the GENERAL®RADIO Experimenter

INDEX TO GENERAL RADIO EXPERIMENTER

VOLUME 38

JANUARY through DECEMBER 1964

INDEX BY TITLE

INDEX BY AUTHOR

INDEX BY TYPE NUMBER

TYPE 1150-B DIGITAL FREQUENCY METER
400-kc Solid-State Counter (R. W. Frank: August)

TYPE 1150-BH DIGITAL FREQUENCY METER
New One-Megacycle Counter (December)

TYPE 1151-A DIGITAL TIME AND FREQUENCY METER
Increased Frequency Range for the Type 1151-A Digital Time and Frequency Meter (August)

TYPE 1161-A COHERENT DECADE FREQUENCY SYNTHESIZER
Coherent Decade Frequency Synthesizers (Atherton Noyes, Jr.: September)

TYPE 1162-A COHERENT DECADE FREQUENCY SYNTHESIZER
Coherent Decade Frequency Synthesizers (Atherton Noyes, Jr.: September)

TYPE 1216-A UNIT I-F AMPLIFIER
Measurements on Power Transistors with the Transfer-Function Bridge (February)

TYPE 1217-C UNIT PULSE GENERATOR
Improved Performance from the Unit Pulse Generator (R. W. Frank: December)

TYPE 1240-A BRIDGE OSCILLATOR-DETECTOR
Convenient Generator-Detector Unit for Bridge Measurements (June)

TYPE 1262-C POWER SUPPLY
AC Power Supply for the Vibration Meter (July)

TYPE 1301-A LOW-DISTORTION OSCILLATOR
Low-Distortion Oscillator (May)

TYPE 1308-A AUDIO OSCILLATOR
A New 200-VA Audio Generator (R. G. Fulks: January)

TYPE 1350-A GENERATOR-RECORDER ASSEMBLY
New Talents for the Graphic-Level Recorder (Martin W. Basch: September)

TYPE 1360-B MICROWAVE OSCILLATOR
Type 1360-B Microwave Oscillator (G. P. McCouch: August)

TYPE 1396-A TONE-BURST GENERATOR
A Generator of AC Transients (J. K. Skilling: May)
Relay-Rack Mount for the Tone-Burst Generator (July)

TYPE 1422-CL PRECISION CAPACITOR
A Three-Terminal Precision Capacitor with Low Terminal Capacitances (August)

TYPE 1432 DECADE RESISTORS
New 6-Dial Decade Resistors (December)

TYPE 1432-Z DECADE RESISTOR
New, Megohm, Wire-Wound Resistors and Decades (February)

TYPE 1521-A GRAPHIC LEVEL RECORDER
Automatic Plotting of Antenna Patterns (May)

TYPE 1521-B GRAPHIC LEVEL RECORDER
New Talents for the Graphic Level Recorder (Martin W. Basch: September)

TYPE 1559-B MICROPHONE RECIPROCITY CALIBRATOR
A Reciprocity Calibrator for the WE 640AA and Other Microphones (December)

TYPE 1565-A SOUND-LEVEL METER
A Compact, Inexpensive Sound-Level Meter (W. R. Kundert: October-November)

TYPE 1607-A TRANSFER-FUNCTION AND IMMITANCE BRIDGE
Measurements on Power Transistors with the Transfer-Function Bridge (February)

TYPE 1615-A PRECISION CAPACITANCE BRIDGE
The Precise Measurement of Small Dimensions by a Capacitance Bridge (A. E. Sanderson and F. Van Veen: February)

TYPE 1632-A INDUCTANCE BRIDGE
Bridge Assembly for Precision Inductance Measurement (June)

TYPE 1644-A MEGOHM BRIDGE
A Bridge to Teraohm Territory (Henry P. Hall: July)

TYPE 1680-A AUTOMATIC CAPACITANCE BRIDGE ASSEMBLY
Wescon 1964 (August)

TYPE 1900-A WAVE ANALYZER

TYPE 1910-A RECORDING WAVE ANALYZER
New Wave Analyzer has 3 Bandwidths, 80-DB Dynamic Range (Arnold Peterson: April)

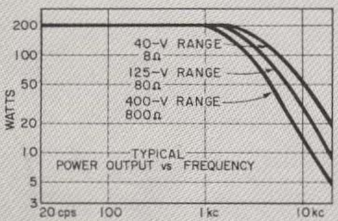
TYPE 1910-A RECORDING WAVE ANALYZER
New Talents for the Graphic Level Recorder (Martin W. Basch: September)

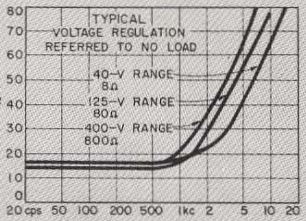
TYPE 1911-A RECORDING SOUND AND VIBRATION ANALYZER
New Talents for the Graphic Level Recorder (Martin W. Basch: September)

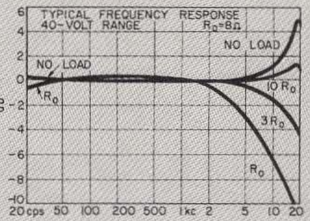
TYPE W20MT3A VARIAC® AUTOTRANSFORMERS
New Metered Variac® autotransformers (October-November)

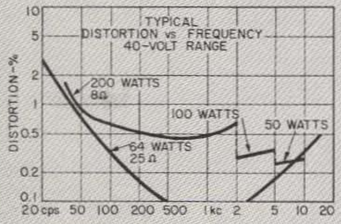
TYPE W20HMT3A VARIAC® AUTOTRANSFORMERS
New Metered Variac® autotransformers (October-November)

THE GENERAL RADIO EXPERIMENTER









Type 1308-A

AUDIO OSCILLATOR AND POWER AMPLIFIER

VOLUME 38 NUMBER 1

JANUARY, 1964

IN THIS ISSUE

200-VA Audio Generator
Digital Analog Converter
VARIAC® Autotransformers

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CONTENTS

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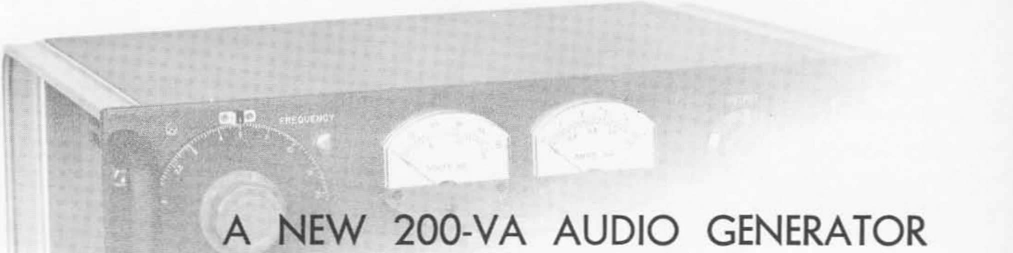
A NEW 200-VA AUDIO GENERATOR

(*see cover photograph*)



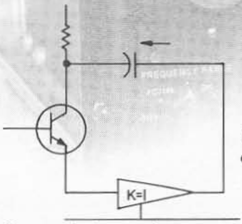


Figure 1. Guarded emitter follower.

One of the primary uses of high audio power is in the testing of electronic devices over a range of power-supply frequencies. The new Type 1308-A Audio Oscillator and Power Amplifier is well suited for this function and, in addition, has a number of features that fit it for other applications, many of which are not possible with previously available generators.

Among these features are all-solid-state circuitry, low distortion, low dynamic output impedance, and separate meters for output voltage and current. Maximum output of 200 voltamperes can be delivered to matched load impedances of 8, 80, and 800 ohms and a maximum of 5 amperes into lower impedances. The output circuit will pass up to 5 amperes of dc.

The generator is an excellent power source for the measurement of the properties of ferromagnetic materials with the Type 1633-A Incremental-Inductance Bridge at high levels of ac and dc excitation. Other uses include driving shaketables and acoustic transducers, testing servo systems and magnetic amplifiers, and testing regulated power supplies.

For specialized testing, the power amplifier can be driven from an external source, such as a high-stability signal, random noise, or square waves.

CIRCUIT

Oscillator

The small size and good reliability of solid-state circuitry are important advantages for laboratory equipment.

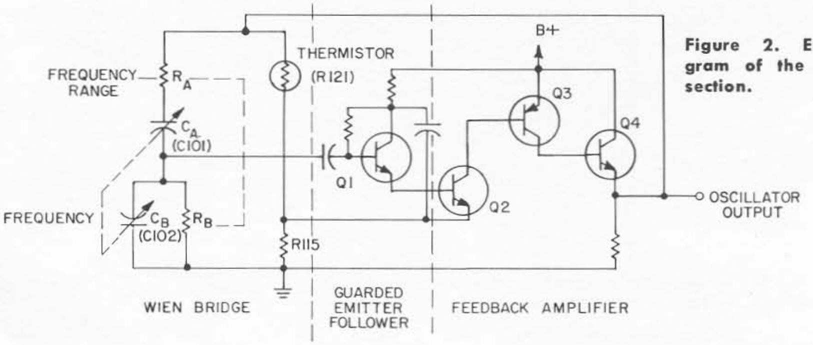


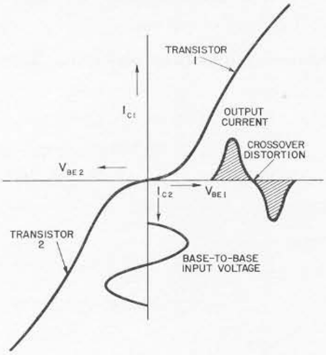
Figure 2. Elementary gram of the oscillator section.

The low impedance levels of transistors, however, are not usually considered compatible with the high impedance of variable air capacitors, which are used to provide infinite-resolution tuning in RC audio oscillators. A common alternative approach is to use ganged variable resistors. This has several disadvantages. From an economic standpoint, good quality, nonlinear potentiometers are expensive, and the limited resolution of wire-wound potentiometers often requires a separate vernier device. To combine the advantage of transistors and variable-capacitor tuning in the Type 1308-A Audio Oscillator and Power Amplifier, a novel feedback system is used. Since the impedance of practical-size variable air capacitors is of the order of 10 megohms at low audio frequencies, the associated amplifier should provide an input impedance of over 1000 megohms to avoid significant loading on the RC network.

Of course, feedback is often used to increase the input impedance of an amplifier. For example, the input impedance of an emitter-follower amplifier is usually approximated by the expression $R_{in} \cong \beta R_L$. It would appear that by an increase in the gain, β, of the stage, the input impedance could be increased indefinitely. However, the collector impedance of the first transistor shunts the input terminal and will limit the input impedance to the order of 10 megohms.

The only way to achieve an impedance in the 1000-megohm range with transistors is to degenerate all the residual impedances of the input transistor. A way of doing this is shown in Figure 1. The collector of the input emitter-follower is driven, or guarded, from the output of a unity-gain amplifier, so that all three terminals of the transistor are at the same potential, and therefore no current flows from the base lead through the transistor's collector-to-base impedance.

A practical realization of this technique is shown in Figure 2. The complete input stage and its bias network are driven from the unity-gain point at the emitter of *Q2*. The input impedance of the resulting amplifier is well over 1000 megohms for the ac signals involved. The three-stage feedback am-



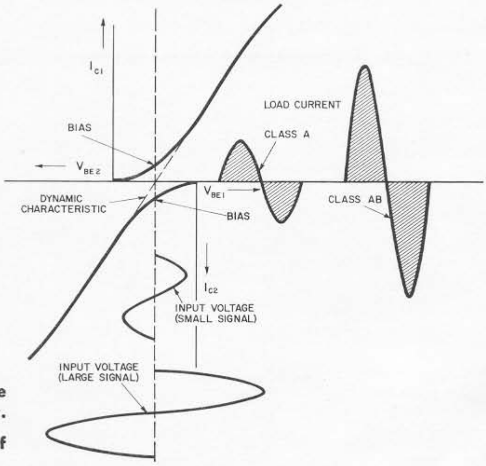


Figure 3 (*above*): **Composite transconductance characteristic of a Class-B transistor amplifier.**

Figure 4 (*right*): **Composite characteristic of Class-A and Class AB amplifier.**

plifier provides sufficient loop gain so that the oscillator characteristics are not affected by changes in transistor characteristics.

Power Amplifier

The high power efficiency and the small size of transistor power amplifiers are well recognized. There are two serious problems, however, that have limited their widespread use in laboratory equipment — stability of the bias point with temperature and protection against overload and consequent failure. The voltage transfer characteristic, or transconductance, of a push-pull Class-B transistor amplifier is very nonlinear near zero current as shown in Figure 3. For this reason, a slight forward bias is usually used to shift the curves to a more nearly linear region, as in Figure 4. Unfortunately, the base-emitter bias voltage needed to keep the desired operating point varies with temperature, so that complicated temperature-sensitive bias networks are needed. It is not possible to keep the temperature-sensitive elements at the same temperature as the small transistor junction, and so some shifts in bias are inevitable.

If, instead, the output stage is driven from a high-impedance current source, the much more nearly linear current-gain transfer characteristic of the transistor is used[1] (see Figure 5). Under these conditions, no quiescent current is needed for distortion-free performance, so that much greater temperature stability can be achieved, and balancing adjustments for the output stage are not needed.

The circuit used is shown in Figure 6. The low dc resistance of the driver transformer assures bias stability of the output transistors. Ten output transistors are used and are mounted on a forced-air-cooled heat sink to provide the power-handling capability. The high-impedance drive is provided by *Q5*. The transistor *Q6* is used to balance the direct current in the drive transformer.

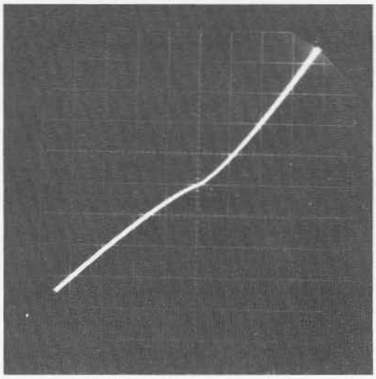


Figure 5. Output current (*vertical*) vs input current (*horizontal*) of the output stage of Figure 6.

The Class-A driver is also instrumental in protecting the output stage against overload by limiting the available drive current. Without this, a short circuit on the output could cause the output stage to draw very heavy current, probably with disastrous results. Two additional forms of protection are used—a thermal overload breaker on the output-transistor heat sink and a trip circuit that disconnects the input signal when the output current or voltage exceeds preset limits.

To achieve a low dynamic output impedance, two techniques can be used—negative voltage feedback, positive current feedback, or some combination of these. Negative feedback is used in this amplifier to avoid the stability and waveform problems that can result

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[1] James J. Faran, Jr. and R. G. Fulks, "High-Impedance Drive for the Elimination of Crossover Distortion," *The Solid State Journal*, December, 1961.

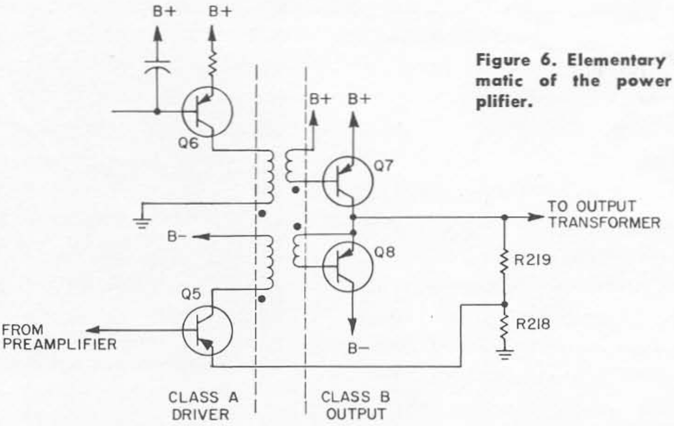

Figure 6. Elementary schematic of the power amplifier.

from positive feedback when reactive loads are used. The large negative feedback also greatly reduces harmonic distortion as well as dependence upon power-supply voltages. A single-ended push-pull configuration is used to provide a convenient point to sample the output and close the feedback loop. Thus, the output transformer is not inside the loop — a decided advantage with the large feedback factor used. Since the transformer is fed from a low-impedance source, its distortion is very low.

APPLICATIONS

Magnetic Measurements

One of the primary uses of this generator is as a signal source for the TYPE 1633-A Incremental-Inductance Bridge[2] in high-power-level measurements on iron-core inductors and transformers. These measurements require the simultaneous application of ac and dc signals to the inductor under test. Since this requirement could not be met by conventionally available power oscillators, new generators were required. The TYPE 1265-A Adjustable DC Power Supply[3] was designed for this purpose, as was the TYPE 1266-A Adjustable AC Power Source[4] which supplies an ac signal for measurements at power-line frequencies. The TYPE 1308-A Audio Oscillator and Power Amplifier can be used to supply the ac signal for measurements throughout the audio-frequency range. The output transformer of this generator provides voltage and current ranges to match the wide range of impedances that can be measured with the bridge, and direct current up to 5 amperes can be passed through the output circuit.

Meters are provided for both current and voltage, so that the excitation applied to the coil under test can be easily determined. The overload-trip circuit is arranged to trip at 50% above full scale on the current meter, so that, on the lowest output ranges, the power delivered to the load can be limited to as little as 80 milliwatts to avoid damage to the unknown inductor.

The ability to provide a low-distortion signal to a nonlinear reactive load is also important. In the measurement of an inductor on the TYPE 1633-A Incremental-Inductance Bridge, the load presented to the generator

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[2] R. G. Fulks and H. P. Hall, "A New System for Measuring the Inductance of Iron-Core Coils," *General Radio Experimenter*, 36, 5, May, 1962, pp 1–12.

[3] H. P. Hall, "The Type 1265-A Adjustable DC Power Supply," ibid, p 11.

[4] Gilbert Smiley, "The Type 1266-A Adjustable AC Power Source," ibid, p 13.

can be almost purely reactive. A reactive load dissipates no power, of course, since the voltage and current are not in phase. Although the Class-B output circuit used in the generator is very efficient with a resistive load, the efficiency drops nearly to zero with a reactive load. Therefore, all the input power must be dissipated in the output circuit, a requirement that usually imposes severe power-factor limitations on the load impedance. In this generator the output circuits have been built to handle this power, so that, under most output conditions, no power-factor derating is required.

Power-Frequency Testing

Another application is in the testing, over a range of power frequencies, of equipment that may be used by the military or in overseas countries. Here, the Type 1308-A Audio Oscillator and Power Amplifier is particularly useful because of its low dynamic output impedance. For example, equipment that uses a capacitor-input rectifier system draws current from the line only near the peaks of the sinusoidal signal. With such a nonlinear load an undistorted signal is possible only when the dynamic output impedance of the oscillator is low — a feature not found on many power oscillators. The waveforms shown in Figure 7 are typical of this situation. With this generator, the output voltage remains sinusoidal even though the output current contains many higher-frequency components.

This oscillator also has many applications where immunity from power-line transients and noise is required. Because of the large amounts of negative feed-back used, the output signal is not sensitive to this type of disturbance. A 5% jump in line voltage will typically cause less than a 0.1% change in output at full power.

In the measurement of hum and other spurious outputs it is also helpful to use some frequency other than the power-line frequency to run equipment under test, so that the desired components can be distinguished from the line-frequency components in the measurement system itself.

Power Amplifier

The usefulness of this generator is greatly enhanced by its ability to function as a power amplifier, driven from an external source. Thus, it can be used to supply high power with extreme frequency stability when driven from a standard-frequency source.

Its good transient response permits its use with special-waveform signals, such as square waves and noise. Usable power output is necessarily reduced with random-noise excitation to avoid tripping of the overload circuits on noise peaks.

Other Uses

Some applications stem not from the high power rating but from other fea-

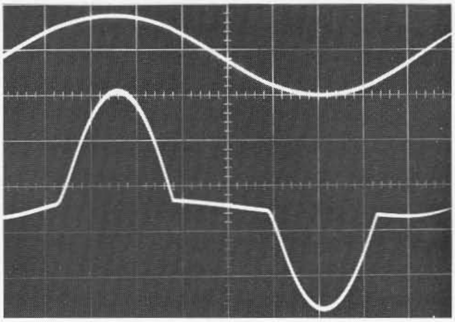

Figure 7. Output voltage (*top*) and output current (*bottom*) of the Type 1308-A Audio Oscillator and Power Amplifier when driving a device that has a capacitive-input rectifier filter. Current is drawn only near the peaks of the input waveform.

tures of the instrument. When the generator idles along at 60 watts or less, its harmonic distortion is well under 0.5% over most of the frequency range. This, combined with the wide output-voltage ranges, has been used for calibrating dynamometer-type voltmeters. The instrument has also been used as a signal source in series with a dc power supply to provide a dc source with adjustable ripple level and frequency for testing power-supply regulators.

Other applications where the multiple voltage ranges are useful are the test of servo systems and magnetic amplifiers, and driving shaketables and other acoustic transducers.

— R. G. Fulks

SPECIFICATIONS

OUTPUT

Power: 200 voltamperes, 50 cps to 1 kc. (See curves on cover.)

Full-Scale Output Ranges: 4, 12.5, 40, 125, 400 volts, rms; 0.5, 1.6, 5 amperes; in any combination up to 200 va.

Optimum Load Impedance: 0.8, 2.5, 8, 80, 800 ohms. Will operate satisfactorily with higher-impedance or nonlinear loads. Output transformer will pass dc equal to rated ac.

Regulation and Response Time: (See cover.) Less than 20% no load to full load—20 cps to 1 kc. (Bandwidth greater than 10 kc provides essentially instantaneous regulation.)

Frequency: Internal oscillator covers 20–20,000 cps in four bands.

Harmonic Distortion at Rated Output: (See cover.)
1%, 100 cps—10 kc
2%, 50 cps—100 cps

Hum: More than 50 db below maximum output.

GENERAL

Overload Protection: Electronic overload circuit trips at approximately 1½ full-scale current (manual reset); thermal protection on transistor heat sink (automatic reset).

Load Power Factor:
0 to 1.0 for continuous operation to 30 C ambient.
0 to 1.0 for intermittent operation to 50 C ambient.
0.7 to 1.0 for continuous operation to 50 C ambient.

Meters: 0 to 5, 15, 50, 150, 500 volts.
0 to 0.05, 0.16, 0.5, 1.6, 5 amperes.

Power Requirements: 105 to 125 (or 210 to 250) volts, 50 to 60 cps, 70 to 500 watts, depending on load. For 50-cycle supply, maximum output must be reduced 20%.

Amplifier:
Input Impedance—10 kilohms.
Sensitivity—Approximately 2 volts needed for full output.

Terminals: Binding posts and 4-terminal connector at rear.

Cabinet: Rack-bench.

Dimensions: Bench model—width 19, height 7, depth 16¼ inches (485 by 180 by 414 mm), over-all; rack model—panel 19 by 7 inches (485 by 180 mm), depth behind panel 15 inches (385 mm).

Net Weight: 91 pounds (42 kg).

Shipping Weight: 105 pounds (48 kg).

Type		*Code Number*	*Price*
1308-AM	**Audio Oscillator and Power Amplifier,** Bench Model	1308-9801	**$1150.00**
1308-AR	**Audio Oscillator and Power Amplifier,** Rack Model	1308-9811	**1150.00**

U.S. Patent No. D187,740.

NEW GRO REPRESENTATIVE FOR GREECE

We announce the appointment of the Greek firm of Marios Dalleggio as exclusive General Radio Company (Overseas) representative for Greece, succeeding the firm of K. Karayannis, who have represented us in that country for many years. Effective January 1, 1964, Marios Dalleggio took over these responsibilities and is now directly serving our customers in Greece with competent technical assistance and advice.

All inquiries, whether technical or commercial, concerning General Radio products, should be addressed to:

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Athens 139, Greece
Tel: 710.669
Cable: DALMAR-ATHENS

OPERATION OF VARIAC® AUTOTRANSFORMERS ON 208/120-VOLT LINES

Users of Variac® autotransformers should seriously consider the advantages inherent in the increasingly popular 208/120-volt, 3-phase distribution system. Because the wye voltage of this system is 120 volts (rather than 139 volts as in a 240-volt system), certain restrictions on Variac autotransformers in 3-phase circuits no longer apply. The 208/120-volt, 60-cycle system allows the use of Types W5L and W8L; other models can be connected for overvoltage, or step-up, as shown in the accompanying table. This tabulation points out the possibility of trading voltage range for KVA on 208-volt circuits. Note that Types W5L and W8L increase the available KVA per dollar at a sacrifice of overvoltage operation and with operation limited to 60 cps only.

The step-up connection makes possible outputs adjustable to 485 volts from a 208-volt source, but it should be noted that, for this connection, regulation is not so good as for the line and overvoltage connections.

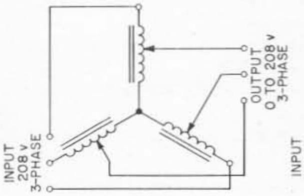

Figure 1

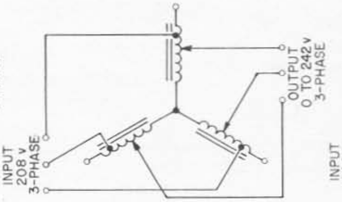

Figure 2

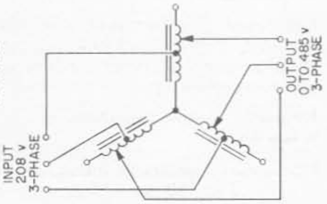

Figure 3

Type	*Circuit **	*Input Volts*	*Frequency, Cps*	*Output Volts*	*KVA at Max. Volts*	*Price*	*KVA/$*
W2G3	Line	208	50-60	0-208	1.12	$ 52.00	0.0215
W2G3	Overvoltage	208	50-60	0-242	1.00	52.00	0.0192
W5G3	Line	208	50-60	0-208	2.81	61.00	0.0460
W5G3	Overvoltage	208	50-60	0-242	2.52	61.00	0.0413
W5LG3	Line	208	60	0-208	3.96	59.50	0.0666
W8G3	Line	208	50-60	0-208	3.96	70.00	0.0566
W8G3	Overvoltage	208	50-60	0-242	3.57	70.00	0.0510
W8LG3	Line	208	60	0-208	4.68	70.00	0.0668
W10G3	Line	208	50-60	0-208	4.68	108.00	0.0433
W10G3	Overvoltage	208	50-60	0-242	4.20	108.00	0.0389
W20G3	Line	208	50-60	0-208	9.36	156.00	0.0600
W20G3	Overvoltage	208	50-60	0-242	8.40	156.00	0.0538
W30G3	Line	208	50-60	0-208	12.96	264.00	0.0510
W30G3	Overvoltage	208	50-60	0-242	12.60	264.00	0.0478
W50G3	Line	208	50-60	0-208	18.00	397.00	0.0454
W50G3	Overvoltage	208	50-60	0-242	21.00	397.00	0.0529
W5HG3	Step-up	208	50-60	0-485	0.84	71.50	0.0117
W10HG3	Step-up	208	50-60	0-485	1.68	114.00	0.0147
W20HG3	Step-up	208	50-60	0-485	3.36	162.00	0.0207
W30HG3	Step-up	208	50-60	0-485	5.04	264.00	0.0191
W50HG3	Step-up	208	50-60	0-485	10.50	397.00	0.0264

*** Line, Figure 1; Overvoltage, Figure 2; Step-up, Figure 3**

REPRINTS

Reprints are available of a number of articles by General Radio engineers published in technical journals. Recent papers include:

Reprint No.	*Title*	*Author*	*Publication*	*Date*
A-79	A New Look at the Phase-Locked Oscillator	H. T. McAleer	Proceedings of IRE	April, 1959
A-80	VHF Matching Network Design	A. E. Sanderson	Proceedings of IRE	July, 1959
A-81	A New Design Procedure for Optimum Matching Networks	A. E. Sanderson	Electronic Industries	July, 1959
A-82	A Novel Method of Frequency Multiplication	H. T. McAleer	Electronic Industries	August, 1959
A-83	A Standard Program Cuts Costs	H. C. Littlejohn	Electronic Industries	Oct., 1959
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A-85	How to Design Scales that Humans Can Read	H. C. Littlejohn	Electronic Design	Sept., 1960
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A-90	Industry's Watchdog: The Stroboscope	F. T. Van Veen	Safety Maintenance	Jan., 1961
A-91	High-Impedance Drive for the Elimination of Crossover Distortion	James J. Faran, Jr. and R. G. Fulks	The Solid State Journal	Dec., 1961
A-92	A New High-Precision Method for the Measurement of the VSWR of Coaxial Connectors	A. E. Sanderson	IRE Transactions on Microwave Theory and Techniques	Nov., 1961
A-93	R-F Leakage Characteristics of Popular Coaxial Cables and Connectors, 500 Mc to 7.5 Gc	J. Zorzy and R. F. Muehlberger	Microwave Journal	Nov., 1961
A-94	Precise Delay Measurement	H. T. McAleer	Electronics	Jan., 1961
A-95	An Accurate Substitution Method of Measuring the VSWR of Coaxial Connectors	A. E. Sanderson	Microwave Journal	Jan., 1962
A-96	The Use of Active Devices in Precision Bridges	H. P. Hall and R. G. Fulks z	Electrical Engineering	May, 1962
A-97	Thyristor-Tunnel Diode Combination Generates Fast 10-ma Pulses	J. K. Skilling	Electronic Design	Feb., 1962
A-98	A Spectrum Analyzer from General Lab Instruments	R. W. Harley	Electronic Industries	Feb., 1962

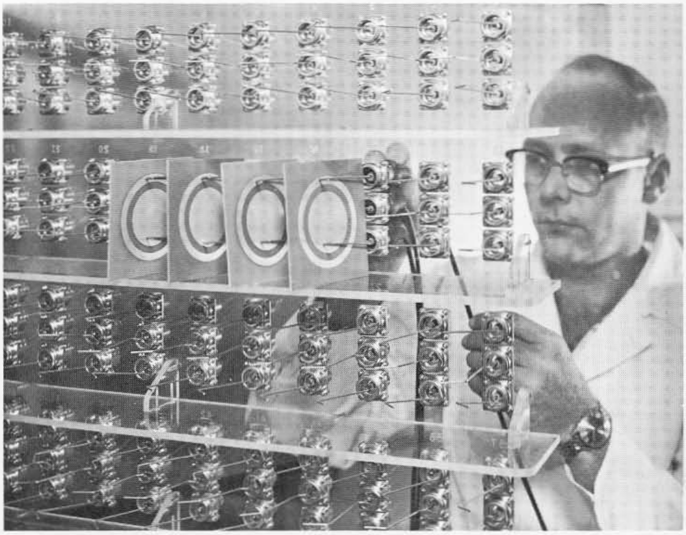
Reprint No.	*Title*	*Author*	*Publication*	*Date*
A-99	The Measuring Devices of Electronics	D. B. Sinclair	Proceedings of IRE	May, 1962
A-100	Noise and Its Measurement	F. T. Van Veen	Electronics World	May, 1962
A-101	New Complementary Transistors Make Series Schmitt Circuits Practical	J. K. Skilling	Electronics	August, 1962
A-102	Dynamic Notch Filter	H. T. McAleer	Electronic Equipment Engineering	Nov., 1962
A-103	The Image-Parameter Design of the General Two-Section Elliptic-Function Filter	W. N. Tuttle	1962 IRE Convention Record	Nov., 1962
A-104	Magnetic Pickup Generates Frequency Markers	W. F. Byers	Electronics	Dec., 1962
A-105	Tunnel-Diode Delay-Line	H. T. McAleer	Electronic Equipment Engineering	Nov., 1962
A-106	Simple Method for Plotting Tunnel-Diode Switching Waveforms	J. K. Skilling	Electronics	March, 1963
A-107	Novel Feedback Loop Stabilizes Audio Oscillator	R. G. Fulks	Electronics	April, 1963
A-108	Design Chart for Constant-K Delay Lines	G. R. Partridge	Electronic Design	June, 1963
A-110	Electronic Standards and Measurement	I. G. Easton	Electronic Industries	July, 1963
A-111	Direct-Reading Instruments	F. T. Van Veen	Electronics World	August, 1963

Reprints of several articles that have appeared in the *Experimenter* can also be supplied:

Reprint No.	*Title*	*Type No.*	*Experimenter Date*
E-101	A New, High-Sensitivity Electrometer	1230	March, 1956
E-102	The Type 1603-A Z-Y Bridge	1603-A	July, 1955
E-103	A High-Precision Impedance Comparator	1605-A	April, 1956
E-104	The Measurement of Cable Characteristics		May-Aug., 1957
E-105	An Instrument Designed to Calibrate Capacitive Fuel-Gage Testers	P-582	Feb., 1958
E-106	A Graphic Level Recorder with High Sensitivity and Wide Ranges	1521-A	June, 1959
E-107	A Transfer-Function and Immittance Bridge for the 25–1500 Mc Range	1607-A	March, 1958 May, 1959
E-108	A New Universal Impedance Bridge	1650-A	March & April, 1959
E-109	Measurements of the Equivalent-Circuit Parameters of Tunnel Diodes	1607-A	July-Aug., 1960
E-110	A Generator of Random Electrical Noise	1390-B	Dec., 1951 Dec., 1959 Jan., 1960
E-111	New Eyes for Industry (Strobotac® electronic stroboscope)	1531-A	Sept., 1960
E-112	Rapid VSWR Measurements with Admittance Meter	1602-B	May, 1960
E-113	A Close Look at Connection Errors in Capacitance Measurements		July, 1959

Single copies free upon request.

COAXIAL CONNECTORS AT DC



Courtesy Spaulding Fibre Company

DC TO MICROWAVE — That's the frequency range covered by Type 874 Coaxial Connectors. And for critical measurements at dc the positive contact, good shielding, and convenient plug-in features of the connector are just as important and useful as at microwave frequencies.

An excellent example of dc use is provided by the accompanying photograph which shows these connectors in a test chamber at Spaulding Fibre Company of Tonawanda, New York. In this photograph, samples of Spauldite laminates are being mounted on the inner door of the test chamber, whose temperature and relative humidity can be held precisely at a desired value or varied according to a predetermined time schedule.

The samples are 4″ x 4″ x thickness (usually 1/16″ to 1/8″) with sprayed conductive-silver-paint electrodes in the ASTM "Bullseye" pattern. They are being tested for volume resistivity and surface resistance, which is usually measured at the end of 96 hours' exposure to 90% relative humidity at 35C. Contact is made to the silver paint electrodes by means of spring brass wire fingers, gold plated to give low contact resistance and freedom from corrosion. The contact fingers are silver soldered to the center terminal of the General Radio Type 874-PB Coaxial Panel Connectors.

By means of shielded patch cords, each sample can be connected in turn to equipment capable of measuring resistances as great as 5 x 10^{15} ohms. At these values of resistance, shielding becomes very critical. Values obtained on a new glass fabric base epoxy laminate, used in critical military printed circuits, are on the order of 477,000,000 megohms/cm. volume resistivity and 5,700,000 megohms surface resistance.

General Radio Company

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VOLUME 38 NUMBER 2

FEBRUARY, 1964

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CONTENTS

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

COVER

The inner conductors of Type 900 Precision Coaxial Connectors are measured to one millionth of an inch by the Type 1615-A Capacitance Bridge. See page 4.

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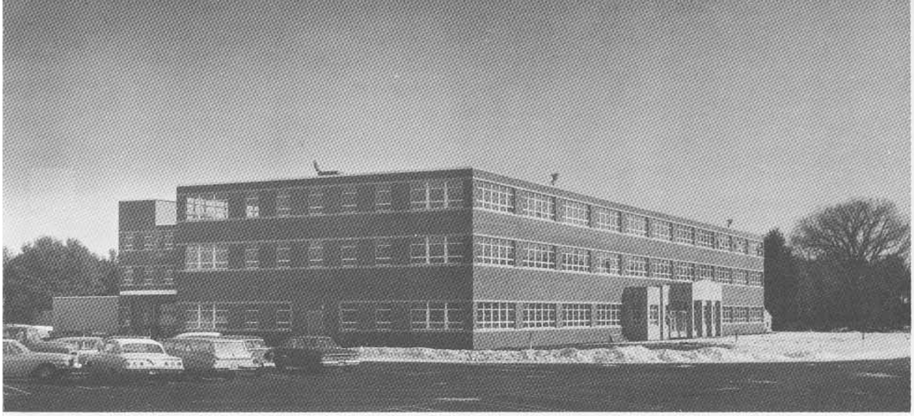

GR'S NEW BOLTON PLANT

Early in February, about 150 General Radio employees will shift their daily operations about 10 miles west of Concord, to our new plant in Bolton, Mass. Thus begins a new and significant phase in the growth of General Radio.

Less than six years have passed since GR "went suburban," moving from Cambridge to its new 300,000-square-foot headquarters in West Concord. Only a few years after this move, a 100-acre tract in nearby Bolton was purchased in preparation for the next major Company expansion.

The decision to divert expansion to a new site rather than to continue building on our 88-acre Concord property was based on several factors. Maintaining the "small company" familiarity long enjoyed by our employees would become more difficult as the Concord plant population grew. Traffic, too, would become a problem. It was therefore decided that the working force at Concord should be limited to 1000. As the number of employees at Concord passed 900 a year ago, construction began on a building in Bolton.

The new plant will be set up autonomously on a product basis, designing and manufacturing microwave and signal-generating equipment. Therefore, in the future, all GR coaxial connectors and components, slotted lines, coaxial bridges, Unit Oscillators, and signal generators will be made at the Bolton plant, which is specially equipped with the high-precision production machinery required in the manufacture of such items.

The long-term plans for Bolton include a plant about the same size as our present plant at Concord and in the same multiple-tee configuration. The building just completed is the first tee, and the design of this 80,000-square-foot unit provides for the eventual expansion to over three times its present size.

The Bolton site is on State Route 117, less than two miles east of the intersection with Interstate Route 495, now under construction. The plant site is partly wooded, with a stream dammed to form a small pond. Bolton is a small, rural community of 1200, on the eastern edge of Worcester county, and about 20 miles west of Route 128.

Engineering Manager of the Bolton plant is Robert A. Soderman, well known in the electronics industry for his work on standards and on coaxial measuring devices. Philip W. Powers, formerly Assistant to the Vice President for Manufacturing, becomes Manufacturing Manager at Bolton.

THE PRECISE MEASUREMENT OF SMALL DIMENSIONS BY A CAPACITANCE BRIDGE

One of the advantages of being a manufacturer of precision measuring instruments is the chance to apply one precision device to the design and production of another. An example is the use of our TYPE 1615-A Precision (0.01%) Capacitance Bridge to measure dimensions of parts of our TYPE 900 Precision Coaxial Connector to within a few millionths of an inch.

The principle of measuring distance by measuring capacitance is based on the relation between the capacitance of an air capacitor and the spacing between its electrodes. In the application described here, a rod is positioned in a hollow cylinder with a fixed spacing between the rod and the inside wall of the cylinder. The rod and the cylinder form the electrodes of a capacitor. Since the hollow cylinder is a special jig whose dimensions are accurately known, the spacing is governed essentially by the diameter of the rod.

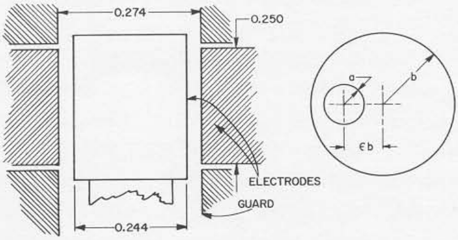

Figure 1.

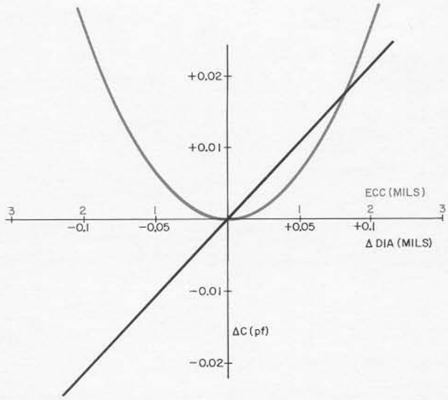

Figure 2. Capacitance deviation vs eccentricity of rod.

The capacitance, C, per unit length of a coaxial air capacitor is as follows:

$$C = \frac{1.4140}{\cosh^{-1}\left[1 + \frac{(b\text{-}a)^2 - (\epsilon b)^2}{2ab}\right]} \text{pf/inch}$$

where the dimensions a, b, and ϵ are as defined in Figure 1.

The resolution of the capacitance-distance measurement technique is increased at least a hundredfold if the bridge is used to compare two capacitances rather than to measure the unknown capacitance directly in terms of an internal standard. Therefore, in the actual measurement, a standard rod is first inserted as a reference, the unknown is then substituted, and the difference between the capacitances is measured. The bridge null detector, calibrated to indicate the deviation of unknown from standard directly, can readily indicate deviations as small as one millionth of an inch.

Of course, a deviation in capacitance could be due to eccentricity of the "unknown" rod as well as to a difference in its average diameter. Therefore, in the graph (Figure 2) showing the relation between capacitance deviation and distance deviation, a curve is added to show the equivalent effect of eccentricity. As the curve shows, one can center the rod in the jig by adjusting the rod for minimum capacitance.

For the high precision required, it is necessary to eliminate the effects of the leads from the bridge to the unknown. Thus the jig is connected as a three-terminal capacitor, and is measured as such by the TYPE 1615-A Bridge.

The absolute accuracy of this measurement depends on the accuracy of the standard rod. Rods with tolerances as small as ±10 microinches are commercially available. The sensitivity of capacitance to changes in distance is inversely proportional to the spacing between rod and jig. Decreasing this spacing will add leverage to the relation, in the direction of increased precision. As the spacing is reduced, however, the linearity of the capacitance-distance relation is sacrificed. The optimum spacing therefore represents a compromise between sensitivity and linearity.

— A. E. SANDERSON
— F. VAN VEEN

NEW, MEGOHM, WIRE-WOUND RESISTORS AND DECADES

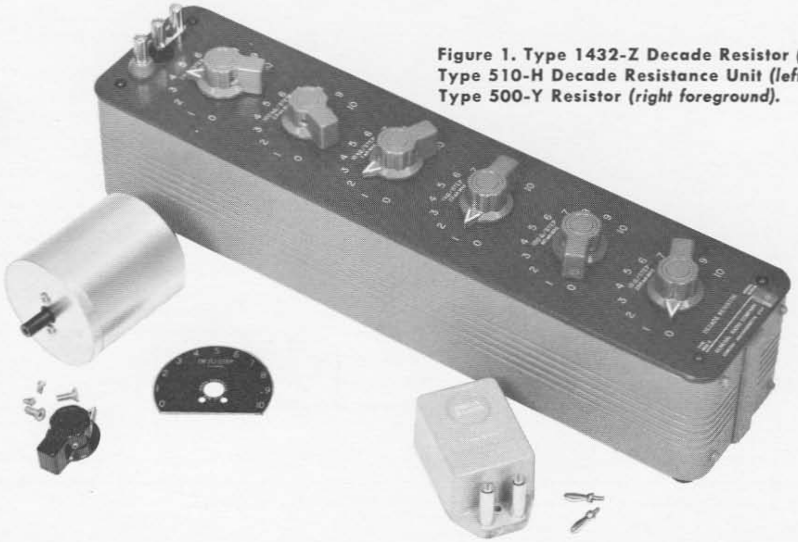

Figure 1. Type 1432-Z Decade Resistor *(rear)*. Type 510-H Decade Resistance Unit *(left foreground)*. Type 500-Y Resistor *(right foreground)*.

The development of a new, fine-wire 1-megohm resistor has made it possible to extend to higher resistances the range of our series of separately boxed, fixed resistors (TYPE 500), our decade-resistance units (TYPE 510), and our multiple-decade-resistance boxes (TYPE 1432).

Separate 2-megohm, 5-megohm, and 10-megohm fixed units are now available that use the appropriate number of the new resistors in series. The decades use ten units to give a total of 10 megohms in 1-megohm steps.

Like other GR resistors of 500 ohms and higher, these new units are singlelayer wound on a thin, card-type form. This type of resistor has lower inductance and capacitance than does a spool-wound resistor and, therefore, has much better ac properties. High-valued resistors of this type must use very fine wire if they are to be wound on a form of reasonable size. Recently developed winding techniques have made practical the use of 0.5-mil Evanohm wire, which makes possible one-megohm units that are only slightly larger in size than those of lower resistance values. It is easy to imagine the difficulties of winding wire of this size when one realizes that it is about ¼ the diameter of human hair!

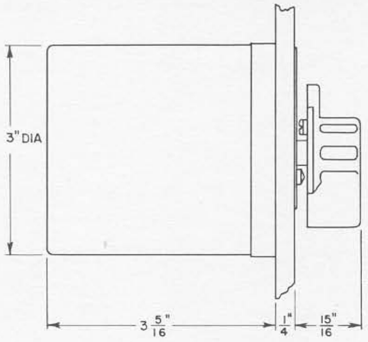

Figure 2. Dimensions of Type 510 Decade-Resistance Unit.

