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THE DESIGN OF A LOW COST SOUND LEVEL METER

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Conventional sound level meters generally use precision ceramic microphones and discrete solid state circuitry. This report describes a design using an electret microphone and integrated circuit operational amplifiers. The advantages of this design are low cost, ease of manufacture, stable gain, and low power consumption. Construction details are included to permit local manufacture. The complete instrument is capable of meeting the [illegible] 2, General Purpose Sound Level Meter, requirements of ANSI S1.4-1971, American National Standard Specification for Sound Level Meters.

PREFACE

The author would like to express his appreciation for the support given by Dr. Alvin F. Meyer and the staff of the Office of Noise Abatement and Control, Environmental Protection Agency, Washington, D. C. Thanks are also due to Dr. Henning E. vonGierke and the staff of the Bionics and Biodynamics Division, Aeromedical Research Laboratory, Wright-Patterson Air Force Base, Ohio, for their assistance in the free-field calibration of the microphones and sound level meter. Finally, I wish to acknowledge the American National Standards Institute for their permission to quote from American National Standard ANSI S1.4-1971, Specification for Sound Level Meters.

INTRODUCTION

The general purpose sound level meter has been the standard field instrument of the acoustician and noise control engineer for many years. Recent widespread general interest in environmental noise pollution has created a need for a low-cost instrument that can be used by the average citizen for assessing environmental noise. Unfortunately, most low-cost "noise meters" fail to be sufficiently accurate to be of use.

There exists an American National Standard (ANSI S1.4-1971)* which specifies the accuracy required for an instrument to be acceptable as a sound level meter. Indeed, there are three different levels of accuracy specified, depending on the conditions of use of the instrument. Further, since measurement of noise pollution involves questions of legal definitions of acceptability and unacceptability of noise levels, only those instruments which are legally acceptable are likely to be of use. In general, legal requirements necessitate an instrument which satisfies the provisions of ANSI S1.4-1971.

At the time this sound level meter development was conceived there was no low-cost sound level meter available which met ANSI S1.4-1971 requirements. Recent developments in integrated circuit and microphone

*ANSI S1.4-1971, American National Standard Specification for Sound Level Meters, is available from American National Standards Institute, Inc., 1430 Broadway, New York, N.Y. 10018.

technologies indicated that it might be possible to produce a low-cost sound survey sound level meter. ** Such a sound survey meter was constructed, using an A weighting network only. *** This original instrument considerably exceeded specifications, and, in fact, met most of the ANSI S1.4-1971 requirements for a Type 2, or general purpose, instrument (with A weighting only, of course).

Because of the simplicity of the original instrument and the ease with which it met design specifications, it was decided to see if the design could be extended to a general purpose (Type 2) instrument with A, B, and C weighting networks. That design is reported here; it does meet ANSI S1.4-1971 Type 2 specifications.

** A sound survey, or Type 3, instrument is the least precise instrument in the ANSI S1.4-1971 classification. It is suitable for determining the overall sound level. General purpose, or Type 2, instruments are intended for more precise and complete sound data compilation in the field, usually in conjunction with tape recorders and/or analyzing filters for spectral analysis. Precision, or Type 1, instruments are intended for laboratory calibration of other instruments, although the trend today is to use them in the field as well.

*** Sound level meters have three frequency compensation networks; A, B, and C. The C network has essentially a flat response and in a sense corresponds to the human ear's frequency response to tones of 100 dB SPL. (Sound Pressure Level). The B curve attenuates the lower frequencies somewhat, and in a sense corresponds to the ear's response to 70 dB SPL. The A curve attenuates the lower frequencies a considerable amount and in a sense corresponds to the ear's response to 40 dB SPL. Most noise legislation is written in terms of A level weighted noise (usually written as "X" number of dBA), since humans are less responsive to and less disturbed by low frequency noise and can therefore tolerate more intense low frequency sounds such as would be allowed by a noise ordinance specified in dBA. ANSI S1.4-1971 permits special purpose sound level meters to have only one weighting network. A sound survey instrument with an A network only would be the lowest cost instrument which would be of use in monitoring noise pollution.

This technical report is in several sections. First, the design philosophy and its execution are covered in some detail. This section is primarily intended for those who may wish to produce, modify, or improve on the design. Second, a comparison of the performance of the instrument with ANSI S1.4-1971 specifications is given. Finally, detailed constructional information for the home builder or model shop is given.

GENERAL DESIGN

The sound level meter is basically a rather simple device. It consists of a microphone to convert sound level to voltage levels, an audio amplifier to amplify the voltage levels, some frequency compensation networks, a calibrated attenuator to extend the range, and an indicating detector and meter. To satisfy the requirements of ANSI S1.4-1971, however, requires a fair degree of precision and reproducibility in the actual sound measurement, which in turn necessitates close tolerances in the internal components and design in the sound level meter.

The most critical component of a sound level meter is the microphone. Normal high-fidelity microphones, and even those used commercially for high quality sound recording, are generally inadequate for sound level meter use. Type 2 and 3 sound level meters require microphone response only over the range of 20 Hz to 10 kHz, but over most of that range the microphone response must be uniform. In addition, the microphone must be omnidirectional, even at the higher frequencies, which in turn physically requires a small microphone and case. Finally, the sensitivity of the microphone should be stable, both in time and under varying conditions.

Sound level meter microphones are usually of the piezoelectric ceramic variety, generally costing about $70 up for units that will meet Type 2 specifications. Capacitor microphones are capable of more linear and wider frequency response than other types, but they have the disadvantages of high unit cost, sensitivity to moisture, and the necessity for an internal preamplifier and a power supply for the preamplifier and the microphone polarizing voltage.

Recently the electret microphone has been developed, which is a capacitor microphone with electrical charge permanently impregnated in the dielectric between the capacitor plates, obviating the need for a separate polarizing voltage power supply. Further, current manufacturing technology uses semiconductor techniques to fabricate the preamplifier as an integral part of the electret microphone. The cost of these units can be quite low, and their performance rivals that of the traditional capacitor microphone.

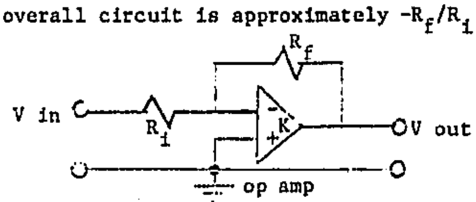
A number of foreign and domestic electret microphones were tested; there was a low-cost domestic model which met the requirements for use in a sound level meter. This model, the Thermo-Electron Corp. Model 814, was selected and adapted physically so that the resulting unit would fit in a standard microphone coupler or calibrator for subsequent sound level meter calibration. The Model 814 units which were measured met Type 2 specifications. The roll-off of the frequency response at low frequencies of the Model 814 also automatically satisfies one of the provisions of ANSI S1.4-1971.

The electrical design of a conventional sound level meter is straight-forward, consisting of a high gain audio amplifier, an attenuator calibrated in 10 dB steps, a number of frequency compensation networks (A, B, C filters), a detector, a meter calibrated in 1 dB steps over a 15 dB range, and an overall gain control for setting overall calibration. Current conventional practice has been to use discrete transistors as the active gain elements.

Since the sound level meter must maintain calibration over a wide range of conditions, this fact implies that the amplifier gain is stable and constant under the same range of conditions. This stability is usually accomplished through the use of inverse feedback, which in turn requires a larger number of amplifier stages to achieve the same overall gain, thereby raising the cost.

The use of integrated circuits, specifically operational amplifiers, allows the use of very high gain, and therefore large amounts of inverse feedback, at very low cost. When operational amplifiers (op amps) are used and the amount of inverse feedback is sufficiently great, the overall gain of the total circuit is essentially independent of the actual gain of the operational amplifier.

Specifically, in the circuit below, K is the gain of the op amp, R_f is the feedback resistor, and R_i is the input resistor; the input impedance of the op amp is assumed to be very high compared to R_i. Then the gain of the overall circuit is approximately $-R_f/R_i$, as long as $R_f/R_i << K$.



There are a number of advantages in the use of op amps in a circuit such as a sound level meter:

1. Cost: Each op amp has a gain, without feedback, of greater than 10^5 and a cost of less than \$1.00. Discrete components and wiring costs to accomplish the same specifications would cost at least an order of magnitude more.

2. Simplicity: A single component with two external resistors replaces a large number of discrete transistors and resistors.

3. Stability: The high gain permits a large amount of inverse feedback which results in stable performance and in insensitivity of gain to external variations.

4. Power Consumption: The op amp operates at a low power level, giving long battery life.

5. High input and low output impedances: these characteristics allow multiple op amps to be cascaded and interfaced easily with other circuits, such as frequency compensation networks, detectors, and indicating instruments.

The use of op amps in place of conventional circuitry entails one disadvantage, the necessity for a dual power supply. There are techniques by which an op amp can be used with a single power supply, but some of the margin of stability is sacrificed, and that approach is not embodied here.

In order to change the gain of an op amp circuit, one needs to merely change either R_f or R_i. In order to keep the overall input impedance relatively constant (approximately equal to R_i), R_f is changed to accomplish the variable attenuation. ANSI S1.4-1971 suggests 10 dB steps in the calibrated attenuator, so R_f is changed by multiples of $\sqrt{10}$. (10 dB = 20 $\log_{10}\sqrt{10}$.)

