OPERATING INSTRUCTIONS

2-

TYPE 1559-A

MICROPHONE RECIPROCITY CALIBRATOR

G E N E R A L R A D I O C O M P A N Y
A

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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 ± (0.1 db × 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).

U.S. Patent No. 2,966,257.

General Radio Experimenter reference: Vol. 37 No. 4, 5, April-May 1963.

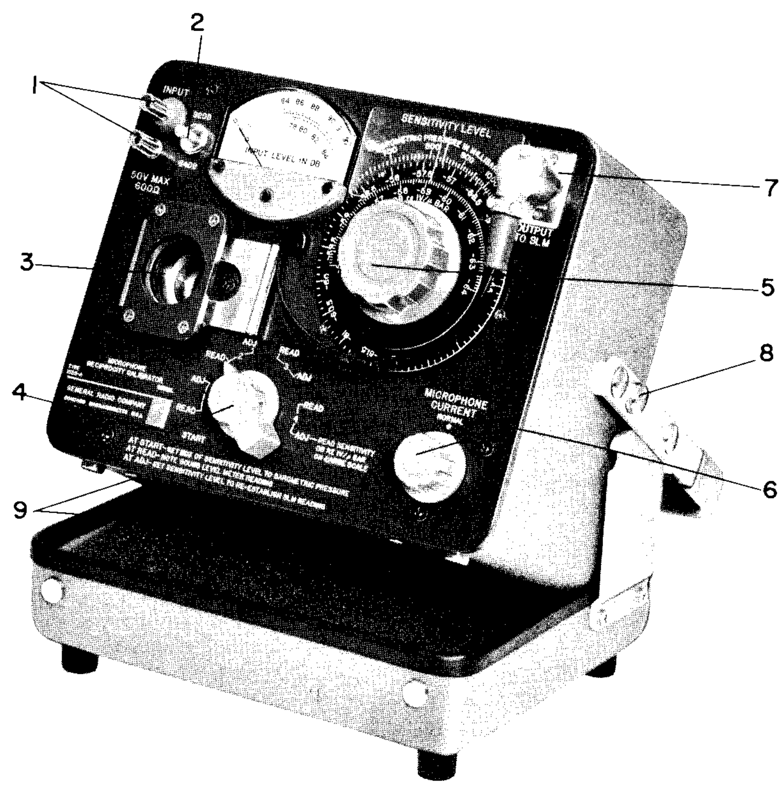

Figure 1-1. Type 1559-A Microphone Reciprocity Calibrator.

SECTION 1

INTRODUCTION

1.1 PURPOSE.

The Type 1559-A Microphone Reciprocity Calibrator (Figure 1-1) is a primary calibrator for the General Radio Type 1560-P3 PZT Microphone. Without any calculations, one can rapidly determine the sensitivity of a microphone in db re 1 volt/μbar. The instrument's high accuracy makes it suitable for standardization measurements, while its ease of operation makes it useful for daily checks on sensitivity.

This instrument can also be used as a source of constant acoustic output over a wide frequency range to make rapid calibration checks on microphones and sound-level meters or to set the reference level of analyzing systems.

1.2 DESCRIPTION.

1.2.1 GENERAL. The reciprocity calibrator includes the circuit and the structure required for the closed-coupler (cylindrical cavity) reciprocity calibration procedure, which is widely recognized as the preferred method of performing the absolute calibration of laboratory standard microphones. The instrument also includes an analog computer, which performs the calculations necessary to determine microphone sensitivity. The reversible transducer needed in the calibration procedure is the cartridge of the Type 1560-P3 PZT Microphone, which is built into the coupler. The auxiliary transducer is a PZT cylinder, which forms the cylindrical wall of the coupler.

The PZT cylinder used in the reciprocity calibration also serves as a stable acoustic source when the instrument is used as a sound-level calibrator. A meter, calibrated in terms of the sound-pressure level produced, indicates the absolute value of the signal applied to the PZT cylinder.

1.2.2 CONTROLS AND CONNECTORS. Table 1 lists controls and connectors on the instrument panel.

TABLE 1

CONTROLS AND CONNECTORS

Fig. 1-1 Ref	Name	Type	Function
1	INPUT	Binding post pair	Input connection from oscillator to Type 1559-A.
2	92DB-84DB	3-position toggle switch	Selects meter range.
3	Microphone connector	3-terminal Cannon Type XLR locking connector	Receives microphone to be calibrated.
4	Transfer-function switch (READ-ADJ)	9-position selector switch	Sets necessary electrical transfers.
5	SENSITIVITY LEVEL	Continuous rotary control	Adjusts value of resistance attenuator.
6	MICROPHONE CURRENT	Continuous rotary control	Controls level of driving current of reversible transducer.
7	OUTPUT TO SLM	3-terminal Cannon Type XLR locking connector	Output connection to sound-level meter.

1.2.3 ACCESSORIES SUPPLIED. Supplied with the reciprocity calibrator are a Type 274-NP Patch Cord, an 18-inch output cable for connection to the sound-level meter, and an adaptor for a 640-AA microphone.

1.2.4 CARRYING CASE. The Type 1559-A is mounted in a General Radio Flip-Tilt case. The captive protective cover serves as a mounting base when the instrument is in use. Owing to the friction of the rubber seal, the instrument can be operated at almost any angle from horizontal to vertical. The cables and instruction book are in the cover, in a protective polyurethane compartment.

1.3 ACCESSORIES REQUIRED.

1.3.1 GENERATOR. An audio oscillator is required to drive the Type 1559-A Microphone Reciprocity Calibrator. Ideally, this oscillator should have an output impedance of 600 ohms and should be able to deliver 1 watt into a 600-ohm load. The Type 1304-B Beat Frequency Audio Generator fulfills these requirements and, in addition, is readily coupled to a recorder such as the Type 1521-A Graphic Level Recorder. Although the Type 1559-A Microphone Reciprocity Calibrator is designed to use the changes in output voltage of a 600-ohm generator as the various transfers are connected (the input impedance varies between 600 ohms, 5000 ohms, and several hundred picofarads), oscillators of other output impedances can be used. Two such oscillators are the Type 1311-A Audio Oscillator, which supplies 11 fixed frequencies between 50 and 10,000 cps, and the Type 1210-C Unit R-C Oscillator, which is continuously adjustable over the audio spectrum. The Type 1311-A should be used on the 30-volt output position and the Type 1210-C on the 0-7-volt output position. The need for the 600-ohm generator impedance is most evident when the Type 1559-A Microphone Reciprocity Calibrator is being used for sound level calibration. The output impedance of both the Type 1311-A Audio Oscillator and the Type 1210-C Unit R-C Oscillator can be made 600 ohms by adjustment of their respective output level controls or by addition of series resistance.

1.3.2 DETECTOR. The detector required to measure the output signals of the Type 1559-A Microphone Reciprocity Calibrator should have an input impedance of at least 5 megohms and be capable of measuring a several-millivolt signal with a signal-to-noise ratio of at least 20 db. In addition, the detector should have a scale suitable for observing 1% changes in signal level. The detector can be a Type 1551-C Sound level Meter, a Type 1558-A Octave-Band Noise Analyzer, or a Type 1564-A Sound and Vibration Analyzer. One of these is usually the instrument whose microphone is to be calibrated.

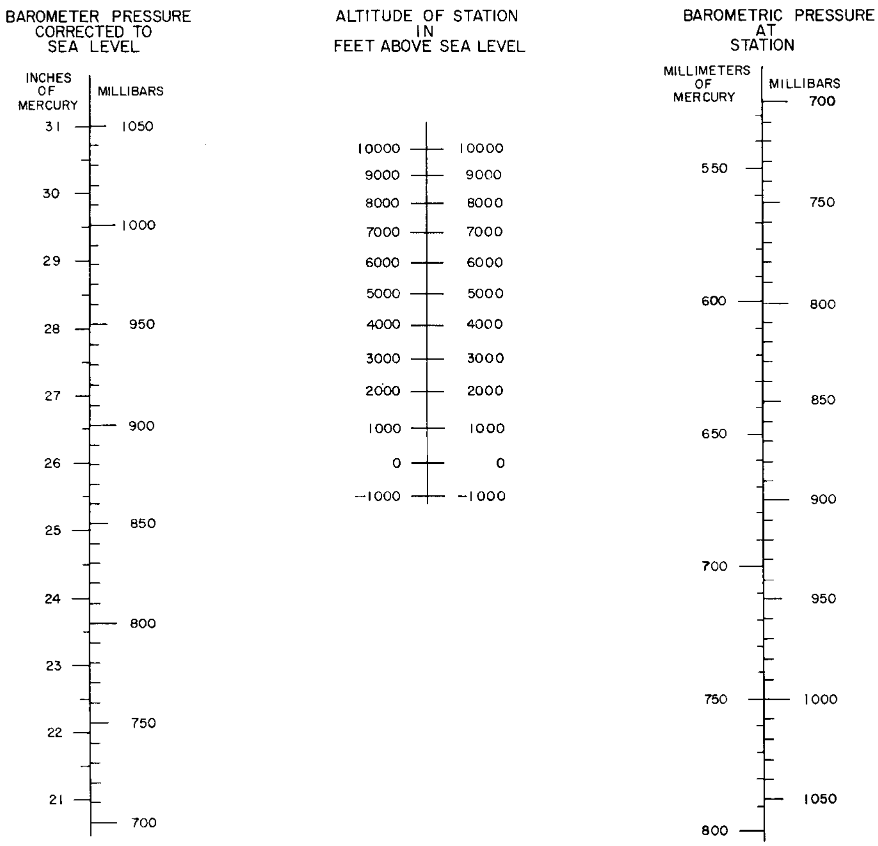

Figure 1-2. Nomograph for applying altitude correction to barometric pressure. Place straight-edge across proper points on center and left-hand scales and read actual pressure on right-hand scale. See Appendix 2 for altitudes above sea level for many cities in the U.S. and Canada.