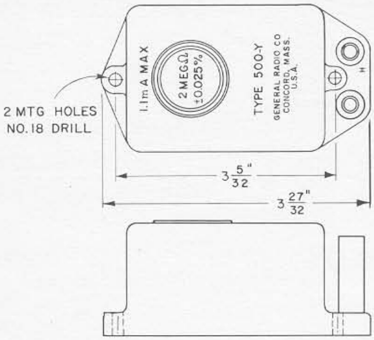

Figure 3. Dimensions of Type 500 Resistor.

SPECIFICATIONS

TYPE 500 RESISTORS

Dimensions: See sketch.
Net Weight: 2 ounces (60 grams).
Shipping Weight: 8 ounces (230 grams).

Type	*DC Resistance*	*Max Current*	*Accuracy*	*Code Number*	*Price*
500-Y	2 megohms	1.1 ma	0.025%	0500-9725	**$28.00**
500-Z	5 megohms	0.7 ma	0.025%	0500-9726	**62.00**
500-ZZ	10 megohms	0.5 ma	0.025%	0500-9504	**95.00**

TYPE 510-H DECADE-RESISTANCE UNIT

Dimensions: See sketch.
Net Weight: 11 ounces (310 grams).
Shipping Weight: 2 pounds (1.0 kg).

DC Resistance					
Per Step	*Total*	*Accuracy**	*Max Current*	*Code Number*	*Price*
1 megohm	10 megohms	0.025%	0.7 ma	0510-9708	**$98.00**

* Each of the 10 resistors in each decade is adjusted to be accurate at its terminals within the tolerance given. Resistance increments are accurate to this same tolerance.

TYPE 1432 DECADE RESISTOR

Dimensions: Width 4⁵⁄₁₆ inches (110 mm), height 4¾ inches (120 mm); length, 15¾ inches (400 mm) for Type 1432-Y and 18¼ inches (470 mm) for Type 1432-Z.

Net Weight: Type 1432-Y — 6 pounds, 5 ounces (2.9 kg); Type 1432-Z — 7 pounds, 8 ounces (3.4 kg).

Shipping Weight: Type 1432-Y — 7 pounds (3.2 kg); Type 1432-Z — 9 pounds (4.1 kg).

	Resistance		*No. of*	*Type 510*		
Type	*Total*	*Per Step*	*Dials*	*Decades Used*	*Code Number*	*Price*
1432-Y	11,111,000 ohms	100 ohms	5	D, E, F, G, H	1432-9725	**$229.00**
1432-Z	11,111,100 ohms	10 ohms	6	C, D, E, F, G, H	1432-9726	**262.00**

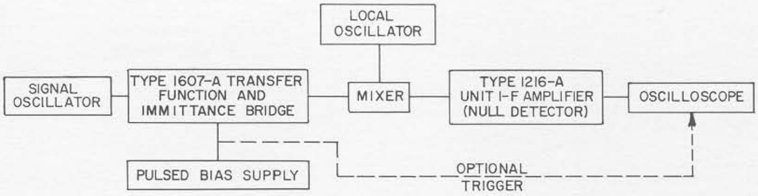

Figure 1. Block diagram of the measurement system, showing bridge, pulsed bias supply, and oscilloscope.

MEASUREMENTS ON POWER TRANSISTORS WITH THE TRANSFER-FUNCTION BRIDGE

The measurement of the impedances and other characteristics of transistors at very-high and ultra-high frequencies can be carried out under normal operating conditions with the Type 1607-A Transfer-Function and Immittance Bridge. With some power transistors, however, the heat to be dissipated creates a problem, because it is not always convenient to provide a heat sink for the transistor while it is being measured.

At our suggestion, a number of users of the bridge solved the problem by pulsing the bias supply to the transistor, permitting higher power levels to be used without excessive heating. (See Figure 1.)

Pulsing prevents the use of the meter indication of null balance on the Type 1216-A Unit I-F Amplifier, because of the two different impedance states, bias-off and bias-on. Therefore, an oscilloscope, connected to the video output terminals of the i-f amplifier, is used as the null indicator, and the null is adjusted at the bias-on portion of the pulse.

Figure 2 shows a pulsed bias supply as used by Clark Division, National Semiconductor Corporation. Similar circuits have been used by other manufacturers.

Transistors in the double-ended stud package, TO-3, or TO-8 package, for example, can be measured by use of this pulse technique. We have recommended that a General Radio Type 1607-P201 triode tube mount be modified to accept these larger packages. In the version used by Clark, a Jettron model 74-026 socket was fitted into the tube mount after the tube socket was removed. The emitter lead was grounded

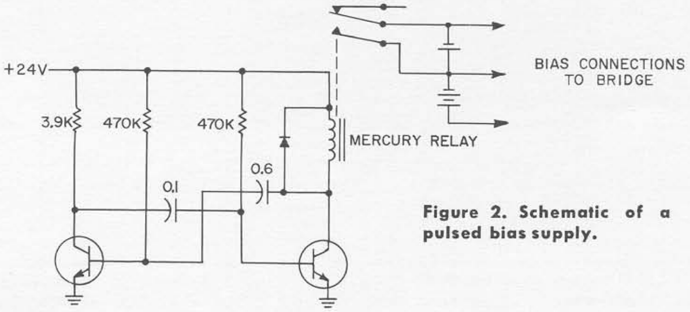

Figure 2. Schematic of a pulsed bias supply.

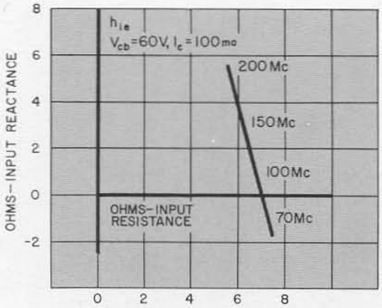

Figure 3.

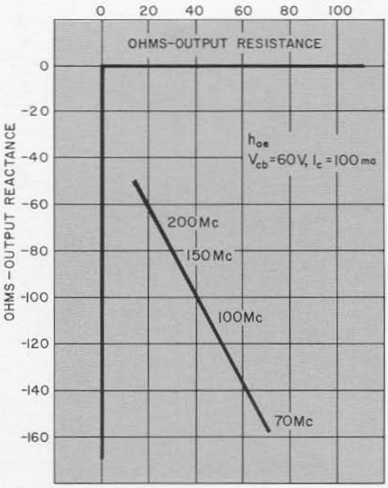

Figure 4.

with a copper strap. The base and collector leads were brought over to the normal connections within the coaxial lines. A Ferroxcube choke coil (#VK 200 10/3B) was also connected between the base lead and the feedthru capacitor supplied in the mount. This allowed the connection of a 0.5-μf capacitor across the external bias connections on the mount to stop low-frequency oscillations, which may occur at certain settings of the bridge. In addition, the leads from the emitter-base supply were kept as short as possible in order to prevent parasitic oscillations.

Typical results for the Clark 100-series transistors are shown in Figures 3 and 4.

NOTE: We are indebted to S. W. Daskam Manager, Applications Division, National Semiconductor Corporation, Clark Division, for much of the information in this article.

— Editor

View of the recently remodeled plant of Ing. S. and Dr. Guido Belotti at Piazza Trento 8, Milan, Italy. The firm of Belotti have been sales representatives for General Radio products in Italy since 1930. Inset shows Dr. Guido Belotti.

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IEEE–1964

Opening March 21 at the Coliseum, New York — the electronics industry's largest and oldest show. Simultaneously, at the Hilton Hotel, other electrical apparatus will be on display.

General Radio will be at the Coliseum as usual. As in past years, the GR booth will be on the third floor, directly opposite the escalator. This will be the thirtieth year that General Radio has exhibited its wares at this show, having participated in every scheduled annual IRE exhibit since the first one was held in 1930.

Not surprisingly, surveys have shown that the primary attraction for most engineers is the third-floor exhibit of instruments and test equipment. Measurement and test are basic to both science and industry, and each year's show brings new tools to aid the busy engineer.

FIVE NEW FOR '64

GR will show four brand-new instruments, plus one not seen previously at this show: A frequency synthesizer, a tone-burst generator, a standard-frequency oscillator, a megohm bridge, and an electric-wave analyzer. These new devices are supplemented by many recently announced products, most of which you have read about in the *Experimenter*, plus others from General Radio's extensive line of over 900 cataloged items. All are described briefly on the following pages. Complete descriptions of the new instruments will appear soon in the *Experimenter*.

So, come to the greatest electronics show on earth, and be sure to drop in at Booths 3201 to 3208 for a closer look at GR's new and up-to-date instruments. Our development and sales engineers will be on hand to help you.

A Glimpse of the Future

Booths 3201-3208
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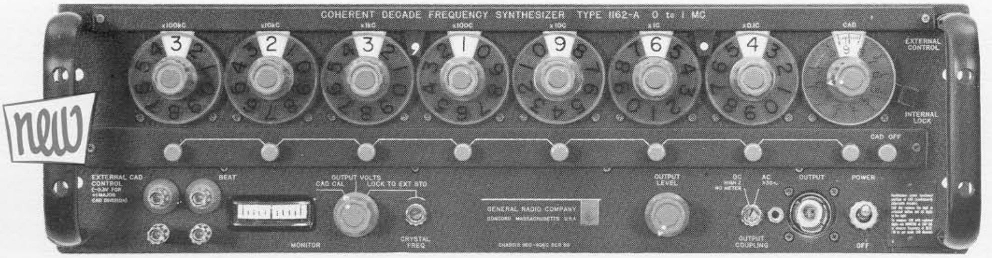


COHERENT DECADE FREQUENCY SYNTHESIZERS

TYPE 1161-A and TYPE 1162-A

The new General Radio frequency synthesizers combine the simplicity and resettability of step adjustment with the convenience of search and comparison provided by continuous adjustment.

The Type 1162-A Coherent Decade Frequency Synthesizer supplies known frequencies from 0 to 1 Mc in step increments as small as 0.1 cps and includes also a continuously adjustable decade that can be switched in beyond the smallest discrete step or at any point in the digit series. The Type 1161-A is nearly identical, except that its maximum frequency is 100 kc and its smallest discrete step is 0.01 cps.

Heart of each of the new synthesizers is a set of seven identical plug-in modules, called DI (for digit-insertion) units, operating from a built-in 5-Mc, room-temperature, crystal oscillator. For maximum accuracy, this oscillator can be phase locked to an external frequency standard operating at 5 Mc or any submultiple thereof, such as the Type 1115-B Standard-Frequency Oscillator.

The continuously adjustable decade (CAD) develops a frequency whose major portion (some 90%) is derived from the crystal oscillator. The remainder is produced by a stable, free-running oscillator. The resultant frequency can be quickly standardized by comparison with the output of the DI units.

Operation of the synthesizers is simple and straightforward. The seven rotary switches on the DI units are set so that the desired frequency is indicated by the rear-lit, in-line dials. Comma and decimal point are included in the read-out. To replace any digit, and those following it, by the CAD, one simply pushes a button below that decade. Only those digits that are in circuit are illuminated. When used to supplement the frequency determined by the digital setting, the CAD can, theoretically, be set to a resolution of better than 0.0001 cps in the Type 1162-A and 0.00001 in the Type 1161-A. Practically, of course, the usable resolution is determined by the oscillator stability and the time interval of interest.

Output voltage, indicated by a front-panel meter, is adjustable up to 2 volts into 50 ohms. Both ac and dc output coupling means are provided. The panel meter is also used to indicate phase-lock to an external standard and as a zero-beat indicator to calibrate the CAD against any selected series of frequency digits set on the DI dials.

The frequency of the CAD can also be varied by an externally introduced voltage for sweeping, fm modulation, or phase-locking to external signals. The external-control input is dc coupled. Frequency markers can be derived from the calibration circuitry. The output frequency is readily applied to automatic recording of the frequency response of networks and the frequency drift of oscillators.

In addition to the main output of the synthesizer, several other useful outputs are provided: 100 kc, 1 Mc, 5 Mc, 42 Mc, 50 Mc, 5.0-5.1 Mc, 50-51 Mc, and 18 volts dc.

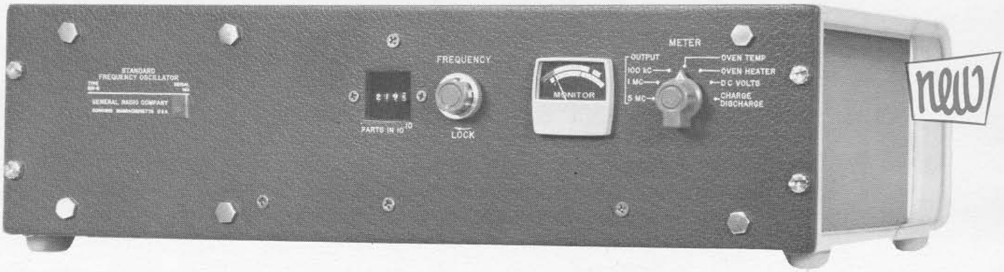
Each synthesizer is available complete with all seven DI units (A-models) or in a stripped-down version (A3C-models) with only the first three digits installed. Other digits can be added to the latter when desired. The continuously adjustable decade is included in each version, so that 6-figure resolution can be achieved in the stripped-down models. You may buy only as many digits as you need.

Small and compact (5¼-inch rack panel), each synthesizer includes a power supply for line operation. Battery operation is also possible, with a single battery supplying 22 to 28 volts.

Type	*Max f*	*Digits*	*Price**
1162-A	1 Mc	7	To be announced at our booth
1162-A3C	1 Mc	3	
1161-A	100 kc	7	
1161-A3C	100 kc	3	

* YOU WILL BE PLEASANTLY SURPRISED.

TYPE 1115-B STANDARD-FREQUENCY OSCILLATOR



This new crystal oscillator combines high stability with the physical ruggedness necessary to withstand vibration and shock. It uses a 5-Mc, 5th-overtone crystal in an all-solid-state circuit of silicon transistors. Both crystal and circuit are held at constant temperature by a proportionally controlled oven. Fiberglas-epoxy etched circuits, cased transformers, and Mil grade electrolytic capacitors make the unit acceptable for many military and government applications.

Sine-wave output is available at 5 Mc, 1 Mc, and 100 kc, each 1 volt into 50 ohms.

Power supply is 90–130/180–260 volts at 40 to 1000 cps or 24 to 35 volts dc. A nickel-cadmium battery is floated across the internal dc supply. In the event of power failure, the battery will operate the standard up to 35 hours.

- Stability: Frequency variations with load or voltage are of the order of 1 or 2 parts in 10^{11}. Temperature effects are less than 1 x 10^{-11} per degree C.

- Spectral Purity: Line width at the 2000th harmonic (10 Gc) is 0.25 cps.

- Aging: Less than 5 in 10^{10} per day after 30 days; less than 1 in 10^{10} is typical after one year.

Price: **$2050.00**

TYPE 1900-A WAVE ANALYZER

This new heterodyne-type wave analyzer has many features that recommend it to the modern electronics laboratory, among them:

- Wide frequency range — 20 to 54,000 cps.
- Three bandwidths — 3, 10, and 50 cps.
- Two recorder outputs — dc and 100 kc.
- 80-db dynamic range for 100-kc output.
- Input impedance of one megohm for all ranges.
- Self-contained voltage-calibrating system.
- 30 microvolts to 300 volts, full-scale.
- Three meter speeds for easier noise analysis.
- Linear frequency scale for optimum tuning characteristics over full range.
- A 3-position function switch selects any one of three modes of operation:

  NORMAL — The filtered input component is available at the output jack.

  AFC — Same as NORMAL, but with afc added to hold analyzer in tune despite small drifts in frequency.

  TRACKING GENERATOR — The output is a sine wave, tunable over the 54-kc range and always in tune with the analyzer. Thus, the analyzer can be used as both generator and detector, simultaneously.

Four quartz crystals are used in the 100-kc i-f filter to achieve the desired selectivity.

The 80-db dynamic range of the 100-kc output makes possible many measurements with a graphic level recorder that are not possible with most analyzers.

The features of a large, mirror-backed meter, in-line frequency readout, excellent frequency settability, high frequency stability, and a quick calibration test make the analyzer exceptionally easy to use.

The Type 1900-A Wave Analyzer will be described in an early issue of the *Experimenter*. It is available in bench or relay-rack mount and, assembled with the Type 1521 Graphic Level Recorder, as the Type 1910-A Recording Wave Analyzer.

Price: **$2150.00**

TYPE 1396-A TONE-BURST GENERATOR

The Tone-Burst Generator is a unique instrument, which, when fed from an external oscillator, generates pulses, or bursts, of the input frequency. It is useful for testing the time response of ac circuits and for simulating the pulsed ac signals commonly used in audio and ultrasonic equipment, such as sonar.

In addition to its many applications in the direct measurement of sonar transducers and amplifiers, it has been used as a generator for bridge measurements where high peak power is needed but average power must be kept within the dissipation capabilities of the bridge arms. Other important applications are in the measurement of loudspeaker transients and of room acoustics.

The input-signal frequency range is dc to 500 kc. The number of cycles in the burst and the time interval between bursts are adjustable by front panel controls. Burst duration (open gate) and closed-gate intervals can be 2, 4, 8, 16, 32, 64 and 128 cycles or 1, 3, 7, 15, 31, 63 and 127 cycles. Closed-gate intervals can also be set from one millisecond to 10 seconds in one-period increments. Open and closed intervals are independent.

The output burst is coherent, i.e., both the starting and ending phase of the burst is invariant from pulse to pulse. The starting and ending phase is adjustable by front-panel controls over a range of 0 to 360°. A description will appear in an early issue of the *Experimenter*.

Price: **$490.00**

TYPE 1644-A MEGOHM BRIDGE

This new megohm bridge, which replaces the venerable Type 544, has many new features that will recommend it to those who measure high resistance, insulation resistance, volume resistivity, and capacitor leakage:

- Ten decade ranges to measure resistance values from 1000 ohms to 1000 teraohms (10^3 to 10^{15} ohms).
- 1% accuracy to 10^{13} ohms.
- $\triangle R$ dial with ±5% range for measurement of small differences to 0.1% — can be used for matching resistors and for voltage-coefficient measurements.
- Self-checking circuits allow quick intercomparison of all internal resistance standards against those of lowest value, which are GR precision wirewound units. Adjustable trimmers are provided for the three highest-value resistance standards to keep them in agreement with the more stable lower-value standards.
- High-sensitivity null detector with electrometer-tube input provides excellent resolution.
- Seven test voltages from 10 volts to 1000 volts in 1-2-5 steps. For any intermediate values, one simply plugs an external resistor into panel binding posts.
- Ratio arms of bridge circuit have 100:1 ratio, so voltage across unknown varies less than 1% as balance control is turned over its full range (versus 10% in Type 544-B).
- Highly regulated power supply and quick charging and discharging circuits are provided for leakage measurements on capacitors.
- Guarded for two- and three-terminal measurements on grounded or ungrounded unknowns located either at bridge terminals or at considerable distances with connection through shielded cables.
- Flip-Tilt case provides both portability and optimum viewing angle.

Price: **$625.00**

. . . and see these recently announced products

TYPE 1564-A
Sound and Vibration Analyzer

Continuously variable, 2.5 cps to 25 kc in four decade ranges; $\frac{1}{3}$-octave and $\frac{1}{10}$-octave band pass. Can be driven by Type 1521 Graphic Level Recorder for automatic recording of sound and vibration spectra. See *Experimenter*, September–October, 1963.

TYPE 1862-C Megohmmeter

Direct-reading to 2,000,000 megohms at a test voltage of 500 volts and to 200,000 megohms at 100 volts. For rapid measurements of resistors and insulation resistance. See *Experimenter*, July, 1963.

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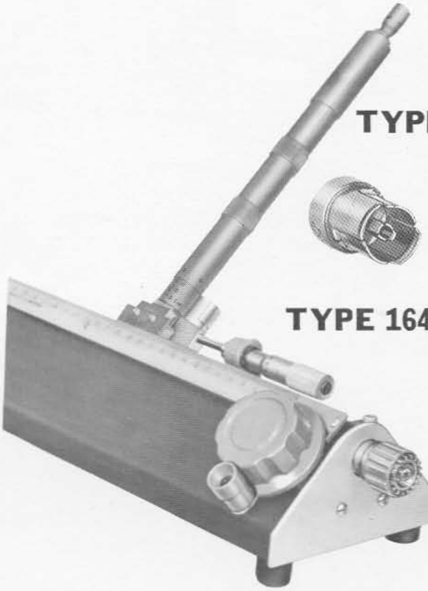
TYPE 900 Precision Coaxial Connectors and Elements

Low VSWR (<1.002 to 1 Gc, <1.01 to 9 Gc), low loss, low leakage. Precision-built for standardization and other exacting requirements. See *Experimenter*, February-March and November, 1963.



TYPE 874 Coaxial Elements

General Radio's well known line of connectors, fittings, attenuators, terminations, filters, lines, and line stretchers, with adaptors to most other commonly used types.

TYPE 1640-A Slotted Line Recorder System

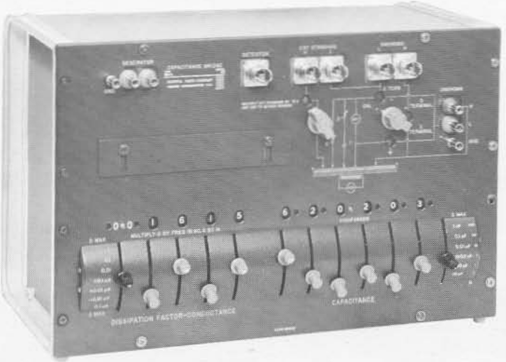
A precision slotted line, Type 900-LBA, with a modified Type 1521 Graphic Level Recorder for the automatic plotting of VSWR on 4-inch chart paper. Sensitivity can be set to correspond to full-scale values of VSWR from 1.008 to 1.20. See *Experimenter*, November, 1963 for a description of the slotted line. The complete system will be described in an early issue.

TYPE 938-G, -H, -J Binding Posts

Binding-post body and stud are copper to minimize thermal emf to copper wire. Copper parts are gold plated to maintain low and constant connection resistance. Tops, either metal or insulated, have double-hexagon (12-point) shape for easy finger tightening and to fit common 12-point socket and box wrenches.

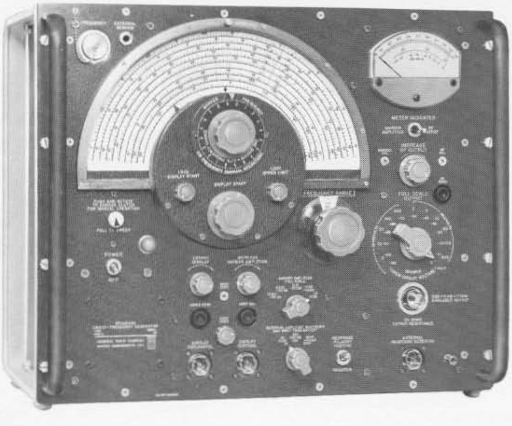
TYPE 1615-A Capacitance Bridge

Measures 2-terminal and 3-terminal capacitance from 10^{-17} to 10^{-6} farads (10 attofarads to 1 microfarad) with a resolution of 1 in 10^6 and an accuracy of 0.01% over most of the range; also measures loss as either dissipation factor or conductance. See *Experimenter*, August-September, 1962.



COUNTERS

The new, improved Type 1150-B Digital Frequency Meter (10 cps to 400 kc) and the Type 1151-A Digital Time and Frequency Meter (dc to 400 kc), supplemented by the Type 1136-A Digital-to-Analog Converter and the Type 1137-A Data Printer. See *Experimenter*, April, 1962, June, 1963, and December, 1963.



TYPE 1025-A
Standard Sweep-Frequency Generator

A standard-signal generator with swept-frequency or cw output — accurately known output voltage; marker calibrated and adjustable in frequency and amplitude; 0.7 to 230 Mc in ten bands, plus two bandspread ranges. See *Experimenter*, January 1963.

TYPE 1308-A Audio Oscillator and Power Amplifier

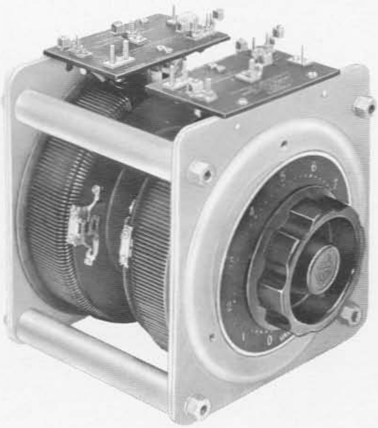
A 20 cps-to-20 kc generator for frequency changing and for measurements at high power levels. Full-scale output ranges of 4, 12.5, 40, 125, 400 volts, rms; 0.5, 1.6, 5 amperes; in any combination up to 200 va. See *Experimenter*, January 1964.

TYPE 1806-A Electronic Voltmeter

A peak-responding instrument accurate to 2% of indication (*not* full scale) usable up to 1500 Mc (±2 db). Ac, dc, and ohms scales; voltage scale is logarithmic. Probe is new design, with accessory tips, ground clips, etc. Available in Flip-Tilt case or on relay-rack panel. See *Experimenter*, July 1963.

TYPE 1608-A Impedance Bridge

A precision *R-L-C-G* bridge with 0.1% accuracy, digital readout, automatic decimal-point location, and illuminated indication of the units of measurement. Internal oscillator and detector for 1-kc operation; modules for other frequencies can be supplied. See *Experimenter* for March, 1962.



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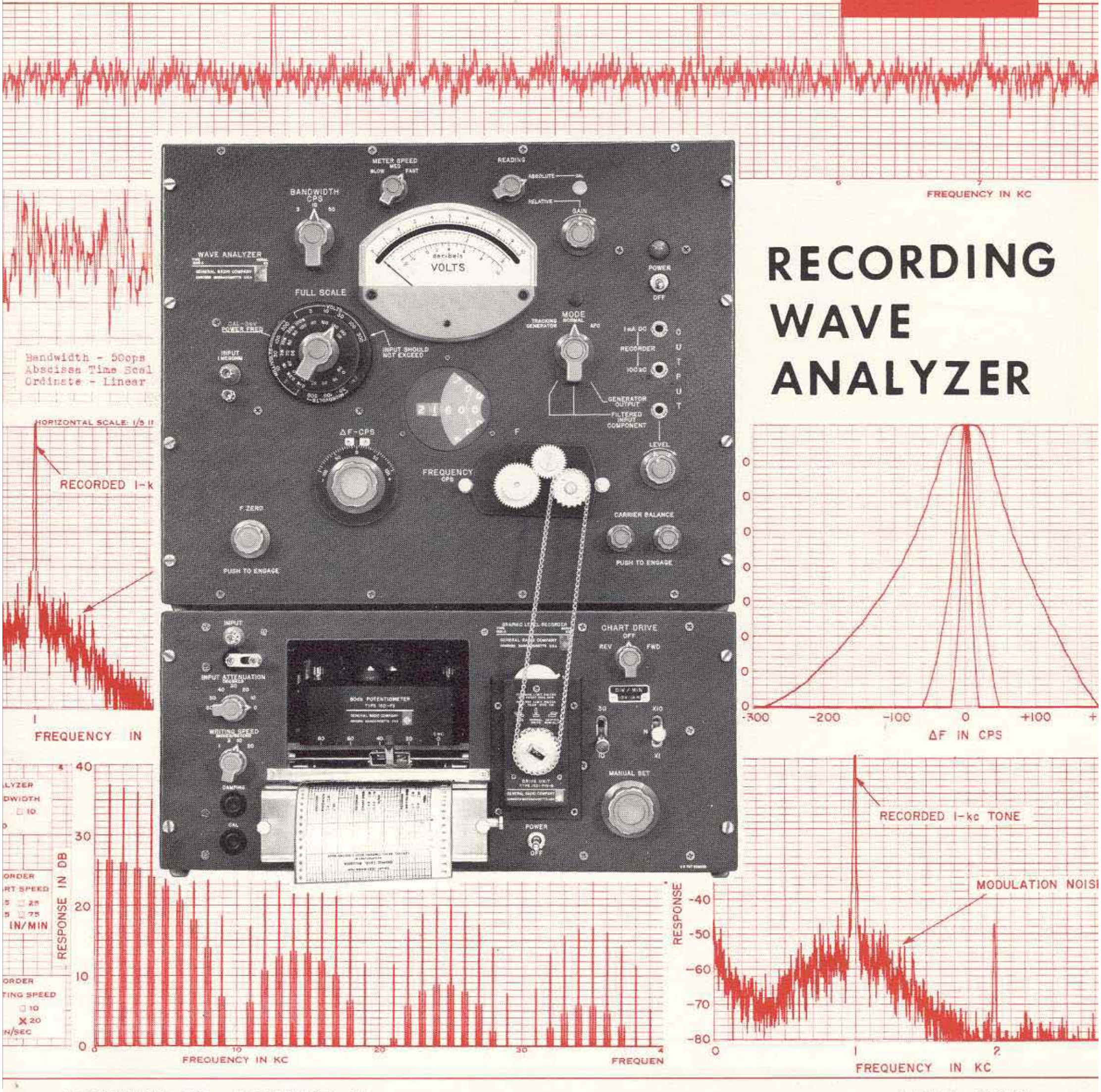

RECORDING WAVE ANALYZER

VOLUME 38 NUMBER 4 APRIL 1964

IN THIS ISSUE

Figure 1. Panel view of the Type 1900-A Wave Analyzer.

NEW WAVE ANALYZER HAS 3 BANDWIDTHS, 80-DB DYNAMIC RANGE

The new Type 1900-A Wave Analyzer, shown in Figure 1, is one of the most versatile measuring instruments ever devised.

In its primary function as an electric-wave analyzer or selective voltmeter over the range from 20 to 54,000 cps, it provides three different bandwidths — 3, 10, and 50 cps — and a wide sensitivity range to cover a variety of spectrum-analysis requirements.

Its three meter speeds, together with the three bandwidths, make it exceptionally useful for noise analysis.

CONTENTS OF THIS ISSUE

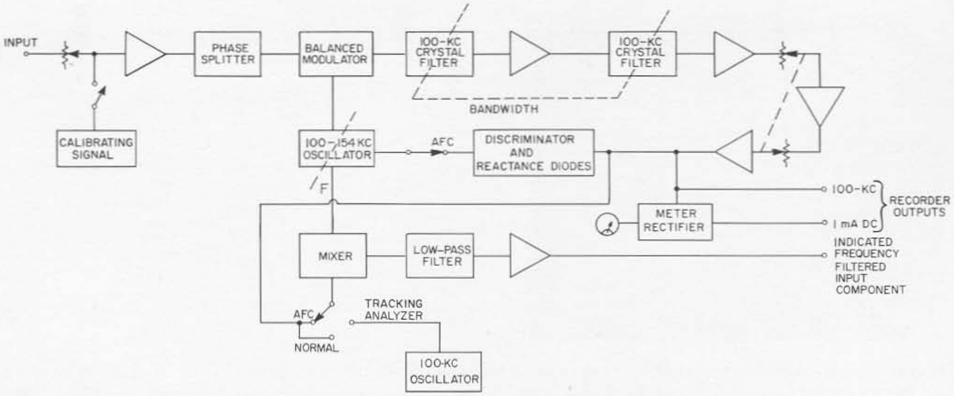

Figure 2. Block diagram of the analyzer.

The linear frequency scale, the three bandwidths, and a high-level, 80-db-dynamic-range output make the combination of a TYPE 1521 Graphic Level Recorder and TYPE 1900-A Wave Analyzer a recording analyzer of outstanding usefulness. Another output for use with 1-ma dc recorders is also included.

The analyzer also functions as a tunable filter, and it has a generator output that tracks the tuning of the analyzer, thus providing both a power source and a tuned-voltmeter detector for network measurements.

The additional features of a large, mirror-backed meter, in-line frequency readout, precise frequency settability, excellent frequency stability, a constant one-megohm input impedance, automatic frequency control, and a quick calibration test make the analyzer easy to use.

DESCRIPTION

General

The TYPE 1900-A Wave Analyzer is a heterodyne type of analyzer. As can be seen from the block diagram, Figure 2, the main filter is a 100-kc quartz-crystal filter. Any frequency in the range from 20 to 54,000 cps can be heterodyned with the local oscillator, which is tunable from 100 to 154 kc, to produce a 100-kc difference frequency, which is applied to the filter. The amplified output of the filter drives a metering circuit and supplies a voltage for recording.

This basic analyzing system is arranged to include the features necessary for a wide variety of measurement applications; these important features will be described in relation to typical applications.

INPUT CIRCUIT

The input control for the instrument is a constant-input-impedance, 1-megohm attenuator. A 54-kc low-pass filter in the input amplifier reduces the response to signals beyond the operating frequency range of the instrument. This filtering is essential to minimize responses at the 100-kc filter frequency and at image frequencies. These responses could otherwise lead to serious errors, particularly in the measurement of wide-band noise.

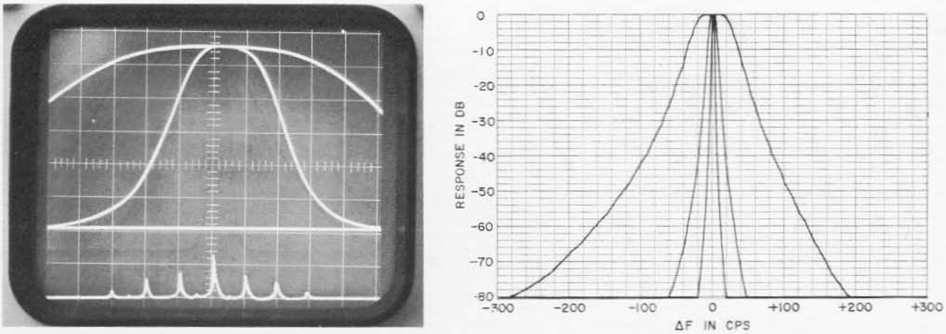

Figure 3 (*right*). Filter characteristics for the three bandwidths (3, 10, and 50 cps) as plotted automatically on the Type 1521 Graphic Level Recorder. (*left*) Photo of trace on storage oscilloscope, showing detail of 3-cycle and 10-cycle bands. Frequency source was a Type 1162-A Coherent Decade Frequency Synthesizer. Markers are 1 cps. Vertical scale is linear.

LOCAL OSCILLATOR

The oscillator uses the series-tuned Vackar circuit[1] with a large, high-Q, universal-wound coil and stable capacitors to achieve a high degree of frequency stability. The frequency-control capacitor of the oscillator is shaped so that the frequency is a linear function of the dial rotation. The linear scale makes possible the use of a combination of dial and counter to get high resolution and an in-line readout. But, more importantly, when the analyzer is tuned manually, this linearity makes the transient behavior the same over the full range of the dial. When a recording is made and the dial is driven at a constant rate, the behavior is again uniform, and the fastest speed of sweep suitable for a given bandwidth is appropriate over the full frequency range. The resulting chart has a linear frequency scale, which has important advantages for analysis. This feature will be discussed more fully below.

The series tuning arrangement of the oscillator circuit has made possible a new circuit for a calibrated cycles-increment control that is useful over the entire tuning range of the oscillator. This control covers the range of ±100 cps with respect to the setting of the main frequency-control dial. The cycles-increment control is particularly helpful when the 3-cycle bandwidth is used in the measurement of components that are closely spaced in frequency, as for example, low-frequency side-band components about a carrier. It is also useful as a vernier adjustment during recording.

QUARTZ-CRYSTAL FILTER

The use of four low-temperature-coefficient quartz crystals has made possible the development of a filter that can be switched to three different bandwidths and which has excellent characteristics over a relatively wide range of ambient temperatures. The bandwidths selected are 3, 10, and 50 cps, which are adequate for almost any analysis problem. Typical , response characteristics are shown in Figure 3.

The importance of being able to select any one of three bandwidths is easily demonstrated by some simple examples. If the components in the spectrum to be measured are only 10

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[1] J. K. Clapp, "Frequency Stable LC Oscillators," *Proceedings of the IRE*, August, 1954.

cps apart, the selectivity of the 3-cycle bandwidth is essential; the 10- and 50-cycle bandwidths would not adequately separate the components. If the components are spaced farther apart, the broader bandwidths should ordinarily be used, because any frequency instability of the incoming signal is then less troublesome. For example, in a measurement of the distortion of a tape recorder, the flutter may make the pointer of the analyzer meter fluctuate violently as an attempt is made to tune in the component in a narrow band, and no satisfactory measurement is possible. But the 50-cycle bandwidth will tolerate the fluctuations encountered in any good tape recorder, and the measurement is easy.

Time saving is another important advantage of the wider bandwidths. The speed with which a given frequency range can be swept varies in the limit as the square of the filter bandwidth. Thus, if the 50-cycle bandwidth provides adequate resolution, the effective response speed over a given frequency range can be as much as 25 times as fast as it is for the 10-cycle bandwidth. This increased speed can be very important in recording, but it is also both useful and apparent when the analyzer is tuned by hand. For noise signals, the differences in time required for analysis by the different bandwidths are even more significant. This point is discussed further in the section on noise analysis.

Figure 4. View of the Type 1910-A Recording Wave Analyzer, consisting of the Type 1900-A Wave Analyzer and the Type 1521 Graphic Level Recorder.

VOLTAGE CALIBRATION

A voltage from the power line is clipped and compensated to provide a component at the fundamental power-line frequency whose amplitude is essentially constant over a wide range of input voltage and ambient temperature. This fundamental component is used as the reference calibrating signal, so that the sensitivity of the instrument can be easily checked at any time. The calibrating signal is always at the power-line frequency so that it can be located without difficulty.

OUTPUTS FOR RECORDING

The new analyzer has a number of outputs, two of which are specifically provided for recording purposes. The most important is the 100-kc filtered-and-amplified signal for driving the Type 1521 Graphic Level Recorder. This output has an 80-db dynamic range and enough power so that the full capabilities of the recorder can be utilized, and the recorder and the analyzer, shown in Figure 4, make a remarkably useful combination, which is available as the TYPE 1910-A Recording Wave Analyzer.

Dynamic Range

The 80 db or more of dynamic range in the filtered output is obtained for signals of 0.3 volt or higher. The term "dynamic range" is used here to signify the linear range from maximum output to the noise level without readjustment of the controls. This range in many other instruments is significantly less than the analysis range one obtains by resetting the attenuator that controls the meter reading. In this analyzer the two are similar, since the meter attenuator covers a 70-db range, which combines with a 20-db range of the meter to give a 90-db analysis range.

Writing Speed and Bandwidth

When the output of the analyzer is recorded, much detailed information about the spectrum of a signal can be obtained automatically. The detail that can be obtained is illustrated by the charts reproduced in Figure 5. In one instance more than 3400 components of a particular signal were recorded, and each of the components was clearly defined.

Such a recorded analysis can proceed with little attention after it is once set up. But it often pays to consider carefully how the analysis should be done, because the time required varies greatly with the bandwidth and with the recorder characteristics. When a periodic

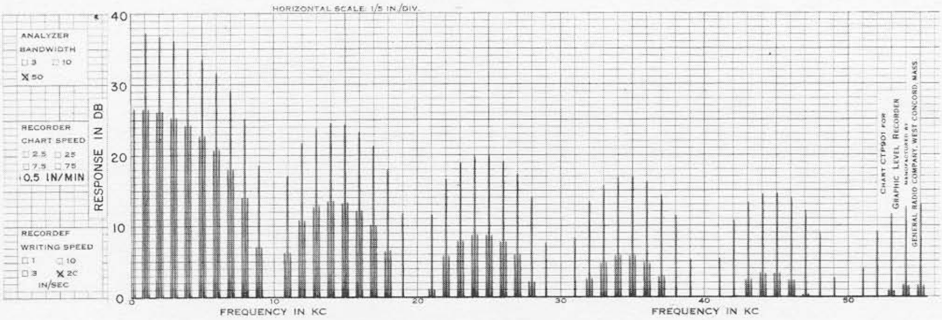
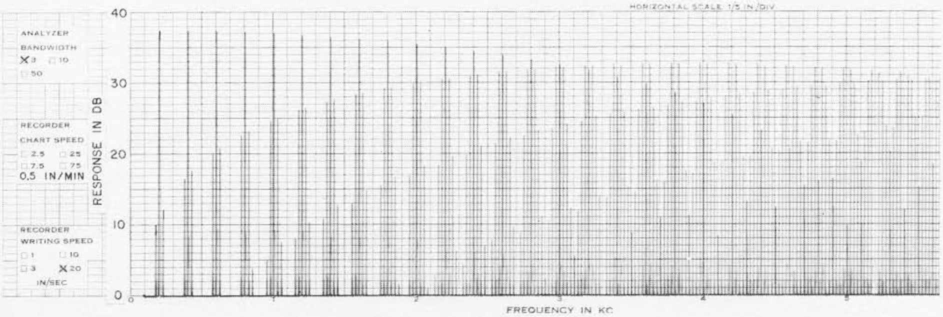


Figure 5. Plots of pulse waveforms made on the recording analyzer: (a, *above*) 100-μsec pulse at 1-kc repetition rate. Pulse was amplitude modulated from ¼ to full amplitude by a 200-cycle, non-coherent sine wave. (b, *below*) 20-μsec pulse at an average repetition rate of 200 cps. The pulse was position modulated at a 25-cycle rate.



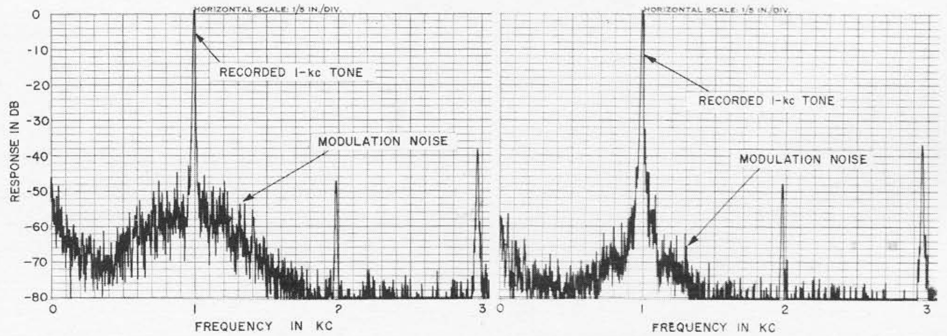


Figure 6. Charts of modulation noise on a 1-kc tone for two different types of magnetic tape. Note that one is about 10 db better than the other. Such measurement can be made easily with the recording analyzer, owing to the 80-db dynamic range. For these records, chart speed was 2.5 inches per minute; writing speed, 10 inches per second; bandwidth, 10 cps.

signal is analyzed, the recorder's fastest writing speed should be used to speed up the recording. Its fast writing speed makes the Type 1521 Graphic Level Recorder particularly useful.

The widest bandwidth that provides adequate selectivity should also be used, since the inherent response time of the filter is inversely proportional to the bandwidth. Here the three bandwidths make possible a near-optimum choice for most analyses. The time required to analyze over a 25-kc range is approximately 2 minutes, 20 minutes, and 2 hours for the 50-, 10- and 3-cycle bandwidths, respectively.

Linear Scale

The recorded display from the Type 1900-A Wave Analyzer is linear in frequency. This linear display has the important advantage that harmonic components of a periodic signal are uniformly spaced, so that the harmonic relations are obvious. If the signal is more complex, for example, a modulated carrier or other combinations of signals, where there are component frequencies that are sums and differences of other component frequencies, such relations are also readily apparent on a linear frequency scale.

DC Output

The second output for recording is in series with the indicating meter so that a simple, 1-ma dc recorder can be used. This arrangement provides a convenient method of recording, but the recording is seriously limited in speed and in dynamic range, compared to the one made from the 100-kc output.

NOISE ANALYSIS

Meter Speed

The new analyzer is well suited for the analysis of noise. The slow meter response is one essential feature, and the choice of bandwidths and the linear frequency scale simplify many noise analyses.

Three different meter speeds are provided. The fastest time constant is essentially that of the meter alone, about 1/6 second. This speed is always used for measurement of components of periodic signals. The slowest time constant provided is about 5 seconds, and this and the intermediate value are used for noise measurements. The im-

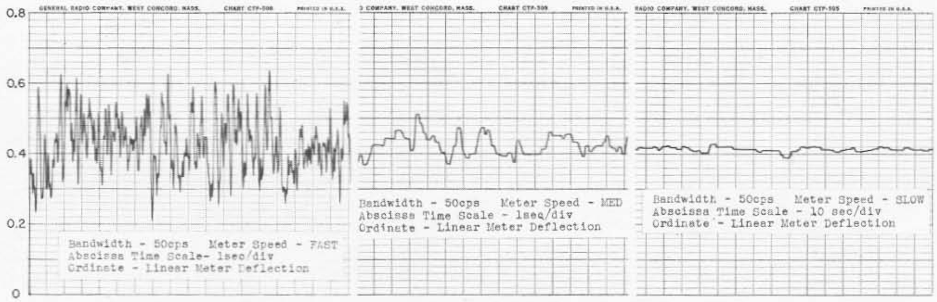


Figure 7. Chart of analyzer meter current (dc output) as a function of time for random noise, with 50-cycle bandwidth, as recorded with FAST, MEDIUM, and SLOW meter switch settings.

portance of these slower responses for noise measurement can be readily appreciated when the problems associated with noise analysis are reviewed.

