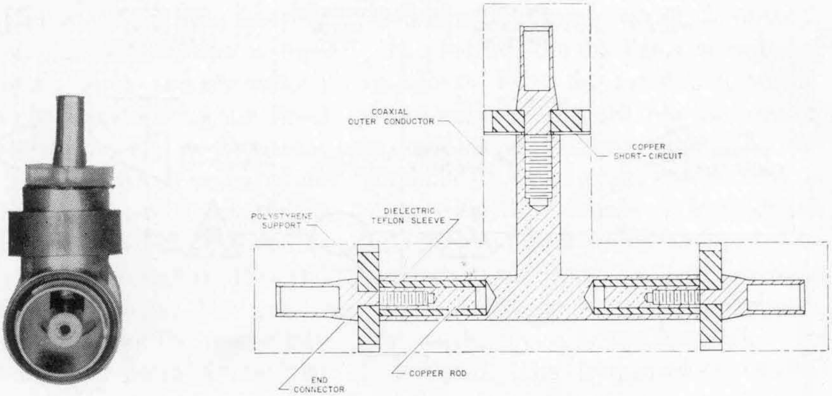


Figure 6. View and diagram of high-pass filter.

is somewhat longer, because of the necessity of matching a higher VSWR. The 5-centimeter line stretcher, which is a shortened form of the standard Type 874-LA Adjustable Line, is shown in Figure 5.

High-Pass Filters for the feedback path were formed out of Type 874-T Tee Connectors. Each of the filters includes a series coupling capacitor in both the input and output center conductors, together with a shunt stub, whose length is adjusted to resonate with the series capacitors at a frequency somewhat below the intended frequency of oscillation. The series capacitors were formed by use of a thin sleeve of Teflon, as shown in Figure 6; the area of this coaxial capacitor was adjusted to produce a capacitance of 5 $\mu\mu$f, which gave the desired impedance level at the cutoff frequency.

The *d-c feed element* consists of a feedthrough 1500-$\mu\mu$f, disk-ceramic capacitor in a Type 874-B Basic Connector, as shown in Figure 7. This mount provides a short circuit to high-frequency current at the position of the capacitor. A quarter-wave stub is formed from an appropriate length of line with the capacitor at its end; thus the addition of the d-c power does not affect the a-c configuration. In order that the d-c power be kept from the signal generator and the bolometer when amplification is measured, Type 874-K Coupling Capacitors are used in the input and output circuits. For the oscillator, only one blocking capacitor is required in the feedback path in order to keep the collector supply isolated from the emitter supply; the capacitors in the filters normally provide this isolation.

ADMITTANCE MEASUREMENTS

The Type 874 Coaxial-Line Equipment has also been used for the determination of short-circuit input and output admittances of transistors in the u-h-f range. The impedance measurement at the terminal of interest is made through the use of the slotted line and a transmission-line chart, by measurement of the VSWR, referring back to the position of the transistor terminal. An accurately known short circuit is established at the other transistor terminal through the use of a half-wavelength short-circuited section of coaxial line.

MORE NEW CAPACITORS

In a recent[1] issue of the EXPERIMENTER, new designs for laboratory standard mica capacitors were announced. These design improvements are now extended to the less-precise, lower-priced TYPE 505 Capacitors and to the decade capacitors in which TYPE 505 Units are used. In the decade capacitors a new switch, and in the decade assemblies a redesigned cabinet, offer additional advantages.

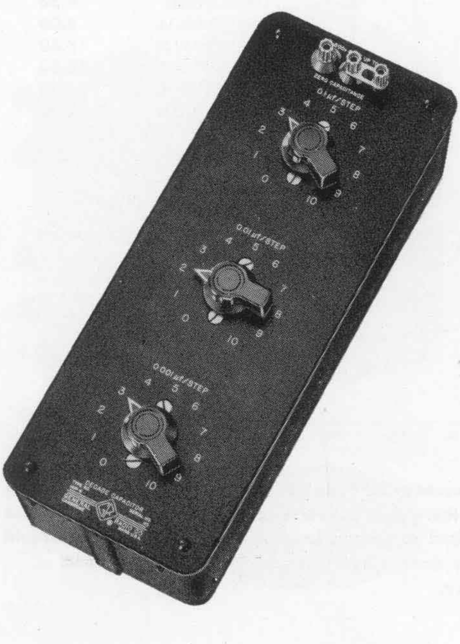
Figure 1. View of Type 505 Capacitors showing the two case sizes and the arrangement of terminals.

TYPE 505 CAPACITORS

The silvered-mica electrodes and other improvements embodied in the new TYPE 1409 Standard Capacitors[1] are now available in the TYPE 505 Capacitors, and these units are now manufactured to new and considerably improved specifications of tolerance and dissipation factor. The capacitors are housed in low-loss molded-phenolic cases and are equipped with both screw- and plug-type terminals and with flanges for mounting. They are used both as laboratory "secondary standards" and as circuit elements in measuring equipment as, for example, in a number of General Radio bridges in the 1-percent-accuracy class.

[1]Easton and McElroy, "New, Silvered Mica, Standard Capacitors, TYPE 1409," *General Radio Experimenter*, 32, 2, July, 1957.

Figure 2. Panel view of the Type 1419-K Decade Capacitor.



Dissipation factor of these units, in the 1000-μμf and higher sizes, does not exceed .0003. The losses in the phenolic case increase the dissipation factor slightly for units of 500 μμf and smaller. Leakage resistance is 5000 megohm-microfarads or 100,000 megohms, whichever is the lower. The first figure represents the performance of the mica, while the second represents the phenolic case and is controlling below 0.05 μf.

The same high-quality silvered-mica sheets are used in the construction of the TYPE 505 Capacitors as are used in the TYPE 1409 Standard Capacitors. Accuracy of adjustment is ± 0.5%, in contrast to the 0.1% adjustment of the TYPE 1409. The lower accuracy and the less-expensive packaging result in a unit that sells at a price substantially lower than that of the 1409[1], but whose characteristics and stability are entirely adequate for many laboratory, production-line, and instrument applications.

SPECIFICATIONS

Accuracy: ±0.5% or ±3μμf, whichever is the larger.

Temperature Coefficient: Approximately +0.0035% per degree Centigrade between 10° and 50° Centigrade. Calibration is made at 23° C., at a frequency of 1 kc.

Dissipation Factor: 0.0003 for 1000 μμf and higher; 500 μμf, 0.00035; 200 μμf, 0.0004; 100 μμf, 0.0006.

Frequency Characteristics: See plots below. Series inductance is approximately 0.055 μh for units in small case and 0.085 μh for large case. Series resistance at 1 Mc is approximately 0.03 ohm for small case and 0.05 ohm for large case, varying as square root of frequency above 100 kc.

Leakage Resistance: Greater than 100,000 megohms, when measured at 500 volts, except for the TYPES 505-T, 505-U, and 505-X, for which it is greater than 50,000, 25,000, and 10,000 megohms, respectively.

Maximum Voltage: See table. At higher frequencies the allowable voltage decreases and is inversely proportional approximately to the frequency. These limits correspond to a temperature rise of 40° Centigrade for a power dissipation of 1 watt for the small case and 2.5 watts for the large case.

Terminals: Screw terminals spaced ¾ inch apart. Two TYPE 274-P Plugs are supplied with each capacitor. High terminal (inside foil) is marked H.

Mounting: Mica-filled, low-loss phenolic cases.

Dimensions: See sketch. Over-all height, 1⅝ inches for large case, 1 inch for small case, exclusive of plugs.

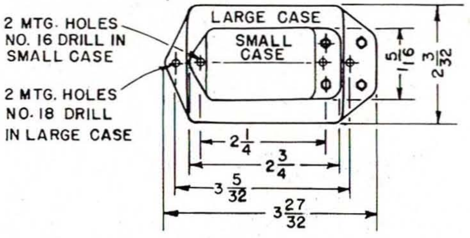


Figure 3. Dimension sketch of Type 505 Capacitors.

Type	*Capacitance*	*Maximum Peak Volts*	*Frequency Limit for Max. Volts*	*Weight in Ounces*	*Code Word*	*Price*
505–A	**100** μμf	700	12Mc	4	CONDENALLY	**$ 8.00**
505–B	**200** μμf	700	7	4	CONDENBELL	**6.50**
505–E	**500** μμf	500	3.5	4	CONDENCOAT	**6.00**
505–F	**0.001** μf	500	2	4	CONDENDRAM	**6.00**
505–G	**0.002** μf	500	1.1	5	CONDENEYRE	**6.50**
505–K	**0.005** μf	500	500kc	5	CONDENFACT	**6.50**
505–L	**0.01** μf	500	320	5	CONDENGIRL	**8.50**
505–M	**0.02** μf	500	200	6	CONDENHEAD	**9.00**
***505–R**	**0.05** μf	500	100	11	CONDENCALM	**13.50**
***505–T**	**0.1** μf	500	50	12	CONDENCROW	**16.50**
***505–U**	**0.2** μf	500	25	13	CONDENWIPE	**24.00**
***505–X**	**0.5** μf	500	10	15	CONDENWILT	**52.50**

*Mounted in large case.