ANSI S1.4-1971 requires that the decade attenuator on other ranges be accurate within 0.5 dB of the 80 dB SPL setting, for a Type 2 instrument. The design here uses two decade attenuators, alternately changing the gain on one of the two variable op amp states by $\sqrt{10}$. The feedback resistors are 2% components, except on the 80 dB SPL range where they are 1% components. If we assume that the 1% resistors are -1% in error and the 2% resistors are +2% in error, then the maximum possible attenuator error, relative to the 80 dB SPL range is:

$$20 \log_{10}\left(\frac{1.02}{.99}\right)^2 = 0.52 \text{ dB maximum error.}$$

This error is slightly in excess of the maximum permissible error. However, the probability of the error exceeding 0.5 dB is extremely small, on the order of 0.1%. Further, the difference between 0.5 and 0.52 dB is not measurable on the indicating meter.

[A Simple Type 3 instrument with a single attenuator would need only 5% feedback resistors, as the attenuator tolerance is 1 dB for Type 3 instruments.

$$20 \log_{10}\left(\frac{1.05}{.95}\right)^2 = .87 \text{ dB maximum error}].$$

The input resistor, R_4, is a 5% component, for it affects only the overall gain, not the relative gain between various attenuator positions. The overall gain is adjusted by making the first R_f (R_3) variable and adjusting the gain of the sound level meter so that its indicated sound level agrees with a standard sound level in a calibrator. A difference in microphone sensitivity can also be compensated by varying R_3.

Three op amps are used, the first one of which is operated at a constant gain of approximately 20-30 dB. The dynamic range of this stage is approximately 90 dB, thereby limiting the instrument to a maximum range of 75 dB SPL. In this case the range has been selected to be 45 dB to 120 dB SPL.

The range of the instrument could have been widened by varying the first op amp gain with the attenuator as well. However, that would require a three-section attenuator, increasing cost, and also decreasing the tolerance permissible on the attenuator resistors. Were 1% components used throughout,

$$20 \log_{10}\left(\frac{1.01}{.99}\right)^3 = 0.52 \text{ dB maximum error.}$$

The input network to the first op amp also contains the C network low frequency compensation. This network consists of the source impedance of the electret microphone internal amplifier, the input resistor R2 to the first op amp, and the series capacitor C2. This network attenuates the low frequencies at a rate of 6 dB for each halving of frequency (6 dB/octave), beginning at 31.6 Hz, where the attenuation is 3 dB. (The C network compensation is also part of the A and B compensation, as required by ANSI S1.4-1971.) The variable feedback resistor R_3 changes the gain of the first stage to permit overall calibration of the instrument with reference to an external acoustic calibrator.

The gain of the second stage is controlled by the decade attenuator. The decade attenuator adjusts the gain of the second stage between 0 dB and 30 dB in 10 dB steps.

At the output of the second stage is a switch, selecting A, B, or C frequency compensation. In the case of C compensation, the networks are always in the circuit and are located elsewhere in the instrument, so the switch selects only a resistor R9 which attenuates the gain by approximately 1.8-1.9 dB. ANSI S1.4-1971 requires this attenuation for B and C compensation relative to A compensation. [This relative attenuation refers to high frequency gain, above 5 kHz.] C4 has no appreciable effect on the frequency response above 20 Hz.

When the switch selects B compensation, this resistor is retained, and capacitor C7 is switched in, forming a 6 dB/octave low frequency attenuation network. The gain of this network, which includes R12, is down 3 dB at 158.5 Hz.

Finally, when A compensation is selected, the attenuation resistor R9 and the B network R9-C7 are switched out, and a pair of cascaded 6 dB/octave resistor-capacitor low frequency compensation networks, R10-C5 and R11-C6, are connected. These networks interact, so that the instrument response is down 3 dB at 738 Hz, is attenuated 6 dB/octave approximately between 738 Hz and 107.7 Hz, and is attenuated 12 dB/octave approximately below 107.7 Hz. The input resistance R12 of the following op amp stage also forms part of these compensation networks. The gain of the third and final op amp stage is also controlled by the decade attenuator, and varies from 0 dB to 30 dB in 10 dB steps.

Following the third op amp is the high frequency C network, R17-C9, which attenuates at 6 dB/octave above 7943 Hz and is down 3 dB at that point. In addition, the high frequency roll-off of the 814 microphone helps satisfy the requirement that above 20 kHz the attenuation approaches 12 dB/octave.

The A, B, and C networks are formed of resistor-capacitor pairs, as described in ANSI S1.4-1971. Capacitors with 10% tolerance are available, and have been selected for use here. The frequency response tolerances allowed by ANSI S1.4-1971, given later in the report, are such that the attenuation due to a single R-C pair may be in error by $\pm$ 1 dB for a Type 2 instrument, this error being in addition to the basic $\pm$ 1 dB tolerance of the instrument. An analysis of an R-C network reveals that the total error of the two components is approximately 12% for a 1 dB error in response. Therefore, 2% resistors as well as 10% capacitors satisfy this requirement.

If commonly available capacitors with wider tolerances, such as -10 + 100%, are used, then the pertinent resistors (R9, R10, R11, R17) will have to be selected so that the instrument has the proper electrical response as in Fig. 1. In this case the resistors can be selected from a common bench stock, and will, in general, have lower nominal values than those specified in Fig. 14. Methods of verifying the electrical response are described elsewhere in the report.

At the output of the high frequency C network following the third op amp, the signal branches to the output jack to drive an external analyzer, and also goes to the detector, and thence to the indicating meter.

Germanium diodes are used in the detector, since silicon diodes cause upper meter scale expansion and lower meter scale compression due to their transfer characteristics. That is, if silicon diodes are used, the upper 5 dB range occupies nearly the entire meter scale, and the lower 10 dB range is compressed into a small scale increment.

A SPST switch selects a large load capacitor for SLOW response.

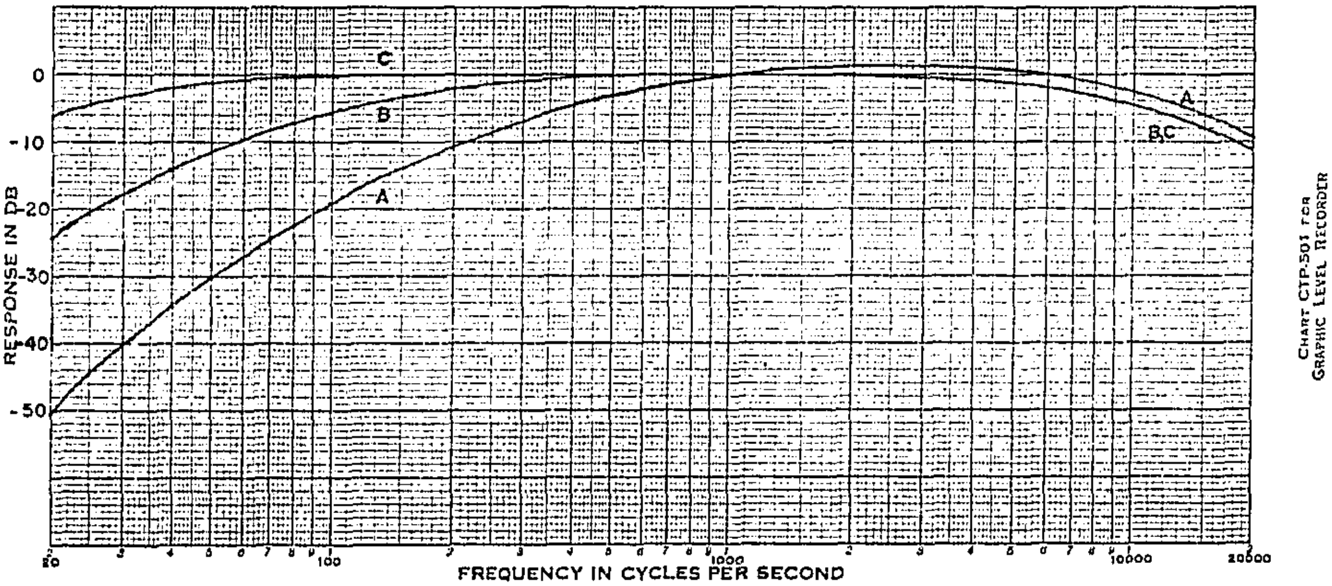


Figure 1

Sound Level Meter Random-Incidence Relative Response Level as a Function of Frequency for Various Weightings.

The function switch has a position where the two batteries are placed in series with the meter and an attenuating resistor in order to indicate battery condition.

Calibration is accomplished by use of an external standard calibrator.

VALIDATION AND CALIBRATION AS A TYPE 2 GENERAL PURPOSE SOUND LEVEL METER

In general, this section follows the sequence in ANSI S1.4-1971 and addresses itself to those requirements. Only those requirements for Type 2 instruments will be given, and are to be assumed as having been extracted from ANSI S1.4-1971 without further reference to that document.

Tolerances

The required frequency response is given below and in Fig. 1 for the various weighting networks.