The indicated meter reading produced by an applied random-noise signal, whether it is electrically generated noise or acoustic noise transformed by a microphone into an electrical signal, fluctuates considerably. These fluctuations reflect the irregularities in the process of noise production. In fact, all signals contain some random-noise energy, and many contain enough so that the indication is not at all steady.

The charts of Figure 7 show graphically the behavior of the pointer of the indicating instrument as a function of time when samples of the same random noise were measured with the 50-cycle bandwidth and the three different meter speeds. It is clear that the average value is essentially the same for each sample, but the fluctuations are markedly greater for the faster meter speeds than for the slow one, and these differences are inherent in the nature of the measurement. It is obviously much easier to obtain a good estimate of the average value with the slow meter speed. The charts illustrate also that a maximum or minimum reading for a noise signal has little significance. The extent of the fluctuations does have some significance, however, with regard to the statistical estimate of the confidence to be given to the selected average value.[2, 3]

Bandwidth

If the narrower bandwidths are used, the fluctuations are even greater, and only the slower meter speeds can be used to obtain a satisfactory average value. A relatively simple principle applies here. The narrow bands are used to get fineness of detail. The finer the detail that is desired, the more time is needed to obtain the result to a certain degree of confidence. The averaging time required is essentially inversely proportional to the bandwidth.

If the analyzer is swept through a range of frequencies in order to observe the spectrum, it is necessary to stay in each bandwidth along the frequency span long enough to get a satisfactory measurement. This factor combines with the averaging time to make the required total sweep time inversely proportional to the square of the band-

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[2] R. B. Blackman and J. W. Tukey, *The Measurement of Power Spectra*, Dover, New York, 1958.

[3] R. P. Rona, "Instrumentation for Random Vibration Analysis," pp 7–27 to 7–30 in *Random Vibration*, edited by S. H. Crandall, Technology Press, Cambridge Massachusetts, 1958.

width, again pointing up the importance of having three bandwidths available. If only the detail of the 50-cycle bandwidth is needed, a relatively short time for the analysis suffices. If the detail of the narrower bands is necessary, the required time is correspondingly longer, and a fast scan is useless or, even worse, misleading.

Unless these aspects of noise analysis are understood, one can easily be led into using an analyzer that is entirely unsuitable to the problem, using an analyzer incorrectly, accepting data that are misleading, or even rejecting useful data.

Spectral Density

In order to compare measurements of random noise made with different bandwidths, it is customary to convert the measured value to an equivalent one for a bandwidth of one cycle per second. This equivalent value is often called the spectral density. The conversion for a measurement made on the wave analyzer is simple, because it is independent of the center frequency and depends only upon the particular bandwidth used.

AUTOMATIC FREQUENCY CONTROL

In one mode of operation of the analyzer, the local-oscillator frequency is controlled by the filtered signal by means of a quartz-crystal discriminator and reactance diodes. When a component has been tuned in, it can be locked by means of this automatic frequency control to stay within the pass band of the analyzer over a wider frequency range than the normal pass band. The characteristics of the control circuit, however, limit the rate at which the frequency can change without dropping out of lock to a relatively slow one, and the control circuit is not effective for a noise signal. Thus, whenever possible, it is preferable to use the 50-cycle bandwidth rather than automatic frequency control. If a component is to be observed for a long time and might drift beyond the 50-cycle pass band, the afc is useful in compensating for such a drift.

TUNABLE FILTER

The analyzer also functions as a tunable, selective filter and amplifier. This type of operation is achieved by a second heterodyne operation in which the amplified and filtered signal at 100 kc is beat with the local oscillator to restore the filtered component to its original frequency. The tunable filter has the excellent selectivity characteristics of the particular bandwidth chosen, and the output amplitude is proportional to the component amplitude.

The applications for this mode of operation are generally those for a highly selective filter, for example, separating out an individual component of a complex signal for study. The study may consist of an accurate determination of the component frequency stability by means of a digital frequency meter (counter), or it may simply be determining the existence of a particular component in the midst of interfering components.

If a signal from the Type 1390 Random-Noise Generator is applied to the input of the analyzer, the output will be a narrow band of noise. The center frequency of this noise can be set by means of the analyzer frequency control. When this type of noise is made audible by means of a loudspeaker, it can be used for acoustical transmission

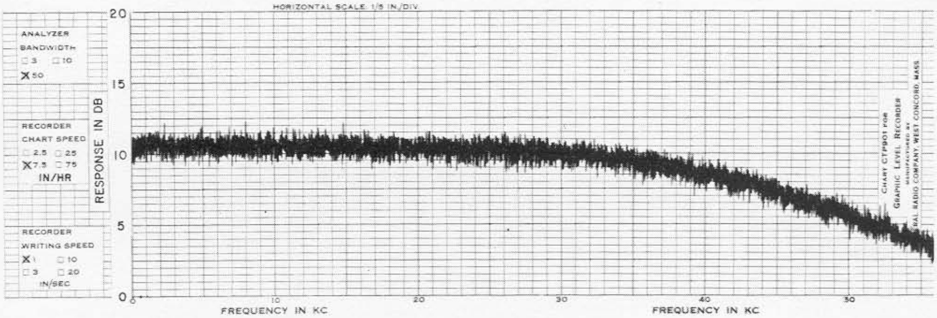

Figure 8. Chart of 0- to 20-kc output of Type 1390 Random-Noise Generator as recorded with 50-cycle bandwidth.

tests, for reverberation measurements, and for some psychoacoustical tests.

TRACKING GENERATOR

In one mode of operation the local-oscillator voltage is heterodyned with a 100-kc crystal-oscillator voltage to produce a beat signal whose frequency is always the same as that to which the analyzer is tuned. As the local oscillator is tuned from 100 to 154 kc, the frequency of the beat signal varies from zero to 54 kc. This beat signal is amplified to provide a maximum of at least 2 volts across 600 ohms. This output can be used to drive a network, amplifier, tape recorder, impedance bridge, or other system to be tested. The output of the device to be tested can then be measured by the analyzer, and the analyzer will stay in tune to the fundamental component as its frequency is varied. In this way the effects of hum, distortion, and noise are essentially eliminated from the measurement.

When an accurately known signal must be applied to the device under test, the output from the generator is sufficient to drive a Type 546-C Audio-Frequency Microvolter. Alternatively, the wave analyzer can measure its own output but, of course, not at the same time as it measures the output of the device under test.

The 100-kc output for driving the Type 1521 Graphic Level Recorder can be used at the same time that the tracking-generator output is used. Thus, the response characteristic of a device can be plotted automatically with the wave analyzer supplying the signal, the detector, and the output for recording.

SUMMARY

The Type 1900-A Wave Analyzer, with its three highly selective filter bandwidths covering the frequency range from 20 to 54,000 cps, its high sensitivity, its high and constant input impedance, its three meter speeds for noise analysis, its linear frequency scale, its tunable filter, its tracking generator, and its afc, provides a new degree of versatility in measuring instruments that will make it one of the most widely used analyzers in electronics.

— Arnold Peterson

CREDITS

The author wishes to acknowledge the many contributions made by others in the design of this instrument and, in particular, the assistance of R. J. Ruplenas in the circuit development. — Editor

TYPE 1910-A RECORDING WAVE ANALYZER

The Recording Wave Analyzer consists of the following items:

- Type 1900-A Wave Analyzer
- Type 1521 Graphic Level Recorder
- Type 1521-P10B Drive Unit
- Type 1900-Pl Link Unit
- 10 Rolls Type 1521-9464 Chart Paper
- 10 Rolls Type 1521-9465 Chart Paper
- Type 1521-P3 80-db Potentiometer*

Both bench and rack models are available. The bench model is shipped completely assembled. The rack model is supplied with supports for installation in a standard 19-inch rack.

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* A 40-db potentiometer is installed in the recorder. The 80-db unit is supplied in addition.

SPECIFICATIONS

TYPE 1900-A WAVE ANALYZER

FREQUENCY

Range: 20 to 54,000 cps. The frequency is indicated on a counter and a dial with a linear graduation, 1 division/10 cps.

Accuracy of Calibration: ± (½%+5 cps) up to 50 kc; ± 1% beyond 50 kc.

Incremental-Frequency Dial (△F): ± 100 cps. Accuracy is ± 2 cps below 2 kc, ±5 cps up to 50 kc.

Automatic Frequency Control: At frequencies below 10 kc, total range of frequency lock is 400 cps for the 50-cycle band and 150 cps for the 10-cycle band, as defined by 3-db drop in response from full-scale deflection. At 50 kc, the lock ranges decrease to one-half these values.

SELECTIVITY: Three bandwidths (3, 10, and 50 cps) selected by switch.

3-Cycle Band: At least 30 db down at ±6 cps from center frequency, at least 60 db down at ±15 cps, at least 80 db down at ±25 cps and beyond.

10-Cycle Band: At least 30 db down at ±20 cps, at least 60 db down at ±45 cps, at least 80 db down at ±80 cps and beyond.

50-Cycle Band: At least 30 db down at ±100 cps, at least 60 db down at ±250 cps, at least 80 db down at ±500 cps and beyond.

Effective bandwidth for noise equal to nominal bandwidth within ±10% for 10- and 50-cycle bands and ±20% for 3-cycle band.

INPUT

Impedance: One megohm on all ranges.

Voltage Range: 30 microvolts to 300 volts full scale in 3, 10 series. A decibel scale is also provided.

Voltage Accuracy: After calibration by internal source, the accuracy up to 50 kc is ±(3% of indicated value + 2% of full scale) except for the effects of internal noise when the attenuator knob is in the maximum-sensitivity position. In that position the internal noise is about 5% of full scale for the 3- and 10-cycle bands and 10% of full scale for the 50-cycle band. From 50 to 54 kc, the above 3% error becomes 6%.

OUTPUT

100-kc Output: Amplitude is proportional to amplitude of selected component in analyzer input signal. With the Type 1521 Graphic Level Recorder connected through the adaptor cable supplied, at full-scale meter deflection output is at least 3 volts. Dynamic range from overload point to internal noise is >80 db with attenuator knob fully clockwise.

Recording Analyzer: The analyzer in combination with the Type 1521 Graphic Level Recorder produces continuous, convenient records of frequency spectra over the complete range of the analyzer. The end frames of the bench models can be bolted together to form a rigid assembly.

DC Output: One milliampere in 1500 ohms for full-scale meter deflection, one side grounded.

Filtered Input Component: Output at least 1 volt across 600-ohm load for full-scale meter deflection with output control at maximum.

Tracking Generator: 20 cps to 54 kc; output is at least 2 volts across 600-ohm load with output control at maximum.

GENERAL

Residual Modulation Products and Hum: At least 75 db down.

Terminals: Input, Type 938 Binding Posts; output, telephone jacks.

Power Requirements: 105 to 125 (or 210 to 250) volts, 50 to 60 cps, approximately 40 watts.

Accessories Supplied: Type 1560-P95 Adaptor Cable Assembly, phone plug, Type CAP-22 Power Cord, spare fuses.

Other Accessories Available: Type 1900-P1 Link Unit for coupling to Type 1521 Graphic Level Recorder.

SPECIFICATIONS (Cont)

Cabinet: Rack-bench.

Dimensions: Bench model — width 19, height 16¼, depth 15¼ inches (485 by 415 by 390 mm), over-all; rack model — panel 19 by 15¾ inches (485 by 400 mm), depth behind panel 13¼ inches (340 mm).

Net Weight: 56 pounds (26 kg).

Shipping Weight: 84 pounds (39 kg).

TYPE 1910-A RECORDING WAVE ANALYZER

Dimensions: Bench model — width 19, height 25¼, depth 15¼ inches (485 by 645 by 390 mm), over-all: rack model — width 19, height 24½ (485 by 625 mm), depth behind panel, 13¼ inches (340 mm).

Net Weight: 116 pounds (53 kg).

Shipping Weight: 190 pounds (87 kg).

Type		*Price*
1900-AM	**Wave Analyzer,** Bench Model	$2150.00
1900-AR	**Wave Analyzer,** Rack Model	2150.00
1910-AM	**Recording Wave Analyzer,** Bench Model (for 60-cycle supply)	3500.00
1910-AR	**Recording Wave Analyzer,** Rack Model (for 60-cycle supply)	3500.00
1910-AMQ1	**Recording Wave Analyzer,** Bench Model (for 50-cycle supply)	3500.00
1910-ARQ1	**Recording Wave Analyzer,** Rack Model (for 50-cycle supply)	3500.00
1521-9464	**Chart Paper,** 0–10 kc, 100-foot roll	2.75
1521-9465	**Chart Paper,** 0–50 kc, 100-foot roll	2.75

USEFUL FORMULAS, TABLES, AND CURVES FOR RANDOM NOISE

Under the above title we have prepared a 6-page publication listing relationships and data that are commonly used in working with random noise. It will be found particularly useful by those who deal with noise phenomena only occasionally and need a handy reference to refresh their memories. Free on request; ask for publication IN-103.

CORRECTION

Several eagle-eyed readers have pointed out that the schematic of a pulsed bias supply for use in transistor measurements (*Experimenter*, February, 1964, page 7) shows that the bias source is shorted when the relay operates. This is quite true, but, as used by Clark Division, National Semiconductor Corporation, who devised the circuit, the shorting does no harm since they use a constant-current bias supply, rather than a battery.

We apologize to our puzzled readers for omitting this fact.

SWIEEECO

This ancient Apache rallying cry stands for Southwestern IEEE Conference and Show, now in its 16th year. General Radio will be there, in booths 301-302-303. On display will be the new instruments shown at IEEE — New York and described briefly in the March issue of the *Experimenter*. General Radio engineers will be on hand to welcome you and to demonstrate the new equipment.

Dallas Memorial Auditorium **April 22-24, 1964**

General Radio Company
WEST CONCORD, MASSACHUSETTS, U.S.A.

PRINTED IN U.S.A.

THE GENERAL RADIO
EXPERIMENTER

A GENERATOR OF AC TRANSIENTS

Tone-burst waveforms are useful signals in many diverse fields of electronics, such as psychoacoustic instrumentation, generation of controlled periodic line transients, and synthesis of the time "ticks" on standard-time radio transmissions. At General Radio, tone bursts have been used in routine tests of filters and ac meters as well as for such unusual purposes as the alignment and test of an instrument for instantaneous frequency analysis of the high-frequency sound emissions of bats.

These waveforms also have many applications in the test and calibration of sonar transducers and amplifiers and in the measurement of loudspeaker distortion and response to transient excitation. Still other uses are found in the measurement of room acoustics, automatic-gain-control circuits, and ac meter response.

Tone-Burst Generation

A tone burst can be generated by a pulse generator, a sinusoidal signal source, and a switch or gate, which, on command from the pulse generator, either passes or blocks the passage of signal from the source. The switching device may be a relay, a motor-driven contactor, a photoresistor-light source combination, a transistor, or a diode bridge. Such a combination generally requires some design and fabrication of components by the assembler and may often be less than satisfactory in convenience, reliability, size, cost, and performance. Performance requirements, in particular, are sometimes more demanding than can be satisfied by a simple timing system, especially in regard to coherence.

Coherence

A coherent tone-burst signal is one in which each burst starts at the same point in the signal being gated or switched, and each burst ends at the same point in the signal cycle. For example, each tone burst might start at the positive-slope zero crossing of the sinusoidal signal, continue for two full

VOLUME 38 NUMBER 5 MAY 1964

IN THIS ISSUE

Measurement of Antenna Patterns
Low-Distortion Oscillator

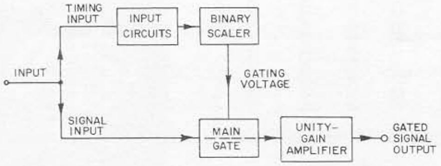


Figure 1. Elementary block diagram of the Type 1396-A Tone-Burst Generator.

cycles, and end at a positive-slope zero crossing. It is obvious that the spacing between bursts must be an exact whole number of signal periods (cycles) in order to maintain coherence. This leads to the conclusion that, to be coherent, a tone burst must be produced from a single autonomous signal. A switch actuated by two independent timers (one controlling the on time, and the other the off time) cannot in practice produce a coherent burst, since the on and off times must be exact multiples of one period of the gated signal, which is a nearly impossible stability requirement. To produce a coherent burst, the gating signals must be locked to the desired subharmonics of the gated signal.

The influence of coherence on performance is demonstrated by analysis of the frequency components in a tone burst, which consist of the fundamental and harmonics of the repetition rate of the tone burst. The expression for amplitude of these harmonics is given in the appendix, below. As an example, Figures 8 and 9 show the amplitude of the first thirty-one harmonics of tone bursts of one cycle on, one cycle off, and of eight cycles on and eight cycles off, respectively. The figures show the spectra for two gating phases of each tone burst. In one case switching occurs at zero crossings, and in the other case switching is at the peak value of the signal. The spectrum varies smoothly between the limits shown as a function of gating phase. The examples indicate clearly that the frequency content of a tone burst depends upon the number of cycles in the burst, the spacing between bursts, and upon the gating phase of the burst. The effects of phase are significant for shorter bursts at short spacings. Therefore, to produce a tone burst with defined characteristics, tight control of phase as well as cycle content is necessary.

For example, consider the case of a burst of exactly eight cycles width, but of uncontrolled phase. The result is that each pulse has constant energy, but the way in which this energy is distributed in the frequency spectrum is not controlled. Unless the tone burst is used in an extremely wide-band system the observed system responses will be inaccurate and not reproducible.

THE TONE-BURST GENERATOR

The Type 1396-A Tone-Burst Generator provides an instrumentation bridge for the gap between continuous-wave testing and step-function, or pulse, testing. A digital method of controlling gating action allows the production of signals that easily meet the requirements of tight control of frequency content and phase. Figure 1 is a block

CONTENTS OF THIS ISSUE

Figure 2. View of the Type 1396-A Tone-Burst Generator.

diagram. Instead of using the common system of timers to establish the off and on times, with a complex locking system to maintain a coherent output, this instrument uses a binary scaler to establish the number of cycles in the burst and between bursts and a simple trigger system to control the phasing. The binary scaler essentially divides the input frequency to the desired subharmonic frequency for gating. A simple reset system allows the same scaler chain to be used for both off and on intervals. The use of binary circuits has resulted in an economical, rugged, and compact instrument, which is quite simple to operate, drift free, and requires no routine maintenance.

The settings of the controls (Figure 2) determine the number of cycles for which the gate will be open and, independently, the number of cycles for which the gate will be closed. The choice offered here by the binary scaler is 2, 4, 8, 16, 32, 64, or 128 cycles. Another control allows the scalers to be started at one instead of zero, which changes the choice of cycle counts to 1, 3, 7, 15, 31, 63, or 127. The scalers then control a simple transistor gate, which operates on the externally applied periodic input signal to produce tone bursts.

Additional features of the Tone-Burst Generator are a switch that holds the gate open for preliminary alignment of external equipment (if necessary); trigger controls, which allow complete control of the phase of the gate and input signal; the ability to use separate input signals for the gate timing and gated signals; and a timed mode for extremely long periods between bursts. In the timed mode, the closed gate interval is set by a one-millisecond-to-ten-second timer, and an internal gate system maintains coherence of gated and gating signal. The timer circuit operates as a locked oscillator and is used for very long intervals where exact cycle count is not required for accuracy. Although sinusoidal input signals are assumed in most of the applications listed below, the instrument will function on any periodic waveforms. If pulses are applied to the Type 1396-A, it performs as a word generator, or frequency divider.

APPLICATIONS

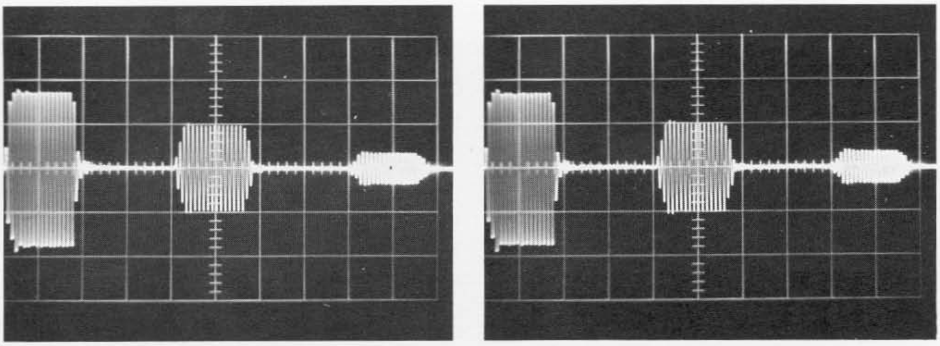
The wide range of applications of the Type 1396-A Tone-Burst Generator is due to the nature of tone-burst signals, which span the two fields of continuous-wave testing and of pulse or step-function testing.

Electro-Acoustical Transducers

One common application for tone bursts is the testing of transducers in an ambient not free of echoes. The tone-burst test techniques can be used to separate direct and reflected signals and to eliminate standing-wave effects. Examples of this are the testing of sonar transducers in a tank that produces reflections and of speakers or microphones in a chamber that produces echoes. With continuous-wave testing, errors in frequency and phase curves can result from the addition of reflected signals to the direct response. Such errors introduce familiar standing-wave patterns in the response curves.

With a tone-burst test signal energizing the transducer, one can separate the direct response and the reflected response by observing the response as a function of time. As an example, two one-inch-diameter speakers were mounted in one end of an eight-foot tube with the opposite end closed. Figures 3a and 3b are the voltage waveforms observed across one speaker when the other is driven with tone bursts of 2.95 kc and 3.0 kc, respectively. Note the large pulse at the left, which is the direct transmission from one speaker to the other. Its constant amplitude indicates that the frequency response is the same at both frequencies. The middle and right-hand pulses are the first and second reflections from the far end of the tube.

Figures 4a and 4b are the voltage waveforms observed across the same



Figures 3a (*left*) and 3b (*right*). Waveforms received by one of two transducers mounted in the end of a closed tube, when the other transducer is driven by a tone burst of (a) 2.95 kc. and (b) 3.0 kc. From left to right, the pulses are the direct response, the first reflection from the tube end, and the second reflection from the tube end. Notice the consistency in amplitude of the direct pulse at the two frequencies; compare with Figures 4a and 4b.

speaker when the other was driven, again, with a signal of 2.95 kc and 3.0 kc, but with the gate of the Tone-Burst Generator held open to produce continuous waves. Note that the reflection phenomena now cause large differences (3:1) in the response of the system at the two frequencies. It would be difficult to determine the true speaker response from the continuous-wave data.

Self-Reciprocity Transducer Calibration

A transducer can be calibrated in terms of its response to its own echo when the transducer to be tested and a rigid reflecting surface are placed in an otherwise anechoic space.[1] The Tone-Burst Generator is a convenient source of excitation signal for such a system.

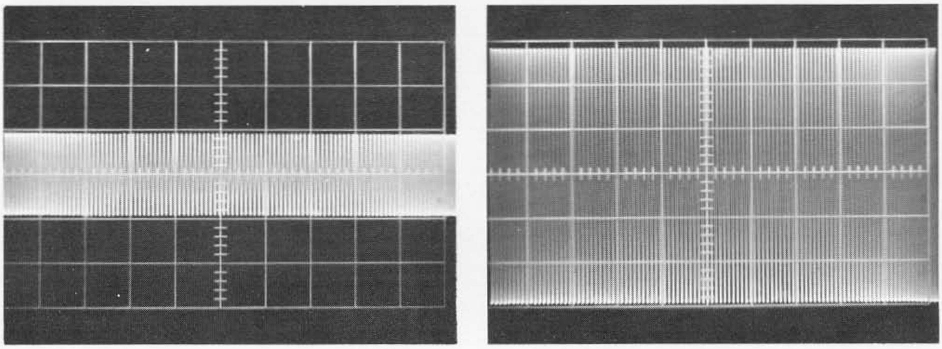
Sonar transducers have been calibrated by a self-reciprocity system with tone-burst excitation of a bridge containing the transducer as the unknown.[2] From two impedance measurements it is possible to calibrate the transducer. A further advantage of tone-burst excitation for the bridge is that high peak power can be applied without danger of exceeding the dissipation limits of the bridge arms.

Amplifier Testing

Tone-burst signals are nearly ideal waveforms for tests of amplifier performance. In sonar circuitry they are used to measure amplifier pulse-envelope distortion, and rise and fall times.

Music Power Tests

Peak-power tests of amplifiers may use tone-burst signals to avoid overloads on the power supplies, with consequent shift in bias points, and also to avoid excessive power dissipation. Music power (peak) output tests of power amplifiers for consumer use require a brief tone burst to be applied and its amplitude increased until 5% distortion is observed.[3] Distortion can be detected by observation of the amplifier output waveform if the distortion level is sharply defined. When an accurate distortion measurement is desired, a dual-channel or differential-input oscilloscope can be used, and the amplifier input subtracted from the output to leave only the distortion products.



Figures 4a (*left*) and 4b (*right*). Waveforms produced in the same manner as those in Figure 3, except that the driving signal is a continuous one of (a) 2.95 kc. and (b) 3.0 kc. The variation of amplitude indicates the presence of standing waves, which obscure the transducer's frequency characteristic.

---

[1] Leo L. Beranek, *Acoustics*, McGraw Hill, 1954, pg 382 ff.

[2] Gerald A. Sabin, "Transducer Calibration by Impedance Measurements," *Journal of the Acoustical Society of America*, Vol 28, No. 4, pp 705-710, July 1956.

[3] *EIA Standard, RS-234-A*, November 1963, "Power Output Ratings of Packaged Audio Equipment for Home Use." Electronic Industries Association, 11 West 42nd Street, New York 36, New York ($ .25).

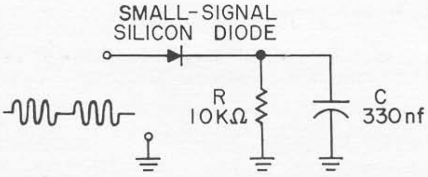


Figure 5a. Example of a simple rectifying circuit tested with a tone burst.

Measurement of Room Acoustics

The reflections produced in a concert hall are determining factors in the acoustical quality of the space. In a test system, a sound source, which may be a pistol shot or a speaker system, is on the stage. A microphone, placed in the seating area, drives the necessary analyzing equipment. Comparisons of pistol-shot and continuous-wave excitation of a hall have shown significant differences in determining reverberation time, a cardinal acoustical property.[4] Such differences indicate that the duration of the exciting signal is important, and, therefore, that a tone burst of controlled properties is desirable.

An excellent discussion of the response of four concert halls (La Grande Salle, Montreal; Clowes Hall, Indianapolis; Symphony Hall, Boston; and Philharmonic Hall, New York City) to tone-burst tests is given by Schultz and Watters.[5]

Testing of Low-Speed Digital Equipment

The Type 1396-A Tone-Burst Generator can operate on any periodic waveform. If square or rectangular waveforms are applied to the instrument, it can generate pulse words at a bit rate determined by the gate settings. Such words are useful in testing digital equipment. For testing binary devices the MINUS ONE setting of the CYCLE COUNTS switch is useful, since it permits testing with words containing an odd number of bits.

Filter Testing

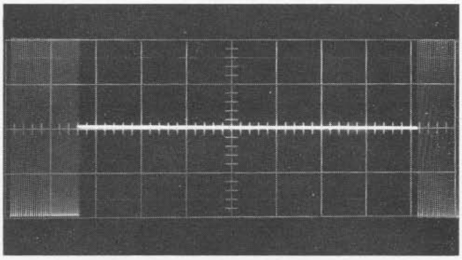
The response of a bandpass filter to a suddenly applied signal in its pass band is a common measurement.

This type of signal cannot be simulated by the usual cw generator, and ordinary pulse waveforms will produce ringing, which is difficult to analyze. With the Tone-Burst Generator, the envelope of the transient can be observed and measured.

---

[4] Theodore J. Schultz, "Problems in the Measurement of Reverberation Time," *Journal of the Audio Engineering Society*, October, 1963.

[5] Theodore J. Schultz and B. G. Watters, "Propagation of Sound Across Audience Seating," *Journal of the Acoustical Society of America*, Vol 36 No. 5, May, 1964.



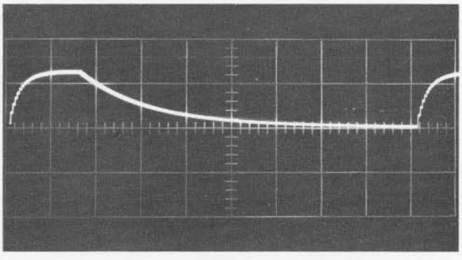
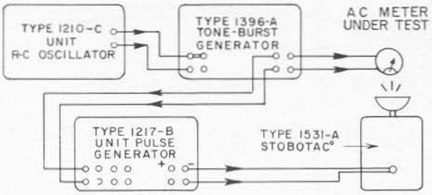


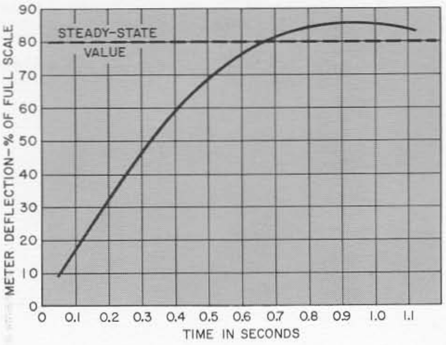
Figure 5b (*above*). Open-circuit voltage waveform of Tone-Burst Generator output (32 cycles of 10-kc signal per burst). Scales are 2 volts per major division vertically and 2 msec per major division horizontally.

Figure 5c (*right*). Waveform of capacitor voltage when the voltage waveform of Figure 5b is applied to the circuit of Figure 5a. Scales are the same as in Figure 5b.

Figure 6a (*below*). Test system for measuring deflection vs time for an ac meter.

Figure 6b (*right*). Deflection as a function of time for an ac meter excited by a tone burst.





Loudspeaker Distortion Measurements

Distortion measurements can be made with tone-burst excitation of speakers.[6,7] A gated microphone is used to respond to the signal produced by the speaker after the tone burst has been cut off. This "hangover" is a measure of the distortion of the speaker. Such systems are capable of using sweep techniques and being at least semi-automated.

Testing of Rectifying-Type Circuits

Detector and other rectifying circuits lend themselves directly to tone-burst testing. The rectification efficiency and time constants of such circuits can be tested easily with tone-burst excitation. For example, consider the waveforms of Figures 5b and 5c, which were taken from the simple rectifier circuit of Figure 5a.

AC Meter Ballistics

Tone-burst response tests for characteristics such as rise time, fall time, and overshoot, are frequently required for rectifying meters, particularly VU meters. Figure 6a shows a test system for measuring the meter deflection as a function of time.[8] The frequency at which the test is performed must be low enough so that the meter can reach full scale in 128 cycles. The tone bursts consist of 128 cycles of test frequency, and their spacing is adjusted so that the meter returns to rest at zero after each burst. The TYPE 1217-B Unit Pulse Generator acts as a delay circuit. Its negative output pulse starts as the Tone-Burst Generator's gate opens, and the pulse ends at a time determined by the settings of the PULSE DURATION controls. The end of this pulse initiates a microsecond flash of the STROBOTAC® electronic stroboscope. The PULSE DURATION controls set the time between the energizing of the meter and the flashing of the bright-light source. The ambient light should be controlled to permit accurate observation of deflection when the flash occurs, and to allow the scale to be seen between flashes.

Figure 6b is a plot of deflection *vs* time for an ac meter when energized by a burst of 128 cycles of 40-cycle signal. The rise time from 10% to 90% of full scale is 0.5 second, and the overshoot is 6%, which corresponds to a

---

[6] M. C. Kidd "Tone-Burst Generator Checks A-F Transients," *Electronics*, Vol 25, No. 7, pp 132–135, July 1952.
[7] M. J. Whittemore, "Transistorized Tone Burst System for Transient Response Testing of Loudspeakers," *Journal of Audio Engineering Society*, Vol 10, No. 3, pp 200–203, July 1962.
[8] This system is patterned after a similar system for dc meters, a description of which appeared in the January-February 1962 issue of the *Experimenter*.

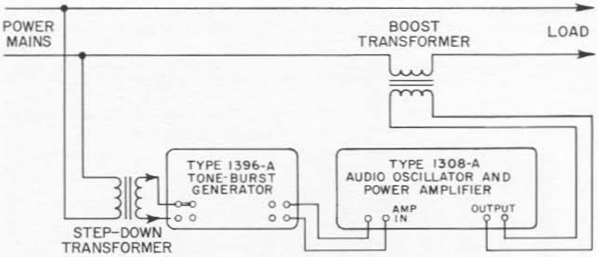


Figure 7. Tone-burst system for generating power-line transients.

meter cutoff frequency of approximately 0.9 cps.

High-Power Transients

Tone-burst testing allows the average signal power to be kept arbitrarily low, although the pulse, or burst, power level may be very high. This low-duty ratio condition may be necessary if the device under test has nonlinearities (i.e., the test properties depend on power level) and if the test equipment cannot operate continuously at the desired signal or power levels.

The General Radio Type 1308-A Audio Oscillator and Power Amplifier can be combined with the Type 1396-A Tone-Burst Generator to produce audio-frequency tone bursts whose power content may be as high as 200 watts. The Tone-Burst Generator can be used to drive the power amplifier portion of the Type 1308-A. For higher frequencies, the Type 1233-A Power Amplifier, which delivers up to 15 watts, can be used.

Generation of Line Transients

A method of producing controlled transients in a power-line signal is shown in Figure 7. The step-down transformer isolates the instruments from line voltage and drops the voltage to the proper range for operation of the instruments (one-half volt, rms). The boost transformer may be omitted if the total load current is less than 5 amperes rms.

Others

In addition to those briefly outlined above, the Tone-Burst Generator has many applications. As a calibrated source of ac transients, it is invaluable in evaluating the characteristics of audio and supersonic devices.

— J. K. Skilling

APPENDIX

Frequency Content of Tone Bursts

Some applications may require a knowledge of the frequency components of the tone burst. For a sinusoidal signal, the burst voltage can be expressed as a Fourier series having only sine or cosine terms as follows:

$$e(t) = \sum_{n=1}^{\infty} a_n \begin{Bmatrix} \sin \\ \cos \end{Bmatrix} \left[\frac{2\pi n t}{(N+M)\,T} \right]$$

$e(t)$ = the tone-burst voltage.

a_n = the amplitude of the nth component.

n = harmonic number (1, 2, 3, 4, etc.).

N = number of cycles of signal in the burst (OPEN count in the Tone-Burst Generator).

M = number of cycles (periods) of signal between bursts (CLOSED count in the Tone-Burst Generator).

T = the period of the signal being gated.

The sine series is used if the signal is gated on and off at zero crossings, and the cosine series if gating is at the peak point of the sinusoidal input voltage. The equation indicates that a tone burst is equivalent to a signal of amplitude a_1 at the repetition rate of the tone burst, plus a signal of amplitude a_2 at twice the repetition rate (the second harmonic), plus a signal of amplitude a_3 at three times the repetition fre-

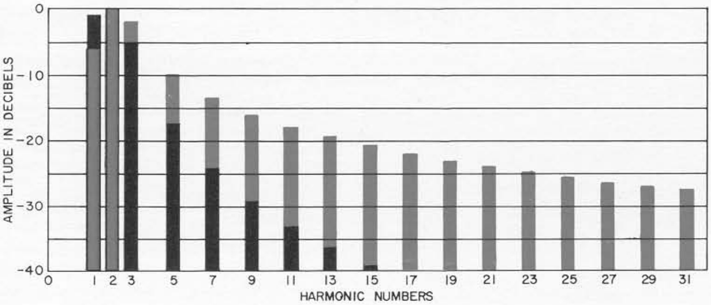


Figure 8. Amplitude of the first 31 Fourier harmonics of a one-cycle-on, one-cycle-off tone burst. Switching at zero crossings in black; switching at peak points in red.

quency (the third harmonic), and so on, indefinitely. The amplitude of each component in the above series is given by:

$$a_n = E\frac{N}{N+M}\left[\frac{\sin x}{x} \mp \frac{\sin y}{y}\right]$$

where:

$$x = 2N\left(\frac{n}{N+M} - 1\right)\frac{\pi}{2}$$

$$y = 2N\left(\frac{n}{N+M} + 1\right)\frac{\pi}{2}$$

E = the amplitude of the signal being gated.

The values of N and M are on the Tone-Burst generator controls. When x or y equals zero, the two fractions involved assume indeterminate forms, but the proper value of the fraction under these conditions is one.

As an example of the use of these equations, consider a tone-burst signal having one cycle on and one cycle off (M = N = 1). The amplitude equation is:

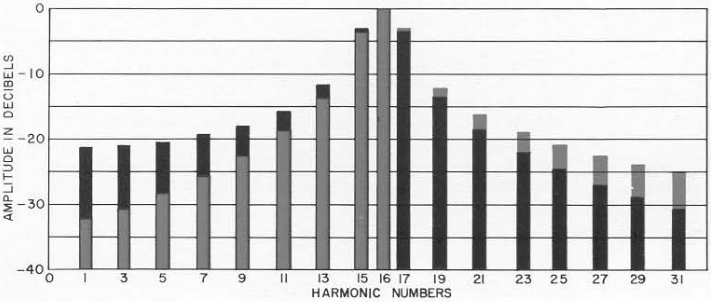
$$a_n = E\left[\frac{\sin (n-2)\frac{\pi}{2}}{(n-2)\ \frac{\pi}{2}} \mp \frac{\sin (n+2)\frac{\pi}{2}}{(n+2)\frac{\pi}{2}}\right]$$

The two fractions in the bracketed expression are subtracted if the input signal is gated at zero crossings and added if gating is at the peak. The table below gives the amplitudes for values of n equal to 1, 2, 3, 4, and 5 with both zero crossings and peak-point gating:

n	*Zero-crossing gating*	*Peak-point gating*
1	0.424 E	0.212 E
2	0.500 E	0.500 E
3	0.255 E	0.382 E
4	0	0
5	0.061 E	0.152 E

Figure 8 is a plot of the first thirty-one harmonics of the above signal. Figure 9 shows, as a second example, the first thirty-one harmonics of an eight-cycle-on, eight-cycle-off tone burst. The two curves were taken from an automatic plot of the frequency spectrum produced by using a General Radio Type 1900-A Wave Analyzer and Type 1521 Graphic Level Recorder. In the two examples the tone burst had N = M, for which case the amplitudes are zero for even values of n (except zero). Therefore, when a tone burst is "square", i.e., has equal on and off time, there are no even harmonics except the one that may be at the input-signal frequency.

Figure 9. Amplitude of the first 31 Fourier harmonics of an 8-cycle-on, 8-cycle-off tone burst. Switching at zero crossings in black; switching at peak points in red.



SPECIFICATIONS

SIGNAL INPUT (signal to be gated)

Frequency Range: dc to 500 kc.

Maximum Voltage Level: ±7 volts (5 volts, rms).

Input Impedance: Approximately 10 kilohms.

TIMING SIGNAL (signal that controls gate timing)

Frequency Range: dc to 500 kc.

Maximum Voltage Level: ±10 volts.

Minimum Voltage Level: 1 volt, peak-to-peak.

Input Impedance: Approximately 7 kilohms.

Triggering: Slope selectable, trigger level adjustable from −7 to +7 volts.

GATE TIMING: Gate-open and -closed intervals can be independently set to 2, 4, 8, 16, 32, 64, or 128 cycles (periods) of timing signal. By means of a MINUS ONE switch, intervals can be set to 1, 3, 7, 15, 31, 63, or 127 cycles. The gate-closed intervals can also be timed in increments of one period of timing signal from 1 msec to 10 sec. Fixed timing errors are less than 0.5 μsec.

GATED SIGNAL OUTPUT

Gate-Open Output: Maximum signal level is ±7 volts. Total distortion is less than −60 db (compared to maximum level) at 1 kc and 10 kc.

Gate-Closed Output: Less than 140 millivolts, peak-to-peak, (−40 db) with maximum signal input.

Pedestal Output (dc potential difference between open- and closed-gate output): Can be nulled from front panel. Less than 50-millivolt change with line voltage.

Switching Transients: Less than 140 millivolts, peak-to-peak, (−40 db compared to maximum signal input).

Output Impedance: 600 ohms.

GATING VOLTAGE OUTPUT (signal for triggering oscilloscope): Rectangular waveform of approximately + 12 volts at 10-kilohm source when the gate is closed and approximately −12 volts at 20 kilohms when the gate is open.

GENERAL

Ambient Operating Temperature: 0 to 50 C (32 to 122 F).

Power Requirements: 105 to 125 (or 200 to 240, or 210 to 250) volts, 50 to 60 cps, 15 watts, approximately.

Accessories Supplied: TYPE CAP-22 Power Cord.

Accessories Required: External source for any desired frequency range between 0 and 500 kc.

Cabinet: Bench type with rubber feet. Front feet are extendible to tilt cabinet.

Dimensions: Width 8, height 5⅞, depth 7½ inches (205 by 150 by 195 mm), over-all.

Net Weight: 6½ pounds (3 kg).

Shipping Weight: 10 pounds (4.6 kg).

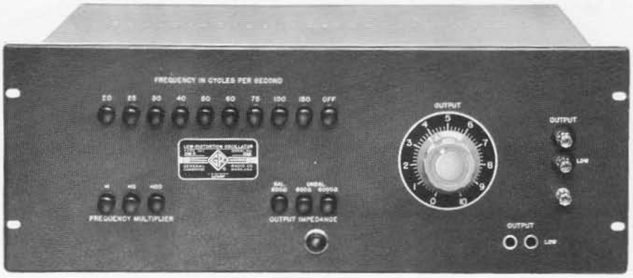
Type		*Price*
1396-A	**Tone-Burst Generator**	**$490.00**

PRICE CHANGES

Economies recently achieved in manufacture have made possible substantial price reductions in certain models of our TYPE 500 Resistors, TYPE 980 Decade Capacitor Units, and TYPE 1419 Polystyrene Decade Capacitors.

Increased material costs have necessitated price increases in a few items.

Type		*Old Price*	*New Price*
500-V	**Resistor,** 200,000 ohms	$ 8.50	**$ 7.50**
500-W	**Resistor,** 500,000 ohms	17.00	**11.00**
500-X	**Resistor,** 1 megohm	27.00	**16.00**
980-B	**Decade Capacitor Unit,** 0.01-μf steps	56.00	**45.00**
980-C	**Decade Capacitor Unit,** 0.001-μf steps	57.00	**45.00**
980-D	**Decade Capacitor Unit,** 0.0001-μf steps	57.00	**50.00**
1419-A	**Polystyrene Decade Capacitor,** 1.110 μf in steps of 0.001 μf	205.00	**180.00**
1419-B	**Polystyrene Decade Capacitor,** 1.1110 μf in steps of 0.0001 μf	262.00	**230.00**
874-QNP	**Locking Adapter to Type N Jack**	5.00	**5.50**
1265-AM, -AR	**Adjustable DC Power Supply**	875.00	**1050.00**
1630-AL	**Inductance-Measuring Assembly**	2440.00	**2660.00**
1630-AV	**Inductance-Measuring Assembly**	3230.00	**3450.00**



LOW-DISTORTION OSCILLATOR

We have received a number of inquiries for the TYPE 1301-A Low-Distortion Oscillator, and we are glad to announce that this instrument is still available from stock.

The Low-Distortion Oscillator provides push-button selection of 27 fixed frequencies between 20 and 15,000 cps. These are the recommended test frequencies for audio distortion measurements in radio-broadcasting stations.

This oscillator and the TYPE 1932-A Distortion and Noise Meter comprise a system for the fast and accurate measurement of distortion and noise level in audio-frequency circuits.

SPECIFICATIONS

FREQUENCY

Control: A frequency of 20, 25, 30, 40, 50, 60, 75, 100, or 150 cps is selected by a push button. Push-button multipliers of 1, 10, and 100 are provided.

Accuracy: +(1½% + 0.1 cps).

Stability: Frequency changes with line voltage or output load are negligible. Drift is not greater than 0.02% per hour after the first 10 minutes.

OUTPUT

Impedance: Selected by push button; 600 ohms, balanced; 600 or 5000 ohms, grounded.

With balanced load, 600-ohm balanced output is balanced for all audio frequencies. The 5000-ohm output varies with potentiometer setting between 1000 and 6000 ohms. Potentiometer also has slight effect on 600-ohm grounded impedance.

Voltage (Max): 30 volts, open circuit; 6.6 volts with 600-ohm load constant with frequency within ±1 db.

Power: 18 milliwatts into 600 ohms; 100 milliwatts into 5000 ohms.

DISTORTION AND NOISE LEVEL

Distortion: 5000-ohm output, not more than 0.1%; 600-ohm output, not more than 0.1% between 50 and 7500 cps, and not more than 0.25% below 50 cps.

AC Hum: Not more than 0.05% of output voltage.

GENERAL

Terminals: Jack-top binding posts with standard ¾-inch spacing, a ground terminal, and a standard Western Electric double output jack on the front panel; duplicate output terminals on the rear of the instrument.