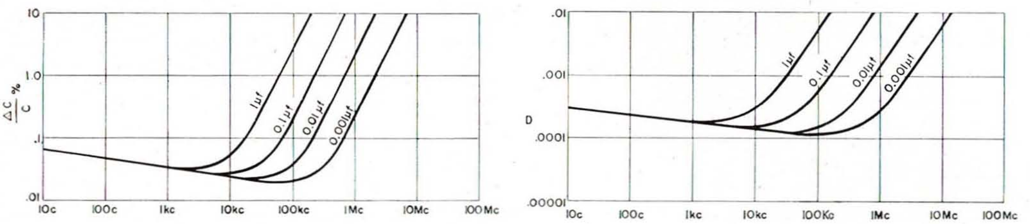


Figure 4. *(Left)* Change in capacitance as a function of frequency for Type 505 Capacitors. These changes are referred to the values which the capacitors would have if there were neither interfacial polarization nor series inductance. Since the capacitors are adjusted to their nominal values at 1 kc, the 1-kc value on the plot should be used as a basis of reference in estimating frequency errors. *(Right)* Dissipation factor as a function of frequency.

THE TYPE 980 SWITCH

By the use of an appropriate switch, four individual capacitor units can be paralleled in various combinations to provide a decade sequence from 1 to 10. The new TYPE 980-P1[2] Switch, replacing the former TYPE 380-P3, is designed for this purpose. The switching sequence is designed for the use of a 1-2-2-5 series of capacitance values. This combination was selected from the several available ones to utilize for the decades the same nominal capacitance values that are stocked as individual units. The operating principle of the switch is the same as that of its predecessor, employing sequential paralleling action by means of leaf springs, which contact the common rotor by the action of shaped cams. The outstanding characteristics of this new switch are the low capacitance, extremely low dielectric losses, and very high leakage resistance, all obtained by the use of cross-linked (thermosetting) polystyrene in the supporting structure and shaft.

[2]Actually in use for several years, but not hitherto announced in the *Experimenter*.

Type		*Code Word*	*Price*
980-P1	**Switch**	SWITCHBIRD	**$11.00**

THE TYPE 980 DECADE CAPACITANCE UNITS

The new switch and the improved TYPE 505 Capacitors are combined to make the new TYPE 980 Decade Capacitors. The low losses of these "decades" make them suitable for use in a-c bridges, resonant circuits, and filters.

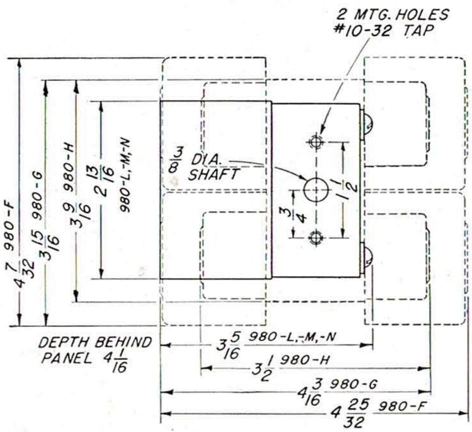
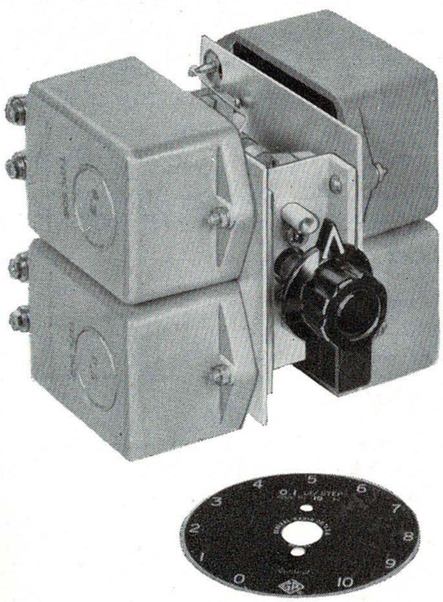


Figure 6. Dimension of Types 980-F, -G, and -H Decade Capacitor Units.

Figure 5. View of the Type 980-F Decade Capacitance Unit.



In a resonant circuit, for instance, the Q of 3000 is sufficiently high relative to losses in practical inductors that the capacitor loss can usually be ignored. The high leakage resistance makes them useful in many d-c circuits. Two new decades are now available, the TYPE 980-G and TYPE 980-H, with capacitance steps of 0.01 μf and 0.001 μf, respectively, in addition to the older TYPE 980-F, which has 0.1-μf steps.

SPECIFICATIONS

Electrical specifications are the same as those for Type 505 Capacitors.

Dimensions: See sketch.

Net Weight: Type 980-F, 3 pounds, 12 ounces; Type 980-G, 2 pounds; Type 980-H, 1 pound, 10 ounces.

Type		*Code Word*	*Price*
980-F	**1.0 μf in 0.1 μf steps**	ACUTE	**$128.00**
980-G	**0.1 μf in 0.01 μf steps**	AVOWD	**60.00**
980-H	**0.01 μf in 0.001 μf steps**	AWAIT	**45.00**

TYPE 1419-K DECADE CAPACITOR

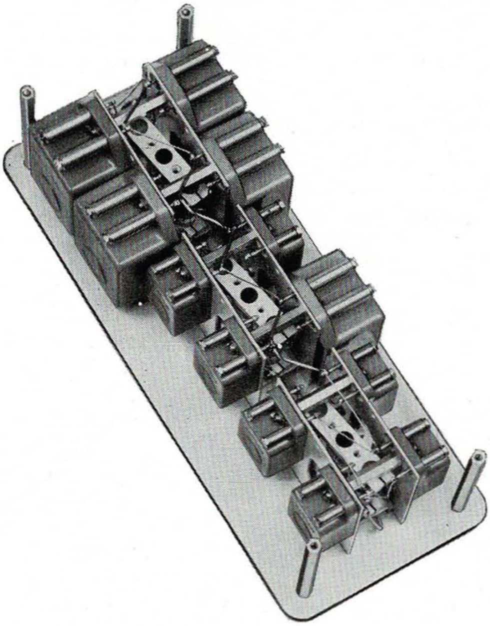


Figure 7. Interior view of the Type 1419-K Decade Capacitor.

An assembly of individual decade units, traditionally referred to as a "decade box," is a basic and popular piece of laboratory equipment. The Type 219-K Decade Capacitor, a fixture in the General Radio catalog for a great many years, is now replaced by a new and improved model, Type 1419-K.

The previous model used for the .01 μf- and .001 μf-per-step decades high quality, molded mica capacitors specially made by a leading manufacturer; the new model uses the Type 505 Capacitors, described above, throughout. The new, low-loss switches are, of course, used. The result is a threefold reduction in dissipation factor on these decades. As to stability of capacitance value, observations to date suggest constancy of capacitance, well within 0.1% for a period of several years and quite probably indefinitely, since no systematic drift in capacitance value approaching this figure has as yet been observed.

The Type 1419-K is housed in an aluminum cabinet, similar in design and appearance to the companion Type 1432-Decade Resistors and Type 1419-A Polystyrene Decade Capacitor.[3] As with all G-R laboratory components announced recently, three terminals are provided to permit use as a grounded two-terminal device or with case only grounded and both active terminals above ground.

SPECIFICATIONS

Dimensions: (Length) 14¼ x (width) 5½ x (depth) 6$\frac{3}{16}$ inches, over-all.

Net Weight: 11 pounds, 9 ounces.

[3] "New Decade Capacitors with Polystyrene Dielectric," *General Radio Experimenter*, 31, 2, July, 1956.

Type		*Code Word*	*Price*
1419-K	**1.110 μf in 0.001 μf steps**	CREEK	**$255.00**

Note: Other previously listed Type 980 Decade Capacitance Units and Types 219 and 1419 Decade Capacitors are still available. These include the Type 219-M Decade Capacitor and the Types 980-L, -M, and -N Decade Capacitance Units.

REDUCING TRANSFORMER NOISE WITH THE SOUND-LEVEL METER

Users of General Radio equipment often devise ingenious ways of applying their instruments to specialized problems. A good example of this ingenuity is reported by Mr. Theodore R. Specht, design engineer, Transformer Division, Westinghouse Electric Corporation in Sharon, Pennsylvania.

Mr. Specht was faced with the problem of determining whether the vibrations in a transformer core had resonant modes or were random. If the core is resonant it will vibrate in modes that cause high sound levels about the core. A combination of the General Radio vibration-measuring equipment and an oscilloscope, as shown in the block diagram in Figure 1, were used to make the determination.

A Type 759-P35 Vibration Pickup and an integrating-circuit Control Box convert a Sound-Level Meter to a vibration meter. The Type 760-B Sound Analyzer, which is a narrow-band, tunable amplifier, is used to evaluate the fundamental or any one of the harmonics of the vibration under study. In this case, the fundamental is twice the transformer test frequency.

Figure 2. Amplitude and phase response of the Type 760-B Sound Analyzer.

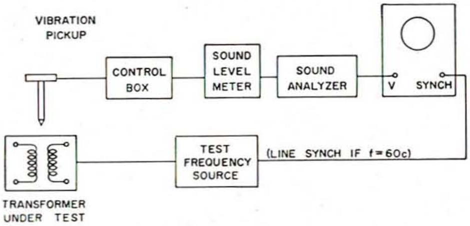


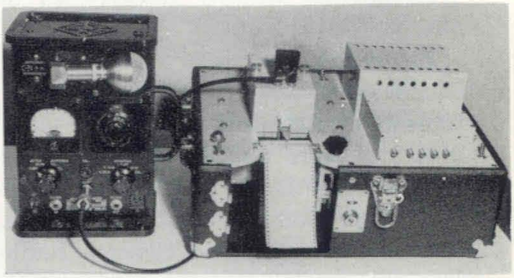
Figure 1. Block diagram of the vibration-measuring system.

The output of the analyzer is applied to the vertical deflection plates of the oscilloscope. A linear horizontal time sweep synchronized by the test frequency source is used. If the test frequency is 60 cycles, the oscilloscope can be synchronized internally by line synchronization.