Sound Level Meter Random-Incidence Relative Response Level As a Function of Frequency for Various Weightings

Frequency Hz	A Weighting Relative Response dB	B Weighting Relative Response dB	C Weighting Relative Response dB
10	-70.4	-38.2	-14.3
12.5	-63.4	-33.2	-11.2
16	-56.7	-28.5	- 8.5
20	-50.5	-24.2	- 6.2
25	-44.7	-20.4	- 4.4
31.5	-39.4	-17.1	- 3.0
40	-34.6	-14.2	- 2.0
50	-30.2	-11.6	- 1.3
63	-26.2	- 9.3	- 0.8
80	-22.5	- 7.4	- 0.5
100	-19.1	- 5.6	- 0.3
125	-16.1	- 4.2	- 0.2
160	-13.4	- 3.0	- 0.1
200	-10.9	- 2.0	0
250	- 8.6	- 1.3	0
315	- 6.6	- 0.8	0
400	- 4.8	- 0.5	0
500	- 3.2	- 0.3	0
630	- 1.9	- 0.1	0
800	- 0.8	0	0
1000	0	0	0
1250	+ 0.6	0	0
1600	+ 1.0	0	- 0.1
2000	+ 1.2	- 0.1	- 0.2
2500	+ 1.3	- 0.2	- 0.3
3150	+ 1.2	- 0.4	- 0.5
4000	+ 1.0	- 0.7	- 0.8
5000	+ 0.5	- 1.2	- 1.3
6300	- 0.1	- 1.9	- 2.0
8000	- 1.1	- 2.9	- 3.0
10000	- 2.5	- 4.3	- 4.4
12500	- 4.3	- 6.1	- 6.[illegible]
16000	- 6.6	- 8.4	- [illegible]
20000	- 9.3	-11.1	-11.2

The total allowable tolerance limits, including microphone random response, are as follows:

Total Tolerance Limits for Sound at Random Incidence for Type 2 Sound Level Meter

Frequency Hz	A Weighting dB	B Weighting dB	C Weighting dB
20	+5.0,-∞	+4.0,-∞	+3.0,-∞
25	+4.0,-4.5	+3.0,-3.5	+2.0,-2.5
31.5	+3.5,-4.0	+2.5,-3.0	+1.5,-2.0
40	+3.0,-3.5	+2.0,-2.5	+1.0,-1.5
50	±3.0	±2.0	±1.0
63	±3.0	±2.0	±1.0
80	±3.0	±2.0	±1.0
100	±2.5	±2.0	±1.0
125	±2.5	±2.0	±1.0
160	±2.5	±1.5	±1.0
200	±2.5	±1.5	±1.0
250	±2.5	±1.5	±1.0
315	±2.0	±1.5	±1.0
400	±2.0	±1.5	±1.0
500	±2.0	±1.5	±1.0
630	±2.0	±1.5	±1.0
800	±1.5	±1.5	±1.0
1000	±2.0	±2.0	±1.5
1250	±2.0	±2.0	±1.5
1600	±2.5	±2.5	±2.0
2000	±3.0	±3.0	±2.5
2500	+4.0,-3.5	+4.0,-3.5	+3.5,-3.0
3150	+5.0,-4.0	+5.0,-4.0	+4.5,-3.5
4000	+5.5,-4.5	+5.5,-4.5	+5.0,-4.0
5000	+6.0,-5.0	+6.0,-5.0	+5.5,-4.5
6300	+6.5,-5.5	+6.5,-5.5	+6.0,-5.0
8000	+6.5,-6.5	+6.5,-6.5	+6.0,-6.0
10000	+6.5,-∞	+6.5,-∞	+6.0,-∞

The measured electrical response of the USAFA/EPA sound level meter is given in Fig. 2. To this response must be added the random incidence response of the microphone, given in Fig. 3. The sum of Figs. 2 and 3 meet the requirements of Fig. 1 within the above tolerance limits.

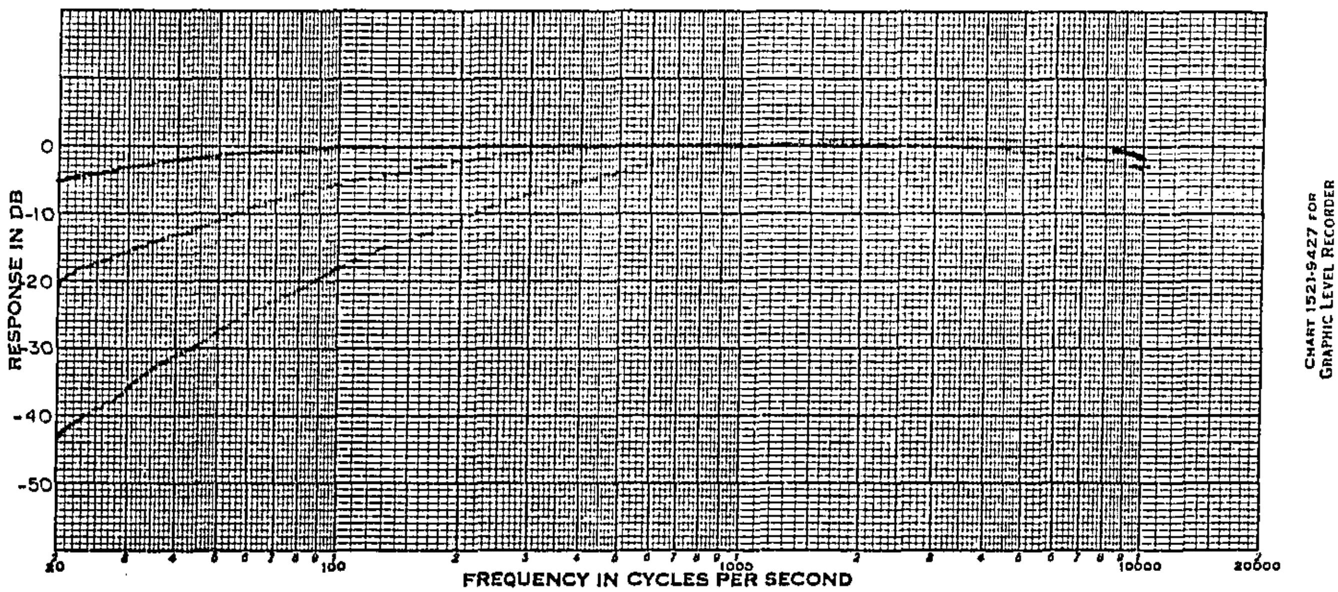


Figure 2

Electrical Relative Response Level of USAFA/EPA Sound Level Meter.

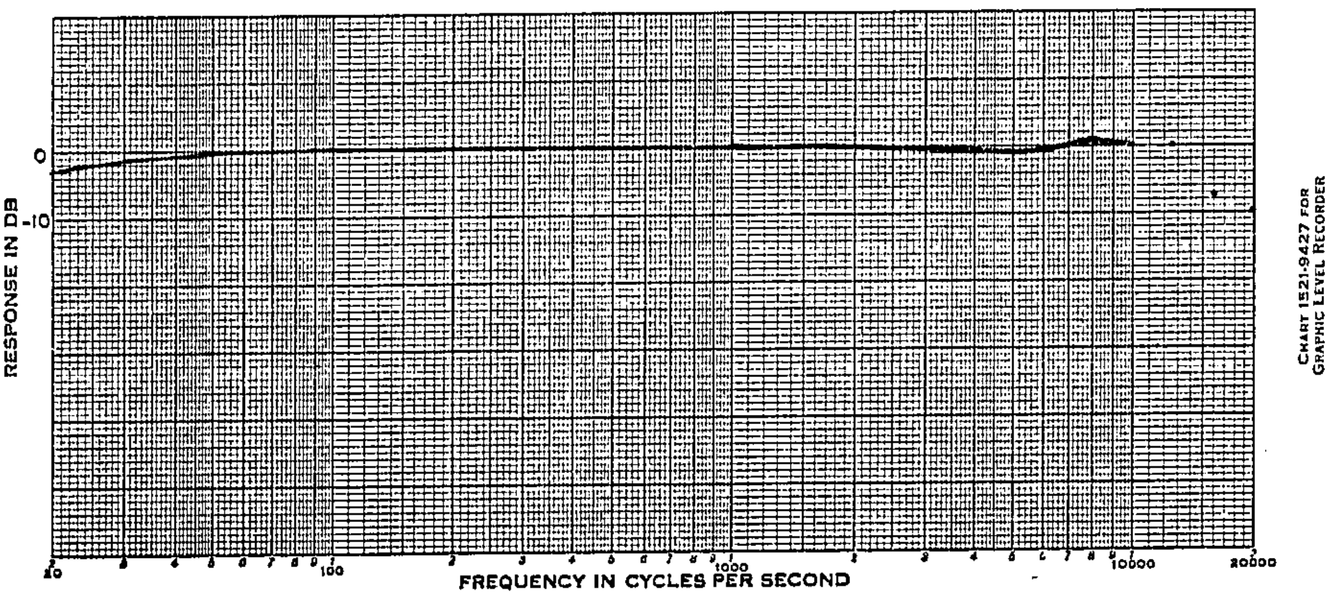


Figure 3

Random-Incidence Relative Response Level of Thermo-Electron Corp Model 814 Microphone.

The attenuator must have the following tolerance for its settings, with respect to the 80 dB setting:

Within $\pm$ 0.5 dB	63 to 2000 Hz
Within $\pm$ 1.0 dB	22.4 to 11,200 Hz.

The attenuator satisfies the requirement. (See preceding section for analysis of attenuator design and component tolerance).

Internal Noise and Distortion

On all attenuator settings, except the three most sensitive, the internal noise of the instrument must be at least 40 dB below the maximum scale reading, with an acoustically shielded microphone in place.

When the shielded microphone is replaced by equivalent electrical impedance, the noise level must be at least 5 dB below the lowest sound level the instrument is intended to measure.

When the output meter is replaced by its equivalent impedance, the sine wave response from 22.4 to 11,200 Hz must be linear within 1 dB up to 10 dB above maximum scale reading.

Omnidirectional Responses and Tolerances

The random incidence response of the 814 microphone, as mounted on the sound level meter, is given in Fig. 3. With respect to the random incidence response, the free-field response at various angles may not deviate more than the following tolerances:

Maximum Allowable Deviation of Free-Field Relative Response Level with Respect to Random-Incidence Relative Response Level When the Angle of Incidence is varied from 45° to 90° from the Axis About Which the Response is Most Nearly Cylindrically Symmetrical.

These allowances are added arithmetically to the respective tolerance limits previously given.

