THE GENERAL RADIO
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ABSOLUTE CALIBRATION OF PZT MICROPHONES

Reciprocity techniques[1,2,3,4,5] have long been recognized as the preferred means of determining the absolute pressure calibration of microphones. By these methods the sensitivity, defined in terms of voltage output per unit of acoustic pressure, is determined from the measurement of voltage ratios, mechanical dimensions, and electrical impedance. The techniques have been refined over a period of years to the point where agreement between laboratories to 0.1 db or better, on stable microphones, is consistently obtained. These values represent the best available measure of microphone sensitivity in the present state of the art. Such accuracies are not easily realized, however, and are in fact obtained only by meticulously careful laboratory work, together with a fair amount of calculation. An hour or more is normally allowed to obtain reliable results at a single frequency.

[1] W. R. MacLean, "Absolute Measurement of Sound Without a Primary Standard," *Journal of the Acoustical Society of America*, 12, 140–146 (1940).

[2] R. K. Cook, "Absolute Pressure Calibration of Microphones," *Journal of Research*, National Bureau of Standards, 25, 489–505 (1940); also *Journal of the Acoustical Society of America*, 12, 415–420 (1941).

[3] L. L. Beranek, *Acoustic Measurements*, Sec. 4.2, John Wiley & Sons, Inc. (1949).

[4] A. L. DiMattia and F. M. Weiner, "On the Absolute Pressure Calibration of Condenser Microphones by the Reciprocity Method," *Journal of the Acoustical Society of America*, 18, 341–344 (1946).

[5] American Standard Method for the Pressure Calibration of Laboratory Standard Pressure Microphones, Z24.4–1949.

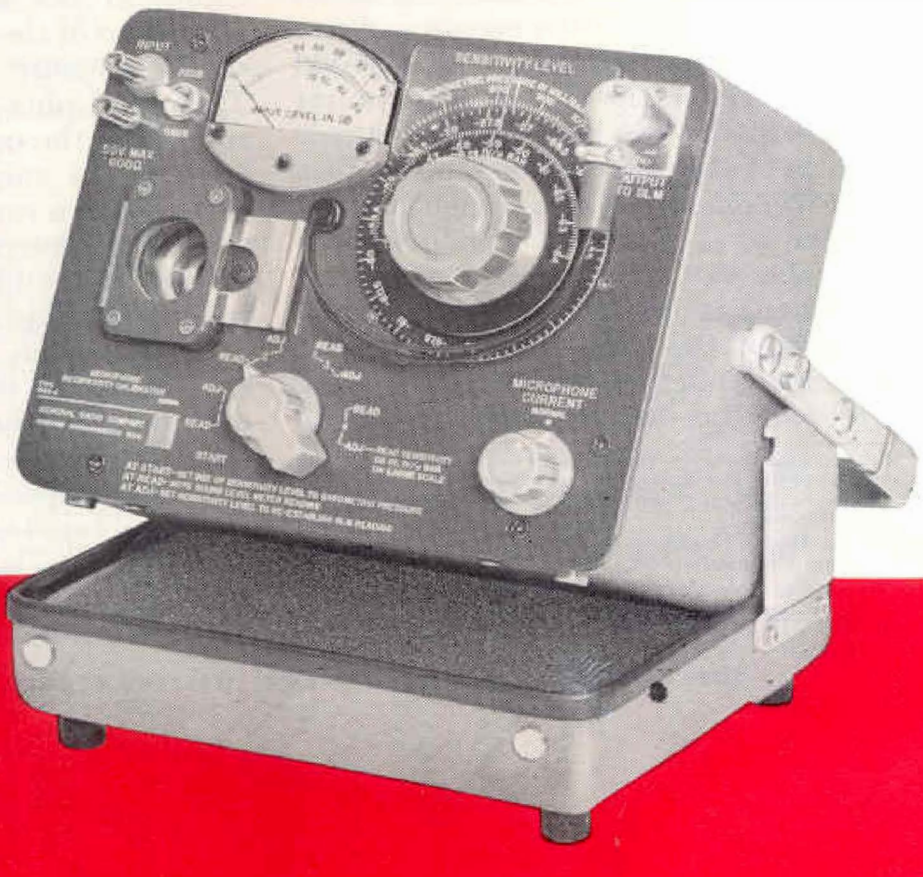

Figure 1. The Type 1559-A Microphone Reciprocity Calibrator is supplied in a Flip-Tilt case for convenient bench use. A relay-rack model is also available.

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A new General Radio development, the TYPE 1559-A Microphone Reciprocity Calibrator, reduces the reciprocity measurement to a matter of routine for General Radio piezoelectric microphones. The instrument is portable, and the measurement technique is so simplified that a measurement at any one frequency can be made in a minute or so. Before important measurements are undertaken, field checks of microphone sensitivity can be made with this calibrator to an accuracy comparable to that hitherto obtainable only in the best standardizing laboratories.

Basic Principles *(see also page 3)*

In addition to the transducer to be calibrated, the reciprocity technique requires two other transducers, one of which is reciprocal,[*6,7] and an acoustic cavity. One transducer is used as a sound source which excites the remaining two transducers (microphones) with a sound pressure. The ratio of the open-circuit voltages of the two microphones equals the ratio of the microphone sensitivities. If the two microphones are then coupled together by a known acoustic impedance (the cavity) and the reciprocal microphone is driven as a sound source, the ratio of the open-circuit voltage of the second microphone to the driving current of the first microphone can be theoretically related to the product of the microphone sensitivities. The two relationships, one for the *ratio* of microphone sensitivities and one for the *product* of microphone sensitivities, can then be solved for the sensitivity of either microphone. The acoustic impedance[8] of the cavity is the independent calculable quantity in terms of which microphone sensitivity is established.

