the GENERAL RADIO Experimenter

INDEX

TO

GENERAL RADIO EXPERIMENTER

VOLUMES XII AND XIII

June, 1937 to May, 1939

GENERAL RADIO COMPANY
CAMBRIDGE MASSACHUSETTS
U. S. A.

INDEX
TO GENERAL RADIO EXPERIMENTER
Volumes XII and XIII, June, 1937 through May, 1939

INDEX BY TITLE

A-C Impedance Bridges, A New Null Detector for (H. W. Lamson: April, 1939)

A-C Measurements, Shielded Connectors for (M. A. Gilman: July, 1938)

A-C Operated Direct-Current Amplifier for Industrial Use (J. K. Clapp: February, 1939)

A-C Operation for Type 613-B Beat-Frequency Oscillator (April, 1938)

Adjustable Attenuator, Type 449-A (November, 1937)

Ammeter, The Type 726-A Vacuum-Tube Voltmeter as a Radio-Frequency (D. B. Sinclair: August-September, 1938)

Amplifier for Industrial Use, A-C Operated Direct-Current (J. K. Clapp: February, 1939)

An Analyzer for Noise Measurement (H. H. Scott: February, 1939)

Analyzer for Noise Measurement, An (H. H. Scott: February, 1939)

Analyzer, The New Wave - Some of Its Features (L. B. Arguimbau: December, 1938)

Anniversary Convention, At the Silver (June, 1937)

Antenna Measurements with the R-F Bridge, Broadcast (D. B. Sinclair: February, 1938)

Antenna Power with the Type 726-A Vacuum-Tube Voltmeter, Checking (D. B. Sinclair: May, 1939)

Antenna, Type 418-G Dummy (October, 1937)

Attenuator, Type 449-A Adjustable (November, 1937)

Background Noise Corrections in the Measurement of Machine Noise (L. E. Packard: December, 1937)

Balanced Circuit Measurements, Shielded Transformers for (W. G. Webster: January, 1938)

Beat-Frequency Oscillator, A-C Operation for Type 613-B (April, 1938)

Beat-Frequency Oscillator for Wide-Band Measurements, A (D. B. Sinclair: January, 1939)

Beat-Frequency Osçillator, Modern Improvements for the (H. H. Scott: March, 1938)

Behavior of Type 505 Condensers at High Frequencies, The (D. B. Sinclair: April, 1938)

Bridges, A New Null Detector for A-C Impedance (H. W. Lamson: April, 1939)

Bridge, A 60-Cycle Schering (H. W. Lamson: June, 1938)

Bridge, A Wide-Range Capacitance Test (L. E. Packard: June, 1938)

Bridge, Broadcast Antenna Measurements with the R-F (D. B. Sinclair: February, 1938)

Bridge Measurements, A Visual Balance Indicator for A-C (January, 1938)

Bridge, The Megohm (R. F. Field: July, 1937)

Broadcast and Sound Recording Circuits, A Peak-Reading Power-Level Indicator for Monitoring (A. E. Thiessen: October, 1937)

Broadcast Antenna Measurements with the R-F Bridge (D. B. Sinclair: February, 1938)

Broadcast Transmitter, Multi-Frequency Distortion Measurements on the (A. E. Thiessen: March, 1939)

Capacitance Measurements, Connection Errors in (R. F. Field: January, 1938)

Capacitance Test Bridge, A Wide-Range (L. E. Packard: June, 1938)

Capacitance Test Bridge for Measuring Grounded Samples, A Modification of the (February, 1939)

Checking Antenna Power with the Type 726-A Vacuum-Tube Voltmeter (D. B. Sinclair: May, 1939)

Coil or Condenser Checking, A New Instrument and A New Circuit for (W. N. Tuttle: August-September, 1937)

Condenser, A High-Frequency Model of the Precision (D. B. Sinclair: October-November, 1938)

Condenser Checking, A New Instrument and A New Circuit for Coil or (W. N. Tuttle: August-September, 1937)

Condenser, Improvements in the Type 568 (M. A. Gilman: October-November, 1938)

Condensers at High Frequencies, The Behavior of Type 505 (D. B. Sinclair: April, 1938)

Condensers, Type 739 Logarithmic (A. G. Bousquet: August-September, 1938)

Connection Errors in Capacitance Measurements (R. F. Field: January, 1938)

Connector, Type 759-P8 (July, 1938)

Connectors for A-C Measurements, Shielded (M. A. Gilman: July, 1938)

Convention, At the Silver Anniversary (June, 1937)

Corrections in the Measurement of Machine Noise, Background Noise (L. E. Packard: December, 1937)

Detector for A-C Impedance Bridges, A New Null (H. W. Lamson: April, 1939)

Dial Plates, New (June, 1937)

Dimmer, The Variac as a Series (October-November, 1938)

Direct-Current Amplifier for Industrial Use, A-C Operated (J. K. Clapp: February, 1939)

Distortion and Noise Meter, Modification of Type 732-A (March, 1939)

Distortion and Noise Meter, Radio Receiver Tests with Type 732-A (L. E. Packard: July, 1938)

Distortion Measurements on the Broadcast Transmitter, Multi-Frequency (A. E. Thiessen: March, 1939)

Dummy Antenna, Type 418-G (October, 1937)

Errors in Capacitance Measurements, Connection (R. F. Field: January, 1938)

Experiments in the Psychology of Hearing (M. A. Gilman: May, 1938)

Fork in Continuous Operation, The Precision (H. W. Lamson: October-November, 1938)

Frequencies for the Musician, Standard (August-September, 1937)

Frequency-Limit Monitor for the High-Frequency Bands, A (D. B. Sinclair: February, 1938)

Frequency Monitors, Visual-Type (H. H. Dawes: December, 1938)

Ganged Variacs for Three-Phase Operation (January, 1939)

Generator, Improvements in the Standard-Signal (November, 1937)

Hearing, Experiments in the Psychology of (M. A. Gilman: May, 1938)

Higher Modulation Levels for the Type 605-B Standard-Signal Generator (December, 1938)

High Frequencies, A Standard for Use at - The Type 663 Resistor (D. B. Sinclair: January, 1939)

High Frequencies, New Type 493 Vacuum Thermocouples for Use at (D. B. Sinclair: March, 1939)

High Frequencies, The Behavior of Type 505 Condensers at (D. B. Sinclair: April, 1938)

High-Frequency Bands, A Frequency-Limit Monitor for the (D. B. Sinclair: February, 1938)

High-Frequency Model of the Precision Condenser, A (D. B. Sinclair: October-November, 1938)

High-Frequency Voltage Standard, A (L. B. Arguimbau: June, 1937)

High-Frequency Voltage Standard, A - Type 664-A Thermocouple (L. B. Arguimbau: May, 1938)

Impedance Bridges, A New Null Detector for A-C (H. W. Lamson: April, 1939)

Improved Output Meter, An (W. G. Webster: June, 1937)

Improvements in the Standard-Signal Generator (November, 1937)

Improvements in the Type 568 Condenser (M. A. Gilman: October-November, 1938)

Indicator for A-C Bridge Measurements, A Visual Balance (January, 1938)

Indicator for Monitoring Broadcast and Sound Recording Circuits, A Peak-Reading Power-Level (A. E. Thiessen: October, 1937)

Logarithmic Condensers, Type 739 (A. G. Bousquet: August-September, 1938)

Low-Distortion Oscillator, A (H. H. Scott: April, 1939)

Measuring 100,000 RPM (March, 1938)

Megohm Bridge, The (R. F. Field: July, 1937)

Meter, An Improved Output (W. G. Webster: June, 1937)

Modern Improvements for the Beat-Frequency Oscillator (H. H. Scott: March, 1938)

Modification of the Capacitance Test Bridge for Measuring Grounded Samples, A (February, 1939)

Modification of Type 732-A Distortion and Noise Meter (March, 1939)

Modulation Levels for the Type 605-B Standard-Signal Generator, Higher (December, 1938)

Monitor for the High-Frequency Bands, A Frequency-Limit (D. B. Sinclair: February, 1938)

Monitoring Broadcast and Sound Recording Circuits, A Peak-Reading Power-Level Indicator for (A. E. Thiessen: October, 1937)

Monitors, Visual-Type Frequency (H. H. Dawes: December, 1938)

Multi-Frequency Distortion Measurements on the Broadcast Transmitter (A. E. Thiessen: March, 1939)

Musician, Standard Frequencies for the (August-September, 1937)

New Dial Plates (June, 1937)

New Industrial Stroboscopes, Two (C. E. Worthen: May, 1939)

New Instrument and A New Circuit for Coil or Condenser Checking, A (W. N. Tuttle: August-September, 1937)

New Null Detector for A-C Impedance Bridges, A (H. W. Lamson: April, 1939)

New Type 493 Vacuum Thermocouples for Use at High Frequencies (D. B. Sinclair: March, 1939)

New Wave Analyzer, The - Some of Its Features (L. B. Arguimbau: December, 1938)

Noise, Background Noise Corrections in the Measurement of Machine (L. E. Packard: December, 1937)

Noise Measurement, An Analyzer for (H. H. Scott: February, 1939)

Noise Steps Out (L. E. Packard: December, 1937)

Null Detector for A-C Impedance Bridges, A New (H. W. Lamson: April, 1939)

Obsolescence, Repairs vs. (H. H. Dawes: July, 1937)

100,000 RPM, Measuring (March, 1938)

Operation of the Variac in Oil (S. A. Buckingham: May, 1939)

Oscillator, A-C Operation for Type 613-B Beat-Frequency (April, 1938)

Oscillator, A Low-Distortion (H. H. Scott: April, 1939)

Oscillator, An Ultra-High-Frequency (A. Peterson: October, 1937)

Oscillator for Wide-Band Measurements, A Beat-Frequency (D. B. Sinclair: January, 1939)

Oscillator, Modern Improvements for the Beat-Frequency (H. H. Scott: March, 1938)

Output Meter, An Improved (W. G. Webster: June, 1937)

Peak-Reading Power-Level Indicator for Monitoring Broadcast and Sound Recording Circuits, A (A. E. Thiessen: October, 1937)

ates, New Dial (June, 1937)

Portable Stage-Lighting Control (R. B. Lewis and L. T. Herndon, Jr., Glendale, California, Junior College: July, 1938)

Power-Level Indicator for Monitoring Broadcast and Sound Recording Circuits, A Peak-Reading (A. E. Thiessen: October, 1937)

Precision Condenser, A High-Frequency Model of the (D. B. Sinclair: October-November, 1938)

Precision Fork in Continuous Operation, The (H. W. Lamson: October-November, 1938)

Psychology of Hearing, Experiments in the (M. A. Gilman: May, 1938)

Radio-Frequency Ammeter, The Type 726-A Vacuum-Tube Voltmeter as a (D. B. Sinclair: August-September, 1938)

Radio-Frequency Source for the Laboratory, A (November, 1937)

Radio Receiver Tests with Type 732-A Distortion and Noise Meter (L. E. Packard: July, 1938)

Receiver Tests with Type 732-A Distortion and Noise Meter, Radio (L. E. Packard: July, 1938)

Remodeling Type 605-A Standard-Signal Generators (November, 1937)

Repairs vs. Obsolescence (H. H. Dawes: July, 1937)

Resistor, The Type 663 - A Standard for Use at High Frequencies (D. B. Sinclair: January, 1939)

Schering Bridge, A 60-Cycle (H. W. Lamson: June, 1938)

Series Dimmer, The Variac as a (October-November, 1938)

Shielded Connectors for A-C Measurements (M. A. Gilman: July, 1938)

Shielded Transformers for Balanced Circuit Measurements (W. G. Webster: January, 1938)

Silver Anniversary Convention, At the (June, 1937)

60-Cycle Schering Bridge, A (H. W. Lamson: June, 1938)

Source for the Laboratory, A Radio-Frequency (November, 1937)

Stage-Lighting Control, Portable (R. B. Lewis and L. T. Herndon, Jr., Glendale, California, Junior College: July, 1938)

Stage-Lighting Unit, Variacs Used as Controls in Flexible (P. K. McElroy: March, 1938)

Standard, A High-Frequency Voltage (L. B. Arguimbau: June, 1937)

Standard, A High-Frequency Voltage - Type 664-A Thermocouple (L. B. Arguimbau: May, 1938)

Standard for Use at High Frequencies, A - The Type 663 Resistor (D. B. Sinclair: January, 1939)

Standard Frequencies for the Musician (August-September, 1937)

Standard-Signal Generator, Higher Modulation Levels for the Type 605-B (December, 1938)

Standard-Signal Generator, Improvements in the (November, 1937)

Standard-Signal Generator, Standardizing the (L. B. Arguimbau: August-September, 1937)

Standard-Signal Generators, Remodeling Type 605-A (November, 1937)

Standardizing the Standard-Signal Generator (L. B. Arguimbau: August-September, 1937)

Stroboscopes, Two New Industrial (C. E. Worthen: May, 1939)

Thermocouple, Type 664-A - A High-Frequency Voltage Standard (L. B. Arguimbau: May, 1938)

Thermocouples for Use at High Frequencies, New Type 493 Vacuum (D. B. Sinclair: March, 1939)

Three-Phase Operation, Ganged Variacs for (January, 1939)

Toward a Silent Subway (May, 1939)

Transformer, The Variac (May, 1938)

Transformers for Balanced Circuit Measurements, Shielded (W. G. Webster: January, 1938)

Transmitter, Multi-Frequency Distortion Measurements on the Broadcast (A. E. Thiessen: March, 1939)

Two New Industrial Stroboscopes (C. E. Worthen: May, 1939)

Ultra-High-Frequency Oscillator, An (A. Peterson: October, 1937)

Vacuum Thermocouples for Use at High Frequencies, New Type 493 (D. B. Sinclair: March, 1939)

Vacuum-Tube Voltmeter as a Radio-Frequency Ammeter, The Type 726-A (D. B. Sinclair: August-September, 1938)

Vacuum-Tube Voltmeter, Checking Antenna Power with the Type 726-A (D. B. Sinclair: May, 1939)

Variac as a Series Dimmer, The (October-November, 1938)

Variac in Oil, Operation of the (S. A. Buckingham: May, 1939)

Variac Transformer, The (May, 1938)

Variacs for Three-Phase Operation, Ganged (January, 1939)

Variacs Used as Controls in Flexible Stage-Lighting Unit (P. K. McElroy: March, 1938)

Visual Balance Indicator for A-C Bridge Measurements, A (January, 1938)

Visual-Type Frequency Monitors (H. H. Dawes: December, 1938)

Voltage Standard, A High-Frequency (L. B. Arguimbau: June, 1937)

Voltage Standard, A High-Frequency - Type 664-A Thermocouple (L. B. Arguimbau: May, 1938)

Voltmeter as a Radio-Frequency Ammeter, The Type 726-A Vacuum-Tube (D. B. Sinclair: August-September, 1938)

Voltmeter, Checking Antenna Power with the Type 726-A Vacuum-Tube (D. B. Sinclair: May, 1939)

Wave Analyzer, The New - Some of Its Features (L. B. Arguimbau: December, 1938)

Wide-Band Measurements, A Beat-Frequency Oscillator for (D. B. Sinclair: January, 1939)

Wide-Range Capacitance Test Bridge, A (L. E. Packard: June, 1938)

INDEX BY TYPE NUMBER

70 Variacs
The Variac Transformer (May, 1938)

80 Variacs
The Variac Transformer (May, 1938)

100 Variacs
Ganged Variacs for Three-Phase Operation (January, 1939)
Operation of the Variac in Oil (S. A. Buckingham: May, 1939)
Portable Stage-Lighting Control (R. B. Lewis and L. T. Herndon, Jr., Glendale, California, Junior College: July, 1938)

200 Variacs
Ganged Variacs for Three-Phase Operation (January, 1939)
Portable Stage-Lighting Control (R. B. Lewis and L. T. Herndon, Jr., Glendale, California, Junior College: July, 1938)
Variacs Used as Controls in Flexible Stage-Lighting Unit (P. K. McElroy: March, 1938)

274 Shielded Plugs
Shielded Connectors for A-C Measurements (M. A. Gilman: July, 1938)

318-A Dial Plate
New Dial Plates (June, 1937)

418-G Dummy Antenna
Type 418-G Dummy Antenna (October, 1937)

449-A Adjustable Attenuator
Type 449-A Adjustable Attenuator (November, 1937)

483-F Output Meter
An Improved Output Meter (W. G. Webster: June, 1937)

493 Thermocouple
New Type 493 Vacuum Thermocouples for Use at High Frequencies (D. B. Sinclair: March, 1939)

505 Condensers
The Behavior of Type 505 Condensers at High Frequencies (D. B. Sinclair: April, 1938)

516-C Radio-Frequency Bridge
Broadcast Antenna Measurements with the R-F Bridge (D. B. Sinclair: February, 1938)

544-B Megohm Bridge
The Megohm Bridge (R. F. Field: July, 1937)

568 Variable Air Condensers
Improvements in the Type 568 Condenser (M. A. Gilman: October-November, 1938)

575-D Piezo-Electric Oscillator
Visual-Type Frequency Monitors (H. H. Dawes: December, 1938)

578 Transformer
Shielded Transformers for Balanced Circuit Measurements (W. G. Webster: January, 1938)

581-A Frequency-Deviation Meter
Visual-Type Frequency Monitors (H. H. Dawes: December, 1938)

605-A Standard-Signal Generator
Higher Modulation Levels for the Type 605-B Standard-Signal Generator (December, 1938)
Remodeling Type 605-A Standard-Signal Generators (November, 1937)

605-B Standard-Signal Generator
Higher Modulation Levels for the Type 605-B Standard-Signal Generator (December, 1938)
Improvements in the Standard-Signal Generator (November, 1937)

608-A Oscillator
A Low-Distortion Oscillator (H. H. Scott: April, 1939)

613-B Beat-Frequency Oscillator
A-C Operation for Type 613-B Beat-Frequency Oscillator (April, 1938)

613-P1 Power Supply
A-C Operation for Type 613-B Beat-Frequency Oscillator (April, 1938)

631-B Strobotac
Two New Industrial Stroboscopes (C. E. W.: May, 1939)

648-A Strobolux
Two New Industrial Stroboscopes (C. E. W.: May, 1939)

663 Resistors
The Type 663 Resistor - A Standard for Use at High Frequencies (D. B. Sinclair: January, 1939)

664-A Thermocouple
Type 664-A Thermocouple - A High-Frequency Voltage Standard (L. B. Arguimbau: May, 1938)

671-A Schering Bridge
A 60-Cycle Schering Bridge (H. W. Lamson: June, 1938)

684-A Modulated Oscillator
A Radio-Frequency Source for the Laboratory (November, 1937)

686-A Power-Level Indicator
A Peak-Reading Power-Level Indicator for Monitoring Broadcast and Sound Recording Circuits (A. E. Thiessen: October, 1937)

700-A Wide Range Beat-Frequency Oscillator
A Beat-Frequency Oscillator for Wide-Band Measurements (D. B. Sinclair: January, 1939)

707-A Cathode-Ray Null Indicator (H. W. Lamson: April, 1939)

713-B Beat-Frequency Oscillator
Modern Improvements for the Beat-Frequency Oscillator (H. H. Scott: March, 1938)

715-A Direct-Current Amplifier
A-C Operated Direct-Current Amplifier for Industrial Use (J. K. Clapp: February, 1939)

721-A Coil Comparators
A New Instrument and A New Circuit for Coil or Condenser Checking (W. N. Tuttle: July, 1937)

722 Precision Condensers
A High-Frequency Model of the Precision Condenser (D. B. Sinclair: October-November, 1938)
Connection Errors in Capacitance Measurements (R. F. Field: January, 1938)

726-A Vacuum-Tube Voltmeter
Checking Antenna Power with the Type 726-A Vacuum-Tube Voltmeter (D. B. Sinclair: May, 1939)
The Type 726-A Vacuum-Tube Voltmeter as a Radio-Frequency Ammeter (D. B. Sinclair: August-September, 1938)

732-A Distortion and Noise Meter
Modification of Type 732-A Distortion and Noise Meter (March, 1939)
Radio Receiver Tests with Type 732-A Distortion and Noise Meter (L. E. Packard: July, 1938)

732-B Distortion and Noise Meter
Multi-Frequency Distortion Measurements on the Broadcast Transmitter (A. E. Thiessen: March, 1939)

732-P1 Range Extension Filters
Multi-Frequency Distortion Measurements on the Broadcast Transmitter (A. E. Thiessen: March, 1939)

732-P5, -P6 Coils
Multi-Frequency Distortion Measurements on the Broadcast Transmitter (A. E. Thiessen: March, 1939)

736-A Wave Analyzer
The New Wave Analyzer - Some of Its Features (L. B. Arguimbau: December, 1938)

739 Logarithmic Condensers
Type 739 Logarithmic Condensers (A. G. Bousquet: August-September, 1938)

740-B Capacitance Test Bridge
A Wide-Range Capacitance Test Bridge (L. E. Packard: June, 1938)

740-BG Capacitance Test Bridge
A Modification of the Capacitance Test Bridge for Measuring Grounded Samples (February, 1939)

759-A Sound-Level Meter
Noise Steps Out (L. E. Packard: December, 1937)

759-P8 Connector
Type 759-P8 Connector (July, 1938)

760-A Sound Analyzer
An Analyzer for Noise Measurement (H. H. Scott: February, 1939)

775-A Frequency-Limit Monitor
A Frequency-Limit Monitor for the High-Frequency Bands (D. B. Sinclair: February, 1938)

814-AR Amplifier
A Visual Balance Indicator for A-C Bridge Measurements (January, 1938)

815-A Precision Fork
The Precision Fork in Continuous Operation (H. W. Lamson: October-November, 1938)

834-A Electronic Frequency Meter
Measuring 100,000 RPM (March, 1938)

INDEX BY AUTHOR

Arguimbau, L. B.
A High-Frequency Voltage Standard (June, 1937)
Standardizing the Standard-Signal Generator (August-September, 1937)
The New Wave Analyzer - Some of Its Features (December, 1938)
Type 664-A Thermocouple - A High-Frequency Voltage Standard (May, 1938)

Bousquet, A. G.
Type 739 Logarithmic Condensers (August-September, 1938)

Buckingham, S. A.
Operation of the Variac in Oil (May, 1939)

Clapp, J. K.
A-C Operated Direct-Current Amplifier for Industrial Use (February, 1939)

Dawes, H. H.
Repairs vs. Obsolescence (July, 1937)
Visual-Type Frequency Monitors (December, 1938)

Field, R. F.
Connection Errors in Capacitance Measurements (January, 1938)
The Megohm Bridge (July, 1937)

Gilman, M. A.
Experiments in the Psychology of Hearing (May, 1938)
Improvements in the Type 568 Condenser (October-November, 1938)
Shielded Connectors for A-C Measurements (July, 1938)

Herndon, Jr., L. T.
Portable Stage-Lighting Control (July, 1938)

Lamson, H. W.
A New Null Detector for A-C Impedance Bridges (April, 1939)
A 60-Cycle Schering Bridge (June, 1938)
The Precision Fork in Continuous Operation (October-November, 1938)

Lewis, R. B.
Portable Stage-Lighting Control (July, 1938)

McElroy, P. K.
Variacs Used as Controls in Flexible Stage-Lighting Unit (March, 1938)

Packard, L. E.
A Wide-Range Capacitance Test Bridge (June, 1938)
Background Noise Corrections in the Measurement of Machine Noise (December, 1937)
Noise Steps Out (December, 1937)
Radio Receiver Tests with Type 732-A Distortion and Noise Meter (July, 1938)

Peterson, A
An Ultra-High-Frequency Oscillator (October, 1937)

Scott, H. H.
A Low-Distortion Oscillator (April, 1939)
An Analyzer for Noise Measurement (February, 1939)
Modern Improvements for the Beat-Frequency Oscillator (March, 1938)

Sinclair, D. B.
A Beat-Frequency Oscillator for Wide-Band Measurements (January, 1939)
A Frequency-Limit Monitor for the High-Frequency Bands (February, 1938)
A High-Frequency Model of the Precision Condenser (October-November, 1938)
Broadcast Antenna Measurements with the R-F Bridge (February, 1938)
Checking Antenna Power with the Type 726-A Vacuum-Tube Voltmeter (May, 1939)
New Type 493 Vacuum Thermocouples for Use at High Frequencies (March, 1939)
The Behavior of Type 505 Condensers at High Frequencies (April, 1938)
The Type 663 Resistor - A Standard for Use at High Frequencies (January, 1939)
The Type 726-A Vacuum-Tube Voltmeter as a Radio-Frequency Ammeter (August-September, 1938)

Thiessen, A. E.
A Peak-Reading Power-Level Indicator for Monitoring Broadcast and Sound Recording Circuits (October, 1937)
Multi-Frequency Distortion Measurements on the Broadcast Transmitter (March, 1939)

Tuttle, W. N.
A New Instrument and A New Circuit for Coil or Condenser Checking (August-September, 1937)

Webster, W. G.
An Improved Output Meter (June, 1937)
Shielded Transformers for Balanced Circuit Measurements (January, 1938)

Worthen, C. E.
Two New Industrial Stroboscopes (May, 1939)

PRINTED IN U.S.A.

THE General Radio EXPERIMENTER

VOLUME XII NO. 8 JANUARY, 1938

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also IN THIS ISSUE

Page

A VISUAL BALANCE INDICATOR FOR A-C BRIDGE MEASUREMENTS 5

SHIELDED TRANSFORMERS FOR BALANCED CIRCUIT MEASUREMENTS 6

CONNECTION ERRORS IN CAPACITANCE MEASUREMENTS

● **WHEN A CONDENSER** is connected into a circuit, some type of connecting wires must be used. These wires will have capacitances to each other and to other parts of the circuit, with the result that the capacitance actually introduced into the circuit is different from that of the condenser alone. Even when one condenser is substituted for another, using exactly the same leads, the capacitance of these connections may be different in the two cases, particularly if the two condensers differ in size and shape. Such connection errors, while negligible in many cases involving large capacitances, become of importance in the measurement and intercomparison of small capacitances and of standards.

How many different types of connection capacitances are there and what are their magnitudes? An actual example will serve to illustrate them. Suppose that two TYPE 722 Precision Condensers are to be connected together. With their panels touching, their terminals are three inches apart. Let these terminals be connected by two No. 16 bare copper wires spaced ¾ of an inch apart (standard General Radio spacing). The wire should be bare to eliminate both the extra capacitance intro-

FIGURE 1. The accuracy to which the calibration of a TYPE 722-D Precision Condenser (shown at right) can be specified depends to a considerable degree upon the errors discussed in this article

duced by the insulation, whose dielectric constant is greater than unity (3 perhaps), and the added dielectric loss in this insulation. The wire should be of small diameter because its capacitance varies as the logarithm of the ratio of its diameter to some other length, spacing of the wires, or distance to ground. Precision condensers are two-terminal condensers with one terminal connected to the panel and shield. One of the connecting wires is, therefore, connected to the panel and to ground.

There are three types of capacitance involved: capacitance between the two wires, capacitance between the high wire and the panel, and capacitance between the high wire and ground. The calculated values of these three capacitances are 0.22 $\mu\mu$f, 1.07 $\mu\mu$f, and 0.79 $\mu\mu$f, respectively. They are, however, by no means additive. The grounded wire shields the panel so that part of the capacitance to the panel is transferred to the grounded wire. Similarly, part of the capacitance to an infinite ground is transferred to the panel which is shielding it. The actual total capacitance is 1.19 $\mu\mu$f. This is certainly not negligible when measuring capacitances of 1000 $\mu\mu$f or smaller.

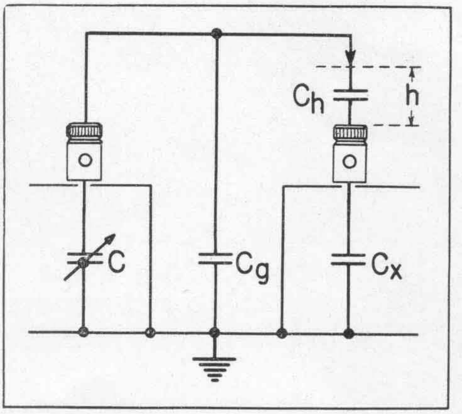


FIGURE 3. The stray capacitances C_g and C_h produce errors in the measurement of the unknown condenser C_x

It should then be sufficient, when connecting two condensers in parallel, to add the capacitance of the added condenser and the connecting wires. Unfortunately, the latter, as indicated above, is not a constant for a given pair of wires, but depends greatly upon the distance of these wires to all grounded panels and hence on the size and shape of the added condenser. It is, therefore, usual in substitution measurements to keep the leads connected to the standard condenser with the unknown in position and with its grounded terminal already connected. The high lead is in position and just not touching the high terminal of the unknown. Such a disposition of ap-

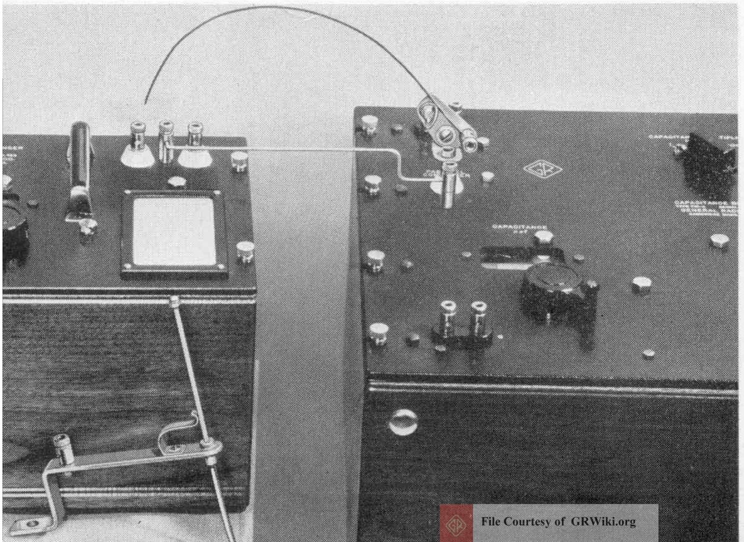


FIGURE 2. This fine wire connector, by means of which Curve *A* of FIGURE 5 was obtained, is used in calibrating all precision condensers in our laboratories. An older type of connector is shown leaning against the condenser cabinet, and produces a much greater error as shown in Curve *B* of FIGURE 5

paratus is shown in Figure 2. Having made a sufficient measurement, such as balancing a bridge, for this condition, the unknown condenser is connected into circuit and the second balance made. In this manner the effect of the leads is taken into account, for this should be the same in both measurements. It appears, however, that the capacitance measured depends upon the original separation of the high lead and the high terminal of the unknown.

Figure 3 illustrates the various capacitances which enter the problem. For the first measurement the high lead has a total capacitance C_g to ground and a capacitance C_h to the high terminal of the unknown capacitance C_x, both of these capacitances corresponding to a certain separation h. The total capacitance of the system is

$$C + C_g + \frac{C_h C_x}{C_h + C_x}.$$

The high lead is then brought into contact with the high terminal, making $h = 0$ and $C_h = \infty$. The standard condenser is then changed to a capacitance C' such that the total capacitance of the system is the same as before. The change in capacitance ΔC of the standard condenser is

$$\Delta C = C_x + \Delta C_g - C_h$$

where C_h is written for $\frac{C_h C_x}{C_h + C_x}$ because in general C_h is very small compared to C_x. Other observations are then made for different distances of separation h, and the capacitance changes ΔC plotted against h, as shown in Figure 4. If in moving the high lead over the distance h, the ground capacitance C_g does not change, i.e., $\Delta C_g = 0$, the plot of ΔC against h will have a horizontal asymptote, which is the true value of C_x. Even under the most favorable conditions, there will be some change in this ground capacitance as the spacing h is changed. If the high lead is a fine wire and is kept a considerable distance from all grounded surfaces, the change in C_g will be approximately a linear function of h. The plot of ΔC will then have a slanting asymptote whose intercept is the value of C_x. The finer the wire and the greater the distance to ground, within limits, the more nearly horizontal is this asymptote. For a large wire near the grounded panels the change in C_g is such that this plot of ΔC has a maximum and changes by such a large amount that it is impossible to draw an asymptote.

Observations made with a TYPE 716-A Capacitance Bridge on a TYPE 722-D Precision Condenser are plotted in Figure 5. Curve A was obtained with the connector shown mounted on the bridge in Figure 2. The fine steel wire is kept as

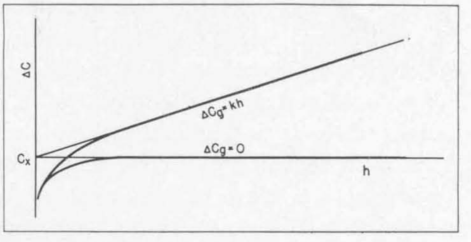


FIGURE 4. Theoretically, the measured capacitance of an air condenser plotted as a function of the distance h shown in FIGURE 3 has either a horizontal or a vertical asymptote

far from the grounded panels as possible and is raised by means of a cam which is mounted on the triangular support. The slanting asymptote is well defined and gives a value of 99.13 $\mu\mu$f for the capacitance of the unknown condenser. The curve has this value for a separation h of ¼ inch. Hence, with this connector and a ¼-inch separation, it should be possible to measure capacitance to within ± 0.01 $\mu\mu$f. Curve B was obtained using the connector which is shown leaning against the precision condenser. Only the vertical rod moves, and its capacitance to ground should change only slowly. The supporting bar is, however, wide enough to shield the rod and cause the ground capacitance to change rapidly as the rod is raised. Hence all measured values of ΔC are low, and no asymptote can be drawn. The panel of the precision condenser was next depressed 5 inches and Curve *C* obtained. This shows a great improvement over Curve *B*, but the slanting asymptote is not easily defined. The critical separation *h* is 1⅜ inches. Curve *D* was obtained with No. 16 parallel wires at the same height from the panel as the hole in the terminal. There is no possibility of drawing an asymptote, and the critical separation is only 0.1 inch.

The fine wire connector is now used for all accurate capacitance measurements in the General Radio testing laboratory. The critical separation of ¼ inch is always obtained by adjustment of the height of the high terminal and the cam then used to make quick connection or disconnection. Observations can be repeated to 0.01 $\mu\mu$f and to 0.02 $\mu\mu$f even when the condensers are removed and then reassembled. Different types of condensers, both standard and unknown, can affect the value of the critical separation so that 0.1 $\mu\mu$f is at present set as a conservative error.

There are, of course, many ways of connecting condensers in parallel so that their capacitances add with only slight error. TYPE 509 Condensers are built to be stacked one on top of another. Plugs projecting downward from the terminals fit into the jack tops of the terminals below. The plugs add a capacitance of about 0.5 $\mu\mu$f. There is a decrease in capacitance amounting to about 0.3 $\mu\mu$f when similar units are placed below and above. These condensers are, therefore, most accurately measured by using two dummy cases between which they are always placed. The error of measurement is ± 0.01 $\mu\mu$f.

When the power factor of a condenser, as well as its capacitance, is to be measured, extra care must be taken to keep the contact resistance of the connections low. The equivalent series resistance of a condenser varies inversely both as the capacitance and as the frequency. Even at a frequency of 1 kilocycle the resistance of a 1 μf condenser of power factor 0.0005 is only 0.08 ohm. The use of plugs and jacks under these circumstances is questionable.

In the most precise work the condenser is provided with a third terminal connected to guard electrodes or to the shield from which the main terminals of the condenser are now insulated, and the bridge is provided with a guard circuit to which the extra terminal is connected. By these devices the connection capacitances and their power factors are removed from the direct measurement.

— ROBERT F. FIELD

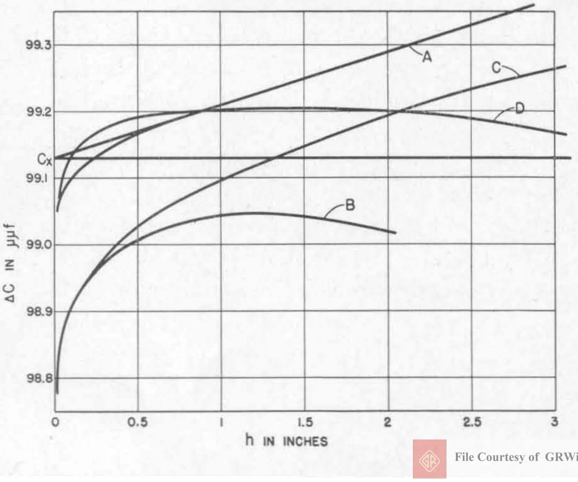


FIGURE 5. Different types and arrangements of connectors produce differently shaped plots of measured capacitance against the distance *h*. Curve *A*, taken with the fine wire connector of FIGURE 2, is the only one of the four curves which has a well-defined asymptote

A VISUAL BALANCE INDICATOR FOR A-C BRIDGE MEASUREMENTS

● **THE PRECISION OF BALANCE** of a-c bridges is a direct function of the sensitivity of the null indicator. At a frequency of 1000 cycles, where most electrical communications measurements are made, magnetic head telephones, by virtue of their mechanical resonance, have adequate sensitivity when used with an amplifier. For commercial power frequencies and for the higher audio range, however, headphones are not suitable, being limited by their own lack of sensitivity as well as that of the ear. For these frequencies, a visual indicator is desirable.