Power Input: 105 to 125 (or 210 to 250) volts, 25 to 60 cps, 45 watts. Specify line voltage and frequency when ordering.

Operation from 400-cycle supply is possible if line voltage is between 110 and 125 volts; power-frequency hum is increased at 200- and 400-cycle output.

Accessories Supplied: TYPE CAP-22 Power Cord, multipoint connector, TYPE 1301-201 Plug Assembly, spare fuses.

Mounting: Relay-rack panel. End frames are available for table mounting. (See price table below.)

Panel Finish: Standard General Radio gray crackle.

Dimensions: Width 19, height 7, depth 13½ inches (475 by 180 by 345 mm), over-all.

Net Weight: 31½ pounds (14.5 kg).

Shipping Weight: 35 pounds (16 kg).

Type		*Price*
1301-A	**Low-Distortion Oscillator**	**$595.00**
FRI-412-2	**Aluminum End Frames**	**15.00 pair**

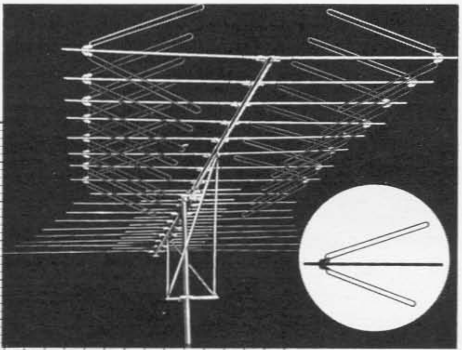
Figure 1.

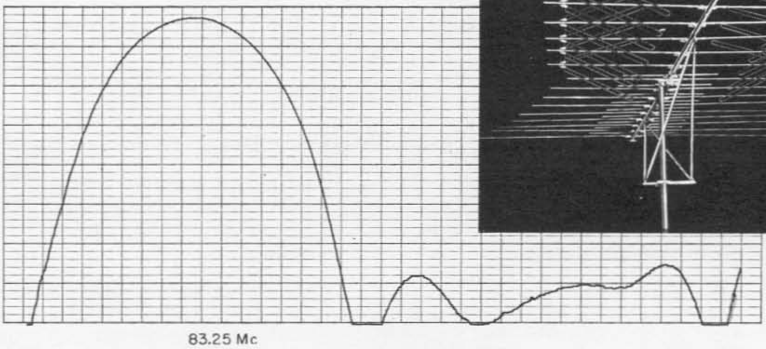
AUTOMATIC PLOTTING OF ANTENNA PATTERNS

The Type 1521-A Graphic Level Recorder is shown here (Figure 1) at Channel Master Corporation plotting automatically the directivity pattern of a Super-Crossfire antenna. A Selsyn transmitter is mounted on the shaft of the motor that rotates the antenna. The Selsyn receiver drives the recorder through a chain and spur gear (to do this, the gear shift on the recorder must be in neutral, as shown). By choice of gear ratio, the chart can be calibrated in the desired number of degrees per division. A 40-db range on the vertical scale is ordinarily used. The receiving antenna is not visible in the photograph. The driving oscillator, which can be partially seen just over the shoulder of the operator, is a General Radio Unit Oscillator, with the Type 1263 Amplitude-Regulating Power Supply to ensure constant excitation level. Figure 2 shows a typical record plotted on this equipment for the Channel Master #3607 Super-Crossfire antenna of Figure 3.

Figure 2 (*below*). Typical antenna pattern at 83.25 Mc.

Figure 3 (*right*). View of the antenna with inset showing detail of one element.





THE GENERAL RADIO
EXPERIMENTER

THE STABILITY OF STANDARD-FREQUENCY OSCILLATORS

In the measurement of physical quantities, the demands of science, industry, and the military are for constant improvement in accuracy. Standards and measuring devices, as a result, must meet ever tighter specifications. This trend is well illustrated by Figure 1, which shows the increase in accuracy of the U. S. Frequency Standard over a period of some 40 years.

Atomic frequency control, which is used in the U. S. Frequency Standard, provides both the best accuracy and the best long-term stability. At present, however, there is little indication that it will replace the quartz-crystal oscillator as a working standard. There are two reasons for this: Atomic frequency control devices — at least those that have been available commercially — not only have been very expensive but have demonstrated a serious lack of reliability.

LONG-TERM STABILITY

In the crystal oscillator, the long-term stability of the quartz crystal itself has been the limiting factor. Most standard-frequency oscillators use either the 5-Mc or the 2.5-Mc fifth-overtone

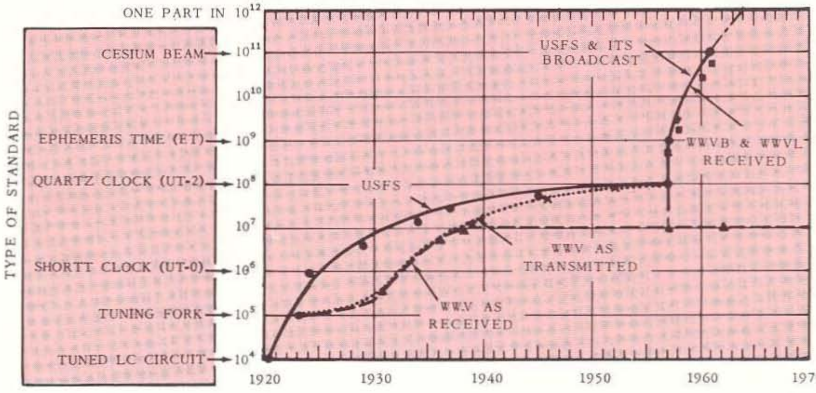


Figure 1. Accuracy trend of the U. S. Frequency Standard.

VOLUME 38 NUMBER 6

JUNE 1964

IN THIS ISSUE

Bridge Oscillator-Detector
Inductance Measuring Assembly
Stage-Lighting Control

crystals[1] developed by Bell Telephone Laboratories. Their ultimate aging rates are less than 1 in 10^{10} per day for the 5-Mc unit and less than 1 in 10^{11} per day for the 2.5-Mc. The choice between the two frequencies is generally dictated by cost and convenience. The 2.5-Mc crystal is twice as large as the 5-Mc and much more expensive; in addition, for comparable performance, it requires better (dynamic) temperature control.

Development work on quartz crystals is continuing, and better units can be expected in the future.[2] Present well-designed oscillator circuits do not contribute to long-term frequency drift (aging) to any measurable extent, and any improvement in the crystal characteristics will be directly reflected in the over-all stability of the oscillator.

SHORT-TERM STABILITY

The short-term stability of a crystal oscillator (defined here as the frequency deviations for averaging times from 100 μsec to 10 sec) is, at the longer averaging times, predominantly controlled by oscillator defects and, for very short averaging times, approaches the limits set by the thermal noise of the crystal.

Thermal Noise

It has been shown[3] that the equivalent noise resistance of a quartz crystal is the same as the effective series resistance and that the frequency deviation due to this source can be expressed as

$$\frac{\Delta f}{f} = \frac{2\pi}{\tau f_o} \frac{E_N}{E_S} \qquad (1)$$

where τ = averaging time.

f_o = oscillator frequency.

E_N = noise voltage.

E_S = signal voltage.

or, expressing E_N and E_S by

$$E_N = \sqrt{4kTBR}$$

and

$$E_S = \sqrt{PR},$$

then

$$\frac{\Delta f}{f} = \frac{2\pi}{\tau f_o} \sqrt{\frac{4kTB}{P}} \qquad (2)$$

and, with $B = \frac{1}{Q} f_o$,

$$\frac{\Delta f}{f} = \frac{2\pi}{\tau} \sqrt{\frac{4kT}{PQf_o}}. \qquad (3)$$

where R = effective series resistance.

T = absolute temperature.

B = bandwidth of network.

P = quartz driving power.

k = Boltzmann's constant.

Q = storage factor of quartz.

Equation (3) indicates that:

1. The observed frequency deviation is inversely proportional to the averaging time τ. If the measured deviation does not follow this rule, the stability is not determined by the crystal alone.
2. Increasing the crystal drive improves the stability.
3. Increasing Q improves the stability.

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[1] A. W. Warner, "High-Frequency Crystal Units for Primary Frequency Standards," *Proceedings of the IRE*, Vol 40, pp 1030–1033, September 1952.

[2] A. W. Warner, "Use of Parallel Field Excitation in the Design of Quartz Crystal Units," *Proceedings of the 17th Annual Symposium on Frequency Control, 1963*, pp 248–266.

[3] E. Hafner, "Stability of Crystal Oscillators," *Proceedings of the 14th Annual Symposium on Frequency Control, 1960*, pp 192–199.

CONTENTS OF THIS ISSUE

4. Higher oscillator frequency improves stability.

For these precision crystals, however, statement 3 is dependent on 4 because the maximum Q is inversely proportional to the frequency [4] and Qf_o is constant.

As an example, if we substitute these typical crystal constants in equation (3):

$f_o = 5 \times 10^6 \qquad P = 0.7 \times 10^{-6}$

$Q = 2.5 \times 10^6 \qquad T = 350°\text{K}$

then

$$\frac{\Delta f}{f} = \frac{3 \times 10^{-13}}{\tau}.$$

This means that, for a one-second averaging time, the frequency deviations due to the thermal noise of the crystal do not exceed 3×10^{-13}.

How close do modern crystal oscillators get to this figure? Actual measurements on the new General Radio Type 1115-B Standard-Frequency Oscillators have shown the following results:

$\frac{\Delta f}{f} = 4 \times 10^{-12}$ for one-second averaging time

$= 4 \times 10^{-10}$ for one-millisecond averaging time.

This shows that, for a one-second averaging time, the oscillator circuit contributes just over one order of magnitude more than the crystal. For one millisecond, the effects of the circuit are almost negligible, as the measured stability is only 35% worse than that of the crystal alone. Figure 2 shows the theoretical stability as well as some measured data.

From the discussion above it appears that present oscillator designs are satisfactory for very long averaging times (aging) and very short averaging times. In between, say from tenths of seconds to hundreds of seconds, the stability potential of the crystal is not fully utilized. This is only partially correct, however, as there is temperature disturbance caused by the crystal, which is significant for averaging times of tens to hundreds of seconds.

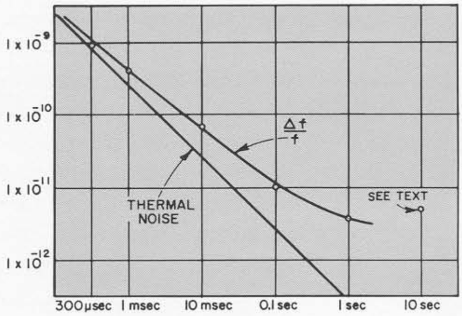

Figure 2. Theoretical and measured stability of a crystal oscillator.

Temperature Gradients

Crystal units generally show great sensitivity to temperature gradients. In a vacuum-mounted crystal, heat is conducted to the quartz mostly through the wire supports, and rapid temperature fluctuations can produce spot temperature differences, creating a temperature gradient in the crystal. Thus, if the temperature of the oven fluctuates but little, the frequency effects are much larger than those due to the temperature coefficient alone. Temperature-control circuits, like any other circuit, are susceptible to noise, and some temperature fluctuations are inevitable. Temperature rates of change as low as 10 millionths of a degree per second (2×10^{-6} °C/sec) are sufficient to cause frequency changes larger than those indicated by the steady-state temperature coefficient of the crystal.[5]

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[4] A. W. Warner, "Design and Performance of 2.5 Mc Quartz Crystal Units," *BSTJ*, Vol XXXIX, No. 5, September 1960, pp 1193–1217.

[5] Contract DA 36-039 SC 73078, "An Ultra Precise Standard of Frequency," *Eleventh Interim Report* (*Bell Telephone Laboratories*), pp 33–37, April 23, 1959.

The limiting factor in the tenths-to-seconds range is the $1/f$ noise of the oscillator and level-control circuits. For higher frequencies (above 1 kc) the noise figure of the semiconductors is quite small, say a few db, but, as we go to lower frequencies, beyond the low-frequency noise corner, the spot noise figure gets much larger. It is not easy to decide whether this effect is due to nonlinearities in the oscillator circuit or to the level sensitivity of the crystal.

Drive Level

At the normal operating point of 70 microamperes, the 5-Mc crystal shows about 1×10^{-9}/db for level sensitivity.[6] This sensitivity increases with increasing crystal current and for moderate drive levels is approximately:

$$\frac{\Delta f}{f_0} = Di^2 \qquad (4)$$

where f_o = frequency at zero driving power.

D = a constant determined by the type of crystal and is about 1 for the 5-Mc crystal.

i = crystal current.

Figure 3 shows how, as the driving power is increased, the relative drive level becomes more and more critical. For a 1-db change in level,

$$\frac{\Delta f}{f_0} = 0.2\ Di^2. \qquad (5)$$

This effect is in the opposite direction from the effect of drive level on thermal noise (see equation (3) and statement 2). As a result, the drive level can be increased only up to a certain point. For higher levels, the fluctuations (i.e., noise) from the level-control circuit become predominant, and the over-all performance is poorer.

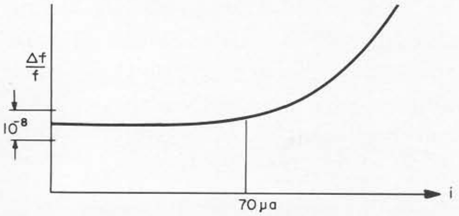

Figure 3. Drive-level sensitivity of 5-Mc crystal.

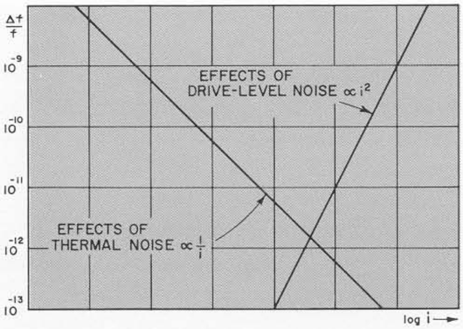

Figure 4. Effects of crystal current on short-term stability.

Figure 4 shows a typical relation for τ = one second. As the level-control circuitry is improved, higher and higher drive levels can be used. The thermal noise decreases as $1/i$, but the disturbance due to level sensitivity increases as i^2. The best compromise is dictated by the performance of the level-control circuitry. For the 5-Mc crystal, operating at one-microwatt drive, level variations must be less than 0.01% to keep the resultant frequency disturbances to less than 1×10^{-12}. This calls for a drive-level stability of about 1×10^{-10} watt. The fact that this stability has to be achieved at high frequencies does not make the task any easier.

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[6] A. W. Warner, 'Crystal Unit Design for Use in a Ground Station Frequency Standard," *Proceedings of the 10th Annual Symposium on Frequency Control, 1956*, pp 190–196.

ADDITIONAL STABILITY PARAMETERS

Other factors affecting the short-term stability are temperature, load changes, vibration, and power-supply effects. In general, they are specified separately from the short-term stability data.

Temperature Control

The effects of temperature can be reduced to acceptable amounts depending only on economics of cost, weight, and power consumption. The most difficult factor is dynamic stability, i.e., the elimination of transient temperature changes much larger than steady-state changes for the same ambient range. Present-day instruments show over-all temperature coefficients as low as a few parts in 10^{12} per degree C. Under laboratory conditions this can be considered negligible because it is masked by either thermal noise or aging, except possibly in the range of $\tau = 0.1$ to $\tau = 1000$ seconds. If the requirements of the contemplated applications warrant the expense, temperature control can be improved. This will be necessary if and when active devices with lower $1/f$ noise and crystals with lower aging rates are available. While two-stage ovens are more popular, single-stage ovens can be made to perform quite well. Reduction of ambient changes as seen by the crystal is not limited by the stabilization factor of the oven control but by temperature gradients between the crystal and the temperature-sensing element. Although two-stage ovens are easier to design for low gradients and stability of the control system, single-stage ovens can be built with stabilization factors over 50,000 and gradients of less than 10 millidegrees Centigrade. They have the advantages of lower cost and lower complexity, and, often most important, they require less power or less volume.

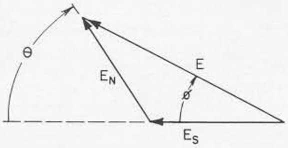

Figure 5. Vector diagram showing phase shift due to stray coupling to output.

Loading

Frequency variations due to changes in the loading at the output of the oscillator have been a very serious problem for all laboratory applications. Loading effects are caused primarily by pickup of output current in the oscillator circuit. Let us assume that a small amount of output signal is introduced into the oscillator loop. Figure 5 shows this case in exaggerated form. From the vector diagram in Figure 5,

$$E = \sqrt{(E_S + E_N \cos\theta)^2 + (E_N \sin\theta)^2} \quad (6)$$

and

$$\tan\phi = \frac{\sin\theta}{\dfrac{E_S}{E_N} + \cos\theta}. \quad (7)$$

where E_S = the signal in the loop without pickup.
E_N = the pickup.
E = the sum of both.

It is obvious that, regardless of the magnitude of E_N, ϕ is zero if θ is zero, and a maximum of ϕ occurs for

$$\theta = \pm 2\,(\mathrm{n} - 1)\frac{\pi}{2}.$$

If a phase shift occurs inside the oscillator circuit, the frequency must shift to produce phase shift of equal magnitude but of opposite sign in the crystal network. The frequency shift due to such phase shift is

$$\frac{\Delta f}{f} = \frac{\tan\phi}{2\,Q} \quad (8)$$

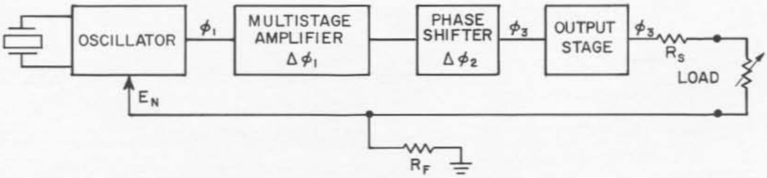

Figure 6. Typical block diagram for a precision oscillator.

and, as a function of θ,

$$\frac{\Delta f}{f} = \frac{1}{2\,Q} \frac{\sin\theta}{\dfrac{E_S}{E_N} + \cos\theta}$$

and, if $E_S \gg E_N$, $\dfrac{\Delta f}{f} \approx \dfrac{1}{2\,Q}\dfrac{E_N}{E_S}\sin\theta$ (9)

Obviously, the best solution would be to ensure that E_N is small enough to be negligible. This is quite difficult, because even when E_N is very small, it still has considerable effect. For example, if

$$E_N = 1 \times 10^{-5},\ E_S = 1 \times 10^{-2}\,,$$
$$\text{and } Q = 2.5 \times 10^{6}$$

then

$$\frac{\Delta f}{f} = 2 \times 10^{-10} \sin\theta$$

To keep E_N as low as 1×10^{-5} requires well over 100 db of isolation and shielding between output stage and oscillator, and E_N is often larger. So far, it has been shown only that the frequency is offset owing to pick-up if θ is not equal to zero or 180°. As soon as E_N changes (owing to a change in output current), this frequency offset changes unless θ is zero or 180°.

If it could be ensured that θ is zero or 180° for all conditions of loading, no frequency changes would occur. As long as the load is strictly resistive, this is possible. Figure 6 is a block diagram of an oscillator with amplifier stages.

The conditions to make $\theta = 0$ are $\phi_1 = \phi_3$, which requires $\Delta\phi_1 + \Delta\phi_2 = 0$ for any resistive load.

The phase-shifter shown in Figure 6 can be the tank circuit of one of the amplifier stages, which can be detuned slightly to compensate for whatever phase shifts may exist in all amplifier stages. Under these conditions, any resistive load change will affect the magnitude of E_N but not the phase. Changes in magnitude are not very important, since they represent no more than a change in gain in the oscillator loop, which is taken care of by the level-control circuit.

This condition cannot be met if either the output impedance or the load impedance is not strictly resistive. Any reactive load causes a phase shift as long as R_S is not zero, and, if the source impedance is reactive, resistive load changes result in variations of θ. The best compromise is to make R_S as small as possible, so that moderately reactive loads are acceptable.

It is not likely that load changes are reflected through the chain of amplifier stages. Experiments have shown that as few as two or three stages after the oscillator will provide all the isolation needed, but a larger number of stages is usually required to obtain enough gain.

Vibration

Crystal units are quite sensitive to vibration, and, while this problem is most severe for missile or airborne applications, it cannot be ignored for laboratory applications. Great efforts have been made to develop crystals with low sensitivity to acceleration.[7]

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[7] Contract DA 36-039 SC 73078, "An Ultra Precise Standard of Frequency," *Final Report* (*Bell Telephone Laboratories*), December 1960.

Precision crystals have frequency-*vs*-acceleration coefficients of 1×10^{-9} to 1×10^{-10} per g (gravitational constant), and efforts have been concentrated in the direction of eliminating resonances in the frequency range of interest. Once the crystal design ensures freedom from resonances, little more can be done in the way of mounting it in the instrument — at least not for low frequencies.

Power Supply

Power-supply variations can be held to a few parts in 10^{11} as oscillator voltage coefficients of less than 5×10^{-9} per volt are usual.

STABILITY SPECIFICATIONS

No accepted standards exist for the specification of short-term stability. These data are obtained for constant operating conditions, i.e., constant ambient, load, line, etc., and the effects of variations in these quantities are listed separately. The method most suitable for the evaluation of the oscillator performance in systems applications is to specify the "standard deviation," σ, for a specified confidence limit. This is, of course, the same as the "rms deviation." Sometimes rms phase deviation is listed as a measure of short-term stability. This phase deviation can be computed from the frequency:

$$\Delta\phi = (2\pi f)\,\frac{\Delta f}{f}\,\tau \qquad (10)$$

where τ is the averaging time.

If the value of $\frac{\Delta f}{f}$ is in terms of rms units, the $\Delta\phi$ is also in rms units.

The term "short-term stability" is not generally used for averaging times over 10 seconds; to fill the gap between 10 seconds and the averaging times for aging or drift, the term "fluctuations" has been used. For increasing averaging times, the rms values become less and less useful because the frequency fluctuates around a mean value that is changing very slowly as a result of aging. To state a meaningful rms value, it is necessary to subtract the aging slope. Such a regression analysis can easily be accomplished. The data so obtained become more and more important as the aging rate decreases with time and may ultimately determine the usable stability on a day-to-day basis.

SPECTRUM

Spectral purity is particularly important for microwave-spectroscopy and for other applications requiring high multiplication ratios. The spectrum of an oscillator provides information beyond that given by long-term and short-term stabilities. It shows the presence of discrete sidebands and the distribution of noise. To compare the spectra of two oscillators, it is necessary to know the frequency and the analyzer band-width. Figure 7 shows a typical spectrum, which is obtained by the

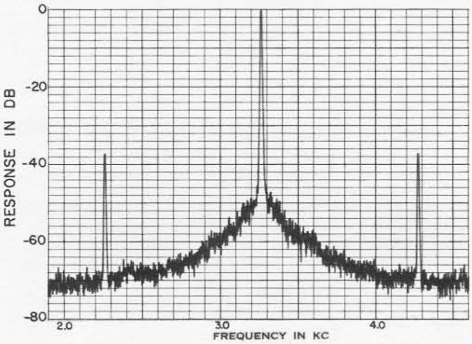

Figure 7. Spectrum showing discrete 1-kc sidebands at 10 Gc with 10-cycle bandwidth in analyzer.

multiplication of the frequencies of two oscillators to 10 Gc. These frequencies are adjusted to be about 3×10^{-7} apart (slightly over 3 kc at 10 Gc). The center line of the spectrum is adjusted for 0 db. The first sidebands are just visible at about −46 db, discrete sidebands of −37 db are at ±1 kc from the carrier, and the noise pedestal is about −70 db. Such a spectrum can be used to predict the performance at any other frequency and for different bandwidths.

To obtain the ratio of noise to signal at other frequencies, the following approximation may be used as long as the noise-to-signal ratios are at least −20 db, i.e., if the noise is better than 20 db down:

$$N_2 = 20 \log \frac{(f_2)}{f_1} + N_1 \quad [\text{db}] \qquad (11)$$

where N_2 is the noise-to-signal ratio at f_2 and N_1 at f_1, in db.

This means that multiplying the frequency 10 times increases the noise-to-signal ratio by a factor of 10. To evaluate the noise for a different analyzer bandwidth, it is convenient to express the noise in terms of root-cycle bandwidth. This is the noise-to-signal ratio for a one-cycle bandwidth.

$$N_{\text{norm}} = N_2 - 10 \log B \qquad (12)$$

where B = bandwidth.

The relative amplitude of discrete sidebands is not affected by any change of bandwidth. Using these relations to refer the spectrum shown in Figure 7 to 5 Mc, we have

f_1 = 10 Gc $\quad f_2$ = 5 Mc
analyzer bandwidth = 10 cps
N_1 = −37 db for the ±1-kc sidebands.
N_1 = −70 db for the noise pedestal.
Then, from (11)
N_2 = −103 db for sidebands.
N_2 = −136 db for noise in 10-cycle bandwidth
and from (12)
N_2 = −146 db for noise in one-cycle bandwidth.

TYPE 1115-B STANDARD-FREQUENCY OSCILLATOR

Careful evaluation of the basic oscillator parameters, as outlined above, has led to the design of this new oscillator unit. From the beginning it was agreed that the unit should use the 5-Mc, 5th-overtone crystal, include frequency dividers to 1 Mc and 100 kc, and have self-contained emergency power for at least 24 hours. The choice of the 5-Mc crystal was dictated by the belief that

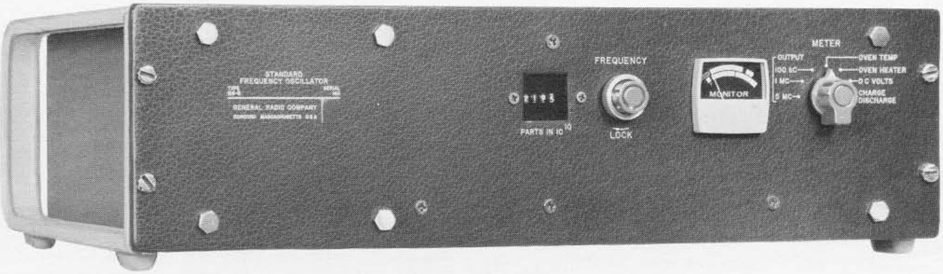

Figure 8. Panel view of Type 1115-B Standard-Frequency Oscillator.

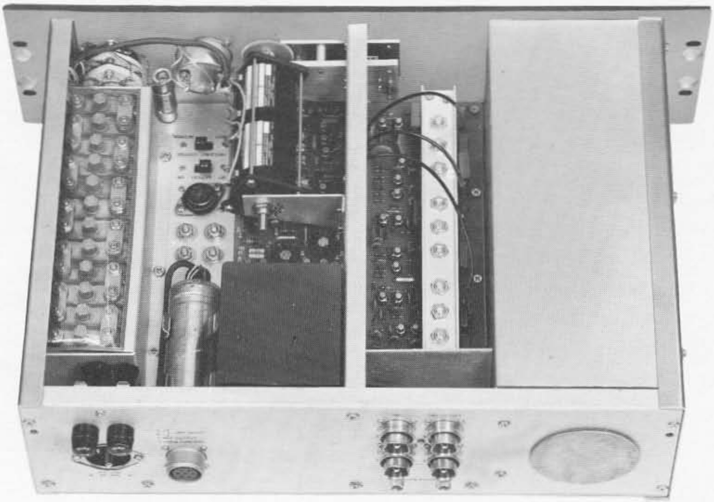

Figure 9. View of oscillator with cover removed.

this unit could meet the requirements for working standards of the majority of users at a cost substantially lower than that of 2.5-Mc units. Except for aging of the crystal, the GR TYPE 1115-B shows a performance comparable to or exceeding that of any 2.5-Mc oscillator.

Figure 10 is a block diagram of this unit. The crystal, oscillator, and AGC circuits are housed in a single-stage proportional-control oven. Two stages of isolation amplifiers and the output amplifier follow. Regenerative dividers are used to divide to 1 Mc and 100 kc. The power supply consists of an automatic battery charger, explosion-proof battery, and regulator.

The crystal is a gettered unit. No long-term aging data are available at this time, but a record of several months' aging shows some improvement over the aging characteristics of ungettered units. One important advantage of the gettered units is a better restarting characteristic, i.e., if the oscillator has been off and is turned on again, these units settle down much faster than do the ungettered ones.

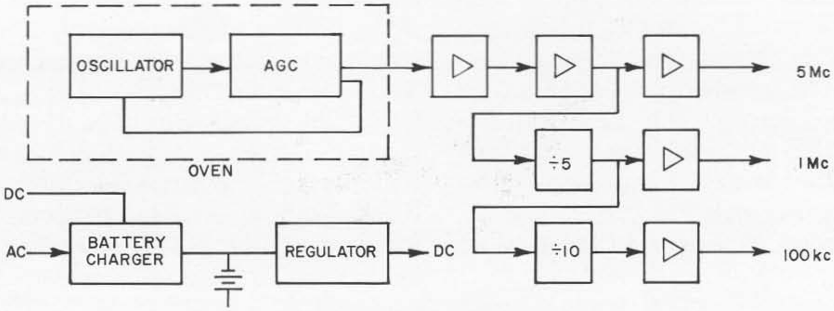

Figure 10. Block diagram of Standard Frequency-Oscillator.

OSCILLATOR AND AGC

The effects of component changes on the frequency of a crystal oscillator have been analyzed in the past.[8] Figure 11 shows the basic arrangement of the crystal network and oscillator circuit. For the 5-Mc, 5th-overtone crystal, a 1-pf change of C_1 or C_2 (0.3%) amounts to a frequency variation of about 5×10^{-10}. The shunt capacitances C_1 and C_2 are about 330 pf each, and this network requires a transconductance of 15 milliamperes per volt to sustain oscillations. Such a transconductance would be difficult to achieve with vacuum tubes of stable long-term performance but can be obtained with transistor circuits.

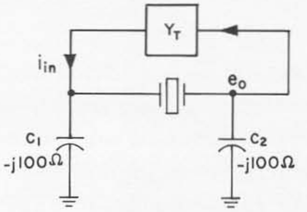

Figure 11. Basic oscillator network.

The ideal, active device for Y_T has high input and output resistance and no input or output capacitance. In addition, the magnitude of Y_T must be controlled by the AGC circuit to hold the amplitude constant. The gain of transistors is usually controlled by variation of the dc current. This method, however, is undesirable, because the current variation changes the capacitances of the transistors. Better performance is obtained if only the ac gain, and not the dc operating point, is varied. The circuit shown in Figure 12 meets these requirements.

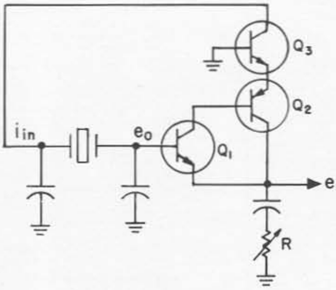

Figure 12. Basic oscillator circuit.

Transistors Q_1 and Q_2 are in a circuit configuration that applies 100% feedback from the output to the emitter of the input stage Q_1. The voltage gain from the base of Q_1 to the output terminal is very nearly unity. If we assume that R is the only impedance from this point to ground, the current through R will be very nearly $\frac{e_0}{R}$. Because this same current flows through Q_3 (with the exception of small amounts lost through the bases of Q_1 and Q_3), the transconductance of this circuit is predominantly controlled by R. This resistance can be varied with no change in the dc operating point of any of the transistors. The circuit has an input impedance of over 30 kilohms shunted by less than 2 pf and an output impedance of several hundred kilohms shunted by less than 2 pf. A transconductance of 15 milliamperes per volt is readily obtained when R is about 65 ohms. Because of these high input and output impedances, variations of transistor parameters are of little consequence. As the collector-to-base capacitances of modern planar transistors are typically stable to better than 10% per 10,000 hours at constant temperature and voltage, the resultant change of

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[8] E. P. Felch and J. O. Israel, "A Simple Circuit for Frequency Standards Employing Overtone Crystals," *Proceedings of the IRE*, Vol 43, No. 5, pp 596–603, May 1955.

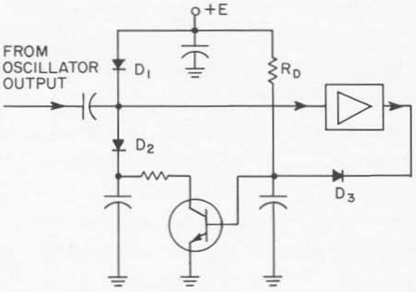


Figure 13. Basic AGC circuit.

frequency is less than 1×10^{-10} per year. This is negligible compared with the aging of 5-Mc crystals, which is orders of magnitude greater.

Electronic control of the transconductance is obtained by variation of the dc bias current through a pair of diodes (Figure 13). The rf output of the oscillator is amplified by a two-stage amplifier and rectified by D_3. As long as there is no rf voltage, R_4 is biased on (saturated) to pass a maximum of current through the AGC diodes, D_1 and D_2, for maximum transconductance to start the oscillations. As the amplitude increases, D_3 reduces the turn-on drive of Q_4 (from R_D) until Q_4 gets out of saturation. Any further increase in rf amplitude reduces the current through D_1 and D_2, which reduces the gain. R_D adjusts the point where Q_4 gets unsaturated and thus sets the rf level.

A variable capacitance diode (varactor) is used to adjust the frequency of the oscillator. The bias for this diode is varied by a potentiometer mounted on the panel. A digital read-out indicates frequency increments of 1×10^{-10} per digit. The total range of this electronic tuning is 2700×10^{-10}. Careful investigation has shown no measurable aging due to the varactor. The series resistance of the varactor used is negligible compared with the resistance of the crystal. Excellent linearity of tuning is ensured by a variable load on the arm of the potentiometer (a second resistance element on the same shaft). See Figure 14. The linearity of this arrangement is typically better than $\pm 7 \times 10^{-10}$ (out of 2700×10^{-10}) or about $\pm 0.25\%$. Figure 15 shows a typical curve for the tracking error. The resolution of the potentiometer is such that the oscillator can be adjusted to within 2×10^{-11} of any frequency inside the range.

The advantages of electronic tuning are obvious. The varactors are small and do not require a shaft through the oven wall as is required for mechanically varied capacitors.

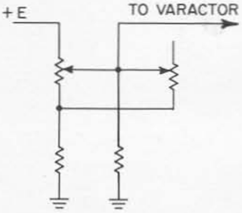


Figure 14. Linearizing network for varactor.

In addition, the use of varactor tuning permits control of frequency, by dc voltage, from a remote location and phase-locking of the oscillator by means of an external phase detector. External control voltage can be applied through a connector on the rear skirt of the instrument. Sensitivity is of the order of

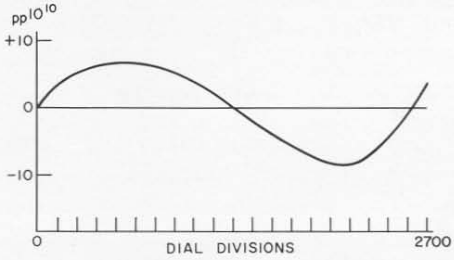


Figure 15. Tracking error of varactor tuning.

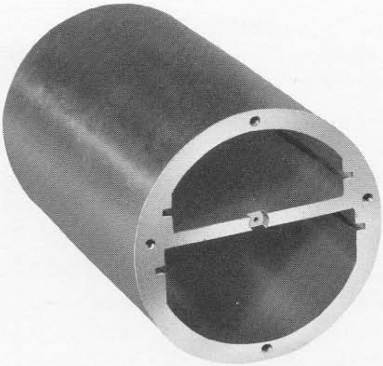


Figure 16. View of the investment casting in which the crystal and its associated circuit elements are mounted.

1.5 millivolts for a frequency change of 1×10^{-10}.

OVEN

A single-stage oven with proportional control holds the temperature of critical components within less than 10 millidegrees C. Power consumption of this oven was considered important because of battery operation in case of line failure. The power consumption is only about 500 milliwatts for operation at room temperature. The insulation of the oven is a combination of a Dewar flask and polyurethane foam, in which the flask is completely embedded. This assembly has survived shock tests of 50 g's, 11 msec, in any direction (MIL STD 202 Method 205 Condition C). The oven chamber is a copper investment casting (Figure 16). Plug-in circuit boards provide easy access to components.

EMERGENCY POWER

A nickel cadmium battery of 4 ampere-hours is floated across the dc supply. The cells of this battery are of the pressure-relief type and cannot explode. In case of power-line failure, operation for 35 hours is ensured at room temperature and up to 24 hours at 0°C. An external dc supply of 22 to 35 volts can also be used. If ac power, external dc, and internal battery are connected, the power will be drawn from the source that provides the highest voltage to the regulator circuit. The change-over is made by diodes and is completely continuous.

The battery is recharged by a current-limited voltage source. As long as the battery voltage is significantly lower than the float voltage, the limit current flows. As the cut-off voltage is approached, the current rapidly decreases. This method ensures rapid recharging after power failure and maintains the battery at optimum charge conditions. The float, or trickle-charge, voltage is temperature compensated to vary approximately −2 millivolts per degree C per cell to correct for changes in the emf of the battery over the full temperature range.

PERFORMANCE

Aging

Typical aging rates are a few parts in 10^{10} per day after 30 days of operation and are down to about 1 in 10^{10} per day after 12 months.

Short-Term Stability

Figure 18 is a block diagram of the measuring system used. The 5-Mc outputs of the oscillators are multiplied 2000 times each (effectively to X-band),

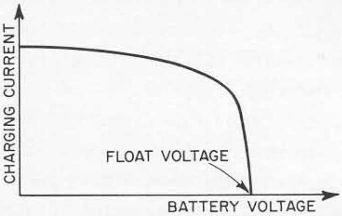


Figure 17. Battery recharge characteristic.

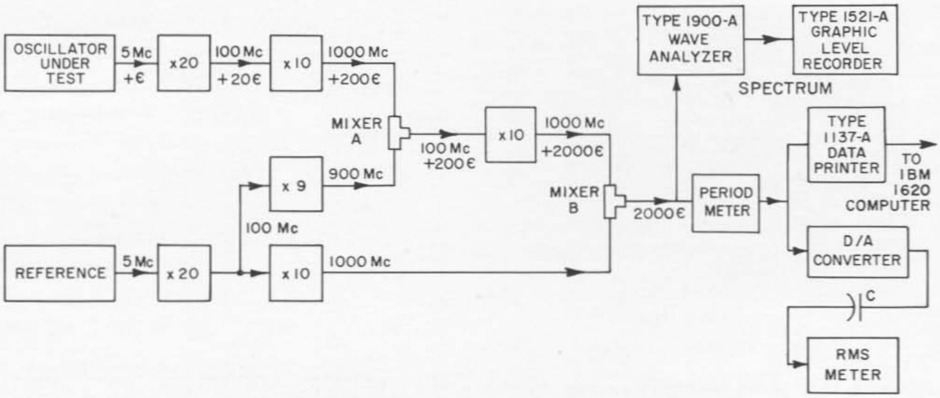
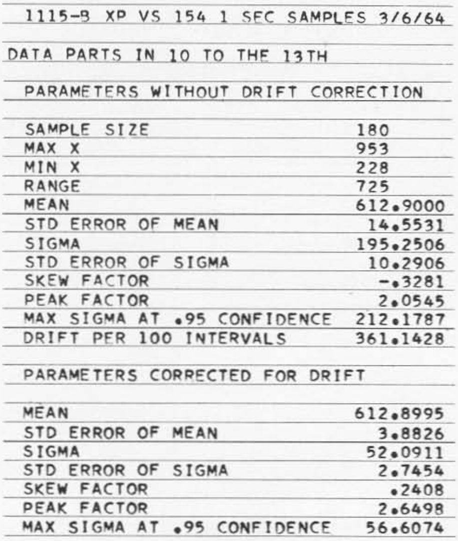


Figure 18. Block diagram of measuring system.

and the period of the beat note is measured by digital techniques. The result is processed by an IBM 1620 computer to obtain statistical data. For short averaging times (less than 10 milliseconds) the rms deviation is also measured directly by data converted from digital to analog form, which is fed into an rms meter. This meter is ac coupled and responds only to the deviations from the mean. The deviation indicated by this meter agrees to better than 10% with the data from the computer.

Figure 19 shows the data for one-second averaging time as they are produced by the computer. The data were taken at a time when Serial No. 154 was still aging rapidly (a few days after initial turn-on), and a large amount of drift is noticeable. This drift was then removed from the data. The results are in parts in 10^{13} for the mean and for sigma. The skew factor and the peak factor are parameters that provide an estimate of how nearly normal the distribution is. The skew factor is 0 and the peak factor 3.0 for a perfectly normal distribution. The maximum sigma at 95% confidence is for two oscillators compared with each other and, to obtain the sigma for one oscillator, should be divided by $\sqrt{2}$. The maximum sigma for one oscillator is 4×10^{-12}. Data for other averaging times are listed in Table I and plotted in Figure 20. The increase of deviation from one-second to 10-second averaging time is due to ambient temperature variation. The 10-second data were recorded over a 25-minute time interval. With



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 1115-B XP VS 154 1 SEC SAMPLES 3/6/64

DATA PARTS IN 10 TO THE 13TH

 PARAMETERS WITHOUT DRIFT CORRECTION

 SAMPLE SIZE                      180
 MAX X                            953
 MIN X                            228
 RANGE                            725
 MEAN                        612.9000
 STD ERROR OF MEAN            14.5531
 SIGMA                       195.2506
 STD ERROR OF SIGMA           10.2906
 SKEW FACTOR                   -.3281
 PEAK FACTOR                   2.0545
 MAX SIGMA AT .95 CONFIDENCE 212.1787
 DRIFT PER 100 INTERVALS     361.1428

 PARAMETERS CORRECTED FOR DRIFT

 MEAN                        612.8995
 STD ERROR OF MEAN             3.8826
 SIGMA                        52.0911
 STD ERROR OF SIGMA            2.7454
 SKEW FACTOR                    .2408
 PEAK FACTOR                   2.6498
 MAX SIGMA AT .95 CONFIDENCE  56.6074
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Figure 19.

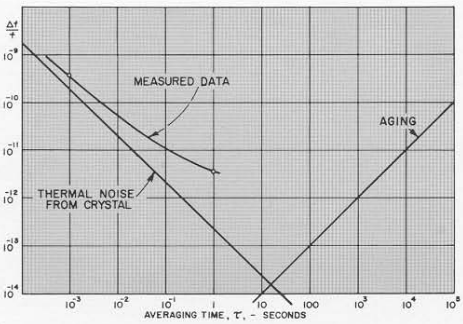


Figure 20. Measured data.

a typical temperature coefficient of $5 \times 10^{-12}/°C$, it is obvious that temperature fluctuations of a fraction of a degree account for this increase. Also shown is the theoretical stability resulting from the thermal noise of the crystal resistance, as calculated from formula (3) on page 2.

Phase deviation can be computed from the frequency deviation by means of equation (10).

For 5 Mc,

$$\frac{\Delta f}{f} = 4 \times 10^{-12} \text{ and } \tau = \text{one second.}$$

$$\Delta \phi = 125 \times 10^{-6} \text{ radians.}$$

TABLE I SHORT-TERM STABILITIES

Sigma at 95% confidence

Averaging Time	*Sigma*
10 sec	5.5×10^{-12}
1 sec	4×10^{-12}
0.1 sec	1×10^{-11}
10 msec	7.3×10^{-11}
1 msec	39×10^{-11}
300 μsec	80×10^{-11}

SPECTRAL PURITY

The measuring system shown in Figure 18 was also used to obtain spectrum data. The beat frequency between the two oscillators, multiplied 2000 times, is analyzed with a TYPE 1900-A Wave Analyzer, set for 10-cycle bandwidth, and recorded with a Type 1521 Graphic Level Recorder. The exceptional dynamic range of this combination makes it possible to present the spectrum in a particularly useful form. The oscillators are adjusted to have a beat frequency of about 3 kc (3000×10^{-10}). Figure 21 is a spectrum obtained by this method. The first visible sidebands appear about 45 db down from the main line, and the noise pedestal is 70 db down. There are no distinct sidebands visible. As this spectrum was taken after multiplication to the equivalent of X-band, it follows from formula (11) from page 8 that this corresponds to −111 db for the first visible noise near the main line and to −136 db for the noise pedestal, referred to the 5-Mc output of the oscillator. For one oscillator, another 3 db should be subtracted; 10 db should be subtracted to refer the noise to 1-cycle bandwidth. The two numbers are −124 db/$\sqrt{\text{cps}}$ for the noise near the main line and about −149 db/$\sqrt{\text{cps}}$ for the noise pedestal.

