PREPRINT NO. 582

SOLID STATE CONDENSER MEASURING MICROPHONE ASSEMBLY

by
W. T. Kapuskar
Research and Development
Hewlett-Packard GmbH
Boeblingen, West Germany

PRESENTED AT THE

34th CONVENTION

APRIL 29 – MAY 2, 1968

AUDIO
A
E S
®

AN AUDIO ENGINEERING SOCIETY PREPRINT

Convention Price . . . . . . $ .25
By Mail to Members . . . . .$ .50
By Mail to Non-Members . $ .85

SOLID STATE CONDENSER
MEASURING MICROPHONE ASSEMBLY

W. T. KAPUSKAR

Research and Development, Hewlett-Packard GmbH,
Boeblingen, West Germany

Introduction

Instrumentation for acoustical measurement usually starts with a transducer which converts the audio sound pressure into electrical quantities. The transducers or microphones are based on different principles of operation. One would invariably choose a condenser microphone when the whole frequency band has to be taken into consideration and when tolerances of flatness of response are tight. However, a condenser microphone needs an impedance converter (converting the high impedance at the input into a low impedance at the output) directly connected next to it, and vacuum tube preamplifiers have been used for this purpose for a long time. Their replacement by solid state amplifiers was felt to be a rather difficult problem. Some of the most important properties expected of a preamplifier are: high input impedance; low input capacitance; low output impedance; and low noise. A vacuum tube used as a cathode follower fulfils these requirements to a large extent. In order to avoid disturbances in the acoustical field to be measured - especially at higher frequencies - the dimensions of the whole microphone assembly have to be small. Efforts have been made to reduce the size of the condenser microphone cartridge, however the size of the preamplifier is practically limited by the size of the vacuum tube. Thus the replacement of the vacuum tube by solid state circuitry is urgently required, and the advantages one would gain from this are: more flexible cables; better gain (practically unity); and less microphonics.

Basic Considerations

With the low leakage field effect transistors (FET) which are available today one can consider designing high input impedance circuits. The microphone cartridge needs a DC polarization voltage of 200 V, and it is practical to obtain the necessary supply voltage for the circuitry by reducing this voltage to a convenient value which would be dictated by the transistors. This reduces the number of conductors in the shielded cable to only three, i.e., +200 V, Ground and output (in contrast to a vacuum tube preamplifier). A relatively thin, and hence more flexible, cable is chosen with a nominal capacitance of 27 pF per foot. Robust three-contact audio connectors are used, making extension cables very simple.

One Inch Microphone Preamplifier - HP Model 15108A

Figure 1 is the circuit diagram of the one inch microphone preamplifier HP Model 15108A. The polarization voltage for the microphone cartridge is applied via resistors R10, R7 and R1. The RC-combination R10, C10 reduces the ripple in the supply voltage. C8 provides a feedback, multiplying in effect the value of R1 and thus reducing its shunting effect on the input impedance. C1 is included to block the DC voltage from the gate of the FET. The supply voltage is brought down to +45 V by using two RC-stages R9, C6 and R8, C4, C5. The breakdown diode CR1 clamps this voltage and thus damage to the transistors through accidental higher supply voltages is avoided. A low noise n-channel silicon FET with very high mutual conductance (20 mA/V) is used at the input. The gate bias is determined by the voltage divider R5, R3 and is applied via R2**.

Normally, a FET is connected as a source-follower, analogous to a cathode-follower circuit, in order to attain high input impedance. The FET and the p-n-p transistor shown in Figure 1 constitute a good combination to form a preamplifier having high input and low output impedance. (In effect, the mutual conductance of the FET is multiplied by the current gain of the p-n-p transistor.) The input impedance is considerably increased since condenser C2 is used as a bootstrap between source and gate. The DC component at the output is blocked by capacitor C7, making it short-circuit proof.

To restrict the noise made by the preamplifier to a minimum, low-noise transistors and metal film resistors are used. Together with an input adapter, which consists of a 1800 pF capacitor to block the DC polarization voltage, the preamplifier can be used as an impedance converter for diverse applications. Diodes CR2 and CR3 (low leakage, low capacitance) are added to avoid damage to the FET through excessive transients at the input.

Figure 2 shows the exploded view of the preamplifier. The circuitry consists of two printed circuit boards. The component distribution is such that leakage paths are reduced considerably. Varnishing is used to provide protection against moisture.

Table 1 shows the specifications for the one inch preamplifier. The input impedance is more than 300 MΩ and the input capacitance is typically 4 to 6 pF. The maximum output current is 0.6 mA. This corresponds to a nominal load of 500 pF at 20 kHz. (In terms of microphone cable it means a length of about 20 feet.) Typical A-weighted noise with 68 pF (which equals the nominal capacity of a one inch microphone cartridge) across the output is 10-15 μV.

This preamplifier was primarily designed for use with the Loudness Analyzer HP Model 8051A. Figure 3 shows an oscillogram on this instrument when the preamplifier input is shunted by 68 pF, the range switch of the instrument being set for the most sensitive range i.e., 12 sones. (For comparison purposes, an oscillogram of a single clapping sound is also shown in this figure. The "loudness" of this clap was 108 sones. It can be seen from this that the noise of the preamplifier is sufficiently low.

Half Inch Microphone Preamplifier - HP Model 15118A

As a further improvement of the solid state preamplifier it was felt that the preamplifier noise, as well as its input capacitance, should be further reduced., This is especially important when half inch condenser microphone cartridges are used instead of one inch cartridges. (The nominal capacitance of a half inch cartridge is 27 pF as against 68 pF for a one inch cartridge.) The preamplifier noise is principally reduced by increasing the bias resistances, and input capacitance has been reduced by improved circuitry as we shall see below.

Figure 4 shows the schematic of the half inch microphone preamplifier HP Model 15118A. Since the outside diameter of this preamplifier is half that of the previous one, miniaturized components had to be used. Unfortunately, availability of such components has influenced the overall design.