The copper-oxide-rectifier meter in conjunction with an amplifier provides adequate sensitivity and is convenient to use. To facilitate the use of this visual indicator, the Type 814-AR Amplifier (a relay-rack model) is provided with space for mounting a standard-size meter. This amplifier, in conjunction with a copper-oxide meter, is an excellent detector for 60-cycle measurements.

The meter, mounted on the amplifier panel, is shown in Figure 1. Space behind the meter is used for batteries.

This meter is also used in the Type 483-F Output Meter*. Its impedance is 20,000 ohms and its frequency characteristic is considerably better than any previously obtainable. Two volts are required for full-scale deflection, and the smallest scale division is 0.1 volt. A deflection of one-quarter division, or 0.025 volt, is easily detected.

About 4 microvolts applied to the amplifier input will give this deflection on the meter. With 10 volts applied to the Type 716-A Capacitance Bridge, this means that capacitance and power factor can be balanced to a few millionths.

The sensitivity of the meter is essentially constant up to 10 kilocycles and about equivalent to that of head telephones at 10 kilocycles and 100 cycles. Head telephones at low frequencies, however, tend to emphasize harmonics because of mechanical resonance effects, and, at frequencies as low as 60 cycles, there is always the possibility that the ear will re-combine harmonics to produce the fundamental.

Experimenter, June, 1937.

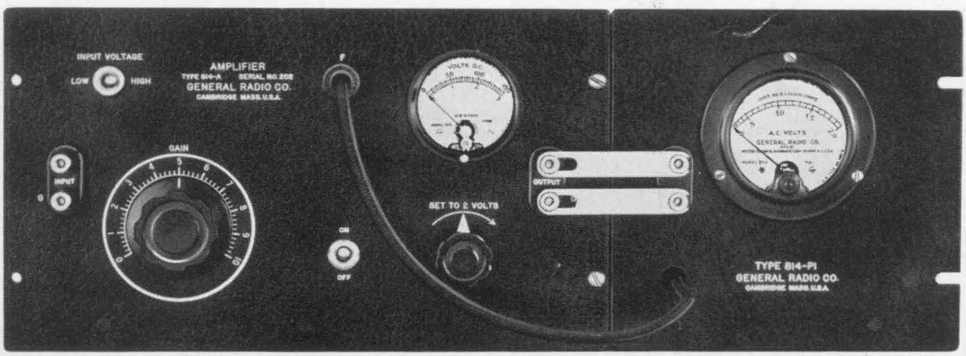


Figure 1. The Type 814-AR Amplifier with meter and filter. The filter can be mounted at the rear of the instrument, and is connected to the panel jack through a hole in the panel

Sharpness of balance with either meter or headphones is greatly increased by the use of a filter to exclude harmonics. TYPE 814-P Tuned Circuits* have been designed for this purpose and can be connected in the grid circuit of the last amplifier tube by plugging into a jack on the amplifier panel. These circuits are stocked in two models, one operating at 1000 cycles and 400 cycles, and the other tuned to 60 cycles. Other single-frequency and multiple-frequency units can be built to order.

Experimenter, March, 1937.

Type	*Description*	*Code Word*	*Price*
814-AR	Amplifier	ALONE	$97.50
814-P2	Tuned Circuit — 400 and 1000 cycles	AMBLE	17.50
814-P3	Tuned Circuit — 60 cycles	AMPLE	12.00
488-D1	Rectifier Meter	OURMETSEAT	30.00

This instrument is licensed under patents of the American Telephone and Telegraph Company solely for utilization in research, investigation, measurement, testing, instruction, and development work in pure and applied science.

SHIELDED TRANSFORMERS FOR BALANCED CIRCUIT MEASUREMENTS

● **ONE OF OUR RECENT** routine measurement problems required a balanced power source at several hundred kilocycles. To obtain this, a shielded transformer operating at these frequencies was necessary. TYPE 578 Transformers were tried, and proved to be excellent for the purpose. These transformers were originally designed for use with impedance bridges and were described in the *Experimenter* for April, 1934 and October, 1935.

Two shields are used on the TYPE 578 Transformer so that it can be used in either direction. The shields completely surround each winding and make the terminal capacitances equal. This double shielding also reduces the magnitude of the terminal capacitances, which is desirable for work at high frequencies in order to avoid too great a shunting effect on the secondary load impedances.

Figure 2 shows the TYPE 578 Transformer as the coupling device between an unbalanced and a balanced system. The capacitances which must be equal (or of negligible magnitude) are C_1 and C_2. Each of these consists of the terminal capacitance of the winding to shield in series with one-half the shield-to-shield capacitance. The magnitude of C_1 and C_2 is about 40 $\mu\mu$f each and they do not differ by more than 3 $\mu\mu$f.

FIGURE 1.
The TYPE 578 Transformer

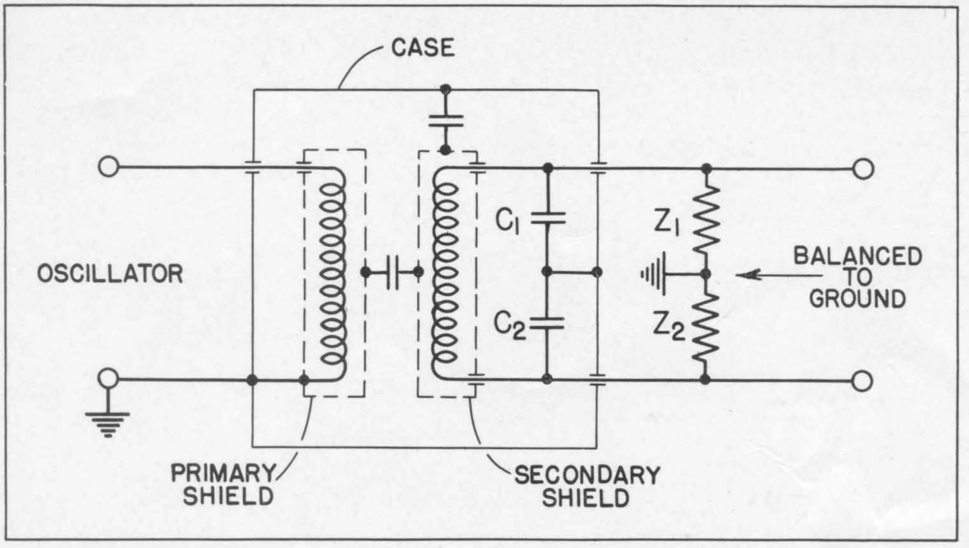


FIGURE 2. This diagram shows the shielding arrangement and the capacitances which are associated with each terminal. For the connection shown, C_1 and C_2 are about 40 $\mu\mu$f each. Note that the transformer windings are not center-tapped

With Z_1 and Z_2 each equal to 3000 ohms resistive, the unbalance caused by the maximum inequality of transformer terminal capacitances is, at 0.5 megacycle, about 1.5% in impedance and 2° in phase. At lower frequencies and with lower values of Z_1 and Z_2, the unbalance is, of course, correspondingly less. At audio and low radio frequencies and with 500-ohm circuits, little, if any, unbalance will be noticed.

When the transformer is used to obtain a balanced source for measurements of gain or attenuation, the magnitude of Z_1 and Z_2 is not important since the voltages across them are usually held constant to simulate a zero-impedance generator.

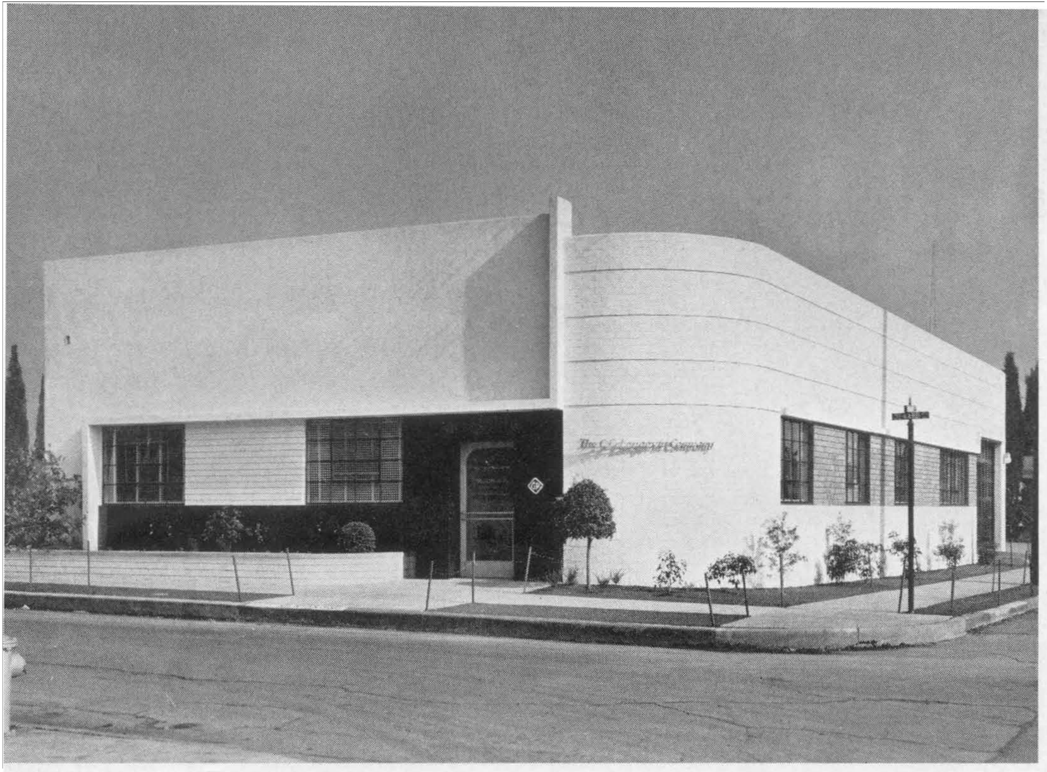
When a vacuum-tube voltmeter is used to measure equal voltages across Z_1 and Z_2, even order harmonics in the voltage wave can produce unequal voltage readings if the voltmeter is not a true square-law device. To avoid this, it is desirable to use a filter between generator and transformer.

Three models of this transformer are available, covering an effective frequency range of 20 cycles to 0.5 megacycle. — W. G. WEBSTER

Type	Frequency Range*	Impedance Range* Primary	Impedance Range* Secondary†	Code Word	Price
578-A	50 cycles to 10 kc	50 Ω to 5 KΩ	1 KΩ to 100 KΩ	TABLE	$15.00
578-B	20 cycles to 5 kc	60 Ω to 6 KΩ	1 KΩ to 120 KΩ	TENOR	15.00
578-C	2 kc to 500 kc	20 Ω to 2 KΩ	4 KΩ to 40 KΩ	TEPID	15.00

*Range for voltage transfer within 6 db of maximum value. At extreme ends of both impedance and frequency ranges, the combined loss may be 12 db.

†The low impedance winding is considered to be the primary.



Of modern architecture in keeping with its general surroundings is our new Hollywood office at 1000 North Seward Street. We share the occupancy of this building with the C. C. Langevin Company, who for nearly a decade and a half have represented us on the Pacific Coast. The specialization of the Langevin organization in sound work and the diversification of our own activities made separation of the two organizations advisable. The pangs of parting were greatly softened by the arrangement which makes Mr. Langevin our genial landlord.

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

GENERAL RADIO COMPANY

30 STATE STREET - CAMBRIDGE A, MASSACHUSETTS

BRANCH ENGINEERING OFFICES

90 WEST STREET, NEW YORK CITY

1000 NORTH SEWARD STREET, LOS ANGELES, CALIFORNIA

THE General Radio EXPERIMENTER

VOLUME XII NO. 9 FEBRUARY, 1938

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also
IN THIS ISSUE

Page

Broadcast Antenna Measurements with the R-F Bridge 5

A FREQUENCY-LIMIT MONITOR FOR THE HIGH-FREQUENCY BANDS

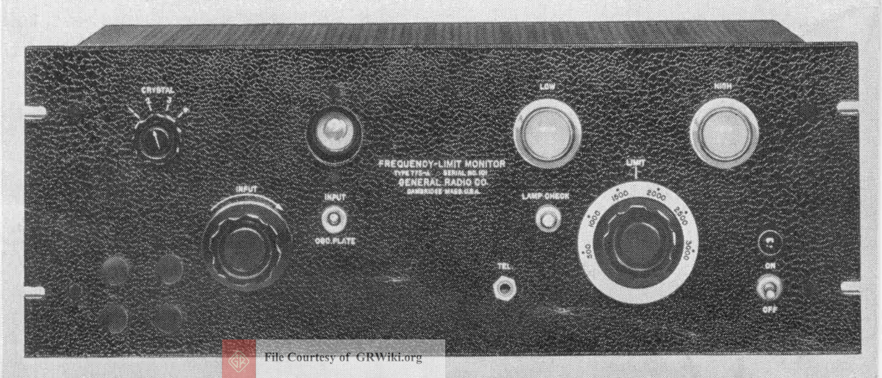
● **THE INCREASING USE** of frequencies between 1500 kc and 30,000 kc for special services, such as police, maritime, and aircraft communication and international broadcasting, in recent years has resulted in sufficient congestion to warrant frequency assignments within fairly close accuracy tolerances.

In order to maintain transmitter frequencies within the accuracy limits required by law, it is essential that each station maintain either a frequency monitor or rather elaborate frequency-measuring equipment.

Since the total investment in plant for stations in the high-frequency spectrum is often very small in comparison with that for most standard broadcast stations, it is difficult to justify the relatively large outlay involved in the purchase of a highly precise direct-reading monitor such as is required in the broadcast band. On the other hand, since operating personnel must often be kept at a minimum, it is desirable to have available an instrument which tells at a glance whether the transmitter frequency is within its legal accuracy limits.

The Type 775-A Frequency-Limit Monitor is designed to meet the

Figure 1. Panel view of the Type 775-A Frequency-Limit Monitor



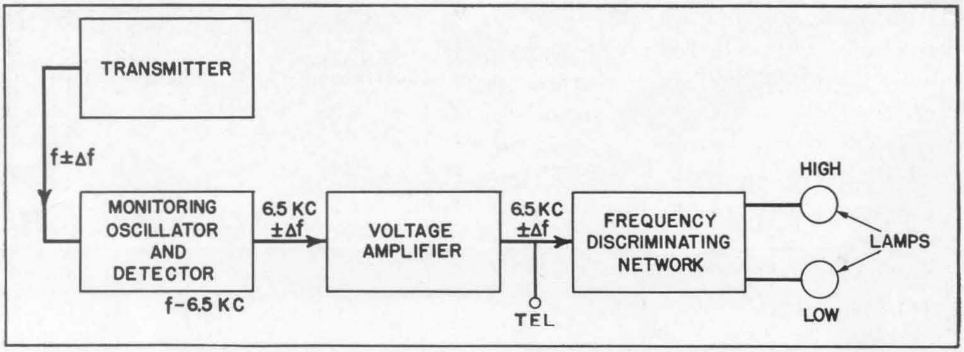


FIGURE 2. Functional diagram showing the operation of the frequency-limit monitor

need for a simple, compact, self-contained, and moderately priced frequency monitor to cover the frequency range from 1500 kc to 30,000 kc.

The requirements to be met by a frequency monitor for the high-frequency spectrum are quite different from those for the standard broadcast band.

In the broadcast band, sufficient congestion exists so that in many cases several different stations are assigned to the same channel. Under such conditions, when interference conditions arise, the interference is of the close heterodyne or "flutter" type. This type of interference becomes most annoying when the interfering signals differ sufficiently in frequency to produce an audible beat note. While nominally the accuracy tolerance on broadcast station frequencies is ± 50 cycles, the Federal Communications Commission, therefore, actually requires much closer adherence to the true assigned frequency.

In order to check broadcast station frequencies to a sufficient degree of accuracy, it is required by law that each station shall maintain a continuously indicating, direct-reading frequency monitor of very high accuracy. The General Radio TYPE 475-A Frequency Monitor, used in conjunction with the TYPE 681-A Frequency-Deviation Meter, has long been approved for this class of service and is now in use in hundreds of stations the world over.

At frequencies above the standard broadcast band, conditions are radically different. Because of the larger number of channels available, the greater relative importance of "sky waves" in comparison with "ground waves," and the negligible amount of "chain" operation, sharing of common channels by continuous services is much less.

Such interference as occurs in the high-frequency range is consequently more often of the adjacent channel heterodyne type than of the close heterodyne type common to the broadcast band.

The frequency tolerances in the high-frequency bands have been set up to minimize such interference. Since adjacent channel heterodyne interference is not sensitive to small frequency changes within these tolerances, literal compliance with the accuracy limits set up is consequently sufficient to insure maintenance of reliable service. A monitor which tells at a glance whether the transmitter frequency is, or is not, within its legal accuracy limits is a convenient type to use for the high-frequency range.

The TYPE 775-A Frequency-Limit Monitor is designed for such a function. Mounted on the panel are two warning lamps and a dial, which is set to the frequency limit assigned to the station to be monitored. So long as the transmitter frequency remains within the assigned limits, both lamps remain dark. If the transmitter frequency increases beyond the assigned accuracy limit, one warning lamp lights. If the transmitter frequency decreases beyond the assigned accuracy limit, the other lamp lights.

For more accurate monitoring, the LIMIT dial may be set to closer tolerances than those required by law. The warning lamps simply indicate when the deviation in transmitter frequency exceeds the limits set on the dial.

A functional diagram of the TYPE 775-A Frequency-Limit Monitor is shown in Figure 2. The instrument consists of a highly stable quartz-controlled monitoring oscillator which produces a voltage rich in harmonics, a detector which mixes the transmitter frequency and a harmonic of the local monitoring frequency to produce a low-frequency beat note, and a frequency-discriminating circuit which lights a warning lamp when the beat frequency departs from a value of 6.5 kc by more than a predetermined amount.

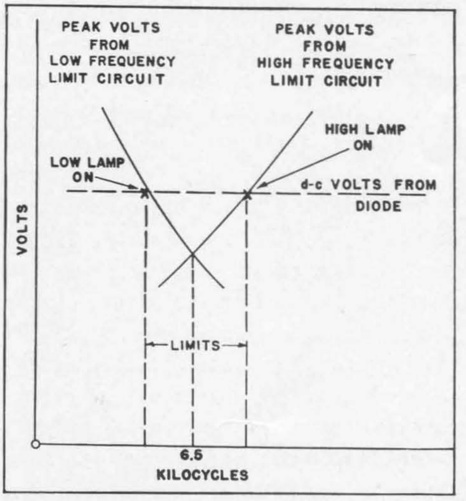
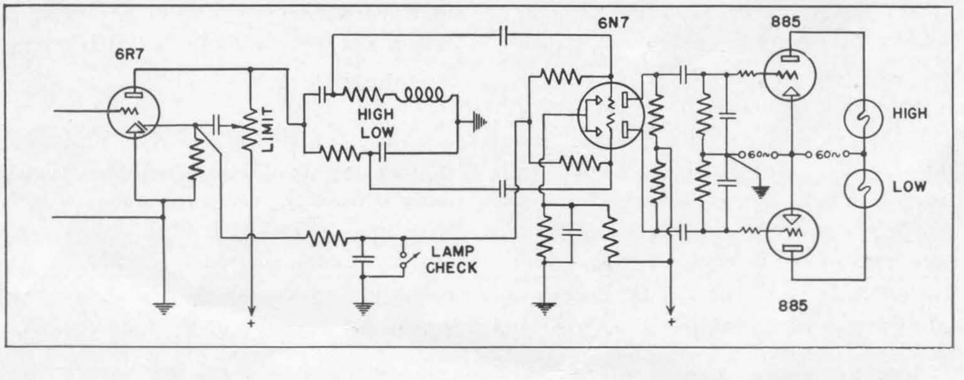


FIGURE 3. Voltage-frequency characteristics of the frequency-discriminating circuit

Provision is made for the use of four

FIGURE 4. Schematic wiring diagram of the limit-indicating section of the frequency-limit monitor. The beat-frequency voltage obtained from the detector is impressed upon the grid of the 6R7 duplex-diode-triode. The a-c plate voltage of the 6R7 is developed across the frequency-discriminating circuit, the characteristics of which are shown in FIGURE 3. The voltage obtained from each branch of this circuit is fed to a grid of the 6N7 dual triode, which is biased to cut-off. Each plate of the 6N7 feeds a gas triode which has a warning lamp in its plate circuit. In shunt with the frequency-discriminating circuit is a potentiometer which is used to obtain a fraction of the total a-c plate voltage. This fraction is rectified by one of the 6R7 diodes and used to bias the grids of the 6N7 beyond their normal cut-off voltage. The d-c bias, controlled by the setting of the LIMIT dial, determines the frequency at which the lamps will light. When an a-c voltage on either grid exceeds this bias, plate current flows, tripping one of the 885's and lighting a warning lamp



separate crystals to monitor four different frequencies. The quartz plates are of the low-temperature-coefficient type and are protected against large changes in ambient temperature by a simple temperature-control system which maintains the compartment temperature at 50° C. ±3° C. An individual tuning condenser for each crystal is mounted on the panel and a selector switch on the panel simultaneously switches the quartz plate, tuning condenser, and input circuit when different transmitter frequencies are to be monitored.

An electron-ray tube is used to indicate when the local monitoring oscillator is correctly adjusted. By means of a switch mounted on the panel, it may also be connected to indicate when the correct input from the transmitter is obtained. The accuracy of the instrument is not critically affected by either local oscillator adjustment or input voltage.

The dial on the panel used to set the accuracy limits is engraved for frequency deviations from ±500 cycles to ±3000 cycles. With this span of adjustment the frequency range of the instrument is as indicated in the specifications below.

A simple push-button switch on the panel is provided for routine checking of the instrument under operating conditions. Once installed and put in proper operation, no further adjustments are necessary except for changing the LIMIT dial when switching from one frequency to another.

The instrument is entirely self-contained. It may be operated from any 110-120 volt, 40-60 cycle line.

— D. B. Sinclair

SPECIFICATIONS

Frequency Range:
For limits of ±0.10%: 1500– 3000 kc
For limits of ±0.05%: 1500– 6000 kc
For limits of ±0.04%: 1500– 7500 kc
For limits of ±0.03%: 1700–10,000 kc
For limits of ±0.02%: 2500–15,000 kc
For limits of ±0.01%: 5000–30,000 kc

Accuracy of Monitoring Frequency: The absolute accuracy is 0.003% when using Type 376-M Quartz Plate.

Stability of Monitoring Frequency: The frequency stability is 0.001% over long periods of time.

Quartz Plate: Type 376-M Quartz Plates are to be used with this instrument and must be ordered separately.

Accuracy of Frequency Discriminating Network: When operated at proper input voltage, the warning lamps will light at frequencies which are within ±200 cycles ±10% of the LIMIT dial reading.

Tubes: Supplied with instrument —
1 — Type 6A8 Pentagrid Converter
1 — Type 6J7 Pentode
1 — Type 6R7 Duplex-Diode Triode
1 — Type 6N7 Dual Triode
2 — Type 885 Gas Triodes
1 — Type 6X5 Rectifier

Mounting: Standard 19-inch relay-rack mounting or table mounting.

Accessories Required: Type 376-M Quartz Plate.

Dimensions: Panel (width) 19 inches x (height) 7 inches x (depth) 10⅝ inches, overall.

Net Weight: 29⅝ pounds.

Power Supply: 110-120 volts, 40-60 cycles.

Power Input: Approximately 72 watts with heater ON and approximately 45 watts with heater OFF, with 115-volt line.

Type		*Code Word*	*Price*
775-A	(Including tubes, but less quartz plate)	DOUGH	$240.00
376-M	Quartz Plate (for use with Type 775-A)	LABOR	50.00 each

This instrument is manufactured under the following U. S. Patents and license agreements:
Patents of the American Telephone and Telegraph Company, solely for utilization in research, investigation, measurement, testing, instruction and development work in pure and applied science.
Patents and patent applications of Dr. G. W. Pierce pertaining to piezo-electric crystals and their associated circuits.

BROADCAST ANTENNA MEASUREMENTS WITH THE R-F BRIDGE

• IN THE PAST FEW YEARS the TYPE 516-C Radio-Frequency Bridge has been widely used by broadcast engineers for measuring the impedance of antennas and their associated coupling and feeding systems. The bridge method of measurement is rapid, convenient, and accurate. Radiating systems can be lined up quickly and, once adjusted, can be maintained at top performance through routine checks.

The application of the bridge to measurements of this sort is best illustrated by discussing a typical broadcast installation recently measured. A functional diagram of the radiating system at Station WEEI* is illustrated in Figure 2. This radiating system is designed to reduce the radiation in the east-west direction in order to avoid possible interference with Station WTAG in Worcester, Mass., which is operating on the adjacent channel. It consists of two vertical antennas, W and E, which are fed through a bridging transformer T, phasing networks ϕ_W and ϕ_E, concentric transmission lines L_W and L_E and impedance matching networks Z_W and Z_E.

By adjusting the bridging transformer T, and the phasing networks ϕ_W and ϕ_E, the ratio of magnitudes and the phases of the currents in the two antennas may be varied to give the desired field-strength pattern.

*C.B.S., Boston, Mass., 590 kc. We are indebted to the management and staff of WEEI for permission to carry out measurements on the radiating system of this station, which was chosen as a representative example of modern broadcast installation.

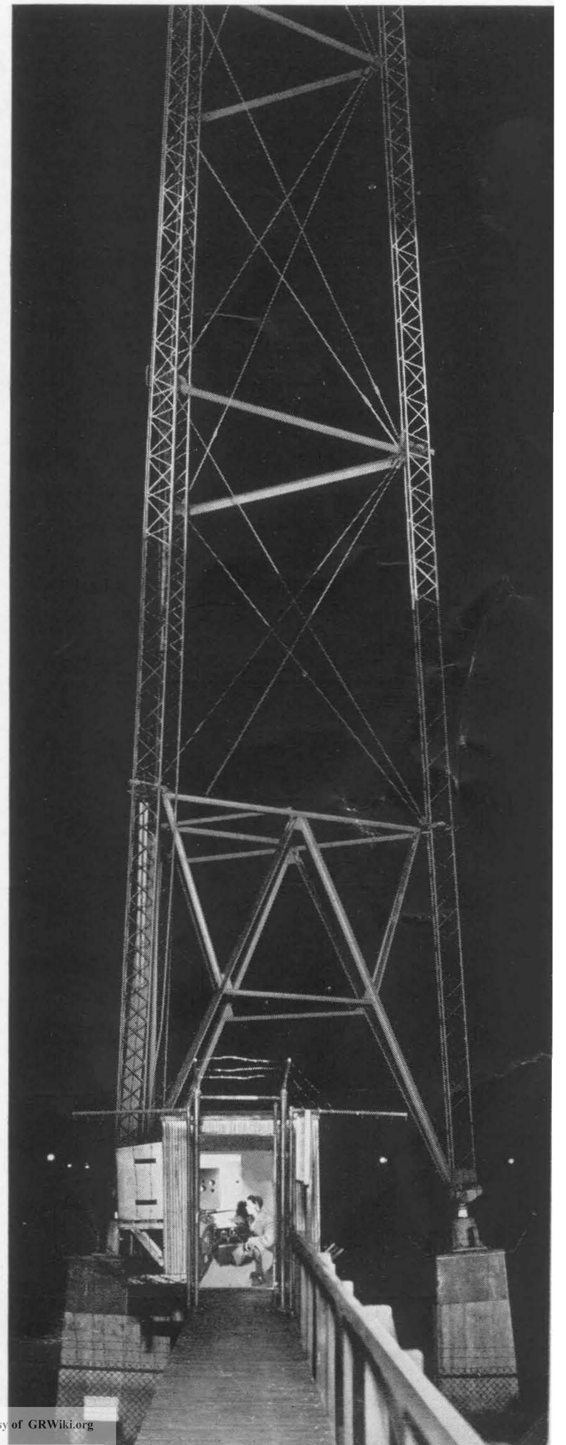


FIGURE 1. One of the antenna towers at WEEI. The structure at the base of the antenna houses the impedance matching network and meters for reading antenna current

In lining up this radiating system the most important measurements are:

(1) Resistance and reactance of antenna at operating frequency.

(2) Characteristic impedance of lines.

(3) Impedance in which each line is terminated (input impedance of impedance-matching network).

(4) Input impedance of line when terminated with impedance-matching network.

(5) Characteristic impedance of phasing networks.

(6) Input impedance of phasing networks with system connected.

Each of these measurements is discussed briefly below.

1. Antenna

The antenna impedance is determined by breaking the system at the section *A–A* and measuring the impedance at the antenna and ground leads where they connect to the impedance-matching network *Z*.

A single measurement at the operating frequency is usually sufficient, but a frequency characteristic of the antenna is sometimes valuable in determining whether there is any disturbing effect caused by resonant sections of guy wires or any undesirable resonances at harmonics of the assigned station frequency. The measured resistance and reactance of the east antenna are shown plotted as a function of frequency in Figure 3.

For this installation, quarter-wave resonance is seen to occur at 685 kc, half-wave resonance at 1070 kc, and three-quarter-wave resonance at 1715 kc. At the operating frequency the antenna resistance is 20 Ω and the reactance 41 Ω capacitive. Expressed in complex notation, this impedance is: $Z_A = 20 - j41$.

When measuring directive systems of this sort an error may occur because of the mutual impedance between the two antennas.* For the system tested, this error was small at the operating fre-

*John F. Morrison, "Simple Method for Observing Current Amplitude and Phase Relations in Antenna Arrays," *Proc. I. R. E.*, October, 1937.

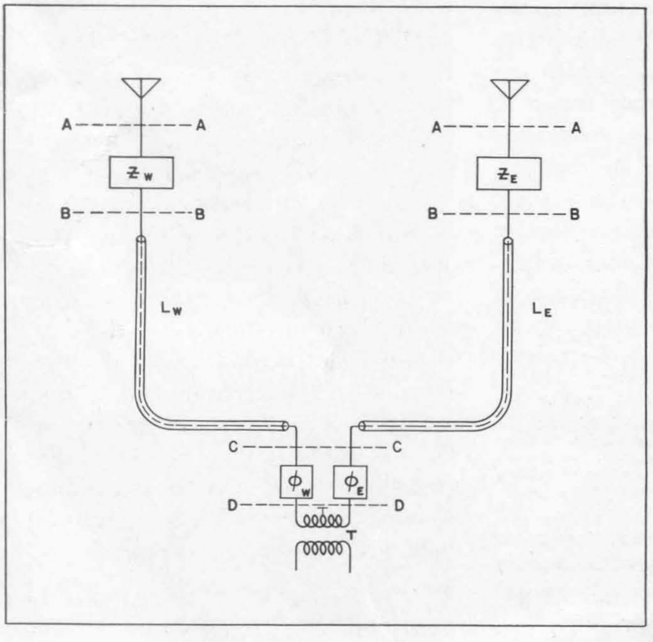


FIGURE 2. A diagram of the antenna system at WEEI. Z_E and Z_W are the impedance matching networks, L_E and L_W the concentric lines and ϕ_E and ϕ_W the phasing networks. The bridging transformer, *T*, is a coupling unit between the phasing networks and the transmitter

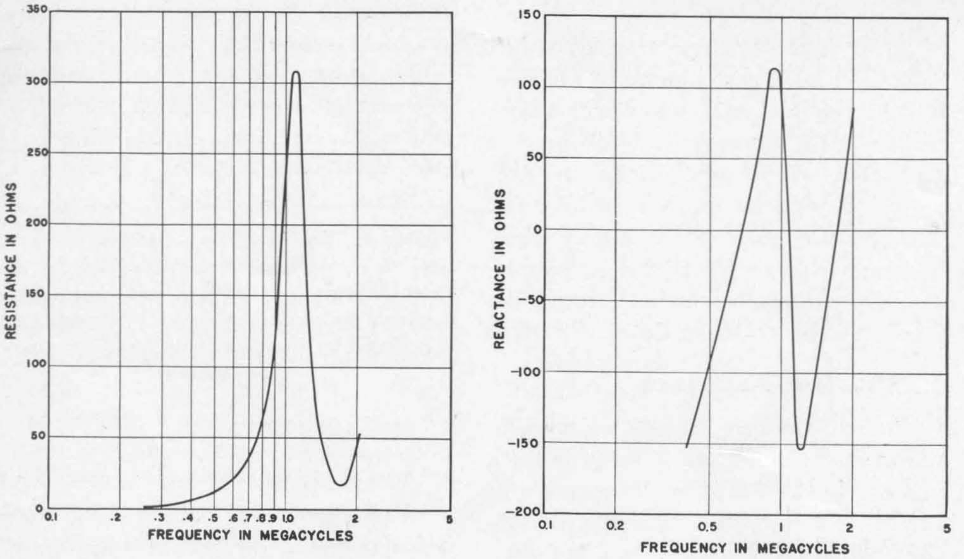


FIGURE 3. (*Left*) Resistance characteristic of the east antenna at WEEI. (*Right*) Reactance characteristic of the same antenna

quency, both resistive and reactive components looking into the east antenna changing about 1 Ω when the west antenna was opened and grounded at the base. All measurements on one antenna and its feeding system were made with the other antenna connected back through its feeding system to the transmitter.

2. Concentric Lines

To determine the characteristic impedance of the concentric lines, the system is broken at *B–B* and *C–C*. Measurements of the imput impedance of the line are then made from one end with the other end open and shorted. The characteristic impedance of the line is computed from the expression

$$Z_o = \sqrt{Z_{o/c} Z_{s/c}} \quad .$$

The lines used in the system tested are nitrogen-filled and approximately 1000 feet long. They are designed for a characteristic impedance of 65 Ω. A typical check on this figure is the measured value for the west line, L_W, of 65.4 − j0.56.

3. Impedance-Matching Networks

The impedance-matching networks Z_W and Z_E are designed to work between impedances of 65 + j0 and 20 − j41. They are of the so-called impedance-inverting type illustrated in Figure 4.*

In adjusting such networks the TYPE 516-C Radio-Frequency Bridge can be used to measure the impedances of the individual elements composing them and their input impedances when they are connected to the antennas. For perfect matching, when the system is broken at section *B–B*, the impedance at the input terminals of the impedance-matching networks with the antennas connected should be equal to the characteristic im-

*For a discussion of impedance-matching networks see, for instance, Carl G. Dietsch, "Antenna Terminations," *Electronics*, Sept., 1935, and "Terminating Concentric Lines," *Electronics*, December, 1936.

pedance of the line, namely, $65 + j0$.

The degree of matching to be achieved is governed by practical considerations rather than theoretical. Too great a mismatch will cause serious standing waves to form on the concentric lines. The standing current waves may result in excessive power loss in the line and the standing voltage waves may cause the line insulation to break down.

4. Phasing Networks

The networks ϕ_W and ϕ_E are used, in the example of Figure 2, to produce a phase relation between the currents in the two towers which results in the desired radiation pattern. These are symmetrical T-networks of the type illustrated in Figure 5. They are designed to have an image impedance of $65 + j0$ at the operating frequency and consequently match the line.

The design and adjustment of such networks is beyond the scope of this article, but the application of the Type 516-C Radio-Frequency Bridge to their measurement is similar to the application to the impedance-matching networks. The individual elements may first be measured, the characteristic impedance may be determined from open- and short-circuit measurements, and the final measurement of the input impedance made when terminated in the complete radiating system. This last measurement at *D–D* for perfect matching should, of course, be $65 + j0$.

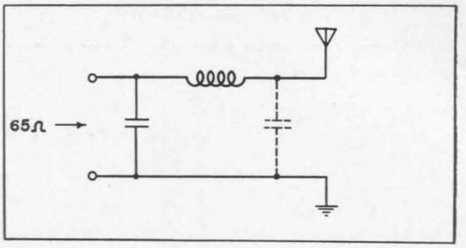


Figure 4. The impedance-matching network used to couple the transmission line to the antenna. This is an artificial quarter-wave line in which the condenser shown by dotted lines is replaced by the effective parallel reactance of the antenna

5. Maintenance

Once adjusted, the system should be checked periodically, particularly when current readings indicate that something may have changed. A measurement with the system broken at the section *D–D*, looking into the phasing network ϕ, which results in a resistive value of the proper magnitude, is usually sufficient indication that the impedances throughout the system are properly matched.