Frequency Hz	Type 2 dB
31.5 to 2000	±2
2000 to 4000	±2.5
4000 to 5000	±3
5000 to 6300	±3.5
6300 to 8000	±4.5

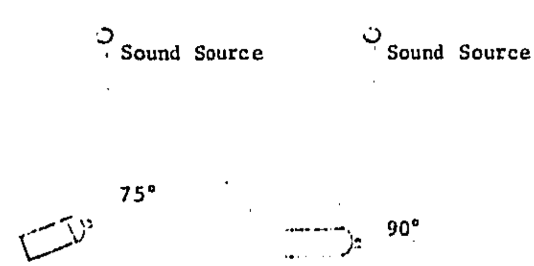
Maximum Allowable Deviation of Free-Field Relative Response Level for Sounds Arriving at Any Angle of Incidence with Respect to Random-Incidence Relative Response Level for Any Angle of Incidence.

These allowances are added arithmetically to the respective tolerance limits previously given.

Frequency Hz	Type 2 dB
31.5 to 2000	±3
2000 to 4000	+3,-4
4000 to 5000	+4,-6
5000 to 6300	+5,-8
6300 to 8000	+7,-9

The Model 814 microphone on the USAFA/EPA sound level meter satisfied these requirements.

Should one desire to make free-field measurements, the most accurate response is obtained when the angle between the sound source and the sound level meter is approximately 75° to 90°, for this sound level meter.



The correction for normal incidence (0° - microphone pointing at sound source) is given in Fig. 4.

Indicating Instrument Characteristics

The scale is calibrated in 1 dB steps over a 15 dB range, from +10 dB above the attenuator setting to -5 dB below. The scale is accurate within ±0.2 dB full scale to within ±0.65 dB at the lower limit.

The indicating instrument is of the square law type and satisfies within 0.5 dB the rule of combination measurement procedure as specified in Appendix B, ANSI S1.4-1971.

When the instrument is in "FAST" response, an applied 0.2 second pulse of 1000 Hz sinusoid results in a reading 0 to 4 dB less than that for a continuous signal of the same frequency and amplitude. A suddenly applied and maintained signal between 125 and 8000 Hz results in less than 1.1 dB overshoot. The steady reading is 4 dB less than full scale.

When the instrument is in "SLOW" response, an applied 0.5 second pulse of 1000 Hz sinusoid results in a reading of 2 to 6 dB less than that for a continuous signal of the same frequency and amplitude. A suddenly applied and maintained signal between 63 and 8000 Hz results in less than 1.6 dB overshoot. The steady reading is 4 dB less than full scale.

At any frequency between 31.5 and 8000 Hz, "SLOW" and "FAST" readings differ by less than 0.1 dB for a steady input.

There is a battery indicator to indicate adequate battery voltage. The instrument is calibrated by means of a standard acoustic calibrator. If a resistive load impedance of 10,000 ohms or greater is connected to the output, the reading is affected by less than 0.5 dB over the frequency range 22.4 to 11,200 Hz. The nominal output voltage is 0.5 . lts rms across 10,000 ohms for a full scale reading.

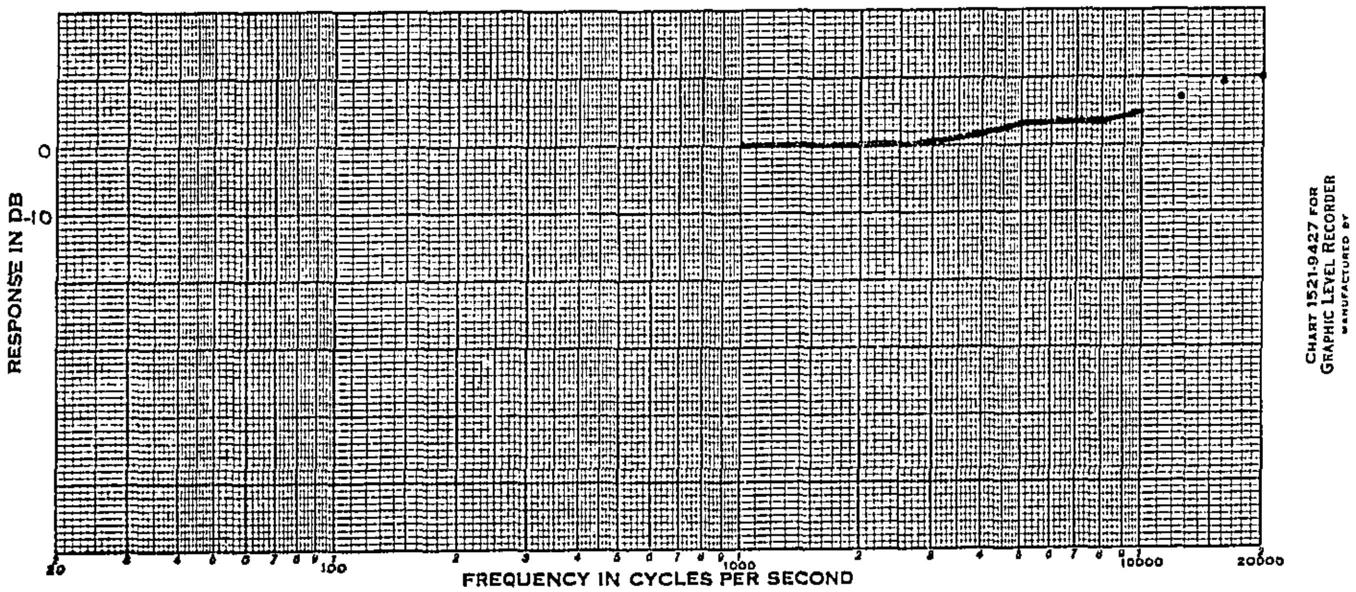
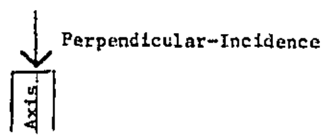


Figure 4

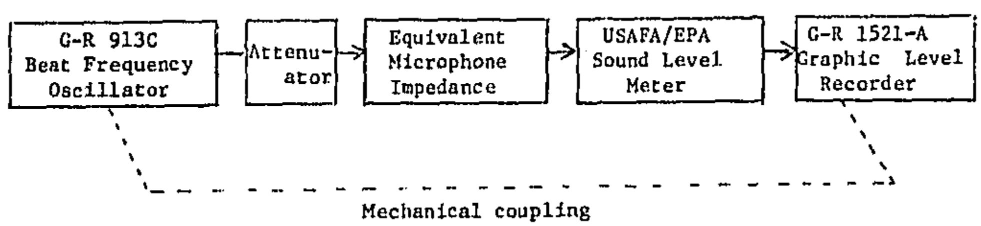
Correction for Free-field Perpendicular-Incidence Response for TEC 814 Microphone, to be added to Random-Incidence Response.



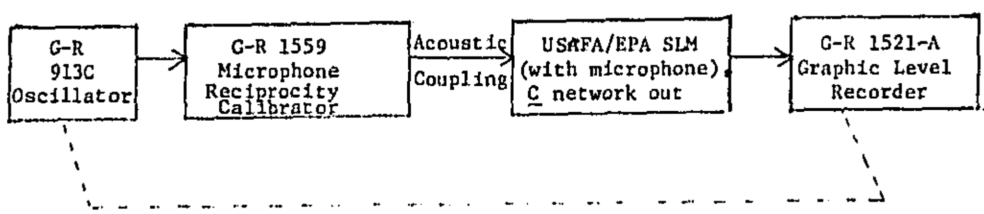
Specific tests were not made to determine compliance with the temperature, humidity, vibration, airborne noise, and magnetic and electrostatic fields provisions of ANSI S1.4-1971. Whether or not a completed instrument meets these provisions would also be a function of the instrument layout and method of manufacture and is not inherently part of the electrical and acoustical design. The microphone and operational amplifiers as separate devices easily meet the specification requirements.

Methods of Verification

The electrical response of the sound level meter was determined as follows:



The microphone calibration between 20 Hz and 1000 Hz was determined as follows:



Above 1000 Hz the microphone, mounted on the sound level meter, was free field calibrated in an anechoic chamber at the angles of incidence suggested in Appendix A ANSI S1.4-1971. The calibration was by comparison with the response of a B & K Model 4145 secondary standard microphone to a known acoustic source. The calibration wae at the 1/3 octave frequencies specified in ANSI S1.4-1971 between 1 kHz and 20 kHz. As a check, the response of the sound level meter was compared to that of a G-R Precision Sound Level Meter with a Model 1560-P7 Precision Microphone which had been calibrated. The 1559-B Microphone Recriprocity Calibrator was used as a sound source between 1 kHz and 8 kHz.

The "FAST" and "SLOW" response tests used a multivibrator with different "on" and "off" times to trigger a 1 kHz oscillator as a signal source. The remainder of the calibration verification used normal standard laboratory procedures.

CONSTRUCTION DETAILS

The basic instrument detailed here uses the Thermo-Electron Model 814 microphone and is housed in a 2 1/8 x 3 x 5 1/4 inch minibox. The unit which was tested for omnidirectional response and for which the earlier curves were derived was housed in a 3 x 4 x 5 inch minibox. Since the smaller 2 1/8 x 3 x 5 1/4 box results in less sound diffraction, improved high frequency response should result, and the resulting random incidence response should be somewhere between those of Fig. 3 and Fig. 4. The earlier model is shown in Fig. 5, and the current model in Fig. 6.

If it is desired to duplicate the earlier model (to achieve the response of Fig. 4), the microphone mount cover, Fig. 7, will have to be enlarged so that the base is 3" x 4". The heights of both the microphone mount and the cover should be increased by 3/8".