Sometimes a figure is given for line "width." This is, of course, strictly a colloquialism, as a line cannot have any width. What is meant is: how far from the carrier are the sidebands 3 db down? Figure 22 shows the center part of the

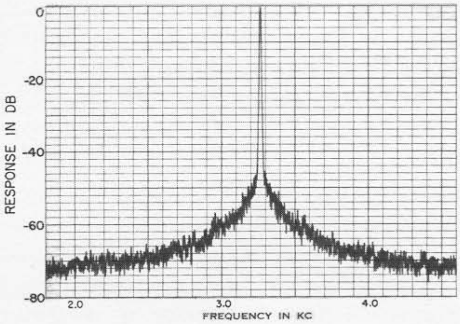


Figure 21. X-band power spectrum of two Type 1115-B Standard-Frequency Oscillators. Analyzer bandwidth is 10 cps.

spectrum plotted with an analyzer bandwidth of 0.54 cps (by use of a special analyzer filter), and Figure 23 shows the response of the filter. As Figure 22 shows no broadening of the response of the filter, it can be stated that the line "width" is less than 0.25 cps at X-band.

OTHER FACTORS AFFECTING THE FREQUENCY

Temperature

Temperature control of the crystal and other critical components keeps the over-all temperature coefficient typically less than $5 \times 10^{-12}/°C$. Transient response is such that frequency excursions stay within the specified steady-state limits for sudden changes in temperature over the range of 0 to 50°C.

Load

Loading effects have been reduced to negligible amounts by careful arrangement of ground loops. Very little output is fed back into the oscillator, as evidenced by the fact that tuning of the output circuit does not affect the frequency to any measurable extent, i.e., less than 2×10^{-11}. In addition to resistive loads, reactive loads can be tolerated. A reactive load of 50 ohms (620 pf) causes, typically, 3×10^{-11} frequency shift.

Vibration

The only component significantly affected by vibration is the crystal unit. The acceleration coefficient is about 1 to 1.3×10^{-9} per g in the most sensitive direction, and, for low frequencies, there is little reduction of vibration from the instrument frame to the crystals. As the frequency is raised, some attenuation is afforded by the foam insulation of the oven.

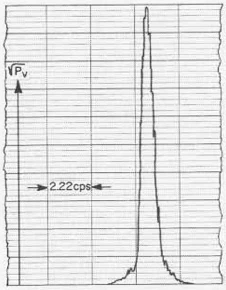


Figure 22. Center portion of spectrum of Figure 21, measured with 0.54-cycle bandwidth. Vertical scale is linear ($\sqrt{\text{power}}$).

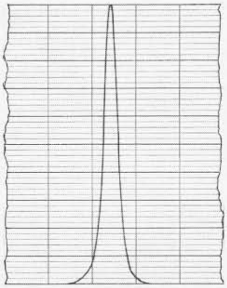


Figure 23. Analyzer passband characteristic used for spectrum of Figure 22.

Power-Supply

Power-supply changes have little effect on frequency. The frequency does not change more than $\pm 1.5 \times 10^{-11}$ for any safe operating condition of ac or dc supply voltage or for the range of voltages from a fully charged to a completely discharged internal battery.

MONITOR CIRCUITS

A single meter is used to monitor the 5-Mc, 1-Mc, and 100-kc output levels, oven temperature, oven heater voltage, dc supply voltage, and battery current. In all functions, clearly marked sectors on the meter indicate the ranges for normal operation.

GENERAL

The instrument uses all-silicon, solid-state circuitry. All components are of high quality, consistent with the requirements of long continuous service. All electrolytic capacitors are tantalum except for the ac power-supply filter capacitor, which is a Mil-grade aluminum electrolytic. All etched circuits use Fiberglas-epoxy boards. The rugged, mechanical construction will withstand abuse during shipment and the mobileservice environment. The instruments meet the requirements of MIL STD 167 for vibration and will withstand 30-g shocks of 11-msec duration in any direction.

— H. P. Stratemeyer

CREDITS

The author wishes to acknowledge the many contributions made by others in the design of this instrument and, in particular, the assistance of W. J. Riley in development, G. E. Neagle for the mechanical design, and W. N. Tuttle for writing the program for the computer for statistical evaluation of short-term stability.

SPECIFICATIONS

OUTPUT

Frequencies: 5 Mc, 1 Mc, 100 kc.

Frequency Adjustment: 2700 × 10^{-10} (1 × 10^{-10} per dial division). Can also be varied by external voltage.

Voltage: 1 volt, rms, $^{+50}_{-10}\%$ into 50 ohms at each frequency.

Spectral Line Width: <0.25 cps at 10 Gc.

FREQUENCY STABILITY

Short Term: Standard Deviation (sigma) is less than stated below (95% confidence):

Averaging Time	*Sigma*
0.3 msec	100 × 10^{-11}
1 msec	50 × 10^{-11}
10 msec	10 × 10^{-11}
0.1 sec	1.5 × 10^{-11}
1 sec	1.0 × 10^{-11}
10 sec	1.0 × 10^{-11}

Aging: < 5 × 10^{-10} per day after 30 days; < 1 × 10^{-10} per day is typical after one year.

Temperature: <5 × 10^{-10} from 0 to 50 C.

Load: < ±2 × 10^{-11} from open circuit to short circuit.

Supply Voltage: < ±2 × 10^{-11} from 22 to 30 volts, dc; < ±1 × 10^{-11} for ±10% ac line-voltage changes.

POWER REQUIREMENTS (AC or DC)

AC: 90 to 130 (or 180 to 260) volts, 40 to 2000 cps, 8 watts at 115 volts.

DC: 22 to 35 volts; 4 watts at 24 volts.

Emergency: Internal battery, 24–35 hours, depending on ambient temperature.

GENERAL

Construction: Ruggedized; rack-bench cabinet.

Dimensions: Bench model — width 19, height 5¼, depth 14½ inches (485 by 135 by 370 mm), over-all; rack model — panel 19 by 5¼ inches (485 by 135 mm); depth behind panel 12½ inches.

Net Weight: 35 pounds (16 kg).

Shipping Weight: 39 pounds (18 kg).

Type		*Price*
1115-BM	**Standard-Frequency Oscillator, Bench Model**	**$2,050.00**
1115-BR	**Standard-Frequency Oscillator, Rack Model**	**$2,050.00**

PAPERS SOUGHT FOR CONFERENCE ON AUTOMOTIVE ELECTRICAL AND ELECTRONICS ENGINEERING

Original papers covering the forefront of the art are sought for the First National Conference on Automotive Electrical and Electronics Engineering to be held September 22 and 23 in Detroit, at the McGregor Memorial Center of Wayne State University.

Within the context of automobiles and traffic, the following subject categories will be considered:

1. Systems and Automatic Control
2. Communication and Signalling
3. Vehicle Propulsion and Control
4. Energy Storage and Conversion
5. Sensors and Gauges
6. Components and Devices
7. Test Instrumentation
8. Manufacturing Processes and Techniques
9. Electronics in Sales and Distribution

Each prospective author should submit an abstract (500 to 1000 words) not later than July 15th to the Chairman of the Papers Committee, Mr. E. A. Hanysz, General Motors Research Laboratories, G. M. Tech. Center, Warren, Michigan. The author should indicate the length of time required for presenting and discussing the paper. This length may be as short as 10 minutes or less, but should definitely not exceed 30 minutes.

The Conference is sponsored by Southeastern Michigan Section and PTG-IECI of IEEE, University of Michigan, Michigan State University, Wayne State University, and University of Detroit.

General Chairman is Ole K. Nilssen, Applied Research Office, Ford Motor Company, Dearborn, Michigan.

CONVENIENT GENERATOR-DETECTOR UNIT FOR BRIDGE MEASUREMENTS

The Type 1232-A Tuned Amplifier and Null Detector[1] and the Type 1311-A Audio Oscillator[2] have been combined in a single, convenient unit for use with audio-frequency bridges and other null-balance devices. This new assembly, the Type 1240-A Bridge Oscillator-Detector, occupies a minimum of bench space and is provided with removable panel extensions, which adapt it for rack mounting. The combination can also be easily disassembled so that component instruments can be used separately.

The oscillator supplies 11 fixed frequencies from 50 cps to 10 kc. The detector is tunable continuously from 20 cps to 20 kc, with additional spot frequencies of 50 kc and 100 kc.

---

[1] A. E. Sanderson, "A Tuned Amplifier and Null Detector with One-Microvolt Sensitivity," *General Radio Experimenter*, 35, 7, July 1961.

[2] R. G. Fulks, "High Performance, Low-Cost Audio Oscillator with Solid-State Circuitry," *General Radio Experimenter*, 36, 8 and 9, August-September 1962.

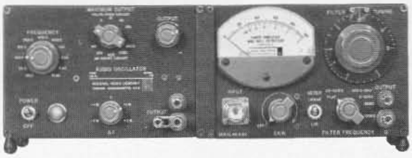
SPECIFICATIONS

Dimensions: Width 19, height 6, depth 7¾ inches (485 by 155 by 200 mm), over-all.

Net Weight: 13½ pounds (6.5 kg).

Shipping Weight: 28 pounds (13 kg).

Type		*Price*
1240-A	**Bridge Oscillator-Detector**	**$565.00**

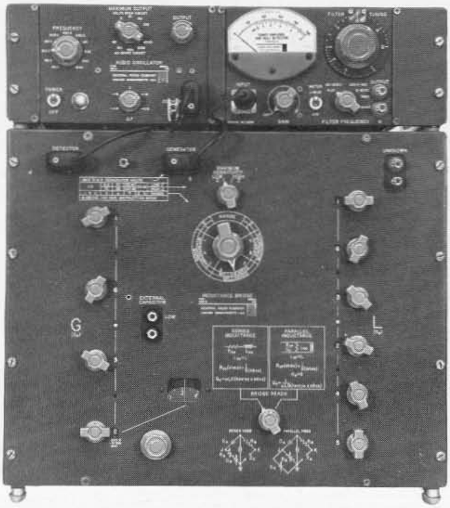


Panel view of the Bridge Oscillator-Detector Assembly.

Panel view with panel extensions attached for relay-rack mounting.

BRIDGE ASSEMBLY FOR PRECISION INDUCTANCE MEASUREMENT

For the precise measurement of inductance and the intercomparison of inductance standards, the Type 1632-A Inductance Bridge[1] offers both accuracy and convenience. Its wide range of inductance, from 0.0001 μh to 1111 h, embraces a variety of applications. It can measure rf coils at 1 kc (where stray capacitance is not a factor) to an accuracy of 0.1%. It can compare two 10-henry standard inductors at 100 cps to a precision of 1 part in 10^5.



Panel view of the Inductance Measuring Assembly.

Although designed primarily for measurements at 1 kc and lower frequencies, it is usable, with little impairment in accuracy, up to 10 kc.

This bridge is now available in combination with the TYPE 1240-A Bridge Oscillator-Detector[2] as the TYPE 1660-A Inductance Measuring Assembly.

SPECIFICATIONS

Dimensions: Width 19½, height 23, depth 10½ inches (495 by 590 by 270 mm), over-all.

Net Weight: 62 pounds (29 kg).

Shipping Weight: 92 pounds (42 kg).

Type		*Price*
1660-A	**Inductance Measuring Assembly**	**$1555.00**

---

[1] J. F. Hersh, "A Bridge for the Precise Measurement of Inductance," *General Radio Experimenter*, 34, 11, November 1959.

[2] See page 17.

INEXPENSIVE VARIAC® AUTOTRANSFORMER LIGHTING CONTROL

By Fred B. Otto

The control board described here was designed and built by the author in order that the eight Variac® autotransformers, obtained by the Mansfield Players over the past several years, could be operated with the convenience and versatility of a lever action and a mechanical master found in professional boards. Because the operator can hold several levers in each hand and can also master them to a single lever, he can easily carry out operations that are impossible with knobs. Since, like many other amateur theatrical groups, the Mansfield Players are challenged by a budget that is practically nonexistent, the board was designed to use materials that are inexpensive and readily available.

The autotransformers were mounted in two rows to conserve space and to bring the handles closer together. Eight 3-inch V-belt pulleys were then mounted on a ½-inch shaft, which was mounted in two holes in the box. A 1½-inch pulley was used as a mounting for the master handle. Since it was found that a setscrew was not sufficient to keep this pulley from slipping when all eight dimmers were mastered, a hole was drilled through the pulley and shaft, and a cotter pin inserted. The spacing between pulleys was maintained by short pieces of pipe cut to length and slipped over the shaft. A smooth pipe was mounted near the first row of autotransformers, as shown in Figure 1, to guide the cord.

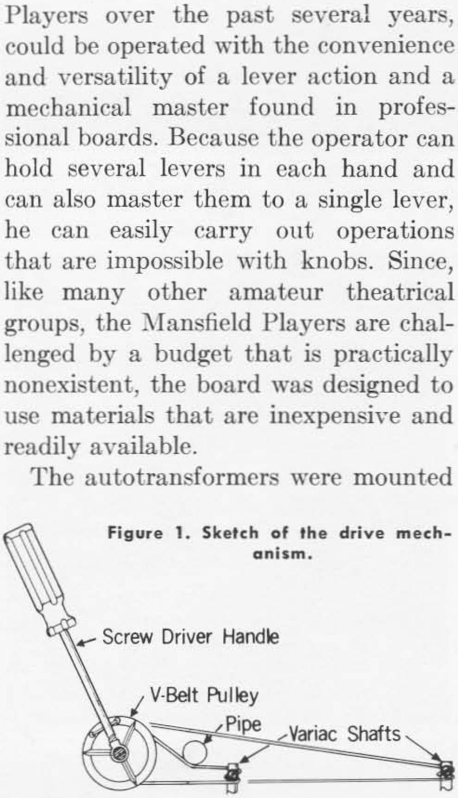
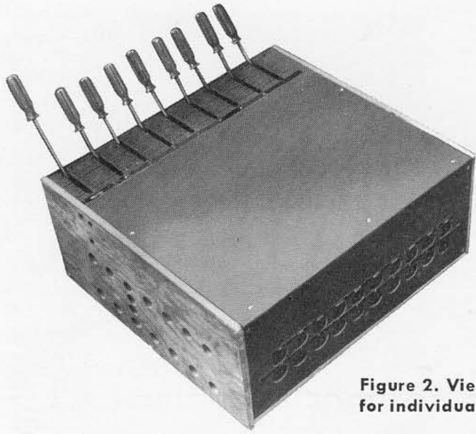


Figure 1. Sketch of the drive mechanism.

The connection between the V-belt pulley and the autotransformer shaft was made by means of a piece of heavy Venetian-blind cord. The cord was secured to the shaft of the Variac by means of a machine screw worked through the cord and into a hole that had been drilled and tapped in the side of the shaft about ½ inch from the end. The cord was given one and a half turns around the shaft of the Variac and then was tied to the V-belt pulley



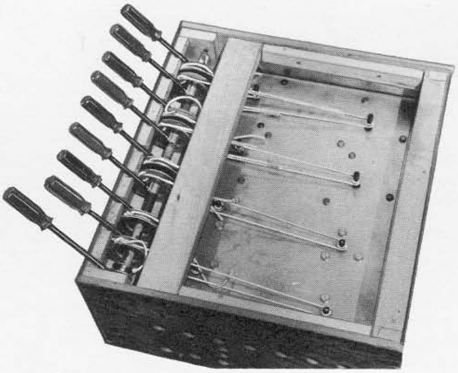


Figure 2. View of the control board, showing outlets at the rear for individual circuits. Figure 3. View with cover removed, showing details of the control mechanism.

by means of two holes drilled in its flange. Though it was found sufficient to wrap the cord around the shaft of each Type W5 Variac autotransformer, it would probably be necessary to use a small thread spool on the shafts of the higher power Type W10 and Type W20 Variac autotransformers and to use a correspondingly larger pulley.

Inexpensive screwdrivers with 5/16-inch-diameter shafts were used for handles. The shafts were heated to remove the temper, the tips cut off, and the shafts threaded to fit the 5/16-inch setscrew holes of the pulleys.

The difference in diameter between the pulley and the autotransformer shaft causes the Variac to turn the full 320° when the lever is moved through about 90°. Mastering is accomplished by a simple twist of the handle in the setscrew hole so that it tightens against the shaft, causing the pulley to turn with the shaft. It should be noted that with this arrangement dimmers can be mastered at different points so that some dimmers can be maintained several points above or below the rest during fades. The 2-inch spacing of the handles was chosen to be large enough for them to be held separately, and yet to be as small as possible so that the maximum number of handles could be moved at once.

This board with its low cost, light weight, and high degree of controllability has proved to be well suited to our needs and may well be equally suited to the needs of other groups.

Mr. Fred B. Otto, who designed and built this control board for the Mansfield Players, is a graduate of the University of Maine, at present studying for his Ph.D. in physics at the University of Connecticut. In addition to his association with the Mansfield Players, he has also worked with the Maine Masque Theater and the Parish Players of Winchester, Massachusetts.

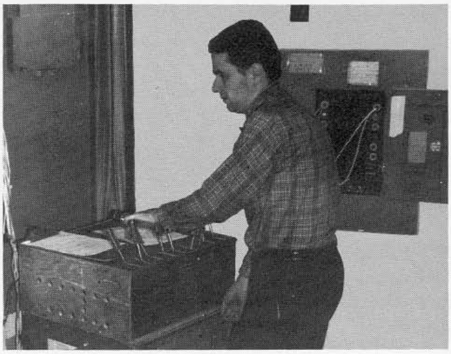
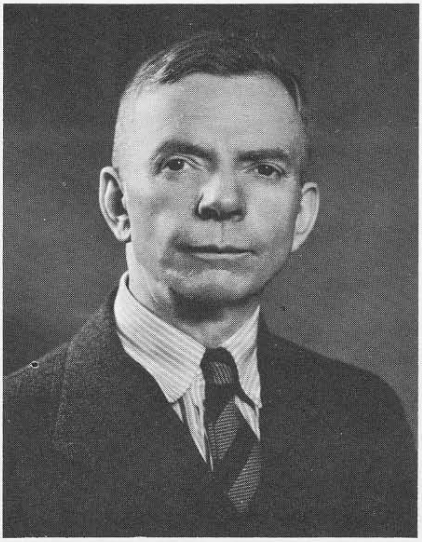


Figure 4. The author at the controls.

Melville Eastham

1885 — 1964



Melville Eastham, founder of General Radio Company and its president from 1915 to 1944, died on May 7. His professional and business career spanned the growth of electronic engineering from its beginnings as wireless telegraphy to the present and was marked by important contributions to science, industry, and national defense.

He was born in Oregon City, Oregon, June 26, 1885, and was educated in the Oregon public schools. He moved to Boston in 1906 as a cofounder of Clapp-Eastham Company, a manufacturer of radio receiving and transmitting equipment. In 1915 he founded General Radio Company.

He was a Fellow of the Institute of Electrical and Electronics Engineers and of the American Association for the Advancement of Science, and a member of the Acoustical Society of America, the American Physical Society, and the American Meteorological Society. In 1945 he was awarded the honorary degree of Doctor of Engineering by Oregon State College.

As one of the leaders of the Office of Scientific Research and Development, he was instrumental in marshalling the electronic-engineering effort during World War II, and played a principal role in the development of the Loran navigational guidance system.

Mr. Eastham was responsible for many important electrical standards, components, and construction techniques. Widely recognized as a pioneer in progressive employer-employee relations, he initiated in the early days of General Radio many employee benefits that were later widely adopted in industry. Largely through his technical guidance and his humanitarian approach to corporate management, General Radio was able to grow to a prominent position in the electronics industry while preserving its unusual system of self-ownership.

Melville Eastham's many friends in the electronics industry may wish to know that a fund in his memory has been established for the general purposes of the Massachusetts Institute of Technology. Contributions may be sent to the Melville Eastham Memorial Fund, Massachusetts Institute of Technology, Cambridge, Massachusetts.

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THE GENERAL RADIO
EXPERIMENTER

A BRIDGE TO TERAOHM TERRITORY

Thirty-one years is a long time for an instrument to be on the market. Imagine introducing an instrument now that will still be in a catalog dated 1995! Although the Type 544 Megohm Bridge has been modified occasionally, it is still basically the same instrument that it was in 1933,[1,2] and it is still a popular item. The longevity of this "circuit classic" may be some sort of record, and is a tribute to its design and its designer.

This instrument is a self-contained Wheatstone bridge system, which uses a vacuum-tube detector to achieve the sensitivity necessary for the measurement of high resistances. While there

Figure 1. Panel view of the Type 1644-A Megohm Bridge. The Flip-Tilt case permits the panel to be positioned at any desired angle. Inset shows the older Type 544-B.

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[1] R. F. Field, "Bridge + Vacuum Tube = Megohm Meter," *General Radio Experimenter*, 8, 1 and 2, June–July 1933.

[2] R. F. Field, "The Megohm Bridge," *ibid.*, 12, 2, July 1937.

VOLUME 38 NUMBER 7 JULY 1964

ALSO IN THIS ISSUE

hasn't been much change in the Wheatstone bridge in over a hundred years, except for improvements in the resistors used, there have certainly been advances in electronic circuits, which are used in the detector and voltage source.

In the new TYPE 1644-A Megohm Bridge (Figure 1) these advances have made practical these major improvements over the earlier TYPE 544:

1. Wider resistance range, extended three decades higher and two decades lower to give a total of 10 ranges, which cover 10^3 and 10^{15} ohms.

2. Better accuracy; now 1% to 10^{12}, 2% to 10^{13}, and 10% to 10^{14} ohms. To get this accuracy at high resistances would have been difficult with the single-tube detector of the older instrument.

3. Seven internal test voltages, 10 volts to 1000 volts in 1-2-5 steps. Any other voltage in this range can be obtained with just one external resistor. Measurements at these lower test voltages are made possible by the more sensitive detector.

4. A $\Delta R\%$ dial for measurements of differences as small as 0.1%, for voltage- and temperature-coefficient investigations, and for precise comparisons against external resistance standards. These uses also require the high sensitivity of the new detector circuit.

5. A 100:1 minimum ratio between the ratio-arm resistor and the unknown as compared with 10:1 in the older instrument. This results in several advantages: The voltage on the unknown changes by only 1% over the dial range instead of by 10%; the ratio-arm resistor has a maximum of only 10 volts applied, so that its change with voltage is negligible; a lower-resistance ratio arm can be used on any given range, which, in several cases, permits use of a more stable resistor; and the lower resistance results in a shorter time constant when capacitor leakage resistance is measured. This extra factor of 10 in "bridge ratio" results in a 10-to-1 loss in bridge sensitivity, but is more than made up for by the improved detector.

6. A new internal self-calibration circuit permits checking of the resistance of the wire-wound and metal-film ratio-arm resistors and adjustment of the carbon-film types used on the three highest ranges.

As is apparent from the photographs, the styling is changed. The new Flip-Tilt case allows the panel to be tilted at any angle for the maximum convenience and comfort of the operator and provides a protective cover during transportation or storage.

CIRCUITS

The Bridge

The basic bridge circuit, Figure 2, is familiar to anyone who has taken freshman physics. It differs from the simple Wheatstone bridge circuit in two ways: T-networks are used in the ratio arm, R_S, on the top ranges, and a $\Delta R\%$ adjustment can be inserted in the fixed arm, R_P. One should also note that the main adjustment arm R_N is the arm opposite the unknown, so that

CONTENTS OF THIS ISSUE

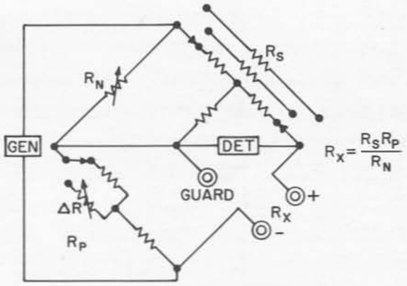

Figure 2. Basic bridge circuit.

its value is inversely proportional to the resistance measured. As a result, the R dial extends to infinity as R_N goes to zero.

Ten ratio-arm resistors are used to obtain the ten resistance ranges. The five lowest-valued resistors are wire-wound and the next two are ¼% metal-film units. The top three ranges use high-resistance carbon-film types, which are neither so precise nor so stable and, therefore, have trimming adjustments, which can be set precisely by means of the internal self-calibration circuit.

The T-networks that make up the ratio arms on the two highest ranges allow the use of relatively low-valued resistors to obtain very high effective resistance. For those who have forgotten the Y-Δ transformation, Figure 3 will indicate how this is accomplished. If R_1 and R_3 are large and R_2 is small, the equivalent value of R_Y can be very large. The other resistances of the equivalent Δ network fall across either the adjustable arm, R_N, where the resulting error is negligible if values are properly chosen, or across the detector, which results only in a loss in sensitivity. One advantage of this network over single resistors is that the low-resistance units are more stable; their use also keeps the bridge output impedance reasonably low to reduce capacitance-pickup and time-constant effects.

The main R adjustment, R_N, is the familiar cam-adjusted, wire-wound rheostat used in all our 1% bridges. The winding mandrel of this unit is shaped to give a logarithmic dial scale over a 10:1 range for constant percentage accuracy.

The R_P arm is fixed unless the ΔR% switch is pushed, in which case a rheostat is inserted to give a ± 5% adjustment for the measurement of small resistance differences. This switch has a spring return so that the rheostat cannot be unintentionally left in the circuit where it could cause an erroneous reading on the main dial.

The junction of the R_N and R_P arms is brought out to the front panel as a guard point for measuring three-terminal systems. This is particularly useful for measurements on very high resistances, where guarded shields are necessary to avoid both leakage across the unknown and capacitance-pickup effects. Resistance from the + UNKNOWN terminal to the GUARD terminal shunts the detector and causes no direct error although it will, if low enough, reduce the detector sensitivity. Resistance from the − UNKNOWN terminal to the GUARD terminal shunts R_P and will cause an error if it is below 50 megohms, which is relatively low compared with the values measured on this bridge. The guard will always tolerate the leakage resistance of shielded wires or of

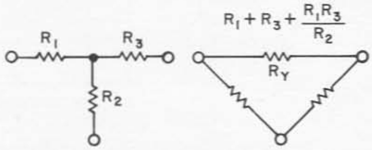

Figure 3. Delta-wye transformation.

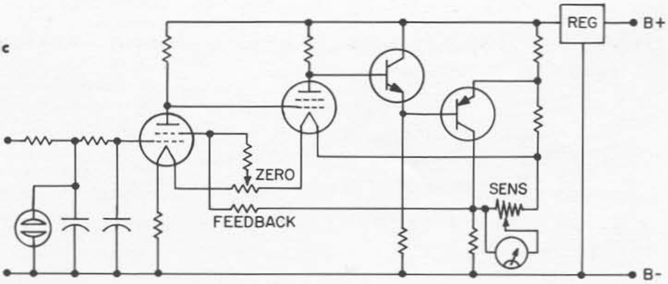

Figure 4. Elementary schematic of the detector.

anything that can be legitimately called insulation.

The Detector

The key to high-resistance measurements is high detector sensitivity and high detector input resistance. As noted above, other features can be traded for sensitivity but only if the sensitivity is adequate. The detector circuit used is shown (simplified) in Figure 4 for circuit enthusiasts. The input stage is a subminiature electrometer tube; this puts the input resistance up in the 10^{14}-ohm range and keeps the grid current negligible. The subminiature tube that follows the electrometer reduces the impedance level so that two transistors can be used to complete the feedback loop. The feedback is returned to the screen grid of the electrometer, and the zero controls are also connected to this point.

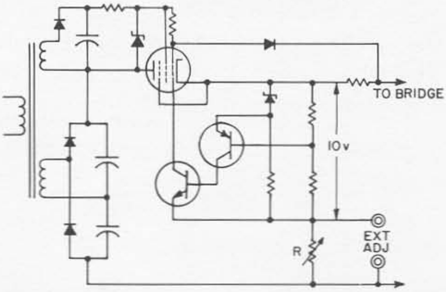

Figure 5. Schematic of the high-voltage supply.

The input tube is preceded by an RC filter to reduce the amplitude of ac signals, particularly hum, that might be picked up on the leads to the unknown resistance. A neon tube and the following 100-megohm resistor limit the grid current that could be drawn if high voltage were inadvertantly applied to the detector. The amplifier output drives a null-detector-type meter.

The sensitivity of the detector of the Type 1644 Megohm Bridge is over 200 times that of the Type 544. With well-aged tubes it can hold 100 microvolts for long periods, and voltage differences down to 10 microvolts can be detected with care.

The High-Voltage Supply

While the high-voltage supply requires a vacuum tube as a series regulator, the use of transistors and Zener diodes makes practical the flexible circuit outlined in Figure 5. Here one resistor, *R*, controls the output voltage because the controlling bridge is balanced only for a given fixed current. This makes adjustment easy both internally and by external resistance.

This regulator has a typical regulation factor of 1000, can be shunted without damage, and is current-limited to approximately 8 milliamperes on the higher voltage ranges. A current of this magnitude can be painful, but is not generally considered dangerous.[3]

APPLICATIONS

Resistance

The most obvious application is the measurement of high-valued resistors, but the procedure for this measurement is so simple and straightforward it hardly requires mention. However, the use of the ΔR% dial for measurements of small differences in resistance is of interest to those making voltage or temperature-coefficient measurements. The bridge is close to ideal for the former because of its wide voltage range, detector sensitivity, and resolution of better than 0.1% on the ΔR% dial. Examples of ΔR% *vs* voltage for several resistors are shown in Figure 6. Temperature-coefficient measurements, of course, require a test chamber, and here the GUARD terminal is most useful to permit the use of shielded leads.

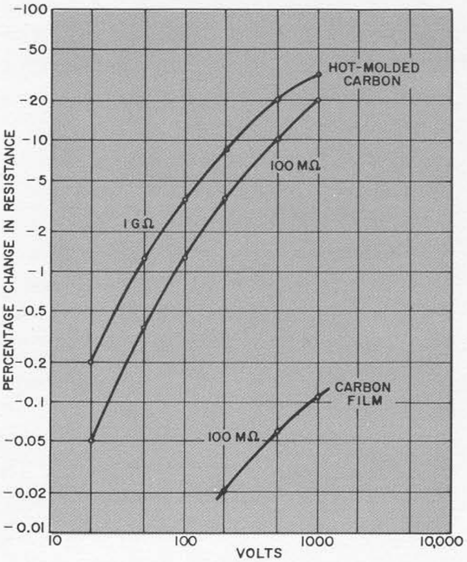

Figure 6. Voltage-coefficient data as measured on the bridge for two types of carbon resistors.

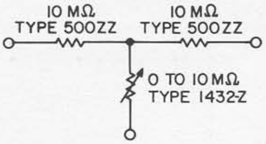

Figure 7. Adjustable resistance standard covering a range of 100 megohms to one teraohm.

An interesting use of the ΔR% dial is in precision substitution measurements with external wire-wound standards. One may well ask where to find wire-wound standards in the gigaohm range. We make and sell two-terminal wire-wound resistors up to 10 megohms (TYPE 500-ZZ), and, with the aid of the Y−Δ transformation (Figure 3), one can easily make 0.1%, wire-wound, three-terminal resistances up to high teraohm ranges. A handy adjustable resistance standard, shown in Figure 7, covers the range from 100 megohms to 1 teraohm quite nicely. Unfortunately, there are limitations. The equivalent resistance to guard on one side shunts the R_P arm of the bridge, effectively changing its value, but this error can easily be accounted for in the calibration relationship between the decade-box setting and the equivalent resistance. The other resistance to guard shunts the detector, causing a reduction in sensitivity at very high values of equivalent resistances. Thus, it takes 1000 volts applied for easy balance to 0.1%, when the T-network of Figure 7 is adjusted to give an equivalent 100 gigaohms.

Insulation Measurements

The extended range of the new bridge is necessary for studies of many of the newer insulating materials. The guard

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[3] Edwin Schecter, "Prevention of Electric Shock Hazard as a Basic Design Consideration," *Electrical Manufacturing*, January, 1960.

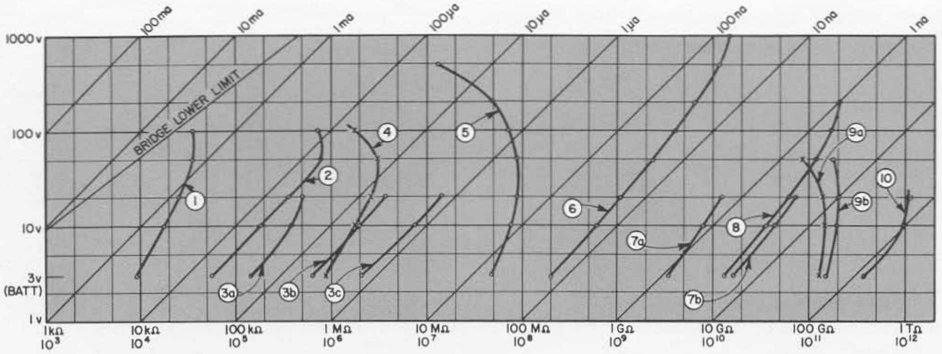


Figure 8. Leakage resistance of several semiconductor devices as measured on the megohm bridge. Key:

(1) 2N442 50-w Ge transistor (older type), R_{CBO}
(2) 2N1540 90-w Ge transistor, R_{CBO}
(3) 2N1304 Small Ge transistor, (a) R_{CEO}, (b) R_{CES}, (c) R_{CBO}
(4) 1N118 Ge diode, back resistance
(5) 1N3493 Si rectifier (200 v), back resistance
(6) 1N3256 Si rectifier (800 v), back resistance
(7) 2N2714 Si transistor, (a) R_{CEO}, (b) R_{CBO}
(8) 1N1298 Si diode, back resistance
(9) 2N2218 Si transistor, (a) R_{CEO}, (b) R_{CBO}
(10) 1N300 Si diode (selected), back resistance

is required for the standard ASTM electrode arrangements for both surface- and volume-resistivity measurements on insulation samples, and likewise it is often necessary to "guard out" alternate leakage paths in order to measure a particular piece of insulation in complex switch gear or machinery. The ability to make measurements with the unknown grounded as well as ungrounded finds application when measurements must be made to a grounded case or frame. The wider choice of voltages should permit measurements under conditions closely approximating those of normal operation, and the 1000-volt test voltage probably will find some use in hi-pot testing.

One should note that, while a bridge measurement in contrast to a megohmmeter measurement[4] requires a balancing adjustment, one can use the bridge for limit testing by setting the dial to the test limit and noting only the direction of the unbalance on the meter.

Leakage Resistance Measurements on Capacitors

An important application for a megohm bridge is the measurement of the leakage resistance of capacitors, and several features are included in the new design for this application. The charging circuit can charge 1 microfarad to 1000 volts in less than a second, independent of the resistance range setting; the discharge circuit is much faster. The high-voltage supply is well regulated to minimize the coupling of line transients to the detector, and the high bridge ratio and use of T-networks result in shorter time constants for the combination of the unknown capacitor and the bridge output resistance. In extreme cases, when very-low-leakage, high-capacitance units are measured or when large dielectric absorption is present, this type of measurement becomes tedious to make with a bridge, but

---

[4] H. P. Hall, "Redesigned Megohmmeter Simplifies Insulation-Resistance Measurement," *General Radio Experimenter*, 37, 7, July 1963.

those who have made such measurements realize that it is tedious with any type of test circuit.

Semiconductor Measurements

A relatively new application for a megohm bridge is in the measurement of the leakage characteristics of semiconductor devices. The lower test voltages of the new bridge permit measurement on transistors and diodes that would not tolerate the 100 volts supplied by the older bridge. Note that the range of the bridge easily covers the back resistance of low-leakage silicon types as well as germanium units whose resistance is many orders of magnitude lower (Figure 8). The measurement of these devices is straightforward and simple, but the interpretation of the shape of the curves is more subtle and is left to the reader. Note, however, that these devices have a positive voltage coefficient, while resistors have a negative one.

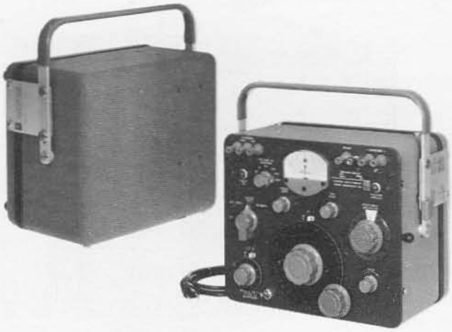


Figure 9. The Flip-Tilt case completely open (*right*) and closed for carrying (*left*).

General

This new bridge with its many features is designed to meet present-day requirements for high-resistance measurement. Its range, accuracy, choice of test voltages, and ease of operation make it suitable for a wide range of applications in the design, production, test, and maintenance of electrical and electronic products.

— Henry P. Hall

SPECIFICATIONS

Resistance Range: 1 kilohm to 1000 teraohms (10^3 to 10^{15} ohms) in ten decade ranges.

Accuracy: 10^3 to 10^{10} ohms, ±1%.
After self-calibration: 10^{10} to 10^{12} ohms, ±1%; 10^{13}, ±2%.
10^{14} ohms, ±10%.
10^{15} ohms, ± one scale division.

Test Voltage:

Fixed Voltages	10	20	50	100	volts
Minimum Resistance for Unknown	1	3	7	20	kilohms

Fixed Voltages	200	500	1000	volts
Minimum Resistance for Unknown	50	150	500	kilohms

Voltage accuracy is ±3% ±0.5 volt.

Short-Circuit Current: <15 milliamperes at 10 to 50 volts; <10 milliamperes at 100 to 1000 volts.

ΔR% Dial: ±5% range; accurate to ±0.2% or, for small changes, to ±0.1%.

Minimum Test Voltage for 1% Resolution: (for approximately 1-mm meter deflection).

Multiplier Setting	*Max R_x*	*Volts*
100 G or less	10^{11}	10
100 G	10^{12}	100
1 T	10^{13}	200

Power Requirements: 105 to 125 (or 210 to 250) volts, 50 to 60 cps, 13 watts.

Cabinet: Flip-Tilt.

Dimensions: Width 12¾, height 12½, depth 7¾ inches (325 by 320 by 200 mm), over-all; with case closed and including handle.

Net Weight: 18 pounds (8.5 kg).

Shipping Weight: 22 pounds (10 kg).

Type		*Price*
1644-A	**Megohm Bridge**	**$625.00**

AC POWER SUPPLY FOR THE VIBRATION METER

The Types 1553-A and —AK Vibration Meters, which are normally battery operated, can be converted to power-line operation with the new Type 1262-C Power Supply.

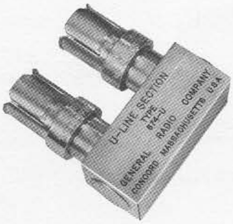
This convenient ac power pack can be attached to the Flip-Tilt case of the vibration meter, as shown in the photograph. **Price: $135.00**

SPECIFICATIONS

Volts	*Frequency cps*	*Watts*	*Filament Supply*		*Plate Supply*		*Dimensions*	*Net Weight*	*Shipping Weight*
			volts	*ma*	*volts*	*ma*			
105–125	50–400	3	#1 1.3	31	4.5	61	7⅞ x 9⅛ x 3¼ inches (200 x 235 x 83 mm)	2½ lb (1.2 kg)	8 lb (3.7 kg)
195–250	50	6	#2 1.3	31	4.5	61			
			#3 1.3	11	4.5	61			

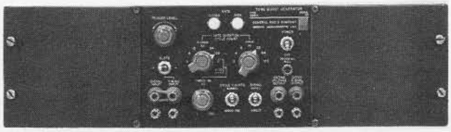
COAXIAL U-LINE SECTION

The U-Line Section is, as its name implies, a section of coaxial line in the shape of the letter U. It is supplied as an accessory with our Type 1607-A Transfer Function and Immittance Bridge, but is also a useful component in many coaxial line set-ups. In response to many requests, we are now making it generally available. **Price: $25.00**



RELAY-RACK MOUNT FOR THE TONE-BURST GENERATOR

The Type 1396-A Tone-Burst Generator, described in the May, 1964, issue of the *Experimenter*, can be adapted for relay-rack mounting through the use of panel extensions, as shown in the accompanying photograph. Panel height is 5¼ inches.



Order Type 480-P308 Adaptor Plate Set. **Price: $7.00**

ERRATA — JUNE ISSUE The following errors have been noted in our June issue:

Page 11, line 11: R_4 should be Q_4.

Page 11, Figure 13: transistor should be labelled Q_4.

Pages 3 and 14: Figures 2 and 20 are transposed.

General Radio Company

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THE GENERAL RADIO
EXPERIMENTER

**TYPE 1123-A
DIGITAL
SYNCHRONOMETER**

WESCON/64

FRONTIERS IN ELECTRONICS

- AUTOMATIC CAPACITANCE BRIDGE
- CAPACITANCE MEASURING ASSEMBLY
- MEGOHM BRIDGE
- DIGITAL SYNCRONOMETER
- STANDARD-FREQUENCY OSCILLATOR
- FREQUENCY SYNTHESIZERS
- COAXIAL EQUIPMENT
- SLOTTED LINE RECORDER SYSTEM
- DIGITAL FREQUENCY METER
- DIGITAL TIME AND FREQUENCY METER
- DIGITAL-TO-ANALOG CONVERTER
- GRAPHIC LEVEL RECORDER
- SOUND AND VIBRATION ANALYZER
- WAVE ANALYZER
- TONE-BURST GENERATOR

**TYPE 1680-A
AUTOMATIC CAPACITANCE
BRIDGE ASSEMBLY**

VOLUME 38 NUMBER 8

AUGUST 1964

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LOS ANGELES SPORTS ARENA—BOOTHS 1344-1346

AUTOMATIC BRIDGE AMONG NEW INSTRUMENTS AT WESCON

We have always considered WESCON (Western Electronic Show and Convention) a major event in our exhibit schedule, and we accordingly try to schedule the introduction of important new instruments for the occasion. Last year our TYPE 1900-A Wave Analyzer was unveiled at WESCON. This year, an automatic capacitance bridge heads the list of new products bound for Booth 1343–1346 at the Los Angeles Sports Arena.

TYPE 1680-A
AUTOMATIC CAPACITANCE BRIDGE ASSEMBLY

The "automatic bridge," up until now, either has not been a true bridge at all or has been a monster system with a five-digit price. GR, whose experience with impedance bridges goes back nearly a half-century, has now produced an instrument-sized, instrument-priced, automatic capacitance bridge that is sure to be the standard for such instruments for many years to come.

The Automatic Capacitance Bridge Assembly requires only connection of the unknown. The bridge selects the proper range, achieves balance, and presents the value of the unknown on an in-line Numerik digital readout that includes capacitance, dissipation factor

CONTENTS OF THIS ISSUE

or conductance, decimal points, and units. All this information is also presented in binary-coded decimal form (1-2-4-2 BCD) for use by printers or other data-handling equipment. The entire balance operation consumes about a half second.

Three switch-selected generator frequencies are available: 120, 400, and 1000 cycles per second. Capacitance range is 100 picofarads (full-scale) to 100 microfarads at 400 and 1000 c/s (resolution is 0.01 picofarad) and 1 microfarad (full-scale) to 1000 microfarads with a 120-cycle signal. Dissipation-factor range is 0.0001 to 1.0, and the bridge will measure parallel conductance from 0.1 nanomho to 1 mho at 400 and 1000 c/s, 1 micromho to 1.0 mho at 120 c/s.

Basic accuracy of capacitance measurement is ±0.1% of reading ±0.01% of full scale. Accuracy of frequencies supplied by the transistorized oscillator is ±1%.

The new bridge features several operating modes to accommodate a wide range of possible applications. In the tracking mode, for example, it will continuously follow variations in a capacitor under test, permitting automatic recording of the effects of temperature or other environmental conditions. In the tracking-sampled mode, the bridge tracks the variations but yields data only on command.

All this automation comes in a rack-bench instrument only 10½ inches high, with a price requiring only four digits ($4850).

TYPE 1123-A DIGITAL SYNCRONOMETER

The standard clock face of the Syncronometer® time comparator has gone the way of bridge balance controls, as you can see from the picture of our new Type 1123-A Digital Syncronometer. Hours, minutes, and seconds appear on an in-line Numerik digital readout. The readout, however, is only one of many significant differences between this Syncronometer and its predecessors.

The Syncronometer is a time-indicating instrument normally operated by a 100-kc input signal from a precision frequency standard, such as the General Radio Type 1115-B. An automatic disabling circuit stops the "clock" if the input signal changes frequency or if it misses even one cycle. There is therefore no danger that the user will unknowingly accept data spoiled by a momentary input failure.

Syncronometer time can be compared with standard time (e.g., from WWV) within ±10 microseconds *without* being itself disturbed. After the comparison is complete, Syncronometer time can be synchronized against standard time with one push of a button.

The new instrument was designed with remote operation in mind. Any number of them can be started simultaneously from one location, with a preset time delay between local and remote units of 0 to 999.99 milliseconds.

The time indicator, as mentioned, is a six-place Numerik register. Digits can be changed during operation, and the register can be set to recycle after any number of hours from 1 to 99.

Timing pulses at frequencies from 100 kc/s down to 0.1 c/s (in decimal submultiples) are available at output connectors. A 0.2-microsecond marker is also available for high-resolution time intercomparisons, as with Loran C.

The all-solid-state Syncronometer® time comparator operates from standard ac power lines but also includes its own nickel-cadmium (explosion-proof) batteries for automatic takeover in emergencies.