6. Measurement Technique

The panel of the Type 516-C Radio-Frequency Bridge is shown in Figure 7 and the circuit diagram in Figure 8.

The bridge is designed for measuring unknown impedances either in terms of a standard condenser and power factor condenser, as a Schering bridge, or in terms of a standard condenser and an inductance-compensated decade resistor, as a direct-reading impedance bridge.

For the type of measurement to be

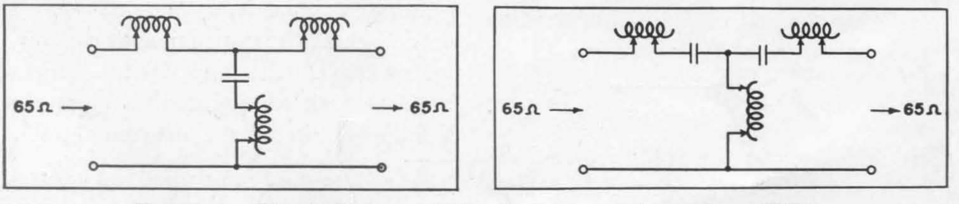


Figure 5. Circuit diagrams of the phasing networks used at WEEI

made on broadcast radiating systems, data are most conveniently taken with the bridge used as a direct-reading impedance bridge. For such measurements the bridge method has a considerable advantage over other methods in convenience and speed of operation. Users of the bridge in the field have stated that it is possible to make, in a few hours, measurements which might consume several days' time with resonance methods.

The full advantage of the bridge's direct-reading feature is obtained for the measurement of impedances having a resistive component between 0 and 100 Ω and a reactive component corresponding to a series capacitance between 40 and 1150 $\mu\mu$f. For the measurement of impedances which have an inductive reactance, or a capacitive reactance falling outside this range, a condenser in series with the unknown impedance must be used. For the measurement of impedances which have a resistive component between 100 and 600 Ω, an external resistor may be connected in series with the internal inductance-compensated decade resistor in the bridge. Type 500 Resistors are well adapted for such service and are recommended for values up to 500 Ω.

For accuracy and flexibility of operation in making antenna measurements, the use of a series condenser is recommended in practically all cases. It is seldom possible in a broadcast installation to connect the bridge to the points between which impedance is to be measured without the use of relatively long leads. Leads which are three or four feet long may well have inductive reactances of from 1 to 10 Ω at broadcast frequencies and such a reactance, measured as part of the unknown impedance,

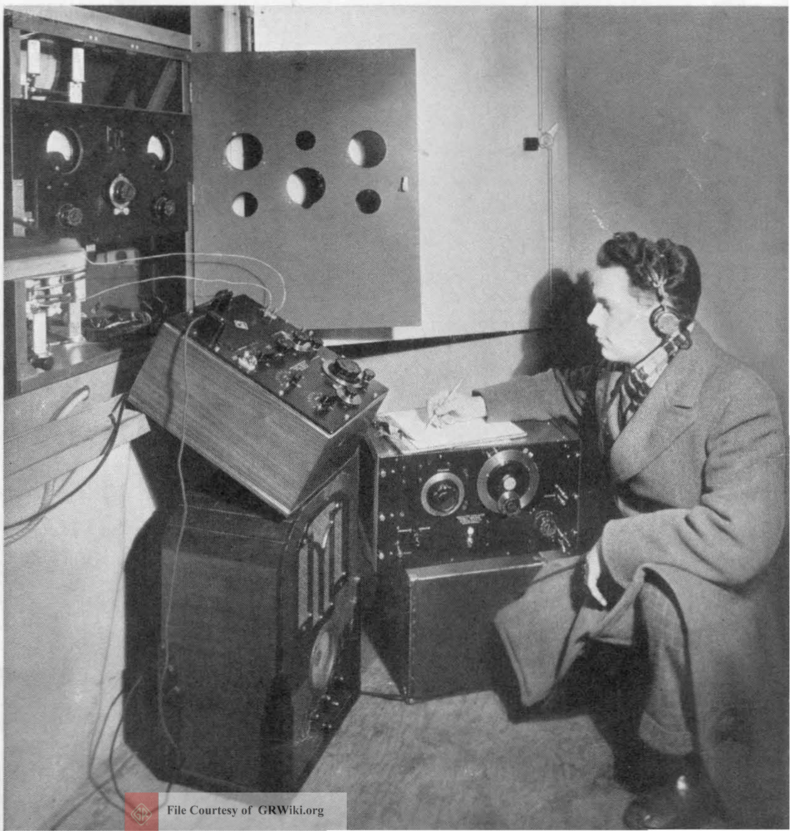


Figure 6. This photograph shows the radio-frequency bridge, the modulated oscillator, and radio receiver set up in the "dog house" at the base of the antenna. The equipment at the extreme left of the picture includes the impedance-matching networks and meters for reading antenna current

may lead to serious errors in low-impedance measurements. With a series condenser, the effect of long leads may be eliminated by making two balances, one with unknown impedance shorted at its terminals and one with short removed.

The procedure to be followed in making such measurements is as follows:

(1) A series fixed condenser is chosen, the capacitance of which lies between 40 and 1150 $\mu\mu$f. The value of condenser chosen should be such that when the unknown impedance is placed in series the effective capacitance will still be within those limits.

(2) The bridge is connected to the unknown impedance with the fixed condenser in series with the high lead, and the unknown impedance is then short-circuited at its terminals.

(3) The internal inductance-compensated decade resistor in the bridge is set to zero and the bridge balanced with the internal standard condenser and the power factor adjustment. The setting, C_1, of the standard condenser is recorded.

(4) The short-circuit is removed from the terminals of the unknown impedance and the bridge rebalanced with the internal decade resistor and the internal standard condenser. This gives the setting, R, of the resistor and a setting, C_2, of the standard condenser.

The change of resistance in the bridge, R, is then equal to the resistive component of the unknown and the change of reactance in the bridge,

$$\frac{1}{\omega}\left(\frac{1}{C_1} - \frac{1}{C_2}\right) = \frac{1}{\omega}\left(\frac{C_2 - C_1}{C_1 C_2}\right),$$ is equal to

the reactive component of the unknown.

Since the leads to the unknown impedance are included in circuit in both measurements, their impedance drops out in taking impedance differences and no error is introduced. A small residual error is left, which is caused by the capacitance of the high lead and series condenser to ground, but this is usually negligible for low-impedance measurements.

The bridge is ordinarily used with a modulated oscillator as power source and a radio receiver as detector. It has been found that, if distortion occurs in the audio modulating voltage or in the modulation process, false readings may be obtained when the radio set is not accurately tuned to the carrier frequency. The error is most pronounced when the reactance to be measured varies with frequency in a manner markedly different from the reactance of the internal standard condenser. Conditions under which this error may be important are readily recognized by the presence of a

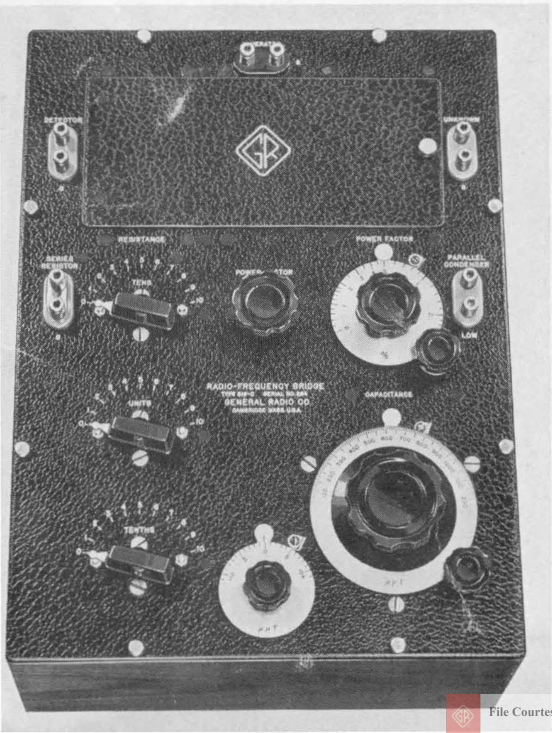


FIGURE 7. Panel photograph of the TYPE 516-C Radio-Frequency Bridge

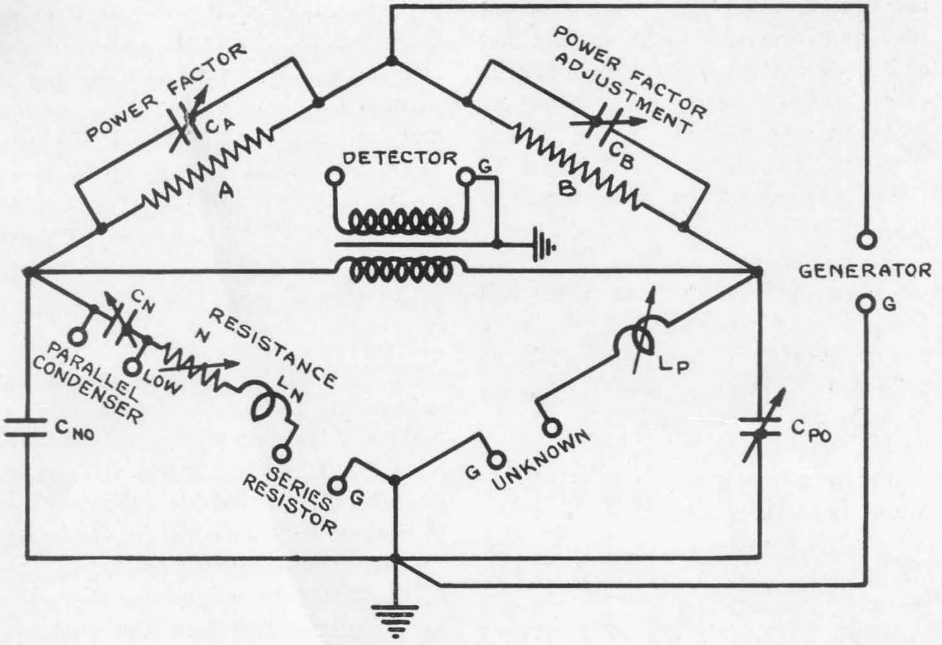


FIGURE 8. Circuit diagram of the TYPE 516-C Radio-Frequency Bridge. Careful adjustment in our laboratory of C_{PO} and L_P to compensate for residual impedances makes the bridge direct reading in capacitance and resistance

strong second harmonic of audio frequency at the bridge balance. The second harmonic is caused by the beating together of the first-order side-bands and does not of itself cause any error in the bridge balance.

By using an unmodulated oscillator for a power source and a radio set with a beat oscillator coupled to the *i–f* stages, this error is avoided since the bridge is then operated at a single frequency. A modulated source is considerably more convenient to use, however, and, in general, careful tuning to the carrier will yield a sufficiently accurate result.

The complete set-up of equipment recommended for antenna measurements consists of:

(1) TYPE 684-A Modulated Oscillator (can be used either modulated or unmodulated).

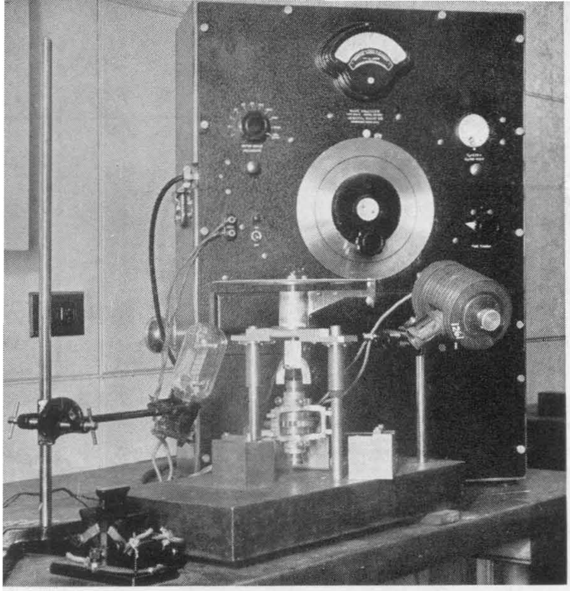
(2) TYPE 516-C Radio-Frequency Bridge.

(3) One 200 μμf, one 500 μμf, and one 1000 μμf TYPE 505 Condensers.

(4) One 100 Ω and two 200 Ω TYPE 500 Resistors.

(5) Radio receiver. If the receiver is used with a local beat oscillator in the *i–f* circuit to beat with an unmodulated wave from the bridge, it should be provided with a good sensitivity control. This is necessary because, for loud signals, a local beat oscillator will tend to maintain the audio output constant, irrespective of input signal, over a fairly wide range at high input levels. Under such conditions it is impossible to determine when a balance is approached and the balance point is "knife-edge" in width.

— D. B. SINCLAIR



MISCELLANY

● **MANY GENERAL RADIO** instruments designed primarily for the communications field find their way into industrial research laboratories, where the use of electrical methods of measurement in investigating mechanical phenomena is constantly increasing. One instrument which seems to be almost universal in its application is the TYPE 636-A Wave Analyzer. The photograph at left shows this instrument as used in the laboratories of the Sperry Gyroscope Company in connection with vibration studies. We are indebted to the authors and to *Electrical Engineering* for permission to reproduce this photograph which was used to illustrate an article by O. E. Esval and C. A. Frische entitled "Dynamic Balancing of Small Gyroscope Rotors," appearing in the June, 1937, issue.

● **GENERAL RADIO** engineers participate in technical conferences — at the 1938 Winter Convention of the A.I.E.E., H. H. Scott and L. E. Packard attended the conference on Sound and Vibration; W. N. Tuttle the conference on Network Analysis and Synthesis. A. E. Thiessen will lead the discussion on Modulation and Distortion Measurements at the Broadcast Engineering Conference sponsored by Ohio State University, February 14 and 15.

Mr. Scott, on February 15, will speak before the Engineers' Club of Philadelphia on the industrial applications of General Radio instruments.

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

GENERAL RADIO COMPANY

30 STATE STREET - CAMBRIDGE A, MASSACHUSETTS

BRANCH ENGINEERING OFFICES

90 WEST STREET, NEW YORK CITY

1000 NORTH SEWARD STREET, LOS ANGELES, CALIFORNIA

THE General Radio EXPERIMENTER

VOLUME XII NO. 10 MARCH . 1938

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also IN THIS ISSUE

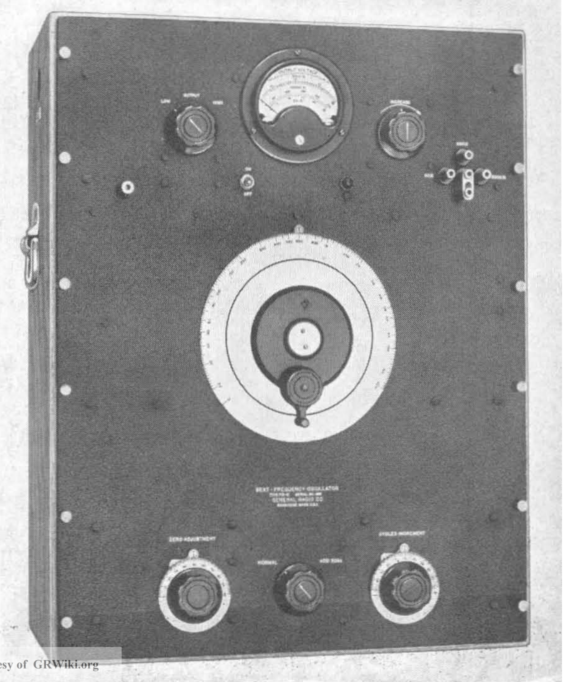
Page
VARIACS USED AS CONTROLS IN FLEXIBLE STAGE-LIGHTING UNIT 5
MEASURING 100,000 RPM 7

MODERN IMPROVEMENTS FOR THE BEAT-FREQUENCY OSCILLATOR

● **THIS MONTH ANOTHER** best seller comes out in a new edition. Basically the same as its predecessor, but brought up to date in all details, the new TYPE 713-B Beat-Frequency Oscillator possesses several features which are particularly desirable when making measurements on high-fidelity audio-frequency and supersonic equipment.

Among the more important features of the new oscillator are: (1) an increase of the frequency range to 40 kilocycles, (2) a logarithmic frequency scale over the range up to 20 kilocycles, (3) lower harmonic content and the practical elimination of a-c hum, (4) the provision of three different output impedances which remain practically constant regardless of the setting of the volume control, and (5) an output circuit which may be operated either grounded or ungrounded and which is suitable for operation into the average low-

FIGURE 1. Panel view of the TYPE 713-B Beat-Frequency Oscillator



impedance audio-frequency transmission line.

The frequency range between 20 and 40 kilocycles has hitherto been available on special order only. The importance of this range for general laboratory measurement as well as in the rapidly growing supersonic field is now sufficient to justify its inclusion as a standard feature.

The change from the low to the high range is made by shifting the frequency of the fixed oscillator (and consequently the output frequency) by 20 kilocycles. This process is controlled by a panel switch which simultaneously changes the circuits associated with the CYCLES INCREMENT dial so that its calibration is correct for either setting of the FREQUENCY RANGE switch.

A new variable condenser with carefully designed compensating adjustments gives a logarithmic variation of frequency with dial reading for the range up to 20 kilocycles. This is covered in a dial rotation of 250°.

The frequency characteristics of audio-frequency equipment are usually plotted using a logarithmic frequency scale, and consequently the logarithmic oscillator scale is a considerable advantage. Angular dial increments are then proportional to linear increments on the frequency scale. Points on the plot can be spaced evenly, avoiding the crowding which occurs when using a linear oscillator dial. When operating a recorder from the output of the equipment under test, the oscillator dial can be geared directly to a recorder using logarithmic or semi-logarithmic paper.

Waveform and hum level have been improved over that of the TYPE 713-A by providing better balance in the detector circuit and using a degenerative audio amplifier.

The output circuit includes a doubly-shielded transformer which couples the output tubes to a constant-impedance attenuator and a tapped autotransformer. The autotransformer provides three different output impedances, namely, 50, 500, and 5000 ohms, and is

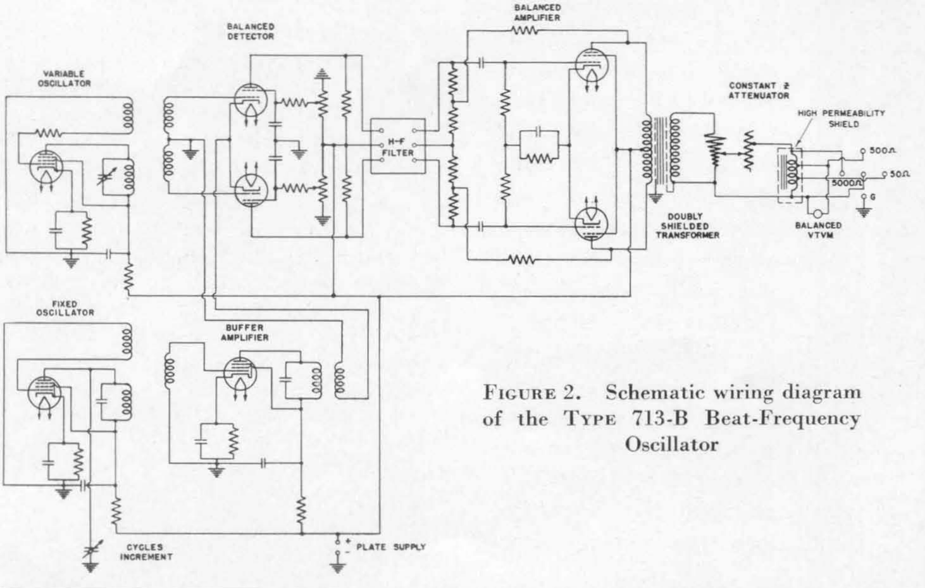


FIGURE 2. Schematic wiring diagram of the TYPE 713-B Beat-Frequency Oscillator

enclosed in a high-permeability shield so that no hum is introduced into the output. The arrangement of the output terminals makes possible rapid and easy connection to any one of the three output impedance windings. The common output terminal may be grounded, or, when working into balanced lines, may be left floating.

Since it is expected that many owners of the Type 713-A Oscillators will want some of the additional advantages of the Type 713-B, arrangements have been made so that the same changes may be made in earlier models. Either the additional frequency range or the new amplifier and output system, or both, may be added to a Type 713-A Oscillator. It is also possible to change the circuit and condenser so as to provide the logarithmic frequency calibration. With these changes the instrument will have exactly the same performance characteristics as a Type 713-B. Prices will be gladly quoted by our Service Department.

— H. H. Scott

SPECIFICATIONS

Frequency Range: 10 to 40,000 cycles per second.

Frequency Control: The main control is engraved with a logarithmic frequency scale extending up to 20 kilocycles, the total scale length being approximately 17 inches. The FREQUENCY RANGE switch extends the range to 40 kilocycles. There is an INCREMENTAL FREQUENCY control covering a band extending 50 cycles on either side of the frequency determined by the setting of the main dial and the FREQUENCY RANGE switch.

Frequency Calibration: The calibration may be standardized at any time by setting the instrument to zero beat. This adjustment can easily be made with an error of less than one cycle. The calibration of the frequency-control dial can be relied upon to within $\pm 2\% \pm$ one cycle after the oscillator has been correctly set to zero beat, and for one year from date of purchase. The incremental frequency dial is marked with one division for every one-cycle interval over a range of -50 to $+50$ cycles. Its calibration is correct to ± 2 cycles per second or better.

Frequency Stability: Care has been taken in the design of the oscillator to provide adequate thermal insulation and ventilation, thereby greatly minimizing frequency drifts due to temperature changes. The oscillator may be accurately reset to zero beat at any time, thereby eliminating even the small remaining frequency drifts.

Output Impedance: The output circuit includes a tapped autotransformer providing output impedances of 50, 500, and 5000 ohms. The output circuit is electrostatically shielded and isolated from ground, thus making it practical to operate into an ungrounded load such as a transmission line. The output circuit is sufficiently well balanced for operating into the average audio-frequency transmission lines throughout the entire frequency range of the oscillator when using the 50-ohm output terminals. When using the 500-ohm output terminals, the balance is satisfactory up to 15 kilocycles. When using the 5000-ohm output terminals, the balance is satisfactory up to 3 kilocycles. Obviously, the output circuit may be operated ungrounded at higher frequencies than those specified, provided a close balance to ground is not necessary. When it is desired to ground definitely one side of the load, this may be accomplished by means of the grounding strap provided on the oscillator panel.

Output Power and Voltage: The open-circuit output voltage of the oscillator is approximately 150 volts. The maximum power delivered to a matched load is slightly over one watt when the output control is in the HIGH position. When the output control is in the LOW position, the maximum power is approximately 0.02 watt.

For a matched resistive load the output voltage varies by less than ± 0.5 db between 30 and 12,000 cycles, and by less than 1 db between 15 and 16,000 cycles.

Waveform: When the OUTPUT switch is on the LOW position, the total harmonic content is less than 0.2% throughout the frequency range from 250 to 2000 cycles and less than 1% between 70 and 10,000 cycles. At 20 cycles the harmonic content is approximately 3%. When operating on the LOW output position, the harmonic content is practically unaffected by any load impedance between one-half of the rated value and an open circuit.

With the output switch on the HIGH position and when operating the oscillator into a matched load, the maximum amplitude of the harmonics is less than 2% of the output voltage in the audio-frequency range above 70 cycles, regardless of the setting of the volume control. Below 70 cycles the harmonics increase to about 8% at 20 cycles. Operation of the oscillator into an open circuit at full output voltage causes a small increase in the harmonic content, which is, however, negligible for frequencies above 40 cycles or when the OUTPUT control is turned down. Operation of the 5000-ohm terminals into an extremely low impedance, so that they are practically short-circuited, causes the harmonic content to be doubled approximately.

The power-supply ripple is less than 0.1% of the output voltage for either position of the OUTPUT switch and for any value of output voltage which can be read on the panel voltmeter, when the oscillator is operated from a 60-cycle line.

Voltmeter: A voltmeter is provided on the panel for indicating the output voltage of the oscillator. The voltmeter is of the vacuum-tube type employing a balanced circuit, so that no appreciable harmonics are introduced into the output voltage. The voltmeter is provided with three scales, one for each set of output terminals.

Mounting: This instrument is available in either cabinet or relay-rack mounting. The cabinet is a heavy oak case fitted with carrying handles. For relay-rack mounting, the cabinet is replaced with a metal dust cover and shield.

Power Supply: 110-120 volts, 40-60 cycles alternating current. A simple change in the connections to the power transformer allows the instrument to be used on 220-240 volts. The total consumption is about 115 watts.

Tubes: The following tubes are required:

2 — Type 41	2 — Type 6L6
1 — Type 6D6	2 — Type 6H6
2 — Type 6C6	1 — Type 5Y3G

A complete set of tubes is supplied with each instrument.

Accessories: A seven-foot connecting cord is supplied.

Dimensions: Panel, (width) 19 x (height) 24¼ inches, over-all. Cabinet size, including handles, (width) 20½ x (height) 25 x (depth) 11 inches.

Screw holes in the panel are the standard spacing for mounting the instrument in a Type 480 (standard) 19-inch relay rack.

Net Weight: 93 pounds.

Type		*Code Word*	*Price*
713-BM	Cabinet Model	DEBAR	$485.00
713-BR	Relay-Rack Model	DETER	510.00

This instrument is licensed under patents of the American Telephone and Telegraph Company, solely for utilization in research, investigation, measurement, testing, instruction, and development work in pure and applied science.

OUR OFFICE IS CLOSED ON SATURDAY

● **ALTHOUGH OUR PLANT** has been closed on Saturday since 1919 and our office since 1931, we find that many of our customers call or telegraph on Saturdays, expecting rush shipments or replacement parts. While we endeavor to make prompt shipments in order to give our customers the best possible service, it is impractical to arrange for Saturday shipments.

VARIACS USED AS CONTROLS IN FLEXIBLE STAGE-LIGHTING UNIT

● **THE DECEMBER, 1933, AND FEBRUARY, 1936,** issues of the *Experimenter* described other installations in which Variacs were used as dimming controls for the lights in little theatre projects. The switchboard described in this article makes use of some features which were not described in the other two articles, ingenious improvements suggested by Mr. Dawes who was responsible for the unit described in the first article.

The switchboard shown in the illustration, Figure 1, was developed to control the lights on a small church stage. It is not intended to be portable, but installed permanently, hence is mounted on a large 24-inch square steel switch box on a wall. The panel is hinged so that it may be dropped 90° to be worked upon during original installation. The power available is three-wire balanced, 230-volt, 60-cycle, and the panel is so wired that the loads are balanced about its vertical center line.

Reference to the illustration will help clarify the detailed description of the switchboard.

The upper half of the panel contains four Variac circuits. Each Variac, a Type 200-CU, is provided with a 15-ampere, double-pole toggle switch, a

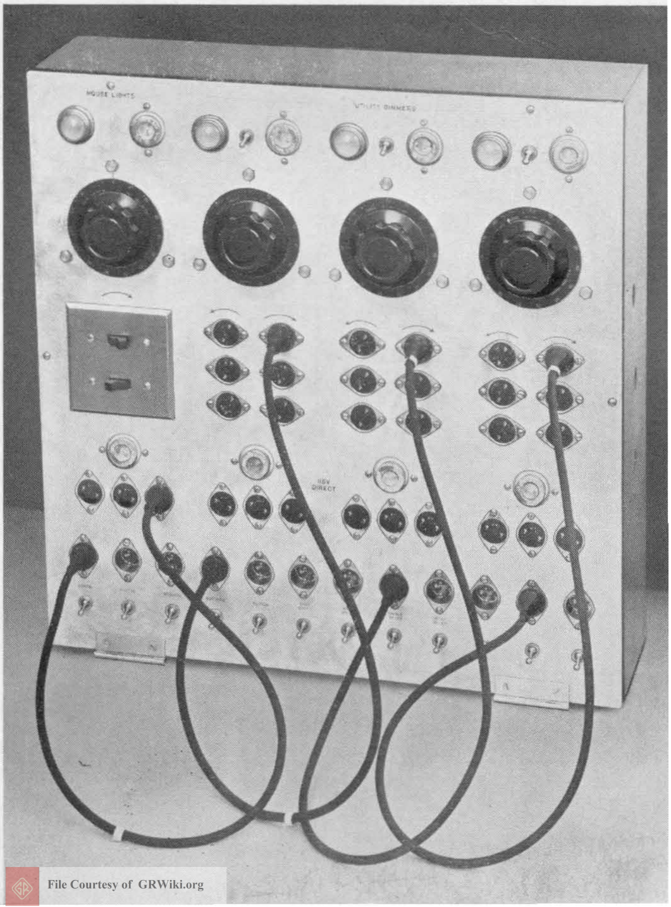


FIGURE 1. Panel view of the stage-lighting control board described in this article. Interesting features of this board are the use of patch cords for flexibility in setting up the circuits and the connection of the Variacs as faders to dim one circuit while bringing up another

fuse, and a pilot light. The primary fusing is adequate for the secondary loading. The pilot light is to prevent the operator's closing the switchboard with the primary of any Variac connected across the line and drawing magnetizing current. The Variac at the left, with the two wall-type toggle switches behind a switch plate directly beneath it, is for control of house lights. The other three are utility dimmers, to be used as needed. Each one has beneath it a number of female cup receptacles for access to its output.

Just below the center and extending horizontally across the panel are four groups of female cup receptacles supplying uncontrolled power direct from the line. Each group of three receptacles is beneath its associated fuse.

Extending horizontally across the bottom of the panel are the controls and terminations for the load circuits. The termination is a male cup receptacle, and its control, directly below it, a 15-ampere double-pole toggle switch. These load positions are labeled to indicate the circuits they control, such as BORDER 2, FLOODS, BABY SPOT, etc.

The special features previously referred to are:

(1) the use of patch cords for flexibility in setting up the circuits, and

(2) provision of means to use the Variacs as fading controls to bring up the lights in one circuit while dimming those in another.

The use of patch cords is advantageous in several ways. Firstly, it is simpler and more flexible than switching, and allows the controlling normally desired to be accomplished with fewer Variacs. Each Variac in the February, 1936, article could supply only two circuits. With the present arrangement any Variac may be connected to any load circuit. Secondly, by selectively inserting the plug ends of the cords into the proper receptacles, the loads may be distributed between Variacs, between sides of the three-wire power line, and between other circuits so as to prevent overloading Variacs or fuses and to produce a balanced load on the system. Thirdly,

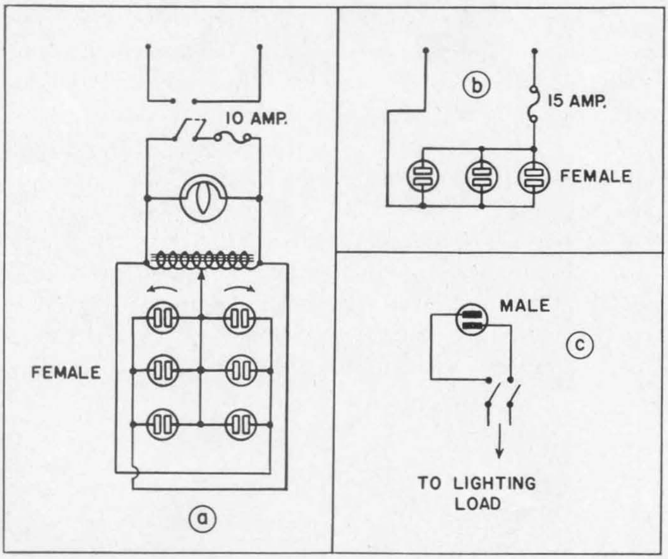


FIGURE 2. Wiring diagrams of each of the basic circuits of the control board

and this is quite important in a semi-public place where many uninformed persons would have access to the switch-board, tampering can be effectively prevented by removing and locking up the patch cords when they are not actually in use during a performance.

The small wiring diagram, Figure 2(a), shows the way in which the Variac is used for fading. Three of the receptacles below each Variac are connected in parallel between the arm and one end of the Variac, the other three in parallel between the arm and the other end. The curved arrows engraved above each group of receptacles indicate the direction in which the Variac knob must be rotated to bring up the voltage on that group. This arrangement not only provides means for achieving special effects, but promotes flexibility by requiring fewer Variacs under certain conditions.

Figure 2(b) shows the wiring of one group of direct 115-volt receptacles, and Figure 2(c) of one set of load-control devices.

In use, the female end of a patch cord would be attached to one male receptacle (in Figure 2(c)), then plugged into a controlled female receptacle (in Figure 2(a)) or into an uncontrolled one (in Figure 2(b)). — P. K. McElroy

MEASURING 100,000 RPM

● **MEASURING AND CONTROLLING THE SPEED** of an ultra-centrifuge rotating at 100,000 rpm presents an interesting problem. Physicists at the laboratories of the U. S. Department of Public Health have developed an ingenious and thoroughly workable solution.

The centrifuge used in this laboratory is driven by a compressed air stream and rotates on a similar stream for its bearing. The obvious method of measurement, using a Strobotac operated at a submultiple of the rotational speed, is open to three objections: (1) that the method does not permit accurate measurement rapidly, because submultiples are too close together on the Strobotac scale; (2) that safety considerations prevent the operator from being too near the centrifuge when it operates at these speeds, and (3) that it provides no means for controlling the speed.

The method now proposed uses a Type 834-A Electronic Frequency Meter to indicate the speed. A beam of light is reflected from the surface of the rotating element and falls on a photo-electric cell. A black spot painted on the rotating surface interrupts the light once each revolution. The amplified output of the photocell is applied to the electronic frequency meter, which reads the speed directly in revolutions per second.

Carrying the project one step farther, a marginal relay in the d-c meter circuit is then used to control the pressure of the air stream driving the centrifuge, providing an automatic speed control.

MISCELLANY

● **AN ENGINEERING COLLOQUIUM** is held each Tuesday afternoon at General Radio for the purpose of discussing problems of interest to members of our engineering and production departments. The speakers are usually members of the engineering staff, but at times we are fortunate in securing speakers from other companies.

One of the most interesting of these meetings was recently addressed by Mr. A. G. Clavier of the L. M. T. laboratories, Paris, who discussed experiments in 20-centimeter radio transmission.

Accompanying Mr. Clavier on his visit to our plant was Mr. George H. Gray, Transmission Engineer of International Telephone and Telegraph Corporation, New York.

● **ANOTHER RECENT VISITOR** was Mr. Paul Fabricant of the Paris firm Radiophon, agents for General Radio equipment in France. Mr. Fabricant also addressed one of these colloquia.

● **MR. H. H. SCOTT** of the engineering staff will speak at three professional society meetings early in April on sound measurement and analysis, stroboscopes, and high speed motion pictures. His schedule is: April 4, Buffalo Section, Society of Automotive Engineers; April 6, Erie, Pennsylvania Section, American Society of Mechanical Engineers; April 8, Madison, Wisconsin Section, American Institute of Electrical Engineers.

● **THE SCIENCE CLUB** of the Western Electric Company at Hawthorne, Ill., was addressed on the subject of "Stroboscopes" by Mr. A. E. Thiessen on February 18.

● **MR. THIESSEN** also spoke at the March 11 meeting of the Boston Section, I. R. E., on "Distortion and Modulation Measurements on Broadcast Transmitters."

● **THREE ENGINEERS** collaborated in the design of the Type 713-B Beat-Frequency Oscillator described in this issue: Messrs. H. H. Scott, L. B. Arguimbau and A. G. Bousquet.

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

GENERAL RADIO COMPANY

30 STATE STREET - CAMBRIDGE A, MASSACHUSETTS

BRANCH ENGINEERING OFFICES

90 WEST STREET, NEW YORK CITY

1000 NORTH SEWARD STREET, LOS ANGELES, CALIFORNIA

PRINTED IN U.S.A.

