14
Electret microphone

Electret microphones are the only application covered in this book which do not use high frequency excitation. A DC bias is used so the circuits are considerably simplified. The price paid for this simplicity is the poorer noise performance, as two mechanisms contribute: the increased low frequency noise of semiconductor junctions and the much higher electrode impedances, as a capacitor's impedance is a direct function of frequency. These drawbacks have been solved by manufacturers of electret microphones by integrating a high input impedance JFET amplifier with the microphone and using a high voltage DC bias on the order of 100–500 V for more sensitivity.

Electret microphones cost less than $1 and have good audio performance. They are available from a variety of sources such as Panasonic and Primo.

14.1 ELECTRET MICROPHONE CONSTRUCTION

An electret microphone is shown in Figure 14.1. The diaphragm may be metallized plastic 20 μm thick. Vents in the electret allow free diaphragm movement, and a small vent in the back of the case allows enough air movement to equalize pressure, but not enough to spoil the low frequency response. The electret is a plastic material, originally Carnauba wax, now often polytetraflouroethylene. The electret traps a charge when biased with a high DC voltage at high temperature and retains it when allowed to cool, with a charge retention time of 2–10 yr. The temperature coefficient of sensitivity is not as good as other microphone types due to electret dielectric constant change. The surface voltage can reach 2 kV, but is kept below Paschen's threshold to avoid air breakdown (see Section 13.2).

Typical electret microphone specifications

Directionality .... > 10 dB
Design load impedance .... 2 kΩ +/– 20%
S/N ratio .... > 40 dB at 1 kHz, 1 mbar, A weighted

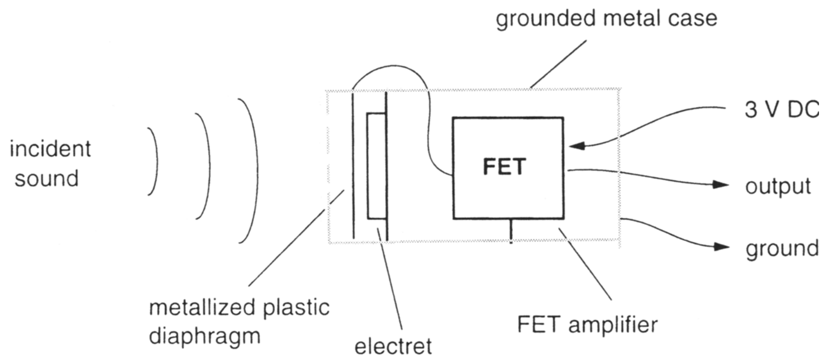

Figure 14.1 Electret microphone

Operating voltage	1.1–9 V
Circuit current	250 mA max
Signal	–67 dBV signal at 1 μbar
Noise	–110 dBV noise in audio range

Circuit description

The FET is typically an n-channel J-FET, such as type 2SK997 made by NEC (Figure 14.2). The microphone is specified with a 2 kΩ load resistor so the circuit will operate down to the 1.5 V provided by battery operation, but the gain increases with load resistance with no performance penalty and noise will decrease slightly. These microphones have a maximum quiescent current on the order of 250 μA, so the maximum resistor which can be used in a 10 V circuit is 10/250 μA or 40 kΩ.

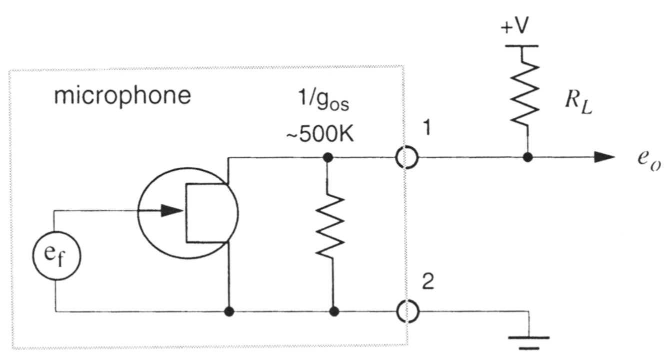

Figure 14.2 Equivalent circuit

The voltage e_f is the sum of a signal source, e_s, and an equivalent input noise component, e_n. The microphone diaphragm is approximately 0.5 cm in diameter. The signal voltage e_s is produced on the capacitance formed by the moving diaphragm and a fixed plate, by the relationships $V = Q/C$ and $C = \varepsilon_0\, \varepsilon_r A/s$, where Q is the charge produced by the electret and C is the capacitance, inversely proportional to spacing s so that

$$e_s = \frac{s}{s_{avg}} \cdot V \qquad 14.1$$

with s_{avg} the average spacing. The FET input capacitance is 5 pF, smaller than the 10 pF diaphragm capacitance.