R10, R7 and R1 again provide the DC polarization voltage for the microphone cartridge. Value of R10 was increased as the value of the capacitor C3 had to be reduced because of space considerations. (R10 and C3 form a filter to reduce ripple in the supply voltage.) Much larger values for R7 and R1 were chosen. This not only reduces the shunting effect on the preamplifier input impedance but also reduces its noise for capacitive source impedances. Reduction of the preamplifier noise can also be achieved by increasing the gate resistance R2, as noted in the footnote to page 2. R11 determines the drain bias. A cheaper n-p-n transistor instead of the p-n-p in the previous schematic is used.

The feedback through C2 in Figure 1 reduces the capacitance between source and gate. A drawback of this circuit is, however, that the capacitance between gate and drain is not reduced. (It is instead slightly increased as the drain is not at zero AC potential.) In the present circuit the drain is returned to the output through capacitor C2 which appreciably reduces the input capacitance. In order to reduce stray capacitances to a minimum the whole circuitry is enclosed inside a shield which is driven by the output. A small resistance R13 in the collector lead of the n-p-n transistor makes the output short-circuit proof.

The constructional details of the half inch preamplifier can be seen in Figure 5. Metal parts are made of stainless steel to provide a robust construction. The contact pin is gold-plated. A platinum spring soldered to the circuit board provides the contact to the driven shield. The mechanical construction provides electrical isolation between the shield and the housing as well as between the shield and the components. As before, CR2 and CR3 safeguard the FET from transients. The leakage problems are solved through constructional measures. Humidity proofing is achieved by varnishing the circuit boards. This still allows an easy repair, if it should be at all necessary, which would have been impossible had the circuitry been epoxy encapsulated.

Table 2 is a summary of the specifications for the half-inch microphone preamplifier HP Model 15118A. It should be noted that input impedance is mainly determined by the diodes CR2 and CR3. Typical input capacitance is 3 pF. Typical A-weighted noise with 27 pF across the input is 10 μV. (This corresponds to a sound pressure level of 34 dB re 2.10^{-4} μbar) This is remarkable as all the resistors used are carbon film resistors.

Figure 6 shows the noise spectrum of the half inch preamplifier with 27 pF across the input - measured with a Real Time Audio Spectrum Analyzer HP Model 8054A. This instrument, again, was set for its most sensitive range of 0 - 40 dB re 1 μV.

Because of its handy size and extremely good frequency response (see specifications of the half inch cartridges) the half inch condenser microphone assembly is especially suitable for precision sound level meters.

One Inch Microphone Preamplifier - HP Model 15108B

To measure extremely low sound levels, one would normally prefer the more sensitive one inch microphone cartridge. The schematic of Figure 4 is used for the improved one inch microphone preamplifier 15108B. Metal film resistances are used except for R10, R7 and R1. This together with the fact that the capacitance of a one inch cartridge is higher reduces the preamplifier noise to very low values. Typical A-weighted noise is 6 μV. (This corresponds to a sound pressure level of less than 16 dB re 2.10^{-4} μbar.) This compares favorably with the vacuum tube preamplifier.

Figure 7 shows the spectrum analysis of the preamplifier noise of the 15108B measured with the Real Time Audio Spectrum Analyzer. For comparison purposes, the preamplifier noise of the older version 15108A is also shown. This indicates the superiority of the improved version, which is the present state of the art.

Cartridge Correction Factor

It should be reiterated at this stage that the input impedance of the preamplifier is greatly influenced by the diodes CR2 and CR3. Without these the input impedance exceeds 1000 MΩ and the input capacitance is less than 1 pF. If care is taken to screw the cartridge on before the power is switched on, the diodes are not essential. In this case all that would be needed is the cartridge open circuit sensitivity and any correction for loss in the preamplifier would be superfluous. In practice, however, one often unscrews the cartridge (for example, to replace it with another cartridge or with the input adapter) with the power switched on. The close proximity of the input pin, the shield and the housing (and this is especially true for the half inch preamplifier) then leaves enough chances for transients to be fed to the gate of the FET. The Input Adapter provision (making the instrument more versatile) further makes it possible for the user to feed DC voltages, in addition to the signal, to the input of the preamplifier. All this brings about an unpleasant premonition that the FET might get damaged some day. Inclusion of diodes CR2 and CR3 eliminates this drawback.

Modification of the cartridge open circuit correction factor is then necessary. The input capacitance of the preamplifier, with the two diodes, lies between 2 and 4 pF. The error introduced by assuming it to be a constant 3 pF capacitance is negligible. Since the cartridges are after all individually calibrated for their open circuit sensitivity, it is an easy matter to include their sensitivity together with the preamplifier and hardly any degree of freedom is lost.

As mentioned above, the circuit components are easily accessible and if necessary the diodes can be disconnected. (One could even disconnect the polarization voltage from the input pin - by disconnecting R1 - if the preamplifier is not being used with a microphone cartridge.)

Quarter Inch Microphone Preamplifier

The superiority of the solid state circuitry over the vacuum tube is very evident when the preamplifier has to be squeezed into quarter inch tubing. With the availability of transistors, including n-channel FETs, in micro-ceramic packages one can at last construct a quarter inch condenser microphone assembly. (Unfortunately, the use of thin film techniques in this area is not very promising because of the high values of resistors and capacitors involved.) One of the possibilities to realize the circuit of Figure 4 in the form of a quarter inch preamplifier would be to divide the components into two groups: those components which must be located at the cartridge end; and the others which could be mounted inside the connector at the other end of the cable. Figure 8 shows such a possible distribution. Five conductor shielded cable is used. (Cables with an outer diameter of less than 0.2" and nominal capacity of 27 pF per foot are available.)

The quarter inch microphone cartridge has a nominal capacity of 6 pF, thus eliminating diodes CR2 and CR3 in previous schematics. But this means that care would have to be taken in removing cartridges with the power switched on.