SECTION 2

OPERATING PROCEDURE

2.1 PRELIMINARY CONTROL SETTINGS.

2.1.1 METER ZERO CHECK. With the instrument off, set the meter pointer to zero, if necessary, by means of the screw-driver adjustment on the meter face.

2.1.2 BAROMETRIC PRESSURE COMPENSATION. For maximum accuracy set the BAROMETRIC PRESSURE IN MILLIBARS control to indicate the actual barometric pressure at your location.

The pressures given by the United States Weather Bureau and by various flight facilities are corrected pressures, i.e., pressures referred to sea level. Most barometers are similarly calibrated to read pressures corrected to sea level. The actual barometric pressure can be specifically requested of your local weather station, or you can correct the published barometric reading for your own location. This correction is a function of altitude, temperature, and pressure, but the principal factor is the altitude correction of one inch of mercury per 1000 feet above sea level. Figure 1-2 includes an altitude correction chart and a conversion nomograph for inches of mercury to millibars. While the pressure set on the BAROMETRIC PRESSURE indicator should be reasonably accurate, an error of a few millibars will not greatly affect accuracy of measurement. An error of 34 millibars (one inch of mercury) in barometric pressure will cause an error of approximately 0.15 db in microphone calibrations and 0.3 db in sound-level calibrations.

2.2 MICROPHONE CALIBRATION.

2.2.1 CONNECTION OF GENERATOR, DETECTOR, AND MICROPHONE.

a. Connect an oscillator (generator) to the INPUT connector and a sound-level meter to the OUTPUT TO SLM connector, using the cables supplied.

b. Set the meter range switch to 92 DB.

c. Set the MICROPHONE CURRENT control to NORMAL.

d. Set the transfer function switch to ADJ 1.

e. Adjust the oscillator output control for less than full-scale deflection of the INPUT LEVEL IN DB meter.

f. Carefully place the microphone to be calibrated in the coupler and lock it in place by moving the slider to the left. Then connect the microphone to the instrument using the microphone connector attached to the panel.

CAUTION

To avoid damage to the microphone, it must be inserted into and removed from the coupler slowly enough so that the pressure in the coupler can equalize with that of the environment.

2.2.2 CALIBRATION PROCEDURE.

a. Set the transfer function switch to START. Turn the SENSITIVITY LEVEL knob until the dot on the larger dial is opposite the actual barometric pressure in millibars.

b. Set the function switch to READ 1. Adjust the sound-level meter for an on-scale reading and note the value of the reading.

c. Set the function switch to ADJ 1. Turn the SENSITIVITY LEVEL knob until the sound-level meter indicates the value noted in step b.

d. Set the function switch to READ 2. Adjust the sound-level meter for an on-scale reading and note the value of the reading.

e. Set the function switch to ADJ 2. Turn the SENSITIVITY LEVEL knob until the sound-level meter indicates the value noted in step d.

f. Set the function switch to READ 3. Adjust the sound-level meter for an on-scale reading and note the value of the reading.

g. Set the function switch to ADJ 3. Turn the SENSITIVITY LEVEL knob until the sound-level meter indicates the value noted in step f.

h. Set the function switch to READ 4. Adjust the sound-level meter for an on-scale reading and note the value of the reading.

i. Set the function switch to ADJ 4. Turn the SENSITIVITY LEVEL knob until the sound-level meter indicates the value noted in step h.

j. Read the microphone sensitivity* in db re 1 volt/μbar on the large dial of the SENSITIVITY LEVEL.

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*Even though the calibration is a pressure calibration, the coupler has been adjusted so that the indicated sensitivity is the random-incidence (diffuse-field) sensitivity.

2.3 SOUND-LEVEL CALIBRATION.

The following procedure applies to precise level calibration of a sound-level meter or an analyzing system.

a. Calibrate the microphone to be used as outlined in paragraph 2.2.

b. With the same connections as in paragraph 2.2, turn the function switch to ADJ 3. Set the smaller dial of the SENSITIVITY LEVEL to the microphone sensitivity determined in step a.

c. Adjust the oscillator output control for a full-scale deflection of the INPUT LEVEL IN DB meter. If it is not possible to set the meter to full-scale, set it for the maximum reading possible and note the value of the reading.

d. Adjust the sound-level meter for an on-scale reading and note the value of the reading.

e. Set the function switch to READ 3. Adjust the MICROPHONE CURRENT knob until the sound-level meter indicates the value noted in step d. If necessary, the oscillator output voltage may be adjusted also.

f. Connect the microphone directly to the sound-level meter.

g. Adjust the gain of the sound-level meter so that its db reading equals that noted on the INPUT LEVEL IN DB meter in step c.

2.4 COMPARISON WITH STANDARD MICROPHONE.

The technique, as outlined in paragraph 2.3, for producing a known sound level in the cavity can also be used to compare the calibration of a General Radio Type 1560-P3 PZT Microphone with that of a Western Electric Type 640-AA laboratory standard microphone. After the Type 1559-A Microphone Reciprocity Calibrator is set to produce a known sound field as described in paragraph 2.3, the Type 1560-P3 PZT Microphone is replaced by the Type 640-AA microphone, inserted in the adaptor sleeve furnished with the calibrator. Using the known sensitivity of the Type 640-AA and the known electrical response of the associated system, one can then compare the sound level measured with the Type 640-AA with that produced in the cavity. When this is done, the primary calibration of a Type 1560-P3 PZT Microphone made with the Type 1559-A Microphone Reciprocity Calibrator has been compared with the NBS calibration of a Type 640-AA microphone, and the agreement is better than 0.2 db for frequencies below 1 kc.

2.5 USE AS AN ACOUSTIC SOURCE.

The PZT cylinder used as the auxiliary transducer in the reciprocity calibration procedure can be used as a stable acoustic source for rapid calibrations of microphones, sound-level meters, and analyzing systems at frequencies between 10 and 2500 cps. The PZT cylinder produces a constant output over this frequency range. The procedure is as follows:

a. Set the meter switch to 92 DB and the function switch to READ 1.

b. Insert the microphone in the coupler and connect it directly to the sound-level meter.

c. Connect an oscillator to the INPUT connector and adjust the oscillator output control for a full-scale deflection of the INPUT LEVEL IN DB meter. If it is not possible to set the meter to full scale, set it for the maximum reading possible.

d. The sound level applied to the microphone is indicated on the INPUT LEVEL IN DB meter. The value given is for atmospheric pressure; see Figure 2-3 for corrections.

If the oscillator output is constant over the frequency range, the input to the Type 1559-A may be swept for recording purposes.

2.6 MICROPHONE RESPONSES.

The frequency response of a microphone is commonly expressed in one of the following manners:

1. Pressure Response - The ratio of the open-circuit voltage output to the value of a pressure variation applied uniformly over the diaphragm surface.

2. Free-Field Response - The ratio of the open-circuit voltage output to the value of the sound pressure of a plane progressive wave before the introduction of the microphone into the sound field. The direction of incidence must be specified.

(a) Free-Field Perpendicular Incidence (0°). The direction of propagation of the sound wave is perpendicular to the plane of the microphone diaphragm, and parallel (0°) to the axis of the microphone (diaphragm normal).

(b) Free-Field Grazing Incidence (90°). The direction of propagation of the sound wave is parallel to the plane of microphone diaphragm and perpendicular (90°) to the axis of the microphone (diaphragm normal).

3. Random-Incidence (Diffuse-Field) Response. The ratio of the open-circuit rms voltage output to the rms value of the sound pressure of a diffuse field (one in which the rms sound pressure is everywhere the same and the flow of energy in all directions is equally probable) before the introduction of the microphone.

For a microphone the size of Type 1560-P3 (about 1 inch in diameter), all of the above responses are equal from subsonic frequencies to about 1 kc.[1]

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[1] A closed coupler (pressure) calibration accounts only for pressure equalization leaks through the diaphragm. Leaks through the case may cause a roll-off at subsonic frequencies.