If the analyzer is tuned to the peak of the vibration fundamental or one of its harmonics, its output will be nearly inverted in phase with respect to its input. From the response curve of the analyzer, shown in Figure 2, it can be seen that if the analyzer is tuned to within 0.2 db of the peak of an input signal the phase of this signal will be within ten degrees of being exactly inverted with respect to the output signal of the analyzer.

Since relative phase measurements are desired, the problem of determining absolute phase shift in the complementary equipment is ignored. The vibration probe is placed at different core locations, and the resulting oscilloscope patterns show phase differences of the vibrations at these locations. If the transformer core is mechanically resonant, the vibration pattern will follow one of the usual modes with zero or 180° phase difference between various places. Design changes must be made if resonance is present. If the vibrations are out-of-phase at different locations separated by distances much less than a half wavelength in air for the frequency in question, the transformer will radiate a minimum of noise. The Sound-Level Meter used in the "normal" fashion may then be used to determine the effectiveness of design changes by a measurement of the sound level at a standard distance from the operating transformer.

HIGH-SPEED SOUND-LEVEL RECORDER



Sound Apparatus Company, manufacturers of Graphic Recorders, has recently improved its Dynamic High-Speed Sound-Level Recorder, Model SL-2, with special emphasis on sound, noise, and vibration measurements. Design features include adjustable writing speed by a patented electronic feedback system; push-button selection of chart speed; scale functions in linear, decibel, or loudness (phon) are available.

The photograph shows Model SL-2b connected to the General Radio TYPE 1551-A Sound-Level Meter. With this simple setup the most complicated acoustical measurements can be recorded rapidly and accurately.

Descriptive literature is available from Sound Apparatus Company, Stirling, N.J.

VARYING THE RISE TIME OF THE UNIT PULSER

The occasion sometimes arises when it is desirable to be able to vary the rise time of a test pulse. This is particularly important when testing circuitry that is designed to handle pulses which may have a wide variety of rise times. A simple external modification can be made to the TYPE 1217-A Unit Pulser to permit the selection of a number of predetermined rise times. To do this, simply connect a trimmer capacitor between the cabinet ground and the OVERSHOOT screw adjustment. With this setup the following can be developed:

Pulse Width	*Rise Time*	*Decay Time*
1 μsec	up to 0.25 μsec	up to 0.3 μsec
2 μsec	up to 0.5 μsec	up to 0.5 μsec
5 μsec	up to 1.0 μsec	up to 2.0 μsec

With increased pulse width the limits for rise and decay times are correspondingly greater.

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Since 1915 — Manufacturers of Electronic Apparatus for Science and Industry

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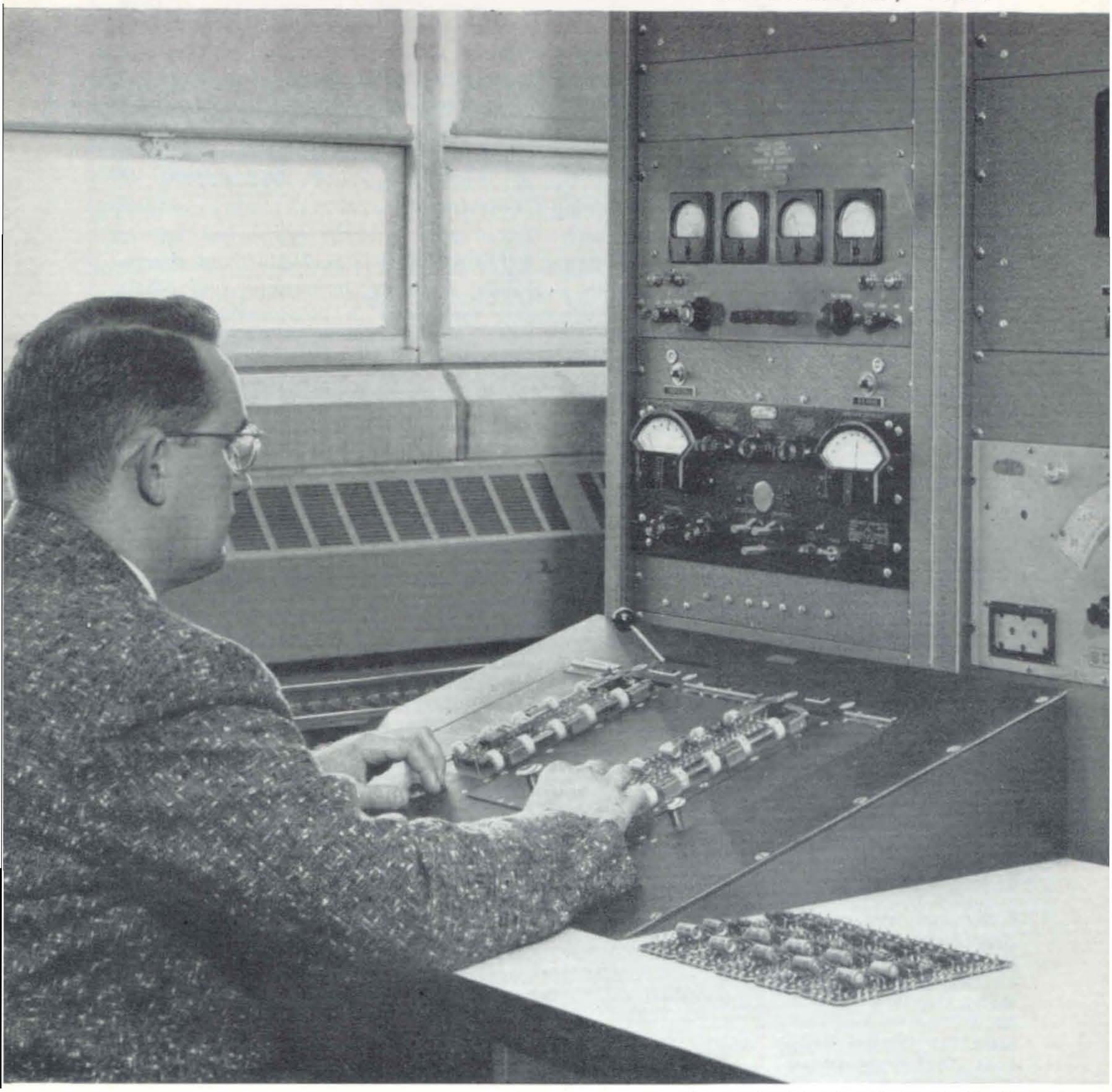

Photo courtesy International Business Machines Corporation

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Automatic Printed-Circuit Tester

the GENERAL RADIO **Experimenter**

Published Monthly by the General Radio Company

VOLUME 32 • NUMBER 6 **NOVEMBER, 1957**

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GENERAL RADIO COMPANY

275 Massachusetts Avenue, Cambridge 39, Mass.

Telephone: TRowbridge 6-4400

NEW YORK: **Broad Avenue at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: **6605 West North Avenue, Oak Park, Illinois**
Telephone — VIllage 8-9400

PHILADELPHIA: **1150 York Road, Abington, Pennsylvania**
Telephone — HAncock 4-7419

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LOS ANGELES: **1000 North Seward St., Los Angeles 38, Calif.**
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Telephone — Toronto EMpire 8-6866

COVER

The automatic printed-circuit tester, developed by International Business Machines Corporation, is shown here in operation at IBM's Kingston, New York, plant. The General Radio Type 1605-A Impedance Comparator, an integral part of the tester, is shown in the left-hand rack just above the inclined panel.

AUTOMATIC TESTING OF PRINTED-CIRCUIT COMPONENTS FOR THE IBM SAGE COMPUTER

The testing of component values on printed-circuit cards at the Kingston, New York, plant of IBM's Military Products Division is carried out by a completely automatic tester. This test system, devised by IBM engineers, is one of the most interesting of the many existing automatic test systems in which the General Radio Type 1605-A Impedance Comparator is used. The cover photograph shows the tester in operation.

In the Automatic Tester, each component is sequenced individually through its appropriate test by means of internal punched-card programming. The components on the printed-circuit card being tested are compared either with those on a precision-built master card or with built-in standards of resistance and capacitance. Each component is tested statically in order to locate components near end-of-life which might easily pass undetected through a functional test. When a component fails to fall within the prescribed limits an error indication occurs.

The automatic tester consists of measuring equipment, a program unit, card fixtures, a stepping switch, and error-detection circuits. The measuring equipment consists of two bridges, a peak detection circuit, and a General Radio Impedance Comparator, Type 1605-A.

The program unit is a modified IBM drum-type reader which uses standard IBM punched cards to indicate which tests are to be used for a particular component, while at the same time setting the limits within which the component value should fall. Flexibility of programming allows more than 500 different printed-circuit cards to be tested merely by use of the appropriate program cards. Two drums, each containing a punched card, are used to program the sequence of tests.

There are two printed-circuit card fixtures, one for the card to be tested and one for the master card. In the operation of the tester, the operator needs only to insert the cards into the fixtures and start the tests. The rest is automatic. The stepping switch completes circuits from the component to be tested to the appropriate measuring equipment for each step of the program sequence.

Within the 1-second test cycle for each individual component, the sequencing is accomplished by a series of pulses which perform the functions of stepping, program reading, test selecting, test pulsing, and resetting. The error-detection circuit is designed to turn off the pulse generator in the event of a component's failure to pass the test.