THE General Radio EXPERIMENTER

VOLUME XII NO. 11 APRIL 1938

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also IN THIS ISSUE

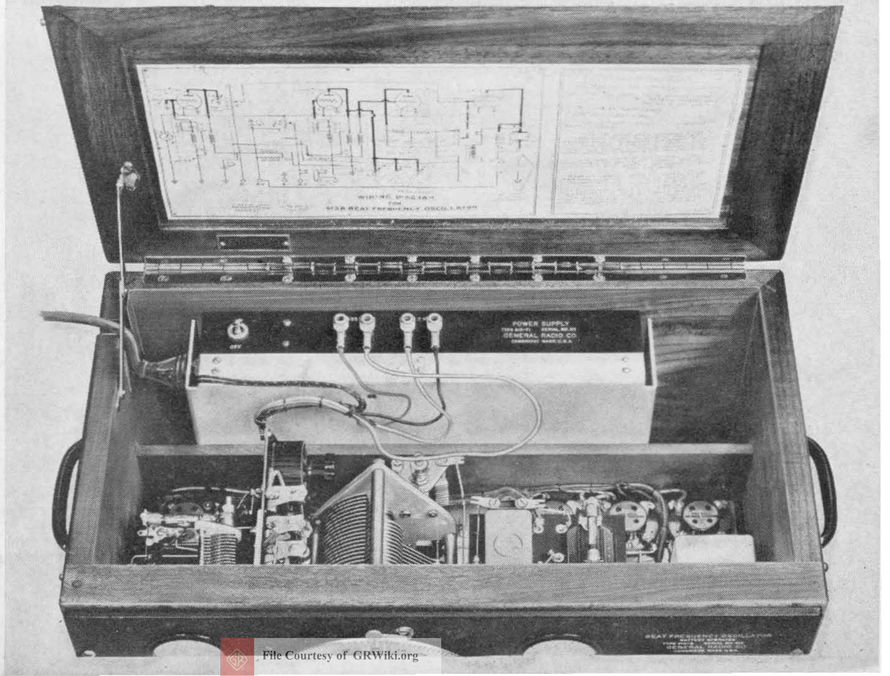
Page
THE BEHAVIOR OF TYPE 505 CONDENSERS AT HIGH FREQUENCIES 4

A-C OPERATION FOR TYPE 613-B BEAT-FREQUENCY OSCILLATOR

● **THE TYPE 613-B BEAT-FREQUENCY OSCILLATOR**, a low-power, battery-operated instrument, has had a wide use in laboratories. Small in size and simple in operation, it is a convenient instrument to use for laboratory and field testing. Many users, however, have felt a need for a-c operation of this oscillator, particularly in permanent installations.

To satisfy this demand, we have developed the TYPE 613-P1 Power Supply. Designed specifically for use with the TYPE 613-B, this power

FIGURE 1. The TYPE 613-B Beat-Frequency Oscillator with TYPE 613-P1 Power Supply installed



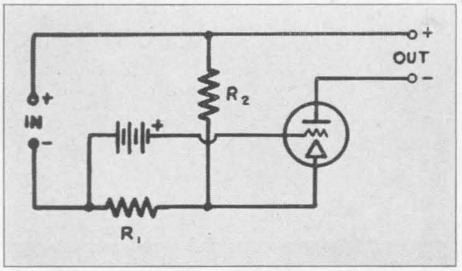


FIGURE 2. Schematic diagram of the voltage regulator

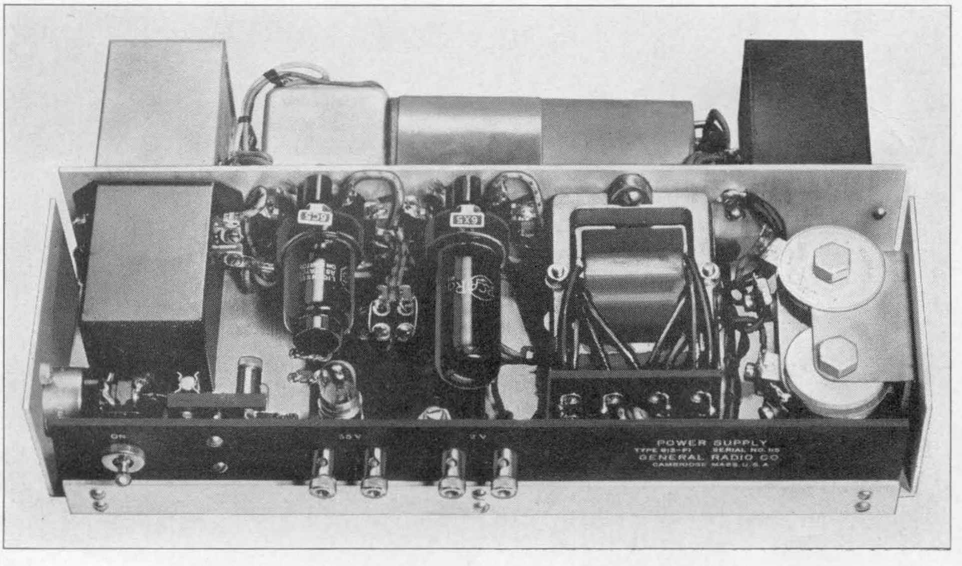
unit fits the battery compartment of the oscillator and need not be permanently installed. The shift from batteries to a-c supply and vice versa can be made in a few seconds, so that the oscillator can be used with a-c supply in the laboratory and with batteries in the field.

Figure 1 is a photograph of the power supply unit itself and Figure 2 shows it installed in the oscillator cabinet. On recent models of the oscillator (Serial No. 402 and above), the ON-OFF switch is arranged to break the a-c line feeding the power supply. On older models, where the panel switch breaks only the filament circuit, the plate supply can be turned off by using a switch provided on the TYPE 613-P1 Unit, or a new switch can be installed in the oscillator by the user.

The circuit of the power supply unit is shown in Figure 3. In the low-voltage circuit for supplying the filaments, a copper-oxide rectifier with adequate filtering is used. The usual thermionic rectifier is used in the high-voltage circuit.

One important feature is the built-in voltage regulator which keeps the output voltage constant over a wide range of line voltages. This is a vacuum-tube type of regulator and is shown in simple form in Figure 4. When the ratio $\frac{R_2}{R_1}$ is made equal to the amplification constant of the vacuum tube, constant voltage is obtained at the output terminals for a wide range of input voltages. By means of the bias E_g the output voltage can be adjusted to the desired value. In the TYPE 613-P1 Power Supply, the bias E_g is obtained from the constant voltage drop

FIGURE 3. Interior view of the TYPE 613-P1 Power Supply



across the neon lamp, *V-3*, and is adjustable by means of the slider on *R-7*.

Excellent voltage regulation is provided by using this system. With the normal load of the TYPE 613-B Beat-Frequency Oscillator, the output voltage varies between 134 and 137 volts for a line voltage range of 100 to 130 volts.

The line-frequency hum level has been kept low by using adequate filtering and by providing an electrostatic shield between the primary and secondary windings of the power transformer. The hum amplitude appearing in the oscillator output is less than 2 millivolts for all line voltage and frequency combinations except 120-130 volts, 42 cycles, where it rises to 3 millivolts. This is equivalent to about 0.01% of open circuit output voltage.

This instrument will operate on all line frequencies between 40 and 60 cycles. Total power input is approximately 15 watts.

SPECIFICATIONS

Output: 2 volts, 0.3 a and 135 volts, 8.5 ma.

Input: 15 watts at 100 to 130 volts, 40 to 60 cycles.

Tubes: One 6X5, one 6C5, one T-4½ neon lamp. All tubes are supplied.

Mounting: Sheet aluminum frame and base to fit battery compartment of TYPE 613-B Beat-Frequency Oscillator.

Terminals: Output voltages are available at terminals for connecting battery leads of TYPE 613-B Beat-Frequency Oscillator.

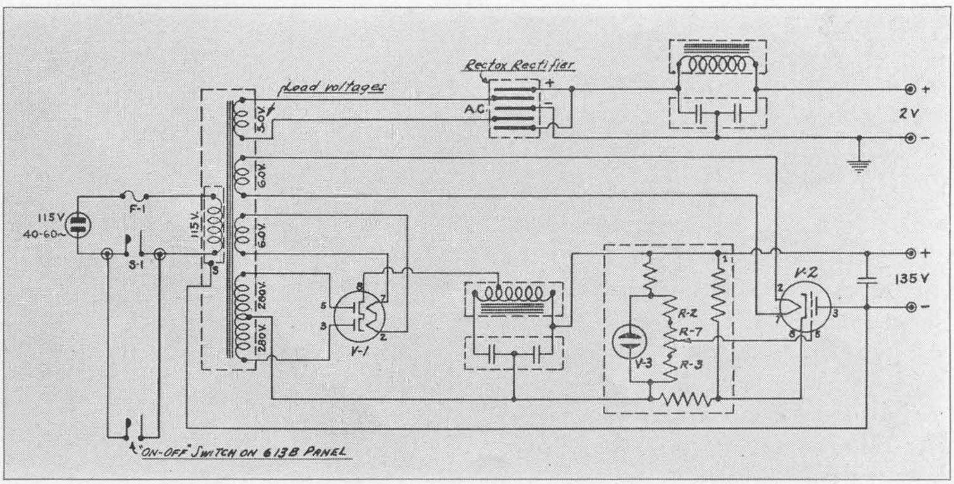
Other Accessories Supplied: Line cord-and-plug assembly; spare fuses; spare neon lamp.

Dimensions: 13½ x 8⅜ x 2⅝ inches, over-all.

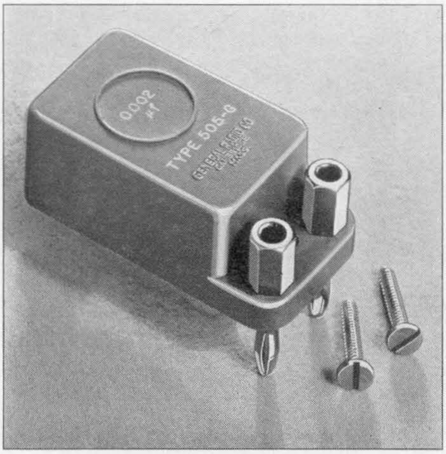
Net Weight: 12½ pounds.

Type	*Code Word*	*Price*
613-P1	POWPACKANT	$70.00

FIGURE 4. Complete circuit diagram of the TYPE 613-P1 Power Supply



THE BEHAVIOR OF TYPE 505 CONDENSERS AT HIGH FREQUENCIES



● **MUCH ATTENTION HAS BEEN DIRECTED** to the determination of the frequency characteristics of fixed and variable resistors and of variable capacitors because these elements are most generally used as impedance standards. Correspondingly precise information on the frequency characteristics of fixed capacitors has not been readily available.

A brief description of the behavior of Type 505 Condensers at frequencies from 50 cycles to 10 Mc seems warranted in view of the uses which many experimenters are now making of these capacitors in high-frequency circuits.

ANALYSIS

In theory, a perfect fixed capacitor would have a pure unvarying capacitance, with no residual inductance and resistance. In practice, of course, such a capacitor cannot be physically realized. An actual capacitor has a true capacitance which varies with frequency in exactly the same manner as does the dielectric constant of the solid dielectric between the plates; it has a residual inductance caused by the magnetic flux set up by the currents in the leads and plates; it has energy losses in the solid dielectric material and, finally, it has energy losses in the metallic structure and in the leads.

As in the case of the variable capacitor,* a fixed mica capacitor may be represented by the equivalent circuit shown in Figure 1.

In this figure, *L* represents the residual inductance of the capacitor, *R* the effective series resistance corresponding to losses in the metallic structure, *G* the effective parallel conductance corresponding to losses in the solid dielectric material, and *C* the true capacitance.

The true capacitance, *C*, as predicted by the Debye† polar molecule theory, should be essentially constant for frequencies up to a transition region in which a decrease in the dielectric constant and a peak in power factor take place. This transition region for mica apparently is absent or occurs at very high frequencies as no such shift in dielectric constant is observed in the region between 50 cycles and 10 Mc. A slight in-

*R. F. Field and D. B. Sinclair, "A Method for Determining the Residual Inductance and Resistance of a Variable Air Condenser at Radio Frequencies," *Proceedings of the I.R.E.*, February, 1935.

†For an authoritative review of contemporary knowledge of dielectric behavior, see E. J. Murphy and S. O. Morgan, "The Dielectric Properties of Insulating Materials," *Bell System Technical Journal*, October, 1937.

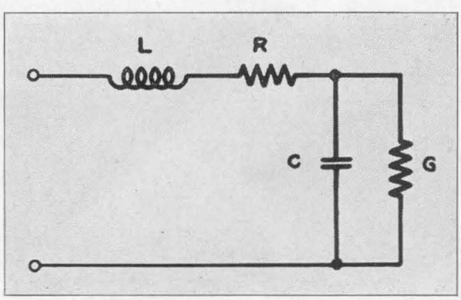


Figure 1. Equivalent circuit of a fixed mica capacitor

crease in effective capacitance occurs at low audio frequencies, however, because of dielectric absorption.

The residual conductance, G, varies with frequency in a rather complicated manner. For many good solid dielectric materials it has been found that the energy loss per cycle per squared potential gradient is essentially constant, irrespective of frequency, and that the conductance, G, therefore increases linearly with frequency*. While this simple law holds very well for variable capacitors having ceramic or quartz insulation, it breaks down for fixed mica capacitors such as the TYPE 505. At low frequencies, losses caused by absorption currents appear to predominate, and the conductance, G, has been found experimentally to follow the law

$$G = k\omega^{1-n}$$

where n is approximately equal to 0.2.† At higher frequencies the conductance, G, increases linearly with the frequency.‡

The power factor component contributed by the dielectric loss is given by the expression $\frac{G}{\omega C}$. At low frequencies the power factor component therefore varies with frequency as $\frac{1}{f^n}$ and at high frequencies the power factor component is constant.

The residual inductance, L, is constant with frequency. It introduces a component of positive reactance in series with the negative reactance of the true capacitance and consequently causes the effective terminal capacitance C_e to de-

*The power loss is given by E^2G. If the energy loss per cycle is constant, the total energy loss per second is directly proportional to frequency, and the effective conductance, G, increases linearly with frequency. This relation may also be derived from the more common statement that the loss factor (power factor × dielectric constant) is constant.

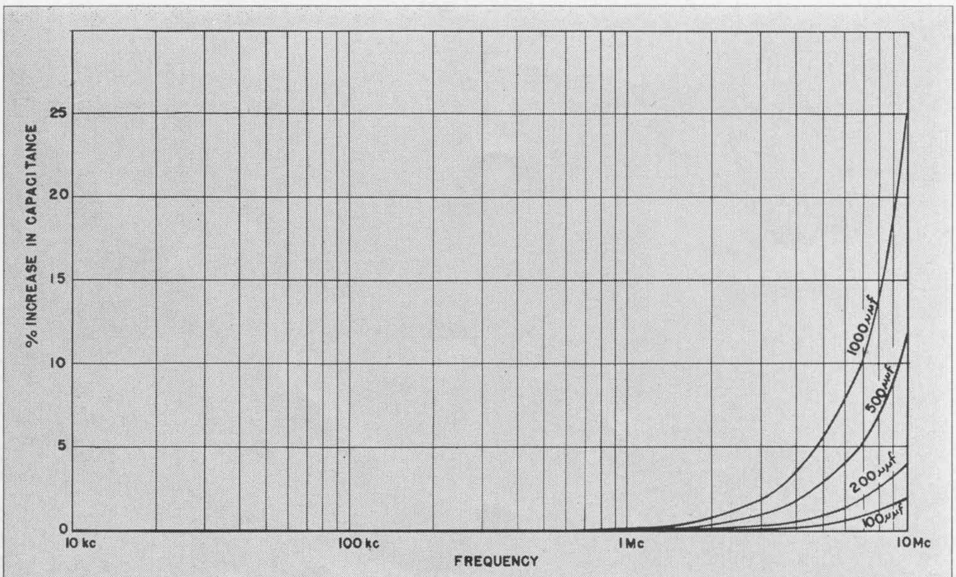
$$\text{Loss factor} = \frac{G}{\omega C} \times \epsilon = \frac{G}{\omega C} \times \frac{C}{C_0} = \frac{G}{\omega}\frac{1}{C_0}$$

where E is the dielectric constant at any frequency and C_0 the capacitance which would exist for $\epsilon = 1$.

†See, for instance, H. J. MacLeod, "Power Loss in Dielectrics; Variations with Frequency," *Phys. Rev.*, Vol. 21, No. 1, p. 53; January, 1923.

‡At very low frequencies, a further component of loss is introduced by the actual leakage conductance through and over the surface of the solid dielectric. Since the leakage conductance of TYPE 505 Condensers is of the order of 0.0005 μmho per microfarad, this loss is ordinarily negligible.

FIGURE 2. The effective capacitance values for four standard TYPE 505 Condensers. Since the low-frequency rise in capacitance would not be noticeable on a plot to this scale, values below 10 kc are not shown



part from the true capacitance, C, at high frequencies.

The residual resistance, R, contributes a negligibly small loss at low frequencies since it is in series with a high capacitive reactance. As the frequency increases, however, the capacitive reactance drops in relation to the residual resistance and the power factor component contributed by metallic losses first becomes comparable with and finally exceeds the component contributed by dielectric losses. The power factor component corresponding to metallic loss is given by the expression $R\omega C_e$. This component actually rises more rapidly than the first power of the frequency because of skin effect in the metal parts and because C_e increases with frequency.

MEASUREMENT

A plot of the effective capacitances of four standard TYPE 505 Condensers as a function of frequency is shown in Figure 2. The capacitances rise slightly at low frequencies,* remain constant for medium frequencies, and rise sharply at high frequencies. The rise at high frequencies depends upon the residual inductance, L, which causes the effective terminal capacitance to follow the law

$$C_e = \frac{C}{1 - \omega^2 LC} \qquad (1)$$

Equation (1) shows that the fractional rise in capacitance at high frequencies increases with the true capacitance C. From the experimental curves it can be seen that this law holds true in general. The 1000 $\mu\mu$f capacitor shows a rise of 1% at a frequency of 2.2 Mc. The 100 $\mu\mu$f capacitor does not rise 1% until a frequency of 7.2 Mc has been reached.

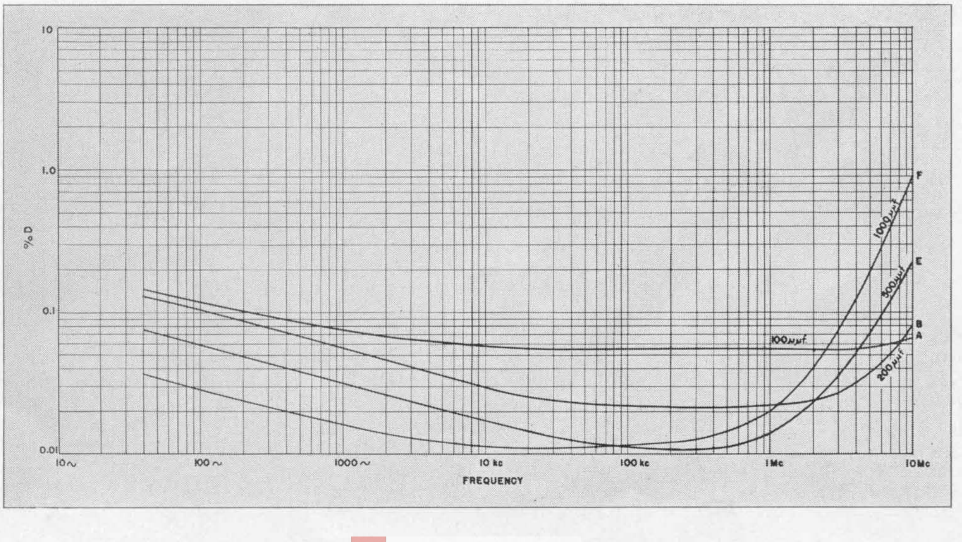
From the increase in effective capacitance at high frequencies the value of the residual inductance may be deduced. Maximum precision in determining the inductance is secured by plotting, in the form of a straight line, data taken at several frequencies.

From Equation (1)

$$\frac{1}{C_e} = \frac{1}{C} - \omega^2 L$$

*The capacitance rise at low frequencies is too small to be visible on the plot of FIGURE 2. The rise is essentially the same for all four capacitors and amounts to about 0.1 $\mu\mu$f at 2000 cycles, 0.2 $\mu\mu$f at 400 cycles, 0.3 $\mu\mu$f at 150 cycles, 0.4 $\mu\mu$f at 85 cycles, and 0.5 $\mu\mu$f at 50 cycles with the capacitance at 100 kc taken as reference. The reason that the capacitance rise is not dependent upon the size of the capacitors appears to be that a large part of the absorption is in the yellow bakelite cases, sealing compound, and residual moisture, and not in the mica.

FIGURE 3. Variation of power factor with frequency for the four sample condensers



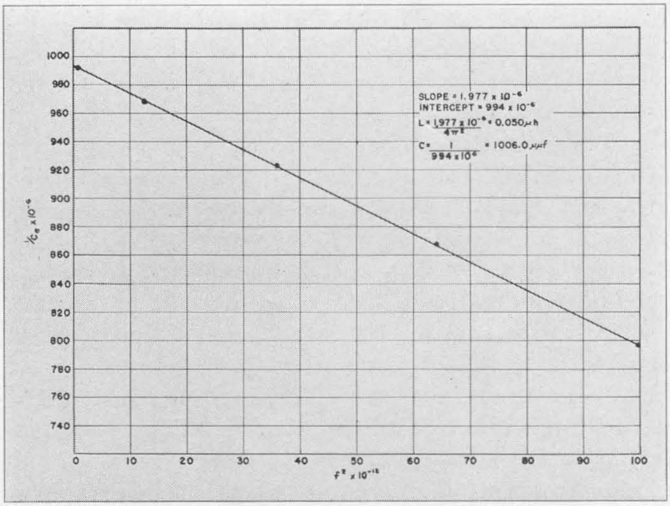


FIGURE 4. The straight-line plot from which the inductance of the 1000 $\mu\mu$f capacitor was obtained. The points shown are those determined experimentally

Therefore, if $\frac{1}{C_e}$ be plotted as a function of ω^2 over the frequency region for which C is constant, a straight line is obtained. The intercept of the straight line with the ordinate axis is equal to $\frac{1}{C}$ and the slope is equal to L.

Figure 4 illustrates the experimental straight-line plot for the 1000 $\mu\mu$f TYPE 505-F Condenser. From the precision with which the experimental points fall on the straight line, it is clear that the implicit assumptions that L and C are constant over the frequency range are valid.

The values of C obtained from the intercepts check the 100 kc capacitance values well within the precision of measurement. The values of residual inductance formed for the four capacitors are all sensibly equal as shown in the following table:

Type	*Capacitance*	*Inductance*
505-A	100 $\mu\mu$f	0.055 μh
505-B	200 $\mu\mu$f	0.053 μh
505-E	500 $\mu\mu$f	0.054 μh
505-F	1000 $\mu\mu$f	0.050 μh

This close agreement, despite the difference in rated capacitance, is taken to mean that the inductance is largely localized in the leads to the capacitors.

Curves of the power factors of these capacitors are shown in Figure 3. The general expression for power factor must include a factor which expresses the dielectric loss and a factor which expresses the metallic loss, as follows

$$D = \frac{G}{\omega C_e} + R\omega C_e \qquad (2)$$

The first component corresponds to the dielectric loss. At very low frequencies the conductance, G, varies approximately as $f^{0.8}$. The power factor component, therefore, varies as $1/f^{0.2}$. At higher frequencies G varies directly as f and the power factor component is constant.

The second component corresponds to the metallic loss. At high frequencies, where it becomes appreciable compared with the dielectric loss component, skin effect in the metal parts is essentially complete and the residual resistance, R, varies approximately as $f^{\frac{1}{2}}$. The power factor component therefore varies as $f^{\frac{3}{2}}$.

Equation (2) shows that the power factor rise at high frequencies varies directly as the effective capacitance C_e. The curves of Figure 3 are seen to bear out this general law. The power factor of the 1000 $\mu\mu$f condenser begins to rise at a frequency of about 200 kc. The power factor of the 100 $\mu\mu$f condenser does not begin to rise appreciably until the frequency reaches 5 Mc.

The residual series resistance, R, causing the high-frequency power factor rise, is roughly the same for all four capacitors. It is therefore believed to reside largely in the leads from the capacitor binding posts to the capacitor plates. The magnitude of the resistance causing the rise is small, about 0.003 Ω at 1 Mc and 0.008 Ω at 10 Mc. It is difficult to reduce this resistance because, when skin effect is complete, the resistance is proportional to the superficial area of the leads and not the cross-sectional area. It has been computed that, in order to reduce the resistance by a factor of 10, it would be necessary to use leads consisting of ½-inch copper rod or tubing.

The power factors of all four capacitors are seen to follow the general trend predicted by the foregoing analysis but they are translated in a vertical direction. This effect is partly caused by losses in the yellow bakelite case, in the sealing compound, and in residual moisture. In each capacitor 2 to 3 $\mu\mu$f of the terminal capacitance occurs between the terminals themselves, with the case material and sealing compound as dielectric. The power factors of these materials are far inferior to the power factor of the mica. As the rated capacitance is increased, the proportion of poor dielectric to good dielectric decreases and, consequently, the over-all power factor is improved and the curves shift downwards.

The experimental data at frequencies from 50 cycles to 50 kilocycles were taken with the General Radio Type 716-A Capacitance Bridge, using both the Schering and parallel resistance connections; data were taken at frequencies from 160 kc to 4 Mc with the General Radio Type 516-C Radio-Frequency Bridge. At frequencies from 5 Mc to 10 Mc a parallel-resonance circuit was used. In all cases measurements were made with a parallel substitution method.

— D. B. Sinclair

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

GENERAL RADIO COMPANY

30 STATE STREET - CAMBRIDGE A, MASSACHUSETTS

BRANCH ENGINEERING OFFICES

90 WEST STREET, NEW YORK CITY

1000 NORTH SEWARD STREET, LOS ANGELES, CALIFORNIA

PRINTED IN U.S.A.

THE General Radio EXPERIMENTER

VOLUME XII NO. 12 MAY, 1938

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also

IN THIS ISSUE

Page
EXPERIMENTS IN THE PSYCHOLOGY OF HEARING 3
TYPE 664-A THERMOCOUPLE 7

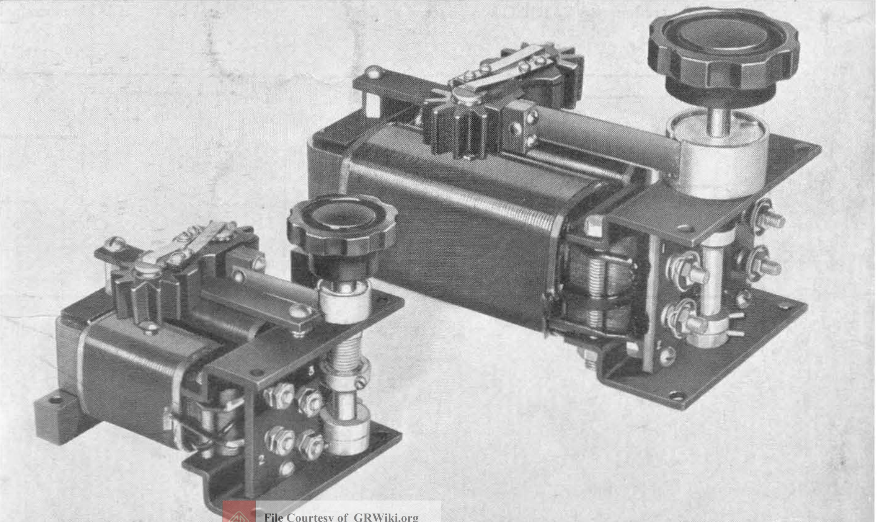
THE VARIAC TRANSFORMER

● **THE VARIAC TRANSFORMER,** an adaptation of the Variac principle to give voltage adjustment over narrow ranges, is now available in five stock models. The latest addition to this line is Type 80-C2, a 220-volt model.

The Variac Transformer is built on a rectangular core, with multilayer windings on the longer two legs of the core. Two carbon brushes make contact with the outside layer on each leg. This straight-line motion is translated into rotary motion by means of a stiff steel tape which winds on a shaft. A 320-degree rotation of this shaft drives the brushes along the entire length of the winding. These details of construction can be seen in the photograph of Figure 1.

Available stock models with their characteristics are listed in the table on page 2. Figure 2 shows the connections. Obviously, input and output connections for the −B and −C models can be reversed, that is,

FIGURE 1. TYPE 70 and TYPE 80 Variac Transformers.



Type	*Input Volts*	*Output Volts*	*Max. Current*
70-A2	115	0–10	6 a
70-B2	100–125	115	2 a
80-A2	115	0–10	20 a
80-B2	90–130	115	7.5 a
80-C2	200–240	220	7.5 a

a variable voltage can be obtained from a constant-voltage line, if desired.

Many other combinations of input and output voltages are possible. The limitation on the design of special models is the variation in output power which can be handled by the core structure. This quantity, called "variable power" for want of a better term, is the difference between the power outputs at maximum and minimum output voltages.

The Type 80 Core will handle 250 watts of variable power, and the Type 70 Core, 50 watts. Variac Transformers designed to the customer's specifications can be supplied within these limits. Prices will gladly be quoted on request.

SPECIFICATIONS

Load Rating: TYPE 70 furnishes 50 watts and TYPE 80 supplies 250 watts of variable power.

Current: See table above. All ratings are for 50- to 60-cycle service.

No-Load Loss: Approximately 5 watts for TYPE 70; 10 watts for TYPE 80.

Terminals: Threaded terminal studs with soldering lugs.

Dimensions: TYPE 70, (length) 4¾ x (width) 3⅜ x (height) 4 inches; TYPE 80, (length) 8½ x (width) 4¼ x (height) 5½ inches, over-all.

Net Weight: TYPE 70, 4¼ pounds; TYPE 80, 13¼ pounds.

Type		*Code Word*	*Price*
70-A2	....	BASIN	**$10.00**
70-B2	....	BASSO	**10.00**
80-A2	....	BATON	**15.00**
80-B2	....	BATTY	**15.00**
80-C2	....	BARON	**15.00**

The trade name VARIAC is registered at the U. S. Patent Office. The VARIAC is manufactured and sold under U. S. Patent 2,009,013.

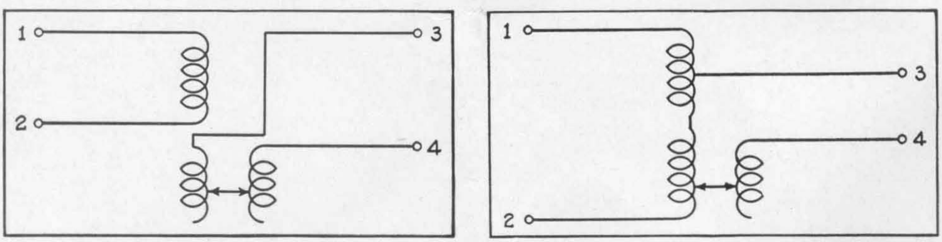


FIGURE 2. (*Left*) Connections for TYPE 70-A2 and TYPE 80-A2. The input terminals are numbered 1–2; the output terminals 3–4. (*Right*) Connections for TYPE 70-B2, TYPE 80-B2, and TYPE 80-C2. Input is applied at terminals 3–4 and the output appears at 1–2.

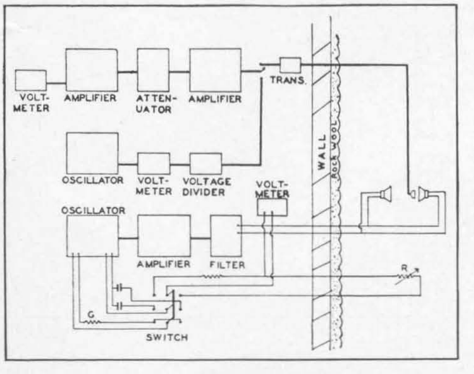
EXPERIMENTS IN THE PSYCHOLOGY OF HEARING

● **MANY GENERAL RADIO INSTRUMENTS** are used by people who are not directly interested in electrical measurements but who have found electrical instruments of some help in studying other phenomena. Accordingly, wave analyzers are bought by soft drink manufacturers, tuning forks are used by geologists, and stroboscopes have been helpful in predicting the effects of earthquakes on structures. Into this category of unusual applications falls the use of many of our instruments by the Department of Psychology of Harvard University. Under the direction of Dr. S. S. Stevens of this department and Dr. Hallowell Davis of the Medical School, a large amount of research has been done on the psychology and physiology of hearing, and in this work electrical instruments have played a very important part.

For many years it has been known that the pitch of some pure tones seems to change slightly as the intensity of the tone is changed, even though the impressed frequency remains constant. Dr. Stevens has made a more thorough investigation of the subjective quality of pitch and its relation to the objective frequency and intensity of a tone. He has also found that three other subjective qualities, those of loudness, volume, and density, may be used to describe a pure tone, and the relation of these to frequency and intensity has been studied. To the layman, loudness and pitch mean definite things, but volume and density are less tangible. However, if we think of a high tone we realize that it seems "small" and "compact" as compared to a low tone. The idea of size corresponds to volume and "compactness" or "concentration" to density.

In studying these tonal qualities the apparatus shown in Figure 1 was set up to present to an observer, alternately, two tones differing slightly in frequency. All the apparatus was kept outside the sound-proof room in which the observer sat, with the exception of the speakers, calibrated microphone, and a rheostat which was used to control the intensity of one of the tones. This rheostat was adjusted by the observer until the two tones sounded equal in pitch, loudness, or any other quality which was being investigated. The intensity of the standard tone being known, that of the second tone was recorded and the proc-

FIGURE 1. Apparatus used for measuring tonal attributes. A TYPE 508 Oscillator was arranged with external condensers so that two frequencies differing by small known amounts could be obtained. These two frequencies were fed, alternately, to speakers near the observer's ears. The switching from one frequency to the other was done automatically at a rate of about 40 alternations per minute, and in such a manner that the tones were allowed to build up comparatively slowly so as to eliminate "clicking" in the speakers. A calibrated microphone, placed in the position normally occupied by the right ear of the observer, was used to obtain absolute values for the intensities used.



ess repeated. Several trials were made at various intensity levels, and different observers were also used.

By applying this procedure, isophonic contours are obtained which represent equal loudness, pitch, density, or volume. For example, in Figure 2 the percentage frequency change needed to keep the pitch constant is plotted against sound pressure, and a family of curves is obtained with the standard frequency as a parameter. If isophonic contours for the four subjective qualities (pitch, volume, density, and loudness) are plotted on one scale for a given frequency and intensity level, the changes in these tonal attributes caused by given changes in frequency and intensity can be compared very easily. This is done in Figure 3, which shows what change in the intensity of a tone must be made in order to compensate for a particular change in frequency, whenever it is desired to hold any one of the subjective aspects at a constant value. Dr. Stevens and his colleagues have interpreted these results to mean various things regarding the physiology of the ear, and much of their work has been to correlate these results with the known facts regarding the process of hearing. Thus the partial tuning of the basilar membrane, the activation of the fibers in the auditory nerve, and similar phenomena are being studied in the light of the information provided by these experiments.

For some time it has been known that a sound stimulus generates an electric wave in the cochlea. Dr. Stevens showed that this effect is reversible. That is, he passed alternating current through the heads of several observers, and they then experienced an auditory sensation. One electrode was strapped to the arm and one was placed in a saline solution in the ear. Several sets of measurements were made in order to determine the amount of energy required at different frequencies to produce a threshold sensation of hearing and then to produce a sensation of shock. These threshold curves are very similar to the curves for normal hearing, as would be expected. At 500 cycles, for example, it takes but 10 decibels above 1 microwatt to produce a sense of hearing, while at 12,000 cycles it takes nearly 30 decibels. At about 125 cycles the two thresholds meet, and then the sensation of hearing by this electrical stimulation becomes rather strange, according to the reports of the observers. Pure tones were used in the measurements of the thresholds, but if

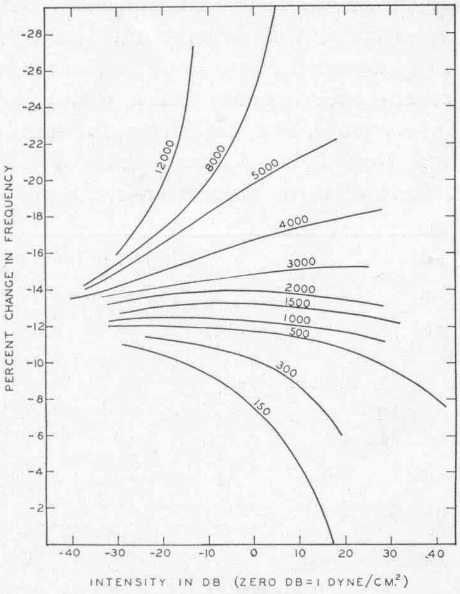


FIGURE 2. Contours showing the relation of pitch to intensity. The per cent change in frequency necessary to keep the pitch of a given tone constant in the face of a given change in intensity is a measure of the effect of intensity upon pitch. The vertical scale was so chosen that a contour with positive slope indicates that pitch increases with intensity. Note that pitch decreases with intensity below 2000 or 3000 cycles, then increases at higher frequencies.

very poor wave-forms such as the familiar saw-tooth discharge wave are used, the lower limit of frequency is extended indefinitely, although there is no longer the sensation of a continuous tone.

Unfortunately, the tones heard under electrical stimulation are greatly distorted and do not sound pure. This fact was demonstrated by sending the output of a radio receiver through the observers. Music and speech were recognizable as such but could not be understood with any degree of accuracy.