Above 1 kc, diffraction effects cause a variation in the responses. See Figure 2-1 for the relationships between the various responses. The calibrator is adjusted to give the random response because a diffuse field closely approximates the usual environment into which a sound-level meter microphone is placed.

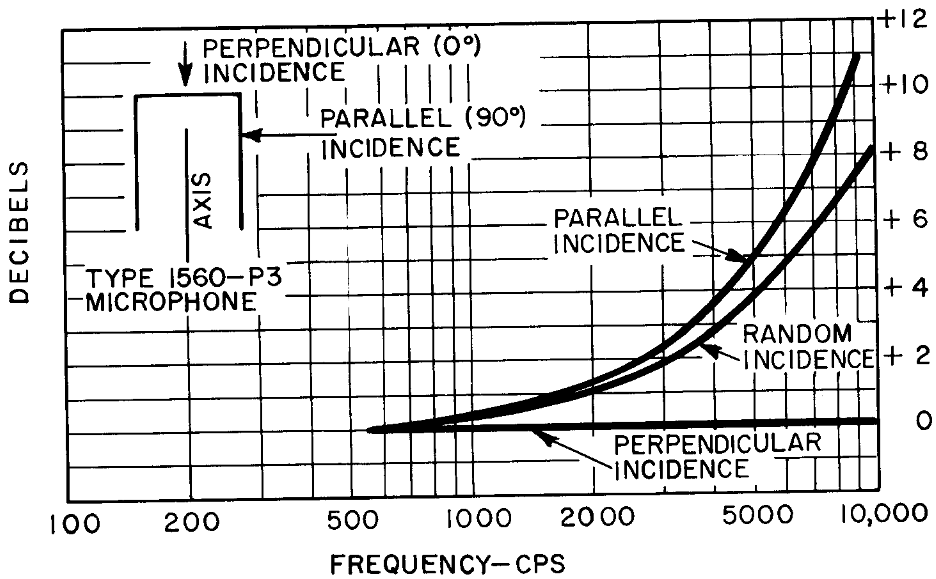


Figure 2-1. Corrections to be subtracted from free-field perpendicular response for random and parallel responses.

2.7 AMBIENT NOISE LEVEL.

To avoid an error in the measurement, the ambient noise level in the coupler, with the microphone to be calibrated in place, should be at least 20 db below the acoustic signal level. To check the signal-to-noise ratio, follow the procedure outlined in paragraph 2.2.1, set the function switch to READ 2, and note the reading of the sound-level meter. Then decrease the input voltage to zero and note the reading of the sound-level meter. This reading should be 20 db below the first reading. If the noise level is too high, either increase the oscillator output (up to 50 volts) or move to a quieter location.

2.8 ERRORS IN MICROPHONE CALIBRATION.

Below 1 kc, the Type 1559-A is a primary absolute calibrator for the Type 1560-P3 PZT Microphone, with the error in determining a microphone sensitivity fixed by (1) the linearity of the potentiometer (±0.5%), (2) the accuracy of measurement of the coupler volume (±1%), and (3) the capacitance tolerance of the current-sampling capacitor (±0.25%). Above 1 kc the "error" in the pressure response due to wave motion is empirically matched to the correction between the pressure and random responses of the microphone. Thus the instrument is direct-reading in the random-response sensitivity of the microphone being calibrated. Figure 2-2 is a plot of the average error of the matching.

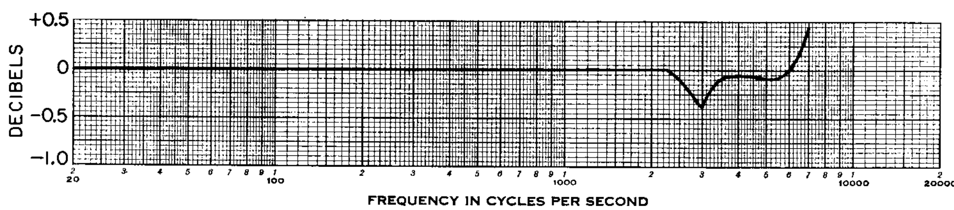


Figure 2-2. Average deviation between calibration by the Type 1559-A Microphone Reciprocity Calibrator and calibration at random incidence.

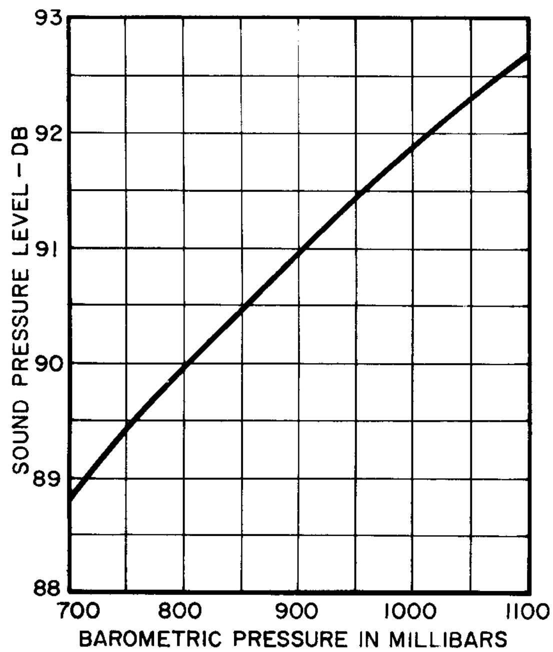


Figure 2-3. Sound-level-calibration output vs atmospheric pressure.

SECTION 3

PRINCIPLES OF OPERATION

3.1 PRINCIPLE OF RECIPROCITY.

The principle of reciprocity is stated as follows: The ratio of response to excitation is unchanged if the points of excitation and observation are interchanged, provided the terminal conditions remain the same. Figure 3-1 illustrates the relationships that follow from the reciprocity theorem for a two-port, four-terminal electrical network. The equation on which the design of the Type 1559-A is based is that the forward current transfer equals the reverse voltage transfer.

$$\left.\frac{I_2}{I_1}\right|_{V_2=0} = \left.\frac{V_1}{V_2}\right|_{I_1=0} \qquad (1)$$

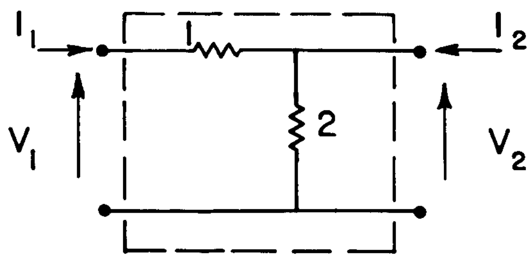


Figure 3-1. The reciprocity theorem applied to a two-port, four-terminal network.

In a two-port four-terminal network

$$V_1 = Z_{11}I_1 + Z_{12}I_2$$

$$V_2 = Z_{21}I_1 + Z_{22}I_2$$

By reciprocity:

$$Z_{12} = Z_{21} = 2$$

$$\left.\frac{I_2}{I_1}\right|_{V_2=0} = \left.\frac{V_1}{V_2}\right|_{I_1=0}$$

$$\left.\frac{I_1}{I_2}\right|_{V_1=0} = \left.\frac{V_2}{V_1}\right|_{I_2=0} = \frac{2}{3}$$

Reciprocity is not restricted to linear and passive electrical networks; it applies to any linear, bilateral, and passive network. The Type 1560-P3 PZT Microphone (Figure 3-2) is such a network.

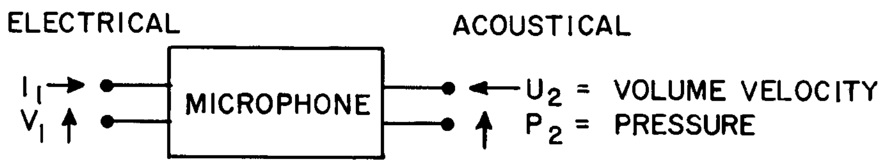


Figure 3-2. Network equivalent of Type 1560-P3 Microphone.

3.2 MICROPHONE CALIBRATION BY THE RECIPROCITY TECHNIQUE.

The Type 1559-A calibrates a microphone by the closed-coupler (cylindrical-cavity) reciprocity technique, which is similar to that described in the American Standards Association Standard Z24.4-1949. The reciprocity technique of calibration is a primary method of calibration, in which no acoustic standards are needed. A microphone calibration with the Type 1559-A requires four balances, with the microphone sensitivity indicated directly on a dial on the panel. The accuracy of measurement depends on the measurement of (1) resistance values of an attenuator, (2) mechanical dimensions of the coupler (cavity), and (3) the value of a current-sampling capacitor.