Condenser Microphone Cartridges

Table 3 and Table 4 show the data for the one inch and the half inch condenser microphone cartridges respectively. The extremely smooth frequency response of the half inch cartridge throughout the entire audio band is noteworthy. This cartridge shows great promise for measurements in a diffuse sound field

Figure 10 discloses a remarkable feature of the microphone cartridges. One of the methods often preferred in determining the frequency response of a condenser microphone cartridge involves the use of an electrostatic actuator[***]. (This method obtains a relative frequency response. The absolute sensitivity is measured at a convenient frequency - say, 1 kHz - by some other method.) The electrostatic actuator has to be placed in close proximity to the diaphragm and extreme care has to be taken in order to avoid damage being done to the delicate microphone diaphragm. As shown schematically in Figure 10, the front plate of the cartridge is isolated from the housing and can thus be used as an electrostatic actuator. (A small insulator ring, to fit over the cartridge and with a spring to make a contact with the front plate, has to be used.)

Power Supply

The supply voltage for the preamplifier is 200 V. Restrictions on its stability are not severe if the preamplifier is not used with the cartridge (i.e., when used as an impedance converter for some other application). If, however, it is used as a microphone assembly a well stabilized voltage is essential. This is due to the fact that the sensitivity of a microphone cartridge is dependent upon the polarization voltage. The microphone assembly consumes less than 0.5 W - this means a current of less than 2.5 mA.

Figure 11 shows the portable power supply designed for the microphone preamplifiers. Its circuit schematic is shown in Figure 12. The power supply uses four standard dry cells. Voltage to the preamplifier is constant within ±2 V and an eight hour service is guaranteed. Rechargeable batteries of the same dimensions as those of the dry cells can also be used. An extra cable with a tiny charging unit is also provided. This unit can also be used to drive the power supply from the mains. The output of the microphone assembly is available at a BNC-Jack. The portable power supply together with a half inch microphone assembly and a tape recorder form an ideal instrumentation set for outdoor recordings.

Acknowledgements

This work was done at Hewlett-Packard GmbH in West Germany. Thanks are due to the Acoustics Section Leader, H. Blässer, and the R&D Manager, W. Ohme, for their guidance and enthusiasm.

Footnotes

Footnote to page 1:

* It is possible to design a FET preamplifier with only two wires. (Mead C. Killon, "A Low Noise Two Wire Condenser Microphone Preamplifier", J. Audio Eng. Soc. 15, 163 (1967)) However, it was felt that the three conductor shielded cable would suit our purpose best. A single coaxial cable is, after all, ruled out as the cable shield and the floating ground should be kept isolated from each other.

Footnote to page 2:

** This value of R2 was chosen high, i.e., 200 MΩ. It turns out that this reduces the preamplifier noise. (Jinichiro Nakamura & Rinske Wakabayashi, "A Transistorized Amplifier for a Condenser Microphone", J. Audio Eng. Soc. 15, 200 (1967))

Footnote to page 5:

*** An electrostatic actuator is a perforated plate placed in front of the microphone diaphragm but kept electrically isolated from it. A DC polarization voltage of, say 200 V, is applied between the diaphragm and tha actuator. If, additionally, a small sinusoidal voltage is applied between the diaphragm and the actuator, the diaphragm is set into vibration and a proportional voltage is available at the output of the microphone assembly. By sweeping the sinusoidal frequency through the entire audio band and keeping its amplitude constant, a response plot of the microphone assembly can be recorded. A correction to obtain free-field response is necessary. This is dependent on the geometry of the cartridge and can be determined once for all time. (This correction has normally to be provided by the manufacturer.)

TABLE 1

SPECIFICATIONS OF THE ONE INCH MICROPHONE PREAMPLIFIER 1510§A

GAIN:	At 1 kHz with 1800 pF input adapter 0 dB ± 0.25 dB
MAXIMUM INPUT VOLTAGE:	30 V peak-to-peak
INPUT IMPEDANCE:	>300 MΩ in parallel with <8 pF
OUTPUT IMPEDANCE:	At 1 kHz = <100 Ω
MAXIMUM OUTPUT CURRENT:	0.6 mA
NOMINAL LOAD:	100 kΩ in parallel with 500 pF
FREQUENCY RESPONSE:	With 1800 pF input adapter and maximum output current = 0 dB ± 0.25 dB from 20 Hz to 200 kHz, for maximum output voltage of 1 V rms 0 dB ± 0.25 dB from 30 Hz to 20 kHz, for maximum output voltage of 10 V rms
DISTORTION:	<1%
NOISE:	A-weighted noise with 68 pF across input = <25 μV rms
SUPPLY VOLTAGE:	200 V ± 5 V, ripple not more than 5 mV
POWER CONSUMPTION:	< 500 mW
DIMENSIONS:	Outside diameter 0.936" (23.77 mm) length 4.725" (120 mm)
WEIGHT:	178 g without cartridge
ACCESSORIES:	Tripod mounting adapter 1800 pF Input adapter 10 feet of cable

TABLE 2

SPECIFICATIONS OF THE HALF-INCH MICROPHONE PREAMPLIFIER 15118A

GAIN:	At 1 kHz with 1000 pF input adapter = 0 dB ± 0.25 dB
MAXIMUM INPUT VOLTAGE:	30 V peak-to-peak
MAXIMUM OUTPUT CURRENT:	0.6 mA
NOMINAL LOAD:	100 kΩ in parallel with 500 pF
FREQUENCY RESPONSE:	With 1000 pF input adapter and nominal load = 0 dB ± 0.25 dB from 20 Hz to 200 kHz for maximum output voltage of 1 V rms 0 dB ± 0.25 dB from 30 Hz to 20 kHz for maximum output voltage of 10 V rms
DISTORTION:	Upto maximum output current = <1%
INPUT IMPEDANCE:	500 MΩ in parallel with 4 pF
OUTPUT IMPEDANCE:	<100 Ω
NOISE:	A-weighted noise with 27 pF across input = <15 μV
DIMENSIONS:	Outside diameter 0.5" (12.7 mm) Length 4.8" (122 mm)
WEIGHT:	with 10 ft of cable: 160 g
ACCESSORIES SUPPLIED:	1000 pF input adapter Tripod mounting adapter