A Unique Device

The uniqueness of the TYPE 1559-A Microphone Reciprocity Calibrator rests on the following design features:

(1) The transducer used to determine the ratio of sensitivities is in the form of a piezoelectric ring[†] which makes up the cavity wall, thereby eliminating the need for physically interchanging the location of microphones during the course of the measurement. Electrical excitation of the ring produces a uniform sound pressure throughout the cavity. This fact, plus the symmetry that results from the use of a transducer in the form of an encompassing cylinder together with a reversible transducer identical to the microphone being measured, makes the coupler usable over a wide frequency range.

(2) A switch is used to connect the circuits for the required operations without the need for physically interchanging the transducers.

(continued on page 4)

* In a reciprocal device, the ratio of response to excitation is unchanged if the points of excitation and observation are interchanged, provided that the terminal conditions remain the same.

[6] Lord Rayleigh, *The Theory of Sound*, Vol II, 108, Macmillan and Company, Ltd. (1877).

[7] S. Ballantine, "Reciprocity in Electromagnetic, Mechanical, Acoustical and Interconnected Systems," *Proceedings of the IRE*, 17, 929–951 (1929).

† A similar and independent development has been recently reported: see "Pressure Calibration of Measuring Microphones by the Reciprocity Method," *Soviet Physics Acoustics*, 26, 2, Oct-Dec 1960, p 246.

[8] P. M. Morse, *Vibration and Sound*, Chapter 6, McGraw Hill (1936).

THEORY, OPERATION, AND READOUT

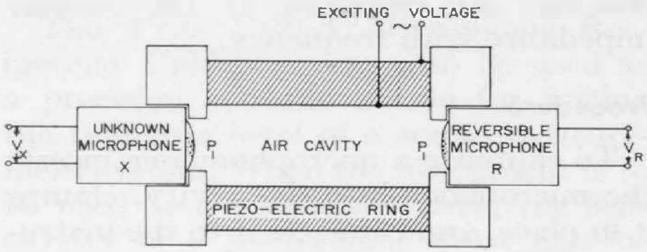


Figure 2a. Conditions for Step 1.

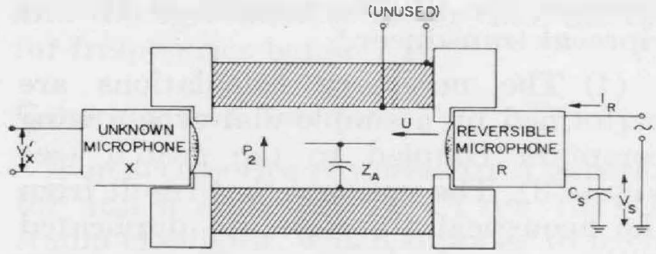


Figure 2b. Conditions for Step 2.

STEP 1 — Both microphones are excited by the same sound pressure, P_1. Their open-circuit voltages V_R and V_X are proportional to their sensitivities, M_R and M_X. Then

$$\frac{M_R}{M_X} = \frac{V_R}{V_X} \qquad (1)$$

STEP 2 — The reversible microphone is driven by a current, I_R, producing a volume velocity of sound, $U = I_R M_R$, in the cavity, whose acoustic impedance is Z_A. This, in turn, produces a sound pressure, $P_2 = U_2 Z_A$ at the unknown microphone, which generates a voltage, $V'_X = P_2 M_X$.

Then,

$$M_R M_X = \frac{V'_X}{I_R Z_A} \qquad (2)$$

Combining (1) and (2),

$$M^2{}_X = \frac{1}{Z_A} \cdot \frac{V_X}{V_R} \cdot \frac{V'_X}{I_R}$$

The impedance, Z_A, is calculated, and all the other quantities are measured. $\frac{V_X}{V_R}$ comes from step 1; I_R is measured in terms of the voltage across a polystyrene capacitor in the current path, $I_R = V_s \omega C_s$; V'_X is measured directly.

$$Z_A = \frac{\gamma P_o}{\omega V_c}$$

where:

γ is the ratio of specific heat of air at constant pressure to that at constant volume

P_o = atmospheric pressure

V_c = cavity volume

The two ω-terms cancel, and

$$M_X = \sqrt{\frac{V_c}{\gamma P_o C_S} \cdot \frac{V_X}{V_R} \cdot \frac{V'_X}{V_S}}$$

$$= \sqrt{k\left(\frac{1}{P_o}\right) \cdot \frac{V_X}{V_R} \cdot \frac{V'_X}{V_S}} \qquad (3)$$

Then M_X in db =

$$10\left[\log\frac{k}{P_o} + \log V_X - \log V_R + \log V'_X - \log V_S\right] \qquad (4)$$

This computation is carried out on a simple analog computer consisting of a function switch and an attenuator that includes a logarithmic potentiometer, shown in Figure 3. The first term is taken care of by an initial setting of the answer dial in terms of barometric pressure. Voltages are measured by a substitution method, and voltage ratios appear as differences in the attenuator settings necessary to produce a constant detector reading. The function switch, in addition to controlling generator, detector, and transducer connections, actuates the brake to hold the answer dial stationary while the attenuator is set to correspond to the amplitude of the numerator voltages in (3), then re-engages the dial for the setting of the denominator voltages. Thus, attenuator setting differences in db are transferred to the answer dial during steps in the computation. The final result, i.e., the sensitivity of microphone X, is read from the computer dial in db *re* 1v/μbar.