Several hypotheses have been advanced to explain the phenomenon of hearing by electrical stimulation, but the one which best fits the facts assumes that the same elements in the ear which produce an electric wave in response to mechanical vibration, also proceed to vibrate when subjected to an alternating electric field. It has been suggested that in this respect the hair cells of the inner ear behave in a manner analogous to tiny piezo crystals.

A most interesting investigation which is being carried on at the present time is the study of the distortion of pure tones produced by the ear. Harmonics so produced are heard subjectively, but are not easily measured or studied in the human ear. By the use of animals, however, Dr. Stevens and Dr. Davis have succeeded in obtaining much interesting information. It has been found that the cochlea of the ear produces an electrical potential which is very similar in form to the sound impressed on the ear, and that this potential is a very good index of the sound energy which reaches the end-organs of the auditory mechanism.

Tones are produced by a Type 713-B Beat-Frequency Oscillator the output of which is fed through an attenuator and then into a speaker box. From there, a rubber tube conducts the sound to the ear itself. The cochlear potential is picked up by a wick electrode from the round window. These potentials were then amplified and fed to a Type 636-A Wave Analyzer, an oscillograph, or a speaker. A calibrated microphone was also used to measure the absolute intensity levels at the ear.

When pure tones are used for the stimuli, an analysis of the electrical output shows that harmonics are introduced when the intensity of the stimulus reaches 40 or 50 decibels above the human threshold. At first the second appears; then, as the level is increased still further, the third, fourth, and even the fifth harmonics appear. As the harmonic content rises, the fundamental output tapers off and reaches a rather constant value by the time the stimulus has reached 100 decibels above the threshold.

One interesting fact is that after a level of about 90 decibels is reached the even harmonics begin to fall off, while the odd climb steadily.

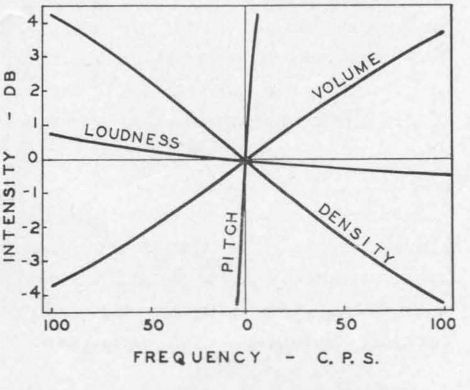
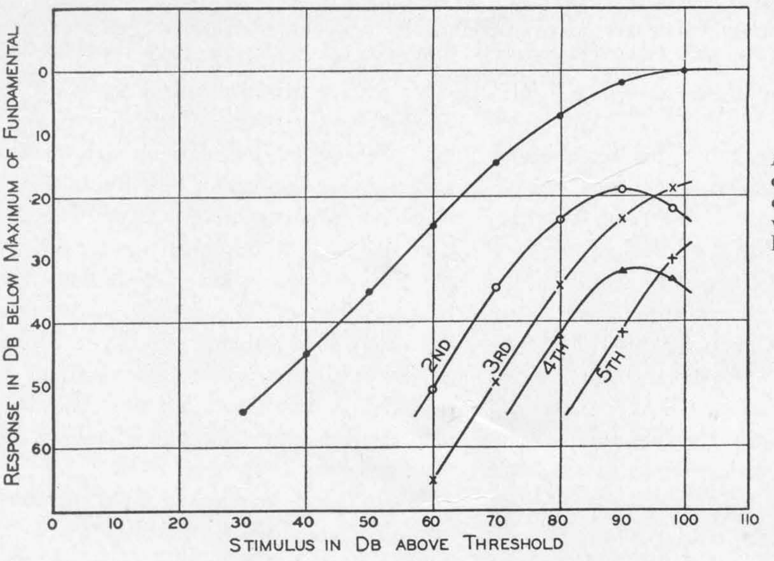


Figure 3. Isophonic contours representing equal pitch, loudness, volume, and density of tones referred to a standard tone of 500 cycles and 60 db. Zero frequency = 500 cycles, and zero intensity = 60 db above the auditory threshold.



Analysis of the cochlear response of a guinea pig when stimulated by a pure tone of 1000 cycles.

These phenomena give rise to a hypothesis concerning the cause of the harmonics in the ear. With small impressed sound pressures the ear has a linear response, but, as the displacement of the ear mechanism increases, first one portion of the mechanism and then another reaches a limit beyond which Hooke's law does not apply and the "characteristic" curve of the ear is nonlinear. If this curve were exactly symmetrical about the operating point, no even harmonics would be present. Since even harmonics were discovered, it is supposed that the constraining muscles of the middle ear impose unsymmetrical limits on the amplitude of vibration. This point was experimentally confirmed by changing the tension of the muscles of the middle ear and noticing that the amounts of even harmonics were correspondingly affected.

Some work was also done with combination tones. Two pure tones differing in frequency by several hundred cycles were introduced into the ear and the cochlear potential again analyzed. It was then found that, in addition to the harmonics of both tones, many combination tones were present. In one instance a total of sixty-six combination tones were found in the output of a cat's ear. Three of these were of the seventh order, while ten were of the sixth order. One interesting thing occurred when two tones were impressed simultaneously: the harmonics of each were reduced appreciably below the level found when only one tone was used.

In addition to the investigations outlined in this article many more researches have been carried on in the past several years in this field. Furthermore, it is certain that more work will be done in the future to obtain information which will lead to an understanding of the nature of hearing. It is still fascinating to realize that the various branches of science can cooperate to produce instruments and techniques which will allow better results to be obtained than when each branch works in its own "back yard."

— Martin A. Gilman

BIBLIOGRAPHY

S. S. Stevens, "The Relation of Pitch to Intensity," *J.A.S.A.*, January, 1935.
S. S. Stevens, "The Attributes of Tones," *Proc. Nat. Academy of Sciences*," July, 1934.
S. S. Stevens, "On Hearing by Electrical Stimulation," *J.A.S.A.*, January, 1937.
S. S. Stevens and H. Davis, "Psychophysiological Acoustics: Pitch and Loudness," *J.A.S.A.*, July, 1936.
E. B. Newman, S. S. Stevens, and H. Davis, "Factors in the Production of Aural Harmonics and Combination Tones," *J.A.S.A.*, October, 1937.

TYPE 664-A THERMOCOUPLE— A HIGH-FREQUENCY VOLTAGE STANDARD

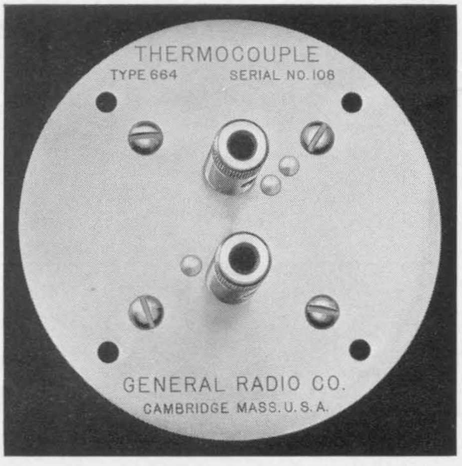


FIGURE 1. Front view of the TYPE 664-A Thermocouple showing the standard-voltage terminals. The circular plate mounts in the shield or on the panel of an r–f generator.

● **ABOUT A YEAR AGO** an experimental thermocouple and resistor combination for the standardization of high-frequency voltages was described in the *Experimenter*.* Since that time, several requests have been received for similar devices, and, as a result, it has been decided to make a high-frequency thermovoltmeter element available as a stock item.

The previously described unit consisted of a thermocouple and a standard resistor in series, both using 0.4-mil nickel-alloy wire. The arrangement had the serious drawback that only about one-half volt could be safely applied to the resistor unit. By using the heater of the thermocouple as the standard resistor, this disadvantage can be overcome. As will be pointed out later, the increased resistance does not introduce any error in the measurement.

One of the factors determining the high-frequency limit is the inductance of the heater, or, more precisely, the inductance-to-resistance ratio. This ratio can be reduced (1) by decreasing the wire diameter and (2) by increasing the resistivity of the material used (changing the length changes the inductance and the resistance but does not alter the ratio appreciably). A decrease in diameter lowers the power handling capacity,

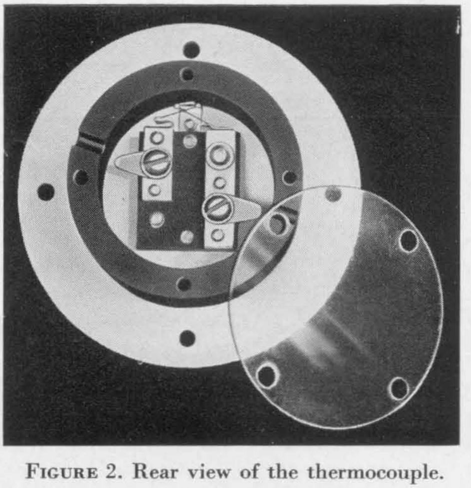


FIGURE 2. Rear view of the thermocouple.

*L. B. Arguimbau, "A High-Frequency Voltage Standard," *Experimenter*, June, 1937.

so that an increase in the resistivity of the heater material is more desirable than the other method. After a numerical consideration of these various factors, a 3-mil carbon heater ¼″ long was chosen. The carbon heater has the disadvantage of having a bad temperature coefficient of resistance but, in addition to its other advantages, it is definitely non-magnetic whereas high-resistance alloys are not entirely free from suspicion in this respect.

The terminal and electrical arrangement, shown in Figure 3, has certain obvious advantages. When the couple is mounted in the case of a shielded generator, the input and output circuits have practically zero mutual reactance, avoiding stray induced output voltages. Since the voltage element is directly across the output terminals, the voltage sensitivity is independent of the resistive or capacitive load and, in particular, of the capacitance between the output terminals. Applying Thevenin's theorem, this means that the effective output impedance is zero, an important practical advantage for high-frequency measurements.

The safe limit of output voltage is about 7 volts. At this voltage the heater resistance is approximately 200 ohms, and the couple output (through 10 ohms) is approximately 4 millivolts.

Since this standard is the best which we have found, no independent check on its accuracy is available. The computed error resulting from inductance is 1% at 700 Mc and 2% at 1000 Mc. Estimated bead capacitance gives an error of 1% at 10,000 Mc, and skin effect is 1% at 16,000 Mc.

—L. B. Arguimbau

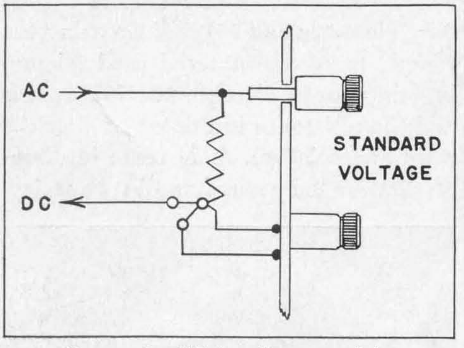


Figure 3a. Wiring diagram of the thermocouple.

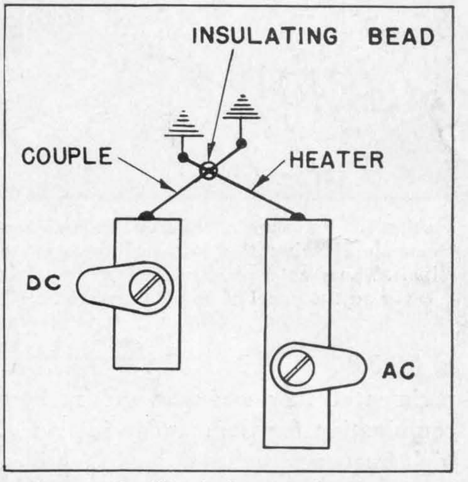


Figure 3b. Sketch showing the arrangement of the elements.

SPECIFICATIONS

Dimensions: Diameter of shield panel, 3 inches; diameter of case, 2 inches; depth behind panel, ¾ inch.

Net Weight: 7 ounces.

Code Word: FANCY.

Price: $25.00.

GENERAL RADIO COMPANY
30 STATE STREET - CAMBRIDGE A, MASSACHUSETTS
BRANCH ENGINEERING OFFICES
90 WEST STREET, NEW YORK CITY
1000 NORTH SEWARD STREET, LOS ANGELES, CALIFORNIA

PRINTED IN U.S.A.

THE General Radio EXPERIMENTER

VOLUME XIII NO. 1 JUNE, 1938

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also IN THIS ISSUE

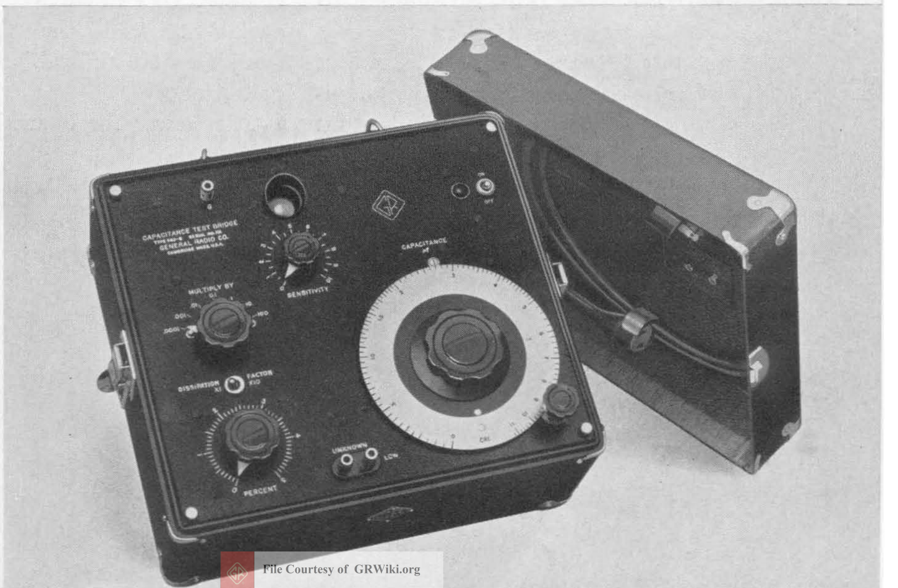
Page

A 60-Cycle Schering Bridge 5

A WIDE-RANGE CAPACITANCE TEST BRIDGE

● THE OUTSTANDING FEATURES of the new Type 740-B Capacitance Test Bridge are its accuracy, portability, simplicity of operation, and wide range of capacitance and dissipation factor — features which make the bridge suitable for industrial use. The bridge is intended for use (1) by the condenser manufacturer or user for checking paper, electrolytic, and mica condensers; (2) by cable and insulated-wire manufacturers for measuring specific inductive capacity, direct and mutual capacitance between conductors, and capacitance between conductors and shields; (3) by transformer manufacturers for measuring winding capacitances and capacitances between winding and case; (4) by spark-plug manufacturers for checking spark-plug capacitance in the production line; and (5) in general capacitance testing.

Figure 1. Panel view of the Type 740-B Capacitance Test Bridge with cover removed



In this new bridge a visual indicator replaces the earphone method of null indication. In industry earphones are prohibited because they are too fatiguing to the operator and because they are unsuitable in the presence of the high noise levels existing in most factories. The TYPE 740-B Capacitance Test Bridge with its visual indicator overcomes these difficulties and offers in addition the utmost in simplicity of operation.

SIMPLICITY

Every effort has been made to minimize the number of controls and to keep manipulation as simple as possible. Referring to the panel photograph, Figure 1, the only dials are the capacitance dial and multiplier switch, which read directly in capacitance; the direct-reading dissipation factor dial; and a sensitivity dial which allows the operator to adjust the sensitivity of the visual indicator to any desired value. Batteries and external or internal oscillators are avoided, and, being designed for 60-cycle operation, the bridge can be set up and operated at any location where a 115-volt, 60-cycle line is available.

To make the bridge entirely suitable for portable use, it is mounted in a light carrying case, of airplane-luggage construction, with cover and handle, so that it can be carried anywhere without damage to knobs, dials, or other important parts. The construction is so rugged that there is little danger of damage, even in inexperienced hands.

Five micromicrofarads to 1100 microfarads for capacitance and 0 to 50% for dissipation factor are the ranges of the bridge — ranges which make it suitable for almost every industrial or laboratory application. At one end of this range is the cable and wire manufacturer, who is generally interested in measurements below 1000 micromicrofarads, and at the other end is the electrolytic condenser manufacturer, who is interested only in capacitances of the order of 10, 100, and 1000 microfarads.

The loss balance control of the bridge is calibrated in per cent dissipation factor ($R\omega C$), and all references to this loss factor will be made in terms of dissipation factor rather than power factor. This is because dissipation factor and power factor equal each other only for values less than 10%. Therefore, in view of the 0-to-50% range of the bridge, it would be a misnomer to refer to the loss factor as anything but dissipation factor.*

THE BRIDGE CIRCUIT

The bridge circuit is shown in Figure 2. The standard arm consists of a fixed condenser in series with a variable resistor. One ratio arm is variable in decade steps and the other is continuously variable and calibrated directly in capacitance.

The power for operating the bridge

*See Table 1, page 7.

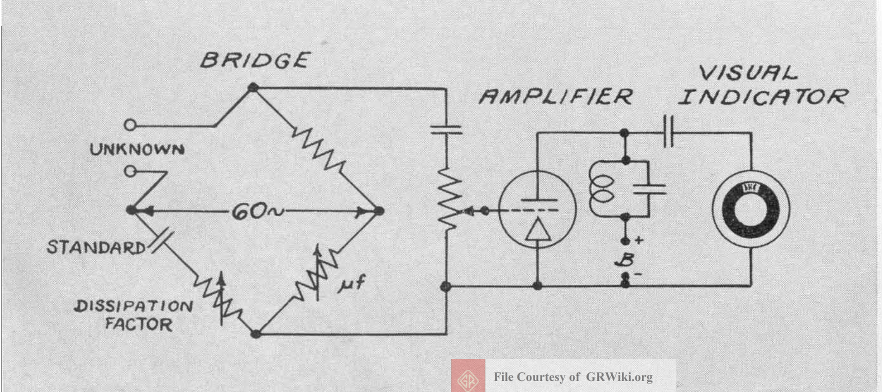


FIGURE 2. Simplified wiring diagram of the TYPE 740-B Capacitance Test Bridge.

circuit is obtained from the 60-cycle line through a shielded isolating transformer. Care was taken in the design and construction of this power transformer to insure complete isolation of the bridge circuit from any variations that might occur in the supply line and to insure a minimum of capacitance between generator terminals and ground. These precautions are necessary in order to maintain the high degree of accuracy of which the bridge itself is capable.

The voltage impressed across the UNKNOWN terminals varies continuously with the bridge setting. For very small capacitances measured on the .0001 capacitance range, the voltage across the unknown condenser is approximately 35 volts, and with increasing capacitance the voltage decreases, so that at 100 microfarads the voltage is approximately one volt.

THE AMPLIFIER AND NULL INDICATOR

The problems involved in obtaining a satisfactory visual null indicator are considerably more exacting than those in obtaining a suitable acoustical indicator. For the acoustical method of balance, the ear can tolerate the presence of considerable harmonic distortion and extraneous electrical noise without materially reducing the accuracy to which the balance can be obtained. In this bridge, an electron-ray tube (the so-called magic eye) is used as a detector. With this type of visual indicator, however, the presence of harmonics or electrical noise causes the "eye" at balance to appear fuzzy, and unless these noises and harmonics are filtered out, a sharp, accurate balance is impossible.

By using a high-gain amplifier and a sharply tuned filter circuit, a visual null indicator having the sensitivity of the amplifier-earphone combination has been obtained. The schematic diagram, Figure 2, shows the connections of the detector circuit. The sensitivity potentiometer controls the gain of the amplifier and hence controls the sensitivity of the visual indicator. This sensitivity control is extremely useful when the full sensitivity of the bridge is not desired or when the bridge is being used as a limit indicator.

RANGE AND ACCURACY

The capacitance readings of the bridge are taken from the settings of a seven-point decade multiplier switch and a six-inch dial having a scale which is approximately logarithmic over one decade. For capacitance the bridge is direct reading from 5 micromicrofarads to 1100 microfarads, and its accuracy over most of this wide range is within $\pm 1\%$.

Dissipation factor readings are taken from a dial which is linear in dissipation factor over two ranges, one of 0 to 5% marked in divisions of 0.1% and the other of 0 to 50% marked in divisions of

FIGURE 3. As shown, the capacitance test bridge is small, light in weight, and easy to carry.

1%. The dissipation factor range chosen is selected by a toggle switch. The accuracy of dissipation factor readings over practically the entire range of the bridge is within ±3/4 of one of the smallest scale divisions. This means that on the 0-to-5% dissipation factor range the error in dissipation factor reading is ±0.075%, and on the 0-to-50% range the accuracy is to within ±0.75%.

60-CYCLE MEASUREMENTS

Intended for industrial use, the new Type 740-B Capacitance Test Bridge was of necessity designed for 60-cycle operation. To the cable, transformer, and electrolytic condenser manufacturer 1000-cycle measurements have been of little value, since much of the equipment manufactured in these industries is intended for low-frequency operation.

Neither of the UNKNOWN terminals is actually connected to ground, although at balance the low terminal of the bridge is effectively at ground potential. Having both terminals ungrounded makes it possible to use the bridge for (1) direct capacitance measurements between transformer windings and between conductors in multi-conductor cables, and (2) for direct measurements of the direct and mutual capacitance between conductors and shields and between transformer windings and cases.

FIGURE 4. The capacitance test bridge set up for the rapid testing of mica condensers.

Specific inductive capacity and its change with moisture absorption are other measurements which can be made, and because of the extremely wide range of the bridge it can even be used for making these measurements on standard 10-foot test samples of insulated wire.

POLARIZING VOLTAGE FOR ELECTROLYTIC CONDENSER MEASUREMENTS

In the standard Type 740-B Capacitance Test Bridge no provision has been made for the connection of a d-c polarizing voltage. Terminals for the connection of a polarizing voltage have been purposely left off, so as to keep the bridge free from terminals which are not always required and which may be confusing to the inexperienced operator. The bridge circuit, however, is so arranged that a d-c polarizing voltage up to 500 volts can be applied, and, for those who are interested in using the bridge for checking electrolytic condensers, special bridges can be supplied with terminals for introducing a polarizing voltage. Figure 5 shows the manner in which the d-c polarizing voltage can be introduced in the circuit.

USE AS A LIMIT BRIDGE

The visual indicator makes it possible to use the bridge for production condenser testing. After a single preliminary adjustment, one condenser after another can be placed across the UNKNOWN terminals and the electric eye will indicate immediately whether or not each condenser is within the allowed tolerance. When the bridge is so used, capacitance checks are made almost instantly and without requiring any careful meter reading or dial adjustment.

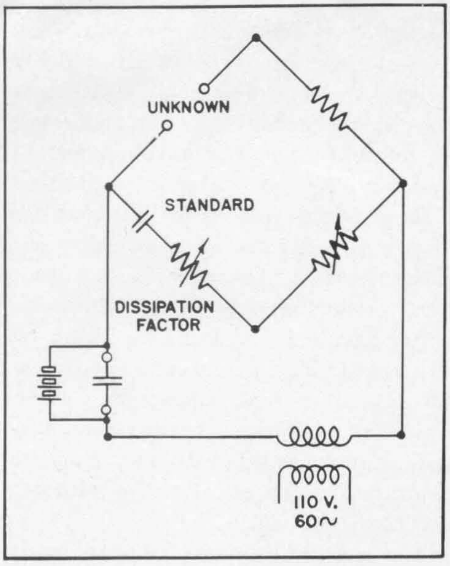


FIGURE 5. Circuit showing method of introducing polarizing voltage.

This capacitance test bridge sets a new standard for accuracy, ruggedness, portability, and simplicity, and makes commercially available a capacitance measuring instrument suitable for production use, as well as routine laboratory measurements. — L. E. PACKARD

SPECIFICATIONS

Power Supply: 115 volts, 60 cycles.

Power Input: 15 watts.

Vacuum Tubes: One each of types 6X5, 6J7, 6E5; all are supplied with the bridge.

Mounting: Portable carrying case.

Net Weight: 19 pounds.

Dimensions: (Length) 14½ x (width) 15 x (height) 9¼ inches, over-all, including cover and handles.

Type	*Code Word*	*Price*
740-B	BABEL	$140.00
Extra terminals installed for polarizing voltage.		10.00

This instrument is licensed under patents of the American Telephone and Telegraph Company, solely for utilization in research, investigation, measurement, testing, instruction, and development work in pure and applied science

A 60-CYCLE SCHERING BRIDGE

● **MEASUREMENTS OF THE DIELECTRIC PROPERTIES** of insulating materials are acquiring a constantly increasing importance to industry. These measurements include not only the testing of materials used as dielectrics in capacitors, and as insulation in transformers, cables, and electrical machinery, but also a multitude of tests on ceramic, fabric, and paper products to determine their composition, moisture content, and the effects of temperature, humidity, and voltage gradient upon them. For such measurements, it is desirable that the necessary bridge equipment be simple and capable of rapid routine measurements. Since much of the material so tested is for use at commercial power frequencies, it is convenient to use the a-c line as a source of bridge power, which eliminates the need for a separate oscillator.

The TYPE 671-A Schering Bridge is designed for this sort of measurement. The power source may be any 115-volt, 60-cycle line.* The voltage across the unknown capacitor can be varied continuously from zero to ten times line voltage by means of a potentiometer and input transformer. A meter is provided, reading in kilovolts the rms potential applied to the bridge and, essentially, to

*The bridge will operate at any frequency between 40 and 60 cycles.

the unknown capacitor. Both the input and output transformers are astatically wound, and the bridge is electrostatically shielded, so that external 60-cycle fields do not affect the measurements. Certain sources of error, difficult to eliminate in a direct-reading type of Schering bridge, are avoided in this bridge by using a substitution method of measurement.

The bridge network consists of two fixed equal resistance arms, R3 and R4 (see Figure 2), shunted by the capacitors, C3 and C4, and two capacitance arms, one containing a fixed capacitor, C1, and the other a standard capacitor, C21, and its trimmer, C22. The unknown external capacitor is connected in parallel with the standard, C21. A suitably shielded and resonated transformer joins the bridge network to some form of null-balance detector not included in the bridge. The junction of the capacitance arms, the metallic housing cabinet, and one terminal of the unknown capacitor are grounded in operation. The input transformer isolates the bridge from grounds in the power supply.

In the TYPE 671-A Schering Bridge the *capacitance balance* is made by means of a TYPE 722 Precision Condenser, C21, the scale of which reads directly the capacitance, C_x, of the unknown capacitor. This scale is calibrated in steps of 0.2 $\mu\mu$f. The maximum capacitance is 1020 $\mu\mu$f. Unknown capacitors of larger value than 1020 $\mu\mu$f may be measured indirectly by a series substitution method. The precision of absolute C_x values measured on this bridge is better than 0.1% of full scale value, or ± 1 $\mu\mu$f. Small differences between two capacitors, or small changes in a given capacitor with time, temperature, humidity, voltage gradient, etc., may be determined with an accuracy of from ± 0.1 to ± 0.3 $\mu\mu$f.

The *resistive balance* of this bridge is accomplished by a separate variable capacitor, C4, the scale of which is calibrated, at 60 cycles, in terms of the function:*

$$S = D_x C_x$$

in which C_x is the capacitance in micromicrofarads and D_x the dissipation factor of the unknown capacitor. The S scale is, therefore, calibrated in micromicrofarad units. The dissipation factor, defined as the ratio of resistance to reactance and hence a pure number, is numerically equal to:

$$D = R_x \omega C_x$$

*A correction factor must be applied for other frequencies.

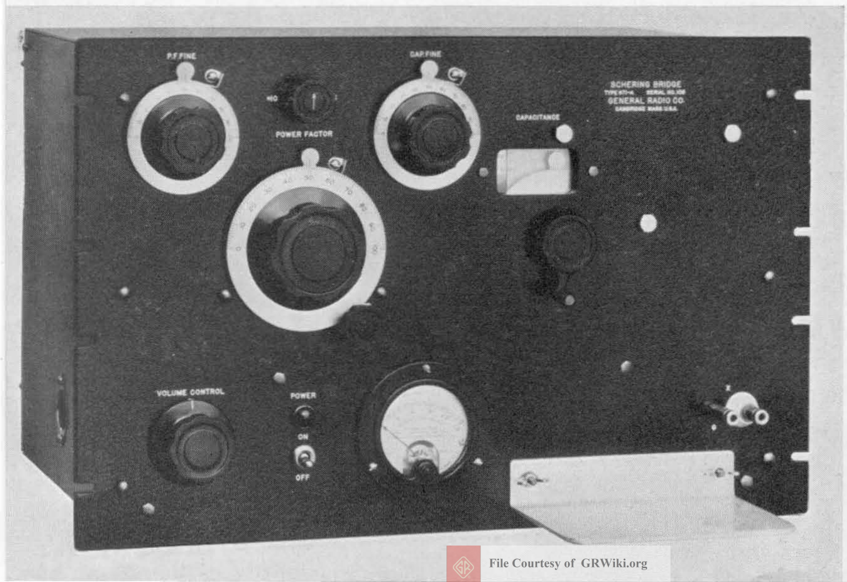
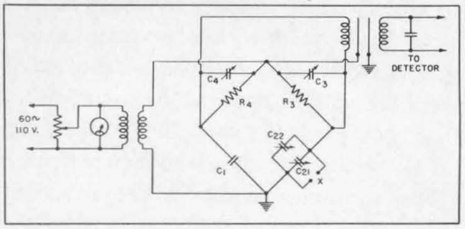


FIGURE 1. Panel view of the 60-cycle Schering bridge. Note the convenient shelf for test specimens.

FIGURE 2. Circuit diagram of the TYPE 671-A Schering Bridge with the power factor multiplier switch in the X1 position.



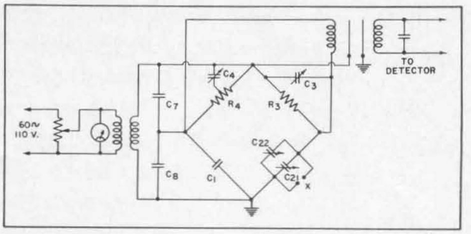


FIGURE 3. Circuit diagram of the bridge with power factor switch in the X.1 position.

where R_x is the equivalent series resistance in ohms and C_x the equivalent series capacitance in farads of the unknown capacitor.

The dissipation factor, D_x, obtained on the Schering bridge is the cotangent of the phase angle or the tangent of the loss angle of the unknown capacitor, while the power factor is the cosine of the phase angle or the sine of the loss angle. Power factor and dissipation factor are essentially equal for low loss dielectrics. The relationship among these four quantities is indicated in Table 1 below.

The maximum S scale value is about 80 $\mu\mu$f. Capacitors having larger values of D_xC_x may, however, be measured by a series substitution method. For the measurement of values of S less than 8 $\mu\mu$f, the range of the power factor dial can be reduced by a factor of ten, thereby increasing the precision of measurement. This is accomplished by throwing a switch which connects the power factor capacitor, C4, as shown in Figure 3. The compensating capacitors, C7 and C8, are also connected in this switch position to retain the same initial capacitance and resistive balances.

The first scale division on the power factor dial is unity in the normal position, or 0.1 in the low-range position. The maximum error in the determination of the value of S for the 1.0 multiplier is $\pm 2\%$ of the dial reading or ± 0.2 $\mu\mu$f, whichever is the larger. The maximum error in the determination of S with the 0.1 multiplier is $\pm 2\%$ or ± 0.05 $\mu\mu$f whichever is the larger. The absolute error of the computed dissipation factor involves this figure in addition to the error of C_x measurement specified above.

The trimming capacitor, C22, and the capacitor, C3, are used in establishing the initial balance of the bridge before the unknown capacitor is attached.

The bridge is provided with a cord for connecting it to the power main, a specially shielded lead for joining it to the

TABLE 1

Phase Angle	*Loss Angle*	*Dissipation Factor*	*Power Factor*	$\frac{DF-PF}{DF}$
90°	0°	.0000	.0000	0
85°	5°	.0875	.0872	0.34%
80°	10°	.1763	.1736	1.53%
75°	15°	.2679	.2588	3.4 %
70°	20°	.3640	.3420	6.1 %
65°	25°	.4663	.4226	9.3 %
60°	30°	.5774	.5000	13.4 %

Power Factor = $\cos \cot^{-1} D_x$

null detector, and a horizontal shelf for supporting small external capacitors when used in a relay-rack mounting.

For all of the contemplated uses of this bridge, it has been found that no guard circuits are required. In the interests of simplicity of operation and minimum expense, no provision for such guard circuits has been made, and thus the bridge is capable of measuring only two-terminal capacitors.

Some form of null-balance detector is, of course, required for use with this bridge. The customary headphones are not satisfactory at commercial frequencies. The best detector is some form of visual null indicator having the required sensitivity and a sufficient degree of selectivity to eliminate all harmonics of the applied frequency which are unavoidably present in the output of a Schering bridge balanced at the fundamental of the applied frequency. The a-c operated TYPE 707 Cathode-Ray Null Detector,* complete in one unit, is ideal for use with this bridge, or a suitable selective amplifier followed by a rectifier type of meter may be employed. For example, the TYPE 814-A Amplifier, the TYPE 814-P3 60-Cycle Filter, and the TYPE 488-D1 Rectifier Meter make a satisfactory combination (see the General Radio *Experimenter* for January, 1938).

— HORATIO W. LAMSON

*This new null indicator will be described in a forthcoming issue of the *Experimenter*.

SPECIFICATIONS

Power Supply: 115 volts, 60 cycles.

Power Input: 30 watts.

Mounting: 19-inch relay-rack panel.

Net Weight: 36½ pounds.

Dimensions: Panel, 19 x 12¼ inches; depth behind panel, 9¾ inches.

Type		*Code Word*	*Price*
671-A		BEGET	$325.00

MISCELLANY

● **MR. H. W. LAMSON** read a paper at the spring meeting of the Acoustical Society of America in Washington on "A Method of Observing Sound Decay and Measuring Reverberation Time."

● **RECENT SPEAKERS** at General Radio afternoon colloquia include Messrs. Hill, Young, Sawin, Pace, and Crites of Westinghouse Electric and Manufacturing Company; Messrs. Riley and Cutts of General Electric Company; and Messrs. Ehle and Marsten of the International Resistance Company.

GENERAL RADIO COMPANY

30 STATE STREET - CAMBRIDGE A, MASSACHUSETTS

BRANCH ENGINEERING OFFICES

90 WEST STREET, NEW YORK CITY

1000 NORTH SEWARD STREET, LOS ANGELES, CALIFORNIA

THE General Radio EXPERIMENTER

VOLUME XIII NO. 2 JULY, 1938

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also IN THIS ISSUE

Page
PORTABLE STAGE-LIGHTING CONTROL 4

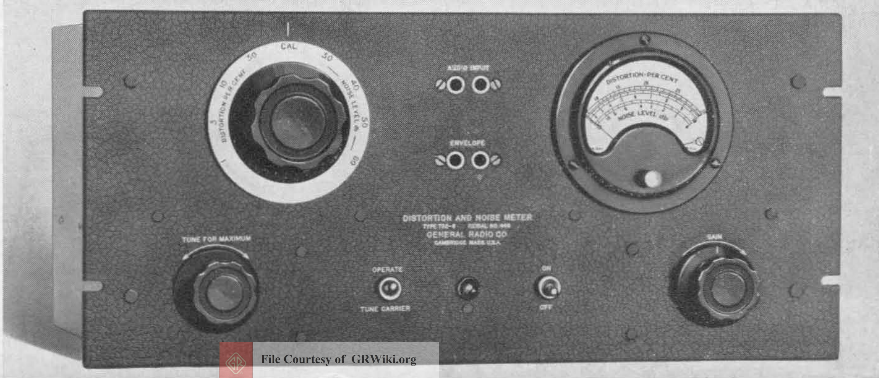
RADIO RECEIVER TESTS WITH TYPE 732-A DISTORTION AND NOISE METER

These receiver characteristics can be measured quickly and accurately with the TYPE 732-A Distortion and Noise Meter.

(1) Signal/noise ratio.
(2) Distortion *versus* power output. Distortion *versus* carrier output. Distortion *versus* per cent modulation.
(3) Audio and over-all frequency characteristics.
(4) Acoustic howl.
(5) Output at given distortion level.
(6) Over-all noise curves *versus* carrier input.
(7) AVC characteristic.
(8) Modulation hum and hum output.
(9) Whistle output at 2d and 3d harmonics of IF.
(10) AFC measurements.
(11) Two signal cross-talk.

• In the selection of instruments for radio receiver testing, the distortion and noise meter is sometimes overlooked, probably because it was originally designed for use in broadcasting stations, yet this instrument

FIGURE 1. Panel view of the TYPE 732-A Distortion and Noise Meter



is one of the most convenient and rapid means available for making many of the standard IRE tests on receivers.