Three transducers and a closed-coupler (the cavity) are needed for the calibration procedure. One transducer (A; see Figure 3-3) is used as a loudspeaker which equally excites unknown microphone X and reciprocal microphone R with a sound pressure. The ratio of the open-circuit voltages of the two microphones R and X equals the ratio of the microphone sensitivities. The ratio of the open-circuit voltage to the exciting pressure is the definition of the microphone sensitivity

$$\frac{V}{P} = M.$$

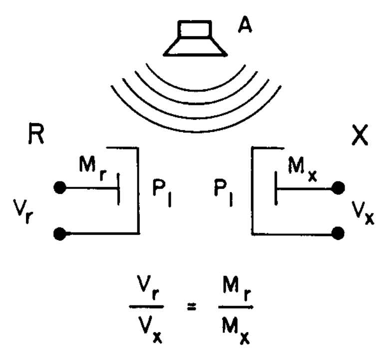


Figure 3-3. Relationships of three transducers in reciprocity calibration.

The sensitivity is commonly expressed as 20 $\log_{10}$ M *re* 1 volt per μbar. If the two microphones are coupled together by a known acoustical impedance (the cavity) and the reciprocal microphone (R) is driven as a loudspeaker, the ratio of the open-circuit voltage of microphone (X) to the driving current of the reciprocal microphone (R) can be theoretically related to the product of the microphone sensitivities. One can then solve the two relationships, one for the ratio of sensitivities of microphones R and X, and one for the product of these sensitivities, to determine the sensitivity of either microphone.

The equivalent circuits of a ceramic microphone are shown in Figure 3-4.

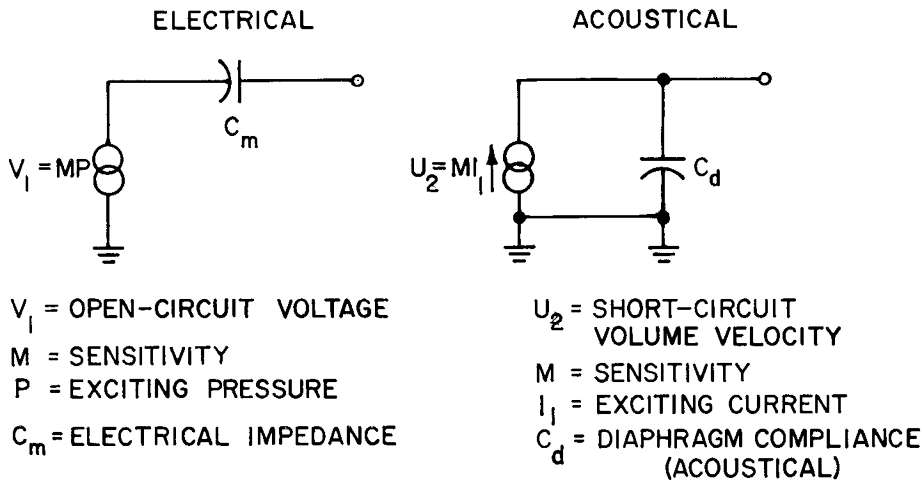


Figure 3-4. Equivalent circuits of ceramic microphone.

3.3 THE TYPE 1559-A RECIPROCITY CALIBRATOR.

In the Type 1559-A Reciprocity Calibrator, transducer A is a piezoelectric ring which produces a sound pressure in a cylindrical cavity when it is excited by a voltage. The microphone to be calibrated (transducer X) is inserted in one end of this cavity, and a similar reciprocal microphone cartridge (R) is mounted in the other end. The symmetry that results from the use of a reciprocal transducer, identical to the microphone being measured, and an auxiliary transducer in the form of an encompassing cylinder extends the usefulness of the coupler over a wide frequency range.

3.4 RATIO AND PRODUCT OF SENSITIVITIES.

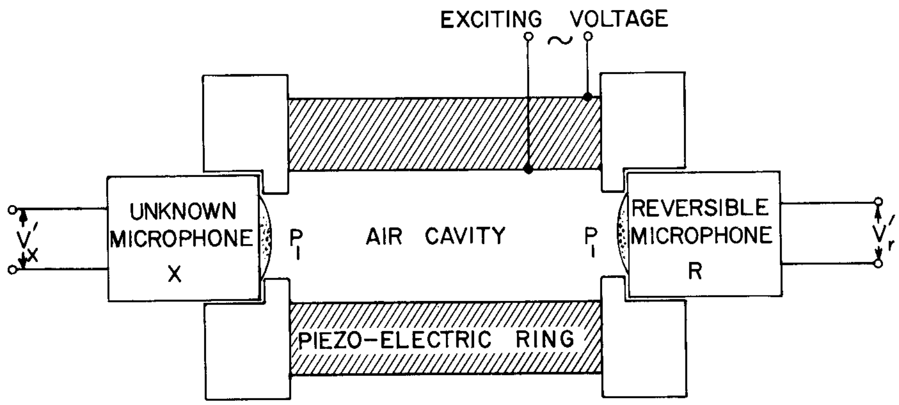


Figure 3-5. Conditions for determining ratio of microphone sensitivities.

Figure 3-5 illustrates the procedure by which the ratio of the microphone sensitivities is determined in the Type 1559-A Reciprocity Calibrator. Figure 3-6 illustrates the procedure for determining the product of the sensitivities of two microphones, one of which is reciprocal, which are coupled together by a known acoustical impedance (Z_a). A current (I_r) into microphone R produces a volume velocity (U) equal to the current (I_r) times the microphone sensitivity (M_r). This volume velocity (U) develops in the cavity a pressure ($P = UZ_a$) which causes an open-circuit voltage (V_x) equal to UZ_aM_x at the terminals of the second microphone. Collecting terms we have:

$$\frac{V_x}{I_r} = M_r Z_a M_x = M_r M_x Z_a \qquad (2)$$

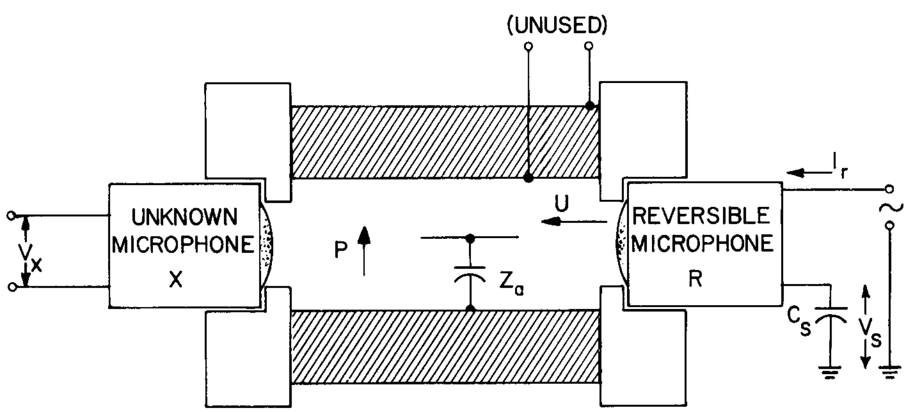


Figure 3-6. Conditions for determining product of microphone sensitivities.

The reciprocity theorem as it applies to a microphone states that the ratio $\frac{U}{I_r}$ equals M_r when the pressure (P) at the acoustical terminals is zero. Practically, this means that the impedance (ammeter) used to measure U, the short-circuit current, must be small compared with the acoustical output impedance so that the current is not changed by the measuring system. In the Type 1559-A the impedance (Z_a) of the coupler is 1/100 of the acoustical output impedance of the microphone. This output impedance is taken into account in the determination of Z_a.

Solving the equations for the ratio and product of sensitivities yields

$$M_X = \sqrt{\frac{V_X'}{V_r'} \; \frac{V_X}{I_r} \; \frac{1}{Z_a}} \qquad (3)$$

3.5 COUPLING IMPEDANCE, Z_a.

A closed volume in an acoustical network can be represented as a capacitor in an electrical analog if the dimensions of the cavity are small compared with the wavelength at the frequency of interest. The compliance (value of the capacitor) equals:

$$C = \frac{V_{cc}}{\gamma P_o} \qquad (4)$$

where V_{cc} = the volume of the cavity in cubic centimeters

γ = the ratio of the specific heats of the gas in the cavity (1.4 for air)

P_o = the pressure of the gas in the cavity in dynes/square centimeter.