Components in series or in parallel combinations can be tested easily since the tester can take advantage of all terminals on printed-circuit cards. The components which can be tested by this automatic tester are resistors from 10 ohms to 20 megohms, with 1.1 percent accuracy; capacitors from 100 micro-microfarads, with 2 percent accuracy; inductances and impedance magnitudes from 2 ohms to 2 megohms, with 2 percent accuracy; IBM-type W, Y, and Z diodes for opens, shorts, and back resistance; and transformers for turns ratio, coupling, shorts, and opens.

Designed to check one component per

second, the tester is capable of checking the most complicated printed-circuit card in 36 seconds, a considerable improvement over manual testing techniques.

Editor's Note:

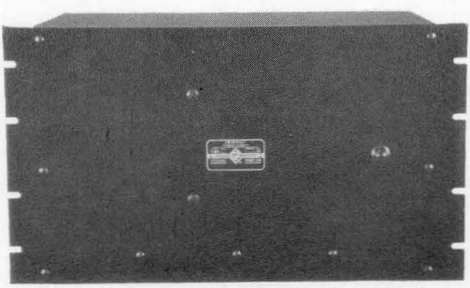
For the information in the above article we are indebted to the Kingston, New York Plant, International Business Machines Corporation.

THE TYPE P-583 EMERGENCY POWER SUPPLY FOR THE TYPE 1100-AP PRIMARY FREQUENCY STANDARD

Continuity of service is an important consideration in many applications of the Type 1100-AP Primary Frequency Standard. This is particularly true of those installations where timekeeping is the primary function of the standard, as in astronomical observatories. To assure this continuity, an emergency power supply furnishing auxiliary a-c power in the event of line failure is needed. One such supply, using a battery-operated dynamotor has been described previously.[1]

Because rotating machines are relatively slow in starting, a vibrator-type inverter, which starts much more rapidly, is used in the new Type P-583 Emergency Power Supply. The inverter operates from a 32-volt storage battery,[2] which is maintained on trickle-charge. *The output of the emergency supply is at 115 volts, 60 cycles.* A transformer is provided in the emergency supply so that the frequency standard can be operated at 115 volts from either 115-volt or 230-volt power service. The service frequency can be either 50 or 60 cycles. Figure 2 is an elementary circuit schematic.

Figure 1. Panel view of the Emergency Power Supply, which is designed for relay-rack mounting.



Upon failure of the 115/230 volt, 50-60 cycle a-c power supply, the relays in the Type P-583 Emergency Power Supply operate (1) to connect the vibrator type inverter to the battery and (2) to transfer the power input terminals of the frequency standard to the output of the inverter. This changeover is accomplished so rapidly that, if the frequency standard is in normal operating condition, no interruption in operation of the Type 1103-A Syncronometer occurs.

If the 1 kc synchronous motor of the Type 1103-A Syncronometer is not in average mechanical condition,[3] addition of capacitors to the power supply filter will insure continuous operation during the changeover. To provide this margin of safety, additional capacitors are provided, with directions for installation.

[1] "Emergency Power Equipment for Frequency Standards," *General Radio Experimenter*, 25, 11, April, 1951.

[2] Battery and charging equipment are not included with the Type P-583 Emergency Power Supply, but must be furnished by the user.

[3] A simple coasting test will indicate the condition of the Syncronometer, as outlined in the operating instructions for the Emergency Power Supply.

If the Type P-583 Emergency Power Supply is purchased with a Type 1100-AP Primary Frequency Standard, these capacitors are installed at the factory.

On resumption of the 115/230 volt, 50-60 cycle a-c supply, the relays of the Type 583 Emergency Power Supply operate (1) to disconnect the inverter from the battery and (2) to connect the power input terminals of the frequency standard to the output of the 115/230 volt line transformer.

In order to assure reasonably uniform "pickup" and "dropout," voltages for the operation of the relays, a tapped transformer is provided. The tap connection should be made to the tap corresponding to the average line voltage at the location of the standard.

Terminals are provided at the rear of the unit for connection of (1) the 32-volt battery, (2) the 115/230-volt 50-60 cycle a-c power line, and (3) the power connection to the frequency standard. A transformer is provided within the unit for changing from 115 to 230-volt service. *The frequency standard is operated at 115-volt supply at all times.* When the power system is 60 cycles, the frequency of the supply to the standard is the same on both normal and emergency supplies. If the power system is 50 cycles, the standard operates on 50 cycles on normal supply and 60 cycles on emergency supply. This change in supply frequency causes no difficulty.

The Type P-583 Emergency Power Supply is not limited in its applications solely to the General Radio Frequency Standard. It can operate any 115-volt, 60-cycle equipment within its continuous power rating of 180 watts.

SPECIFICATIONS

Input: 115/230 volts, 50-60 cycles from power line: 32 volts, 7 amperes, from battery.

Output: 115 volts, 60 cycles, 180 watts continuous.

Accessories Required: 32-volt battery, 120 ampere-hour capacity.

Dimensions: Panel, (length) 19 x (height) 10½ inches; depth behind panel, 13 inches.

Price and delivery will be quoted on request.

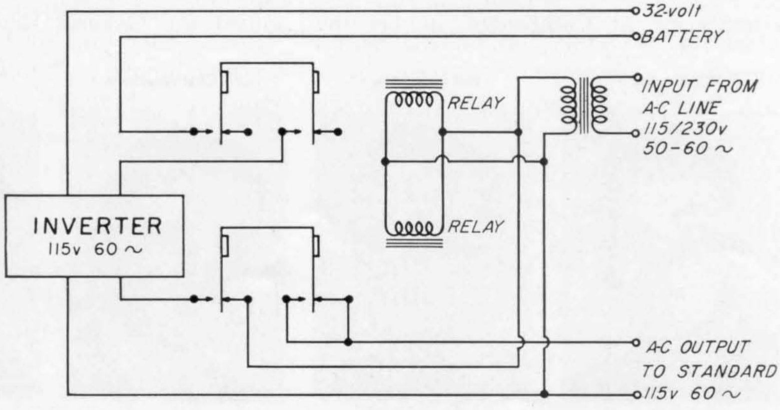


Figure 2. Elementary schematic of the Emergency Power Supply.

DISTRICT OFFICE PERSONNEL

Life in General Radio's rapidly expanding Sales Engineering Department is seldom a static existence. Our sales engineer starts his career at the main office in Cambridge with a training course that includes experience in all the operating departments of the company, with special emphasis on both development and sales engineering. Later, he will probably move out to one of the seven district offices — New York, Philadelphia, Washington, Chicago, Los Angeles, San Francisco, or Toronto. Further progress may entail transfer to another office, an office manager's post, or eventually, return to Cambridge with increased responsibility and scope for his talents.

1957 has seen a number of transfers among our sales engineering personnel:

Fred Ireland, for many years manager of our Los Angeles office, returns to the main office at Cambridge as Exhibits Manager, where he will plan and supervise our rapidly expanding program of trade show exhibits and traveling shows. His new job will take him frequently to all parts of the country. Mr. Ireland came to General Radio in 1934, after receiving his A.B. degree in physics from Harvard. After three years in instrument development and sales engineering at Cambridge, he became manager of the New York office. In 1940 he was made manager of the Los Angeles office.

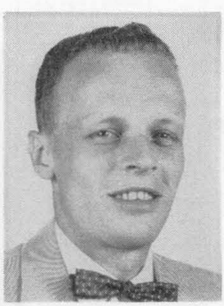
William R. (Bill) Saylor, former manager of our Washington office at Silver Spring, Maryland, is now manager of our Los Angeles office, replacing Mr. Ireland. Mr. Saylor, who received his S.B. and S.M. degrees from the Massachusetts Institute of Technology in 1937, came to General Radio in 1943, after three years in industry and three years in teaching. He became Manager of the Washington office in 1954.

C. William (Bill) Harrison takes over the Washington office, after two years as a sales engineer at the Cambridge office and two years in the New York office. Mr. Harrison received his B.S. in Electrical Engineering from Northwestern University in 1946. He spent the years 1946 and 1951–52 in the U. S. Navy with the rank of lieutenant and was with the General Electric Company from 1948 to 1951. He came to General Radio in 1953.

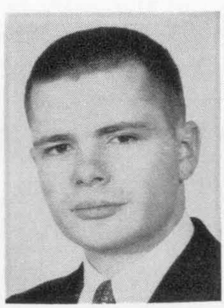
Leo J. Chamberlain goes from Cambridge to replace Mr. Harrison at the New York office. Mr. Chamberlain received his B.S.E.E. degree from Cornell University in 1953. After serving two years in the U. S. Navy (Lt., j.g.), he joined the General Radio Sales Engi-

Bill Saylor

Bill Harrison



Leo Chamberlain



Peter Bishop

Fred Ireland

neering group in 1955. He has toured extensively in the Eastern States with General Radio's traveling exhibits and is the principal author of *GR—An Engineer's Company*, which describes sales engineering opportunities at General Radio. He has also been active in the affairs of the Boston Section, Institute of Radio Engineers, and has conducted a monthly column in the section publication, *The Reflector*.

Peter Bishop, recent Cambridge sales engineering trainee, also goes to the New York office. Mr. Bishop received his S.B. degree in Electrical Engineering from the Massachusetts Institute of Technology in 1954. After two years as a lieutenant in the U. S. Army Signal Corps, he joined the General Radio organization in 1956. For the past few months at Cambridge he has been engaged in development work on a transadmittance meter.

NEW TELEPHONE NUMBERS FOR GENERAL RADIO TORONTO OFFICE

For the convenience of our Canadian customers we have increased the telephone facilities at our Toronto office. Three lines are now available. This change has also necessitated a change in the telephone number. New numbers are:

CHerry 6-2171, 2172, 2173.