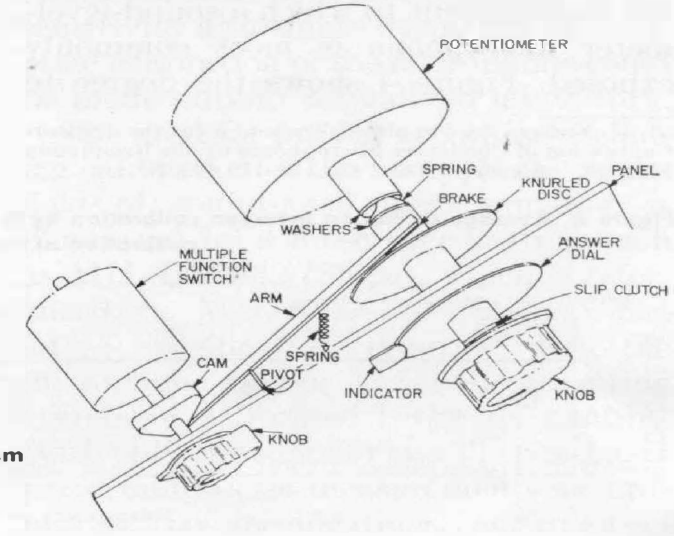


Figure 3. Switching and computer mechanism in elementary form.

(3) A standard capacitor is used to measure the driving current of the reciprocal transducer.[9]

(4) The necessary calculations are performed by a simple dial-type analog computer coupled to the switch (see Figure 3). The voltages that result from the acoustical transfers are duplicated with an electrical network that includes a logarithmic potentiometer. The angular positions of the potentiometer shaft are proportional to the logarithms of the voltages to be measured, and these shaft positions are transferred to the answer dial in such a way that the necessary multiplications and divisions are accomplished in a manner analogous to the use of a slide rule.

(5) The closed coupler reciprocity technique normally yields the pressure response of a microphone, but the American Standards Association Specification for General Purpose Sound-Level Meters S1.4-1961 requires a microphone which has a flat random-incidence (diffuse-field) response. In this calibrator, the deviation of the coupler from a simple acoustical element with increasing frequency is empirically matched to the correction between the random-incidence response and the pressure response. The calibration is then effectively in terms of a diffuse-sound field, which is the environment to which a sound-level-meter microphone is most commonly exposed. Figure 4 shows the degree to which the random-incidence correction matches the deviation of the coupler impedance with frequency.

[9]A. K. Nielson, "A Simplified Technique for the Pressure Calibration of Condenser Microphones by the Reciprocity Method," *Acoustica*, Vol 2 #3, 112–118 (1952).

Procedure

To calibrate a microphone one inserts the microphone into the cavity, clamps it in place, and connects it to the instrument. Then one sets a reference to the barometric pressure and proceeds to make four dial settings. At the completion of the fourth setting, the random-incidence (diffuse-field) microphone sensitivity in db *re* 1v/μbar is read directly from a dial on the instrument panel to an accuracy which varies from 0.2 db at low frequencies to 0.7 db at 7 kc.

The Calibration, Absolute and Traceable

The Type 1599-A Microphone Reciprocity Calibrator is a primary and accurate calibrator of General Radio Company's PZT microphones below 1 kc, while above 1 kc (where the dimensions of the cavity become comparable with the wavelengths of the sound) it is direct reading in the random-incidence (diffuse field) response of the microphones. The calibration of a Type 1560-P3 PZT Microphone by use of this instrument depends on the measurement of length (volume of the cavity) and electrical impedance (capacitance and resistance), and is thus "traceable" to NBS calibrations of those units. An independent cross-check is also possible by comparison with an NBS calibrated 640-AA microphone, as shown later.

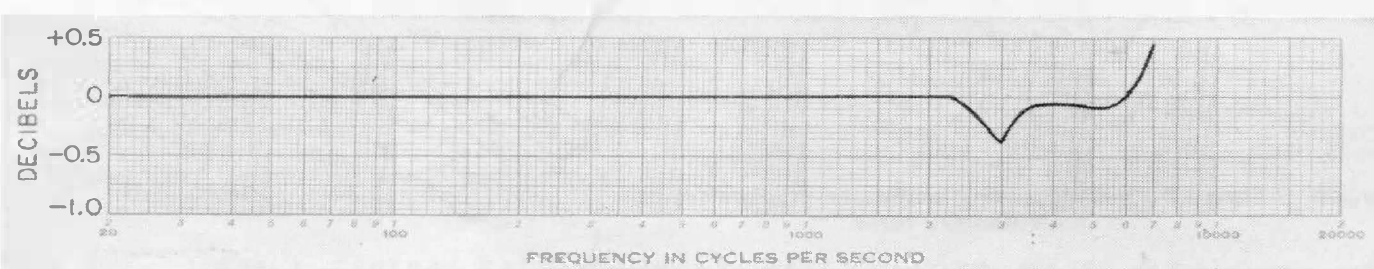


Figure 4. Average deviation between calibration by the Type 1559-A Microphone Reciprocity Calibrator and calibration at random incidence.

A Standard Source

The TYPE 1559-A Microphone Reciprocity Calibrator can also be used as a precision acoustic source for setting the reference level of a sound measurement system. When the instrument is to be used as a precision source, the sensitivity of a microphone must first be determined by the procedure outlined above. This sensitivity is used as a reference to set the driving current for the reversible transducer. For a given input voltage a known sound-pressure level will then be produced in the cavity. A sound-measurement system connected to the output of the microphone can then be set to indicate this known level.

Comparison with Standard Microphone

This technique for producing a known sound level in the cavity can also be used to compare the sensitivity of a General Radio TYPE 1560-P3 PZT Microphone to that of a Western Electric 640-AA Laboratory Standard Microphone or to calibrate a sound-measuring system that uses such a microphone. After the TYPE 1559-A Microphone Reciprocity Calibrator is set to produce a known sound field as above, the TYPE 1560-P3 PZT Microphone is replaced by the 640-AA microphone with the adaptor sleeve furnished with the calibrator. The sound level in the cavity is then measured by the 640-AA microphone and its associated measurement system, and the system calibration can be set according to the known level. Or, if the sensitivity of the 640-AA is known and the electrical response of the associated system is known, one can then compare the sound level measured with the 640-AA and that produced in the cavity. When this is done, the primary calibration of a TYPE 1560-P3 PZT Microphone made with a TYPE 1559-A Microphone Reciprocity Calibrator has been compared to the National Bureau of Standards calibration of a 640-AA microphone, and the agreement is better than 0.2 db for frequencies below 1 kc.