The details of the 814 microphone mount are shown in Fig. 9. The microphone is cemented in the hole so that the face plate of the microphone is flush with the top of the mount. RG-174/U coaxial cable or tonearm phono cable is used for the signal and ground connections, and 26 gauge wire is used for the power supply connection. The wires pass through a hole in the top of the minibox. The microphone mount is attached to the minibox via three 6-32 screws.

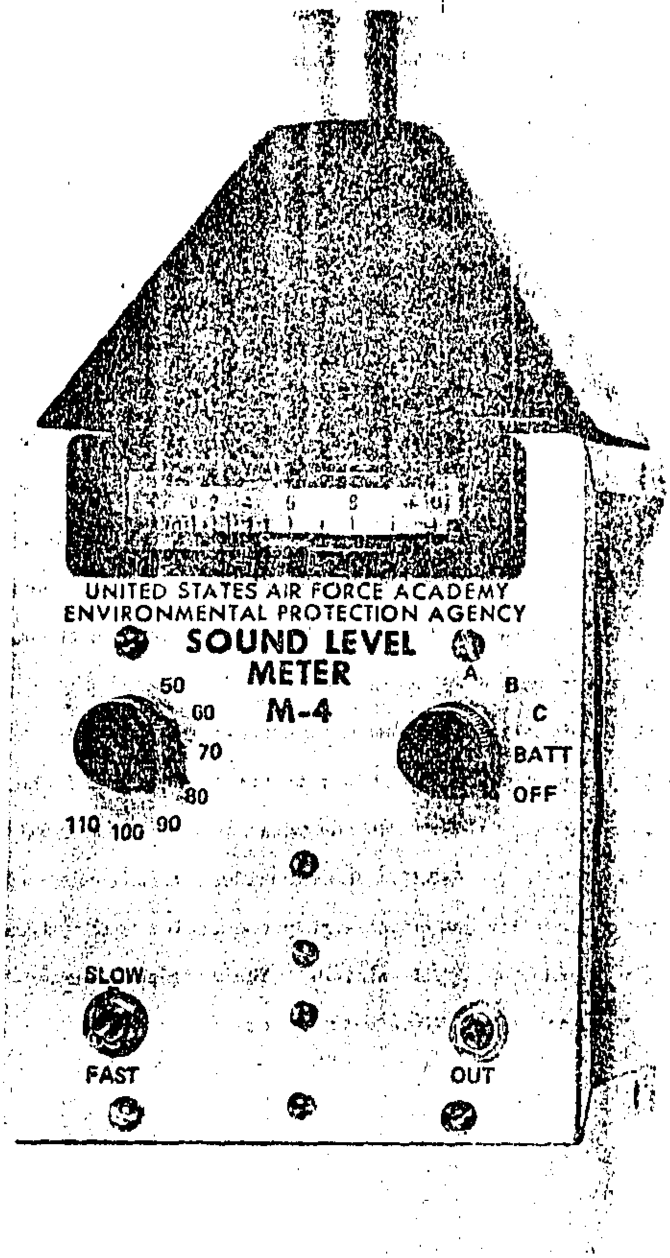


Figure 5
Sound Level Meter, 3 x 4 x 5 inch case

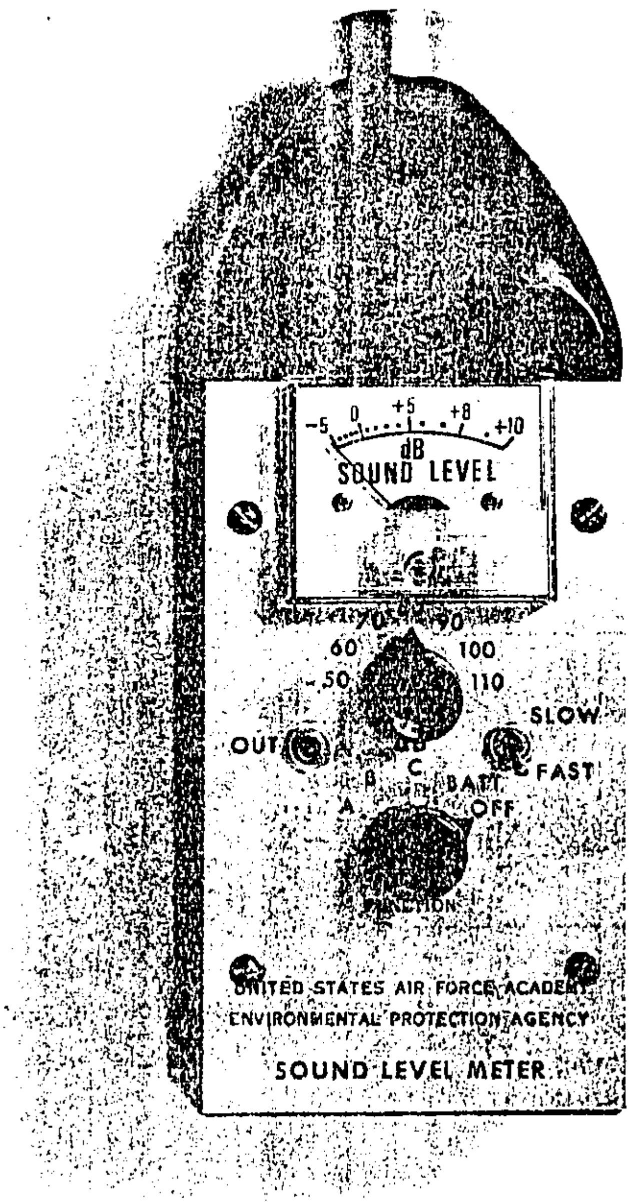
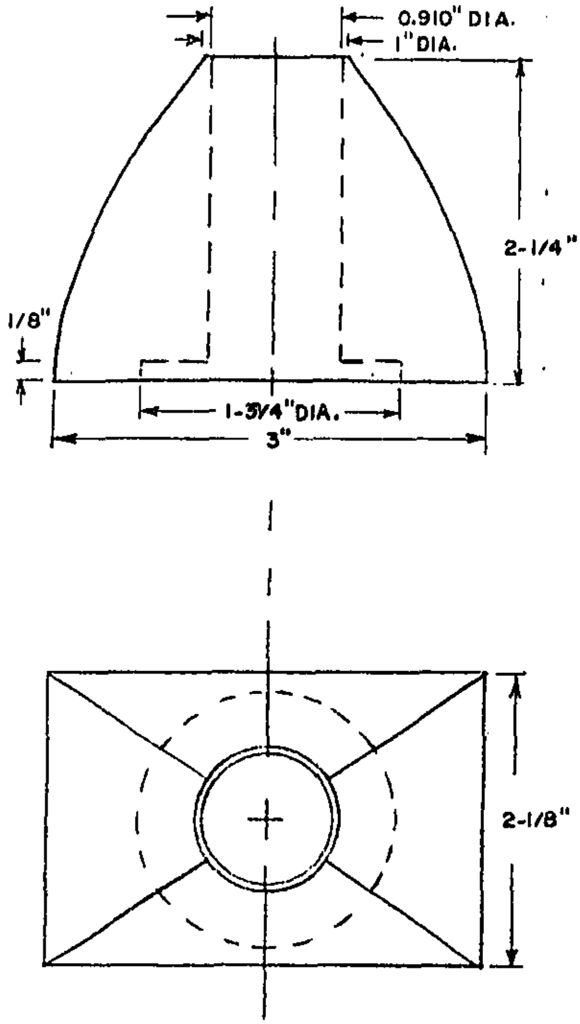