Price: **$2950.00**

NEW MEMBERS OF THE GR900 FAMILY

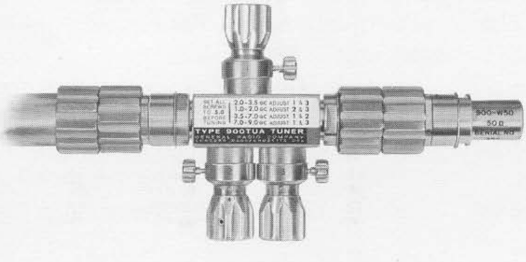
As the GR900 precision coaxial connector gains rapidly in popularity, we are striving to meet the great demand for elements based on this coaxial design. Among those to be introduced at WESCON are:

The **Type 900-TUA Tuner,** used with the Type 900-LB Precision Slotted Line to cancel out residual reflections of rf terminations, measuring instruments, connectors, and adaptors at frequencies between 1 and 9 Gc/s. The tuner comprises a section of 50-ohm coaxial line with three adjustable tuning screws having engraved micrometer scales. These screws are used to tune out reflections. All three can be set to a "neutral" position, where the tuner effectively becomes a reflectionless continuation of the line. The maximum VSWR that can be tuned out under all conditions of mismatch, phase, and frequency is 1.00 + 0.012 times the frequency in gigacycles. Larger reflections can usually be tuned out.

The **Type 900-LZ Reference Air Line,** available in 5-, 7.5-, 10-, 15-, and 30-centimeter sections. In use, the free inner conductor is centered on the center-conductor contacts of the GR900 connectors at the ends, by means of spring-loaded inserts. The absence of any support in the line itself means that these air lines are essentially reflectionless, without even the minor discontinuity of a well designed bead.

Several new Type 900-Q Adaptors, which are used to connect the GR900 series to Types BNC, C, and TNC plugs and jacks.

Types 900-WNC and -WNE Short-Circuit Terminations. The former is de-



The Type 900-TUA Tuner installed between a coaxial line and a matched termination.

signed for use with the reference air line described above, the latter to produce a short circuit at the same reference plane as that of the Type 900-WO Open-Circuit Termination.

Connector Kits for Reference Air Line. Those desiring reference air lines of lengths other than those available as ready-made sections (see above) can now make their own sections out of GR precision rod and tubing (Part No 0900–9508 and 0900–9509, respectively). New connector kits include the necessary parts of the GR900 connector for such line fabrication as well as for the connection of reference air line to components.

WESCON IEEE WEMA®

Frontiers in Electronics

. . . . and also on display

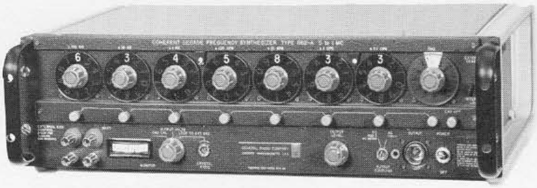
TYPE 1360-B MICROWAVE OSCILLATOR

TYPE 1422-CL PRECISION CAPACITOR

These instruments are described elsewhere in this issue.

TYPE 1521-B
GRAPHIC LEVEL RECORDER

TYPES 1161-A AND 1162-A
COHERENT DECADE
FREQUENCY SYNTHESIZERS



Descriptions of these instruments will appear in the September issue of the *General Radio Experimenter.*

400-kc SOLID-STATE COUNTER

Experience with the Type 1150-A Digital Frequency Meter[1] and with the circuitry of its more sophisticated brother, the Type 1151-A,[2] has made possible a number of improvements that increase reliability, ease of operation, and frequency range.

A new model, the Type 1150-B, now replaces the original A-model. This digital frequency meter is based on the same simple, economical ring counting units used in its predecessors. The upper frequency limit, however, has been raised from 300 kc/s to 400 kc/s,

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[1] R. W. Frank and J. K. Skilling, "A Five-Digit Solid-State Counter for Frequency Measurements to 220 kc," *General Radio Experimenter*, 36, 4, April, 1962.

[2] R. W. Frank, "Zero to 300 kc with Five-Digit Accuracy," *General Radio Experimenter*, 37, 6, June, 1963.

with no increase in price. Also, for increased operating convenience, a trigger-level control has been added, so that one can optimize the input sensitivity for all waveforms from sine waves to low-duty-ratio pulses. This greatly reduces the possibility of erroneous indications from noise or other unwanted signals.

The program of the new counter is based on clock pulses of 0.01 second, in contrast to the one-second intervals of the previous model. Thus, the maximum interval between display and count is reduced to 0.01 second, regardless of the counting and display-time settings. Hence, idle time is less, and the counter program is more efficient.

The Type 1150-B Digital Frequency Meter provides an economical and reliable means of frequency measurement in the electronics industry and, with appropriate transducers, has many applications in general industry.

The counter is available for either bench or rack mounting and, optionally, with output provision for operating the GR Type 1136-A Digital-to-Analog Converter and the Type 1137-A Data Printer.

—R. W. Frank

Type		*Price*
1150-BM	**400-kc Digital Frequency Meter,** Bench Model	**$ 995.00**
1150-BR	**400-kc Digital Frequency Meter,** Rack Model	**995.00**
1150-BPM	**400-kc Digital Frequency Meter** (with output for printer or D/A converter), Bench Model	**1050.00**
1150-BPR	**400-kc Digital Frequency Meter** (with output for printer or D/A converter), Rack Model	**1050.00**

INCREASED FREQUENCY RANGE FOR THE TYPE 1151-A DIGITAL TIME AND FREQUENCY METER

The Type 1151-A Digital Time and Frequency Meter [1] measures frequency, frequency ratio, period, and multiple periods and is equipped with a full complement of input controls. Its guaranteed upper frequency limit, formerly 300 kc/s, has been increased to 400 kc/s, with no increase in price.

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[1] R. W. Frank, "Zero to 300 kc with Five-Digit Accuracy," *General Radio Experimenter*, 37, 6, June, 1963.

THE TYPE 1360-B MICROWAVE OSCILLATOR

An improved model of the popular Type 1360 Microwave Oscillator is now in production. Amplitude and frequency stabilities of the carrier under square-wave-modulated conditions have been markedly improved by a diode clamp circuit in the klystron repeller modulator. In addition, regulation of the supply voltage for the 1-kc square-wave generator has stabilized the modulation frequency. These improvements are particularly valuable to those customers who will use the oscillator with the Type 1640-A Slotted Line Recorder System.[1] The stringent stability requirements on amplitude and modulation frequency in this system are due to the large available scale expansion [2] and the narrow audio bandwidth of the selective amplifier.

The accompanying figure is a graphic record showing the short-term amplitude stability of the new Type 1360-B Oscillator incorporated in a Type 1640-A system. The scale expansion is 1% full scale (1.01 VSWR). The line voltage was varied from 110 to 120 volts at a rate of 1 cycle per second by means of a Variac®autotransformer driven by a Type 1750-A Sweep Drive.

— G. P. McCouch

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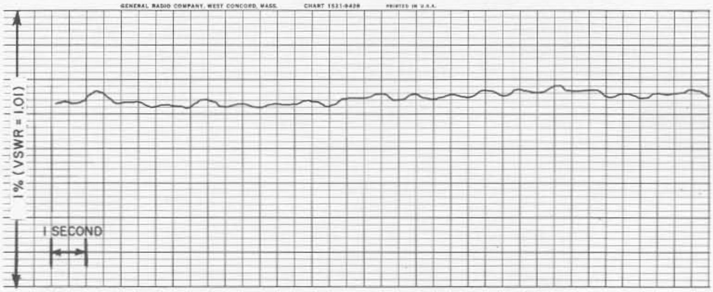
[1] To be described in a forthcoming issue of the *General Radio Experimenter*.

[2] A. E. Sanderson, "A New High Precision Method for the Measurement of the VSWR of Coaxial Connectors," *IRE Transactions on Microwave Theory and Techniques*, November, 1961.

Type		Price
1360-B	Microwave Oscillator	$1175.00



Type 1360-B amplitude stability in presence of 10-volt peak-to-peak line-voltage excursions at 1-cycle rate as measured in a Type 1640-A Slotted Line Recorder System.

A THREE-TERMINAL PRECISION CAPACITOR WITH LOW TERMINAL CAPACITANCES

In any three-terminal capacitor each terminal of the direct capacitance has a capacitance to ground or shield whose magnitude depends on the type of construction. In addition, when the direct capacitance is variable, these terminal capacitances are usually not constant but change with setting. When such a capacitor is used as a standard in bridge measurements or is measured on a bridge, the terminal capacitances can, if large enough, cause an error in capacitance measurement, which depends on the degree of excellence of the guard arrangement provided in the bridge and on the magnitude of the measured capacitance.

The new Type 1422-CL Precision Capacitor has been designed for those uses where terminal capacitances are important. Its direct capacitance range is 10 to 110 pf; its terminal capacitances are of the order of 30 pf and 60 pf, and are quite constant with setting.* Other specifications, as listed below, are similar to those of other units in the 1422 line.

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* The Type 1422-CC, which uses a different construction, has a range of 5 to 110 pf but has much larger terminal capacitance.

SPECIFICATIONS

Direct Capacitance Range: 10 to 110 pf.

Capacitance Scale: 0.02 pf/division.

Accuracy: ± picofarads listed below or ± 0.03%, whichever is greater.

	Total Capacitance	*Capacitance Differences**
Direct-Reading (Adjustment) —	0.1 pf	0.2 pf
After scale correction from calibration chart —	0.04 pf	0.08 pf
After correction from precision calibration (extra charge) —	0.01 pf	0.02 pf

* Divide error by 2 when one setting is made at a calibrated point.

Stability: Capacitance change per year is less than one scale division.

Maximum Voltage: 1000 volts, peak.

Residual Impedances (typical):

Series Inductance — 0.14 μh.

Terminal Capacitances —

High terminal to case	min scale	33 pf
	max scale	32 pf
Low terminal to case	min scale	57 pf
	max scale	54 pf

Insulation Resistance: Greater than one teraohm at 23C and less than 50% RH.

Terminals: GR Type 874 locking-type coaxial connectors; adaptors to other coaxial types are available.

Accessories Supplied: Two Type 874-CL58A Cable Connectors.

Dimensions: Width 9½, height 7, depth 8½ inches (245 by 180 by 220 mm), over-all.

Net Weight: 10¾ pounds (4.9 kg).

Shipping Weight: 15 pounds (7 kg).

Type		*Price*
1422-CL	**Precision Capacitor**	**$340.00**
1422-CLP	**Precision Capacitor** with precision calibration	**390.00**

THE GENERAL RADIO
EXPERIMENTER

VOLUME 38 NUMBER 9 SEPTEMBER 1964

COHERENT DECADE FREQUENCY SYNTHESIZERS

A Modular Design

The term frequency synthesizer can quite properly be applied to any of a variety of devices. For instance, a type of radio transmitter widely used for aircraft communications synthesizes a large number of channels by combining frequencies selected from groups of independent crystals. Such synthesizers are not "frequency coherent," since the output frequency reflects the individual errors of several crystal oscillators. But, if each of the crystals in the groups has adequate accuracy, the synthesized output frequency is accurate enough and stable enough for the intended application.

An example of coherent frequency synthesis is found in the circuitry often used with atomic frequency standards to translate the atomic resonance frequency to a convenient round number, such as 5 Mc/s. Synthesizers of this kind derive all intermediate frequencies and the final frequency from a single source and are thus frequency coherent. However, since only one synthesized output frequency is produced, such a device is limited to its special-purpose use.

Members of a rapidly growing class of general-purpose frequency synthesizer, in which the new GR designs

Figure 1a. View of the Type 1162-A Coherent Decade Frequency Synthesizer.

belong, produce many output frequencies coherently from a single primary source. Output may be at any one of a very large number of discrete frequencies, usually selectable on a decimal-digit basis. This article will describe the outstanding characteristics and novel features, both electrical and mechanical, included in the first two of a family of synthesizers now in production by General Radio Company. Of particular note in these designs are, first, the use of repetitive plug-in subassemblies, which permit many variations to suit particular requirements; second, provision for continuous, smooth coverage of any chosen part of the frequency band, from very wide to very narrow at will; and, third, circuitry for the generation of precision frequency markers. Frequencies are selected by means of a series of stepped digit units, plus a continuously adjustable decade. Remote programming capability is standard for the continuously adjustable unit; it is an extra-cost option for the stepped decades.

TYPES 1161-A AND 1162-A COHERENT DECADE FREQUENCY SYNTHESIZERS

Frequency Ranges

Figure 1a and Figure 1b show the two GR synthesizers. The physical resemblance is no accident; the units are designed to be nearly identical. In fact, one can be transformed into the other by the change of one plug-in module.

Figure 1b. The Type 1161-A Synthesizer is similar in appearance to the Type 1162-A.

The Type 1161-A Coherent Decade Frequency Synthesizer provides any desired output frequency from dc to 100 kc/s, with decimal-digit readout of the selected frequency on a series of up to seven illuminated digit dials and a continuous-coverage dial. The smallest digital step in the fully equipped unit is 0.01 c/s. The fine divisions on the continuous dial, when used at the end of the digit series, are at 0.0001-cycle intervals. For those who do not require such fine digital steps, the design permits digit-insertion units to be omitted at a reduction in price. Figure 2 shows one such stripped-down model with four digit dials plus the continuous coverage dial. The three missing digit-insertion modules can be plugged in, whenever the need arises, to upgrade the unit to a complete instrument.

The Type 1162-A Coherent Decade Frequency Synthesizer has output frequencies up to 1 Mc/s, with a smallest digital increment of 0.1 c/s and finest calibration lines on the continuous dial at 0.001-cycle intervals.

In either synthesizer, the Continuously Adjustable Decade (CAD) can be added on at the end of the series of digital dials or, at the push of a button, can functionally replace all digit dials

CONTENTS OF THIS ISSUE

below any chosen rank and thereby provide wide, single-dial frequency coverage, remotely controlled, if desired.

By virtue of the self-calibrating feature for the CAD, explained in detail later, the partially equipped models, such as the Type 1162-A4C illustrated in Figure 2, can set frequencies to more significant figures than the number of dials would suggest. Thus the Type 1162-A4C can be set to four figures on the digit dials and four more on the CAD, calibrated against the digit dials, for a total of eight significant figures.

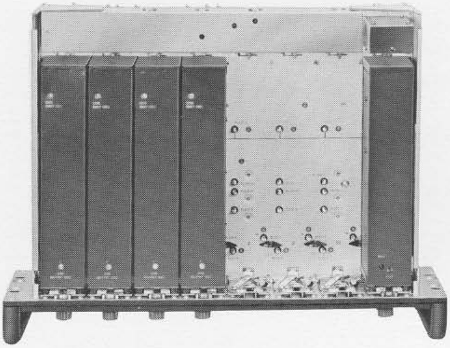
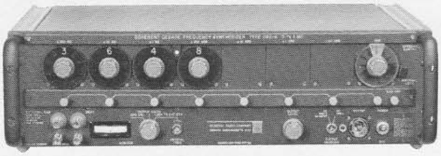
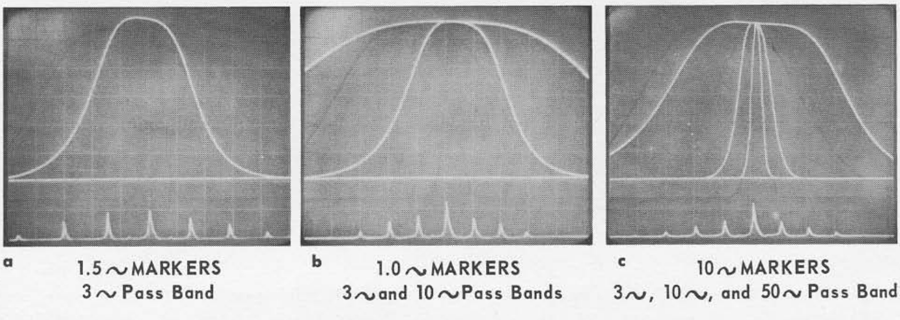


Figure 2. A partially equipped instrument, Type 1162-A4C, top and panel views.



Swept-Frequency Generation with Frequency Markers

The CAD dial is direct-reading; the numbered major divisions correspond to the digits on the step-adjustable dials. As an additional unique and very useful feature, built-in monitor circuits make it possible to set the CAD dial precisely to three or more significant figures, in terms of the digit dials. Provisions are also included for varying the frequency of the continuous unit in accordance with an electrical control input. These monitoring and calibrating circuits assist in the generation of accurate frequency markers, at the center frequency defined by the digit dials and at independently chosen side frequencies. The synthesizers thus become sweep-frequency generators, capable of being swept with precision over frequency bands ranging from a fraction of a cycle to many kilocycles. Figure 3, which will be discussed in more detail later, is an example of this sort of application. The 3-, 10-, and 50-cycle passbands of the GR Type 1900-A Wave Analyzer are shown displayed on a storage oscilloscope, with accompanying center frequency and side markers at small and precise intervals



a 1.5∼MARKERS
3∼Pass Band

b 1.0∼MARKERS
3∼and 10∼Pass Bands

c 10∼MARKERS
3∼, 10∼, and 50∼ Pass Bands

Figure 3. Pass bands of the Type 1900-A Wave Analyzer, with simultaneously generated frequency markers. The signal source for this measurement was a Type 1161-A Synthesizer.

Modular Construction

The circuits of these synthesizers have been packaged in modules carefully chosen as functional elements, which can be combined in a variety of ways to satisfy either general-purpose or specialized requirements. The plug-in modules are pictured in Figure 4 and are briefly described in the following paragraphs. All module circuitry is solid-state and is mounted on one side only of the etched boards. For more detailed descriptions, see page 7.

Digit-Insertion Unit—Type 1160-DI-1. This module, basic to all GR frequency-synthesizer assemblies in this series, is used repetitively to provide selection of each available digit. A DI-1 unit is plugged in behind each of the digit dials visible in Figures 1 and 2.

Continuously Adjustable Decade—Type 1160-CAD. One of these units is used in each instrument to provide continuous frequency coverage on a single dial over wide or narrow frequency regions as selected by push-buttons. It may be omitted from the assembly where continuous coverage is not required.

Ancillary Frequency Source—AFS. In this assembly is the 5-Mc master crystal oscillator from which all frequencies used in the synthesis are derived. It provides an additional output at 42 Mc/s, which is fed to all the DI-1 units and the CAD, and a "picket fence" of frequencies spaced 100 kc/s apart between 3 and 3.9 Mc/s. This picket fence is used in each DI-1 unit for digit-selection purposes.

Calibrating Mixer—CM-1. This simple module compares the output frequency of the CAD unit with the dialed output frequency of any chosen group of DI-1 units for self-calibration or marker generation. If the CAD unit is not installed in a particular assembly, this mixer is omitted also.

Output Mixer OM-1 and Output Multiplier-Mixer OMM-1. These modules, mechanically interchangeable, provide frequency translation between the synthesizing modules and the output circuits of the Types 1161-A and 1162-A Synthesizers, respectively. Replacement of one by the other in the main frame changes the instrument from a Type 1161-A to a Type 1162-A or vice versa.

Figure 4. The basic modules of a Type 1161-A or a Type 1162-A Synthesizer. Left to right *(front)*, Digit-Insertion Unit, Continuously Adjustable Decade, Power Supply, Ancillary Frequency Source; *(rear)* Calibrating Mixer and Output Multiplier-Mixer. Dial light panels for a DI-1 unit and the CAD are resting on the respective boxes.

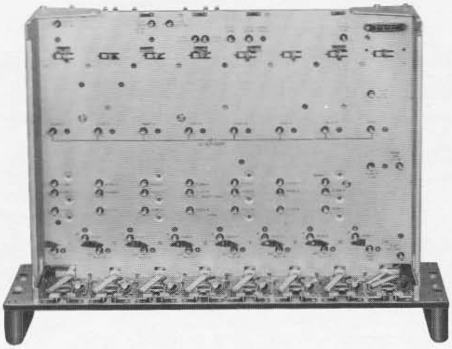


Figure 5. Top view of the Synthesizer chassis.

Power Supply—PS-1. This unit accepts ac power from the line or dc from a 20- to 28-volt battery and supplies 18 volts, regulated, to operate the synthesizer.

Figure 5 shows the main frame into which the modules listed above are plugged to make up either a Type 1161-A or a Type 1162-A Synthesizer. Its deck is of "sandwich" construction, with banana plugs protruding downward to engage the power supply and the AFS and upwards to connect with all other modules. The frame contains the push-button switches that control the functional position of the CAD, the monitoring circuits, and the final output amplifier.

PANEL CONTROLS

Frequency Selection

As may be seen in Figure 1, eight frequency-setting dials, with illuminated numbers on seven of them and a continuously calibrated scale on the eighth, provide an in-line readout of the synthesized frequency to nine or more significant figures. Behind each dial is a digit unit. The signal flows through this synthesizing portion of the instrument from right to left, entering and leaving each digit unit in sequence.

Below each digit dial is a pushbutton. When one of these buttons is pushed (and automatically latched), an rf switch behind it in the sandwich deck performs the following two functions:

1) The output from the digit unit above the actuated button and from all units to the right of it is connected to the Calibrating Mixer. (An output of the CAD unit is permanently connected to the other input of this mixer.)

2) The main output of the continuous unit (CAD) is connected to the input of the group of digit units to the left of the actuated button. The CAD thus functionally replaces the disconnected digit units, as regards their contributions to the output frequency.

Operation of the pushbutton also controls lamp switches behind the panel to extinguish the illumination behind the replaced dial numbers, so that the output frequency is read from the illuminated numbers at the left, followed by the continuous dial reading, with little chance for error.

Monitor Switch and Mixer

The MONITOR switch, in its counterclockwise position (CAD CAL), applies the calibrating-mixer output to the monitor meter. The meter behaves like an analog frequency meter when the CAD output frequency differs substantially from the output frequency of the replaced group of digit units, indicating upscale from center. As the CAD is tuned to within a few cycles of zero beat, the meter follows the beats directly. The CAD unit can thus be adjusted to the frequency of any group of replaced digits on the main dials.

The beat frequency from the calibrating mixer also appears at all times on the binding posts marked BEAT. Whenever this beat frequency is below 50 c/s, the CAD frequency is equal to that indicated by at least three figures of the digit dials used for calibration; if the beat is below 5 c/s, the CAD dial may be relied on to four figures.

When the MONITOR switch is in its central position (OUTPUT VOLTS), the meter measures the voltage at the main output connector, with a scale range from 0 to 2 volts, rms. With a 50-ohm load or higher, the output can always be adjusted to 2 volts or more, by means of the OUTPUT LEVEL control, at any frequency above 30 c/s.

As will be discussed more fully later, the master crystal oscillator may be phase-locked to an external frequency standard.

When a locking signal is introduced (through a jack at the rear of the instrument) and the MONITOR switch is in its clockwise position (LOCK TO EXT STD), the meter verifies proper phase lock of the crystal oscillator to the standard.

External CAD Control and Deviation Indication

The Continuously Adjustable Decade (CAD) can operate in either of two modes, as selected by the coaxial lever switch at the right of its dial. When this switch selects the INTERNAL LOCK mode, the CAD is highly stable, since its output frequency is a synthesis of a relatively large crystal-locked frequency and a small contribution from an LC oscillator.

In the EXTERNAL CONTROL mode, the CAD output is derived completely from a continuously tunable LC oscillator. Part of the tuning capacitance is supplied by a voltage-controllable silicon capacitance diode. The control circuit is dc-coupled to the EXTERNAL CONTROL binding posts at the left of the panel. When the CAD is switched to the EXTERNAL CONTROL mode, the dial light of the CAD is dimmed as an indication to the operator that the switch is in this position.

As marked on the panel, a control signal of −0.3-volt dc will shift the CAD frequency upward, by an amount equal to one major dial division, from a neutral position set by the CAD dial itself. The unit can be swept ±10 major divisions from any starting point within the dial range. When such electronic control is used, the beat frequency appearing at the BEAT binding posts is strictly proportional to the deviation of the CAD frequency from the digits on the replaced dials and increases at the rate of 10 kc/s per major CAD dial division. Since the major (numbered) divisions on the CAD dial correspond directly to the numbers on the digit dial immediately above the actuated pushbutton, a 10-kc beat note indicates, in the Type 1161-A, an *output* frequency deviation ranging from 0.001 c/s to 10 kc/s in decade steps, depending only on which pushbutton has been pressed. In the Type 1162-A, the corresponding range is from 0.01 c/s to 100 kc/s. (The minimum figures occur when the button directly under the CAD itself is actuated; the replaced digit in this case is 0.)

Two other controls on the front panel are screw-driver operated. The CRYSTAL FREQ control is a vernier on the free-running frequency of the master crystal oscillator. It may be used either to set the free-running frequency

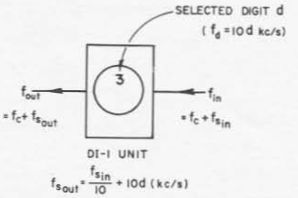


Figure 6. Signal traversing a typical Digit-Insertion Unit.

accurately against a reference or, if the synthesizer is phase-locked to an external standard, to adjust for optimum locking conditions. The other screwdriver control operates a switch that changes the normal ac-coupled output circuit to dc coupling. With dc coupling, the output frequency can be adjusted as low as desired, down to dc, but the output voltage available is only about 1 volt, rms. The output voltage monitor meter is disconnected in this switch position.

With these points in mind, let us now proceed to a consideration of the synthesizing principle used to attain stepped frequency increments as small as may be desired.

THE SYNTHESIZING PRINCIPLE USED IN GR SYNTHESIZERS

Each DI-1 module in the synthesizer receives an input signal at about 5 Mc/s, modifies the frequency of this signal very slightly in two steps, and delivers the modified frequency (again near 5 Mc/s) as an input to the next DI-1 unit in the train. Figure 6 is an elementary diagram showing the essential processes performed in a DI-1 unit.

In Figure 6 each signal (input and output) is shown as having a frequency that, for convenience, may be regarded as the sum of two components. The first component is a "carrier" frequency, which remains unchanged through all the DI-1 units at 5000 kc/s.

The second component is the "signal" component. The signal component always lies between 0 and 100 kc/s.

The signal component is modified by passage through each digit-insertion unit in the following very simple ways, as indicated in the figure. If we denote the total input frequency by

$$f_{in} = f_c + f_{s_{in}} \quad \text{kc/s} \tag{1}$$

and the output frequency by

$$f_{out} = f_c + f_{s_{out}} \quad \text{kc/s} \tag{2}$$

then the DI-1 unit performs operations so that:

$$f_{out} = f_c + \frac{f_{s_{in}}}{10} + 10\,d \quad \text{kc/s} \tag{3}$$

or

$$f_{s_{out}} = \frac{f_{s_{in}}}{10} + 10\,d \quad \text{kc/s} \tag{4}$$

where

f_{in}, f_{out} = total input and output frequencies.
f_c = carrier component, invariant.
$f_{s_{in}}$ = signal component of input.
$f_{s_{out}}$ = signal component of output.
d = selected digit, from 0 to 9 in integral steps.

For convenience in following frequency changes through the train of digit units, we can disregard the carrier component, since this passes through unchanged, and concentrate on only the signal component, as in equation (4).

Figure 7 shows four DI-1 units (A, B, C, D), each with digits selected as indicated, and the signal-component flow through the train, from right to left. Observe the correspondence between the signal component of output frequency from unit A (24.39 kc/s) and

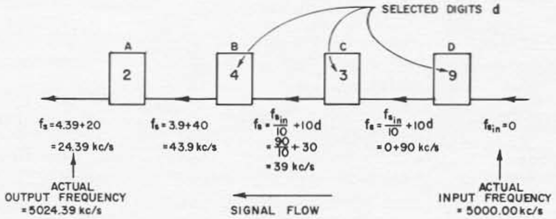


Figure 7. Signal passage through four Digit-Insertion Units, illustrating synthesis of desired signal component.

the digit dial settings (2439). It is clear that the output frequency from *any* unit in such a train of digit units will have a signal component that is, in kilocycles per second:

$$f_s = 10d_1 + d_2 + 0.1\ d_3 + 0.01\ d_4 + \ .\ .\ . \qquad (5)$$

where d_1 represents the dialed digit on the unit at which the output frequency is measured, and d_2 through d_n represent digits dialed on successive units to the right.

Equation (4) defines the two fundamental operations performed on the signal component by each digit unit, which permit frequency synthesis in steps as small as may be desired. These operations are:

1) Divide the input signal component by 10.

2) Add to this a digit component that is 10 times the dialed digit (in kc/s), and pass the result on to the input of the next DI-1 unit in the train.

This general principle is not new. It was disclosed in print at least as early as 1952[1] and has been utilized in a number of modern applications.[2, 3, 4, 5] However, the grouping of necessary circuits into a train of identical digit units, each of which performs the two listed operations, has made possible the very versatile Types 1161-A and 1162-A Synthesizers and forthcoming members of this family.

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[1] Australian Patent No. 148,412, "Frequency Synthesizer," Accepted 29 September 1952, Amalgamated Wireless, Ltd.

[2] U. S. Patent No. 2,829,255, "Digital Frequency Synthesizer System," April 1, 1958, V. W. Bolie.

[3] U. S. Patent No. 2,930,988, "Apparatus for Generating Frequencies," March 29, 1960, A. F. Boff.

[4] U. S. Patent No. 2,934,716, "Variable Frequency Synthesizer," April 26, 1960, J. W. Smith.

[5] U. S. Patent No. 3,125,729, "Digit Controlled Frequency Synthesizer," March 17, 1964, Stone & Hastings.

OPERATING PRINCIPLES

The Digit-Insertion Unit (DI-1)

The principle of the Digit-Insertion Unit is the dual of that of the familiar error multiplier sometimes used to magnify small frequency differences by successive subtractions and multiplications. In the Digit-Insertion Unit, in contrast, we add and divide, to *manufacture* small differences.

As shown at the right of Figure 8, the total input signal to a digit unit lies between 5 and 5.1 Mc/s. To this is added 42 Mc/s generated coherently from the master crystal oscillator. To the resulting sum frequency, which lies between 47 and 47.1 Mc/s, is added the digit component. The digit component may be any one of 10 frequencies from 3.0 to 3.9 Mc/s in 0.1-Mc steps. The desired digit component is selected by means of a phase lock between an oscillator rough-tuned to the desired frequency and one component of a picket fence generated coherently from the crystal oscillator. The final sum frequency, after this second addition, lies between 50 and 51 Mc/s.

The output frequency from the digit unit is one-tenth of this, and therefore lies once more between 5.0 and 5.1 Mc/s. Note that the signal component of the total input frequency has thus been divided by 10, as required by equation (4), and that a digit component has been added, which, in kilocycles per second, is 10 times the dialed digit, as specified in equation (4).

In the DI-1 unit the division by 10 is achieved by the use of the phase-lock technique. The tenth harmonic of the output oscillator is compared in a phase detector with the 50- to 51-Mc signal mentioned above, and the phase-detector output locks the output oscillator at exactly one-tenth of this reference signal.

Both phase locks use automatically switched low-pass filters in the control loop — wide band for capture, narrow band as lock is achieved. Automatic-sensing circuits extinguish the dial lighting if there is no lock. The capture range for each oscillator is so far in excess of requirements, however, that such failure is rare.

Observe that the choice of frequencies used in the above synthesizing process is such that no low-order spurious products approach coincidence in any of the mixers. This means that all important spurious frequencies are relatively far removed from the desired signals and that filtering requirements are therefore not severe. In addition, the simple RC filters in the phase-lock loops are able to remove any such products not completely eliminated by the mixer output filter.

In Figure 8, a decade dial is shown as the frequency-selecting control. In the remotely programmable version of the DI-1 unit, the manual dial has an eleventh position marked "R." At this setting, control is transferred to a rear connector, which allows digit selection by closure to ground in a biquinary code.

The Continuously Adjustable Decade (CAD)

The CAD is very similar in principle to the DI-1. The digit selection uses an oscillator continuously adjustable from 2.9 to 4.1 Mc/s (3.0 to 3.9 corresponds to digits 0 to 9; 2.9 provides range to −1, and 4.1 extends the high side to 11). In the INTERNAL LOCK mode, a 5.0-Mc input signal is added to 42 Mc/s to generate 47 Mc/s, crystal-locked. The digit oscillator, combined with this, produces a signal ranging from 49.9 to 51.1 Mc/s (of which 47 Mc/s is tied to the master crystal ocillator). After divisions by 10 by techniques similar to those in the DI-1, the final output frequency lies between 4.99 and 5.11 Mc/s.

In the EXTERNAL CONTROL mode the output oscillator is allowed to run free, under control of a second section on the two-gang tuning capacitor. Part of the oscillating-circuit capacitance is supplied by a voltage-variable-capacitance diode, for external-control purposes as described earlier.

The Ancillary Frequency Source (AFS)

As discussed above, the DI-1 and CAD units all require an input at 42 Mc/s, and the DI-1 units additionally need a coherent picket fence from 3 to 3.9 Mc/s. The AFS unit provides these two inputs to the digit units. The AFS unit also contains the master 5-Mc crystal oscillator, from which these signals are coherently derived; also included are circuits by which this master crystal oscillator can be phase-locked to any stable 5-Mc signal, or submultiple thereof. Isolation amplifiers make available, at rear-panel connectors, standard frequencies at 100 kc/s and 5 Mc/s for use in auxiliary equipment. A 1-Mc output is connected into the sandwich deck and brought out at lower power level at the rear of the deck. The 42-Mc signal is also available at a rear-deck receptacle.

Figure 9 is a block diagram of the AFS unit. The primary source, at 5 Mc/s, is divided to 1 Mc/s, which is then multiplied to 42 Mc/s in three steps. In another chain, the 1 Mc/s is further divided to 100 kc/s, where pulse-shaping circuits and bandpass filters and amplifiers generate the picket-fence output.

Isolation amplifiers are used liberally to prevent undesired reactions among the various inputs and outputs.

Crystal Oscillator in AFS Unit

The master crystal oscillator is designed for temperature-coefficient turnover near normal room-temperature ambient conditions. It is not temperature-controlled but has adequate stability for most applications when operated

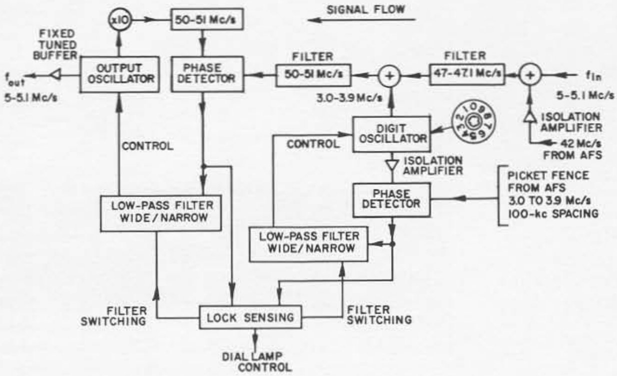

Figure 8. Functional block diagram of Digit-Insertion Unit, Type 1160-DI-1.

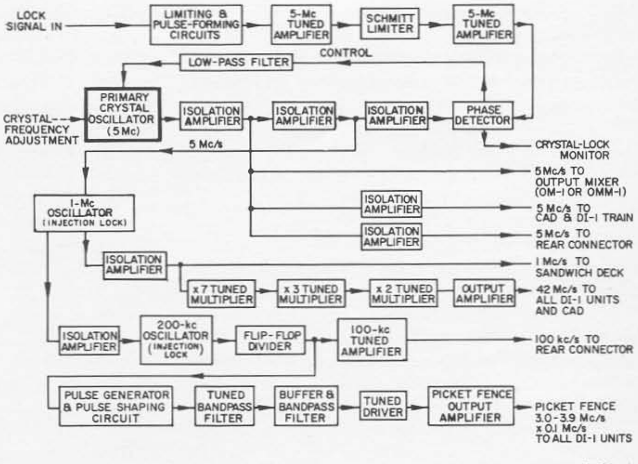

Figure 9. Functional block diagram of the Ancillary Frequency Source.

under reasonably constant ambient temperature; a 48-hour run on one unit, recorded continuously over a weekend in winter, with building heat cut back and re-established during the period, showed variations of only 2 parts in 10^8.

When more stable operation is required, the phase-locking circuitry shown in block diagram form in Figure 9 can be used to establish a tight lock to a more stable standard, such as the Type 1115-B Standard-Frequency Oscillator[6] (see Figure 10). The control signal, at a submultiple of 5 Mc/s, is first limited, and a sharp pulse is formed. The 5-Mc component of this pulse is selected in a tuned amplifier, limited by a Schmitt trigger circuit and amplified again to supply one input to the phase detector. The low-pass filter in the control loop adequately removes low-frequency components that might contribute to phase jitter.

Output Circuits

As has been seen, the output of the final unit in the train of digit units is a signal between 5 and 5.1 Mc/s, which may be considered a carrier component at 5.0 Mc/s, plus a signal component between 0 and 100 kc/s. In the Type 1161-A Synthesizer, the Output Mixer (OM-1) subtracts 5.0 Mc/s from this total output frequency, leaving the signal component as residue. In the Type 1162-A, the final DI-1 output signal is multiplied by 10 in the Output Multiplier-Mixer (OMM-1). From the multiplied frequency is subtracted 50.0 Mc/s, so that, in this case, the residue is 10 times the signal component from the last DI-1 unit, ranging therefore from 0 to 1 Mc/s, depending on dial settings.

The difference frequency in this final mix (0 to 100 kc/s or 0 to 1 Mc/s, depending on whether the OM-1 or the OMM-1 is plugged in) is fed to the final output amplifier, which is an integral part of the main frame. The output amplifier, when ac-coupled, is flat within 1 dB from 30 c/s to well beyond 1 Mc/s. The output impedance is low (approximately 5 ohms), and the available output voltage into loads of 50 ohms or higher is in excess of 2 volts, rms.

In the dc-coupled condition, the final amplifier is eliminated and the output is taken, by way of the level-control potentiometer, from the output mixer. In this case, the output impedance is high and variable (from 0 to about 3 kilohms, depending on level-control setting). The available open-circuit voltage is approximately 1 volt. The output voltmeter is disconnected in this mode of operation.

Power Supply (PS-1)

The plug-in power supply is conventional, supplying 18 volts, regulated, to the balance of the instrument. A toroidal power transformer, in an A-metal case, is used to minimize stray fields.

A special input jack permits operation of the synthesizer from batteries, if desired. The series regulator still functions, so any battery voltage from 20 to 28 volts will provide normal operation.

Figure 10. View of the Type 1115-B Standard-Frequency Oscillator.

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[6] H. P. Stratemeyer," "The Stability of Standard-Frequency Oscillators," *General Radio Experimenter*, 38, 6, June 1964.

APPLICATIONS

When there is a requirement for precision frequencies selectable at will, the combination of a stable, free-running, adjustable oscillator and a frequency counter will often fill the bill, providing one is willing to monitor the oscillator for short- or long-term drift and correct its tuning as required. On the other hand, wherever an adjustable oscillator and a frequency counter can do a precision frequency-generating job, a decade synthesizer will do the job better and more reliably.

Frequency Measurement

In addition to its primary role of frequency *generation*, a synthesizer will often be found most useful in frequency *measurement* by heterodyne techniques. A Lissajous figure between a frequency to be measured and a standard frequency from a synthesizer will provide information on a *continuous* basis (and without any ±1 count uncertainty), instead of as averaged over the counting interval of a frequency counter. This is particularly useful in working with low frequencies, where it is necessary to use multiple-period measurements to achieve accuracy with a counter.

As an illustration, I periodically measure the tuning-fork frequency of my Accutron* wrist watch (nominal frequency 360 cycles per second) by forming a 240-to-1 Lissajous pattern with 86,400.00 c/s from a Type 1161-A Synthesizer. On this display, a frequency deviation as small as a part per million can be observed instantaneously.

The above comments and examples could, of course, apply to any synthesizer capable of sufficiently fine frequency steps. The GR synthesizers, however, offer operational possibilities not available, to my knowledge in any other device of this general character. These advantages accrue from the unique circuitry previously described, which permits the CAD unit to replace a group of digits (as selected by pushbuttons) and, simultaneously, to provide a highly magnified measure of the departure of the output frequency from that displayed on the digit dials, as the CAD frequency is adjusted either manually or electrically.

This feature can be used to advantage in measurement of the frequency characteristics of selective *passive* networks. It is also most useful in the study of frequency drift or of other changes in *active* frequency sources, such as precision crystal oscillators.

Measurement of Active Frequency Sources

Figure 11 is a block diagram, showing how very small frequency changes in a frequency source can be tracked and recorded. The unknown frequency, f_x, is compared in a phase detector (on a 1-to-1 or n-to-1 basis, or by heterodyning) with the output frequency, f_o, from the synthesizer. The dc voltage generated in the phase detector is connected to the EXTERNAL CAD CONTROL input of the synthesizer so that the synthesizer output automatically tracks the unknown frequency.

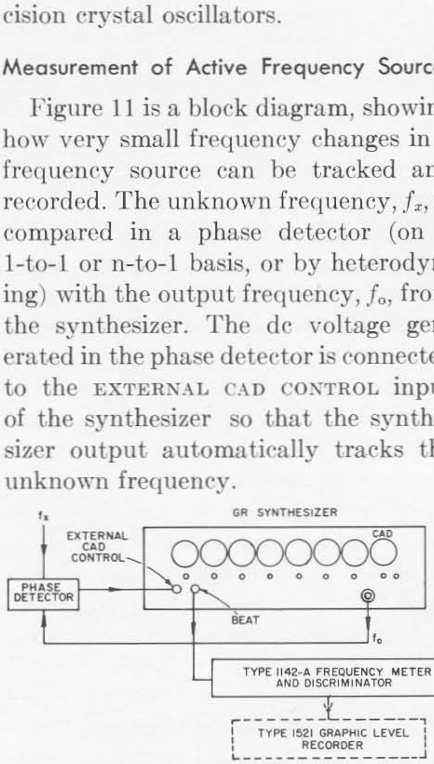

Figure 11. Method of tracking and recording the drift of an unknown frequency, f_x.

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* Registered trademark of the Bulova Watch Company.

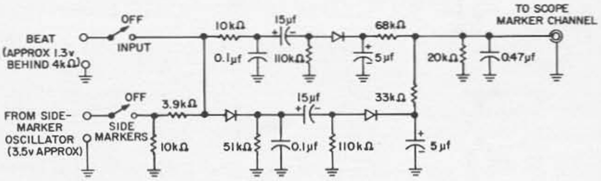

Figure 12. Suggested circuit for generating center-frequency marker and side markers, for use with slow sweeps.

The monitor frequency from the BEAT terminals is measured or recorded. As the synthesizer output frequency varies in response to changes in the unknown frequency, the beat output varies proportionately, at what may be a very highly magnified rate, depending upon which button has been pushed. For example, if the drift is small, the × 1 CPS button might be used. In this case, a change of 1 c/s in the synthesizer output would produce a 10-kc change in the recorded beat frequency — a magnification of 10^4. Smaller or greater magnifications can be used, as required, merely by operation of other pushbuttons.

Measurement of Passive Selective Networks

Figure 3 was noted briefly at the beginning of this article as an example of swept frequency analysis of sharply selective circuits, with self-generated markers. The traces of Figure 3 were obtained with the help of the circuit shown in Figure 12. This circuit was breadboarded for the purpose and is not available in packaged form, but it can be easily duplicated. In Figure 12, the signal from BEAT, after a low-pass filter, is rectified to produce the center-frequency marker occurring when the CAD frequency equals the replaced digit frequency.

Side markers are produced when the frequency at BEAT is equal to a frequency injected from the side-marker oscillator. Since we have the general rule that the frequency at BEAT changes at the rate of 10 kc/s per major CAD division (see page 6), a side-marker-oscillator frequency of 10 k/cs will produce a secondary marker whenever the CAD frequency is removed by one major division from that shown on the replaced digit dials. (A 15-kc side-marker signal thus produces markers at ±1.5 divisions, etc).

To produce the traces of Figure 3, a slowly varying dc voltage (obtained from a battery connected across a variable resistor with grounded center tap) was applied to the EXTERNAL CAD CONTROL connector and also to the horizontal input of a storage oscilloscope. The output of the synthesizer fed the Type 1900-A Wave Analyzer, and the analyzer output, rectified after passing through the internal selectivity, was connected to the vertical input of the oscilloscope on channel No. 1. The output of the marker generator was connected to channel No. 2, at the bottom of the oscilloscope face.

For the display of the 3-cycle pass band in Figure 3a, the pushbutton under × 1 CPS was operated, and the side-marker oscillator was set at 15 kc/s, so that the first pair of side markers occurred at ±1.5 c/s. (The second and third pair of markers are at ±3 c/s and ±4.5 c/s, by harmonic mixing in the marker generator.)