TECHNICAL TRAINING OBSERVATOUR

Ad. Auriema, Inc., General Radio's distributor for Latin America, Spain, and Portugal, has instituted an "Observatour" to give their agents and staffs throughout the world first-hand information on United States manufacturers' newest techniques in production, merchandising, and managing.

The first Observatour held several years ago was general in scope but stressed sales and management. During September 1957 the second tour stressed production methods and engineering developments. In the course of the tour the group traveled approximately 6800 miles and visited 23 manufacturing plants in 19 major cities in the United States from coast to coast.

General Radio was happy to play host to a group of these engineers who are responsible for selling GR products in their respective countries. They were escorted by Mr. N. Lampert of Ad. Auriema's New York Office and spent one and a half days at our Cambridge and Concord plants.

Although the limited time would not permit complete tours of every part of the company, lectures and demonstrations were set up to acquaint the group with details of General Radio's products and manufacturing processes. Round-

General Radio Vice-President D. B. Sinclair details engineering developments to the Observatour visitors: Mr. ATILO CASSIET, from Buenos Aires; Mr. ANDRES LARA SAENZ, from Madrid; Mr. N. LAMPERT, Ad. Auriema, Inc.; Mr. JORGE NASSAR, from Medellin, Colombia. General Radio's Export Manager, S. W. DeBlois, is at the far right.

table discussions were also arranged so that specific problems could be resolved.

The Observatour has certainly proved to be a wonderful means of keeping manufacturers and their export distributors better acquainted and more aware of each other's problems. General Radio has always been pleased to have representatives of its export distributors or any of their customers visit Cambridge at any time to obtain first-hand information. And of course such an invitation is not limited to export customers! A little advance notice of any forthcoming visit will naturally facilitate arrangements to have any specific problems covered.

General Radio Company

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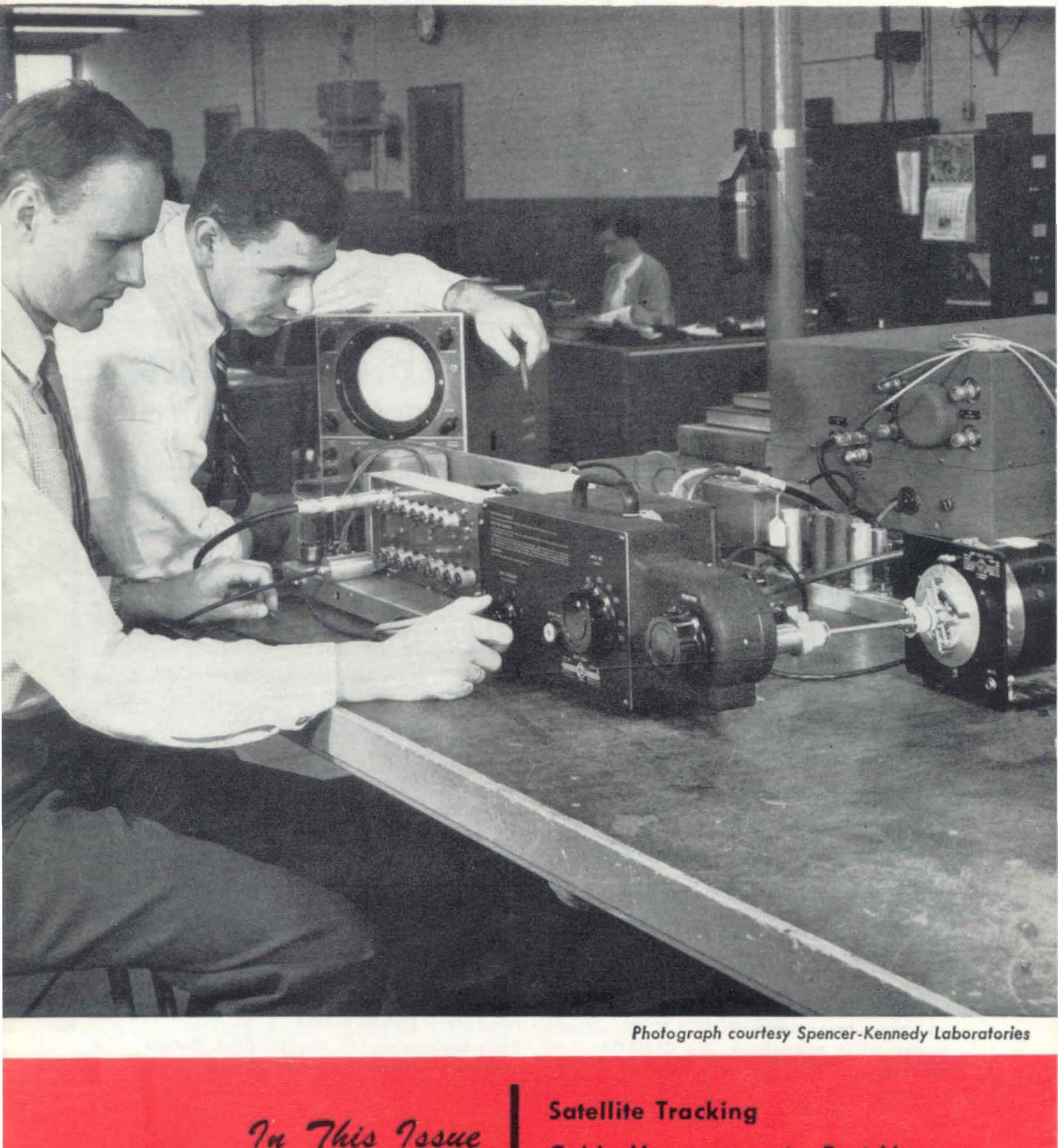
Since 1915 — Manufacturers of Electronic Apparatus for Science and Industry

VOLUME 32 No. 7 DECEMBER, 1957



Photograph courtesy Spencer-Kennedy Laboratories

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the GENERAL RADIO **Experimenter**

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The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in electronic techniques in measurement. When sending requests for subscriptions and address-change notices, please supply the following information: name, company address, type of business company is engaged in, and title or position of individual.

GENERAL RADIO COMPANY

275 Massachusetts Avenue, Cambridge 39, Mass.
Telephone: TRowbridge 6-4400

NEW YORK: **Broad Avenue at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: **6605 West North Avenue, Oak Park, Illinois**
Telephone — VIllage 8-9400

PHILADELPHIA: **1150 York Road, Abington, Pennsylvania**
Telephone — HAncock 4-7419

WASHINGTON: **8055 13th St., Silver Spring, Maryland**
Telephone — JUniper 5-1088

LOS ANGELES: **1000 North Seward St., Los Angeles 38, Calif.**
Telephone — HOllywood 9-6201

SAN FRANCISCO: **1182 Los Altos Ave., Los Altos, Calif.**
Telephone — WHitecliff 8-8233

CANADA: **99 Floral Parkway, Toronto 15, Ontario**
Telephone — CHerry 6-2171

REPAIR SERVICES

EAST COAST: **General Radio Co., Service Dept., 275 Massachusetts Ave., Cambridge 39, Mass.**
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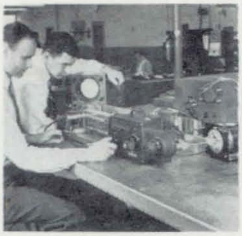
COVER



Engineers at Spencer-Kennedy Laboratories use the GR Type 1750-A Sweep Drive and Type 1208-B Unit Oscillator in development work on the SKL Model 206 Ultra-Wide-Band Amplifier (600 cps to 320 Mc). For wide-band testing, both in development and in production, Spencer-Kennedy finds that this sweep drive speeds up testing, saves time and money while maintaining accuracy.

ON THE TRACKING OF SATELLITES

The technical press has carried recently several letters[1] and articles about Doppler-shift measurements of the radio transmission from the satellites Sputnik I and Sputnik II and the calculation of slant height directly from the frequency shift data.

This article discusses a similar set of measurements and certain refinements in the handling of the data, which were used to predict the path of the satellite and its time of transit for use by the local Moon-Watch group.

The measurements described here were made by two members of the General Radio engineering staff, W. F. Byers and R. J. Ruplenas, who happen also to be radio "hams." From their measurements, it has been possible to calculate the distances of closest approach for each observed transit of the satellite. As one can note from the quoted times of transit, the whole project was extracurricular, undertaken in the true amateur spirit.

Since the satellites travel at almost 18,000 miles per hour, the total Doppler shift at 20 Mc is over 1000 cps, and at 40 Mc it is over 2000 cps. Thus, by listening to the received signal with a suitable reference oscillator beating against it, one can hear and measure the change in beat frequency as the satellite goes by. Simple equipment is adequate for this measurement. Byers and Ruplenas used harmonics of quartz-crystal-controlled oscillators for the reference signals at 20 Mc and 40 Mc. They measured the audio beat tone by comparing it with a stable, calibrated audio oscillator set to multiples of 50 cps, noting the times of coincidence in terms

[1]Letters to the Editor from the Lincoln Laboratory, M.I.T., and the Stanford Research Institute appeared in the November, 1957, issue of *Proceedings of the IRE*.

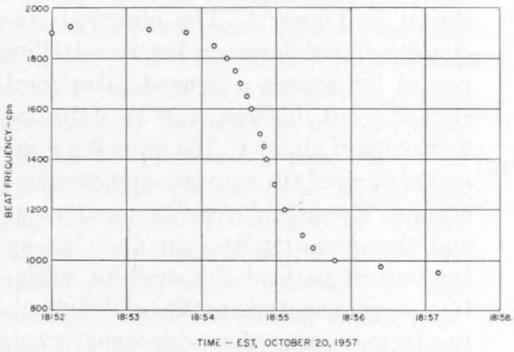


Figure 1. Measured frequency shift of signal from Sputnik I.

of clocks standardized against WWV time signals. More elaborate techniques using tape recorders were considered, but this simple technique was sufficiently good to give useful results.