Generator and Detector

The accessories required are a generator and a detector. The TYPE 1311-A Audio Oscillator, which supplies 10 fixed frequencies between 50 and 5000 cps, is recommended. For continuously adjustable frequencies, either the TYPE 1210-C Unit R-C Oscillator or the TYPE 1304-B Beat-Frequency Audio Generator can be used. For recording applications or for fixed installations, the latter is preferable. The detector can be either the TYPE 1551-C Sound-Level Meter or the TYPE 1558-A Octave-Band Noise Analyzer, usually the instrument whose microphone is to be calibrated.

Applications

Use of the TYPE 1559-A Microphone Reciprocity Calibrator effectively eliminates instrument error from sound-level measurements; the observer can then concentrate his attention on the acoustical factors, such as environment and microphone placement. Hitherto, one could readily calibrate the electrical part of a sound-measuring system, but the calibration of the microphone was restricted to a check on the microphone's sensitivity at a single frequency. A complete calibration of the microphone could be made only at a qualified laboratory.

The need for proved accuracy, including calibration of the microphone, in the field of sound-level measurements, is illustrated by a noise specification such as MIL-E-22842 (Ships), which is referenced to MIL-STD-740 (Ships). The latter specification requires that the microphone used in the sound-measuring system be calibrated every six months. With both the supplier and the purchaser performing noise measurements according to the specifications, accuracy of calibration will be an important factor in the rapid and economical elimination of any discrepancies between the respective measurements.

The manufacture and purchase of equipment to a particular noise specification is not restricted to military applications. Some examples are: (1) The air-moving industry which has specifications on the noise levels that may be generated by fans, blowers, etc.; (2) communities with ordinances restricting the maximum noise level produced by trucks and other vehicles; and (3) airports that have limits on the noise level produced by aircraft using their facilities. Industrial hygienists require proof of the calibration accuracy of their sound-level measuring equipment. In general, requirements for sound-measuring equipment are becoming more stringent because users demand correlation of measurements taken at different locations and consistency of measurements taken at different times.

Simple to operate, direct reading, and accurate, this calibrator provides a reliable and consistent means of standardizing sound measurements.

— Basil A. Bonk

SPECIFICATIONS

MICROPHONE CALIBRATOR

Microphones: This instrument will calibrate the Type 1560-P3 and -P4 PZT Microphones, currently used on the Type 1551-C Sound-Level Meter and the Type 1558-A Octave-Band Noise Analyzer, respectively; also the Type 1560-P1 (Rochelle Salt) Microphone, used on the older Type 1551-B Sound-Level Meter.

Range: Direct reading for microphone sensitivities between -55 db and -65 db *re* 1 volt/μbar.

Frequency Range: 20 to 8000 cps.

Accuracy: ± 0.2 db $\pm$ (0.1 db $\times$ frequency in kc) up to 2.5 kc, ± 0.7 db above 2.5 kc to 7 kc, when reference is set to actual barometric pressure.

PRECISION ACOUSTICAL SOURCE

Frequency Range: 20 to 8000 cps.

Output: 92 db *re* 0.0002 μbar for excitation of 50 volts.

Accuracy: At 92 db, ± 0.1 db + error in determining microphone sensitivity.

SOUND-LEVEL CALIBRATOR

Frequency Range: 20 to 2000 cps.

Output: 92 db *re* 0.0002 μbar for excitation of 50 volts.

Accuracy: ± 0.7 db at standard atmospheric pressure.

GENERAL

Maximum Safe Input Voltage: 50 volts behind 600 ohms.

Accessories Required: Generator and detector. Generator to supply 5 volts or more into a 2000-pf load, and 2.5 volts or more into a 600-ohm 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 1311-A Audio Oscillator are recommended. The Type 1551-B or -C Sound-Level Meter or the Type 1558-AP Octave-Band Noise Analyzer is recommended for the detector.

Accessories Supplied: Cables for connection to generator and detector; adaptor sleeve for 640-AA microphone.

Cabinet: Flip-Tilt; relay-rack model also is available.

Dimensions: Portable model, case closed — width 10, height 8, depth 7½ inches (255 by 205 by 190 mm), over-all; rack model — panel 19 by 10½ inches (485 by 270 mm), depth behind panel 5 inches (130 mm).

Net Weight: Portable model, 13 pounds (6 kg); rack model, 14 pounds (6.5 kg).

Shipping Weight: Portable model, 22 pounds (10 kg); rack model, 29 pounds (13.5 kg).

Type		*Code Number*	*Price*
1559-A	**Microphone Reciprocity Calibrator,** Portable Model	1559-9701	**$475.00**
1559-9820	**Microphone Reciprocity Calibrator,** Rack Model . . .	1559-9820	**475.00**

Patent Applied For.

Note: The relay-rack model of this instrument makes use of an adaptor panel of the type described (for the Type 1650-A Impedance Bridge) on page 7 of the November, 1962, issue of the *Experimenter*. This method of rack mounting is used for all GR Flip-Tilt cases.

TYPE 1120-AB FREQUENCY STANDARD

Emergency power equipment, which assures continuity of service despite interruption of normal power service, is now incorporated in a new assembly of standard-frequency equipment, the Type 1120-AB Frequency Standard. The individual standard-frequency instruments, which have been described previously,[1] are:

- Type 1113-A Standard-Frequency Oscillator
- Type 1114-A Frequency Divider
- Type 1103-B Syncronometer® time comparator

The additional units, which provide emergency power, are:

- Type 1116-B Emergency Power Supply
- Type 1268-A Automatic Battery Charger
- Type 1268-P1 Battery Drawer
- Type 1268-9602 Battery

The entire assembly is housed in a floor-type cabinet rack, as shown in Figure 1.