The output noise of the 2SK997 JFET is 6 μV into a 2 kΩ load impedance with A weighting. This is about 42 nV/$\sqrt{\text{Hz}}$, compared to op amp noise of 4–40 nV/$\sqrt{\text{Hz}}$, so the FET noise will normally dominate the output SNR and a low noise type amplifier need not be used. The 2SK997 FET also lists these specifications:

Voltage gain into 2K .... –4.5 dB/+0.5 dB
V_{DS} .... 20 V
I_{DSS} .... 120–300 μA
g_{OS} .... 850 μmho typ

14.2 EQUIVALENT CIRCUIT

A block diagram of the equivalent circuit is given in Figure 14.3. A 10 kΩ resistor would have 1.27 μV rms noise at a 10 kHz bandwidth, and 12.7 nV/$\sqrt{\text{Hz}}$ noise. Actual resistors have an excess noise which is voltage-dependent and changes with construction, but the excess noise of carbon film resistors should be insignificant in this circuit. For more on resistor noise, see Section 10.4.

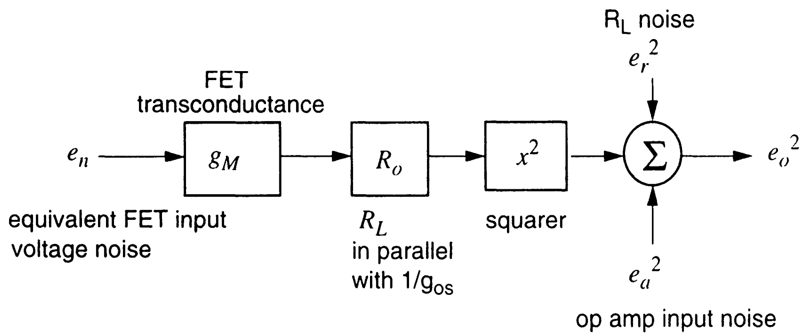

Figure 14.3 Block diagram

$$e_o^2 = \left(e_n g_M \frac{R_L}{R_L g_{os} + 1}\right)^2 + e_r^2 + e_a^2 \qquad 14.2$$

Resistor noise $e_r^2 = 4kTRB$

$4kT = 1.64 \times 10^{-20}$ at 25°C

B = bandwidth, in Hz

Note that the output signal voltage e_o increases linearly with R_L for $1/g_{os} >> R_L$, but the output noise voltage contribution of R_L increases as the square root of R_L, so each time R_L is quadrupled the noise contribution of R_L to the SNR is halved. SPICE models show a limit to this improvement due to two factors:

1. Running out of supply voltage, at $R_L > V_{supply}/250\ \mu A$, or 40 kΩ (10 V). If an active current source is used, this limit is extended
2. The shunting effect of the FET output conductance, about 25 kΩ

The microphone terminal characteristics at DC will be those of a JFET with zero bias. If V_{cc} = 6 V, the load line can be drawn (Figure 14.4).

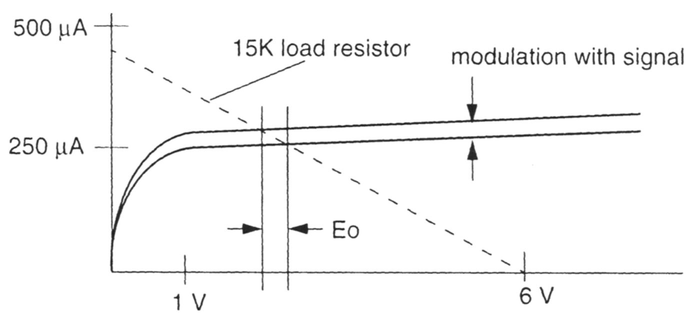

Figure 14.4 Electret microphone load line

At low voltages, the terminal characteristic is a variable resistance, and at high voltages, the characteristic is that of a modulated current source. At 10 kΩ load resistance, the supply voltage must be more than 2.5 V (R_L) + 1.5 V (FET) or 4 V so the load point stays in the linear modulated-current-source region of the FET.