Figure 6
Sound Level Meter, 2 1/8 x 3 x 5 1/4 inch case



MATERIAL - BALSA WOOD OR PLASTIC

FIGURE 7
MICROPHONE MOUNT COVER

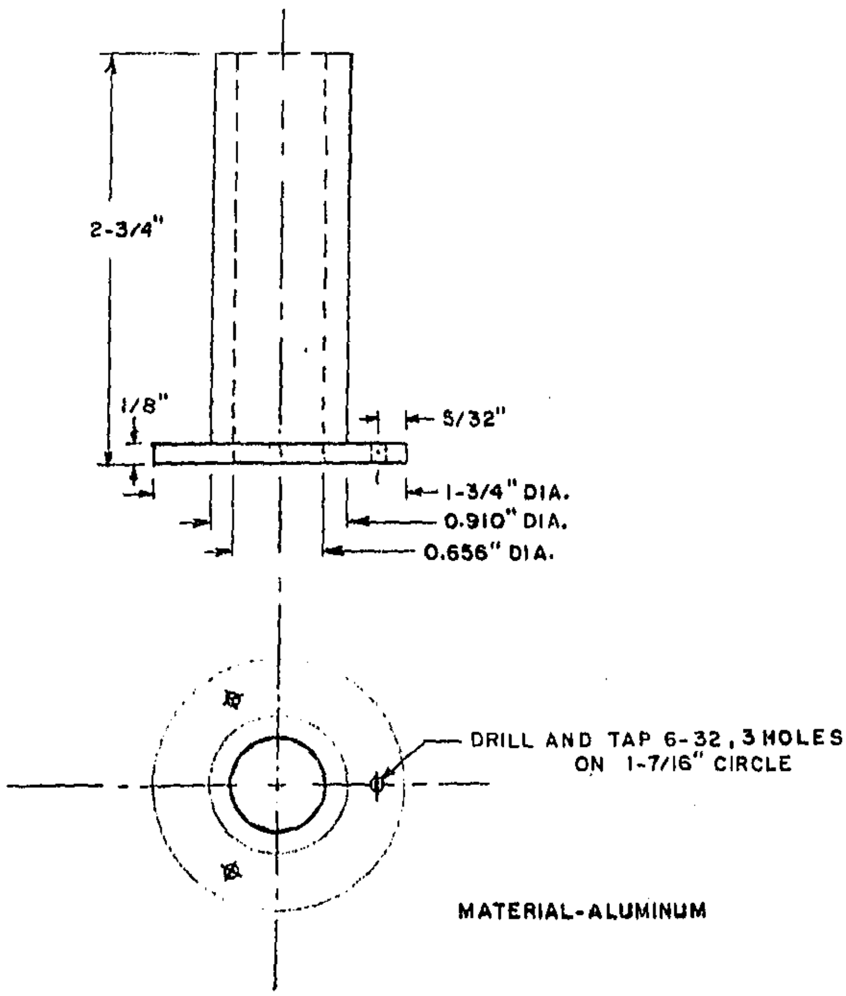


FIGURE 8
MOUNT FOR MODEL 814 MICROPHONE

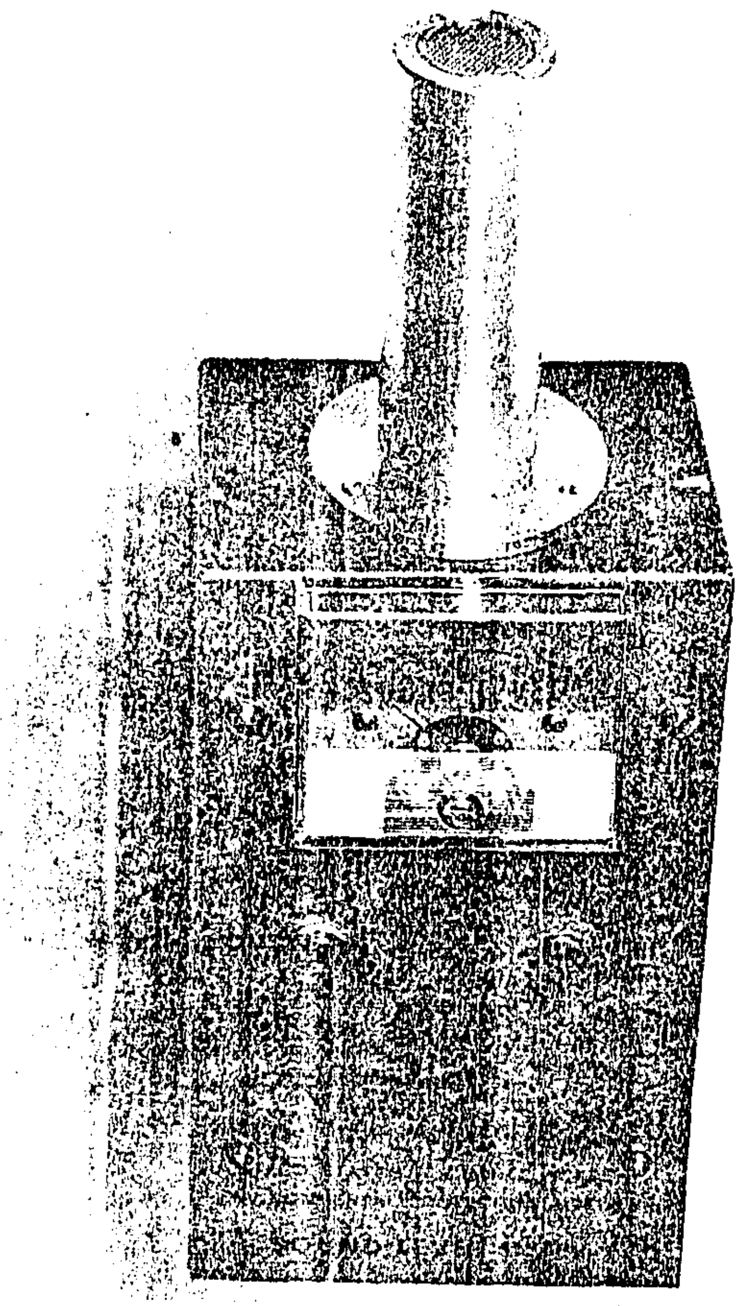


Figure 9

Microphone Mount, Close-Up View

Shown in Fig. 10 is the interior of the minibox, with the meter at the top and the two batteries at the bottom. The switches are on the other side of the printed circuit board.

A full size diagram of the printed circuit board, foil side, is given in Fig. 11, and may be used to photo-etch a duplicate board via normal techniques.

The parts layout and interconnections to the pc board are given in Fig. 12. This is, of course, the opposite (non-foil) side of the board. The original board used foil on both sides, but in the interests of cost, simplicity, and duplication it was re-designed into a one-sided board. This procedure necessitates a number of jumper connections, however, also shown in Fig. 12.

The full schematic diagram is given in Fig. 13, and the parts list in Fig. 14. All parts are mounted on the pc board except for the microphone, switches, output jack, batteries, meter, and R19, which is mounted directly on S2.

Templates for drilling the front, top, and bottom panels are given in Fig. 15 and Fig. 16.