The simple Doppler equation used for the calculation of distance is based on straight-line motion and is:

$$\Delta f \simeq \frac{\pm f_0 v}{c\sqrt{1 + \left(\frac{D}{v\Delta t}\right)^2}} \qquad (1)$$

where

Δf is the frequency shift

v is the velocity of the satellite

c is the velocity of light

f_0 is the mean frequency of the observed signal

Δt is the time relative to the time of closest approach

D is the distance of closest approach (slant range).

This equation can be analyzed to find the distance in terms of the total frequency shift and of the rate of change of frequency at the time of closest approach.[2] But, in order to obtain good accuracy from the data, some refinements were introduced.

[2]This procedure is described in the letters of Reference 1.

The plotted results of one measurement on the signal from Sputnik I are shown in Figure 1. The observed frequency shifted downward as the satellite passed by almost overhead. The total shift of about 1000 cps at 20 Mc indicates a velocity of about 16,760 miles per hour on the basis of the simple Doppler calculations. The actual velocity was higher, and the deviation is accounted for by the curved path of the satellite, variation in propagation paths, and difficulties in measuring the weak signal when the satellite was over 1000 miles away.

The velocity of the satellite is one of the factors in the calculation of distance. The indicated velocity is close enough to the true velocity so that a fair estimate of distance can be obtained using that figure. The distances that will be quoted, however, are based on an estimate of actual velocity (assuming undisturbed motion and neglecting perturbations) obtained by use of Kepler's "third law"[3] for the period of an elliptical orbit and by use of the equation for the velocity at any point in an orbit about the earth. Such an estimate is probably close enough to the true value so that the accuracy of distance calculation is limited by the accuracy of other measurements.

The semimajor axis, a, of the elliptical orbit of an earth satellite is obtained from the equation:

$$a^3 = \frac{gR_e^2 T^2}{4\pi^2} \qquad (2)$$

where g is the acceleration of gravity
R_e is the radius of the earth
T is the period of the orbit.

[3]Kepler's third law states that "the squares of periods of circulation around the sun of the several planets are in the same ratios as the cubes of their mean distances." This was first formulated by Johann Kepler in 1619 and published in his treatise, "De Harmonice Mundi."

The period of the satellite is, therefore, essential for this calculation. One can easily determine this by listening and noting the times of successive transits, and then of transits one or more days apart to include many complete orbits. When minor corrections are made, the period can be obtained to a high degree of accuracy.

Then the velocity, v, at any point in an orbit of an earth satellite is obtained from

$$v^2 = gR_e^2 \left(\frac{2}{r} - \frac{1}{a}\right) \qquad (3)$$

where r is the distance from the center of the mass of the earth to the desired point in the satellite's orbit.

The value of r used in this equation was estimated at first from the initial Doppler measurements to be the radius of the earth plus 200 miles. Subsequent Doppler measurements then made it possible to refine this estimate.

In order to utilize the values in the curved portion of the plotted relation between frequency and time, the theoretical curve, calculated from the simple Doppler equation by use of the value of v obtained above, was fitted to the points. Since no large-scale digital computer was available for this extracurricular calculation, the fitting was done in a preliminary way graphically, and then a final value of D was obtained from the numerical data by an averaging process. In general, the simple graphical fitting was adequate.

The distance of nearest approach thus calculated from the data represented on the graph is 159 miles, and the time of nearest approach was 18:54:51 EST. Some other observations on Sputnik I are as follows:

Date	Time (Nearest Approach)	Distance (Nearest Approach)
10/17/57	19:09:30 EST	410 miles
	20:48	850
10/18/57	19:05:12	284
	20:43:42	1040
10/19/57	19:00:15	197
10/20/57	18:54:51	159
	04:56:30	1210
10/21/57	18:48:42	236

The values for the closer transits are more accurate in both time and distance than those for greater distances. We have not attempted a careful estimate of accuracy for these points but, for the 159-mile distance, the consistency of the data is sufficiently good to lead to an estimate of $\pm$ 2 miles as the probable accuracy, except, of course, for possible systematic errors or blunders.

If one considers the transits at 19 hours on succeeding days, the path shifted with respect to the point of observation from east to west. On October 20 it was almost overhead. The data of October 19 and 21 indicate that on the 20th it was actually west of the observation point by about 30 miles so that the elevation was about 156 miles.

Similar data on Sputnik II are as follows:

Date	Time	Distance (Nearest Approach)
11/4/57	06:24:24 EST	340 miles
11/5/57	06:36:22	629
11/6/57	06:47:48	876
11/7/57	06:58:37	1137
	05:12:00	162
11/8/57	05:21:50	317

From the relative motion of the observer and the path from day to day, one concludes that Sputnik II was almost directly overhead at about 160 miles elevation at the 05:12 transit on 11/7/57. The 05:01 transit on 11/6/57 would have been interesting, but the earlier data indicated that the supreme effort of getting out of bed at this hour should be made on 11/7/57, since then the satellite would be nearly overhead.

The prediction of approximate transit times after two measurements have been obtained is simple, because the period is then reasonably well known. Since the plane of the orbit is inclined with respect to the earth's axis, however, corrections should be made for the fact that the points of the orbit of nearest approach for successive transits do not correspond to exact intervals of one period. A similar correction is necessary from day to day, because of the relative shift of the orbit and the observer.

The distances between successive transits can be used to obtain a rough estimate of the inclination of the orbit. A better estimate can be obtained by measurement of satellite transits for both directions of travel (provided one is not close to the equator). In fact, if convenience and working hours did not have to be considered, it would be possible to make at least four measurements every 24 hours. When enough data are then obtained to find the altitude for both directions of travel, the simple elliptical approximation to the orbit can be specified from measurements at one station. Naturally, better accuracy in specifying the orbit would be possible if data from stations at different latitudes were available.

The task of Moon-Watch teams is made much easier by a knowledge of when the satellite will be visible in a particular area and of the proper orientation of the Moon-Watch telescopes in terms of predicted azimuth and elevation.

The information derived from these Doppler-shift data was used along with other information by the Harvard Observatory Moon-Watch team.

The Doppler-shift measurements have the advantage over visual sightings that they can be obtained regularly without regard to atmospheric conditions or the position of the sun, and there is little chance of a false radio sighting when the Doppler shift is observed. When the radio signals stop, however, optical and radar observations are all that remain. The use of solar batteries to power the satellite transmitters should make Doppler-shift measurements possible over long periods, and then more radio engineers and amateurs can dabble in this new branch of radio astronomy.

— ARNOLD PETERSON

MEASUREMENT OF CABLE CHARACTERISTICS (Part V)

MEASUREMENT OF VSWR OR UNIFORMITY OF IMPEDANCE[18]

While not normally required for most standard cables, this measurement is sometimes desirable in specific applications as a means of checking the uniformity of cable characteristics from point to point along the cable. Furthermore, special experimental cables and new types of transmission lines may have unknown VSWR characteristics, particularly if they are of a radical design. There are several possible methods of making the measurements, and methods of interpreting the results have not been standardized. The measurement usually requires some type of impedance-indicating device, with which the input impedance of a relatively long cable sample is measured continuously or at closely spaced frequencies over one or more frequency ranges. The variation of the impedance is a measure of cable uniformity.

A typical characteristic, measured on a 2400-foot sample of TYPE 874-A2 Cable by means of a TYPE 1601-A V-H-F Bridge[19] for two narrow ranges near 25 Mc and 100 Mc, respectively, is shown in Figure 11.

At ultra-high frequencies, either the TYPE 1602-B U-H-F Admittance Meter[19] (41-1500 Mc) or the TYPE 874-LBA Slotted Line[19] (300-5000 Mc) can be used for VSWR measurement. The TYPE 874-UB Balun can be used to supplement these instruments for measurements on shielded or unshielded twin-conductor cables up to 1000 Mc, although this balun, being tuned, requires readjustment whenever frequency is changed. General Radio Unit Oscillators are satisfactory generators, and either the TYPE 1231-B Amplifier or one of the Type DNT Detectors is a suitable detector for use with the slotted line. The most satisfactory detector for use with the admittance meter is the Type DNT.

More work is needed to devise a fast yet accurate method of making these cable uniformity measurements with simple, commercially available equipment.

[18]Handrick, E., and Kruege, L., "Determination of the Equivalent Reflection Factor of Wide-Band Cables," *Telefunken Ztg.*, v. 28, 1955, p. 235 (in German).

Kruege, L., "Linear Integration of the Reflected Pulses as a New Standard for the Quality of Television Cable Lengths," *Telefunken Ztg.*, v. 28, 1955, p. 241 (in German).

Cotte, M., "Study of a Factory Length of Cable by Measurements of Terminal Impedance," *Cables and Transmission*, v. 9, 1955, p. 161 (in French).

Rosen, A., "Irregular Transmission Lines," *Wireless Engineer*, v. 31, March, 1954, pp. 59–70.

Lorrin, J., "Testing of Manufactured Lengths of Coaxial Lines for Very High Frequencies," *Cables and Transmission*, v. 7, July, 1953, pp. 218–41 (in French).

Widl, E., "Survey of Methods in Use for Measurements on High-Frequency Cables," *Fernmeldetech. Z.*, v. 8, May, 1955, pp. 262–265 (in German).