To determine the value of Z_a for use in the equation of the microphone sensitivity, the finite impedances of the diaphragms of the driving and receiving microphones must be taken into account. The compliance of each microphone diaphragm can be considered equivalent to a volume of 0.2 cubic centimeter. These two volumes are added to the actual physical volume of the cavity in determining the value of V_{cc}. The coupler in the Type 1559-A ceases to act as a simple capacitor above 1 kc. However, the deviation in the impedance of the coupler is used to convert the sensitivity (M) of the microphone being calibrated from a pressure response to a random-incidence (diffuse-field) response.

$$Z_a = \frac{\gamma P_o}{j\omega V_{cc}} \; ; \; \frac{1}{Z_a} = \frac{j\omega V_{cc}}{\gamma P_o} \qquad (5)$$

Substituting for $\frac{1}{Z_a}$ in equation (3) for the microphone sensitivity (M_x) yields:

$$M_x = \sqrt{\frac{V_X'}{V_r'} \quad \frac{V_X}{I_r} \quad \frac{j\omega V_{cc}}{\gamma P_o}} \tag{6}$$

3.6 CURRENT SAMPLER.

The driving current (I_r) of the reciprocal microphone is determined by measurement of the voltage (V_S) across a capacitance current sampler (C_S) placed in series with the microphone. The current (I_r) equals the voltage (V_S) times the value of capacitive admittance (ωC_S). Because the value of the capacitor enters into the calculation of the microphone sensitivity, a stable General Radio Company polystyrene unit is used. An important advantage is gained by the use of a capacitor to measure the current of the reciprocal microphone. Substituting $V_S j\omega C_S$ for I_r in equation (6) for the microphone sensitivity (M_X) yields:

i.e. $I_r = (V_s) \times (\omega C_s)$

$$M_X = \sqrt{\frac{V_X'}{V_r'} \quad \frac{V_X}{V_s} \quad \frac{V_{cc}}{\gamma P_o C_s}} \tag{7}$$

This equation for the microphone sensitivity (M_X) is now independent of frequency. This means that, for a microphone whose sensitivity is constant with frequency, the voltages to be measured will be constant. Also, the constant $\frac{V_{cc}}{\gamma P_o C_s}$ in the above equation need be determined only once.

3.7 RESISTIVE-INSERT TECHNIQUE.

The four voltages determined in the calibration procedure are measured by the use of the resistive-insert, or substitution, technique. The resistive-insert technique is an accurate method of determining the open-circuit voltage of a transducer by the insertion of a known voltage across a resistor connected between the low side of the transducer and ground. See Figure 3-7.

First, the oscillator (1) is connected to terminal (A) to excite acoustically the transducer (T), and the indication of the detector is noted. Then the oscillator (1) is connected to terminal (B) and the attenuator is adjusted until the detector indication is the same as in the first step. The voltage (V_i) across the insert resistor (R) now equals the open-circuit voltage (V_{oc}) of the transducer, assuming that the transducer is acoustically independent of the effects of detector loading. One usually determines the voltage V_i by the measurement of the oscillator voltage (E) and the attenuator setting.

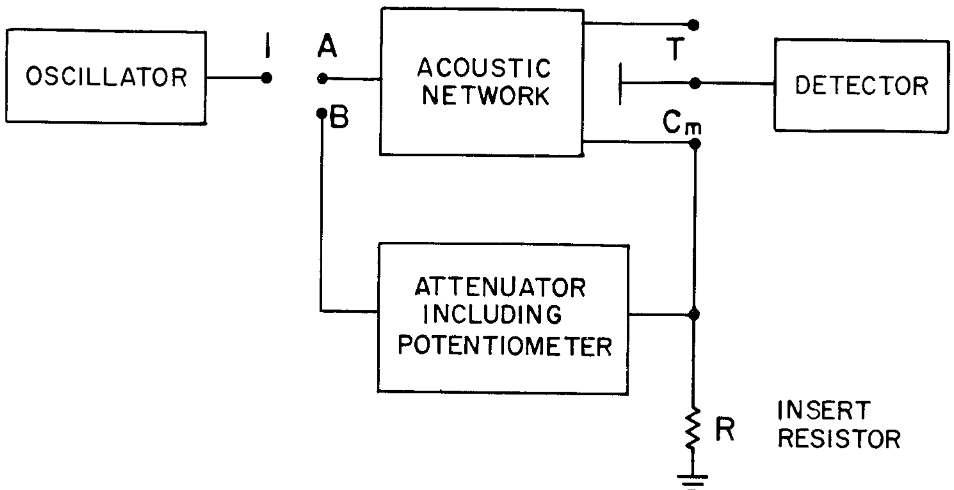


Figure 3-7. Resistive-insert technique.

3.8 ANALOG COMPUTER.

The calculations necessary to determine the microphone sensitivity are automatically performed during the measurement sequence by an analog computer that uses a logarithmic potentiometer in the attenuator for the resistive-insert technique. The computer mechanism is shown in Figure 3-8. The potentiometer has a linear relationship between the angle of shaft rotation and attenuation in decibels, so the shaft position is proportional to the logarithm of the voltage measured. The voltages in the equation for the microphone sensitivity appear as ratios and products, which become subtractions and additions when logarithms are used.

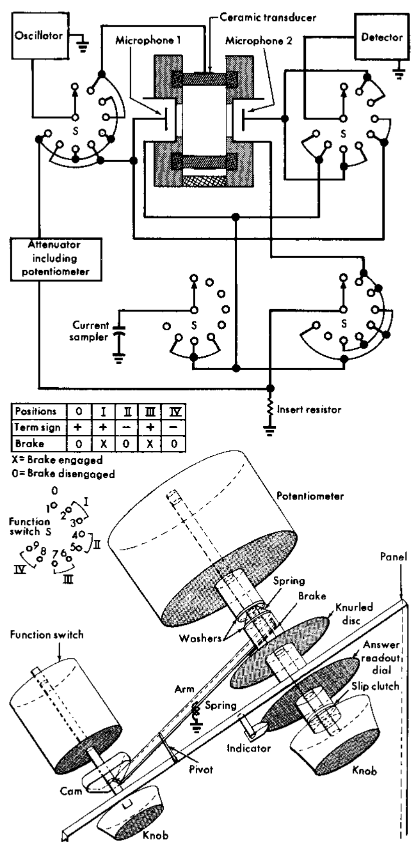


Figure 3-8. Analog computer mechanism.

Equation for Microphone Sensitivity

$$M_X = \sqrt{\frac{V_{cc}}{\gamma P_o C_s} \frac{V_X'}{V_r'} \frac{V_X}{V_s}} \tag{8}$$

$$20 \log_{10} M_X = 1/2 \Big[20 \log_{10} \frac{V_{cc}}{\gamma P_o C_s} + (20 \log_{10} V_X' - 20 \log_{10} V_r') + (20 \log_{10} V_X - 20 \log_{10} V_s) \Big] . \tag{9}$$

First, the constants of the equation are set into the answer dial and the dial is clamped in place. During the first balance the shaft of the potentiometer is set to an angular position proportional to log V_x' . The answer dial is then coupled to the potentiometer shaft and, while the potentiometer shaft is set to an angular position proportional to log V_r^1 during the second balance, the difference between the angular positions (the difference of logarithms) is put into the answer dial. This determines the first ratio of voltages. The db difference of the second ratio of voltages is then added to the answer dial, thereby solving the equation.

3.9 EXPLANATION OF CALIBRATION PROCEDURE.

Equation:

$$20 \log_{10} M_X = 1/2 \left[20 \log_{10} \frac{V_{cc}}{\gamma P_o C_s} + (20 \log_{10} V_X' - 20 \log_{10} V_r') + (20 \log_{10} V_X - 20 \log_{10} V_s) \right] \qquad (10)$$

START:

The drive voltage is disconnected and the answer dial is coupled to the potentiometer (SENSITIVITY LEVEL) shaft so that the constants

$(20 \log_{10} \frac{V_{cc}}{\gamma P_o C_s})$ can be set into it. (Barometric Pressure)

READ 1:

The answer dial is clamped, the drive voltage is connected to the PZT cylinder, and the microphone to be measured is connected to the detector, whose reading is noted. This is step A of the resistive-insert technique.

ADJ 1:

The answer dial is clamped, the drive voltage is connected to the attenuator, and the potentiometer shaft is set angularly to the logarithm of the open-circuit voltage of the microphone noted in READ 1. This is step B of of the resistive-insert technique.

READ 2:

The answer dial is coupled to the potentiometer shaft, the drive voltage is connected to the PZT cylinder, and the reciprocal microphone is connected to the detector, whose reading is noted.

ADJ 2:

The answer dial is coupled to the potentiometer shaft, the drive voltage is connected to the attenuator, and the potentiometer shaft is set angularly to the logarithm of the open-circuit voltage of the reciprocal microphone noted in READ 2. The difference between logarithms

$$(20 \log_{10} V_X' - 20 \log_{10} V_r')$$

is thereby added to the constants on the answer dial.

READ 3:

The answer dial is clamped, the drive voltage is connected to the reciprocal microphone, and the microphone to be measured is connected to the detector, whose reading is noted.

ADJ 3:

The answer dial is clamped, the drive voltage is connected to the attenuator, and the potentiometer shaft is set angularly to the logarithm of the open-circuit voltage of the microphone noted in READ 3.

READ 4:

The answer dial is coupled to the potentiometer shaft, the drive voltage is connected to the reciprocal microphone, and the current-sampling capacitor is connected to the detector, whose reading is noted.