TABLE 3

SPECIFICATIONS OF THE ONE-INCH CONDENSER MICROPHONE CARTRIDGE 0960-0501

PRINCIPLE OF OPERATION:	Responds to pressure
OPEN CIRCUIT SENSITIVITY:	5 mV/µbar (nominal) Individual calibration provided for each cartridge.
POLARIZATION VOLTAGE:	+200 V
CARTRIDGE CAPACITY:	68 pF (nominal)
FREQUENCY RESPONSE:	For normal free-field incidence: Flat within ±1 dB from 30 Hz to 8 kHz Flat within ±2 dB from 8 kHz to 18 kHz
TEMPERATURE COEFFICIENT:	<0.018 dB/^{o}C from -10^{o}C to +70^{o}C
EFFECT OF ATMOSPHERIC PRESSURE:	<0.4 dB for 10% change in atmospheric pressure
MAXIMUM SOUND PRESSURE LEVEL:	140 dB (distortion <3%)
DIMENSIONS:	Diameter 0.936" (23.77 mm) Length 0.75" (19 mm)
THREAD:	0.91" (23.11 mm) - 60 NS 2
CALIBRATION FACILITY:	Built-in electrostatic actuator

<u>TABLE 4</u>

SPECIFICATIONS OF THE HALF-INCH CONDENSER MICROPHONE CARTRIDGE

<u>0960-0502</u>

PRINCIPLE OF OPERATION:	Responds to pressure
OPEN CIRCUIT SENSITIVITY:	1 mV/μbar (nominal) Individual calibration provided for each cartridge
POLARIZATION VOLTAGE:	+200 V
CARTRIDGE CAPACITY:	27 pF (nominal)
FREQUENCY RESPONSE:	For normal free-field sound incidence: Flat within ±1 dB from 20 Hz to 20 kHz Maximun deviation for diffuse field: 1 dB for frequencies upto 3 kHz 2 dB for frequencies upto 5 kHz 4 dB for frequencies upto 10 kHz 6 dB for frequencies upto 20 kHz
TEMPERATURE COEFFICIENT:	<0.01 dB per 1°C from -10°C to +70°C
EFFECT OF ATMOSPHERIC PRESSURE:	<0.1 dB for 10% change in atmospheric pressure
MAXIMUM SOUND PRESSURE LEVEL:	160 dB re 2.10^{-4} μbar (4% distortion)
DIMENSIONS:	Diameter 0.5" (12.7 mm) Length 0.55" (14 mm)
THREAD:	0.46" (11.7 mm) - 60 NS 2
CALIBRATION FACILITY:	Built-in electrostatic actuator

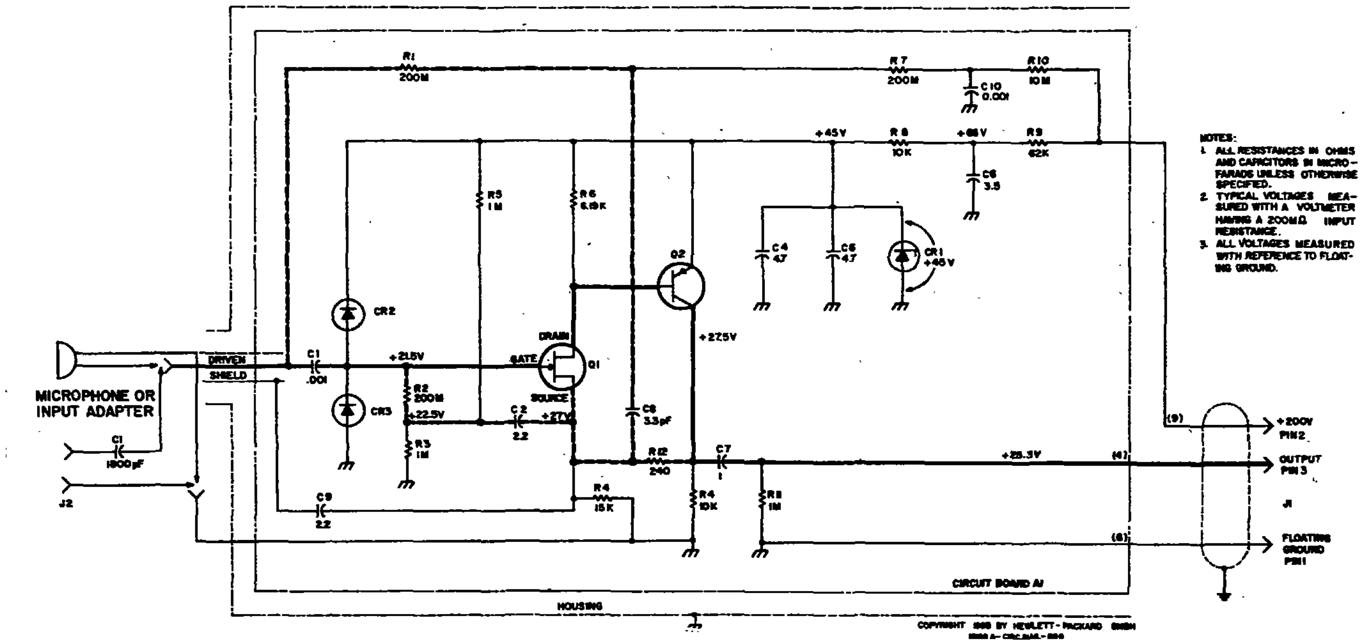


Figure 1 Schematic of the one-inch microphone preamplifier 15108A

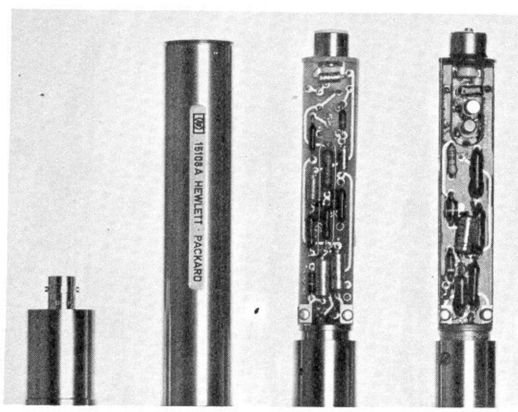
Figure 2 Exploded views of the one-inch microphone preamplifier 15108A.