14.2.1 Miller capacitance

Miller capacitance due to FET drain to gate capacitance *Cdg* plus stray capacitance contributes a response pole (Figure 14.5).

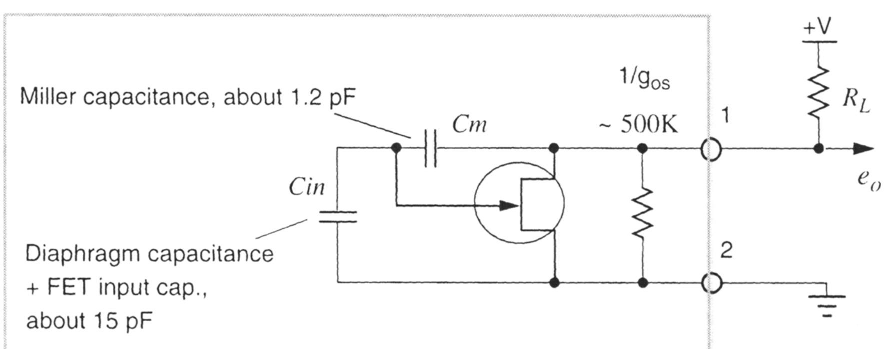

Figure 14.5 Electret microphone equivalent circuit

Since the gate circuit has a very long (seconds) time constant, limited only by small gate leakage currents, the effect of Miller capacitance is broadband instead of its normal high-frequency-only shape. It will reduce the *Rds* impedance as measured at the output by feeding a portion of the drain voltage change back to the FET gate, and the resultant negative feedback decreases *Rds* proportionately to C_m/C_{in}. This results in a reduction of *Rds* from 500 kΩ at DC to about 20 kΩ at audio frequencies. This lower value of *Rds* will shunt the load resistance and decrease the maximum available voltage gain from the FET. The *V-i* curve at the electret microphone output, measured for two devices at a frequency well below the Miller-capacitance induced response pole, is shown in Figure 14.6.

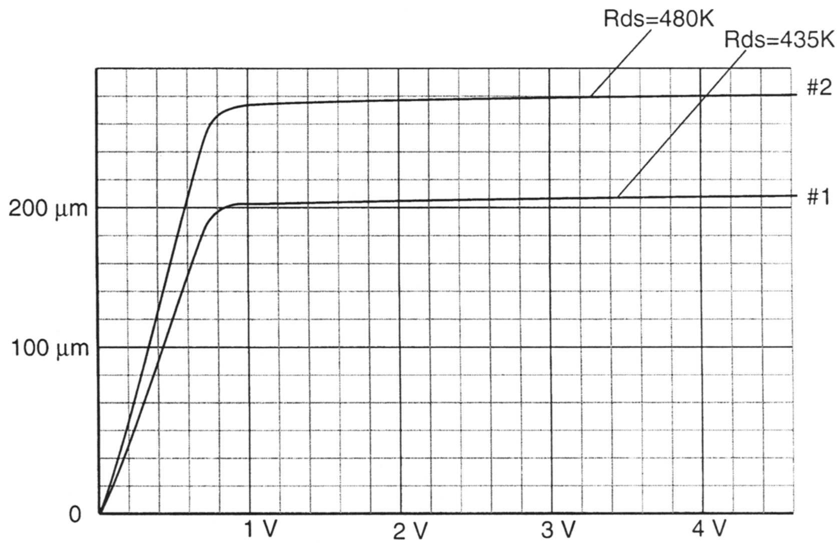

Figure 14.6 Measured electret microphone curves

Note the large increase of output resistance compared to the 25 kΩ high frequency value.