Although the normal input to the distortion and noise meter is a modulated r-f wave, an alternate input circuit is provided for measuring audio-frequency systems, as is shown in the schematic diagram of Figure 2.

The operation of the instrument is evident from this diagram. If we disregard the r-f input circuit, the essential elements are a 400-cycle high-pass filter, a calibrated attenuator, a high-gain amplifier, and a direct-reading vacuum-tube voltmeter.

The amplifier has a flat frequency characteristic which makes it possible to measure the frequency characteristics of receivers, and the high gain of the amplifier permits the use of the instrument as a sensitive vacuum-tube voltmeter.

All measurements of distortion and noise require only a simple calibration adjustment which is determined by the nature of the test being made, after which readings are taken directly from the meter scale. For most of the tests specified at the beginning of this article, the distortion and noise meter is direct reading in the quantities specified on manufacturers' test sheets.

DISTORTION—NOISE—HUM

For the tests listed on page 1, the audio input jacks of the distortion and noise

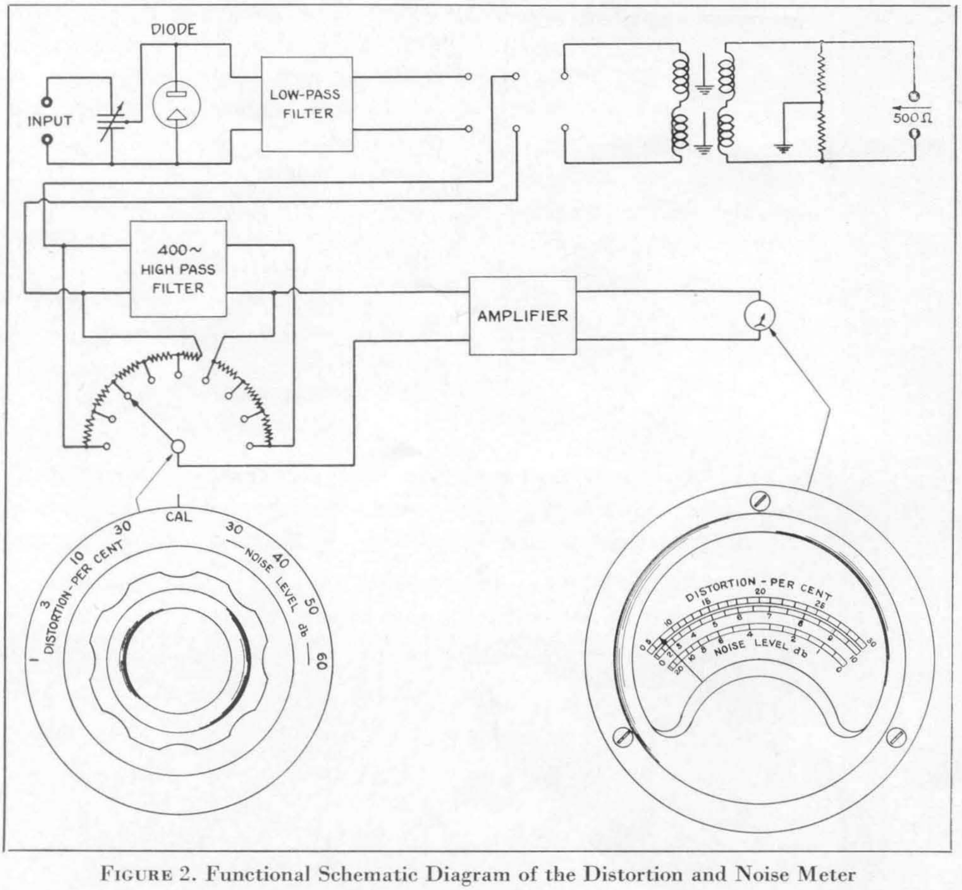


FIGURE 2. Functional Schematic Diagram of the Distortion and Noise Meter

meter are connected across the loudspeaker voice coil or across a dummy load which replaces the voice coil. The receiver is excited by a standard-signal generator modulated at 400 cycles. Percentage distortion under various operating conditions is read directly from the meter.

The high sensitivity of this instrument as a voltmeter is extremely useful in hum and noise measurements. For instance, the hum across the voice coil resistance may be as low as 2 or 3 millivolts. To measure this, the calibration adjustment is made at a convenient value such as one volt. Hum is then read in decibels below one volt and can easily be converted to a voltage ratio. The frequency of the calibrating voltage is usually 400 cycles, since most standard-signal generators have 400-cycle modulation. The amplifier in the distortion and noise meter, however, is sufficiently flat to permit the use of other audio frequencies.

AVC CHARACTERISTIC

The wide range of voltage measurement is also an advantage in AVC measurements. A typical inexpensive receiver may have an AVC ratio of 20 : 1 for an input range of 1000 : 1, and it may overload at voice coil inputs above one watt. With a 3-ohm voice coil resistance, the AVC measurement must be taken at an output level below the overload point of 1.73 volts. If the volume control is set to give this voltage for the high value of carrier input, the voltage at the other extreme is $\frac{1.73}{20}$ or 0.086 volts across the voice coil resistance. Therefore, accurate low-level voltage readings as provided by this meter are necessary.

FIDELITY

The response characteristic is flat over the audio-test range, and, consequently, the instrument can be used for fidelity measurements. The results are read directly in decibels from the attenuator dial and meter scale, avoiding db calculations from voltage readings.

ECONOMY

In keeping with the trend towards lower manufacturing costs and precise production measurements, measuring equipment, capable of increasing accuracy and lowering testing time, is required. The Type 732-A Distortion and Noise Meter offers a means for achieving this manufacturing objective.

— L. E. Packard

This article is based in part upon data supplied by Messrs. L. J. Hartley and C. R. Miner of the Radio Receiver Engineering Department, General Electric Company. Their assistance is gratefully acknowledged.

TYPE 759-P8 CONNECTOR

We have received a number of requests for plugs which will fit the microphone mounting of the Type 759-A Sound-Level Meter. These are useful in connecting vibration pickups and other accessories, and also for connection to electrical circuits, such as telephone lines, for the measurement of circuit noise level.

This plug is now available from stock and is known as Type 759-P8 Connector.

SPECIFICATIONS

Dimensions: (Length) 1½ inches; (diameter) ¾ inch.

Net Weight: 1½ ounces.

Type	*Price*
759-P8	$1.00

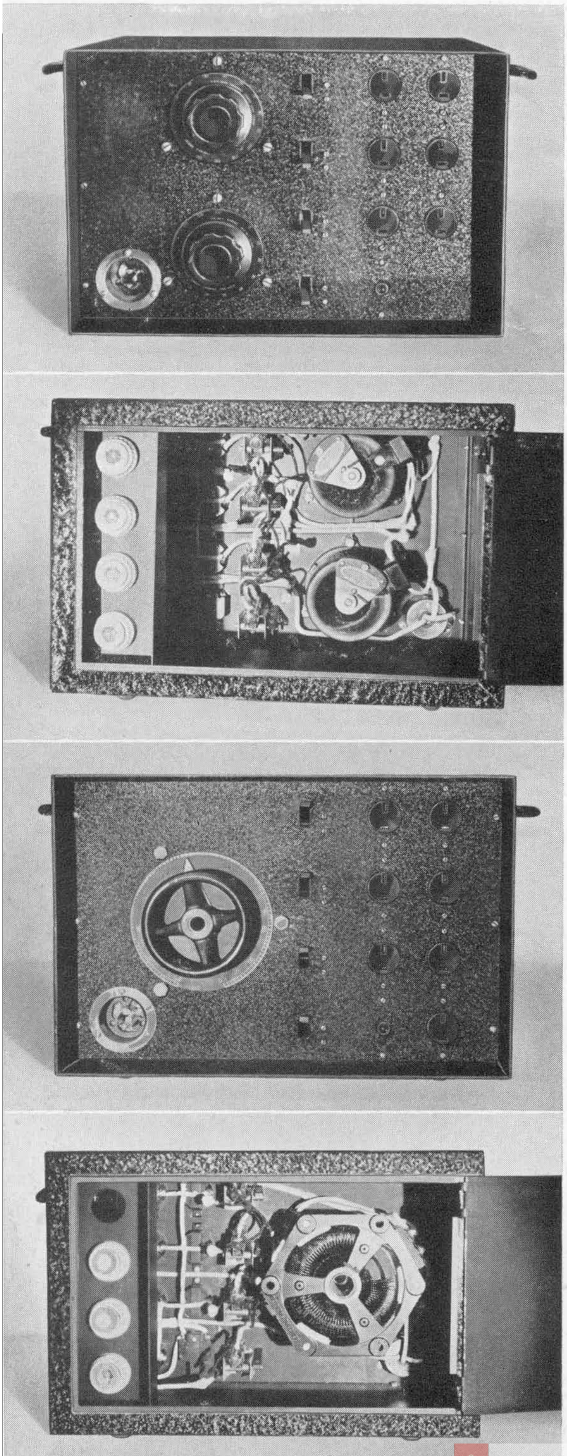
PORTABLE STAGE-LIGHTING CONTROL

by

RICHARD B. LEWIS AND

LEROY T. HERNDON, JR.

(Glendale, California, Junior College)



● **GLENDALE JUNIOR COLLEGE** dramatic productions are presented in a classroom theater and also in larger school theaters apart from the Junior College buildings. Usually the outside engagements provide for no stage-lighting control. To meet the need for complete, flexible stage-lighting control at low cost, a set of four portable dimmer boards have been the solution, both for production within the school and when "on tour." Built in small units to reduce weight and for greater portability, these boards were comparatively low in cost. Each unit measures, in outside dimensions, 12 x 12 x 18 inches, and weighs under 50 pounds.

Three control units have been built using as dimmers two 850-watt TYPE 200-CU Variacs each. The other unit uses one 2000-watt TYPE 100-K Variac. These auto-transformer dimmers provide complete light control from full-up to black-out on any size load up to the capacity of the dimmer.

To insure noiseless operation, 25-

FIGURE 1. Panel and rear interior views of the two lighting control units. The unit shown in the upper two photographs uses two TYPE 200-CU Variacs; that shown in the lower two photographs uses a single TYPE 100-K. A panel layout of the first unit is shown on page 6.

Protecting doors, which can be seen at the right of the rear views, are used at the back of each unit. Both panels are portable, and carrying handles can be seen at the ends of the cabinets.

ampere mercury switches, in specially designed mountings, have been used throughout. Each unit has a master switch and three switches for individual circuits. At the top of each board one switch controls two receptacles not on dimmers. Each 850-watt dimmer is in circuit with two receptacles, controlled by one switch. The 2000-watt dimmer has five receptacles on two switches.

The interior is completely accessible through a steel door which forms the rear of each unit. A sheet steel angle in the left inside rear corner provides a separate compartment and serves as the mounting for the fuse receptacles (metal-sign sockets).

An important feature of these units that has proved very useful is the possibility for proportional control of lighting units by using the output from the 2000-watt board to feed a board containing two 850-watt dimmers.

Before constructing these units, an experimental board was assembled using two 850-watt Variacs and one 2000-watt Variac. Those were mounted in an old standard steel junction box with tumbler switches, standard outlets, a four circuit fuse box, and a 30-ampere outside

FIGURE 3. This experimental board uses one TYPE 100-K and two TYPE 200-CU Variacs. The total cost of parts for this assembly, in addition to the Variacs, was only $5.

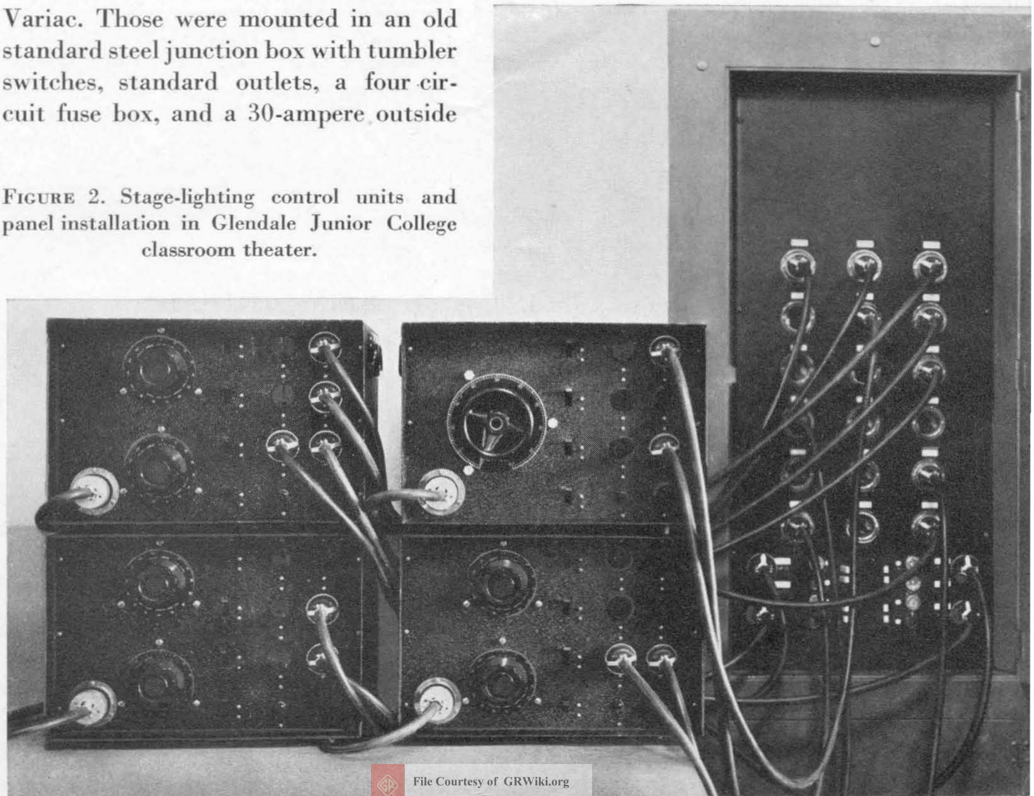


FIGURE 2. Stage-lighting control units and panel installation in Glendale Junior College classroom theater.

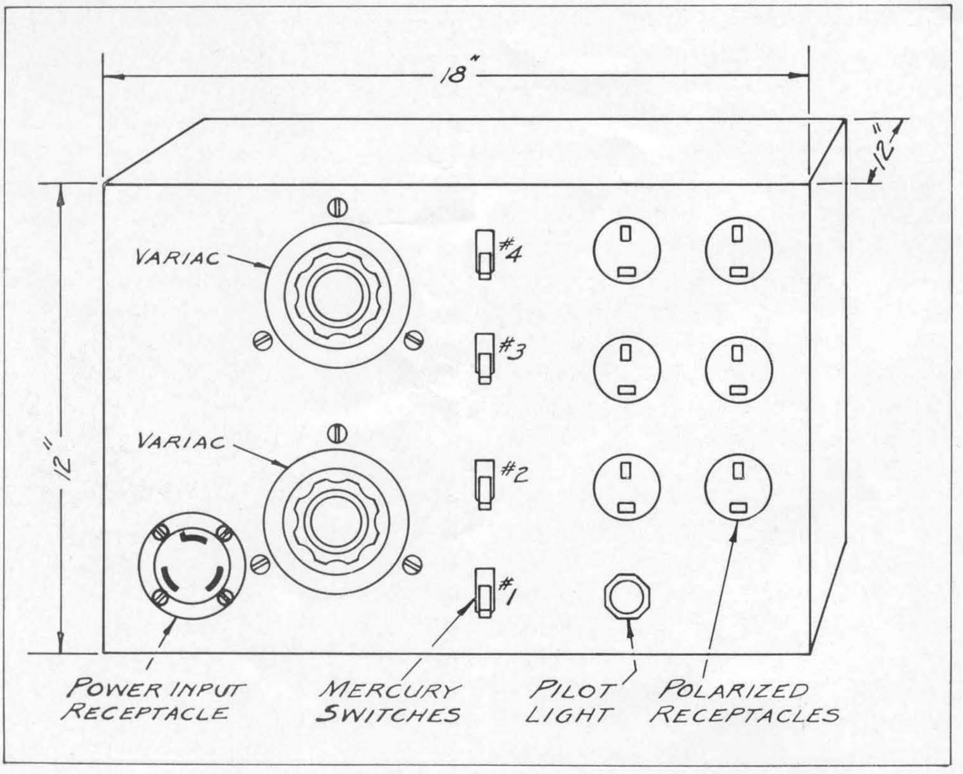


FIGURE 4. A panel layout of the two-dimmer unit. The Variacs are TYPE 200-CU, each rated at 850 watts. The lower switch is a master for the entire board. The output of each Variac is controlled by a switch and has two outlets. The top switch connects the two outlets at the top of the board directly to the a-c line. The power input receptacle is a 3-wire "Twist-Lock" type, providing a ground circuit for the board. The pilot light (lower right) glows when current enters the board.

switch for a master. Costing a little over five dollars for parts in addition to the dimmers, this unit proved the usefulness of such a board, and the low cost indicates how basic lighting control can be within the reach of producing groups with limited budgets.

The accompanying illustrations show the experimental board and the new units.

These boards were designed by L. T. Herndon, Jr., and R. B. Lewis, instructors in Glendale (California) Junior College, and L. R. Salisbury, '38, with the advice of Robert T. Philp, Superintendent of Buildings, and John W. Munn, Head Electrician, Glendale City schools. The mercury switches, polarized output receptacles, and "Twist-Lock" input receptacles are of standard design and can be obtained from a number of manufacturers.

SHIELDED CONNECTORS FOR A-C MEASUREMENTS

● **AS MORE** precise electrical measurements are attempted, previously negligible errors become more important, making it necessary to refine methods and apparatus if correct results are to be obtained.

Capacitive pickup is a well recognized source of errors in measuring circuits, especially in audio- and radio-frequency bridges. These errors result from voltages induced in the leads and apparatus by electrostatic fields. Shielding of equipment and leads is an effective means of minimizing such pickups. Concentric cables, with the outer conductor kept at ground potential, serve as excellent shielded leads. For most work, no particular precautions need be taken to shield the ends and standard General Radio TYPE 274 Plugs and Jacks may be used. One such convenient lead assembly is the TYPE 274-NC.*

For highly precise work more effective shielding is necessary. The TYPE 274-NE Shielded Plug and Cable provides this shielding. It differs from the TYPE 274-NC in having both ends capped with metal castings which are connected to the outside conductor of the concentric cable and which shield the terminals.

In addition to having shielded caps, the new TYPE 274-NE Shielded Plug and Cable employs a higher grade of insulation than has been previously used. At 1000 cycles, the capacitance of the three feet of cable which is used is about 150 $\mu\mu$f and the power factor is only 0.016. The d-c insulation resistance of the cable itself is about 500,000 megohms when measured at 90 volts.

The TYPE 274-ND Shielded Plug Assembly, which is used as the terminals for the TYPE 274-NE, has a piece of low-loss yellow bakelite as its insulating material. Therefore, the d-c resistance of the plug alone is greater than 1,000,000 megohms and its power factor is but 0.01 at 1000 cycles. The capacitance of the plug alone is about 3 $\mu\mu$f.

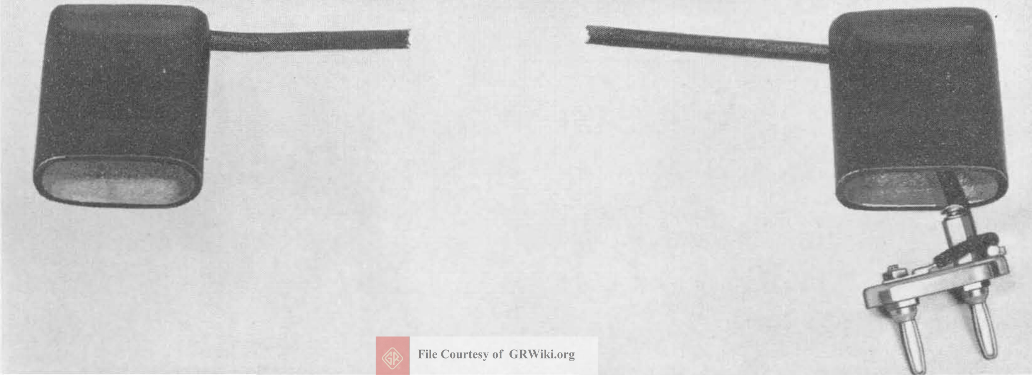
Both the TYPE 274-NE Shielded Plug and Cable and the TYPE 274-ND Shielded Plug Assembly are now stocked for immediate shipment.

— MARTIN A. GILMAN

*See Catalog J, page 159.

Type	*Description*	*Code Word*	*Price*
274-ND	Shielded Plug Assembly	STAPLUGDOG	$1.50
274-NE	Shielded Plug and Cable	STAPLUGEYE	4.00

FIGURE 1. Photograph of the shielded plug and cable. TYPE 274-NE Shielded Plug and Cable consists of the two shielded terminals, as shown, connected by three feet of shielded cable. TYPE 274-ND Shielded Plug Assembly is one double terminal plug with shield. In the photograph the method of construction is shown by the disassembled terminal at the right.



I. R. E. CONVENTION

● **THE TWENTY-SIXTH ANNUAL CONVENTION** of the Institute of Radio Engineers was held at the Hotel Pennsylvania in New York on the sixteenth, seventeenth, and eighteenth of June.

The attendance figures materially exceeded any previously reached and the general atmosphere indicated that there is no mental depression among radio engineers.

An unusually rich program of papers covered a very wide range of subjects, including the considerable attention to television developments which has featured all recent technical programs.

There were two General Radio contributors to the technical program — Mr. L. B. Arguimbau, who delivered a paper on the "Application of Quartz Crystals to a Wave Analyzer," which dealt with his development work on the crystal filter used in the General Radio Wave Analyzer, and Dr. W. N. Tuttle, who gave a resume of "Bridged-T and Parallel-T Null Circuits for Measurements at Radio Frequencies."

The display of technical apparatus and parts which has featured these meetings in recent years was unusually attractive. A good many displays of parts and component materials illustrated the continued progress in refinement of details. The General Radio Company showed a large number of instruments, including several new developments which will be placed on the market during the late summer and early fall. Descriptions of these will appear in forthcoming issues of the *Experimenter*.

GENERAL RADIO COMPANY
30 STATE STREET - CAMBRIDGE A, MASSACHUSETTS
BRANCH ENGINEERING OFFICES
90 WEST STREET, NEW YORK CITY
1000 NORTH SEWARD STREET, LOS ANGELES, CALIFORNIA

THE General Radio EXPERIMENTER

VOLUME XIII NOS. 3 and 4 AUGUST-SEPTEMBER, 1938

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also
IN THIS ISSUE

Page

TYPE 739 LOGARITHMIC CONDENSERS 4

THE TYPE 726-A VACUUM-TUBE VOLTMETER AS A RADIO-FREQUENCY AMMETER

● **AS A VOLTAGE-MEASURING DEVICE** for use in parallel-resonance methods of admittance measurement the vacuum-tube voltmeter has been widely adopted. In this service, because of the low input losses for a given voltage reading[1], the shunting effect of the voltmeter on a high-Q tuned circuit is generally small and high precision in the measurement of small conductances may be attained.

For series-resonance methods of impedance measurement, in which one point of the circuit is grounded, the vacuum-tube voltmeter may be used as a current-measuring device. In this service the voltage drop across a known impedance is used as a measure of the current.

The feature of low input losses is as important in the series-resonance methods as in the parallel-resonance methods, since it is necessary to maintain high-Q tuned circuits for precise measurements of small resistances. It is therefore essential to use, as the

FIGURE 1. Panel view of the TYPE 726-A Vacuum-Tube Voltmeter, showing the probe in which the diode is housed.

[1]At low frequencies, the input conductance of the TYPE 726-A Vacuum-Tube Voltmeter is approximately 0.16 μmho. At high frequencies the input admittance is approximately equal to that of a 6.0 μμf condenser having a 2.5% power factor. For an excellent discussion of the input conductance of a diode rectifier at low frequencies, see C. B. Aiken, "Theory of the Diode Voltmeter," *Proc. I.R.E.*, Vol. 26, No. 7, p. 859, July, 1938.

known impedance, a circuit element which has as nearly pure a reactance as can be obtained.

TYPE 505 Condensers make excellent shunts for use with the TYPE 726-A Vacuum-Tube Voltmeter. For any given capacitance, and at any one frequency, the lower limit of current which can be measured is fixed by the lowest voltage which can be read. The higher limit of current is fixed either by the highest voltage which can be read or by the maximum voltage which the condenser will stand at the particular frequency used. The curves of Figure 3 illustrate, as a function of frequency, the maximum current which can be measured by the TYPE 726-A Vacuum-Tube Voltmeter with four standard TYPE 505 Condensers as shunts. Below 4 Mc the maximum current which can be measured is seen to be limited by the 150 volt maximum reading of the voltmeter. Above 4 Mc the maximum current is limited by losses in the condensers as shown.

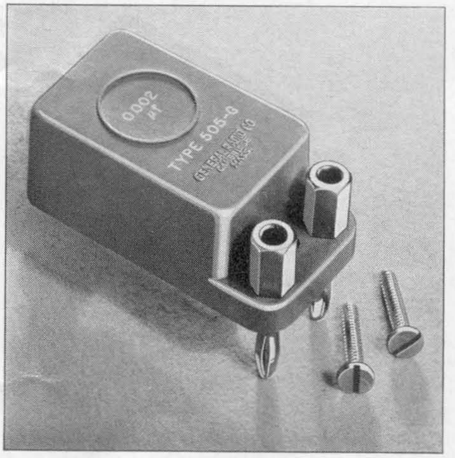
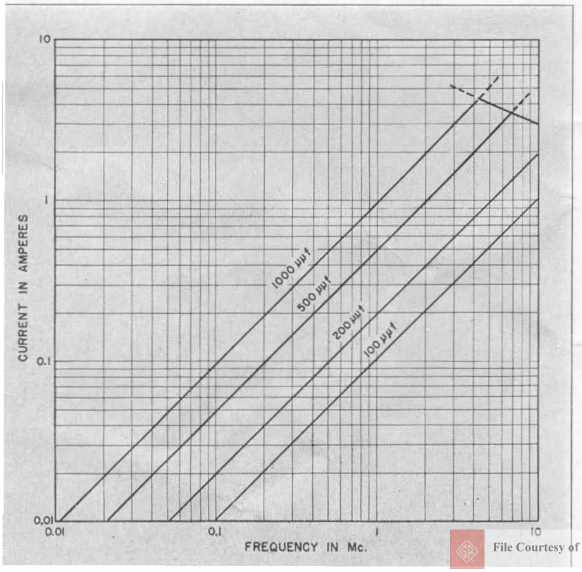


FIGURE 2. TYPE 505 Condenser has plug-in terminals as shown here. In a measuring circuit equipped with jacks, condensers can be easily changed, or stacked in parallel. The voltmeter probe plugs into the jack tops of the condenser terminals.

FIGURE 3. Plot of maximum current, as a function of frequency, which can be read with the TYPE 726-A Vacuum-Tube Voltmeter and four different TYPE 505 Condenser shunts. The lines with positive slope correspond to a 150-volt reading of the voltmeter. The line with negative slope corresponds to 1 watt loss in the condensers.



When the TYPE 726-A Vacuum-Tube Voltmeter is used as an ammeter, the effective series resistance component of the input impedance is the pertinent loss representation. Figure 4 illustrates, as a function of frequency, the effective series resistance of a TYPE 726-A Vacuum-Tube Voltmeter when shunted with four typical TYPE 505 Condensers. By comparison with other types of radio-frequency ammeters, the extremely low losses introduced by the shunted TYPE 726-A Voltmeter are to be emphasized. Using the 1.5 volt range, with a 500 $\mu\mu$f shunt, at a frequency of 1 Mc, the effective series resistance is 0.16Ω and the full-scale current reading is 4.8 ma. The radio-frequency power taken from the circuit is therefore 3.6 microwatts. A well-designed thermocouple for the same current range ordinarily requires a power input of the order of 6 milliwatts for a generated d-c voltage of 10 millivolts open-circuit and consequently has an effective series resistance of approximately 260 Ω. The advantage to be gained through the use of the voltmeter with high-Q circuits is tremendous at low current levels.

In resonance methods of measurement the absolute value of current is generally not needed for calculations since the equations are expressed in terms of current and voltage ratios. When the voltmeter is used in such circuits it is therefore unnecessary to know the variation of effective capacitance of the shunts with frequency in anything except a general way.

When it is necessary to measure the absolute value of the current, the variation of effective capacitance with frequency must be known. This can be easily computed for any Type 505 Condenser by means of the equation

$$C_e = \frac{C}{1 - \omega^2 LC}$$

where C_e is the effective capacitance, C the static capacitance, and L the inductance. For Type 505 Condensers mounted in small cases, the inductance is approximately 0.055 μh and, in large cases, 0.085 μh.[2]

Certain limitations and precautions should be noted in connection with the use of the condenser-shunted vacuum-tube voltmeter as an ammeter.

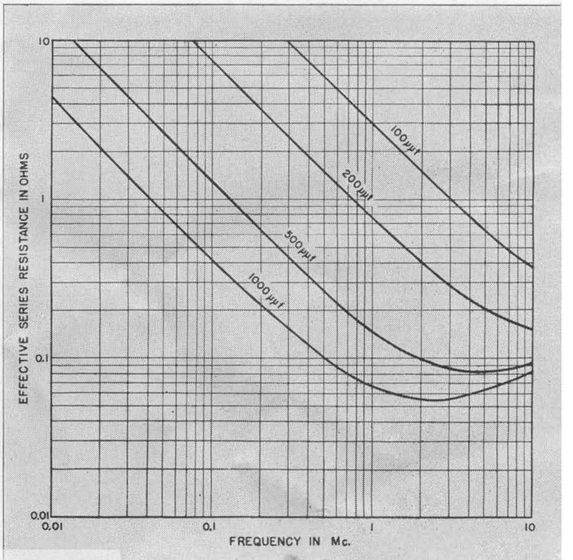
The Type 726-A Vacuum-Tube Voltmeter, while calibrated in r-m-s volts, actually responds to peak values. If used to measure distorted current waves, with a condenser shunt, the relation between various harmonic components will be destroyed because of the frequency dependence of the input impedance. The meter-scale reading when multiplied by $\sqrt{2}$ will not, in this case, give correct results for peak values and the instrument should therefore be used to measure only currents of nearly pure waveform, such as are encountered in resonant circuits.

Because of the unbalanced input circuit of the voltmeter, the shunted combination should only be used when one side can be grounded. Otherwise the high capacitance of the low side of the voltmeter circuit to ground will shunt that part of the circuit under test which lies between that point and ground.

In series-resonance circuits, capacitances to ground are usually the most troublesome residual parameters encountered. When it is necessary to measure absolute values of current with the shunted voltmeter, the magnitude of any shunting residual capacitance should be determined and included in the total effective capacitance. Two positions in which the shunted voltmeter may be used with series-resonance circuits are shown in Figure 5.

For applications in which a flat frequency response is required, the Type 726-A Vacuum-Tube Voltmeter can be

Figure 4. Plot of effective series resistance of Type 726-A Vacuum-Tube Voltmeter when used as an ammeter with four different Type 505 Condenser shunts.



[2]Curves of power factor and capacitance rise for typical Type 505 Condensers are given in the General Radio *Experimenter*, Vol. 12, No. 11, p. 4, April, 1938.

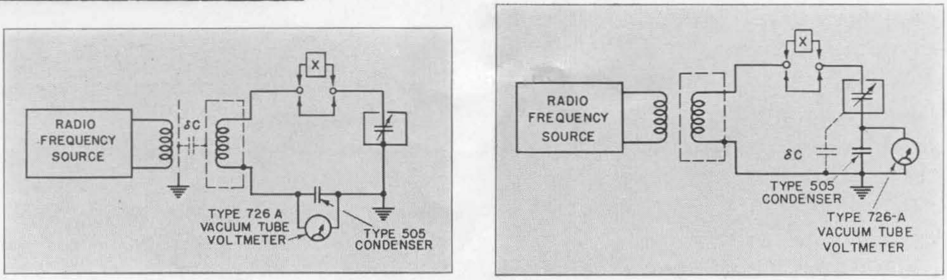


FIGURE 5. Two ways in which the shunted TYPE 726-A Vacuum-Tube Voltmeter can be connected in series-resonant circuits. The residual capacitances shown as δC in the two cases shunt the voltmeter combination and must be included in the effective capacitance.

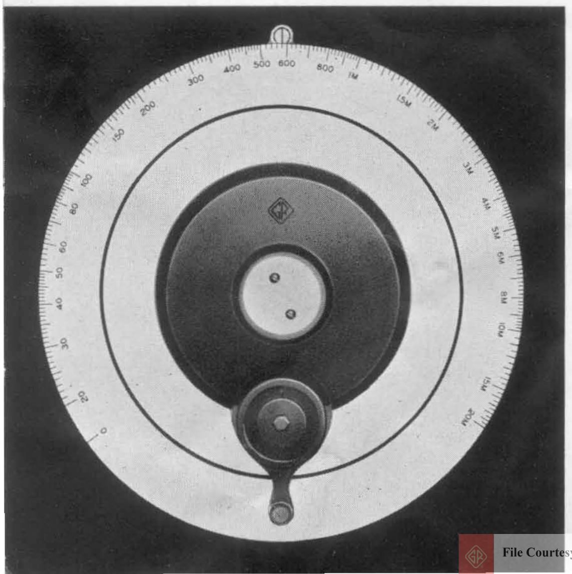
used with TYPE 500 Resistors for shunts. The power required for full-scale deflection on the low range is considerably greater than that required with TYPE 505 Condensers. For a full-scale deflection on the 1.5-volt scale with a current of 4.8 ma, a resistance of 313Ω is required. The resistance and, consequently, driving power are in this case practically the same as those encountered with a thermocouple. At lower currents less power is required with the resistance-shunted vacuum-tube voltmeter than with a thermocouple, while at higher currents the reverse is true.

Both TYPE 505 Condensers and TYPE 500 Resistors are equipped with terminals which permit stacking up of units in parallel. The TYPE 726-A Vacuum-Tube Voltmeter probe can, therefore, be plugged into the shunt and TYPE 274 Plugs in the shunt used as the composite probe terminals.

— D. B. SINCLAIR

TYPE 739 LOGARITHMIC CONDENSERS

● **ELECTRICAL MEASUREMENTS** into which frequency enters as a variable ordinarily require that the frequency be known to the same fractional accuracy throughout the range of the oscillator. Older oscillator designs have not met this requirement merely because the necessary means were not available. With the advent of direct-reading instruments, the need has become, not more urgent, but more apparent.



In order to give a constant fractional accuracy, the variable air condenser, which is the frequency-controlling element in most oscillators, must have plates shaped to give a logarithmic variation in frequency with angular dial rotation. TYPE 739 Logarithmic Air Condenser fulfills this requirement.

Since oscillators are usually of the beat-frequency type or of the "tuned

FIGURE 1. This dial is used with TYPE 739-A Logarithmic Condenser in the TYPE 713-B Beat-Frequency Oscillator. The scale is logarithmic between 20 and 20,000 cycles.

circuit" type, two logarithmic condenser designs have been made available, one to meet the particular requirements of each type of oscillator. The TYPE 739-A Logarithmic Condenser, when associated with the proper circuit constants in a beat-frequency oscillator, will cover three frequency decades logarithmically, 20 to 20,000 cycles, for example. The TYPE 739-B Logarithmic Condenser will provide a constant accuracy calibration in the tuned circuit type of oscillator over a half decade, 1 Mc to 3.16 Mc, for example.

Mechanically, TYPE 739 Condensers are constructed to have a high degree of stability. The cast-aluminum frame and the ball-bearing type of assembly found indispensable in the design of the TYPE 722 Precision Condensers was adopted for the TYPE 739 Logarithmic Condensers. Contact rings provide a low impedance path for grounding the rotor to the frame. Isolantite insulators provide a four-point support for extra stability in alignment of stator stack.

The different applications of the two logarithmic condensers require widely different plate shapes. This will be evident when it is realized that a given angular rotation of the TYPE 739-B Condenser at one end of the scale produces ten times as much capacitance change as it does at the other end, whereas, in the TYPE 739-A Condenser, the ratio of maximum to minimum capacitance increment is 1400.

To obtain the 1400 to 1 ratio of incremental capacitance, the TYPE 739-A Logarithmic Condenser, essentially, is built up of two variable condenser sections on the same shaft. The larger section does not introduce any capacitance change over an appreciable portion of the range of the condenser. It functions at the medium and high capacitance range. The smaller section, consisting of two rotors and two stators, functions primarily over the low capacitance portion of the range. The two rotors of the smaller section are slotted at an angle to provide many sectors for individual adjustment at any portion of the scale. Thus any irregularities in the calibration are easily corrected, and any possible discontinuity at the overlap region of the two sections is avoided.