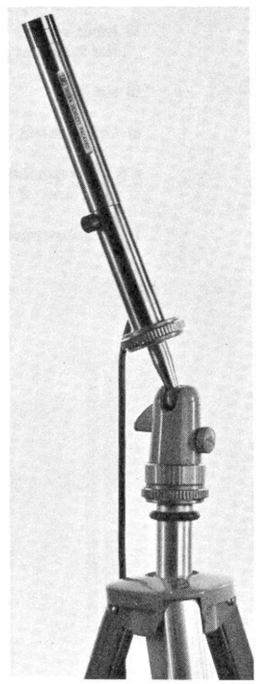
a) Input adapter which can be screwed on to the preamplifier for use as an impedance converter.

b) Housing

c & d) Preamplifier with the outer shell removed, showing both sides of the printed circuit boards.

e) Complete microphone assembly mounted on a tripod.





a b c d e

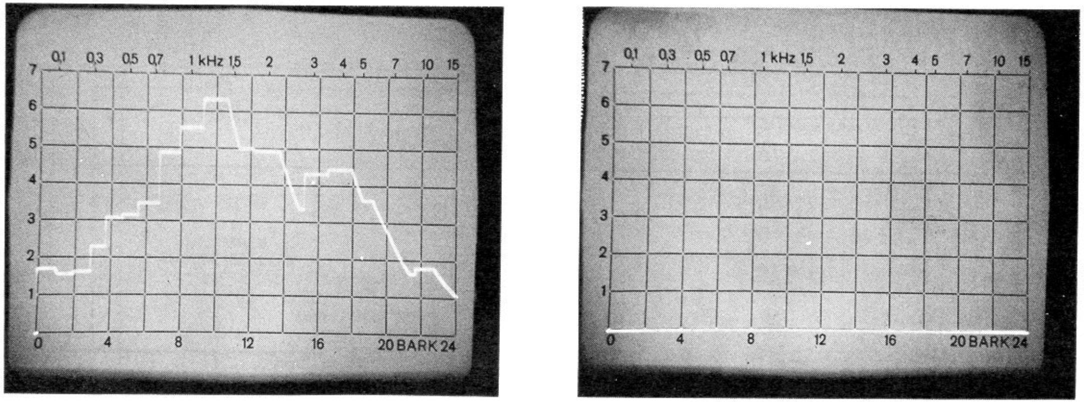


Figure 3 **Oscillograms on the Loudness Analyzer HP Model 8051A.**

a) An oscillogram showing the loudness spectrum of a single clapping sound ('loudness' = 108 sones).

b) An oscillogram of the noise of the 15108A when the input is shunted by 68 pF, the Loudness Analyzer being set on its most sensitive range.

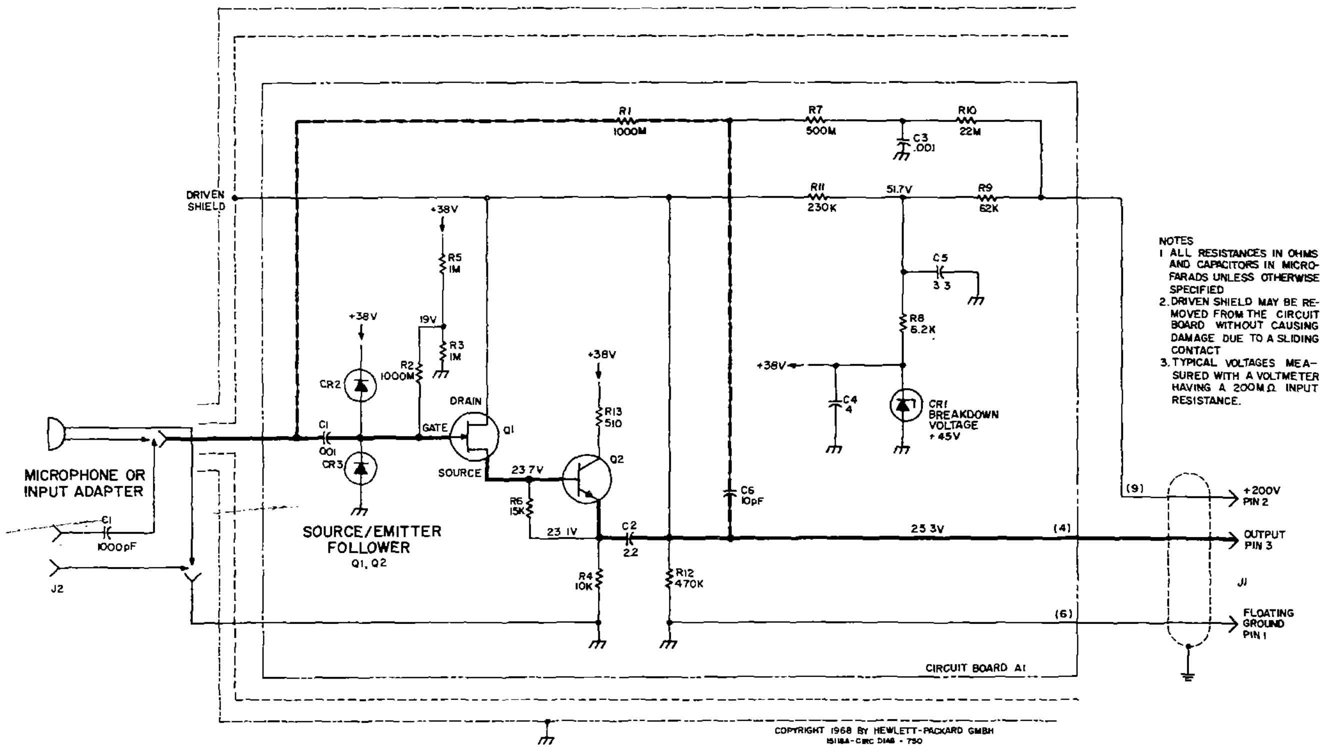


Figure 4 Schematic of the half-inch microphone preamplifier 15118A

Figure 5 Exploded views of the half-inch microphone preamplifier 15118A.