In Figure 3b (showing both the 3- and 10-cycle pass bands) the side-marker oscillator was set to 10 kc/s,

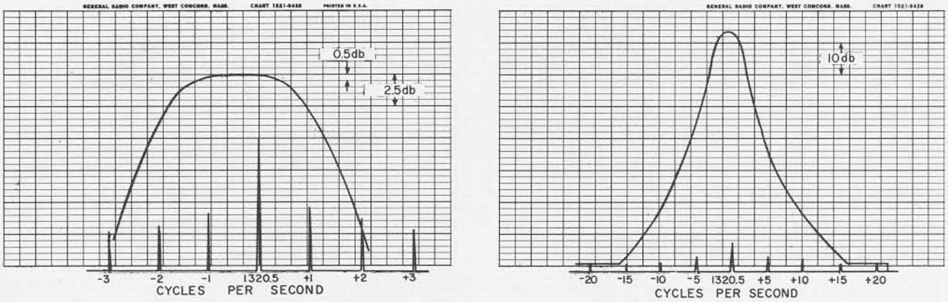

Figure 13. 3-cycle pass band of the Type 1900-A Wave Analyzer recorded by the Type 1521-B Graphic Level Recorder, equipped with an experimental plug-in for generating a sweeping voltage. Frequency markers were generated automatically by use of the circuit shown in Figure 12.

and markers thus occur at 1-cycle intervals. The sweep width is the same as in Figure 3a.

In Figure 3c, the only change is that the button under × 10 CPS has been pushed, so that the sweep width and marker spacing are 10 times as great as in Figure 3b.

Permanent records on strip charts can also be obtained by these methods. Figure 13 shows the 3-cycle pass band of the Type 1900-A Wave Analyzer recorded in this way. The source of sweeping voltage was an experimental plug-in for the Type 1521 Graphic Level Recorder, consisting of a variable resistor geared directly to the paper drive. In this arrangement, the wide-range logarithmic output of the recorder can be used to record the skirt selectivity.

Similar recordings can be made with the help of an X-Y recorder. The deflection on one axis can be made proportional to the frequency appearing at BEAT (by a frequency-to-voltage converter such as the GR Type 1142-A, for instance). The deflection on this axis is thus proportional to the *frequency difference from that shown on all the digit dials*, with scale factor as selected by pushbutton. The CAD can be swept manually or electrically; in either case the recorder deflection is strictly proportional to frequency, independent of variations or lack of linearity in the sweeping input.

Other Applications

The availability of versatile synthesizers such as those here described and their lineal descendants will undoubtedly generate a myriad of uses beyond the simple examples noted above. For instance, they can be incorporated in phase-locked loops to control the frequency of microwave oscillators. Narrow-band frequency or phase-modulation applications represent another fertile field. Transmitter-exciter or receiver-local-oscillator uses are, of course, obvious. By relatively simple circuit modifications, two-phase outputs or outputs with fixed-frequency difference can be achieved. As these synthesizers come into general use, General Radio Company will welcome suggestions for auxiliary equipment that will facilitate still more varied applications.

— Atherton Noyes, Jr.

CREDITS

The Synthesizers described here would not have been possible without the enthusiastic efforts of George H. Lohrer and Charles C. Evans, who are responsible for a major portion of the electrical design. William F. Byers has also been an active participant in this program, particularly in connection with things yet to come.

SPECIFICATIONS

Frequency Range: Type 1162-A, 0 to 1 Mc/s; Type 1161-A, 0 to 100 kc/s.

CAD Dial Calibration: Type 1162-A, 0.001 c/s per division; Type 1161-A, 0.0001 c/s per division.

Other Outputs: Type 1162-A, 0.1, 1, 5, 42, and 50 Mc/s; 5.0-5.1 and 50-51 Mc/s; 18 volts dc. Type 1161-A, 0.1, 1, 5, and 42 Mc/s; 5.0-5.1 Mc/s; 18 volts dc.

Spurious Frequencies: Type 1162-A, at least 60 dB down. Type 1161-A, at least 80 dB down.

Harmonics: At least 40 dB down.

Output Level: Adjustable, 0 to 2 volts into 50 ohms. Output control and meter included.

Output Response: ±1 dB, 50 c/s to maximum frequency. Output also available down to dc at high impedance and lower voltage.

60- and 120-Cycle Sidebands: At least 60 dB down (Type 1162-A), at least 80 dB down (Type 1161-A).

Internal Standard: Room-temperature crystal oscillator. Temperature coefficient of frequency is approximately 1 x 10^{-7}/°C at room temperature. A front-panel frequency adjustment is provided. Crystal frequency can be locked to external standard.

Power Required: 115/215/230 volts, 50 to 60 c/s or 400 c/s, 55 watts, or 20- to 28-volt battery, 1.8 amperes.

Cabinet: Rack-bench; end frames for bench mount and fittings for rack mount are included.

Dimensions: Bench model — width 19, height 5¼, depth 14½ inches (485 by 135 by 370 mm), over-all; rack model — panel 19 by 5¼ inches (485 by 135 mm), depth behind panel 13 inches (330 mm).

Net Weight: 38 pounds (17.5 kg).

Shipping Weight: 45 pounds (20.5 kg).

TYPE 1162-A COHERENT DECADE FREQUENCY SYNTHESIZER 0 to 1 Mc/s

Type	*Units Included*	*Calibrated Digits*		*Smallest Step (Digits Only)*	*Price*
		Decades Only	*Decades + CAD**		
1162-A7C	7 DI Units + CAD	7	9	0.1 c/s	**$5600.00**
1162-A6C	6 DI Units + CAD	6	8	1 c/s	**5160.00**
1162-A5C	5 DI Units + CAD	5	7	10 c/s	**4720.00**
1162-A4C	4 DI Units + CAD	4	6	100 c/s	**4280.00**
1162-A3C	3 DI Units + CAD	3	5	1 kc/s	**3840.00**
1162-A7	7 DI Units	7		0.1 c/s	**5100.00**
1162-A6	6 DI Units	6		1 c/s	**4660.00**
1162-A5	5 DI Units	5		10 c/s	**4220.00**
1162-A4	4 DI Units	4		100 c/s	**3780.00**
1162-A3	3 DI Units	3		1 kc/s	**3340.00**

TYPE 1161-A COHERENT DECADE FREQUENCY SYNTHESIZER 0 to 100 kc/s

Type	*Units Included*	*Calibrated Digits*		*Smallest Step (Digits Only)*	*Price*
		Decades Only	*Decades + CAD**		
1161-A7C	7 DI Units + CAD	7	9	0.01 c/s	**$5460.00**
1161-A6C	6 DI Units + CAD	6	8	0.1 c/s	**5020.00**
1161-A5C	5 DI Units + CAD	5	7	1.0 c/s	**4580.00**
1161-A4C	4 DI Units + CAD	4	6	10 c/s	**4140.00**
1161-A3C	3 DI Units + CAD	3	5	100 c/s	**3700.00**
1161-A7	7 DI Units	7		0.01 c/s	**4960.00**
1161-A6	6 DI Units	6		0.1 c/s	**4520.00**
1161-A5	5 DI Units	5		1.0 c/s	**4080.00**
1161-A4	4 DI Units	4		10 c/s	**3640.00**
1161-A3	3 DI Units	3		100 c/s	**3200.00**

* Direct reading. If CAD is calibrated in terms of the step decades, at least one more significant figure can be added.

DECADE MODULES

Type		*Price*
1160-DI-1	**Step Decade**	**$450.00**
1160-CAD	**Continuously Adjustable Decade** (Including Calibrating Mixer)	**510.00**

U. S. Patent No. 2,548,457. Patents Pending.

NEW TALENTS FOR THE GRAPHIC LEVEL RECORDER

The Type 1521-A Graphic Level Recorder[1] has, in the five years since its introduction, seen service in many branches of physical sciences and engineering. A successor instrument, the Type 1521-B, now offers specialists in acoustics, vibration, and sonar a low-frequency response extended down to 7 cycles per second. Several new accessories are also being added to the growing line of equipment designed to ensure proper use of the recorder with various General Radio analyzers and signal sources. To simplify the job of choosing the right accessories, we are now listing, under distinct type numbers, measurement systems including analyzer or oscillator, recorder, and the appropriate link and drive units, chart paper, and other accessories.

The Type 1521-B Graphic Level Recorder is, like its predecessor, a completely transistorized, single-channel, servo-type recorder, which plots the rms magnitude of an ac voltage on a logarithmic (dB) scale. Plug-in potentiometers provide full-scale ranges of 20, 40, and 80 dB, as well as a linear range for dc recording. Recordings can be made as a function not only of time but also of frequency if the recorder is mechanically coupled to an oscillator or analyzer. This technique produces frequency-response plots automatically in a matter of seconds.

Frequency Response and Writing Speed

The low-frequency response of the new recorder is less than 0.1 dB down at

Figure 1. View of the Type 1521-B Graphic Level Recorder.

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[1] M. C. Holtje and M. J. Fitzmorris, "A Graphic Level Recorder with High Sensitivity and Wide Ranges," *General Radio Experimenter*, 33, 6, June 1959.

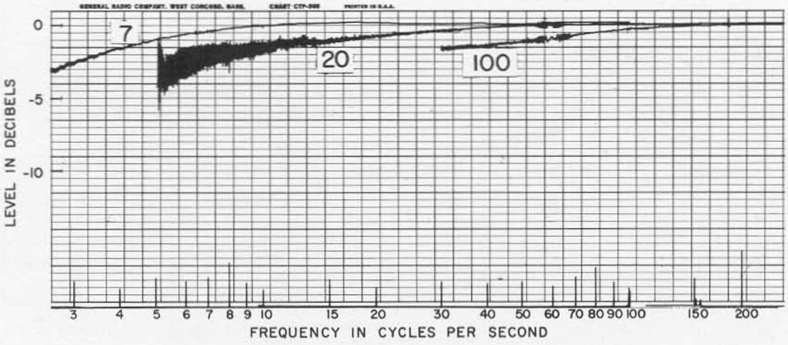

Figure 2. Low-frequency response of the Graphic Level Recorder for various positions of the low-frequency cutoff switch.

20 c/s, less than 1 dB down at 7 c/s, and 3 dB down at 4.5 c/s (see Figure 2). This extended low-frequency response requires a greater detector time constant, reducing the ability of the recorder to follow rapid changes in level. Therefore, writing speed and detector time constant are switched together, so that the user can improve low-frequency response at the expense of writing speed or vice versa. Table 1 shows the four writing-speed positions and their corresponding cutoff frequencies. This information is engraved on the front panel.

TABLE 1

WRITING SPEED AND LOW-FREQUENCY CUTOFF

Writing Speed in/sec	*Low-Frequency Cutoff c/s (Response down 1 dB)*
20	100
10	20
3	7
1	7

The sine-wave frequency response for the three low-frequency cutoffs is shown in Figure 2. For audio-band sweeping, the 20-cycle cutoff position is usually satisfactory. For greater accuracy at low frequencies, the 7-cycle cutoff must be used, but the reduced writing speed requires correspondingly low sweep speeds. Above 50 c/s, the writing speed and sweep speed can be increased during sweep to minimize over-all sweep time and error.

Figure 3 shows the response of the recorder to a ⅓-octave band of noise.

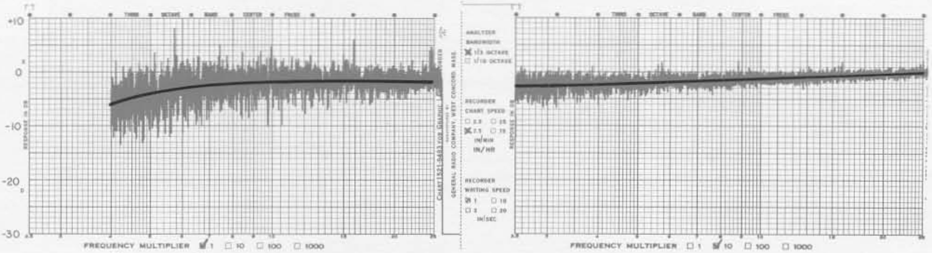

Figure 3. Low-frequency response of the Graphic Level Recorder to ⅓-octave band of pink noise, with a writing speed of 1 in/sec.

ACCESSORIES

Potentiometers

A 40-dB potentiometer is supplied; 20-dB, 80-dB, and linear potentiometers are available as accessories.

Motors

Accessory motors (50-cycle and 60-cycle) are available for slow-speed and medium-speed chart drive. The slow-speed motors produce chart speeds of 2.5 to 75 in/hr, a reduction by a factor of 60 from the speeds available with the standard high-speed motor. The new medium-speed motors, Type 1521-P23 (60 c/s) and Type 1521-P24 (50 c/s), are especially recommended for use with analyzers. The speed at which an analyzer can be swept is inversely proportional to its bandwidth. The Type 1900-A Wave Analyzer has a constant bandwidth of 3, 10, or 50 c/s and therefore requires a constant sweep speed over the full 0- to 50-kc bandwidth of the instrument. These new motors provide chart speeds of 0.5 to 15 in/min, speeds ideally suited to the 10- and 50-cycle bandwidths.

With the constant-percentage-bandwidth Type 1564-A Sound and Vibration Analyzer, the slowest speed of the medium-speed motor (0.5 in/min) is recommended for sweeping near 4.5 c/s. The sweep speed can then be increased to 5 in/min or more on the 25- to 250-cycle range.

The mounting of the new motor has been designed to reduce the coupling of the motor noise to the gear box. The resulting acoustic noise is practically inaudible, an important consideration for acoustical measurements.

Drive and Link Units for Automatic Plotting

The new Type 1521-P10B Drive Unit (Figure 4) is designed to couple the recorder to all General Radio oscillators and analyzers. When attached to the front of the recorder, it is used, in conjunction with a link unit, to couple the chart drive of the recorder to the dial of the frequency source or analyzer (see Figure 5). A continuous-adjustment clutch permits the recorder to be synchronized with the oscillator (or analyzer) dial in the idle position and then engaged in the DRIVE or NON-SLIP position. The DRIVE position includes a slip feature that will protect an instrument containing a dial stop (e.g., the older Type 1554-A Sound and Vibration Analyzer and older models of the Type 1304-B Beat-Frequency Audio Generator). The NON-SLIP position is recommended for use with the Type 1900-A Wave Analyzer and other instruments requiring greater driving torque.

Cam-operated switches in the new drive unit turn the recorder motor off at the beginning and end of a sweep. A switch in the recorder can engage or disengage the Microswitches. These cams are easily set and do not have to

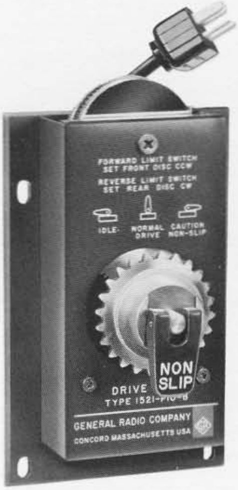

Figure 4. View of the Type 1521-P10B Drive Unit.

be disengaged mechanically when they are not being used.

The new Type 1521-P15 Link Unit is used to connect the recorder and drive unit to the Type 1304-B Beat-Frequency Audio Generator or the Type 1554-A or 1564-A Sound and Vibration Analyzer. (The Type 1900-A Wave Analyzer is coupled by the Type 1900-P1 Link Unit.) The new link unit includes a 24-tooth sprocket to provide a scale factor of 30 dB/decade. (Scale factor, for a logarithmic chart, is the product of dB/in on the vertical scale and in/decade of frequency on the horizontal scale, expressed in dB/decade.) This scale factor is endorsed in the current EIA standard and is used on the GR Type 1521-9427 chart paper used with the Type 1304-B Beat-Frequency Audio Generator. Because many users have expressed preferences for other scale factors, we have designed the new unit for easy interchangeability of sprockets, and we are making available a kit (Type 1521-P16) that includes sprockets with 16, 20, 32, 36, and 40 teeth. The 16-tooth sprocket, used with the Type 1564-A Sound and Vibration Analyzer and with our Type 1521-9469 chart paper, results in a scale factor of 50 dB/decade.

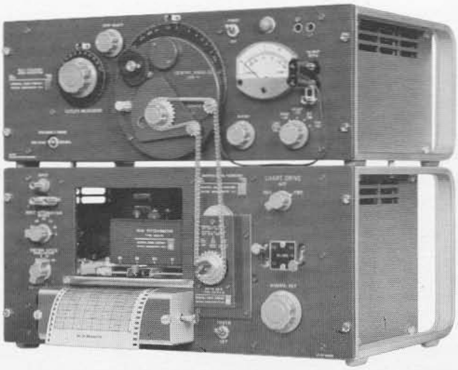

Figure 5.
View of the Type 1350-A Generator-Recorder Assembly.

Table II lists the scale factors corresponding to the various sprockets in the sprocket kit, along with the industries

TABLE II INDUSTRY SCALE FACTORS

Industry Standard	*Scale Factor (dB/decade)*	*Decade Length (inches) for Type 1304 Generator*	*Sprocket (teeth)*	*Pot (dB)*
Institute of High Fidelity Manufacturers	20	2.0	16	40
Proposed International Standard	25	2.5	20	40
Electronic Industries Association	30	3.0*	24	40
Institute of High Fidelity Manufacturers	20	4.0	32	20
Hearing Aid Industry	45	4.5	36	40
Proposed International Standard	50	5.0	40	40
Proposed International Standard	50	5.0**	16	40

* Chart paper available for Type 1304-B Beat-Frequency Audio Generator.
** Decade length applies to Type 1564-A Sound and Vibration Analyzer; chart paper available.

supporting these scale factors. Although we currently catalog chart paper for only the 30- and 50-dB/decade scale factors, we shall be glad to recommend other suppliers to users sending us a description of the chart desired, including decade length, vertical scale, etc.

MEASURING AND RECORDING ASSEMBLIES

The recorder can be used in conjunction with an oscillator or analyzer to plot directly frequency-response data of networks or systems. The setup for these measurements requires the recorder, an oscillator or analyzer, a drive unit, and a link unit. This equipment is assembled and supplied as a complete system under a separate type number. The user will find it advantageous to purchase the system in this manner, since our recommended combination of instruments, parts, and chart paper will automatically be supplied.

Type 1350-A Generator-Recorder Assembly

This is a most useful automatic system for measuring the audio-frequency characteristics of filters, attenuators, networks, loudspeakers, microphones, transducers, and complete acoustic systems (see Figure 5). The Type 1304-B Beat-Frequency Audio Generator is an ideal oscillator for such measurements, since it has a truly logarithmic frequency dial and an output-voltage variation of less than 0.25 dB as the oscillator is swept. Examples of measurements made with this system are shown in Figure 8. Notice the impracticability of a point-by-point frequency-response plot of the sound level in a room.

In addition to the generator and recorder, the Type 1350-A Generator-Recorder includes drive and link units, a kit of sprockets, and a muting switch. The switch short-circuits the output of the oscillator during the blank part of the dial or at low frequencies, so that loudspeakers or systems can be protected while the recorder is continuously swept. Because the blank parts on the chart paper correspond to the length of the blank portion on the dial, successive charts can be recorded with synchronization of the chart and the dial frequency.

Type 1910-A Recording Wave Analyzer[2]

The linear frequency scale, the three bandwidths (3, 10, and 50 c/s), and the high-level 80-dB dynamic-range output of the Type 1900-A Wave Analyzer make it an ideal companion instrument for the Type 1521-B Graphic Level Recorder (see Figure 6). An example of a measurement made with the Recording Wave Analyzer is shown in Figure 9.

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[2] Arnold Peterson, "New Wave Analyzer Has 3 Bandwidths, 80-dB Dynamic Range," *General Radio Experimenter*, 38, 4, April 1964.

Figure 6. View of the Type 1910-A Recording Wave Analyzer.

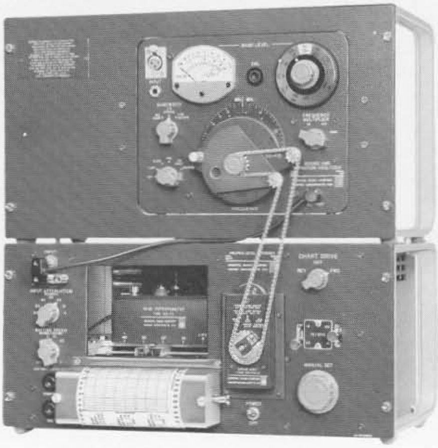


Figure 7. View of the Type 1911-A Recording Sound and Vibration Analyzer.

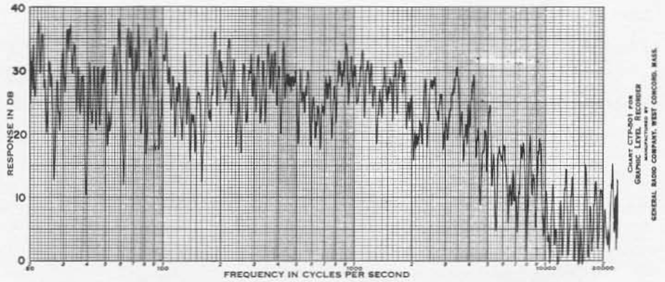
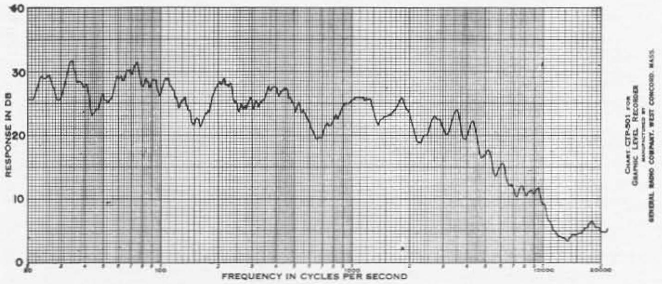


Figure 8. Records of the frequency response of a public address system, taken with (*top*) maximum writing speed and (*below*) minimum writing speed.



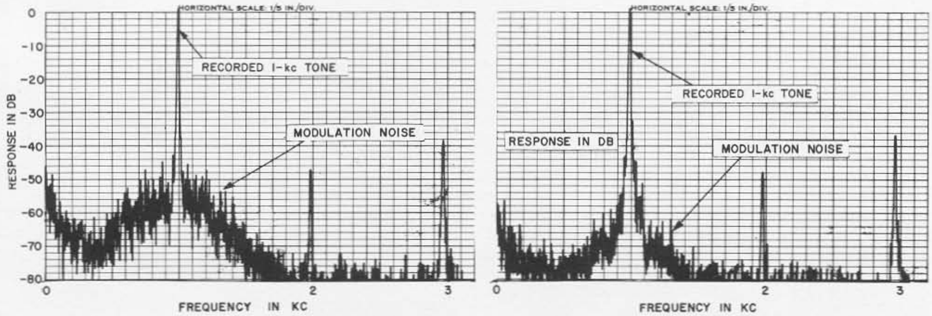


Figure 9. Charts of modulation noise on a 1-kc tone for two different types of magnetic tape. Note that one is about 10 dB better than the other. Such measurement can be made easily with the recording analyzer, owing to the 80-dB dynamic range. For these records, chart speed was 2.5 inches per minute; writing speed, 10 inches per second; bandwidth, 10 c/s.

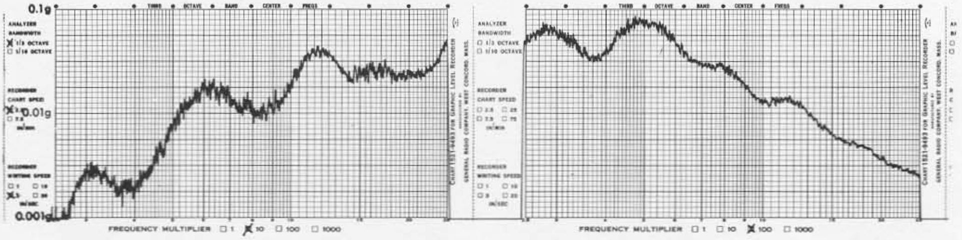


Figure 10. Chart record of a vibration acceleration spectrum measured on the chassis of a calculating machine. For this measurement a high-frequency vibration pickup is used.

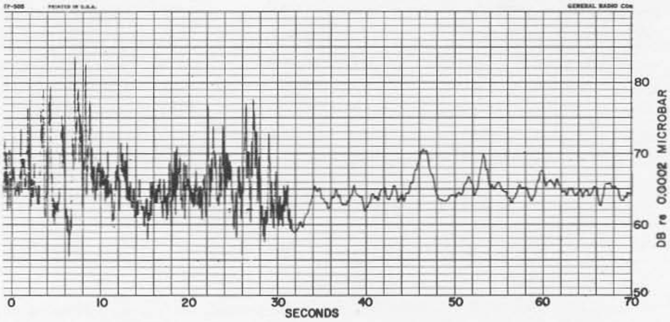


Figure 11. Recording of noise level in a cafeteria with both fast and slow writing speeds and 40-dB potentiometer.

Type 1911-A Recording Sound and Vibration Analyzer

This assembly is based on the Type 1564-A Sound and Vibration Analyzer[3], which has constant-percentage bandwidths of ⅓ and 1/10 octave and a frequency range of 2.5 to 25,000 c/s (Figure 7). This analyzer includes two features especially important in recording: an automatic frequency-range-changing device and a built-in muting switch that short-circuits the output during the blank part of the dial. The extended low-frequency response of the new recorder greatly enhances its use with the Type 1564-A Sound and Vibration Analyzer for vibration measurements. The recorder can be used down to 4.5 c/s (3 dB down) if a response plot of the recorder itself is first made and then compared with the recording made with the analyzer. Figure 10 is an example of a recorded vibration measurement. Another example is our reduction of the acoustic noise in the chart-drive system of the recorder itself. The recorder analyzed its own acoustic noise with the Type 1564-A Sound and Vibration Analyzer and a sound-level meter. The resulting data were observed for peaks in sound level. These were found to be the fourth and fifth harmonics of the motor pinion gear mesh, amplified by the gear-box mounting plate. Isolating the motor from the gear box solved the problem, reducing the noise until it was practically inaudible in a quiet room.

Figure 12. View of the Type 1521-B Graphic Level Recorder with the Type 1551-C Sound-Level Meter.

Figure 13. View of the Graphic Level Recorder bench-mounted with the Type 1151-AP Digital Time and Frequency Meter and the Type 1136-A Digital-to-Analog Converter.

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[3] W. R. Kundert, "New Performance, New Convenience with the New Sound and Vibration Analyzer," *General Radio Experimenter*, 37, 9 and 10, September-October 1963.

Level-vs-Time and DC Recording

The Type 1521-B Graphic Level Recorder, like its predecessor, can also be used for level-vs-time recordings, as, for instance, in the measurement of sound level over long periods of time (see Figures 11 and 12). In addition, the Type 1521-B Graphic Level Recorder can be converted to a 1-mA dc recorder by means of the Type 1521-P4 Linear Potentiometer. The high speed and accuracy of this servo-type dc recorder make it useful with the Type 1136-A Digital-to-Analog Converter and the Types 1150-AP and 1151-AP Counters (see Figure 13).

— Martin W. Basch

SPECIFICATIONS

Recording Range: As supplied, 40 dB full-scale; 20-dB and 80-dB ranges are also available. For dc recording, 0.8 to 1 volt (0.8 to 1.0 mA) full-scale, with zero input position adjustable over full scale.

Frequency Response and Writing Speed

Level Recording: High-frequency response ±2 dB to 200 kc/s. Low-frequency sine-wave response depends on writing speed, as shown in following table:

Writing Speed (approx) in/sec with 0.1-inch overshoot	*Low-Frequency Cutoff c/s (less than 1 dB down)*
20	100
10	20
3	7 (3 dB down at 4.5 c/s)
1	7 (3 dB down at 4.5 c/s)

DC Recording: 3 dB down at 8 c/s (peak-to-peak amplitude less than 25% of full scale).

Potentiometer Linearity

20-, 40-, 80-dB Potentiometers: ±1% of full-scale dB value plus a frequency error of 0.5 dB at 100 kc/s and 1.5 dB at 200 kc/s.

Linear Potentiometer: ±1% of full scale.

Resolution: ±0.25% of full scale.

Maximum Input Voltage: 100 volts ac.

Input Attenuator: 60 dB in 10-dB steps.

Input Impedance: 10,000 ohms for ac level recording; 1000 ohms for dc recording.

Maximum Sensitivity: 1 mV at 0 dB for level recording; 0.8 V full-scale for dc recording.

Paper Speeds

High-speed motor (normally supplied): 2.5, 7.5, 25, 75 in/min. Used for high-speed-transient measurements and production testing with Type 1304 Audio Generator.

Medium-speed motor (supplied on request): 0.5, 1.5, 5, 15 in/min. Used with analyzers and in level-vs-time recordings.

Low-speed motor (supplied on request): 2.5, 7.5, 25, 75 in/hr. Used for level-vs-time measurements of long duration (1 to 24 hours).

External DC Reference: An external dc reference voltage of from 0.5 to 1.5 V can be applied internally to correct for variations of up to 3 to 1 in the signal source of the system under test.

Detector Response: Rms within 0.25 dB for multiple sine waves, square waves, or noise. Detector operating level is 1 volt.

Chart Paper: 4-inch recording width on 5-inch paper. All rolls are 100 feet long. See full list of charts at end.

Accessories Supplied: 40-dB potentiometer, 2 pens, 2-ounce bottle of red ink, 2-ounce bottle of green ink, bottle of potentiometer cleaner, 1 roll of Type 1521-9428 paper, droppers for filling pens, Type CAP-22 Power Cord, spare fuses, adaptor cable for connection to sound-measuring equipment and to other devices having telephone jacks.

Accessories Available: Potentiometers, charts, ink, high-, medium- and slow-speed motors, drive and link units, as listed in price table.

Power Requirements: 105 to 125 (or 210 to 250) volts, 60 c/s, 35 watts. 50-cycle models are available.

Cabinet: Rack-bench.

Dimensions: Bench model — width 19, height 9, depth 13½ inches (485 by 230 by 350 mm), over-all; rack model — panel 19 by 8¾ inches (485 by 225 mm), depth behind panel 11¼ inches (290 mm).

Net Weight: 50 pounds (23 kg).

Shipping Weight: 62 pounds (29 kg).

Type	*Mounting*	*Supply Frequency*	*Paper Speed*	*Price*
1521-BR	Rack	60 c/s	2.5-75 in/min	**$995.00**
1521-BM	Bench	60 c/s	2.5-75 in/min	**995.00**
1521-BRQ1	Rack	50 c/s	2.5-75 in/min	**995.00**
1521-BMQ1	Bench	50 c/s	2.5-75 in/min	**995.00**

DRIVE AND LINK UNITS FOR COUPLING TO GENERATORS AND ANALYZERS

1521-P10B	**Drive Unit** to operate any link unit	**$72.00**
1521-P15	**Link Unit** for coupling to Type 1304-B Beat-Frequency Audio Generator or to Type 1554-A or Type 1564-A Sound and Vibration Analyzer	**26.00**
1521-P16	**Sprocket Kit** for above link unit. These sprockets offer a choice of the following scale factors (ratio of dB/inch vertical scale to decades/inch on horizontal scale): 20, 25, 45, and 50 dB/decade.	**15.00**
1900-P1	**Link Unit** for coupling to Type 1900-A Wave Analyzer	**35.00**

CHART PAPER

Type	Calibration Horizontal	 Vertical(Div)	Chart Length (in) Calibrated	 Blank	Associated Instrument	Price
1521–9427	20 c/s-20 kc/s, log	80	9	4½	1304-B Generator	**$2.75**
1521–9464	0-10 kc/s, linear	40	20	0	1900-A Analyzer	**2.75**
1521–9465	0-50 kc/s, linear	40	16	0	1900-A Analyzer	**2.75**
1521–9493	2.5-25 normalized, log	40	7½	1½	1564-A Analyzer	**2.75**
1521–9469	2.5-25 normalized, log	40	5	1	1564-A Analyzer	**2,75**
1521–9463	2.5 c/s-25 kc/s, log	40	18	3	1554-A Analyzer	**2.75**
1521–9429	25-7500 c/s, log	40	12½	1	760-B Analyzer	**2.75**
1521–9428	Continuous ¼-in div	40	continuous			**2.75**
1521–9466	Continuous ⅝-in div	50	continuous		1134-A, 1136-A D/A Converters	**2.75**

MOTORS

Type		Price
1521-P19	(high-speed, 60 c/s) for paper speeds of 2.5 to 75 in/min	**$59.00**
1521-P21B	(high-speed, 50 c/s) for paper speeds of 2.5 to 75 in/min	**65.00**
1521-P23	(medium-speed, 60 c/s) for paper speeds of 0.5 to 15 in/min	**59.00**
1521-P24	(medium-speed, 50 c/s) for paper speeds of 0.5 to 15 in/min	**65.00**
1521-P20B	(low-speed, 60 c/s) for paper speeds of 2.5 to 75 in/hr	**59.00**
1521-P22	(low-speed, 50 c/s) for paper speeds of 2.5 to 75 in/hr	**65.00**

RECORDING ASSEMBLIES

Factory assembled and ready to use. End frames and rack supports supplied for bench or relay-rack mounting.

Type 1910-A Recording Wave Analyzer

Component Units
- Type 1900-A Wave Analyzer
- Type 1521-B Graphic Level Recorder with medium-speed motor and recorder accessories
- Type 1521-P10B Drive Unit
- Type 1900-P1 Link Unit
- Type 1521-9464 Chart Paper, 10 rolls
- Type 1521-9465 Chart Paper, 10 rolls
- Type 1521-P3 80-dB Potentiometer (inaddition) to 40-dB Potentiometer included with recorder)
- Type 1560-P95 Adapter Cable (phone to double plug)

Type		Price
1910-A	Recording Wave Analyzer (60-cycle supply)	**$3500.00**
1910-AQI	Recording Wave Analyzer (50-cycle supply)	**$3500.00**

Type 1911-A Recording Sound and Vibration Analyzer

Component Units
- Type 1564-9820 Sound and Vibration Analyzer, Rack Model
- Type 1521-B Graphic Level Recorder with medium-speed motor and recorder accessories
- Type 1521-P10B Drive Unit
- Type 1521-P15 Link Unit (with interchangeable 16- and 24-tooth sprockets)
- Type 1521-9469 Chart Paper, 10 rolls
- Type 1560-2141 Adaptor Cable, double plug to offset phone plug

Type		Price
1911-A	Recording Sound and Vibration Analyzer (60-cycle supply)	**$2315.00**
1911-AQI	Recording Sound and Vibration Analyzer (50-cycle supply)	**$2315.00**

Type 1350-A Generator-Recorder Assembly

Component Units
- Type 1304-B Beat-Frequency Audio Generator
- Type 1521-B Graphic Level Recorder and recorder accessories
- Type 1521-P10B Drive Unit
- Type 1521-P15 Link Unit
- Type 1521-P16 Sprocket Kit
- Type 1304-P1 Muting Switch
- Type 1521-9427 Chart Paper, 10 rolls
- Type 1560-P95 Adaptor Cable, phone to double plug
- Type 274-NP Patch Cord, double plug to double plug

Type		Price
1350-A	Generator-Recorder Assembly (60-cycle supply)	**$2000.00**
1350-AQI	Generator-Recorder Assembly (50-cycle supply)	**2000.00**

The Type 1304-P1 Muting Switch supplied with the Type 1350-A assembly is available separately for $37.50.

Coming in September

ELECTRONIC INSTRUMENT MANUFACTURERS' EXHIBIT

Boston to Washington, D.C.

Nine leading manufacturers of electronic instruments have joined together to present the Fifth Annual Electronic Instrument Manufacturers' Exhibit (EIME), which will open September 21 in Massachusetts, make six one-day stands in New York, New Jersey, and Pennsylvania, and close in Washington, D.C. on October 8.

As before, EIME will offer operating displays of the latest in instrumentation, plus the chance to discuss measurement problems with factory engineers. A new feature of this year's EIME is a series of technical sessions, at which engineers from the nine participating companies will give short formal talks on various instrumentation and measurement subjects. These talks will run consecutively throughout the day.

General Radio will exhibit its new Type 1162-A Coherent Decade Frequency Synthesizer, Type 900-LB Precision Slotted Line (and recording system), Type 1150-BH 1-Mc Digital Frequency Meter, Type 1396-A Tone-Burst Generator, Type 1806-A Electronic Voltmeter, Type 1900-A Wave Analyzer, Type 1025-A Standard Sweep-Frequency Generator, Type 1644-A Megohm Bridge, and Type 1115-B Standard-Frequency Oscillator.

Sponsors of EIME, in addition to GR, are: Ampex Corporation, Brush Instruments, Keithley Instruments, Inc., Lambda Electronics, Non-Linear Systems, Inc., George A. Philbrick Researches, Inc., Singer Metrics Division (Panoramic Instruments and Sensitive Research Instruments).

The complete EIME schedule:

Lynnfield, Massachusetts	Monday, Sept 21	Colonial Country Club, Route 128
Syracuse, New York	Wednesday, Sept 23	Randolph House, Exit 37, N. Y. State Thruway
Bethpage, Long Island	Monday, Sept 28	Holiday Manor, Hicksville Road, south of Grumman
Cedar Grove, New Jersey	Wednesday, Sept 30	Friar Tuck, Route 23
North Plainfield, New Jersey	Thursday, Oct 1	Washington House, Route 22
Philadelphia, Pennsylvania	Monday, Oct 5	Marriott Motor Hotel
Red Bank, New Jersey	Tuesday, Oct 6	Molly Pitcher Hotel
Washington, D. C.	Thursday, Oct 8	International Inn

General Radio Company

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THE GENERAL RADIO
EXPERIMENTER

VOLUME 38 NO 10 & 11 OCTOBER–NOVEMBER 1964

A COMPACT, INEXPENSIVE SOUND-LEVEL METER

TYPE 1565-A
SOUND-LEVEL METER

Basic sound-measuring instruments have generally fallen into two easily distinguishable classes. One class included sound-survey meters (or sound meters), whose size and price were right but which couldn't pass muster as approved (i.e., by recognized standards) arbiters of sound level. In the other class were the sound-level meters, which carried the credentials specified by the standards but whose pedigrees came at a price. Also, although smaller than breadboxes, most sound-level meters were unmistakably in the two-hands class. Faced with a choice between the two types, many would-be sound measurers were forced by a tight budget to settle for second best.

A combination of recent developments now gives us the TYPE 1565-A Sound-Level Meter, which is a bona fide *sound-level meter* but whose dimensions and price are more like those of a sound-survey meter. The new sound-level

ALSO IN THIS ISSUE

Metered 20-ampere Variac® autotransformer

meter snuggles easily into the palm of your hand partly through the use of all-solid-state circuitry, partly through an ingeniously designed package that includes a new GR-made ceramic microphone. The instrument weighs just 1¾ pounds and runs for 35 hours on a single C battery.

DESCRIPTION

Packaging

The aluminum-and-plastic case of the new sound-level meter is tapered at the microphone end to minimize the effect of diffraction. Two knobs are prominent on the front panel. The right-hand knob indicates sound-level range; the left-hand knob selects weighting and meter speed and allows the battery to be checked. The output jack, which takes a standard telephone plug, is in the lower left-hand corner of the panel. A threaded insert in the bottom of the case can be used for tripod mounting. A carrying cord (supplied) can also be fastened to this insert.

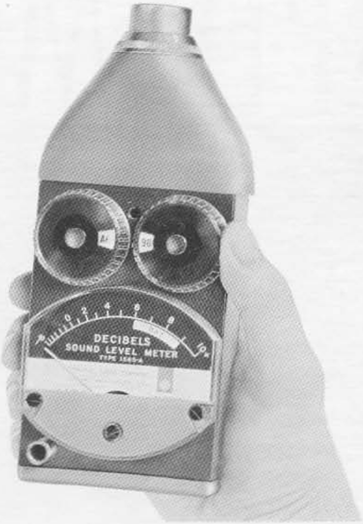

Figure 1. Case and controls are designed for one-hand operation.

Microphone

General Radio's new lead-zirconate-titanate ceramic microphone was developed as a measurement-grade microphone. With a diameter of 0.936 inch, it fits in any fixture designed to accept the current industry-standard Western Electric 640-AA Condenser Microphone. A typical free-field frequency-response curve for the new microphone is shown in Figure 2. The meter can be pressure-calibrated at 400 c/s by means of the Type 1552-B Sound-Level Calibrator or at any frequency from 20 to 2000 c/s with the Type 1559-B Microphone Reciprocity Calibrator.

Circuit

The all-solid-state circuit (see Figure 3) uses a total of seven transistors in

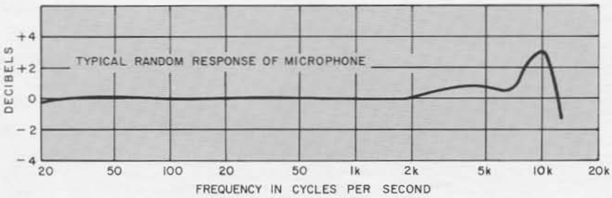

Figure 2. A typical free-field frequency-response curve for the new General Radio Microphone.

CONTENTS OF THIS ISSUE

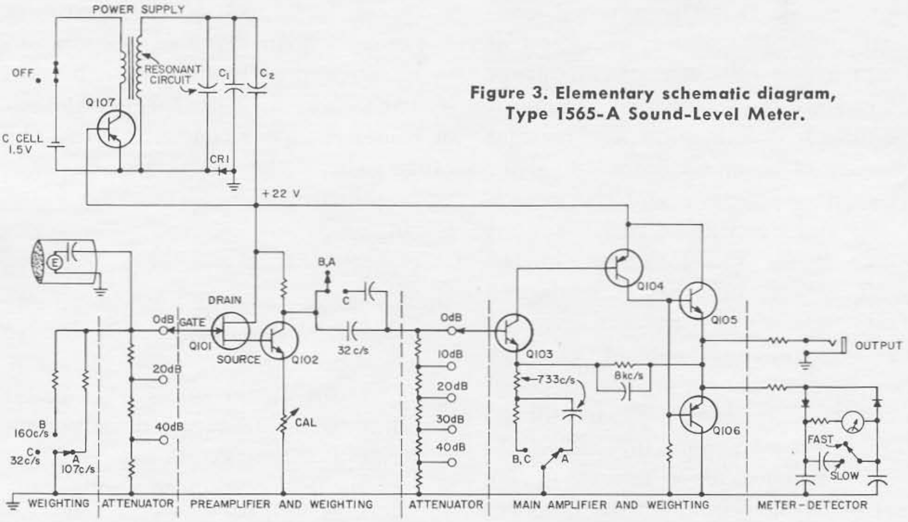

Figure 3. Elementary schematic diagram, Type 1565-A Sound-Level Meter.

two amplifier stages and a power supply.

Transistors *Q101* and *Q102* comprise the preamplifier. *Q101* is a special N-channel field-effect transistor, operating as a "source follower." The gain of the second transistor (*Q102*) can be adjusted by means of a panel screwdriver control to calibrate the instrument. The main amplifier uses four transistors, including a complementary pair (*Q105* and *Q106*) at the output. Feedback is applied to the emitter of transistor *Q103* to stabilize voltage gain. This amplifier drives both the meter-detector circuit and the output terminals.

The attenuator is separated into two sections for best signal-to-noise ratio. One section is located directly at the input and the other between the amplifier stages. The panel control, calibrated from 50 to 130 dB, adjusts attenuation in 10-dB steps.

Each coupling and feedback path in the Type 1565-A Sound-Level Meter serves double duty to form a part of the weighting network. To achieve the A-weighting characteristic, for example, the feedback network in the main amplifier provides 6-dB/octave roll-off at both 733 c/s and 8 kc/s. The coupling network between the preamplifier and the main amplifier adds roll-off starting at 32 c/s, and the combination of the input resistance of the instrument and the microphone capacitance yields an additional 6-dB/octave slope starting at 107 c/s.

Since the equivalent microphone capacitance serves as part of the weighting network, the spectrum is partly weighted before it is introduced to the preamplifier. Therefore, the likelihood of amplifier overload is reduced. Source capacitance cannot be changed, however, without affecting the weighting characteristic.

Power Supply

The unique power supply includes a simple dc-to-dc converter to permit operation from a single 1.5-volt C cell. The circuit is basically a tuned, self-biased, class-C oscillator, operating at a frequency of 130 kc/s. The ac output voltage from the transformer is applied to a full-wave voltage-doubler rectifier consisting of diode *CR1*, the transistor base-emitter junction, and the capacitors *C1* and *C2*. Half of the dc output voltage biases the transistor in the cut-off region, affording the desired class-C operation with a conversion efficiency of about 70 percent. The high efficiency of power supply and amplifier makes possible a battery life of 35 hours, and it is therefore unnecessary to turn the instrument on and off during a series of measurements to conserve the battery.

STANDARDS FOR A SOUND-LEVEL METER

The American[1] and International[2] standards on sound-level meters are written to ensure that measurements made with sound-level meters of various makes and models will be accurate and will agree closely with one another. The American standard specifies seven basic characteristics for a sound-level meter (the International standard is similar). These involve weighting, directionality, crest-factor capacity, attenuator accuracy, detector characteristic, dynamic characteristic of the meter, and internal noise level.

Weighting

Three frequency-response curves, called A, B, and C weighting, are specified. In general, a 1-dB deviation from these weighting curves is allowed for frequencies below 1 kc/s. The tolerance broadens somewhat at high frequencies, where microphone behavior is difficult to control. A meter that does not comply with this specification will yield erroneous readings when presented with an acoustic spectrum much of whose energy is concentrated in the range where the weighting deviates from standard.