ADJ 4:

The answer dial is coupled to the potentiometer shaft, the drive voltage is connected to the attenuator, and the potentiometer shaft is set angularly to the logarithm of the voltage V_S noted in READ 4. The difference between logarithms ($20 \log_{10} V_X - 20 \log_{10} V_s$) is thereby added to the previous terms on the answer dial to solve the equation for the microphone sensitivity. ($20 \log_{10} M_X$ *re* 1 v/μbar) is indicated directly on the answer dial.

SECTION 4

SERVICE AND MAINTENANCE

4.1 WARRANTY.

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

4.2 SERVICE.

The two-year warranty stated above attests the quality of materials and workmanship in our products. When difficulties do occur, our service engineers will assist in any way possible. If the difficulty cannot be eliminated by use of the following service instructions, please write or phone our Service Department (see rear cover), giving full information of the trouble and of steps taken to remedy it. Be sure to mention the serial and type numbers of the instrument.

Before returning an instrument to General Radio for service, please write to our Service Department or nearest district office, requesting a Returned Material Tag. Use of this tag will insure proper handling and identification. For instruments not covered by the warranty, a purchase order should be forwarded to avoid unnecessary delay.

4.3 REMOVAL OF INSTRUMENT FROM CABINET.

To remove the instrument from its cabinet, first open the cabinet as outlined on the side-panel of the flip-tilt mechanism. Lock the cabinet in the cover by means of the slide pins (8, Figure 1-1). Remove four screws (9), and lift the instrument out of the case.

4.4 TROUBLE-SHOOTING.

Because of the passive nature of the instrument, most difficulties can be traced to either an open or short circuit. Such difficulty appears during the operation of the instrument as a failure to secure a detector reading for a given switch position. Servicing is a matter of determining where the signal path is interrupted. For the purpose of tracing, one can consider the instrument divided into two electrical signal paths for each switch position - one from the generator to the transducer, and one from the transducer to the detector. To check paths from the generator to the transducer for the READ positions, remove the microphone to be calibrated and set the genetator to a frequency around 2 kc. With these positions one can hear the sound produced in the cavity.

4.5 RESISTANCE MEASUREMENTS.

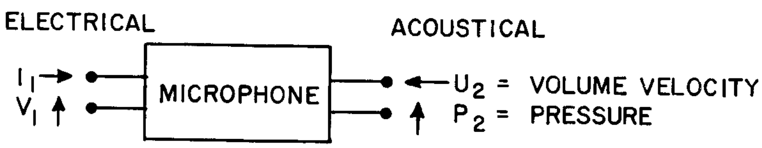
The following table gives test resistance values between various points and ground.

Switch Position	Insulated Terminal of Input Connector	Pin No. 1 of Microphone Connector	Aluminum End Cap of Cavity Assembly Farthest from Panel
START	∞	0	0
READ 1	5 kΩ	0	∞
ADJ 1	600 Ω	56Ω	∞
READ 2	5 kΩ	56Ω	0
ADJ 2	600 Ω	0	56Ω
READ 3	∞	0	∞
ADJ 3	600 Ω	56Ω	∞
READ 4	∞	56Ω	∞
ADJ 4	600 Ω	0	56Ω

APPENDIX 1

PRODUCT OF SENSITIVITIES

A. Reciprocal Microphone.



$$V_1 = Z_{11}I_1 + Z_{12}U_2$$

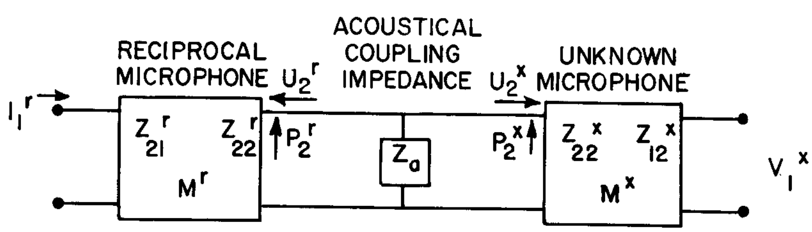
$$P_2 = Z_{21}I_1 + Z_{22}U_2$$

By reciprocity:

$$Z_{12} = Z_{21}$$

If $I_1 = 0$, define $M \equiv \left.\dfrac{V_1}{P_2}\right|_{I_1 = 0} = \dfrac{Z_{12}}{Z_{22}}$ = Microphone Sensitivity

B.



Apply current I_1^r and measure open-circuit voltage V_1^x.

Since: $I_1^x = 0$ $\qquad V_1^x = Z_{12}^x U_2^x$

$$U_2^x = \frac{P_2^x}{Z_{22}^x} \qquad = Z_{12}^x \frac{P_2^x}{Z_{22}^x}$$

$$P_2^r = P_2^x \qquad = \frac{Z_{12}^x}{Z_{22}^x} P_2^r$$

$$U_2^r = -\frac{P_2^r}{(Z_a \| Z_{22}^x)}$$

$$P_2^r = Z_{21}^r I_1^r + Z_{22}^r U_2^r$$

$$P_2^r = Z_{21}^r I_1^r - \frac{Z_{22}^r P_2 (Z_a + Z_{22}^x)}{Z_a Z_{22}^x}$$

$$P_2^r \left(1 + \frac{Z_a Z_{22}^r + Z_{22}^x Z_{22}^r}{Z_a Z_{22}^x} \right) = Z_{21}^r I_1^r$$

$$P_2^r = I_1^r \left(\frac{Z_{21}^r \; Z_a Z_{22}^x}{Z_a Z_{22}^x + Z_a Z_{22}^r + Z_{22}^x Z_{22}^r} \right)$$

$$V_1^x = \frac{Z_{12}^x}{Z_{22}^x} \; P_2^r$$

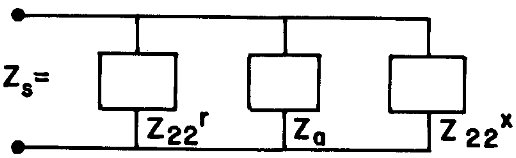
$$= \frac{Z_{12}^x}{Z_{22}^x} \; I_1^r \left(\frac{Z_{21}^r Z_a Z_{22}^x}{Z_a Z_{22}^x + Z_a Z_{22}^r + Z_{22}^x Z_{22}^r} \right)$$

$$Z_{21}^r = Z_{12}^r$$

and, multiplying by $\dfrac{Z_{22}{}^{r}}{Z_{22}{}^{r}}$,

$$= I_1{}^{r} \; \frac{Z_{12}{}^{x}}{Z_{22}{}^{x}} \; \frac{Z_{12}{}^{r}}{Z_{22}{}^{r}} \left(\frac{Z_a Z_{22}{}^{x} Z_{22}{}^{r}}{Z_a Z_{22}{}^{x} + Z_a Z_{22}{}^{r} + Z_{22}{}^{x} Z_{22}{}^{r}} \right)$$

DEFINE Z_s =



$$\frac{V_1{}^{x}}{I_1{}^{r}} = \frac{Z_{12}{}^{x}}{Z_{22}{}^{x}} \; \frac{Z_{12}{}^{r}}{Z_{22}{}^{r}} \; Z_s$$

Since $\dfrac{Z_{12}}{Z_{22}} = M$, $\dfrac{V_1{}^{x}}{I_1{}^{r}} = M_x M_r Z_s$

APPENDIX 2

ALTITUDES ABOVE SEA LEVEL FOR SELECTED CITIES IN U.S. AND CANADA

CITY	FEET ABOVE SEA LEVEL
Akron, Ohio	950
Albany, New York	20
Allentown, Pennsylvania	320
Ashland, Kentucky	530
Atlanta, Georgia	1105
Augusta, Georgia	141
Baltimore, Maryland	81
Bangor, Maine	21
Bay City, Michigan	593
Binghamton, New York	865
Birmingham, Alabama	598
Boise, Idaho	2717
Boston, Massachusetts	45
Brandon, Man.	1204
Buffalo, New York	590
Burlington, Vermont	190
Bridgeport, Connecticut	12
Calgary, Alta.	3439
Cambridge, Massachusetts	80
Camden, New Jersey	30
Campbellton, N.B.	42
Charleston, South Carolina	13
Charlotte, North Carolina	734
Charlottetown, P.E.I.	8
Chicago, Illinois	604
Cleveland, Ohio	600
Colorado Springs, Colorado	6012
Columbus, Georgia	261
Columbus, Ohio	759
Council Bluffs, Iowa	989
Dallas, Texas	437

APPENDIX 2 (cont)