The TYPE 739-A Logarithmic Condenser provides the main frequency control for the TYPE 713-B Beat-Frequency Oscillator[1]. The frequency range of this instrument is 0 to 40 kc, and the frequency calibration is logarithmic from 20 to 20,000 cycles. A photo-etched dial is used, and the condenser is adjusted to meet the direct-

[1]See General Radio *Experimenter*, April, 1938.

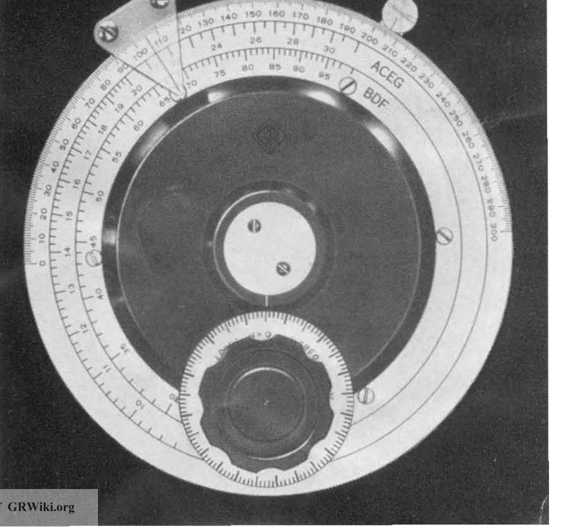


FIGURE 2. In TYPE 605-B Standard-Signal Generator and TYPE 484-A Modulated Oscillator, this dial is used with TYPE 739-B Logarithmic Condenser. Each scale covers a frequency ratio of $\sqrt{10}$, so that each pair of scales (A and B, C and D, etc.) gives a spread of 10 : 1. A scale selector switch (not shown) is used to select the inductance for each range. One property of the logarithmic scale is that equal angles of rotation correspond to equal fractional (or percentage) frequency increments. This permits the use of the percentage increment dial shown on the slow-motion drive.

reading calibration on the dial. A recorder, using logarithmic or semi-logarithmic paper can be geared directly to the oscillator dial for rapid and highly accurate testing.

When the TYPE 739-A Logarithmic Condenser is the tuning element of a beat-frequency oscillator, the frequency of the fixed oscillator must be 9.3 times the required maximum beat frequency. Thus, in the TYPE 713-B Oscillator, the fixed frequency is 186,000 cycles and the variable oscillator frequency is changed from 186,000 cycles for zero beat to 166,000 cycles for the 20,000 cycle setting. The logarithmic condenser must be padded with enough capacitance to obtain a ratio of 1.256 between the net maximum and minimum capacitance in the variable oscillator circuit. Since the capacitance change in the TYPE 739-A Condenser is about 440 $\mu\mu$f, the net padding capacitance must therefore be about 1720 $\mu\mu$f, irrespective of the value of fixed frequency and of the frequency range. The 1720 $\mu\mu$f includes the zero capacitance of the condenser, the distributed capacitance of the coil, wiring capacitance, and, of course, the fixed padding capacitance. The total frequency range is covered in an angular rotation of 250° and the logarithmic portion, three decades, is covered in 240°.

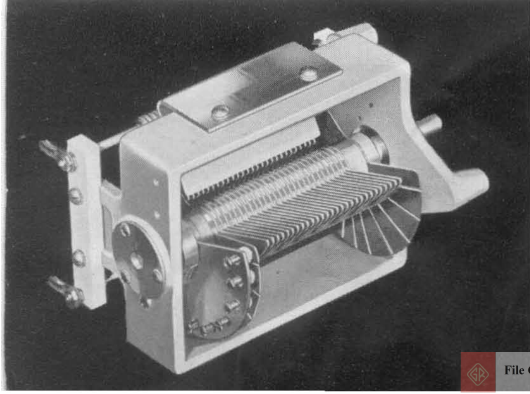
Since the ratio of maximum to minimum incremental capacitance in the TYPE 739-B Logarithmic Condenser is appreciably less than in the other model, the design is somewhat simpler. The logarithmic frequency characteristic is obtained with a single plate shape and no adjusting mechanism is necessary.

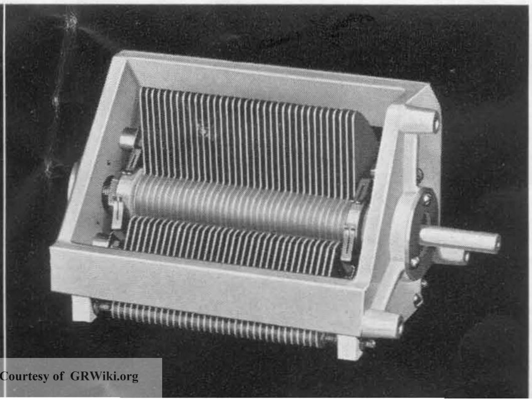
Here again, the logarithmic feature not only provides the highly desirable constant fractional accuracy for the calibration of a tuned-circuit oscillator but also simplifies a direct-reading design and permits the use of pre-engraved or photo-etched dials. The condenser covers a half decade in frequency. Therefore, if the dial is calibrated for the two half decades, the same calibration will apply over a very wide frequency range simply by switching the tuning coils. This is well illustrated in the TYPE 605-B Standard-Signal Generator[2] and in the TYPE 684-A Modulated Oscillator[3]. Both of these instruments make use of the TYPE 739-B Logarithmic Condenser and both cover a frequency range of from 9.5 to 30,000 kilocycles with direct-reading logarithmic calibration. The accompanying figure shows the dial calibration for these instruments. One calibration is for the 9.5 to 30 half decade and the other calibration is for the 30 to 95 half decade. Both instruments have further taken advantage of the logarithmic feature of the

[2]See General Radio *Experimenter*, June, 1936.

[3]See General Radio *Experimenter*, November, 1937.

FIGURE 3. (*Left*) TYPE 739-A Logarithmic Condenser; (*right*) TYPE 739-B.





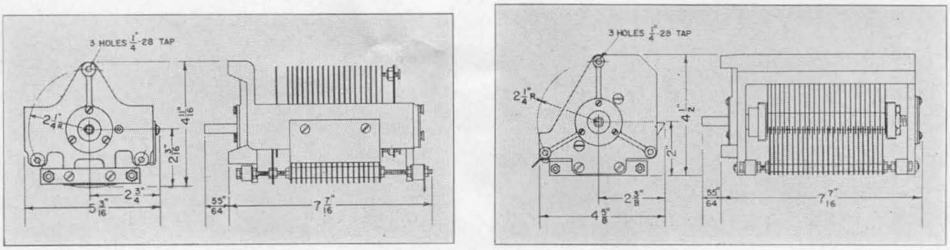


FIG. 4. Mounting dimensions for TYPE 739 Condensers. (*Left*) TYPE 739-A; (*right*) TYPE 739-B.

TYPE 739-B Logarithmic Condenser in providing a fine control calibrated in frequency increments of 0.1% per division which facilitates the type of measurement where percentage frequency change is more important than the absolute value of the frequency.

When the TYPE 739-B Logarithmic Condenser is the tuning control of a tuned-circuit oscillator, the total capacitance at the low-frequency end of the scale must be ten times as great as the total capacitance that obtains at a frequency higher by a factor of $\sqrt{10}$. The actual values are about 1400 $\mu\mu$f and 140 $\mu\mu$f and must include the zero capacitance of the condenser, the distributed capacitance of the tuning coil, and capacitance due to wiring and trimmers. In the TYPE 605-A Standard-Signal Generator and in the TYPE 684-A Modulated Oscillator, a rather simple procedure is followed to adjust the circuit constants. For each coil setting, an individual trimmer condenser is provided and the inductance of each coil is determined by an iron dust core. With the condenser dial set at the low-frequency end, each inductor is adjusted to match the frequency on the dial. Then, with the dial set at the high-frequency end, the correct frequency is obtained by means of the trimmer condenser across the coil.

The angular rotation of the TYPE 739-B Logarithmic Condenser for a frequency range of $\sqrt{10}$: 1 is 165° and it is logarithmic to within 1% for 150° of this range. The net angular rotation is 180° to allow for overlap between coils.

— A. G. BOUSQUET

SPECIFICATIONS

Capacitance Range: The nominal capacitance ranges are given in the price list.

Plate Shape and Frequency Characteristics: The TYPE 739-A is to be used as the tuning condenser of the variable oscillator of a beat-frequency oscillator. Slotted plates are provided on the TYPE 739-A with adjusting screws. When these plates and the effective zero capacitance are correctly adjusted, the variation of frequency with dial setting will be logarithmic within 2%.

The TYPE 739-B is for use in a tuned-circuit radio-frequency oscillator. It has no adjustable plates, but, by proper adjustment of the padding condenser and circuit inductance, the variation in frequency with dial setting, over 150°, can be made logarithmic within 1%.

Maximum Voltage: 500 volts, peak.

Losses: The figure of merit, $R\omega C^2$, is approximately 0.04×10^{-12}.

Terminals: Soldering lugs are provided.

Mounting: See sketch above.

Dimensions: See sketch above.

Net Weight: 3⅓ pounds.

Type	*Nominal Capacitance*		*Code Word*	*Price*
	Maximum	*Minimum*		
739-A	468 $\mu\mu$f	28 $\mu\mu$f	COUPE	$28.00
739-B	1460 $\mu\mu$f	35 $\mu\mu$f	COILY	28.00

MISCELLANY

● **INSTRUMENTATION CONTEST.** Have you read of the prize contest being conducted by the Industrial Instrument Section, Scientific Apparatus Makers of America, 20 North Wacker Drive, Chicago, Illinois?

$500 in prizes are being offered, and the Chairman of the Jury of Awards is Dr. Briggs of the Bureau of Standards. Rule 2 of the contest reads:

> "THEME. Each contestant is to write about an unusual application of a standard instrument or control device, telling briefly what conditions or need impelled the application. By instrument or control device is meant any device used for measurement and control or any accessory used with a device for measurement and control."

If you are interested, it is suggested that you write directly to the Scientific Apparatus Makers of America at the address given above for details. There is no entry fee or restriction based on purchasing any particular instrument.

● **JOINING US LATE LAST SPRING**, the newest member of our engineering staff is Dr. Stephen A. Buckingham. After graduating from Harvard University eleven years ago, Dr. Buckingham joined the Radio Section of the U. S. Bureau of Standards, where he remained for two years, returning to Harvard University to take up graduate work, and later serving as an instructor in Physics. He received his degree of Ph.D. in 1934. In the subsequent four years he has served as physicist and as engineer with the S. D. Warren Company and the Western Electric Company. Dr. Buckingham is specializing in the design of Variacs, as well as our general line of transformers and filters.

● **AS A MEANS** of inducing hypnosis, the Strobotac, we feel, has been overlooked by psychologists, for, unless our eyes deceive us, it is a Strobotac by which Ginger Rogers is hypnotized in the current RKO production "Carefree." To possessors of Strobotacs, this should open up an interesting field of experiment.

GENERAL RADIO COMPANY

30 STATE STREET - CAMBRIDGE A, MASSACHUSETTS

BRANCH ENGINEERING OFFICES

90 WEST STREET, NEW YORK CITY

1000 NORTH SEWARD STREET, LOS ANGELES, CALIFORNIA

THE General Radio EXPERIMENTER

VOLUME XIII NOS. 5 and 6 OCTOBER-NOVEMBER, 1938

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also IN THIS ISSUE

Page

THE PRECISION FORK IN CONTINUOUS OPERATION 7

IMPROVEMENTS IN THE TYPE 568 CONDENSER 10

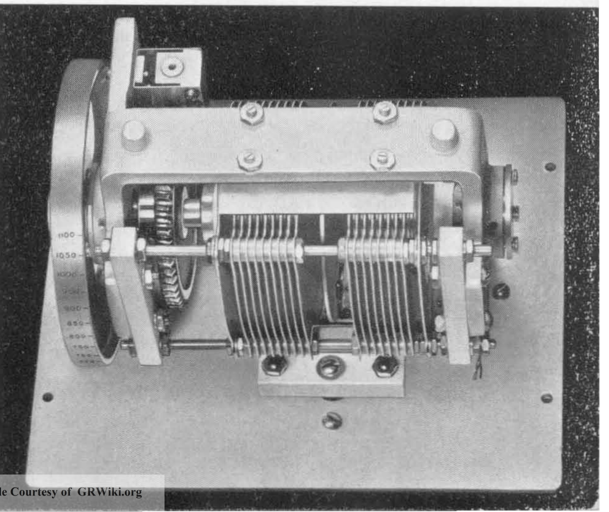
A HIGH-FREQUENCY MODEL OF THE PRECISION CONDENSER

● **FOR MANY YEARS** General Radio Precision Condensers have been used as basic equipment in laboratories all over the world. The ruggedness, stability and accuracy of these condensers have rendered them of fundamental use in all kinds of measurement work where dependable, continuously-adjustable capacitance standards are required.

The principal features which have led to the widespread adoption of General Radio Precision Condensers are the excellence of the mechanical construction, the precision of capacitance setting, and the low and known electrical losses at audio and low radio frequencies.

In recent years, interest in measurements at high radio frequencies has led to the use of these condensers at frequencies in excess of those for which they were designed. Under these conditions electrical errors arise because of the presence of unwanted residual parameters. Unfortunately the high available precision of capacitance setting in many cases tends to create a feeling of false security and the loss of accuracy in the condenser is not recognized.

FIGURE 1. Interior view of the TYPE 722-N Condenser showing the method of feeding the rotor. For a close-up view of the brush mechanism, see page 6.



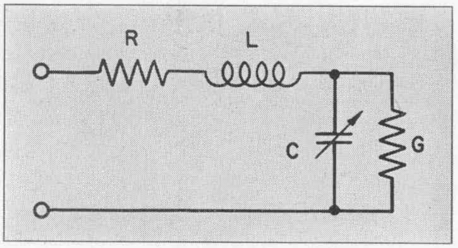


FIGURE 2.
In this circuit the resistance, R, corresponds to losses in the metallic portions of the condenser; the conductance, G, corresponds to losses in the solid dielectric portions of the condenser; and the inductance, L, corresponds to magnetic flux set up by conduction currents in the metal portions of the condenser. The capacitance, C, represents the static capacitance of the condenser.

The addition to the Precision Condenser line of a new high-frequency model, the TYPE 722-N, extends the advantages of highly precise mechanical construction to a condenser whose performance can be accurately predicted at frequencies up to 30 Mc.

RESIDUAL PARAMETERS

The residual electrical parameters which occur in variable air condensers and which cause the behavior to change as a function of frequency are: (1) resistance components corresponding to losses in the metal and solid dielectric portions of the condenser, and (2) inductance caused by the magnetic field set up by conduction currents in the metal structure.

An equivalent circuit which may be used to represent a variable air condenser is shown in Figure 2*.

As a function of dial setting the residual parameters designated by R, G, and L all tend to remain constant. As a function of frequency the inductance, L, remains constant, the conductance, G, increases nearly linearly with frequency and, at high frequencies where it is significant, the resistance, R, increases approximately as the square root of the frequency.

*R. F. Field and D. B. Sinclair, "A Method for Determining the Residual Inductance and Resistance of a Variable Air Condenser at Radio Frequencies," *Proc. I. R. E.*, 24, 2, February, 1936.

EFFECTS OF RESIDUAL PARAMETERS

The residual inductance, L, introduces a component of positive reactance in series with the condenser, which causes the net negative reactance at the terminals to be lower than it should be. The effect of the inductance is therefore to increase the terminal capacitance by a fractional amount which increases as the capacitive reactance decreases and as the inductive reactance increases. The error consequently increases both with frequency and with dial setting. The effective terminal capacitance follows the law

$$C_e \simeq \frac{C}{1 - \omega^2 LC} \qquad (1)$$

The conductance, G, causes a dissipative component in the terminal impedance.

Since the conductance, G, increases linearly with frequency, the corresponding component of dissipation factor

$$D_G = \frac{G}{\omega C}$$

is constant as a function of frequency at any given capacitance setting.

The resistance, R, adds a further dissipative component of terminal impedance.

The corresponding dissipation factor component

$$D_R = R\omega C$$

is ordinarily negligible up to frequencies at which skin-effect in the metal parts is essentially complete. At higher frequencies the resistance, R, increases as the square root of the frequency and the dissipation factor component increases as the three-halves power of the frequency.

A precision condenser is used normally under such conditions that the dissipation factor components, D_G and D_R, and the inductive error are small. The expressions for the effective terminal impedance and admittance of the condenser under these conditions are

$$Z_e = R_e - j\frac{1}{\omega C_e}$$

$$\simeq \left[R + \frac{G}{(\omega C)^2}\right] - j\left[\frac{1 - \omega^2 LC}{\omega C}\right] \quad (2)$$

$$Y_e = G_e + j\omega C_e$$

$$\simeq \left[G + R(\omega C)^2\right] + j\left[\frac{\omega C}{1 - \omega^2 LC}\right] \quad (3)$$

and the over-all dissipation factor is approximately

$$D = D_G + D_R = \frac{G}{\omega C} + R\omega C \quad (4)$$

ERRORS IN MEASUREMENTS CAUSED BY RESIDUAL PARAMETERS

The errors caused by residual parameters in measurements using a variable air condenser as standard depend upon the frequency and upon the method of measurement. At high frequencies, in particular, it has been found that substitution methods of measurement tend to give results of maximum accuracy. In this discussion the parallel-substitution method will be the only method considered.

In parallel substitution methods the susceptance of a given circuit branch containing the standard condenser is set at some particular value corresponding to a desirable capacitance setting. The unknown admittance is then connected in parallel with the standard condenser and the susceptance restored to its initial value by readjusting the condenser. The susceptive component of the unknown is found directly from the change in susceptance of the condenser. The conductive component of the unknown is found from the change in total conductance of the arm when the unknown admittance is in and out of circuit.

Measurement errors can arise from three sources if the residual parameters of the condenser are neglected:

(1) The change in susceptance of the standard condenser between the initial and final condenser readings is not equal to $\omega(C_2 - C_1)$ but is influenced by the residual inductance and is equal to

$$\omega(C_{e_2} - C_{e_1}) = \frac{\omega(C_2 - C_1)}{1 - \omega^2 L(C_1 + C_2)} \quad (5)$$

(2) The conductance of the standard condenser does not remain constant but changes between the initial and final settings by an amount

$$G_2 - G_1 = R\omega^2 C_x(C_{e_1} + C_{e_2}) \quad (6)$$

(3) If parallel-resonance methods, such as the susceptance-variation method,* are used to determine the dissipative component of the unknown, the observed breadth of the resonance curve is influenced by residual inductance. For the breadth of the resonance curve used to determine conductance, the true capacitance difference to be used is

$$\triangle C_e = \frac{C'' - C'}{1 - \omega^2 L(C' + C'')} \quad (7)$$

where C' and C'' are the two readings on either side of resonance.

The effect of residual parameters is greatest in the measurement of small values of power factor such as those of good mica condensers. An example of

*D. B. Sinclair, "Parallel Resonance Methods for Precise Measurements of High Impedances at Radio Frequencies," *Proc. I. R. E.*, December, 1938.

the large errors which may be encountered under extreme conditions is as follows:

The inductance of the 1000 $\mu\mu$f section of a Type 722-D Precision Condenser is approximately 0.065 μh and the metallic resistance at a frequency of 10 Mc is about 0.065 Ω. Suppose this condenser be used to measure the capacitance and power factor of a 1000 $\mu\mu$f Type 505 Condenser at a frequency of 10 Mc.

The effective capacitance of the 1000 $\mu\mu$f Type 505 Condenser at 10 Mc is 1258 $\mu\mu$f and the power factor is 0.9%.[1] Let the initial dial reading of the standard condenser, C_1, be 1100 $\mu\mu$f. The initial effective terminal capacitance is

$$C_{e_1} = \frac{C_1}{1 - \omega^2 L C_1} = 1532 \ \mu\mu\text{f}$$

The final effective terminal capacitance must be

$$C_{e_2} = 1532 - 1258 = 274 \ \mu\mu\text{f}$$

and the final dial reading

$$C_2 = 254 \ \mu\mu\text{f}.$$

The error in taking the difference in dial readings as the unknown capacitance, without correction for inductance, is therefore

$$1 - \frac{1100 - 254}{1258} \times 100 = 32.8\%$$

The component of condenser conductance caused by metallic losses at the initial setting is

$$R(\omega C_{e_1})^2 = 602 \ \mu\text{mho}$$

[1]The effective capacitance is greater than the nominal capacitance because of inductance. See "The Behavior of Type 505 Condensers at High Frequencies," General Radio *Experimenter*, April, 1938.

and at the final setting

$$R(\omega C_{e_2})^2 = 19 \ \mu\text{mho}$$

The change in condenser conductance is therefore -583 μmho when the susceptance is restored after connecting the unknown. The conductance of the 1000 $\mu\mu$f condenser corresponding to a power factor of 0.9% is 867 μmho. The error in taking as the conductance of the unknown the difference in conductance of the circuit when the unknown is connected and disconnected is therefore

$$\frac{583}{867} \times 100 = 67.2\%$$

Very large errors in both capacitance and power-factor measurements are seen to occur. Indeed, in many cases the error caused by metallic resistance is so large as to cause the observed value of power factor to become negative.

LOCATION AND REDUCTION OF RESIDUALS IN TYPE 722-N PRECISION CONDENSER

The minimization of the residual inductance and metallic resistance is seen to be a prime requisite in the design of a high-frequency condenser.

The residual resistance arises in the rotor shaft and stator rod washers, in the washer-to-plate contacts, and in the plates themselves.[2] The residual inductance arises principally from magnetic flux set up by currents in the rotor shaft and stator rod washers. This flux lies in planes parallel to the plates. Currents in the plates themselves set up relatively little flux since they are diffused over large areas.

[2]At high frequencies the current tends to the path of least inductance which is around the plates, rather than through them. The losses in the plates therefore become an appreciable part of the whole. The reason that the metallic resistance remains relatively constant with dial setting is apparently found in the fact that the major loss occurs in the immediate vicinity of the rotor shaft and stator rods where the current density is high. In these regions the current distribution is not so greatly affected by rotor position as elsewhere.

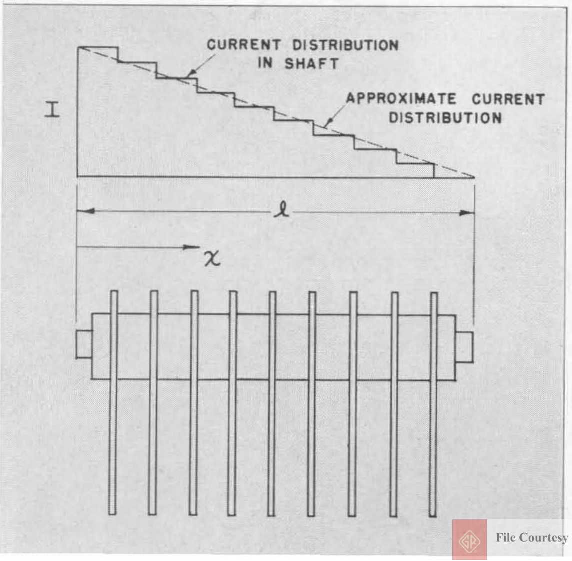


Figure 3. Showing the distribution of current in a rotor shaft fed at the left-hand end.

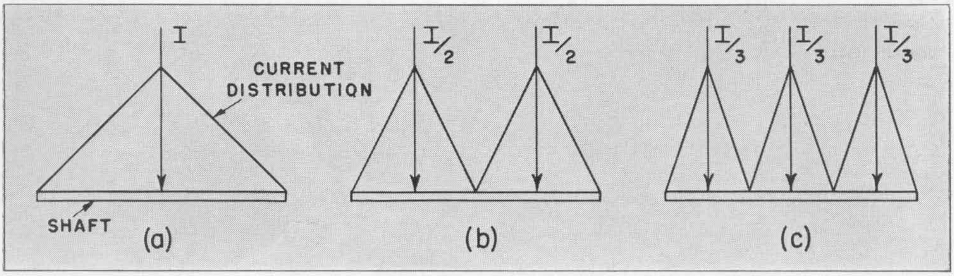


FIGURE 4. Current distribution when current is fed symmetrically to the shaft.

To a very fair degree of approximation the metallic resistance and residual inductance of a variable air condenser can be considered as uniformly distributed along the rotor shaft and stator rods. On this basis a simple analysis of the effect of points of current entry into the stack can be formulated.

Figure 3 illustrates a rotor shaft with current fed in at the left-hand end. To a first approximation the current decreases linearly along the shaft length at frequencies low compared to the first natural frequency.

Suppose the resistance of the shaft to uniform current is R and the inductance L. The effective resistance and inductance for the non-uniform current are easily found from energy considerations.

The current at any distance along the shaft, i, is related to the current at the left-hand end, I, by the expression

$$i = I\frac{l - x}{l}$$

The total power loss, referred to the left-hand end of the shaft, is

$$I^2R_e = \int_0^l i^2 \frac{R}{l}\, dx$$
$$= \frac{R}{l}\,\frac{I^2}{l^2}\int_0^l (l - x)^2\, dx = I^2\frac{R}{3}$$

and the effective resistance $R_e = R/3$.

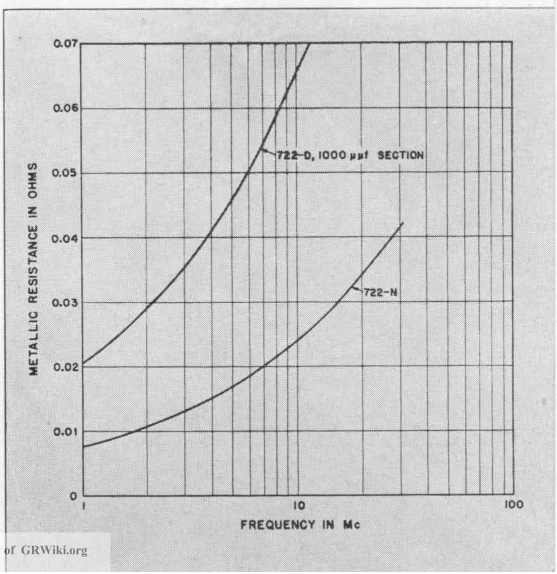
Similarly the total energy storage, referred to the left-hand end of the shaft, is

$$\frac{1}{2}L_eI^2 = \frac{1}{2}\int_0^l \frac{L}{l}\, i^2\, dx$$
$$= \frac{1}{2}\,\frac{L}{l}\,\frac{I^2}{l^2}\int_0^l (l - x)^2\, dx$$
$$= \frac{1}{2}\left(\frac{L}{3}\right) I^2$$

and the effective inductance $L_e = L/3$.

The effective resistance and inductance can be reduced by feeding current symmetrically to the shaft. For instance, if the current be fed at the center instead of the end the current distribution is as

FIGURE 5. Metallic resistance of Type 722-N Precision Condenser as a function of frequency. For purposes of comparison, the resistance of TYPE 722-D is also shown.



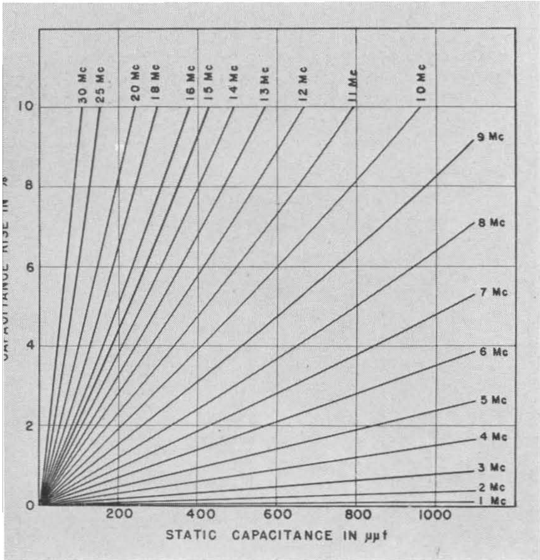
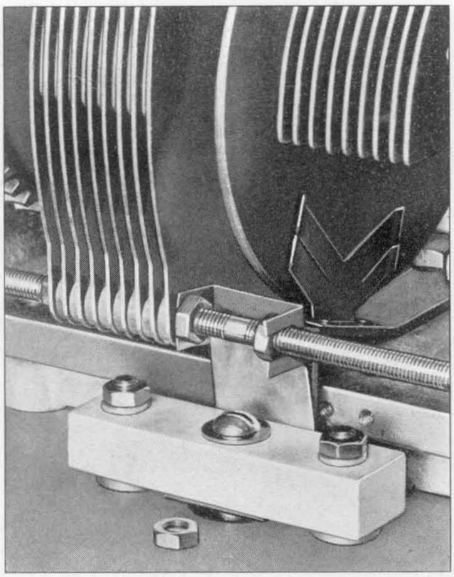


FIGURE 6. Variation in effective capacitance of TYPE 722-N Condenser as a function of static capacitance for various frequencies.

shown in Figure 4(*a*) and the effective resistance is $R_e = R/12$ and the effective inductance $L_e = L/12$.

Multiple current feed reduces the residual parameters still further. Double feed, as in Figure 4(*b*), gives $R_e = R/48$ and $L_e = L/48$; triple feed, as in Figure 4(*c*), gives $R_e = R/108$ and $L_e = L/108$.

FIGURE 7. Showing the leads and the method of connection to the rotor.



The general expression for n points of entry into the stack is $R_e = R/12\, n^2$ and $L_e = L/12\, n^2$.

PRACTICAL APPLICATION OF SYMMETRICAL FEED TO CONDENSER

Change-over from the usual end-feed system to a center-feed system lowers both the metallic resistance and residual inductance by a factor of 4. In practice, it is seldom advantageous to go further than this because the resistance and inductance of the leads to the binding posts quickly become predominant.

In the TYPE 722-N Precision Condenser center-feed has been adopted with a consequent reduction of resistance and inductance in the stack. In addition a heavy strip connector is used to feed the stator stack and a brass disc with a wide brush contactor to feed the rotor. A detailed view of the construction is shown in the accompanying photograph.

The metallic resistance and residual inductance obtained with this construction are lower by a factor of about 3 : 1 than those obtained with the high section of the TYPE 722-D Precision Condenser. For a typical TYPE 722-N Precision Condenser the variation of the metallic resistance with frequency is shown in Figure 5. The residual inductance is constant and is equal to 0.024 μh. The variation in effective terminal capacitance caused by this inductance is illustrated in Figure 6.

Because an insulated rotor shaft is used, no current flows in the ball bearings which support the rotor shaft. This construction prevents the variation of metallic resistance which would otherwise arise in the erratic electrical contacts between the bearing surfaces.

—D. B. SINCLAIR

SPECIFICATIONS

Capacitance Range: 100 to 1100 $\mu\mu$f, direct reading.

Rotor Plate Shape: Semicircular to give a linear capacitance characteristic.

Standard-Calibration Accuracy: The capacitance, measured at 1000 cycles, is indicated directly in micromicrofarads by the dial and drum readings to ± 1 $\mu\mu$f.

Worm-Correction Calibration: A worm correction can be supplied on special order. (See price list.) A mounted chart is supplied giving the correction to at least one more figure than the guaranteed accuracy stated below.

When this correction is used, the capacitance can be determined within ± 0.1 $\mu\mu$f or $\pm 0.1\%$, whichever is the greater, and capacitance differences can be measured to an accuracy of ± 0.2 $\mu\mu$f or $\pm 0.1\%$, whichever is the greater.

Dielectric Supports: Two bars of isolantite support the stator assembly, and a third insulates the high terminal from the panel.

Dielectric Losses: The figure of merit, $R\omega C^2$, when measured at 1000 cycles, is approximately 0.05×10^{-12}.

Other Residual Parameters: See Figures 5 and 6.

Maximum Voltage: 1000 volts, peak.

Temperature Coefficient: Approximately $+0.002\%$ per degree Centigrade.

Mounting: The condenser is mounted on an aluminum panel finished in black crackle lacquer and enclosed in a shielded walnut cabinet. A wooden storage case with lock and carrying handle is included.

Dimensions: Panel, 8 x 9⅛ inches; depth, 8⅛ inches.

Net Weight: 11⅛ pounds; 20¼ pounds with carrying case.

Type	*Description*	*Code Word*	*Price*
722-N	100 to 1100 $\mu\mu$f, direct reading	BOXER	$150.00
Worm-Correction Calibration		WORMY	35.00

When ordering use compound code word, BOXERWORMY.

THE PRECISION FORK IN CONTINUOUS OPERATION

● **THE TYPE 815-A PRECISION FORK** announced in the May, 1936, issue of the *Experimenter* has been widely used as a secondary standard of frequency for standardization and measurement where a precision of one part in ten thousand (0.01%) is adequate. A considerable number have been used as the timing elements in seismographic surveying for oil deposits, as reliably steady sources of alternating current for the stroboscopic regulation of clocks and watches, and as the synchronizing elements in facsimile transmission, etc. They afford a simple means of providing stabilized alternating current in the low audible frequency range without the elaborate equipment required to produce these low-frequency currents from a piezo-electric oscillator.

These forks are constructed of a special stainless steel alloy which gives them a much lower temperature coefficient of frequency (less than ten parts per million negative per degree F.) than ordinary machine steel, so that frequently they are used without temperature control, and their design is such that the voltage coefficient of the driving battery (which for intermittent operation may be simply three dry cells) is quite negligible. They are readily portable and can be made for any frequency between 40 and 200 cycles per second.

The fork is massive, accurately machined, and mounted on rubber shock absorbers. Two microphone buttons are used, one for driving the fork, the other to supply energy at the fork frequency to an external circuit.

The author recently had occasion to investigate how one of these forks would behave on continuous operation under admittedly ideal conditions.

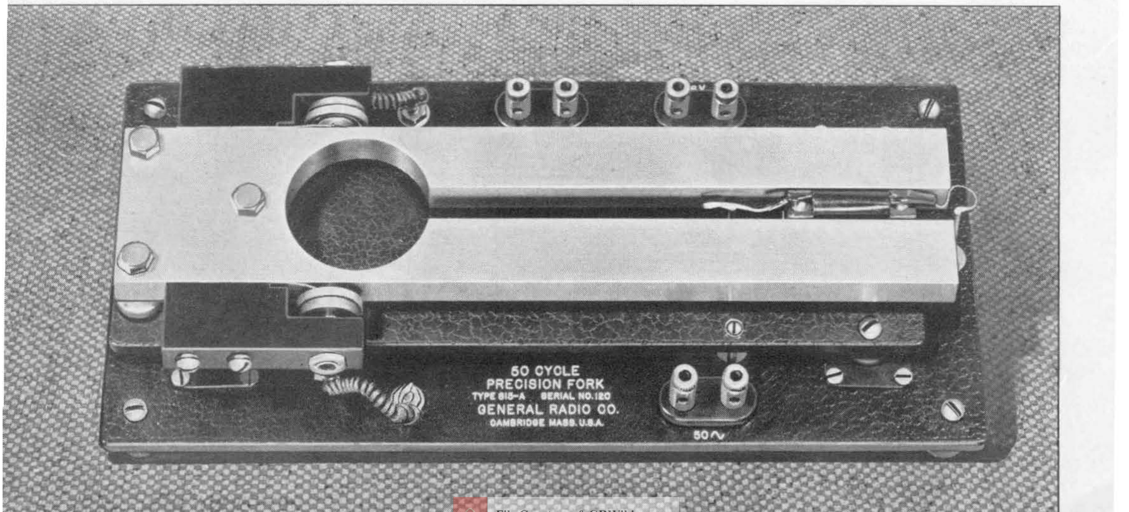
In order to eliminate the small effect of temperature fluctuations, a 50-cycle fork, taken from stock, was placed in a temperature-control box which maintained the temperature at $47.90 \pm 0.15^\circ$ C. at all times. The fork was driven continuously by a 4-volt storage battery so regulated that the driving emf never fluctuated by more than 0.1 volt. The fork was run continuously without any disturbance, adjustment, or interruption for over two months, and its amplified output was used to drive a synchronous clock of such design that any slip of synchronism would have immediately stopped the clock.

Daily readings were made of the fork frequency by two methods: (1) The clock readings were checked against radio time signals from NAA, from which data the *integrated frequency* corresponding to the average frequency over the preceding twenty-four hour period was computed. These time readings were made to better than one-fifth second per day, giving a possible error in the integrated frequency values of the order of one part in 500,000. (2) A value of what we may call a *sample frequency* was obtained by a three-minute stroboscopic comparison between the fork output and 1000-cycle current from our master piezo-electric standard known to be accurate to one part in several million. The technique of this measurement permitted this sample frequency to be determined within the same error of about one part in 500,000. Thus, both the integrated and sample frequency values were known to ± 0.0001 cycle per second.