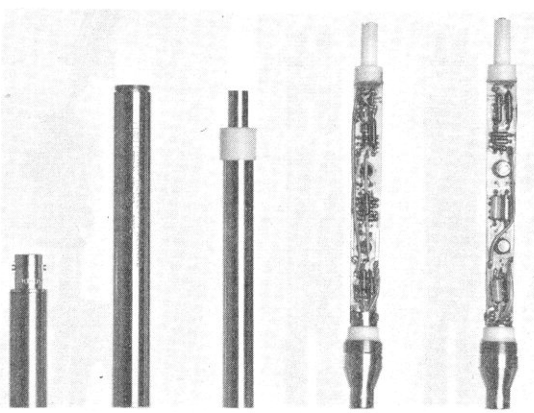
a) Input adapter which can be screwed on to the preamplifier for use as an impedance converter.

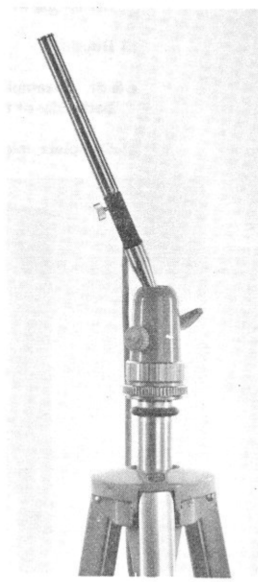
b) Housing

c) Driven shield

d & e) Preamplifier with the outer shell removed, showing both sides of the printed circuit boards.

f) Complete microphone assembly mounted on a tripod.





a b c d e f

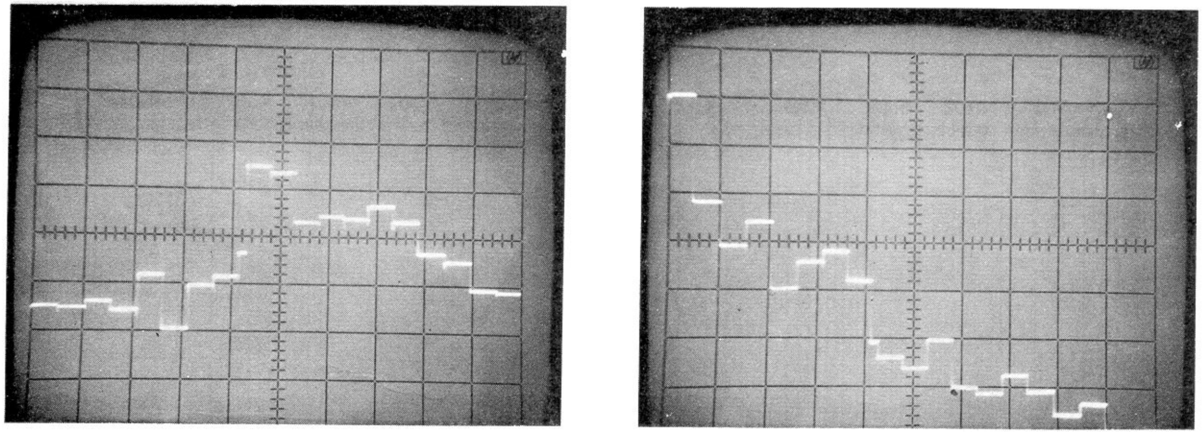


Figure 6 Noise of the half-inch microphone preamplifier 15118A as displayed on the Real-Time Audio Spectrum Analyzer HP Model 8054A.

a) Spectrum of a single clapping sound.

b) Noise of the 15118A when the input is shunted by 27 pF.

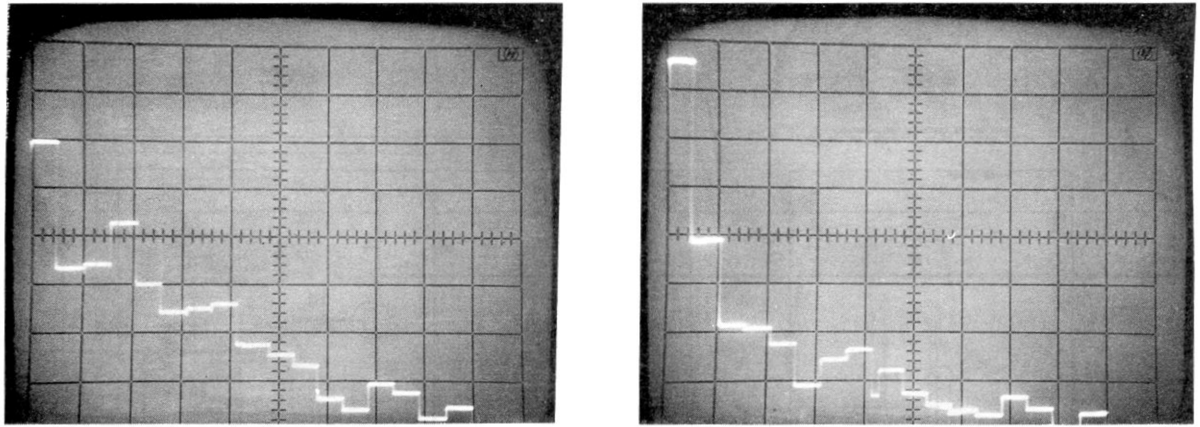


Figure 7 Noise of preamplifiers 15108A and 15108B displayed on the Real-Time Audio Spectrum Analyzer HP Model 8054A.

a) Noise of 15108A.

b) Noise of the preamplifier 15108B.