Standard-Frequency Oscillator

The performance of the Type 1113-A Standard-Frequency Oscillator has amply justified the original evaluations[1] of its over-all stability. The one-year drift record of a typical unit is shown in Figure 2. Note that the drift rate at the end of a year has diminished to less than one part in 10^9 per month, or better than 3 parts in 10^{11} per day.

Of particular interest is the spectrum plot of Figure 3, which indicates a high degree of short-term stability, that is,

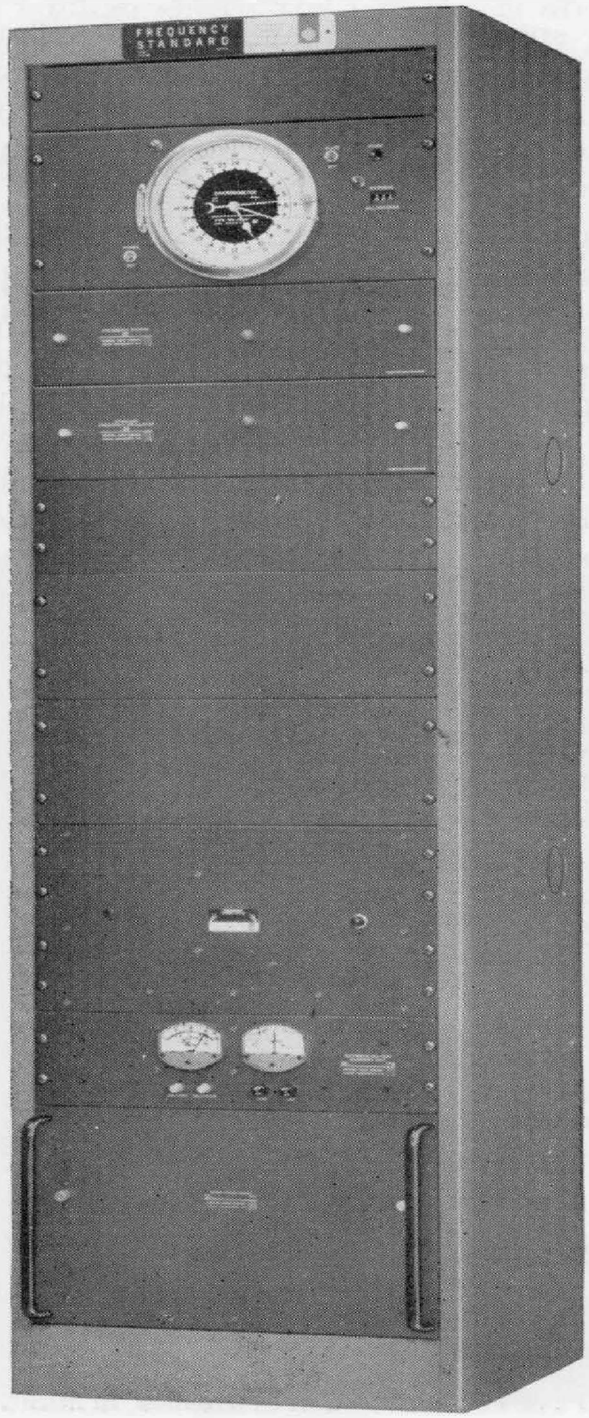


Figure 1. View of the Type 1120-AB Frequency Standard.

[1] R. W. Frank, F. D. Lewis, and H. P. Stratemeyer, "The New GR Frequency Standard," *General Radio Experimenter*, 35, 4, April 1961.

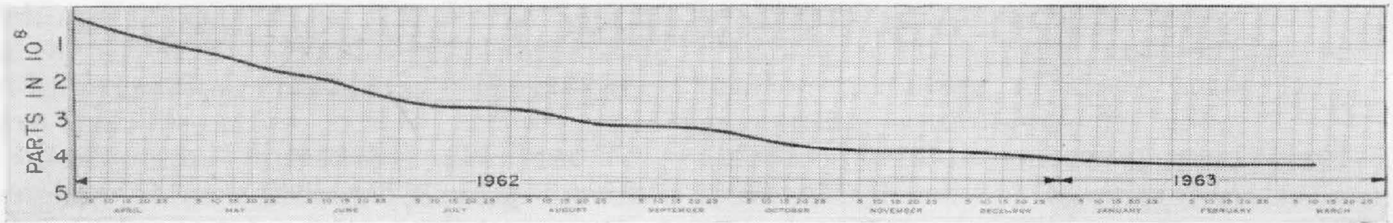


Figure 2. Typical long-term frequency drift of Type 1113-A Standard-Frequency Oscillator.

a very low level of fm noise. Note that this spectrum is that of the oscillator frequency multiplied up to 23,900 Mc, and so it includes not only oscillator instabilities, but also any noise that might be contributed by the multipliers.

Frequency Divider

The Type 1114-A Frequency Divider[1] divides the 5-megacycle crystal frequency to produce sine-wave output frequencies at 1 Mc, 100 kc, 10 kc, 1 kc, and 100 cps, as well as square waves at 100 kc and 10 kc. The divider circuits are designed for low jitter (about 0.5 nsec over-all from 5 Mc to 100 cps) and are all "fail-safe," that is, they have no output in the absence of an input signal.