A portion of the data taken is given in the accompanying plot in which the abscissae represent successive days of the run and the ordinates indicate the observed frequency values. The solid line connects the points corresponding to the daily *integrated* values while the small circles indicate the daily *sample* values. In inspecting this plot, note that the complete range of the ordinate scale represents a variation of only plus or minus one part in 50,000 from the nominal value.

These data, apparently, do not indicate any progressive aging phenomenon although they do show erratic variations about the normal. As would be expected, the day-to-day variations of the sample frequency were more erratic than those of the integrated values. Assuming the mean value of the data to be the nominal value, we see that at no time does either set of data depart from its mean value by more than one part in 50,000,

FIGURE 1. Photograph of TYPE 815-A Precision Fork.



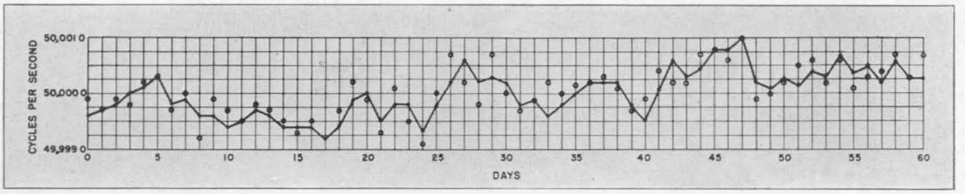


FIGURE 2. Plot of the results of a 60-day test run on TYPE 815-A Precision Fork.

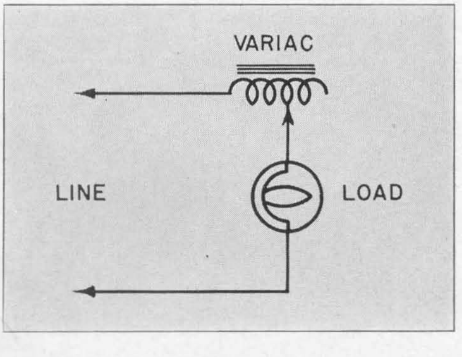
and that, for the most part, the data lie considerably within this range. Simultaneous records were kept of the operating parameters such as microphone current, driving voltage, etc., but no definite relationship could be established between the variation of these measurable parameters and the corresponding frequency fluctuations. The author believes these fluctuations to be caused by eccentricities inherent in such a device as a carbon microphone. These erratic mechanical changes in the physical structure of the microphone button may produce minute changes in the loading of the fork or slight changes in the phase relationship between tine motion and driving current.

The reader must not infer that the TYPE 815-A Precision Fork is good under all conditions, and especially on intermittent service, to one part in 50,000, as obtained in the above data. For an hour or more after starting or moving about, the microphones are engaged in a stabilizing phenomenon, and more erratic variations, as well as some progressive drift, may be expected in the frequency, which prohibits a specification of frequency better than one part in ten thousand. However, for uses embodying continuous operation in a given location and provided with temperature control, a duplication of the author's results may be expected.

— HORATIO W. LAMSON

A 50-cycle model of TYPE 815-A Precision Fork is carried in stock and is priced at $165.00. Forks for other frequencies between 40 and 200 cycles can be built to order. Prices on request.

THE VARIAC AS A SERIES DIMMER



● **ASSOCIATED THEATRICAL SERVICE** of San Francisco reports the use of Variacs as series dimmers for lighting control. The Variac is connected, like a rheostat, in series with the load. The advantage of this arrangement is that Variacs can be substituted for resistance dimmers in existing control systems without in any way changing the wiring.

IMPROVEMENTS IN THE TYPE 568 CONDENSER

● **MANY MANUFACTURERS**, laboratory workers, and amateurs have used Type 568 Variable Air Condensers for assembly into receivers, transmitters, and wavemeters, and for use in experimental equipment at high frequencies. The trend toward their use at ultra-high frequencies, however, has necessitated some changes in design, in accord with the principles discussed in a preceding article.* These changes have been mainly directed toward reducing the high-frequency resistance.

There are two main sources of loss in a variable air condenser. One is the dielectric loss caused by the power factor of the insulating material. Because isolantite is used in Type 568 Condensers, this loss is very small. The other loss, which becomes increasingly important at high frequencies, is the metallic resistance loss in the condenser stack. It is toward the reduction of this loss that the new changes in design have been aimed.

The new Type 568 Condensers use two spiders, one at each end, to feed the current to the rotor, and the terminals to both rotor and stator are brought out at the center of the stacks. As a result the resistance is reduced to approximately one-fourth of its former value. As before, both plate stacks are made integral by complete soldering of all the plates.

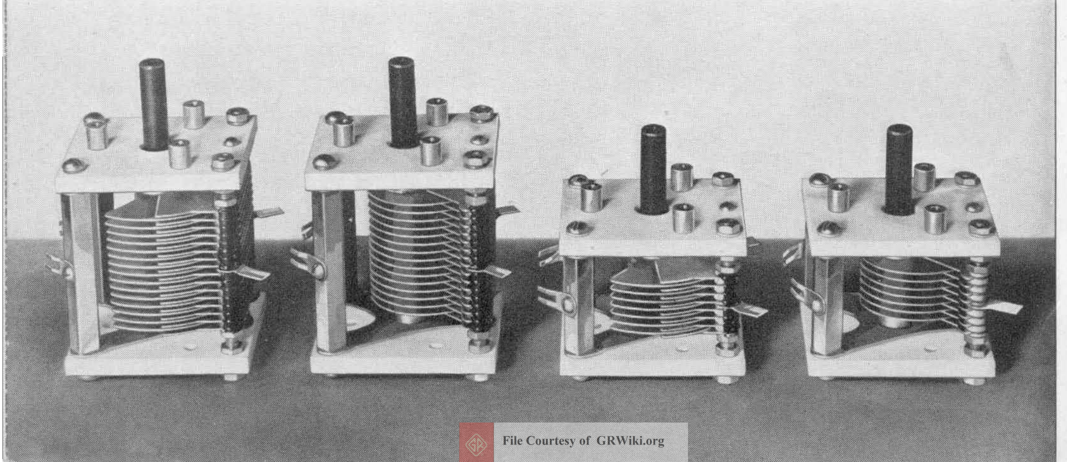
Two new models having increased maximum capacitances have been added to the line of Type 568 Condensers. The Type 568-E has the same plate shape as the older Type 568-D, straight-line capacitance, but an increased stack length doubles the capacitance. Similarly, the new Type 568-L uses the straight-line frequency plates of the Type 568-K but has twice the maximum capacitance. As with the older style, all models can be ganged for tandem operation.

Complete specifications, together with a dimensioned sketch, are given on page 11. All four models are now stocked for immediate shipment.

— Martin A. Gilman

*See page 1.

Figure 1. Photograph of the four stock models of Type 568 Condenser showing the terminals. *Left to right:* Types 568-E, -L, -D, and -K.



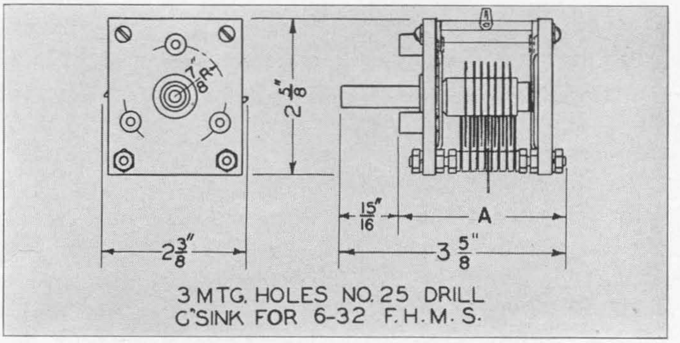


FIGURE 2. Dimension sketch of TYPE 568 Condenser. For values of dimension A, see specifications.

SPECIFICATIONS

Dielectric Losses: The figure of merit, $R\omega C^2$, is approximately 0.03×10^{-12}.

Maximum Voltage: 500 volts, peak.

Rotation Angle: 180° for TYPES 568-D and 568-E, 270° for TYPES 568-K and 568-L.

Dimensions: See sketch. Depth (dimension A) is $2\frac{11}{16}$ inches for TYPES 568-D and 568-K, and $3\frac{11}{16}$ inches for TYPES 568-E and 568-L. All shaft diameters are $\frac{3}{8}$ inch.

Net Weight: $\frac{3}{4}$ pound for TYPES 568-D and 568-K, 1 pound for TYPES 568-E and 568-L.

Type	*Nominal Capacitance*		*Plate Shape*	*Code Word*	*Price*
	Maximum	*Minimum*			
568-D	175 μμf	13 μμf	st.–line cap.	CLOVE	$4.50
568-E	360 μμf	18 μμf	st.–line cap.	CLOWN	7.00
568-K	50 μμf	11 μμf	st.–line freq.	CLOUD	4.50
568-L	100 μμf	14 μμf	st.–line freq.	CAGED	7.00

MISCELLANY

● **SCIENTISTS** from all over the world recently attended a Congress for Applied Mechanics held at Massachusetts Institute of Technology. A feature of the Conversazione, held on the evening of September 13, was the extensive use of the Edgerton Stroboscope. Stroboscopes (and Strobotacs) were used in nine separate exhibits to illustrate mechanical principles.

(1) *Pelton Wheel.* A Pelton water wheel was run at low speed to avoid splash, and was illuminated by two stroboscopic lamps, which clearly showed the action of the water on the buckets.

(2) *Cavitation.* Periodically recurring cavitation in a stream of water was shown by means of a TYPE 548-A Stroboscope.

(3) *Cavitation.* Cavitation on the end of a nickel rod vibrating at very high speed was under observation with a TYPE 631-A Strobotac.

(4) *Water-drop Formation* in a stream of water from a small vane pump was under observation with the light from two Strobotron tubes. The light flashes could be synchronized to the pulses of water sent out by the pump so that the stream of water appeared to stop, go

slowly downward, or actually appear to flow *upwards*. This demonstration is so interesting that the apparatus is set up as a permanent exhibit at M.I.T.

(5) *Smoke Vortices.* Stroboscopic light was used to show the beautiful vortices that are formed when $TiCl_4$ smoke flows through and around the blades of a fan.

(6) *Gasoline-engine Section.* The Ford Motor Company lent a V8 engine that was cut away to show the pistons, valves, valve springs, and oil flow at a speed of 1800 rpm. This made a very effective demonstration when illuminated with stroboscopic light.

(7) *Vibration of Buildings.* Cross-sections of buildings were vibrated with a motor and a TYPE 548 Stroboscope was used to illuminate the model so that the motion could be observed.

(8) *Cantilever Beam Vibration.* A Strobotac was used to show dynamic stresses in a vibrating beam with the aid of Polaroid discs.

(9) *Fatigue of Metal.* Samples of metal when vibrated violently in fatigue tests were under observation with a 60-cycle Stroboscope using a Strobotron lamp.

● **VISIT** booths 13 and 14 at the Rochester Fall Meeting of the I.R.E. General Radio instruments will be on display — General Radio engineers will be in attendance.

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

GENERAL RADIO COMPANY

30 STATE STREET - CAMBRIDGE A, MASSACHUSETTS

BRANCH ENGINEERING OFFICES

90 WEST STREET, NEW YORK CITY

1000 NORTH SEWARD STREET, LOS ANGELES, CALIFORNIA

THE General Radio EXPERIMENTER

VOLUME XIII NO. 7 DECEMBER, 1938

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also
IN THIS ISSUE

Page
Higher Modulation Levels for the Type 605-B . . . 6

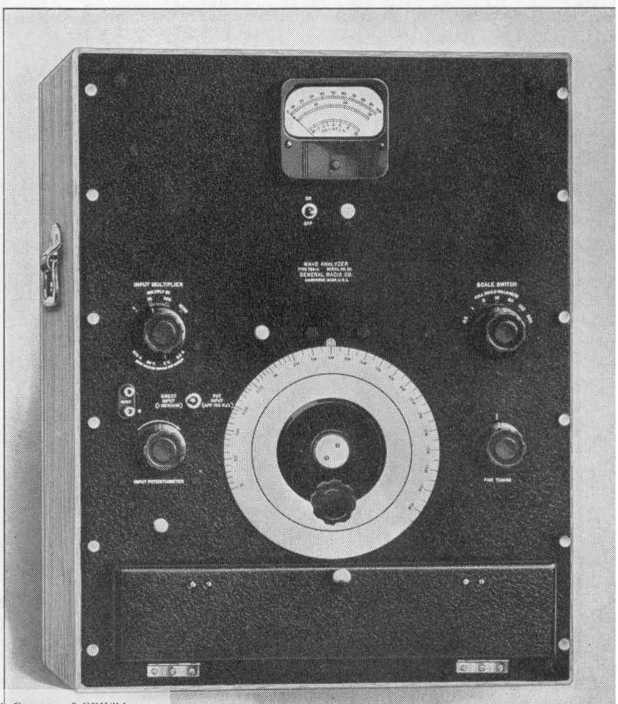
THE NEW WAVE ANALYZER — SOME OF ITS FEATURES

● **SINCE** its announcement five years ago*, the Type 636-A Wave Analyzer has been applied to a wide variety of uses. While the majority of these heterodyne-type analyzers are used in the electrical communication field, industry in general has found them useful in analyzing noise and other mechanical vibrations. Specific uses range from the study of brain waves to the analysis of airplane vibrations. The experience of nearly five hundred users with the older model, plus considerable research work on circuits and circuit elements, has made it possible to design a new instrument, which not only makes the measurements that the older model made, but makes them so much more simply and smoothly that its performance is qualitatively entirely different.

The principle of the heterodyne analyzer is well known. As with the common superheterodyne type of radio receiver, tuning is accomplished by means of a

*L. B. Arguimbau, "Wave Analysis," *Experimenter*, June-July, 1933.

Figure 1. Panel view of the Type 736-A Wave Analyzer. The panel is standard 19-inch relay-rack width.



fixed-frequency filter and a frequency changer, as indicated in Figure 2. Since this principle of operation is used in both models, it is necessary to consider some of the essential details of the design in order to appreciate the degree of improvement obtained in the new instrument.

Perhaps the most important change is that made in the crystal filtering system. At the time the first analyzer was designed, little information was available on quartz crystal filters. It was known that crystals had satisfactory frequency and damping characteristics, but whether serious changes in these characteristics would occur with changing external conditions, such as humidity and age, was not certain.

When only a single crystal is used, slight changes in the characteristics are of little consequence, but with two crystals (which were necessary in the wave analyzer), any drift in frequency of one unit with respect to the other would be quite serious.

In order to avoid the effects of aging, the crystals were ground to have the same frequency, but one of the crystals was made to have a considerably higher damping than the other. Their combination resulted in an over-all characteristic which would be little changed if the crystals shifted by a fraction of a cycle in frequency or if the damping changed. Although this arrangement was adequate to eliminate the effects of aging, it resulted in a response curve which was unnecessarily sharp and which made tuning very critical; slight changes in frequency were sufficient to cause detuning.

Experience has shown that humidity is by far the most important factor affecting crystal stability. Vibration tests have shown the mountings to be less critical than had previously been believed. Consequently, the crystals, when hermetically sealed in their mountings, can be regarded as fixed elements.

With these results as a starting point, three crystals were combined in a flat-top filter. As a preliminary step, an exhaustive series of measurements was made of crystal transmission and band width as functions of terminal impedance*. From the results, the schematic circuit diagram of Figure 3 was determined. Accurate knowledge of these equivalent circuits led to a practical filter design in which the damping factors and frequencies of the crystals could be individually adjusted by trimmers and combined in a way which gives the flat-top curve of Figure 4.

For the user, this curve is of practical importance in several ways. In the first place, it is unnecessary to tune the oscillator for an exact maximum. The response is flat over a band of about four cycles, so that when the dial is adjusted for an approximate maximum, the deflection is very close to that corresponding to the true peak. When this has been done, the circuit remains in tune so that the effect of various circuit changes upon harmonic amplitudes can be studied without continuous ad-

*These measurements were described in detail before the June, 1938, Convention of the Institute of Radio Engineers.

FIGURE 2. Functional schematic diagram showing the principles of operation of the wave analyzer.

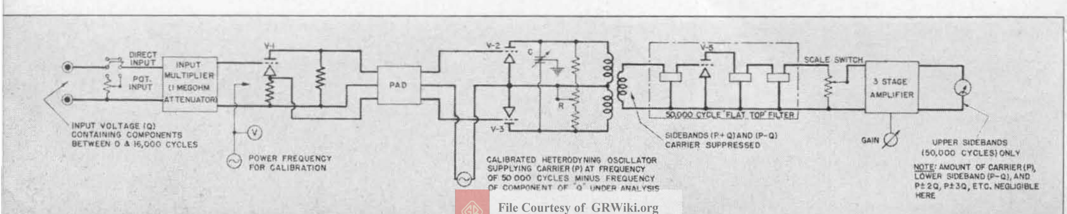
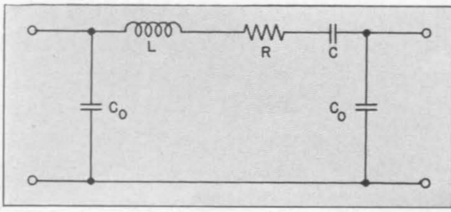


FIGURE 3 (*below*). Simplified equivalent circuit of the three-electrode quartz crystal. Approximate circuit constants are

$L = 1000$ henrys $R = 7000\ \Omega$
$C = 0.009\ \mu\mu f$ $C_o = 6\ \mu\mu f$
$Q = 50{,}000$ $f_o = 50$ kc



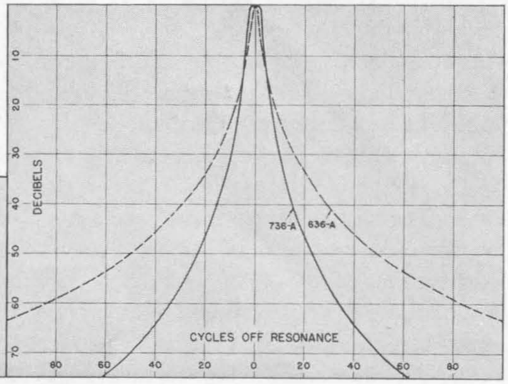


FIGURE 5 (*above, right*). Response curves of the old and new analyzers for frequencies outside the normal pass band. The discrimination to unwanted frequencies is greatly improved. At 60 cycles off resonance the response is 0.06% on the new unit, 0.2% on the old.

FIGURE 4 (*below*). Response curves near resonance for the old and new wave analyzers. The "flat-top" band of 3 or 4 cycles makes tuning much less critical.

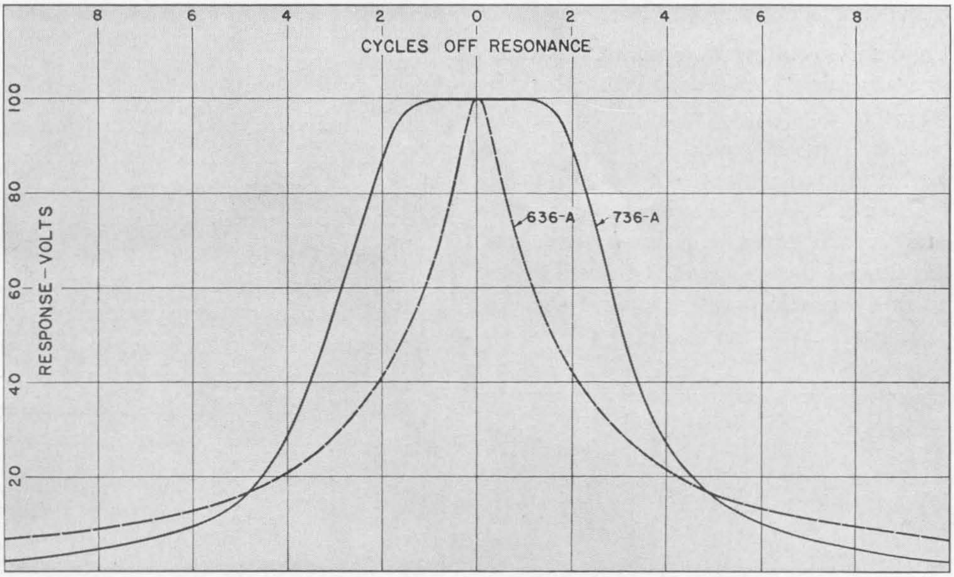
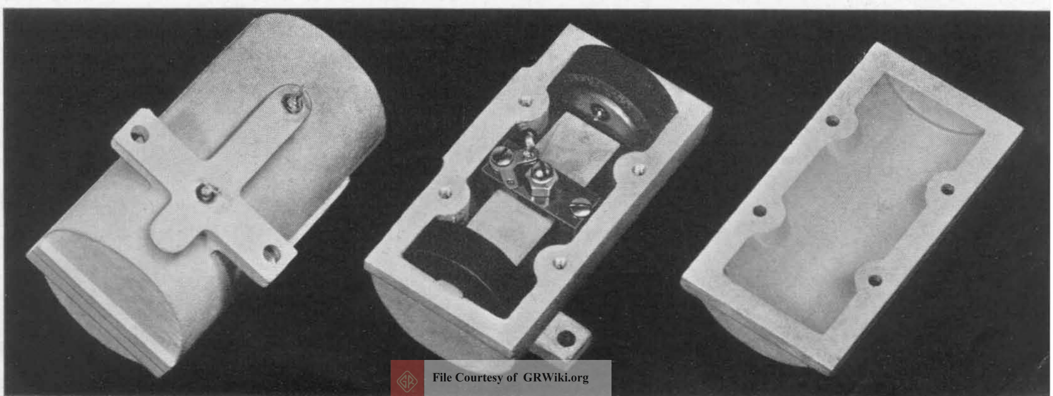


FIGURE 6 (*below*). Three-electrode quartz crystal filter elements. These quartz bars are plated with copper and gold to provide electrodes, and are mounted by felt in a cast aluminum frame which serves as a support and also provides acoustic baffles at the ends to prevent damping. The aluminum castings are mounted in sponge rubber within a sealed cast-aluminum housing.



justment of the tuning controls. In the measurement of disturbances which are not of completely constant pitch, this feature is particularly important.

One example is the analysis of the sound or vibration coming from rotating machinery, gasoline engines, etc. An airplane engine in flight is likely to vary by about $\pm 0.5\%$ in speed. This means that a frequency of 100 cycles will cover a band 1 cycle wide and so can be measured with perfect stability by the analyzer. A component having a frequency of 400 cycles will cover a band 4 cycles wide, and this can be observed with an accuracy of about 10%. Higher frequencies can be recognized, but their measurement is not accurate. With the older type of analyzer, frequencies as low as 70 cycles would give an unstable deflection under the same conditions.

In addition to the improvement in the crystal filter, the instrument has been made a-c operated. This was by no means a routine problem, since the detector tubes in the analyzer are peculiarly susceptible to hum. After much experimentation it was found necessary to supply the heaters of several of the tubes from rectified dc to avoid this difficulty. Similarly, the detectors followed by a high-gain amplifier and voltmeter tube made careful voltage regulation necessary to provide stability and to avoid power supply oscillations.

One innovation is the input circuit, which contains a degeneratively arranged phase-inverter tube to supply the balanced voltage needed for the detectors. This eliminates the transformer which in the older d-c operated analyzer was likely to introduce much more hum than is found in the present a-c unit.

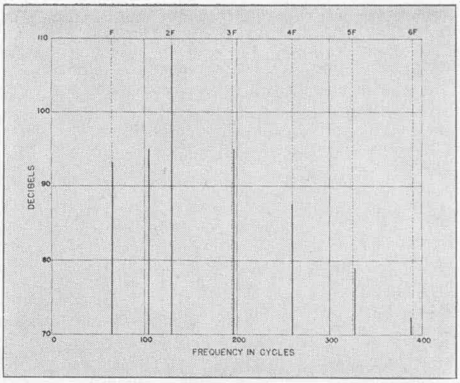
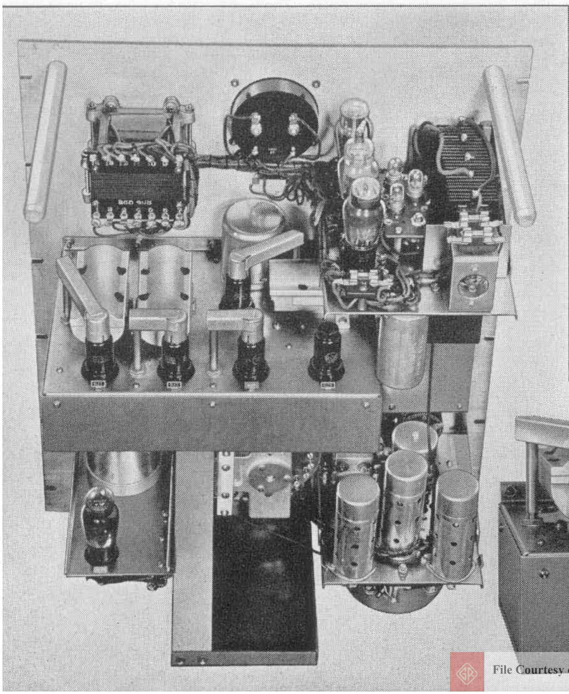


FIGURE 8. Results of measurements made with the TYPE 736-A Wave Analyzer on a phonograph record of airplane noise (courtesy Douglas Aircraft Company).



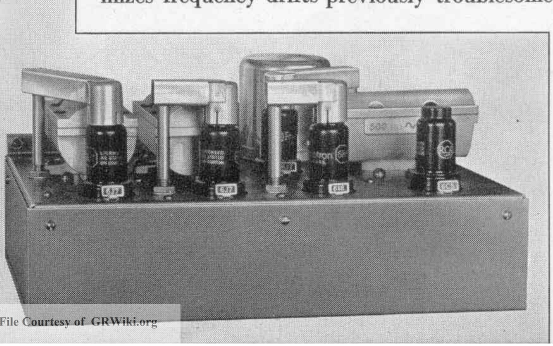


FIGURE 7. Internal view of analyzer showing the mechanical construction. The amplifier (shown also at the right) is of low-impedance aperiodic design; the older type inductive coupling and trimmers are notably absent. The parts are readily accessible. The oscillator is of much more rugged design, which minimizes frequency drifts previously troublesome.

Another improvement which will be appreciated by users of the older instrument is the virtual elimination of any necessity for accurate balancing of the detector circuits.

The General Radio calibration laboratory puts all new instruments through exaggeratedly severe tests in order to check their reliability under service conditions. In line with this policy, one of the new analyzers was packed in its shipping case and driven around for several days with particularly rough handling in a delivery truck. Upon its return to the laboratory it was unpacked and kept in a humidity chamber at 90° F. and 100% humidity for about eight hours. The instrument was then tested before it had a chance to dry out, and it was found that after a 10% readjustment of the gain control (which is a normal procedure in using the instrument) the operation was normal, and the crystal filter was not affected.

— L. B. Arguimbau

SPECIFICATIONS

Frequency Range: 20 to 16,000 cycles.

Selectivity: Approximately 4 cycles "flat top" band width. The response is down 15 db at 5 cycles, 30 db at 10 cycles, 60 db at 30 cycles from the peak. The selectivity is constant over the frequency range.

Voltage Range: 300 microvolts to 300 volts full scale. The lowest division on the meter corresponds to 10 μv. The over-all range is divided into four major ranges: 300 μv–300 mv, 3 mv–3 v, 30 mv–30 v, .3 v–300 v. Each of these ranges is divided into seven scale ranges; for example, the .3 v–300 v range has the following full-scale ranges: 0.3 v, 1 v, 3 v, 10 v, 30 v, 100 v, 300 v.

Direct-reading decibel scales are also provided.

Voltage Accuracy: Within ±5% on all ranges. Spurious voltages from higher order modulation products introduced by the detector are suppressed by at least 70 db. Hum is suppressed by at least 75 db.

Input Impedance: One megohm when used for direct voltage measurements. When used with the input potentiometer it is approximately 100,000 ohms.

Accuracy of Frequency Calibration: ±2%.

Vacuum Tubes Required:

3—Type 6C6	1—Type 6C5
2—Type 6K6G	1—Type 6X5G
3—Type 6J7	1—Type 6F5G
1—Type 6B8	3—Type T-4½ neon lamps

These are supplied with the instrument.

Power Supply: 115-volt, 40- to 60-cycle, vacuum-tube voltage regulator included. A change in the power transformer connection permits the use of 230 volts, 40- to 60-cycles.

Mounting: Shielded oak cabinet.

Dimensions: (Width) 19½ x (height) 25⅛ x (depth) 10⅞ inches, over-all.

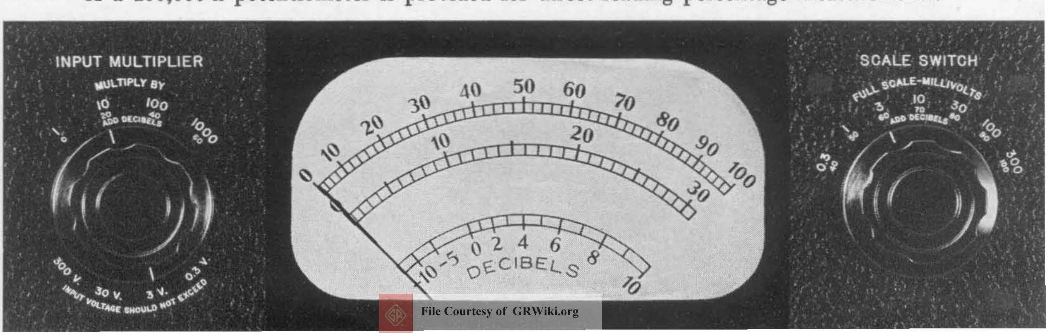
Net Weight: 85 pounds.

Type	*Code Word*	*Price*
736-A	ASKEW	$640.00

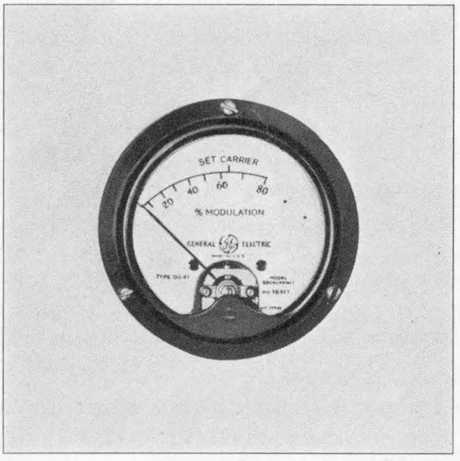
This instrument is manufactured and sold under the following United States Patents and license agreements:
1. Patents of the American Telephone and Telegraph Company, solely for utilization in research, investigation, measurement, testing, instruction and development work in pure and applied science, including industrial and engineering fields.
2. Patent No. 1,542,995.
3. Patent No. 1,967,185.

Figure 9. The input system has been designed to provide a wide voltage range. Full-scale ranges are from 300 microvolts to 300 volts. The smallest meter division corresponds to 10 microvolts. The over-all range is divided into four parts, selected by means of the switch shown at the left. Each of these major ranges is divided into seven scale ranges by means of the switch at the right. For example, the 0.3 v — 300 v range has the following full-scale ranges: 0.3 v, 1 v, 3 v, 10 v, 30 v, 100 v, 300 v.

The newly developed Weston Type 801 Meter with illuminated scale is used. The main scales are linear, but a direct-reading decibel scale is also provided. An alternate input circuit consisting of a 100,000 Ω potentiometer is provided for direct-reading percentage measurements.



HIGHER MODULATION LEVELS FOR THE TYPE 605-B STANDARD-SIGNAL GENERATOR



● **MODULATION** up to 80% is possible with the latest TYPE 605-B Standard-Signal Generators. Current models are equipped for internal modulation at 400 cycles or for external modulation between 30 and 15,000 cycles, up to 80%.

When the 400-cycle internal oscillator is used, the total envelope distortion is less than 3% up to 50% modulation, and between 5% and 10% at 80% modulation.

Provision is also made for obtaining modulation percentages of 90% and 100%, although, at these higher levels, distortion may be serious.

The internal impedance at the external modulation terminals is 4000 ohms. Approximately 4 volts are required for 30% modulation and 12 volts for 80%.

Older TYPE 605-A or TYPE 605-B Standard-Signal Generators can be converted for these higher modulation levels at a charge of $40. This includes the necessary changes in the audio oscillator, the external modulation filter, and the audio-frequency vacuum-tube voltmeter, as well as the installation of a new scale on the percentage modulation meter.

When only external modulation is to be used at levels above 50%, it is possible for the user to install a new scale on the percentage modulation meter and recalibrate the audio-frequency vacuum-tube voltmeter, following directions given in the instruction manual. After this is done, external modulation can be used over the same range as in the new instruments. The internal 400-cycle oscillator, however, will not supply sufficient power for modulation above 50% without the extensive modification specified above. The new meter scale can be supplied for 65 cents. No change is necessary in the meter movement itself.

Listed below are all the changes which can be made on older models of TYPE 605-A or TYPE 605-B Standard-Signal Generators.

Type	*Change*	*Price*
605-A	(1) Addition of 1-volt output jack	$10.00
605-A	(2) New ball-bearing condenser and gear-drive dial	60.00
605-A or 605-B	(3) 80% Modulation	40.00

When changes (2) and (3) are made, at the same time, the price is $90.00 for the combination.

Before returning instruments for modification, write to the Service Department for shipping instructions.

VISUAL-TYPE FREQUENCY MONITORS

MODERNIZATION OF BATTERY MODELS

● **EFFECTIVE** December 15, the price for converting battery-operated broadcast frequency monitors (TYPES 575-D and 581-A) for a-c operation will be $210. This increase in price is based on actual costs of modernizing these instruments during the past two years. The increased age of the monitors necessitates more minor repairs and replacement of small parts than were contemplated when the former price* was set. In addition, extensive changes made in the instruments by operating personnel have made complete disassembly a necessary part of the reconditioning operation, as have the heavy deposits of dust resulting from lack of proper maintenance.

The rebuilt instruments will carry the same guarantee as new equipment. The quoted price will include minor repairs not strictly a part of the reconditioning operation, but necessary major repairs will be subject to additional charge at a fair rate. The time required to do the work will be between ten days and two weeks.

When, in addition to this work, a new TYPE 376-L, low-temperature-coefficient, quartz plate is installed, the total price is $270.

The Federal Communications Commission will grant a permit to operate a broadcasting station for a period of 30 days without a visual monitor, provided it is stated that the frequency monitoring equipment is being returned to the manufacturer for modification and calibration. It is, therefore, essential that the permit be granted before the equipment is returned to us.

Before returning instruments for this modification, write to the Service Department for shipping instructions.

— H. H. DAWES

* *Experimenter*, April, 1937.

MISCELLANY

● **WHEN** meteors suddenly leave wiggly trails on the photographic record of their course, that's headline news to the astronomical world. But Dr. Frederick Whipple of the Harvard Observatory, who noticed the phenomenon in a series of new photographs he had taken, held up the startling announcement while he checked his camera with a General Radio Strobotac. If the motion recorded on the film were real, the meteors 100 miles away were sidestepping about fifteen feet. But meteors have always gone about their business in a more orderly way. Dr. Whipple suspected his equipment. By placing a white dot on the camera box and flashing it with the Strobotac, he discovered that the camera, not the meteor, was oscillating at a rate of sixteen times a second. The dif-

ficulty was traced to the motor in the camera set-up. Again the Strobotac to the rescue of science.

That's not the end of the story, for Dr. Whipple realized that the distance between the wiggles was an accurate meteor speedometer. The speed with which meteors arrive gives the only precise measure of upper air resistance and may be used to trace meteoric paths back to interstellar space. The astronomers used their misfortune to double the number of timed meteor trails previously known in all the observatories of the world. And that *is* headline news.

● **RECENT** visitors to the General Radio plant include: Dr. Giacomo Segre, Chief Engineer of the General Electric Company of Milan; Major E. H. Armstrong of Columbia University; and Mr. Harry Sadenwater of R.C.A. Manufacturing Company.

● **A NOVEL USE** of the General Radio Type 759-A Sound-Level Meter has been in judging the noise produced by the various fraternity floats in the annual Noise Parade during the Homecoming Celebration at Oregon State College. This year the first three entries produced levels of 110, 106, and 103 decibels, respectively. These intensities were taken 40 feet from the source. Pneumatic hammers pounding on large circular saws won first prize. The meter was also used to judge the applause at the Midnight Matinee.

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

GENERAL RADIO COMPANY

30 STATE STREET - CAMBRIDGE A, MASSACHUSETTS

BRANCH ENGINEERING OFFICES

90 WEST STREET, NEW YORK CITY

1000 NORTH SEWARD STREET, LOS ANGELES, CALIFORNIA

PRINTED IN U.S.A.