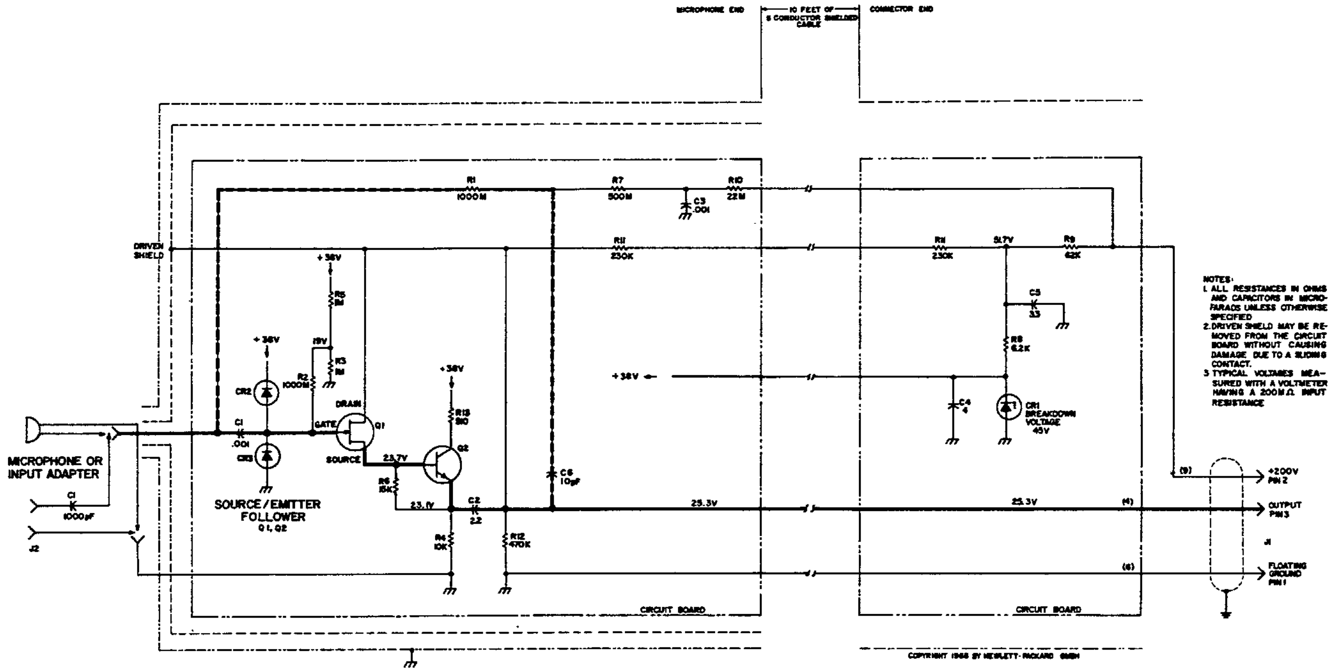


Figure 8 Schematic of a quater-inch microphone preamplifier

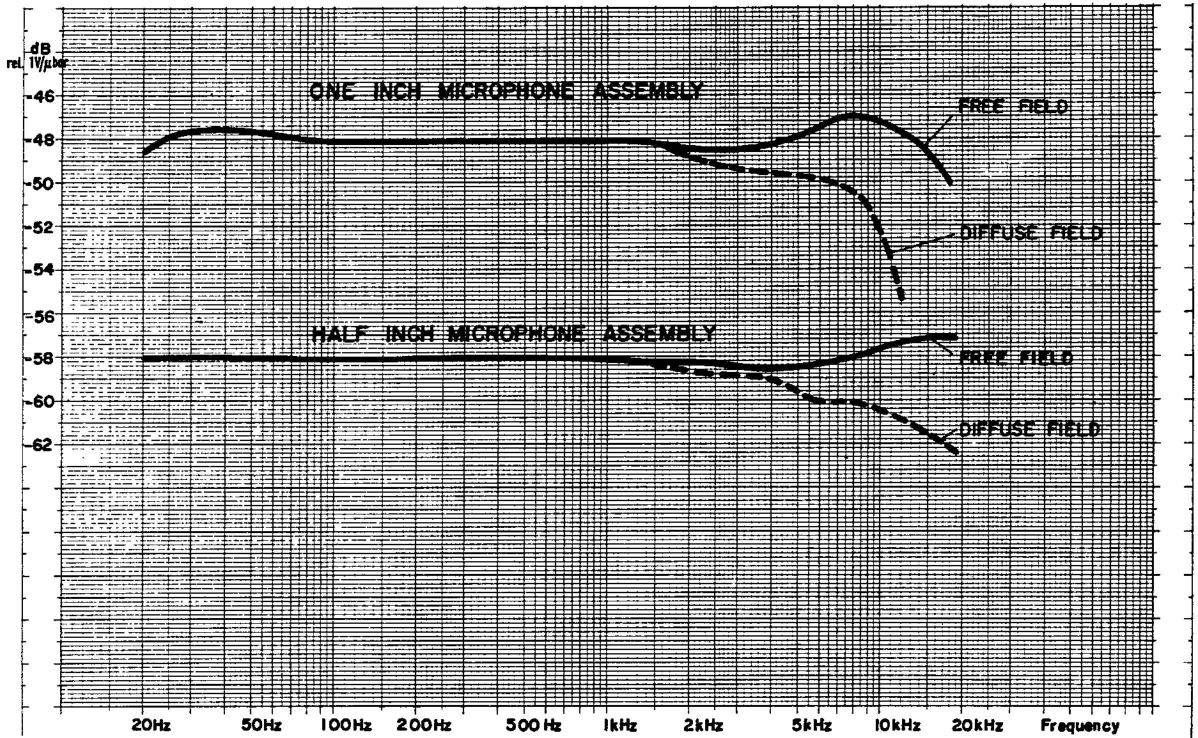


Figure 9 Typical frequency responses of the one-inch and half-inch microphone assemblies.