Time Comparator

The Type 1103-B Syncronometer® time comparator[1] provides a calibration against standard time by comparison with radio time signals. Such comparisons can be made to about 0.1 millisecond. Radio propagation time varies up to ±0.1 millisecond, making over-all accuracy of comparison approximately ±0.2 millisecond. A frequency calibration accuracy of $\pm 1 \times 10^{-9}$ is possible over a 48-hour interval. This unit provides an additional fail-safe feature since even momentary failure of the driving frequency will stop the clock, which will not restart of itself when the drive reappears.

[1] *Loc. cit.*

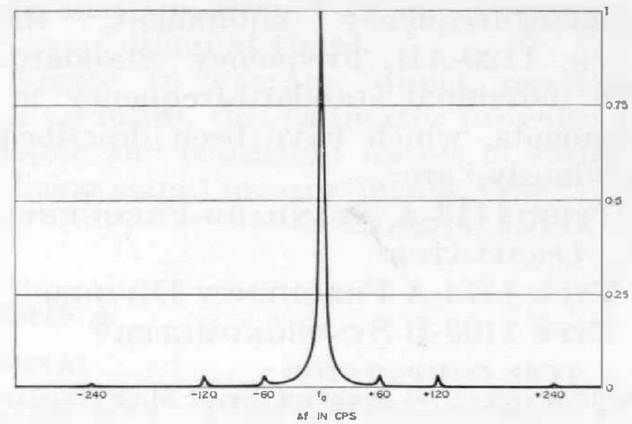


Figure 3. Spectrum of the Type 1113-A Standard-Frequency Oscillator as measured at 23,900 Mc by the National Bureau of Standards.

SPECIFICATIONS

Output Frequencies: 5 Mc, 1 Mc, 100 kc, 10 kc, 1 kc, 100 cps; additional plug-in units for the Type 1114-A Frequency Divider are available to produce output at 400 cps and 60 cps.
Power Requirements: 105 to 125 (or 210 to 250) volts, 50 to 60 cps, 370 watts.
Dimensions: Width 22, height 76½, depth 18½ inches (560 by 1950 by 470 mm).
Net Weight: 475 pounds (220 kg).
Shipping Weight: 645 pounds (300 kg).

Type		*Code Number*	*Price*
1120-AB	**Frequency Standard**	1120-9430	**$5200.00**

Note: Other frequency-standard combinations available include the Type 1120-A, which has the same output frequencies as the -AB model, but without emergency power equipment, and the Type 1120-AH, which furnishes, in addition, frequencies of 10, 100, and 1000 Mc (also without emergency power equipment). All component units are available separately and special assemblies can be devised to meet individual requirements.

EMERGENCY POWER SUPPLY

The TYPE 1116-B Emergency Power Supply is a combination inverter and switching device, designed for use with a 28- to 32-volt storage battery. Upon failure of the power line, the vibrator-type inverter is automatically connected to the battery supply, the power-input terminals of the frequency standard are transferred to the inverter output, and a front-panel lamp glows to indicate emergency operation. This changeover occurs when the line voltage falls below 105 (or 210) volts; the return to line operation takes place at a level between 108 and 113 (or 216 and 226) volts.

The switching is accomplished so rapidly that no interruption occurs in the operation of the frequency standard. The transfer takes place in less than two cycles of the power-line frequency.

On resumption of the power-line service, the standard is automatically switched back to the line, and the inverter is disconnected from the battery.

Switching is accomplished by fast-acting relays and solid-state diodes.

Automatic Battery Charger

The TYPE 1268-A Automatic Battery Charger is designed to maintain at optimum charge condition a 24-cell nickel-cadmium battery to provide emergency power for the TYPE 1116-B Emergency Power Supply.

As soon as line voltage is restored after power failure, a constant current charge of about 4 amperes is applied to the battery. After 6 hours of this charge, a timer changes the operating mode to constant voltage. This float voltage maintains the battery at optimum charge regardless of the trickle-charge current required. Under these conditions the voltage across the battery is about 34 volts. Meters are provided for battery voltage and current.

Battery Drawer

This unit is a relay-rack-mounted drawer capable of housing the 24-cell battery. Ball-bearing slides and quick-release fasteners provide easy access for battery maintenance. Stainless steel is used for the battery holder to insure chemical resistance against the alkaline electrolyte of the nickel-cadmium battery.

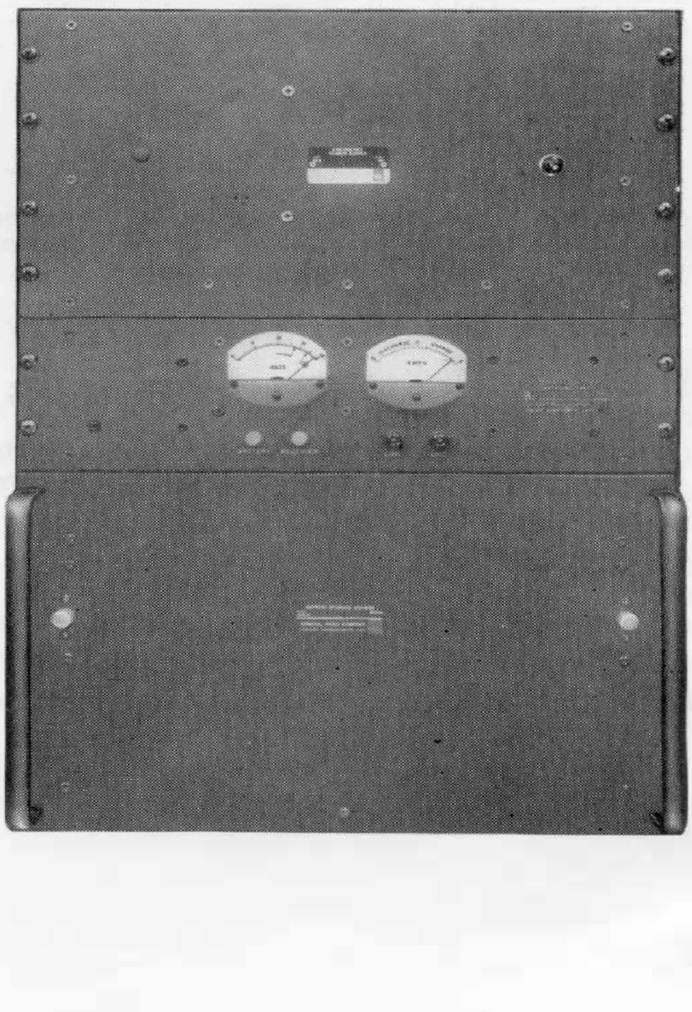


Figure 4. View of the emergency power supply equipment. From top, Type 1116-B Emergency Power Supply, Type 1268-A Automatic Battery Charger, Type 1268-P1 Battery Drawer.