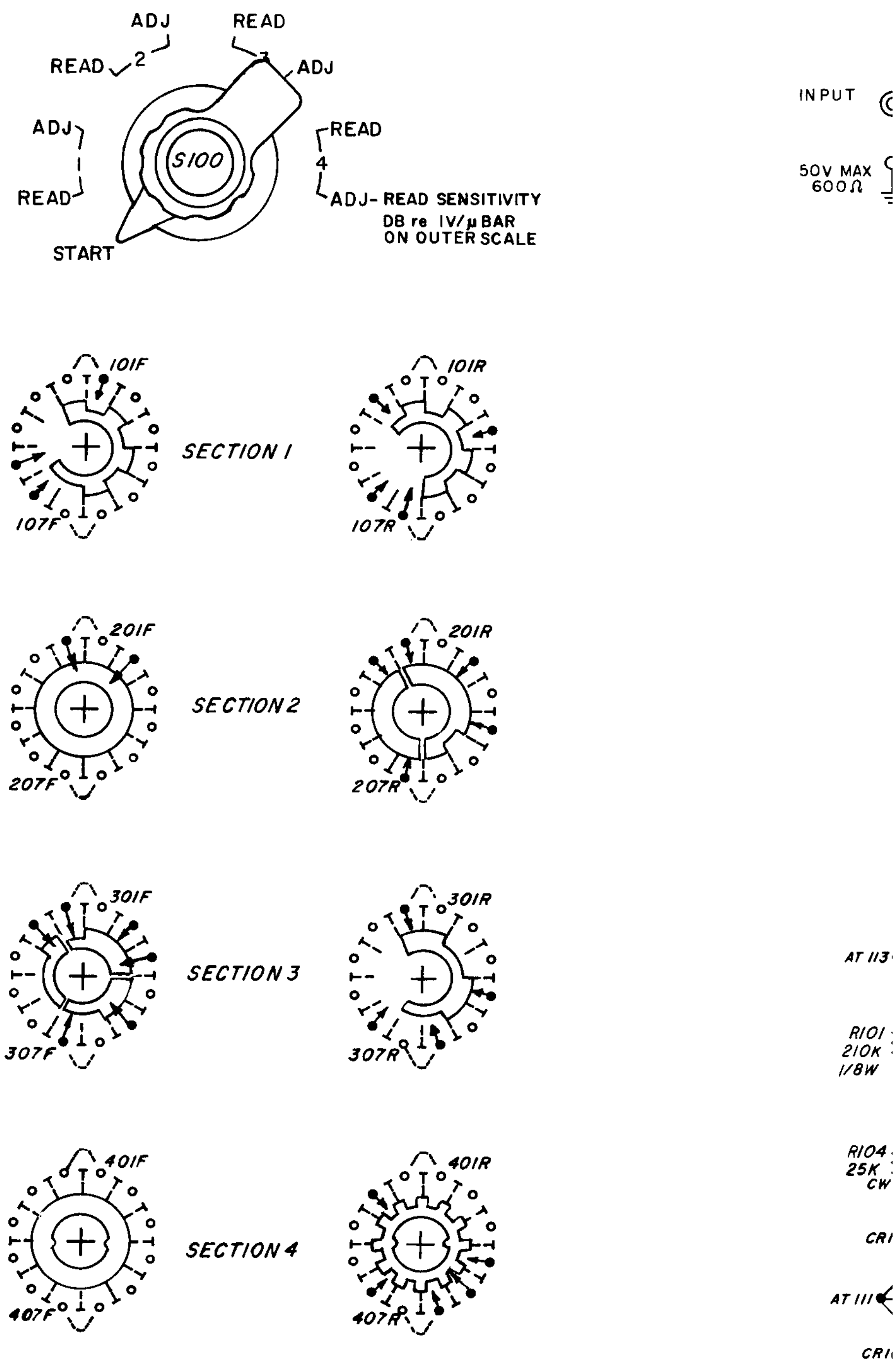
CITY	FEET ABOVE SEA LEVEL
Dartmouth, N.S.	14
Davenport, Iowa	571
Dayton, Ohio	743
Denver, Colorado	5227
Des Moines, Iowa	626
Duluth, Minnesota	626
Edmonton, Alta.	2183
Elizabeth, New Jersey	28
Erie, Pennsylvania	709
Evansville, Indiana	380
Flint, Michigan	716
Fort Smith, Arkansas	445
Fort Wayne, Indiana	780
Fort Worth, Texas	600
Fredericton, N.B.	32
Galveston, Texas	28
Grand Rapids, Michigan	628
Great Falls, Montana	3309
Halifax, N.S.	59
Hamilton, Ontario	300
Harrisburg, Pennsylvania	355
Hartford, Connecticut	36
Houston, Texas	48
Huntington, West Virginia	565
Indianapolis, Indiana	749
Jackson, Mississippi	286
Jacksonville, Florida	25
Jersey City, New Jersey	44
Kansas City, Missouri	750
Knoxville, Tennessee	895
Lansing, Michigan	842
Lexington, Kentucky	966
Lincoln, Nebraska	1169
Little Rock, Arkansas	286
London, Ontario	.804
Los Angeles, California	292
Loisville, Kentucky	454
Manchester, New Hampshire	210
Memphis, Tennessee	238

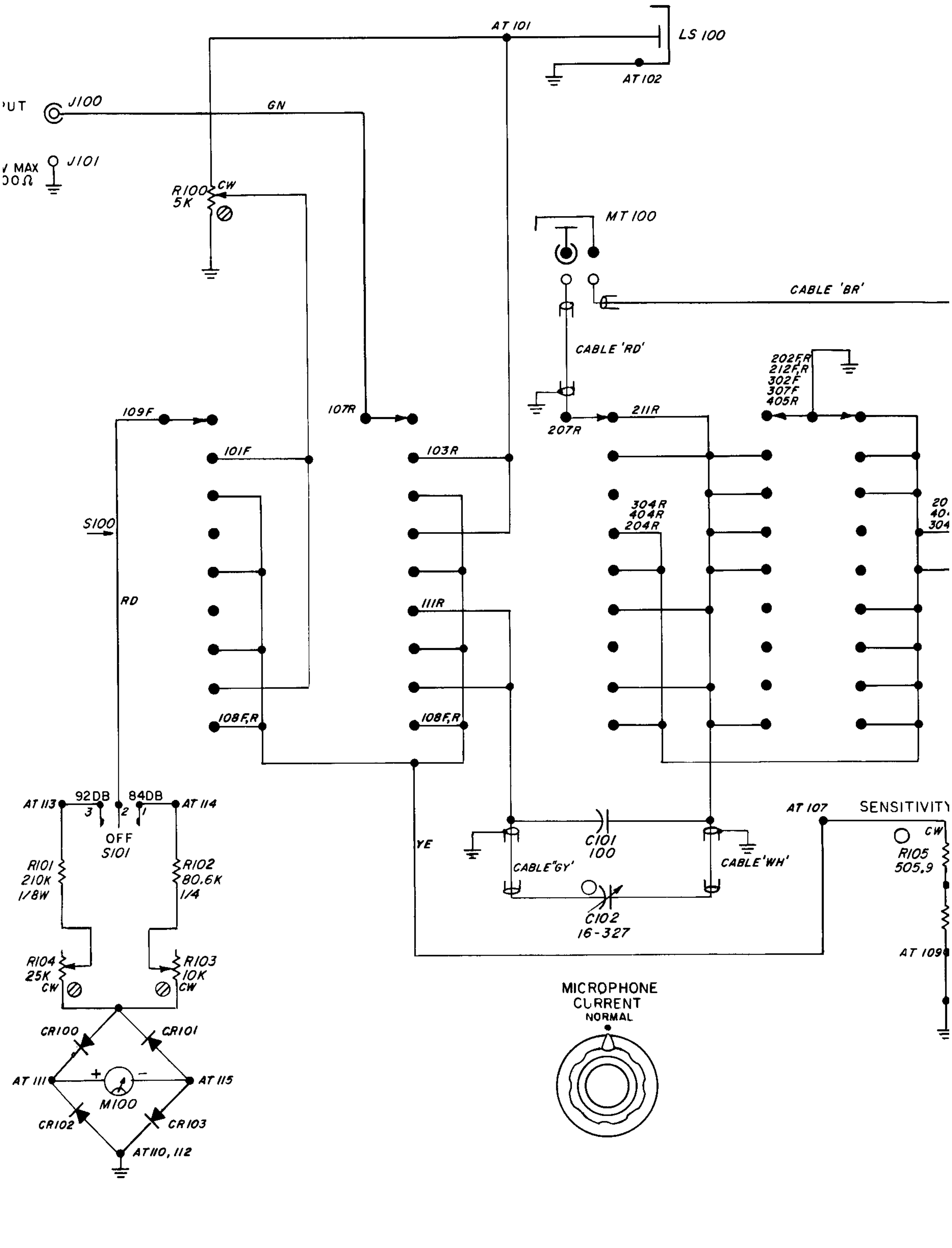
APPENDIX 2 (cont)