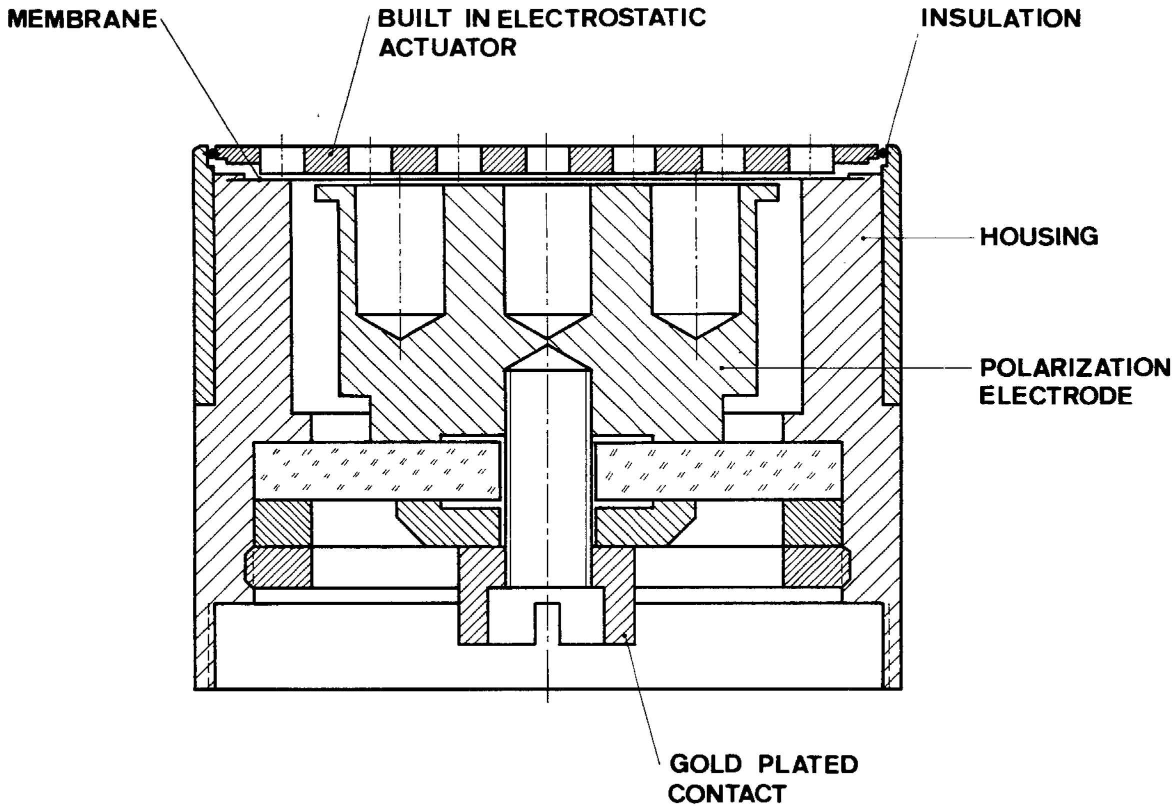


Figure 10 Schematic of the microphone cartridge showing the built-in electrostatic actuator

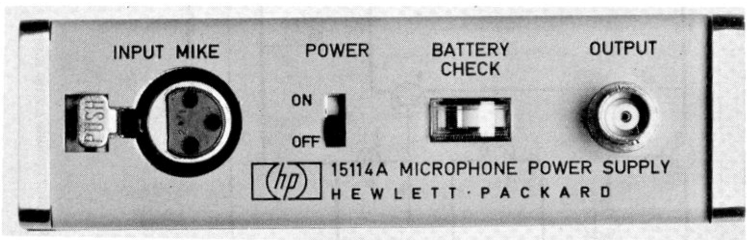


FIGURE 11 MICROPHONE POWER SUPPLY HP MODEL 15114A

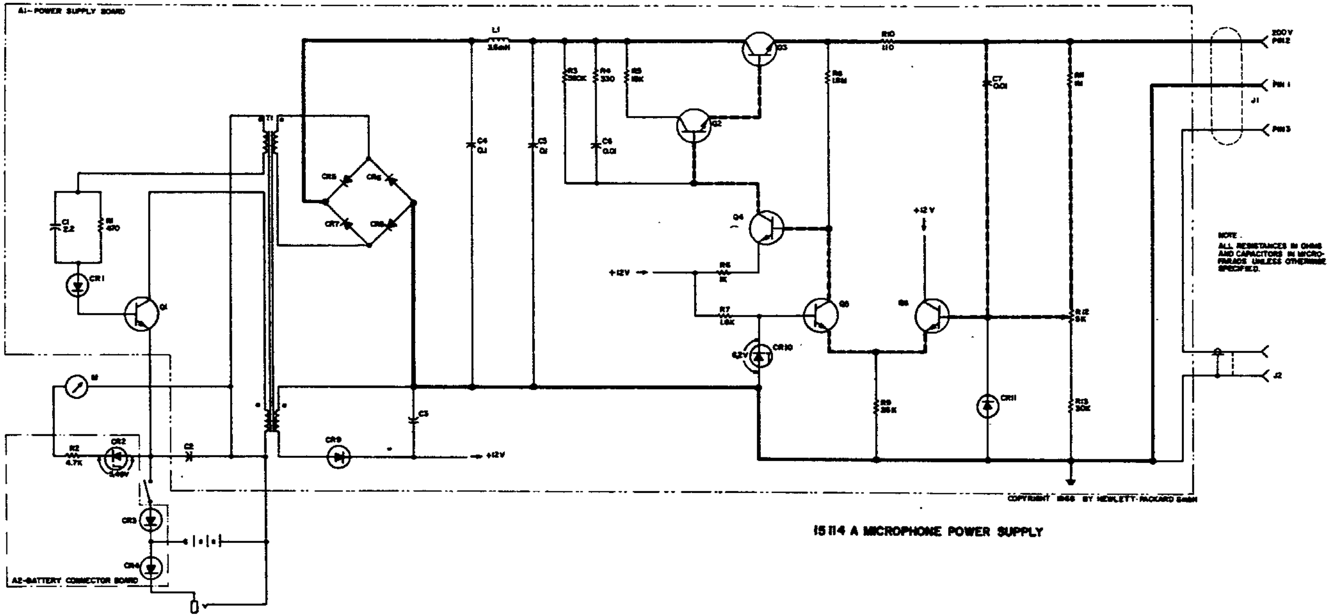


Figure 12 **Schematic of the microphone power supply**