Battery

This 24-cell nickel-cadmium battery is shipped directly from the manufacturer's plant. Its capacity is sufficient to operate the frequency standard for at least 3½ hours.

SPECIFICATIONS

TYPE 1116-B EMERGENCY POWER SUPPLY

Input: 115/230 v, 50–60 cps from power line. 28–32 v, 4.3–3.2 amp from battery (when operating TYPE 1120-AB Frequency Standard).
Output: 115 v, nominal, 60 cps, 180 watts continuous maximum rating.
Operational Range: Battery cuts in when line voltage falls below 105 v and cuts out when restored line voltage reaches a threshold value between 108 and 113 v.
Accessories Supplied: TYPE CAP-22 Power Cord (2); spare power line fuses (2).
Accessories Required: 28-, 30-, or 32-v battery and cables.
Accessories Available: TYPE 1268-A Automatic Battery Charger; TYPE 1268-P1 Battery Drawer; TYPE 1268-9602 Battery.
Cabinet: Relay-rack.
Dimensions: 19 by 10½ inches (485 by 270 mm), depth behind panel 13 inches (330 mm).
Net Weight: 58½ pounds (26.6 kg).

TYPE 1268-A AUTOMATIC BATTERY CHARGER

Constant-Current Charge: 6 hours at 4 amperes, nominal.
Trickle Charge: 33.8 volts ± 2% is maintained at the battery.
Power Required: 105 to 130 (or 210 to 260) volts, 60 cps, 240 watts maximum.
Ambient Temperature Range: 0 to 50 C.
Cabinet: Rack-bench.
Dimensions: Bench model — width 19, height 5¼, depth 11¾ inches (485 by 135 by 300 mm), over-all; rack model — panel 19 by 5¼ inches (485 by 135 mm), depth behind panel 11 inches (280 mm).
Net Weight: 29½ pounds (13.5 kg).
Shipping Weight: 50 pounds (23 kg).

TYPE 1268-P1 BATTERY DRAWER

Cabinet: Relay-rack.
Dimensions: Panel 19 by 12¼ inches (485 by 314 mm), depth behind panel 19 inches (485 mm); interior, battery compartment floor, 16¼ by 14¾ inches (415 by 375 mm), height 10¾ inches (275 mm).
Net Weight: Less battery, 25 pounds (11.5 kg).
Shipping Weight: Less battery, 35 pounds (16 kg).

TYPE 1268-9602 BATTERY

Type: Nickel-cadmium.
Voltage: 28 volts dc, nominal.
Ampere-Hours: 15 ampere-hours. At 4.3 to 3.2 amperes required by TYPE 1116-B Emergency Power Supply, batteries will run at least 3½ hours.
Net Weight: 90 pounds (41 kg), approximately. Battery shipped direct from supplier.

Type		*Code Number*	*Price*
1116-B	**Emergency Power Supply**	1116-9702	**$450.00**
1268-AM	**Automatic Battery Charger,** Bench Model	1268-9801	**450.00**
1268-AR	**Automatic Battery Charger,** Rack Model	1268-9811	**450.00**
1268-P1	**Battery Drawer,** less battery	1268-9601	**195.00**
1268-9602	**Battery**	1268-9602	**250.00**

COMING EXHIBITS

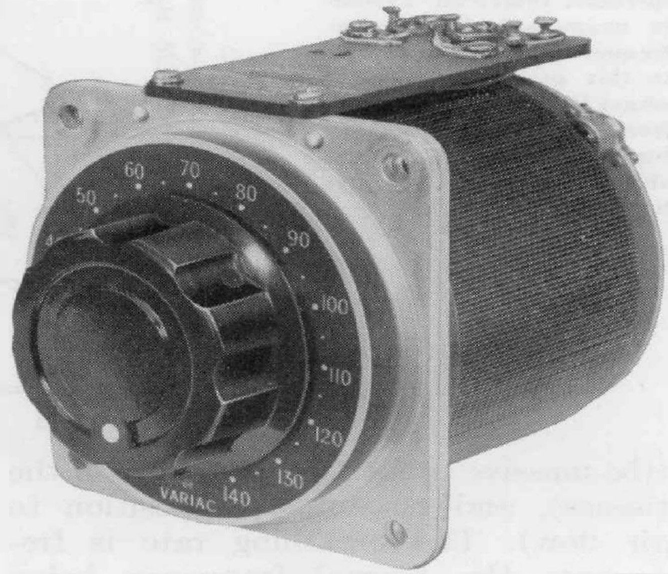
General Radio instruments will be on display at these meetings and exhibits during the month of May. Our engineers will be on hand to welcome you and to answer your questions.