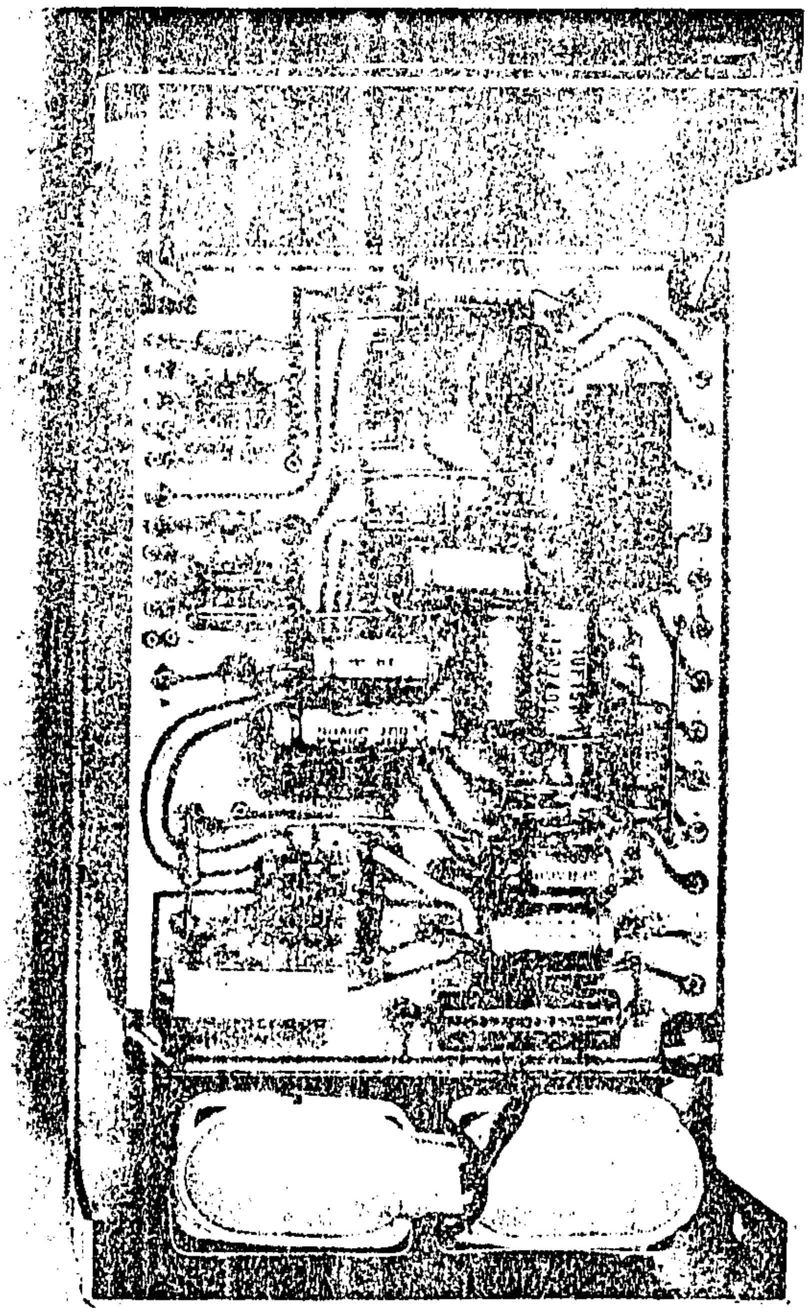


Figure 10
Interior of Sound Level Meter

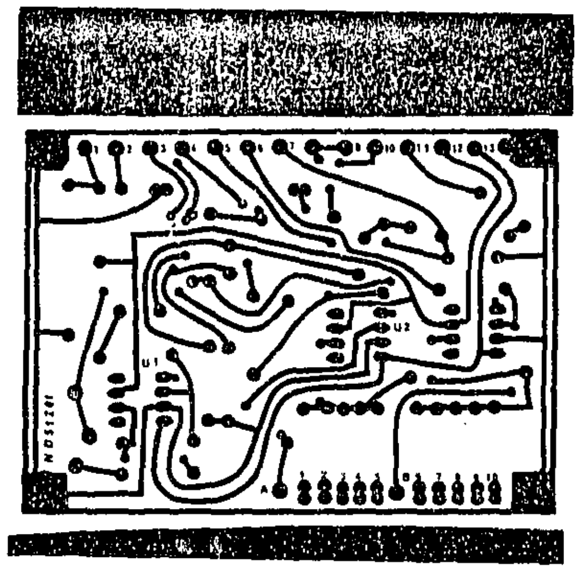
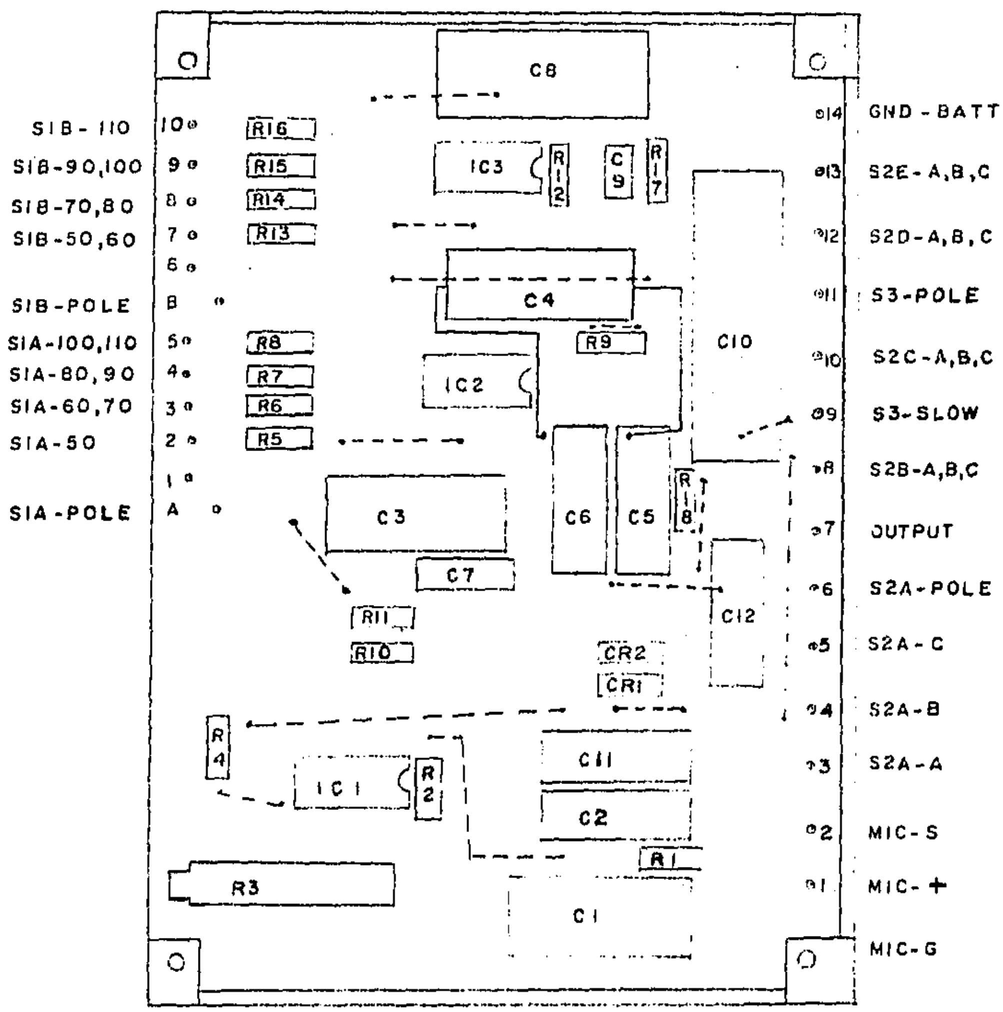


Figure 11

Printed Circuit Board, Foil Side



DOTTED LINES ARE JUMPERS - CONNECT BEFORE COMPONENTS.

FIGURE 12
P C BOARD COMPONENT LAYOUT

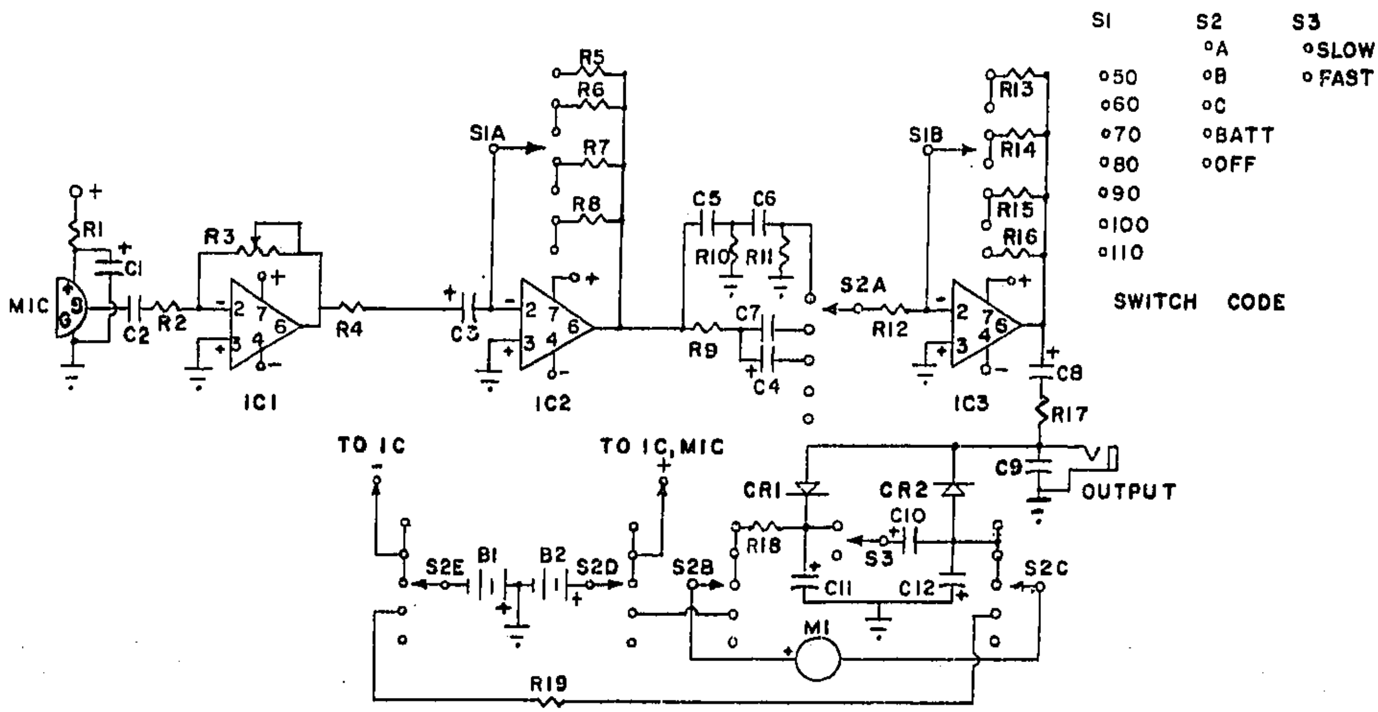


FIGURE 13

SCHEMATIC DIAGRAM

B1,2	8.4V mercury battery (RCA VS 146X), or 9V transistor radio battery
C1	10μF
C2	1μF 10%
C3	10μF
C4	10μF
C5	1μF 10%
C6	1μF 10%
C7	.81μF 10% (.33μF and .47μF in parallel)
C8	10μF
C9	.047μF 10%
C10	100μF
C11	5μF
C12	5μF
CR1,2	1N34A
IC1,2,3	μA741C, "minidip" 8 pin DIP package, integrated circuit operational amplifier
M1	0-100μA meter, Radio Shack Micronta Type 22-037
MIC	Thermo-Electron Corp Model 814 electret microphone
R1	47kΩ
R2	3.3kΩ
R3	50kΩ variable, "Trimpot" type, to fit p.c. board
R4	1kΩ
R5	31.6kΩ 2%*
R6	10kΩ 2%
R7	3.16kΩ 1%
R8	1kΩ 2%
R9	240Ω 2%
R10	560Ω 2%
R11	1.3kΩ 2%
R12	1kΩ 2%
R13	31.6kΩ 2%*
R14	10kΩ 1%
R15	3.16kΩ 2%*
R16	1kΩ 2%
R17	430Ω 2%
R18	8.2kΩ
R19	200kΩ
S1	2P7T wafer switch, minature rotary, Centralab PA-1005
S2	5P5T wafer switch minature rotary, Centralab PA-1021
S3	SPST toggle or slide switch

All resistors 5%, 1/4 watt, unless otherwise noted.
All capacitors -10+100%, 10V, unless otherwise noted.

Misc: Minibox
Battery clips and connectors
Shielded phono cable (tonearm)
p.c. board

* Note: R5, 13, 15 can be formed by series or parallel connecting 2% resistors, such as a 60kΩ and a 63kΩ in parallel for R5, or by using a 1% resistor, depending on local availability and costs. The necessary values for R5, 13, 15 are not readily available in 2% resistors.