Directionality

A sound-level meter, to conform to the American standard, must be equally responsive, within specified limits, to sound waves arriving from all directions. A directional sound-level meter could, of course, be supplied with orientation and calibration data so that, for a given incidence, accurate results could be obtained. But the user might not, for a variety of reasons, be able to duplicate the calibration conditions. The only sure solution to this problem is a true sound-level meter — one whose response does not vary appreciably with incidence.

Crest Factor Capacity

A sound-level meter is designed to measure the rms level of the variation in atmospheric pressure, which is called sound. The peak amplitudes of some sounds are very much greater than their rms amplitudes. Electronic circuits used in a sound-level meter must be able to pass signals whose crest factor (ratio of peak amplitude to rms amplitude) is as high as 13 dB. Obviously, a signal that is distorted by an amplifier of insufficient crest-factor capacity will not produce a correct meter indication.

Attenuator Accuracy

To satisfy both the American and the International standards, the attenuator used in a sound-level meter must be accurate within ±1 dB at all frequencies in its range. The importance of attenuator accuracy is evident,

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[1] ASA S1.4-1961.
[2] IEC Publication 123, 1961.

since the attenuator setting figures directly in the instrument readout.

Detector Characteristic

The detector response must be essentially rms to satisfy several requirements of the standards. Average-response detectors, used in survey meters, yield significant errors when subjected to any waveform other than a simple sinusoid.

Dynamic Characteristic of Meter

The rise time and overshoot of the panel meter are specified for two speeds designated "fast" and "slow." (Both speeds are available in the new sound-level meter.) The "fast" speed allows a short-time average level of a signal to be observed. The "slow" speed gives a long-time average indication and is used when fast-speed fluctuations exceed 3 or 4 dB.

Internal Noise Level

An important requirement for a sound-level meter whose output is to drive an analyzer or other apparatus is low internal noise. In this respect, as indeed in all the above respects, the TYPE 1565-A meets or exceeds the specifications given in the American and International standards.

USES

A sound-level meter is the basic sound-measuring instrument. Almost any noise study begins with elementary sound-level measurements to determine what further investigation will be needed. Industrial and governmental test codes specify test limits and procedures for making sound-level measurements.

The A-weighted sound level is becoming increasingly popular as a measure of the disturbing effect of noise on people. Young[3] has recently shown that subjective ratings of office noise are as well correlated with A-weighted sound level as with other previously used, but more complicated, measures of office noise. Traffic noise laws[4] are now enforced in many cities with the aid of sound-level meters, usually set to indicate A-weighted sound level.

A sound-level meter is useful not only for noise acceptance tests with a single weighting network but also, when measurements are made with all three weighting networks, for determining the approximate shape of a spectrum. A method[5] of determining approximate spectrum shape from sound-level measurements is given in the General Radio *Handbook of Noise Measurement.**

Sound-level meters are used by industrial hygienists to help ensure personal comfort and safety in factories and to detect conditions that might result in hearing loss. Hearing and speech research is conducted by psychologists with the aid of sound-level meters. Engineers concerned with the quiet and normal operation of machinery use the sound-level meter as a basic tool. Sound-level measurements are made by architects and musicians to ensure best production of music, by police and other officials to detect unacceptable levels of neighborhood and traffic noise, and on board naval vessels to help maintain quiet operation and thus avoid detection.

AUXILIARY EQUIPMENT

The TYPE 1565-A Sound-Level Meter was designed primarily for convenient

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[3] R. W. Young, *Journal of the Acoustical Society of America*, Vol. 36, pp. 289–295 (1964).

[4] D. P. Loye, *Noise Control*, Vol. 5, pp. 230–235, July, 1959.

*Available from General Radio Company at $1.00 per copy, postpaid.

Figure 4. Sound-Level Meter with Type 1560-P52 Vibration Pickup.

operation and low cost, and the Type 1551-C Sound-Level Meter[6], with its greater versatility, will undoubtedly continue to be the recognized standard for all types of sound measurements. For the many applications that do not require the greater sensitivity, additional 20-kilocycle (flat frequency response) weighting, or lower distortion of the TYPE 1551-C, the new sound-level meter will provide performance comparable to that of the larger instrument. On the other hand, where a sound-level meter is required as a preamplifier for a narrow frequency analyzer or is to be used with a variety of transducers and other accessories, the TYPE 1551-C is the better choice.

Use with Analyzers

The TYPE 1565-A Sound-Level Meter can be used to drive the TYPE 1556-B Impact-Noise Analyzer to determine the peak amplitude and time duration of impact sounds. It can also be used to drive an octave-band filter set for frequency analysis. However, owing to its higher distortion, it is not recommended for use with analyzers having bandwidths narrower than one octave.

Use as Vibration Meter

Figure 4 shows the TYPE 1565-A fitted with a TYPE 1560-P96 Adaptor and a TYPE 1560-P52 Vibration Pickup. The high capacitance of this pickup provides a low-frequency response extending to less than 20 c/s. The upper frequency limit, determined by the pickup, is 1 kc/s. Acceleration levels from 0.0005 to 30 g can be measured.

The remarkably good performance obtained in such a compact, low-cost instrument brings to sound-level measurements a new order of convenience and expands the range of application of true sound-level measurements.

— W. R. KUNDERT

CREDITS

The writer acknowledges the work of G. E. Neagle, who was responsible for the mechanical design and packaging of the meter.

The microphone was designed by B. B. Bauer and A. L. Di Mattia of the CBS Laboratories and developed for production by B. A. Bonk of General Radio.

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[5] The method was developed by J. R. Cox, Jr.

[6] E. E. Gross, "Improved Performance Plus a New Look for the Sound-Level Meter," *General Radio Experimenter*, 32, 17, October, 1958.

E. E. Gross, "TYPE 1551-C Sound-Level Meter," *General Radio Experimenter*, 35, 8, August, 1961.

SPECIFICATIONS

Sound-Level Range: 44 to 140 dB (re 0.0002 μbar).

Weighting: A, B, and C weighting in accordance with American Standard ASA S1.4-1961 and IEC Publication 123, 1961.

Microphone: Lead-zirconate-titanate ceramic unit.

Output: At least 1.5 V behind 20 kΩ when meter reads full scale. Output is intended primarily for driving a TYPE 1556-B Impact-Noise Analyzer, a graphic level recorder, or headphones. Harmonic distortion, 2% or less for frequencies above 200 c/s and 5% or less for frequencies below 200 c/s (panel meter at full scale).

Meter: Rms response, and fast and slow meter speeds, in accordance with ASA S1.4-1961 and IEC Publication 123, 1961.

Auxiliary Input Provision: A TYPE 1560-P96 Adaptor is available to allow connection to any source fitted with a male 3-terminal microphone connector. Input impedance is approximately 13 MΩ in parallel with 25 pF. For correct weighting, source impedance must be 380 pF ± 5%.

Power Supply: One 1½-V size C flashlight cell. Battery life approximately 35 hours for 2 h/day service.

Environmental Effects:

Operating Temperature Range: 0 to 50°C.

Storage Temperature Range: — 20 to + 70°C (battery removed).

Operating Humidity Range: 0 to 90% RH.

Temperature Coefficient of Sensitivity: + 0.03 dB/°C.

Sensitivity to Magnetic Fields: Equivalent C-weighted sound level of a 1-oersted (80 A/m) 60-cycle field is about 47 dB when meter is oriented for maximum meter indication.

Calibration: Sound-level meter can be pressure calibrated at 400 c/s with a Type 1552-B Sound-Level Calibrator or at any frequency in the range from 20 to 2000 c/s with a Type 1559-B Microphone Reciprocity Calibrator.

Accessories Available: Type 1565-P1 Leather Carrying Case. Type 1560-P96 Adaptor to adapt input to mate with 3-terminal male microphone connector necessary for connection to vibration pickup. Type 1560-P95 Adaptor Cable to connect output to Type 1521-B Graphic Level Recorder or other devices fitted with jack-top binding posts on ¾-in centers.

Dimensions: Width 3$\frac{1}{16}$, height 7⅜, depth 2⅛ inches (78 by 190 by 54 mm), over-all.

Net Weight: 1¾ pounds (0.8 kg).

Shipping Weight: 5 pounds (2.3 kg).

Type		*Price*
1565-A	**Sound-Level Meter**	**$240.00**
1565-P1	**Leather Carrying Case**	**15.00**
1560-P95	**Adaptor Cable**	**3.00**
1560-P96	**Adaptor** to 3-terminal male microphone connector	**11.00**

NEW METERED VARIAC® AUTOTRANSFORMERS

The latest additions to our line of metered Variac® autotransformers are two 20-ampere units with built-in voltmeters and ammeters: the Type W2OMT3A, for 120-volt inputs, and the Type W2OHMT3A, for 240-volt service. Metered Variac assemblies are now available in 5-, 10-, and 20-ampere sizes.

SPECIFICATIONS

	W2OMT3A	**W2OHMT3A**
Input Voltage	120 V	240 V
Frequency	50–60 c/s	
Output Voltage	0-140 V	0-280 V
Current Rating	18 A	8 A
No-Load Loss (60 c/s)	27 W	
Voltmeter Range	0-150 V	0-300 V
Ammeter Range	0-20 A	0-10 A
Meter Accuracy	±3% of full scale	
Switching	2-pole, OFF-ON switch at input from line	
Fusing	20 A	10 A

	Both Models
Terminals	
Line	3-wire cord and plug
Load	3-wire outlet receptacle
Angle of Rotation	320°
Driving Torque	45 to 90 oz-in
Dimensions	
Width	8⅝ in (220 mm)
Height	11⅝ in (300 mm)
Depth	5¼ in (135 mm)
Net Weight	27½ lb (12.5 kg) 25 lb (11.5 kg)
Price	**$140.00**

SALES ENGINEERING NOTES

NEREM

The new sound-level meter featured in this issue will be on display at NEREM (Northeast Electronics Research and Engineering Meeting), November 4, 5, and 6 at Boston's Commonwealth Armory. So will a number of other new GR products, including an automatic capacitance bridge, frequency standard, coherent decade frequency synthesizer, digital time comparator, recording wave analyzer, megohm bridge, counters, and many other instruments and devices. Our booth number is 211-213.

PHILADELPHIA OFFICE MOVES

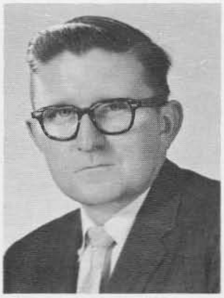
Our Philadelphia Sales Engineering Office has just moved a few miles west into brand-new quarters at Fort Washington Industrial Park, adjacent to the Pennsylvania Turnpike at Fort Washington, Pennsylvania. The new diggings are larger than the old and include better parking facilities, all the better to accommodate the burgeoning business at "PHO." The numerology of the situation is as follows: phone number 215-646-8030, TWX number 215-646-7996, and Zip Code 19034. Manager John Snook and Sales Engineer Carl Alsen stand ready as ever (but even better equipped) to serve.

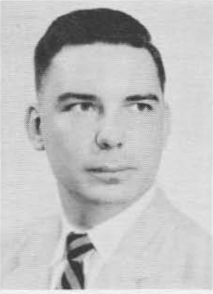
ALABAMA, GEORGIA ADDED TO FLORIDA OFFICE TERRITORY

Our Florida Sales Engineering Office in Orlando now includes in its territory Alabama and Georgia, and thus may be considered our Southeastern States Office. Sales Engineer Richard G. Rogers joins manager John Held of that office to help serve this large and important area. Dick, an electrical engineering graduate of M.I.T., has been with GR since 1960, both at our West Concord headquarters and at our Washington, D.C., Sales Engineering Office.


J. E. Snook


C. W. Alsen


R. G. Rogers


J. C. Held

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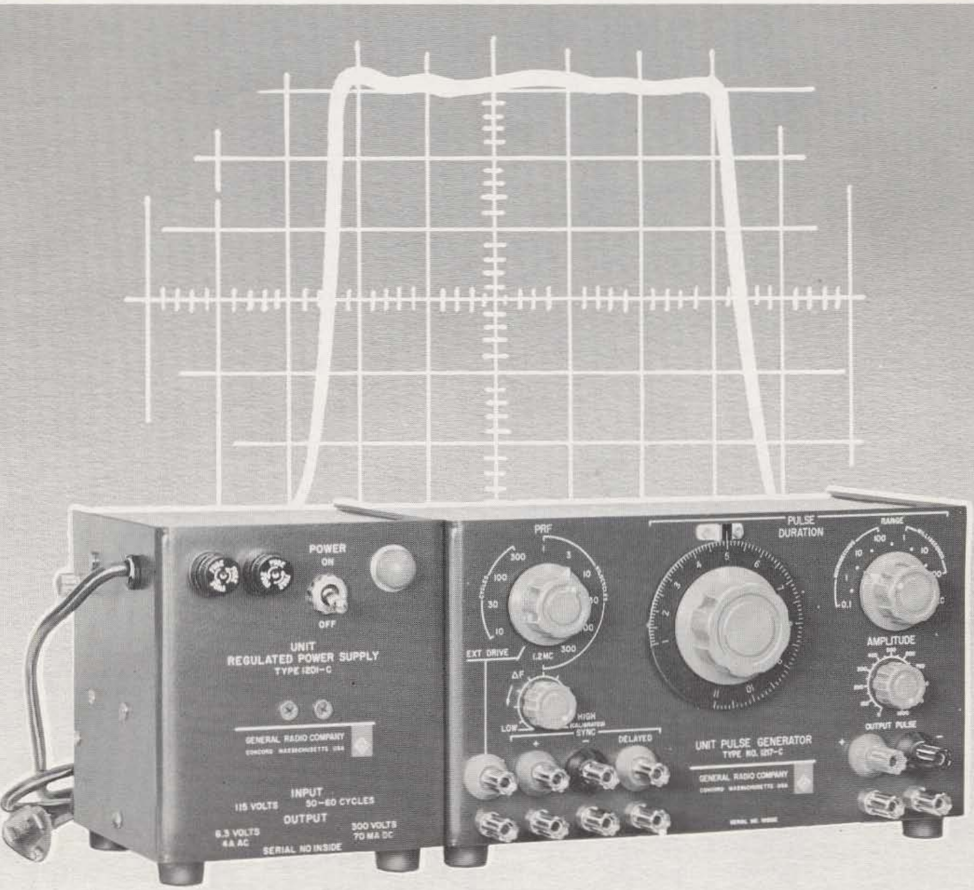

IMPROVED PERFORMANCE FROM THE UNIT PULSE GENERATOR

IN THIS ISSUE

- **Microphone Reciprocity Calibrator**
- **1-Mc Counter**
- **Six-dial Decade Resistors**

THE GENERAL RADIO EXPERIMENTER

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CONTENTS

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IMPROVED PERFORMANCE FROM THE UNIT PULSE GENERATOR

One of our most popular Unit Instruments has long been the TYPE 1217 Unit Pulse Generator. The reason for its popularity is easy to see: It has consistently offered more prf range, pulse duration, and pulse amplitude per dollar than any other instrument of its type. Now, with the introduction of the TYPE 1217-C Unit Pulse Generator, specifications have been again improved significantly. The size remains the same, and the performance per dollar has again been sharply boosted, to a point where the Unit Pulse Generator is a model of value engineering.

For those who are familiar with earlier models of the TYPE 1217, the major improvements in performance are: increased prf to 1.2 Mc/s (internal drive) and 2.4 Mc/s (external drive), and improved transition times to less than 10 nanoseconds with a more symmetrical pulse (see Figure 2).

For those who are unfamiliar with the Unit Pulse Generator, it is a compact, general-purpose pulse source, whose prf can be either internally controlled from 2.5 c/s to 1.2 Mc/s or externally controlled (the input circuits are then arranged as an aperiodic switching circuit) from dc to 2.4 Mc/s. Pulse duration is adjustable from 100 nanoseconds to 1.1 seconds, and ampli-

Figure 1. Type 1217-C Unit Pulse Generator with power supply.

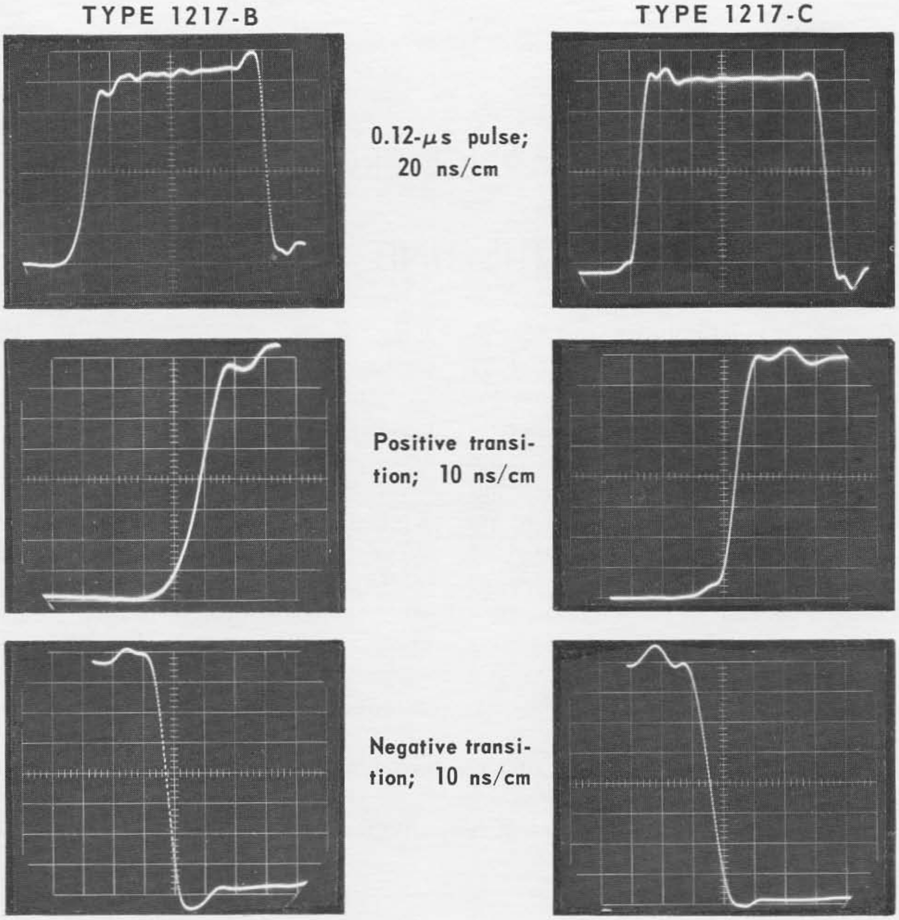

Figure 2. Oscillograms showing improvements in pulse symmetry and rise times in Type 1217-C over its predecessor.

tude of the 40-mA output pulse is also adjustable, up to 40 volts, peak (the AMPLITUDE control is actually calibrated in output impedance). Positive and negative prepulses and a delayed synchronizing pulse are also provided.

The Circuit

The circuit is basically that described in an earlier article on the TYPE 1217-B[1]; a block diagram is shown in Figure 3. A major design objective was economy, and this meant making every circuit component work all the time and to its full capability. The internal prf oscillator uses the same parts — rearranged by switching — that make up the input circuits in the external-drive mode. Another design feature was the com-

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[1] R. W. Frank, "More and Better Pulses from the Unit Pulse Generator," *General Radio Experimenter*, 36, 1–2, January–February 1962.

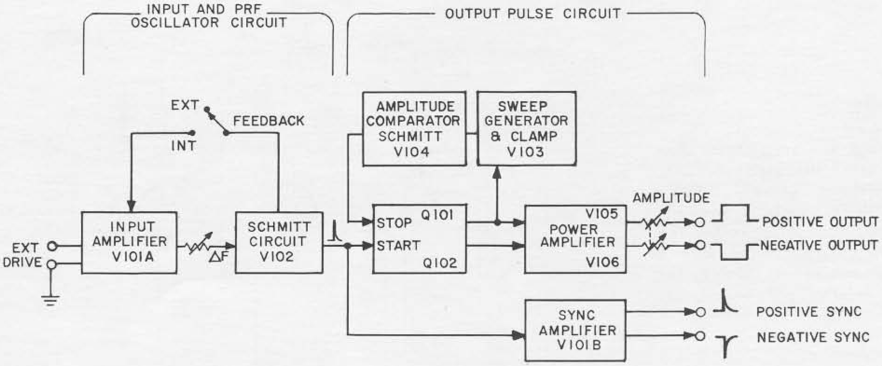


Figure 3. Block diagram.

mon-sense utilization of tubes *and* transistors to exploit the strong points of both.

The main components of the pulse generator are an input system, a pulse-timing circuit, and a power amplifier. Switched for internal control of prf, the input system is a stable, wide-frequency-range oscillator. Switched for external control, the circuit becomes an aperiodic trigger generator, made up of a dc amplifier and a Schmitt trigger. This circuit produces a single, brief, trigger pulse to initiate the action of the pulse-timing circuits once for each cycle of the input driving signal.

The output circuits include a set-reset bistable circuit, an RC ramp generator, and an amplitude comparator. The circuit is similar to that used in all precision pulse generators and makes possible a relatively linear pulse-duration dial scale, low jitter, quick recovery time, and operation highly independent of supply-voltage changes and aging of the active devices. The warmup effects on prf and on pulse duration are shown in Figures 4 and 5.

The set-reset bistable circuit drives a pair of output tubes, which apply current to variable load resistors. The maximum value of these resistors is 1000 ohms, and the output current is over 40 mA; the maximum output voltage is therefore at least 40 volts.

The delayed (synchronizing) pulse corresponds to the late transition of the output pulse. This delayed pulse

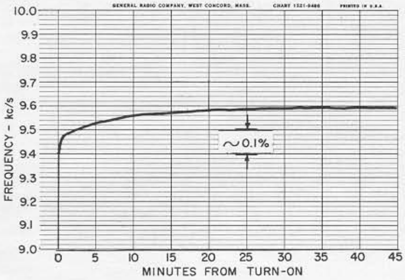


Figure 4. Warmup effects on pulse repetition frequency.

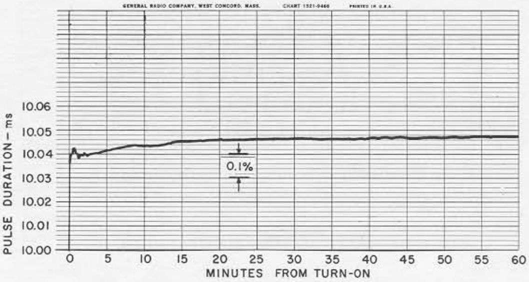


Figure 5. Warmup effects on pulse duration.

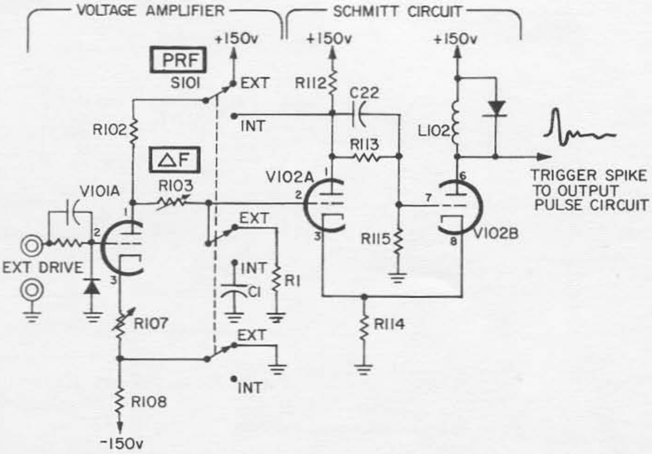


Figure 6. Schematic diagram of the input circuits. Switching at only three points converts a conventional Schmitt circuit, used with external drive, into a wide-range oscillator for internal prf control.

can be used to drive a second pulse generator; a pair of pulse generators therefore makes an excellent delayed-pulse generator, and three make a good double-pulse generator.

Output Pulse Waveform

The improvement in pulse transition time and symmetry comes about from the use of silicon transistors in place of germanium units. The voltage wave-

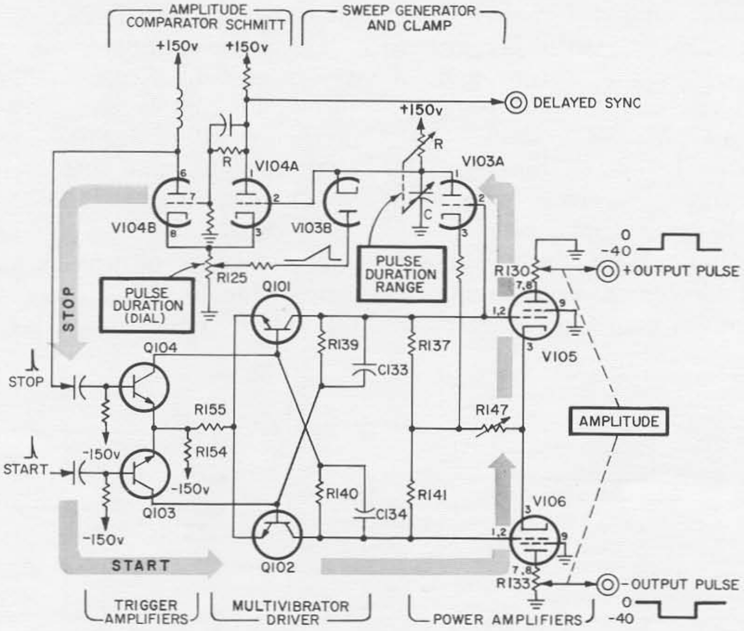


Figure 7. Schematic diagram of timing and output circuits. Transistors *Q101* and *Q102* are connected in a bistable circuit to control conduction of the output power tubes, *V105* and *V106*. Such hybrid design exploits strong points of both tubes and transistors.

form at the output terminals depends on the termination. In Figure 2, the terminating resistance is 50 ohms. All transition times are less than 10 nanoseconds, and some overshoots occur. With no external loading, the very fast current transitions are applied to the 1000-ohm output potentiometer and an inherent stray capacitance of about 30 picofarads, and the voltage rise time is about 60 nanoseconds. Externally added capacitance will increase this rise time by about 2 nanoseconds per picofarad. With this output configuration, no overshoot occurs, and the rise is purely exponential (see Figure 8).

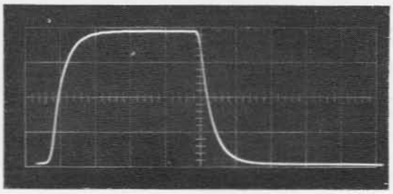


Figure 8. Oscillogram showing effects of 12-pF probe on output pulse.

Pulse DC Component

Notice, in Figure 7, that a dc component negative with respect to chassis ground appears on both the positive and negative pulses. When the amplitude control is fully open, the positive pulse rises from −40 volts to ground, and the negative pulse falls from ground to −40 volts. In other words, only the negative output is truly "ground-based."

TYPE 1217-P2
SINGLE-
PULSE
TRIGGER

In many applications, the output will be capacitively coupled, and the dc component of the pulse will be of no consequence. Even when the dc component is important, however, it is rarely necessary that the positive pulse start precisely from chassis ground. In most cases it is desirable that the pulses make a transition from a potential other than ground. Adjustment at this potential is easy to accomplish. Figure 9 shows a simple method of voltage translation by which the dc level of either a positive or negative pulse can be adjusted as desired. A 400-volt laboratory power supply can thus translate the positive pulse so that it is completely above ground, with only a 10-percent reduction in output impedance. In most applications, no such power need be wasted for dc translation. Pulse amplifiers, "and" gates, etc, can be biased directly from the pulse gen-

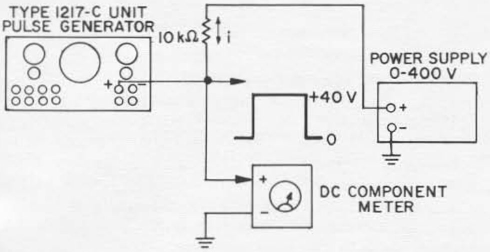
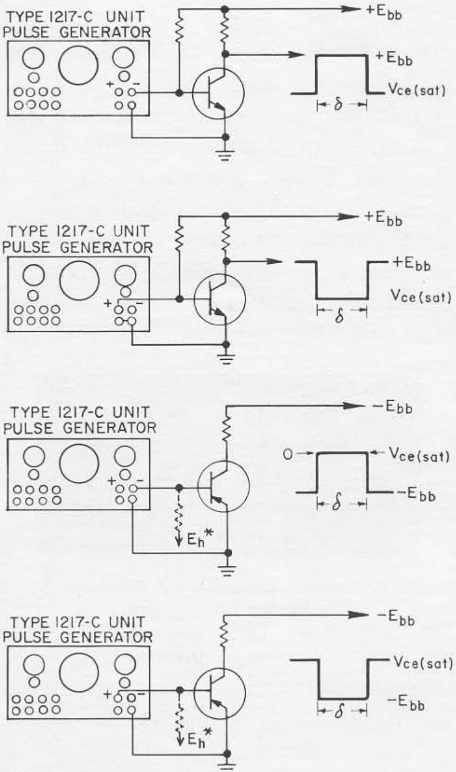


Figure 9. Connection of 400-V laboratory power supply and dc voltmeter for full translation of positive pulse. Any desired dc component can be obtained by adjustment of power-supply voltage. Dc component meter can be used to indicate duty ratio.

Figure 10. Control of transistor switching by Unit Pulse Generator. (top) NPN, normally on, goes off during pulse time. NPN, normally off, goes on during pulse time. PNP, normally off, goes on during pulse time. PNP, normally on, goes off during pulse time.



*HOLD-BACK BIAS MAY BE NECESSARY UNDER SOME HIGH TEMPERATURE CONDITIONS WHERE $I_{cho} R_o > V_{eb}$

erator with low-power networks, as shown in Figure 10.

Uses

The Type 1217-C Unit Pulse Generator is a valuable tool in any laboratory where pulses are used. Its generalized characteristics and low price make it an ideal instrument for school-laboratory experiments in pulse techniques, as well as for work on radar, pulse communication, and computer systems.

Experience has also shown that the pulse generator is a useful source for measurements on transistor systems. It can operate saturated transistor switches, both npn and pnp, without coupling networks (see Figure 10). Since the pulse generator is direct-coupled, the solid-state switches can be operated over its full duration range.

— R. W. Frank

SPECIFICATIONS

PULSE REPETITION FREQUENCY

Internally Generated: 2.5 c/s to 1.2 Mc/s, with calibrated points in a 1–3 sequence from 10 c/s to 300 kc/s, and 1.2 Mc/s, all ±5%. Continuous coverage with an uncalibrated control.

Externally Controlled: Aperiodic, dc to 2.4 Mc/s with 1 V, rms, input (0.5 V at 1 Mc/s and lower); input impedance at 0.5 V, rms, approximately 100 kΩ shunted by 50 pF. Output pulse is started by negative-going input transition.

OUTPUT-PULSE CHARACTERISTICS

Duration: 100 ns to 1 s in 7 decade ranges, ±5% of reading or ±2% of full scale or ±35 ns, whichever is greater.

Rise and Fall Times: Less than 10 ns into 50 or 100 Ω; typically 60 ns + 2 ns/pF external load capacitance into 1 kΩ (40 V).

Voltage: Positive and negative 40-mA current pulses available simultaneously. Dc coupled, dc component negative with respect to ground. 40 V, peak, into 1-kΩ internal load impedance for both negative and positive pulses. Output control marked in approximate output impedance.

Overshoot: Overshoot and noise in pulse, less than 10% of amplitude in correctly terminated measuring system.

Ramp-off: Less than 1%.

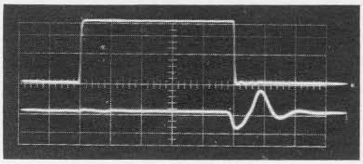
Synchronizing Pulses:

Pre-pulse: Positive and negative 8-V pulses of 150-ns duration. If positive sync terminal is shorted, negative pulse can be increased to 50 V. Sync-pulse source impedance:

positive — approx 300 Ω;
negative — approx 1 kΩ.

Delayed Sync Pulse: Consists of a negative-going transition of approximately 5 V and 100-ns duration coincident with the late edge of the main pulse. Duration control reads time between prepulse and delayed sync pulse. This negative transition is immediately followed by a positive transition of approximately 5 V and 150 ns to reset the input circuits of a following pulse generator. (See oscillogram.)

Stability: Prf and pulse-duration jitter are dependent on power-supply ripple and regulation. With TYPE 1201 Power Supply, external-drive terminals short-circuited, prf jitter and pulse-duration jitter are each 0.01%. With TYPE 1203 Power Supply, they are 0.05% and 0.03%, respectively. (Jitter figures may vary somewhat with range switch settings, magnetic fields, etc.)



1-μs pulse into 50 ohms with delayed sync pulse.

GENERAL

Power Required: 300 V at 60 mA, 6.3 V at 3 A. Type 1203 Unit Power Supply or Type 1201 Unit Regulated Power Supply is recommended.

Accessories Available: TYPE 1217-P2 Single-Pulse Trigger, rack-adaptor panel for both generator and power supply, 19 by 7 in (485, 180 mm).

Cabinet: Unit-Instrument type.

Dimensions: Width 10¾ (15 with power supply), height 5¾, depth 6½ inches (275, 150, 165 mm), over-all. Rack-adaptor panel, 19 by 7 inches (485, 180 mm).

Net Weight: 4½ lb (2.1 kg).

Shipping Weight: 6 lb (2.8 kg).

Type		*Price*
1217-C	**Unit Pulse Generator**	**$275.00**
1217-P2	**Single-Pulse Trigger**	**25.00**
1203-B	**Unit Power Supply** (for 115-volt supply)	**55.00**
1203-BQ18	**Unit Power Supply** (for 230-volt supply)	**60.00**
480-P4U3	**Relay-Rack Adaptor Panel**	**12.00**

A RECIPROCITY CALIBRATOR FOR THE WE 640AA AND OTHER MICROPHONES

Among the great time savers of recent invention was the GR TYPE 1559-A Microphone Reciprocity Calibrator[1], which replaced the tedium of a long, meticulous laboratory calibration with a minute or two of knob turning. The original model, however, accepted only the General Radio measurement microphone, a limitation overcome by the new TYPE 1559-B Microphone Reciprocity Calibrator. Of especial importance is the fact that the new model will also calibrate the Western Electric 640AA-type microphone. Since the Na-

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[1] Basil A. Bonk, "Absolute Calibration of PZT Microphones," *General Radio Experimenter*, 37, 4–5, April–May 1963.

tional Bureau of Standards also reciprocity-calibrates this microphone, there is now a direct traceability link between NBS and the GR Reciprocity Calibrator.

The Reciprocity Calibrator is a portable, compact instrument containing the reference transducers and acoustic cavity necessary to perform the closed-coupler reciprocity calibration, together with an analog computer and switching mechanisms to reduce the entire procedure to a simple routine.

The Type 1559-B Microphone Reciprocity Calibrator will calibrate any microphone whose sensitivity is between −75 dB and −35 dB re 1 V/μbar, whose diameter is less than 1.125 inches and which is adaptable to use in a closed coupler. GR Types 1560-P1, 1560-P3, and 1560-P4 microphones fit directly into the calibrator, and an adaptor is supplied for WE 640AA-type microphones. An adaptor is also available for calibration of GR Types 1551-P1L and 1551-P1H Condenser Microphone Systems.

Accessories required are an audio signal source and a detector (usually the instrument whose microphone is being calibrated). In the calibration of a microphone of the WE 640AA-type, a preamplifier and a source of polarizing voltage are also required; the preamplifier and power supply of the Type 1551-P1 Condenser Microphone Systems are satisfactory for this purpose.

SPECIFICATIONS

MICROPHONE CALIBRATOR

Range: Direct reading for microphone sensitivities between −35 dB and −75 dB re 1 V/μbar.

Accuracy:

Microphone Type	*Accuracy*	*Frequency Range*
WE 640AA and similar types	± 0.2dB ± 0.1dBf_{kc}	20 c/s to 2.5 kc/s
	± 0.7dB	2.5 to 6 kc/s*
GR 1560-P3 and -P4	± 0.2dB ± 0.1dBf_{kc}	20 c/s to 2.5 kc/s
	± 0.7dB	2.5 to 7 kc/s *
GR 1551-P1L	± 0.2dB ± 0.1dBf_{kc}	20 c/s to 2.5 kc/s
	± 0.7dB	2.5 c/s to 5 kc/s

*To 8 kc/s with corrections.

PRECISION ACOUSTICAL SOURCE

Frequency Range: 20 c/s to 7 kc/s.

Output: 92 dB re 0.0002 μbar for excitation of 50 V.

Accuracy: At 92 dB, ±0.1 dB + error in determining microphone sensitivity.

SOUND-LEVEL CALIBRATOR

Frequency Range: 20 c/s to 2.5 kc/s.

Output: 92 dB re 0.0002 μbar for excitation of 50 V.

Accuracy: ±0.7 dB at standard atmospheric pressure.

GENERAL

Maximum Safe Input Voltage: 50 V behind 600 Ω.

Accessories Required: Generator and detector. Generator to supply 5 V or more into a 2000-pF load, and 2.5 V or more into a 600-Ω load. Lower voltage can be used, with a resultant lowering of signal-to-ambient-noise ratio. The Type 1304-B Beat-Frequency Audio Generator, the Type 1210-C Unit R-C Oscillator, and the Type 1310-A Audio Oscillator are recommended. The Type 1551-B or -C Sound-Level Meter is recommended for the detector.

Accessories Supplied: Type 274-NP Patch Cord and an extension cable for connection to generator and detector; and adaptors for reciprocity and comparison calibration of the Western Electric 640AA and equivalent microphones.

Cabinet: Flip-Tilt; relay-rack model also is available.

Dimensions: Portable model, case closed: width 10, height 8, depth 7½ in (255, 205, 190 mm), over-all; rack model: panel 19 by 10½ in (485, 270 mm), depth behind panel 5 in (130 mm).

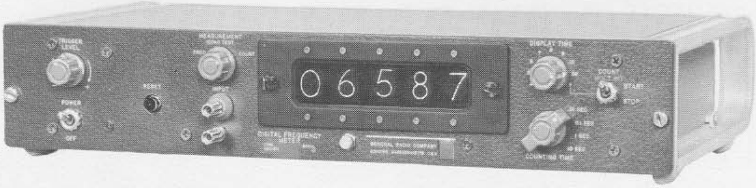
Net Weight: Portable model, 13 lb (6 kg); rack model, 14 lb (6.5 kg).

Shipping Weight: Portable model, 22 lb (10 kg); rack model, 29 lb (13.5 kg).

Type		*Price*
1559-B	**Microphone Reciprocity Calibrator,** Portable Model	**$525.00**
1559-B	**Microphone Reciprocity Calibrator,** Rack Model	**525.00**

US Patent No. 2,966,257.

NEW ONE-MEGACYCLE COUNTER



A new 1-Mc counter has joined the ranks of GR's fast-growing line of digital frequency equipment. The Type 1150-BH Digital Frequency Meter is similar to the 400-kc Type 1150-B[1] in all respects except frequency range. In other words, it is a trim (3½ inches high in a relay rack), economical, solid-state counter with crisp, bright, incandescent readout.

Counting time can be set to 0.01, 0.1, 1, or 10 seconds, and display time is adjustable in 7 discrete steps from 0.16 to 10.24 seconds, or infinity. Other panel controls include a trigger level adjustment, a mode switch (to select frequency measurement, self-check, or count), a reset button, and a toggle switch for manual control of counting time and for counting times that are multiples of 10 seconds.

The new counter is also available as the Type 1150-BPH, equipped for direct connection to either the Type 1137-A Data Printer or the Type 1136-A Digital-to-Analog Converter.

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[1] R.W. Frank, "400-kc Solid-State Counter," *General Radio Experimenter*, 38, 8, August 1964.

SPECIFICATIONS

Frequency Range: Dc to 1 Mc/s.

Sensitivity: 1 V, p-to-p, to 400 kc/s, 2 V, p-to-p, to 1 Mc/s.

Counting Time: 10 ms to 10 seconds, extendible by multiplier switch.

Accuracy: ±1 count ± crystal-oscillator stability.

Display: 5-digit in-line register, incandescent-lamp operated.

Display Time: 0.16, 0.32, 0.64, 1.28, 2.56, 5.12, or 10.24 seconds, or infinity.

Input Impedance: 1 MΩ shunted by 100 pF.

Input Trigger Level: Adequate to permit triggering on zero crossings of signals twice minimum amplitude and on brief pulses of either polarity.

Crystal-Oscillator Stability:

Short-Term: Better than 0.5 ppm.

Cycling: Less than counter resolution.

Temperature Effects: Less than 2½ ppm for rise of 0 to 50°C ambient.

Warmup: Within 1 ppm after 15 minutes.

Aging: Less than 1 ppm/wk after 4 weeks, decreasing thereafter.

Crystal Frequency Accuracy: Within 10 ppm when shipped. Frequency adjustment provided.

Power Required: 105 to 125 or 210 to 250 V, 50 to 60 c/s, 40 W.

Accessories Supplied: Type CAP-22 Power Cord, eight replacement incandescent lamps, spare fuses.

Accessories Available: Type 1136-A Digital-to-Analog Converter and Type 1137-A Data Printer (operate from output of Type 1150-BPH model only).

Cabinet: Rack-bench.

Dimensions: Bench model, width 19, height 3⅞, depth 12½ in (485 by 99 by 320 mm), over-all; rack model, panel 19 by 3½ in (485 by 90 mm), depth behind panel 12¾ in (325 mm).

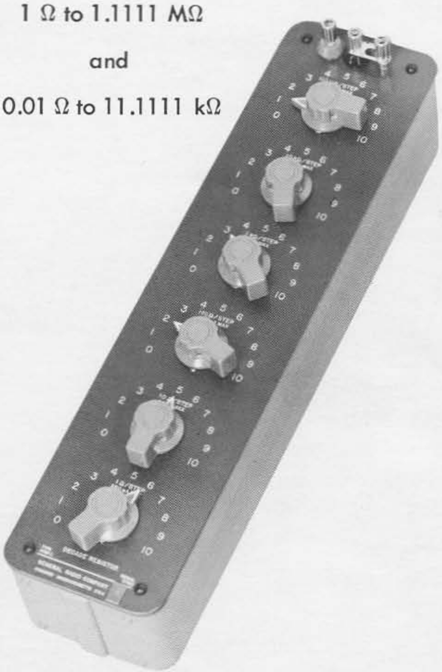
Net Weight: 19 lb (9 kg).

Shipping Weight: 22 lb (10 kg).

Type		*Price*
1150-BHM	**Digital Frequency Meter**, Bench Model	**$1095.00**
1150-BHR	**Digital Frequency Meter**, Rack Model	**1095.00**
1150-BPHM	**Digital Frequency Meter**, with output for printer or D/A converter, Bench Model	**1150.00**
1150-BPHR	**Digital Frequency Meter**, with output for printer or D/A converter, Rack Model	**1150.00**

NEW 6-DIAL DECADE RESISTORS

Two new six-dial models have been added to the GR line of Type 1432 Decade Resistors, one with steps of one ohm, the other with steps of 0.01 ohm. Housed in the laboratory-bench-style aluminum cabinets that are characteristic of the Type 1432 series, these new decade boxes have 11-position rotary switches with silver-overlaid contact studs on the low-resistance decades to ensure stability of resistance. All decades have a silver contact in the zero position in order that the zero resistance of the box be both low and constant. The GR jack-top binding posts accept wire leads, banana plugs, alligator clips, spade terminals, and telephone tips. Three binding posts are used, two for the resistor terminals, the third grounded to the aluminum panel. A removable shorting link is included to permit optional grounding of one side of the resistor.



1 Ω to 1.1111 MΩ

and

0.01 Ω to 11.1111 kΩ

SPECIFICATIONS

Resistance: See price table

Accuracy: See table (right). Resistors are adjusted for incremental as well as total value. Accuracy, as always, is included in the standard General Radio two-year warranty.

Cabinet: Laboratory-bench type.

Dimensions: Width $4\frac{5}{16}$, height $4\frac{3}{4}$, length $18\frac{1}{4}$ in (110, 125, 465 mm).

Net Weight: $7\frac{1}{2}$ lb (3.5 kg).

Shipping Weight: 9 lb (4.1 kg).

Resistance per Step	*Accuracy*	*Max Current for 40° C Rise*
100 kΩ	0.05%	2.3 mA
10 kΩ	0.05%	7 mA
1 kΩ	0.05%	32 mA
100 Ω	0.05%	80 mA
10 Ω	0.05%	250 mA
1 Ω	0.15%	800 mA
0.1Ω	0.5%	1.6 A
0.01Ω	2 %	4 A

Type	*Maximum*	*Per Step*	*Price*
1432-B Decade Resistor	1,111,110 Ω	1 Ω	**$185.00**
1432-W Decade Resistor	11,111.1 Ω	0.01 Ω	**158.00**

GENERAL RADIO COMPANY

extends to all *Experimenter* readers

its best wishes for a

Happy and Prosperous 1965

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