Date	*Sponsor or Title*	*Location*
May 6–10	National Industrial Production Show of Canada	Exhibition Park, Toronto
May 6–10	American Industrial Hygiene Conference	Sheraton-Gibson Hotel, Cincinnati
May 15–18	Acoustical Society of America	Hotel New Yorker, New York
May 20–23	Design Engineering Show	Coliseum, New York

MORE WATTS PER DOLLAR WITH THE NEW W8 VARIAC® AUTOTRANSFORMER

VARIAC® autotransformers, TYPES W8 and W8L, offer increased ratings and increased volt-amperes per dollar, yet occupy the same panel space as the popular TYPE W5. They differ dimensionally from the TYPE W5 in but one respect, an increase in back-of-panel depth of one-half inch. They embody all the features common to the General Radio "W" line of VARIAC autotransformers, and are currently available as basic models only, without cases.

We feel that these two new units will serve a useful purpose by meeting a demand for more power in a limited space. Their increase in volt-amperes-per-dollar is a built-in bonus.



SPECIFICATIONS

Type	W8	W8L*
Input Volts	120	120
Output Volts	0–120 0–140	0–120
Line Frequency	50-60 cps	60 cps
Rated Amperes	8.5	10

Type	W8	W8L*
Max Amperes	11	13
Rated KVA	1.32	1.56
Code Number	3038-5110	3058-5110
Price	**$21.00**	**$21.00**
Volt-Amperes/$	62.9	74.3

* Note that the Type W8L cannot be operated at line frequencies lower than 60 cps, and that it cannot be used to obtain overvoltage.

AC THEORY AND THE HUMAN CHEST

The GR TYPE 1305-A Low-Frequency Oscillator was featured in an unusual demonstration last September at the XXII International Congress of Physiological Sciences at Leiden. In the exhibit, entitled "Interpretation of the Respiratory Pressure-Volume Lissajous Figures," the oscillator was used to produce, on a dual-beam oscilloscope, Lissajous loops analogous to pressure-volume and pressure-volume flow in the human chest. The input data were taken from actual experiments performed on animals and human beings, part of a long-term program conducted by Drs. Wayland E. Hull and E. Croft Long at Duke University Medical Center.

The electrical analog of the human chest is an interesting example of the use of analogous systems to explain natural phenomena. The human chest and lungs are here visualized as a series circuit, containing capacitance (compliance of lung tissues and rib cage), inductance

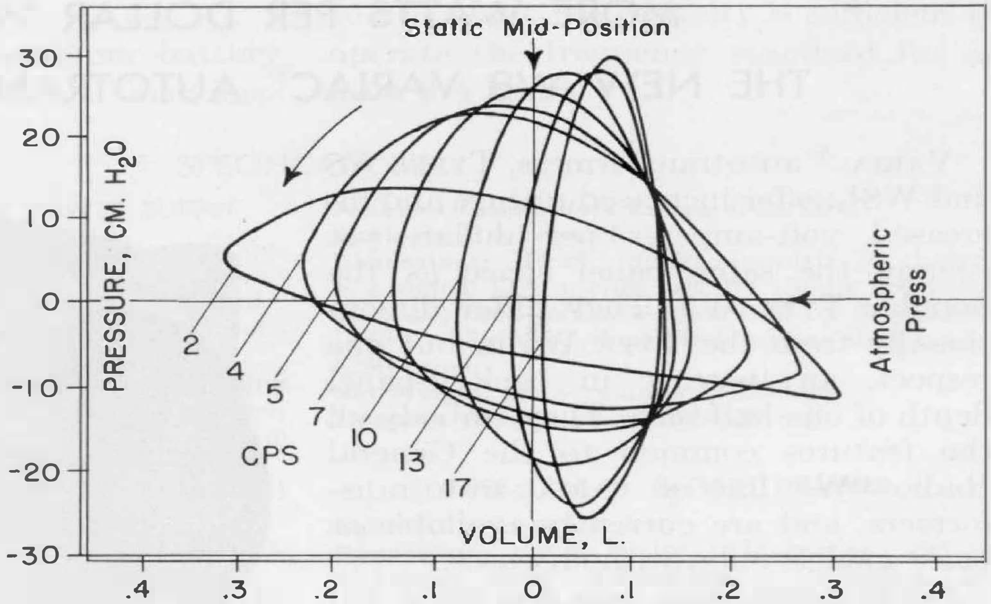


Figure 1. Pressure-volume Lissajous patterns at frequencies indicated. System is asymmetrical at lower frequencies and resonant, in this particular case, at about 10 cycles/sec as seen from vertical loop indicating 90 degrees of phase shift. Data from anesthetized dog.

(by permission of the *Journal of Applied Physiology*)

(the massive or inertant character of the tissues), and resistance (opposition to air flow). The breathing rate is frequency, the normal frequency being about 20 cycles per minute. By the use of an iron-lung-type respirator, breathing rates up to 20 cps can be produced in anesthetized animals. Thus, if pressure is held constant at all frequencies, a frequency-impedance relation can be determined. Similarly, the volume of air moved by the system can be studied as a function of frequency. The alternating pressure supplied in the test is made to approximate a sine wave, so that much of elementary ac theory can be applied in this biological system.

The resonant frequency of both animal and human chests is of the order of 5 cps, and many animals, including dogs, pant at that frequency. To the physiologist, this implies that the maximum air flow is available to cool the mouth, tongue, and air passages for the minimum expenditure of energy.

The relation of volume and pressure in connection with distention of lung and thorax is of especial interest to physicians. Several chest diseases are seen to involve changes in chest "capacitance" or "resistance." Beyond the considerations of chest and lung research lie the exciting possibilities of explaining other biological phenomena by electrical analog.

Our thanks to Dr. E. C. Long and Dr. W. E. Hull of Duke for permission to publish this brief abstract. Those interested in a more complete discussion are referred to *American Journal of Applied Physiology*, 16:439–443, 1961 and 17:609–612, 1962.

Drs. Hull and Long have been actively interested in the use of analogous systems to explain biological phenomena and hope that this approach may stimulate electrical engineering graduates to recognize that biological science offers them the opportunity for work at a truly professional level.

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