Figure 14

Parts List

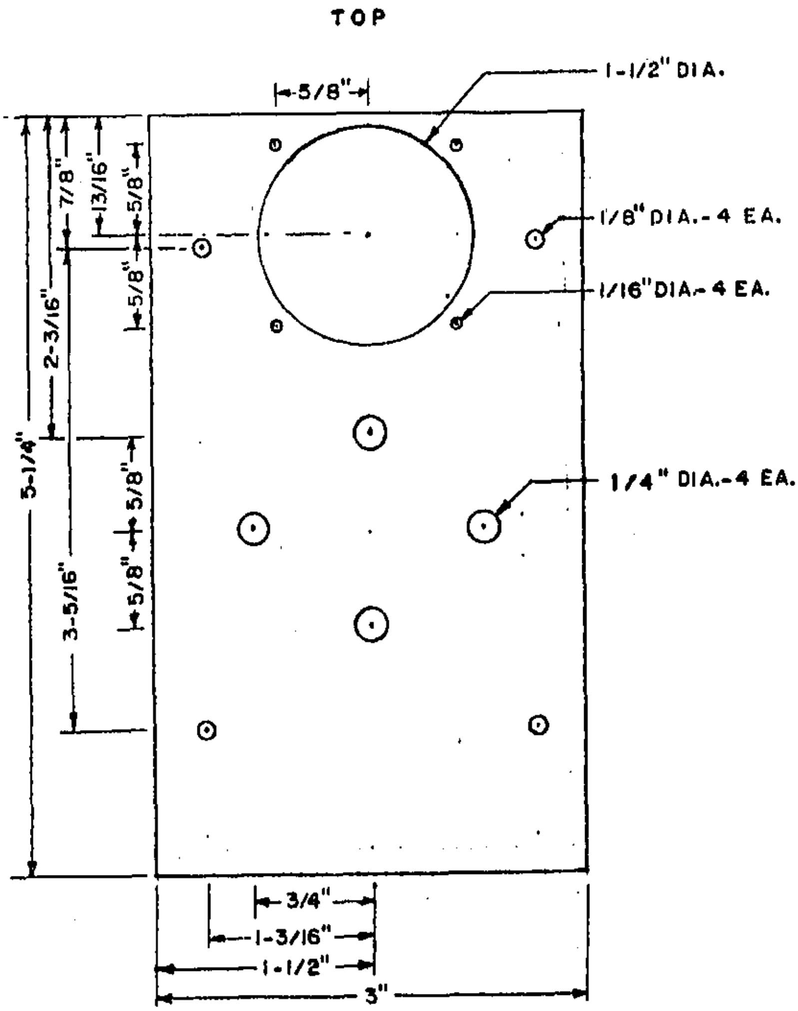


FIGURE 15

FRONT PANEL

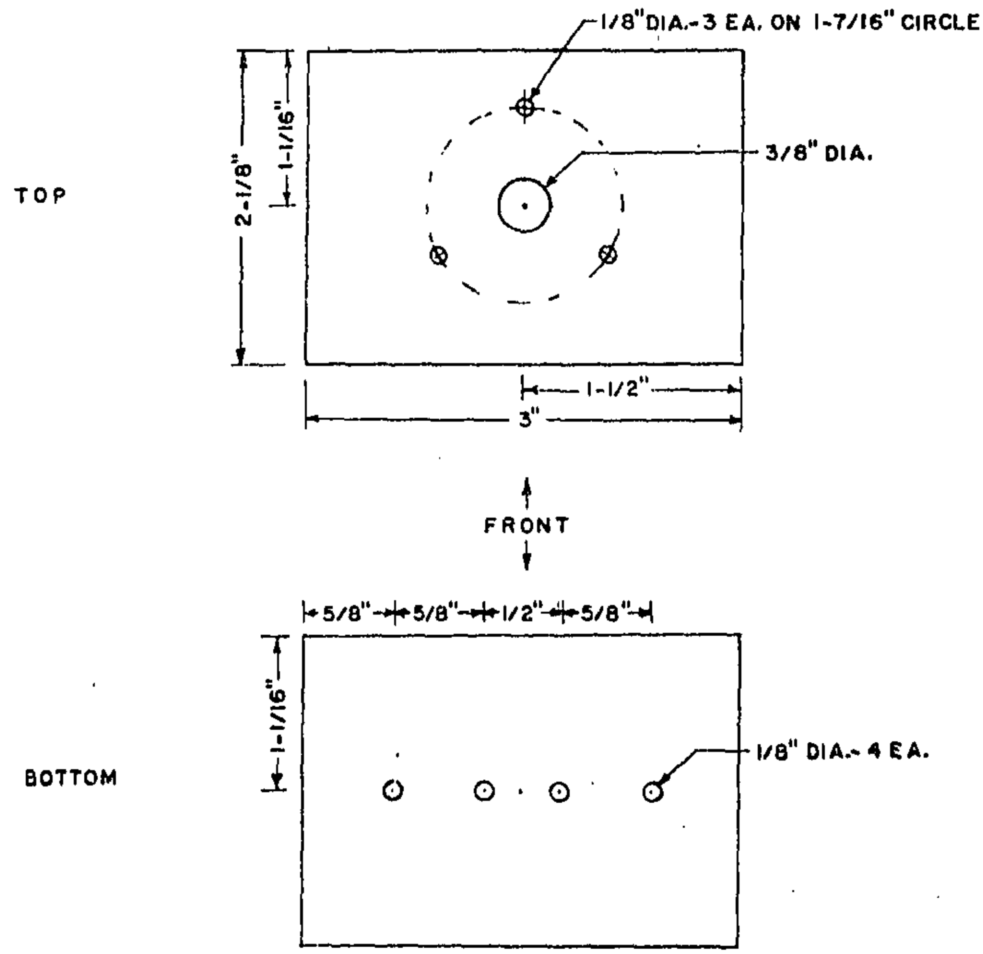


FIGURE 16

TOP & BOTTOM PANELS

The faceplate of the 100μA meter needs to be recalibrated in terms of dB SPL. A conversion table is given below:

+ 10 dB SPL	100μA
+ 9 dB SPL	88μA
+ 8 dB SPL	77μA
+ 7 dB SPL	67μA
+ 6 dB SPL	56μA
+ 5 dB SPL	48μA
+ 4 dB SPL	41μA
+ 3 dB SPL	35μA
+ 2 dB SPL	30μA
+ 1 dB SPL	26μA
0 dB SPL	22μA
- 1 dB SPL	18μA
- 2 dB SPL	15μA
- 3 dB SPL	12μA
- 4 dB SPL	9μA
- 5 dB SPL	7μA

The above calibration chart should be checked on the completed instrument by replacing the microphone input with a variable amplitude signal, such as a 1 kHz sine wave from an oscillator, variable over a 20 dB range, with a maximum output of less than a volt. An A. C. voltmeter, calibrated in dB, either connected across the sine wave oscillator or connected to the output of the sound level meter, would then determine the proper meter calibration for that particular meter and the particular diodes used in the detector. The meter scale can be expanded or compressed somewhat by means of the meter zero adjuster.

Alternative Microphones

The Model 814 specified herein is available from Electronic Enterprises, 3305 Pestana Way, Livermore, CA 94550, for $32 and from Thermo-Electron Corp., 85 First Avenue, Waltham, MA 02154, for $25 each in lots of two or more. The specifications of the Model 814 are as follows:

Sensitivity	−68 dB V (Re: 1V/μbar)
Noise Level	25 dBA
Distortion (10% THD)	120 dB SPL
Vibration Level	80 dB SPL/g
Hum Level	10^{-7}V/g

If only a Type 3, Sound Survey, instrument is desired, the Thermo-Electron Model 5336 microphone may be a lower cost substitute. A number of them were tested, and indeed a few met Type 2 specifications, but in general the low frequency response was inadequate on several of them to satisfy the tighter Type 2 requirements. The specifications are generally the same as those for the Model 814, except that the Model 5336 is more sensitive by approximately 7-10 dB. It is smaller physically and will require modification of the microphone mount, but it is electrically compatible with the circuit. It is available for $10 each in lots of five or more from Thermo-Electron Corp.

Another alternative is the Model XL-9076 of Knowles Electronics, Inc., 3100 North Mannheim Rd., Franklin Park, IL 60131. It is an adaptation of their Model XD-992, a ceramic microphone with integral field effect transistor amplifier (as in the electret microphones) which is being used for Type 2 sound level measurements at present. The XL-9076 is an XD-992 mounted in a 1/2" dia. case so that the resulting unit satisfies Type 2 specifications. It is electronically compatible with this sound level meter if R2 is changed to 1kΩ to provide the proper low frequency attenuation. The microphone mount would become a simple hollow post on which the microphone case would clamp. The price should be competitive (not yet determined at this time), and the unit has the advantage that its intended use is Type 2 sound level measurements. The other specifications are similar to those of the Model 814 above. Although 1/2" dia. acoustic calibrators are becoming common, a sleeve, 1/2" inner dia., 0.910" outer dia., would be necessary to adapt the XL-9076 to older model calibrators.

If the constructor has access to a precision low frequency sound source, such as a General Radio Type 1559-B Microphone Reciprocity Calibrator, the value of R2 can be adjusted so that the sum of the microphone low frequency roll-off and the C network roll-off equals the desired C weighting.

If a particular Model 814 microphone has inadequate sensitivity, the gain of the first op amp can be increased by changing R2 to 1kΩ. C2 must then be changed to 2μF to preserve the C network low frequency attenuation.

CONCLUSIONS

The original charter was to determine experimentally the feasibility of a low-cost sound level meter which would meet the minimum requirements of ANSI S1.4-1971 and which could be reproduced by a reasonably competent electronics manufacturer without recourse to a fully equipped acoustical laboratory. The instrument would be used for sound surveys in an unsophisticated manner by personnel in the field. The instrument was not intended to replace the standard sound level meter in the hands of a trained acoustician or noise control engineer.

The evolved design has been shown capable of meeting the requirements of ANSI S1.4-1971 for a general purpose sound level meter. The parts and manufacturing costs remain low, and may be reduced further by an adept manufacturer.

The completed instrument can be calibrated by standard sound level meter calibrators such as those available in the EPA field offices throughout the U.S.

Although instruments built to this design have met ANSI S1.4-1971 requirements, there is no representation that all such instruments will also meet the requirements. For a manufacturer, some sort of end item testing would be necessary to ensure "certification." There is also no representation that features of the design and circuit are not covered elsewhere by patents.

Mention of particular models, manufacturers, and suppliers in this report should not be construed as endorsement by either the United States Air Force or the Environmental Protection Agency. This report summarizes a research study, not a production contract design.