CITY	FEET ABOVE SEA LEVEL
Miami, Florida	15
Milwaukee, Wisconsin	609
Minneapolis, Minnesota	826
Mobile, Alabama	15
Moncton, N.B.	50
Montgomery, Alabama	191
Montreal, P.Q.	110
Nashville, Tennessee	498
Newark, New Jersey	43
New Haven, Connecticut	21
New London, Connecticut	27
New Orleans, Louisiana	5
New York, New York	35
Norfolk, Virginia	38
Oakland, California	18
Omaha, Nebraska	1040
Ottawa, Ontario	200
Paterson, New Jersey	117
Peoria, Illinois	465
Philadelphia, Pennsylvania	150
Phoenix, Arizona	1085
Pittsburg, Pennsylvania	742
Portland, Maine	34
Portland, Oregon	69
Providence, Rhode Island	43
Quebec, P.Q.	20
Racine, Wisconsin	619
Regina, Sask.	1414
Reno, Nevada	4487
Richmond, Virginia	84
Rochester, New York	509
Saint John, N.B.	21
Saint Louis, Missouri	460
Saint Paul, Minnesota	754
Salt Lake City, Utah	4300
Sacramento, California	30
San Antonio, Texas	657
San Francisco, California	50
Saskatoon, Sask.	1596

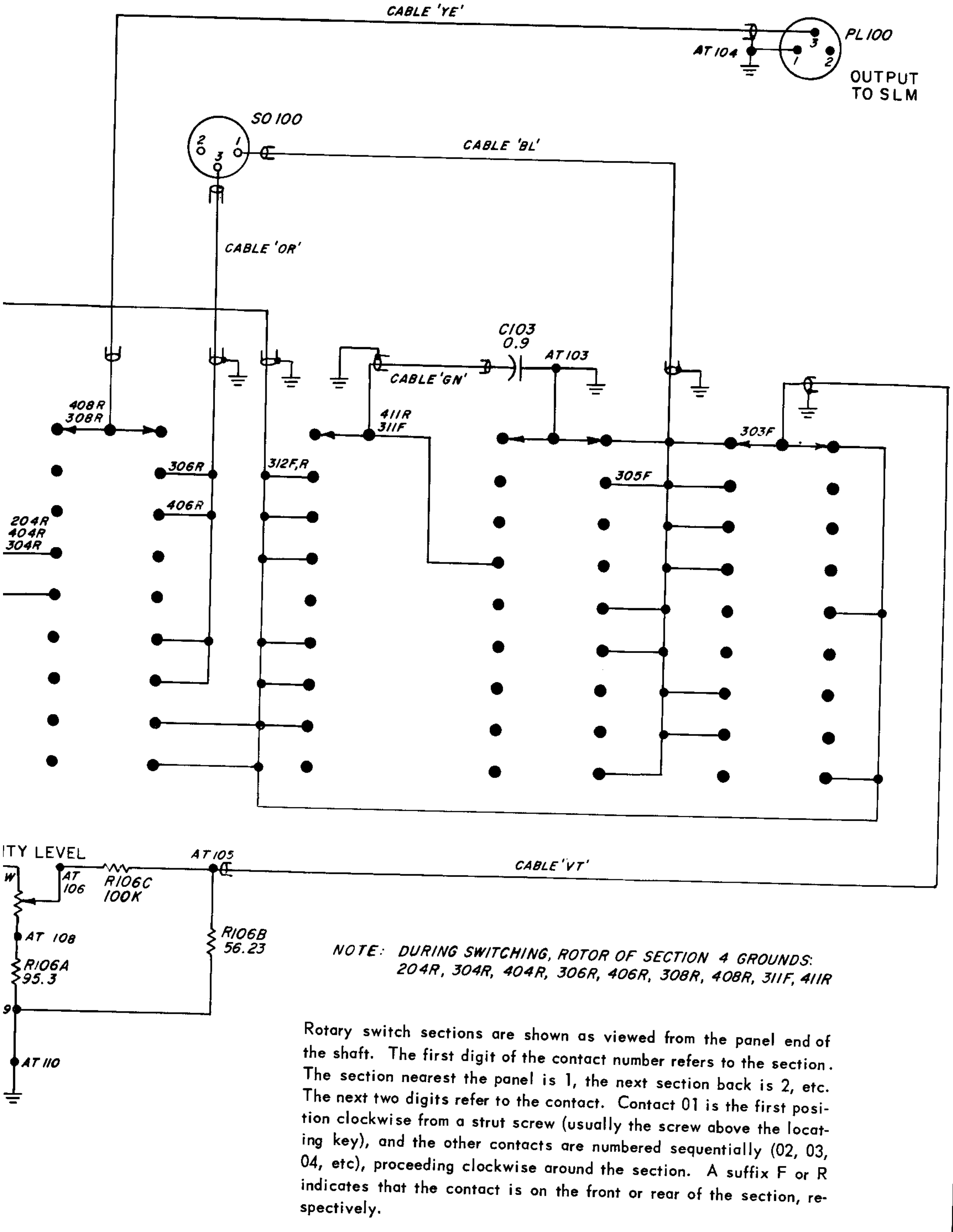
APPENDIX 2 (cont)

CITY	FEET ABOVE SEA LEVEL
Savanah, Georgia	42
Scranton, Pennsylvania	757
Seattle, Washington	51
Shreveport, Louisiana	217
Sioux Falls, South Dakota	1405
South Bend, Indiana	718
Spokane, Washington	1905
Springfield, Massachusetts	101
Sydney, N.S.	10
Syracuse, New York	410
Tacoma, Washington	87
Toledo, Ohio	594
Toronto, Ontario	250
Topeka, Kansas	909
Tuscon, Arizona	2382
Tulsa, Oklahoma	700
Utica, New York	448
Vancouver, B.C.	18
Washington, D.C.	100
Wichita, Kansas	1285
Windsor, Ontario	580
Winnipeg, Man.	727
Youngstown, Ohio	832


ADJ
READ
READ 2
ADJ
ADJ 1
READ
S100
READ
4
ADJ- READ SENSITIVITY
DB re 1V/μBAR
ON OUTER SCALE
START
INPUT
50V MAX
600Ω
101F
107F
SECTION 1
101R
107R
201F
207F
SECTION 2
201R
207R
301F
307F
SECTION 3
301R
307R
401F
407F
SECTION 4
401R
407R
AT 113
R101
210K
1/8W
R104
25K
CW
CR1
AT 111
CR1



AT 101
LS 100
AT 102
'UT
J100
GN
V MAX
OOΩ
J101
R100
5K
CW
MT 100
CABLE 'BR'
CABLE 'RD'
202F,R
212F,R
302F
307F
405R
109F
107R
207R
211R
101F
103R
304R
404R
204R
S100
RD
111R
108F,R
108F,R
AT 113
92DB
84DB
AT 114
3
2
1
OFF
S101
R101
210K
1/8W
R102
80.6K
1/4
YE
C101
100
CABLE"GY'
CABLE'WH'
C102
16-327
AT 107
SENSITIVITY
CW
R105
505.9
AT 109
R104
25K
CW
R103
10K
CW
CR100
CR101
AT 111
M100
AT 115
CR102
CR103
AT110, 112
MICROPHONE
CURRENT
NORMAL



Rotary switch sections are shown as viewed from the panel end of the shaft. The first digit of the contact number refers to the section. The section nearest the panel is 1, the next section back is 2, etc. The next two digits refer to the contact. Contact 01 is the first position clockwise from a strut screw (usually the screw above the locating key), and the other contacts are numbered sequentially (02, 03, 04, etc), proceeding clockwise around the section. A suffix F or R indicates that the contact is on the front or rear of the section, respectively.

Figure 4-1. Schematic Diagram.

PARTS LIST

REF NO.	DESCRIPTION	PART NO.
R100	POTENTIOMETER, Wire-wound, 5kΩ ±10%	6050-1700
R101	RESISTOR, film, 107kΩ ±1% 1/8w	6250-3107
R102	RESISTOR, film, 39.2kΩ ±1% 1/4w	6250-2392
R103	POTENTIOMETER, Wire-wound, 10kΩ ±10%	6050-1800
R104	POTENTIOMETER, Wire -wound, 10kΩ ±10%	6050-1800
R105	RESISTOR, 505.9Ω	0433-4110
R106A	RESISTOR, 95.3Ω ±0.1%	
R106B	RESISTOR, 56.23Ω ±0.25%	0510-4400
R106C	RESISTOR, 100kΩ ±0.25%	
C100	CAPACITOR,Mica,100pf ±10% 500dcwv	4620-1000
C101	CAPACITOR, Mica,100pf ±10% 500dcwv	4620-1000
C102	CAPACITOR, Air, 16-327pf	4380-1400
C103	CAPACITOR, Plastic, 0.9µf ±0.25%	4860-4490
CR100	DIODE, Type 1N645	6082-1016
J100	JACK, Input	4060-0100
J101	JACK, Input ground	4060-1700
M100	METER	5730-1373
PL100	PLUG	4220-3100
SO100	SOCKET	4230-2701
S100	SWITCH, Rotary wafer	7890-3230
S101	SWITCH, Toggle	7910-1605
LS100	TRANSDUCER	1559-0401
MT100	TRANSDUCER	1560-0420

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