Blackband, W. T., and Brown, D. R., "The Two-Point Method of Measuring Characteristic Impedance and Attenuation of Cables at 3000 Mc," *J.I.E.E.*, Part IIIA, *Proceedings at the Radiolocation Convention*, v. 93, n. 9, March-May, 1946, pp. 1383–6.

[19]Directions for making VSWR measurements will be found in the instruction books for these instruments. For specifications and prices, see the latest General Radio catalog.

MEASUREMENT OF INSULATION RESISTANCE

Insulation resistance has to be measured for certain cable types at a potential of not less than 200 volts. General Radio Company manufactures two instruments that will make these measurements: the Type 1862-B Megohmmeter and the Type 544-BA Megohm Bridge. With either of these instruments, the measurement is made at a constant potential of 500 volts, which is a generally accepted value[20], and a guard terminal is available for eliminating, if necessary, any effects of leakage between the leads connecting to the cable sample under test. The basic accuracies of the two instruments are closely comparable. If the measurement of cable insulation resistance is the only application contemplated for the test equipment, the simplicity of operation and lower cost of the Type 1862-B Megohmmeter make it the logical choice in most instances. The Type 544-BA Megohm Bridge, on the other hand, can be adapted more readily to specialized measurements in a research or development laboratory.

FURTHER DISCUSSION OF ATTENUATION MEASUREMENTS

Part II of this series, published in the June *Experimenter*, describes a particular method of attenuation measurement. There are, of course, other ways in which the details of the measurement can be handled, and it is interesting to consider some of these alternatives even though the techniques previously described are still considered the best.

[20]ASTM Standards on Electrical Insulating Materials D257-49T.

Matched vs. Unmatched Unknown Cable Sample: As previously described specifically, the attenuation of an unknown cable sample is measured essentially by a substitution method. The sample is removed from an *otherwise-unchanged* transmission path, which includes both r-f and i-f circuits, between a constant-output generator (the unit oscillator) and a calibrated meter (part of the Type 1216-A Unit I-F Amplifier). The loss in the sample is partially replaced by increasing the loss of an accurate i-f step attenuator, and the remaining loss is measured by the meter, which interpolates between steps of the attenuator.

Let us examine more carefully the significance of "otherwise-unchanged" as used in the preceding paragraph. With reference to Figure 4, Part II (June, 1957, *Experimenter*), the transmission path between generator and output meter includes the generator output coupling loop, a low-pass filter, a 10-db pad, a 3-foot patch cord, another 10-db pad, the unknown sample, a 20-db pad, a crystal mixer with local oscillator, a 30-Mc step attenuator, and several stages of i-f amplification. Few of the junctions between these elements are matched, so that there exist so-called "reflection losses" at many of

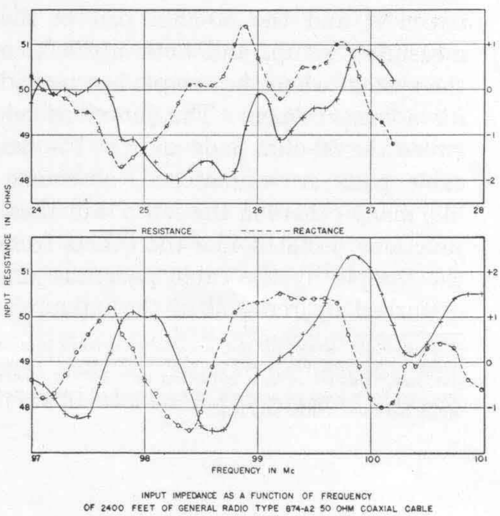


Figure 11. Input impedance as a function of frequency for 2400 feet of General Radio Type 874-A2 50-ohm Coaxial Cable.

these junctions.[21] *However, because of the isolation provided by the pads on either side of the sample, removal of the unknown sample does not* change *conditions at any junctions except those at the sample.* Therefore, the various reflection losses in the system, except possibly for those associated with the sample, are *unchanged* by removal of the sample and consequently have no effect whatever on the measurement.

Reflection losses at the junctions associated with the sample must be considered separately, and there are several different possible situations:

(1) Consider, first, the measurement of a 50-ohm coaxial cable sample. Because of use of 50-ohm pads at both ends of the unknown, matched conditions prevail at both junctions with the sample in, and also at the junction between the pads with the sample out. There are, therefore, no reflection losses associated with the unknown sample in this case.

(2) Consider, next, the measurement of a 75-ohm coaxial cable sample at 3000 Mc. The method that has been described is to fabricate low-reflection pads from extra lengths of the same type cable as that being measured, each length having about 10-db attenuation. One of these "cable pads" is used at each end of the unknown sample between it and the 50-ohm pad in the measuring setup, and both are left in the system when the sample is removed for a measurement. The junctions between the 50-ohm pads and the 75-ohm cable pads are unmatched, of course, like many others in the setup, but these junctions, isolated like the others from the sample by the cable pads, are undisturbed by removal of the unknown, so that this mismatch has no effect on the measurement. It should be especially noted that in this case the nominal impedance of the connectors used between the cable sample and cable pads must equal the nominal impedance of the sample, although the connectors used between the 50-ohm pads and the cable pads are not critical. With the unknown sample in, the cable pads effectively match the sample at both its ends. With the sample out, the cable pads are plugged together directly and match each other. There are, therefore, no reflection losses associated with the unknown sample in this case either.

(3) Consider, finally, the measurement of a 75-ohm coaxial cable sample at 400 Mc. The method we recommend involves using the same 50-ohm pads at both ends as in the case of 50-ohm samples. Cable pads are not recommended, because they would be inconveniently long to give 10-db attenuation at 400 Mc. With the sample in, there is a mismatch at each of its ends corresponding to a VSWR of 1.5 or a reflection coefficient of 0.2,[22] which causes a reflection loss of 0.18 db for each junction or 0.36 db for both.[23] With the sample out and the 50-ohm pads plugged together directly, there is no reflection loss. Therefore, as previously described, a 0.36-db reflection-loss correction must be subtracted from the measured insertion loss to obtain the true attenuation.

The necessity of making this small correction is a very minor disadvantage, which causes no inaccuracy and which is more than justified by the resultant simplicity and convenience of the method. Incidentally, this same method, in which

[21] "Reflection losses" do not necessarily involve loss of power by dissipation, as is true also for the term "insertion loss," but refers to a reduction or "loss" of power received by a load as a result of mismatched impedance levels between source and load.

[22] Assuming that the attenuation of cable sample is 6 db or more, which is great enough to make multiple-reflection effects negligible in this example.

[23] These figures can be easily calculated from the formulas given in Part II, pages 6 and 7 of the June, 1957, *Experimenter*, or read directly from Figure 6 on page 7 of that issue.

no cable pads are included, can also be used at 3000 Mc, since the reflection loss is independent of frequency. However, MIL-C-17B Specification requires that the cable sample be matched, and thus we have recommended using the cable pads as described previously.

The possible benefits to be gained by use of reactive matching networks (triple-stub tuners or the like) between each end of the cable sample and the measuring setup should be considered. Actually, the only possible benefit is the elimination of the very small reflection-loss correction just mentioned for the case of cable impedances other than 50 ohms at 400 Mc, where cable pads are too cumbersome. On the other hand, the use of reactive matching networks for this application has important disadvantages. One is that a fair degree of experience is required to set them properly, and, if improperly set, they can introduce both reflection-loss and attenuation-loss errors of *unknown* values which can be *larger* than the minor, *known* reflection-loss correction they are intended to eliminate. Other disadvantages are the necessity of making the extra adjustments, the space taken up by the tuners, and the extra cost.

Comparative Measurements: If desired, suitable reactive matching networks can easily be assembled from GR TYPE 874 Stubs, Tees, and Line-Stretchers. Some comparative measurements were made to illustrate the foregoing discussion.

(1) At 400 Mc, a 160-foot length of RG-59/U 75-ohm coaxial cable was measured first by using 50-ohm pads and correcting for the 0.36-db reflection loss, and next by using reactive matching networks at each end of the sample to eliminate reflection loss. The networks were initially adjusted, first one and then the other, so as to give maximum detector reading. A more accurate, but insignificantly so, adjustment could have been made using a slotted line or admittance meter, but the slight improvement possible does not warrant the extra complication. The results were: 12.1 db less 0.36 db reflection-loss correction equals 11.74 db by the method recommended and 12.0 db using the reactive matching networks. The difference of 0.26 db is within the accuracy of measurement. The higher figure of 12.0 db is probably due to incidental losses in the networks.

(2) At 3000 Mc a 30-foot length of RG-59/U 75-ohm coaxial cable was measured in three ways: (*a*) Using 50-ohm pads and correcting for the 0.36-db reflection loss, (*b*) using two extra 40-foot lengths of RG-59/U cable as 10-db cable pads, with constant-impedance, 75-ohm, Type N Connectors used between the sample and the cable pads, and (*c*) using reactive matching networks. The results were: 7.8 db less 0.36 db reflection-loss correction equals 7.44 db for method (*a*), 7.4 db for method (*b*), and 7.4 db for method (*c*). The maximum difference of 0.04 db is insignificant.

R-F Standard Attenuator vs. I-F Standard Attenuator plus Interpolating Meter: The use of a continuously-variable r-f standard attenuator to measure unknown attenuations avoids dependence on the linearity of a crystal mixer, but the latter is not in the least undependable. When used as a mixer in a heterodyne system, the crystal is inherently linear, in contrast to its less dependable characteristics when used as a square-law rectifying detector. The heterodyne method of measurement has been used at General Radio for many years for the standardization of voltage and attenuation at radio frequencies.[24] The National Bureau of Standards also uses the principle of an i-f standard attenuator in conjunction with a mixer and local oscillator to measure attenuation at microwave frequencies with extremely high accuracy,[25, 26] and Bell Telephone Laboratories' precision transmission and phase measuring set also uses a precision, fixed-frequency, i-f attenuator in measurements to 0.05 db accuracy.[27] To insure precise linearity in a mixer, it is necessary only to be sure that the local oscillator voltage is sufficiently high. This fact can readily be checked, in the setup we have described, by a measurement of the rectified mixer current with the panel meter of the Type 1216-A I-F Amplifier, for which purpose a toggle switch is provided. It should read between 80 per cent and 100 per cent of full scale. The i-f attenuator has the important advantage of operating at a fixed, relatively low frequency where it can be more readily standardized with higher accuracy than can r-f attenuators at higher frequencies. The step attenuator as used in the Type 1216-A I-F Amplifier avoids the high and frequency-variable initial insertion loss of the waveguide-beyond-cutoff, piston type of r-f attenuator and, with its interpolating meter, can be read more easily and precisely than can a typical signal generator output dial covering 120 db or more in one revolution.

Before the Type 1216-A I-F Amplifier became available, the Type 874-GA Attenuator, which is a continuously-variable, accurate, r-f attenuator, was recommended for cable attenuation measurements, and many cable manufacturers are today using this device with excellent results. Nevertheless, everyone who has tried the i-f step attenuator system that is now available has quickly appreciated the improved convenience, speed, and ease of reading of the new system.

Monitoring Generator Output: The inexpensive unit oscillators recommended do not have output meters, and one must depend upon their constancy of output. In order to insure the latter, it is necessary to drive them with a Type 1201-A Unit Regulated Power Supply as previously described. In addition, and this was not mentioned before, it is desirable to operate the entire setup from a regulated line, because the Type 1201-A Supply does not regulate heater voltage, which influences oscillator output to a small extent. Regulation of the entire setup also will stabilize local-oscillator output, which is especially desirable for 3000-Mc measurements.

The saturable-core, constant-voltage transformer is generally satisfactory for this application and is probably, because of the availability of units with small ratings, the most practical type of regulator if no other equipment requires a regulated line. However, for regulating power to additional equipment also, which would require a larger-capacity regulator, a Type 1570-A Automatic Voltage Regulator[28] is highly recommended.

With regulation as described, recordings show no perceptible change in output, either as a function of time or of input voltage; so it can be safely as-

[24] L. B. Arguimbau, "Standardizing the Standard-Signal Generator," *General Radio Experimenter*, 12, 3 and 4, August-September, 1937.

[25] Grantham, R. E., and Freeman, J. J., "A Standard of Attenuation for Microwave Measurements," *Transactions, AIEE*, v. 64, 1948, p. 535.

[26] Albred, C. M., "Precision Piston Attenuators," National Bureau of Standards, *NBS Report 5078*, May 1, 1957.

[27] Alsberg, D. A., and Leed, D., "A Precise Direct Reading Phase and Transmission Measuring System for Video Frequencies," *Bell System Technical Journal*, Vol. XXVIII, No. 2, April, 1949, p. 221.

[28] It can handle up to 6 KVA, is accurate to ± ¼%, introduces no waveform distortion, and is smaller and lower in price than most competitive regulators. Although it is electromechanical, for most line fluctuations, which are small ones, it is practically as fast as most of the so-called "instantaneous" regulators.

sumed that errors will not be introduced into cable attenuation measurements from this source.

Checking Over-all Accuracy: The equipment that has been described will hold its accuracy for a long time, but a simple check can verify it at any time. Merely use the setup to measure the attenuation of an extra Type 874-G10 10-db Pad, which can in turn be checked at d-c or audio frequencies. The frequency characteristic of this pad is dependably known and is negligible between d-c and 400 Mc. At 3000 Mc its attenuation is known to be 0.3 db higher than its low-frequency value.

The detector system can also be checked directly at 30 Mc by connecting an accurate signal generator to the i-f amplifier input. However, many signal generators cannot be read so precisely as can the i-f amplifier meter and attenuator.

NEW CABLE MEASUREMENT KITS

Since we can supply everything necessary to measure nearly all cable types, it has been suggested by customers that we offer "cable measuring kits" to simplify the job of selecting the right equipment and to avoid the nuisance of overlooking one or two small parts and having to place a separate order for them later. Furthermore, a single source of supply gives assurance that all the equipment will work together properly. We think the suggestion is a good one, and we, accordingly, have worked out a basic kit with two supplementary kits. Order by kit type number; it is not necessary to list individual items.

TYPE 1671-A BASIC COAXIAL CABLE ATTENUATION MEASURING KIT $1456.40

Complete equipment for measuring attenuation of most coaxial cables at 400 and 3000 Mc. Includes all instruments needed plus large assortment of connectors, replacement ferrules, and adaptors for making connections to various cable types.

Quantity	*Type*	*Name*	*Unit Price*	*Total*
1	1208-B	Unit Oscillator		$200.00
1	1220-A2	Unit Klystron Oscillator		272.90
1	1201-A	Unit Regulated Power Supply		85.00
1	874-F500	500-Mc Low-Pass Filter		16.00
3	874-G10	Fixed Attenuator	$25.00	75.00
1	874-G20	Fixed Attenuator		25.00
1	874-MR	Mixer Rectifier		32.50
1	1209-B	Unit Oscillator		235.00
1	1216-A	Unit I-F Amplifier		335.00
6	874-C	Cable Connector	2.00	12.00
6	874-C8	Cable Connector	2.00	12.00
6	874-C9	Cable Connector	2.00	12.00
6	874-C58	Cable Connector	2.00	12.00
6	874-C62	Cable Connector	2.00	12.00
50	FEC-2	Ferrule	.10	5.00
50	FEC-3	Ferrule	.10	5.00
50	FEC-7	Ferrule	.10	5.00
50	FEC-9	Ferrule	.10	5.00
2	874-QNJ	Adaptor with Type N Jack	3.75	7.50
2	874-QNP	Adaptor with Type N Plug	4.50	9.00
2	874-QBJ	Adaptor with Type BNC Jack	4.75	9.50
2	874-QBP	Adaptor with Type BNC Plug	4.75	9.50
2	874-QCJ	Adaptor with Type C Jack	4.75	9.50
2	874-QCP	Adaptor with Type C Plug	6.25	12.50
2	874-QHJ	Adaptor with Type HN Jack	6.50	13.00
2	874-QHP	Adaptor with Type HN Plug	6.50	13.00
2	874-QUJ	Adaptor with Type U-H-F Jack	4.00	8.00
2	874-QUP	Adaptor with Type U-H-F Plug	4.25	8.50
			Total	$1,456.40

TYPE 1671-A2 SUPPLEMENTARY KIT FOR MEASURING COAXIAL CABLE Zo, v, AND C $1447.00

Adds to basic TYPE 1671-A Kit all instruments and accessories needed to measure characteristic impedance, velocity of propagation, and capacitance of most coaxial cables as well as capacitance and capacitance unbalance of most shielded or unshielded twin-conductor cables.

Quantity	*Type*	*Name*	*Unit Price*	*Total*
1	1214-A	Unit Oscillator		$ 75.00
2	874-Q2	Adaptor to GR Type 274	$4.25	8.50
1	874-VQ	Voltmeter-Detector		30.00
1	874-WM	50-ohm Termination		12.50
1	1212-A	Unit Null Detector		145.00
1	1203-B	Unit Power Supply		40.00
1	1951-A	Filter		75.00
1	716-CM	Capacitance Bridge		600.00
1	505-F	Capacitor		6.00
1	720-A	Heterodyne Frequency Meter		455.00
			Total	$1,447.00

TYPE 1671-A3 SUPPLEMENTARY KIT FOR MEASURING BALANCED, TWIN-CONDUCTOR CABLES $462.00

Adds to basic TYPE 1671-A Kit and supplementary TYPE 1671-A2 Kit all accessories needed to measure attenuation, characteristic impedance, and velocity of propagation of shielded or unshielded twin-conductor cables.

Quantity	*Type*	*Name*	*Unit Price*	*Total*
2	874-UB	Balun	$75.00	$150.00
4	874-D20	Adjustable Stub	14.00	56.00
4	874-L10	50-ohm Air Line	5.50	22.00
2	874-UB-P2	200-ohm Terminal Unit	6.50	13.00
2	874-UB-P3	300-ohm Terminal Unit	15.00	30.00
2	874-UB-P4	Adaptor	50.00	100.00
2	874-UB-P4A	Adaptor Cable	18.00	36.00
2	1000-P5	V-H-F Transformer	27.50	55.00
			Total	$462.00

Insulation resistance measurements are usually handled separately from the high-frequency measurements; so the following instruments for measuring insulation resistance are listed below separately:

Type 1862-B Megohmmeter **$255.00**
Type 544-BA Megohm Bridge **365.00**

For automatic line-voltage regulation:
Type 1570-AL Automatic Voltage Regulator $480.00
(Bench, rack, or wall model)

The author wishes to acknowledge the many helpful suggestions received from Robert A. Soderman and the assistance of Edward F. Sutherland, who made the comparative measurements reported.

This article concludes the series, "The Measurement of Cable Characteristics." Reprints will be available soon to anyone who requests them.

— W. R. THURSTON

General Radio Company

extends to all *Experimenter* readers its best wishes for a Merry Christmas and a Happy New Year.

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