ece341_lab2

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Part I

Non-ideal op-amps in microphone amplifiers

This lab designs a microphone amplifier. It takes into account the major non-ideal DC characteristics of opamps.

1 Background

A condenser microphone operates on the principle of a variable capacitor ("condenser") where one plate is stationary and the other ("diaphram") is allowed to move towards or away from the fixed plate (d_z) in response to air pressure variations. Diaphram movement changes the capacitance of the structure. A constant *charge* is applied to this capacititor, usually by a DC voltage source through a $10\,\mathrm{M\Omega}$ to $\mathrm{G\Omega}$ resistor. Therefore the voltage across this capacitor varies in response to air pressure variations as:

$$C_m(t) = \frac{\epsilon_0 A}{(d_{\text{sep}} - k \cdot p_{\text{snd}}(t))}$$

$$Q_{\text{fixed}} = C_m(t) V_m(t)$$

or

$$V_m(t) = \frac{Q_{\text{fixed}}}{C_m(t)} = \frac{Q_{\text{fixed}}\left(d_{\text{sep}} - k \cdot p_{\text{snd}}(t)\right)}{\epsilon_0 A}$$

Since we are only interested in the variations in response to *changes* in air pressure, the audio-related portion of this voltage is:

$$V_{\text{mic}}(t) = -\frac{Q_{\text{fixed}} \cdot k}{\epsilon_0 A} \cdot p_{\text{snd}}(t) = -K_{\text{mic}} \cdot p_{\text{snd}}(t)$$

Electret condenser microphones (ECM) do not require a DC polarization voltage to maintian a constant charge. One of the plates is made of a dielectric material (plastic) with charges embedded in it. Such elements remain effectively permenantly charged.

The voltage changes $V_{\text{mic}}(t)$ resulting from sound pressure variations may be modelled as a Thevenin source with an output impedance consisting of the capacitance of the microphone capsule, shown in Figure 1.

Because this capacitance is quite small, on the order of pF, a very high load resistance is required to ensure the created high-pass filter's corner frequency reaches low enough for audio purposes. For example, a $1\,\mathrm{pF}$ capsule capacitance requires at least a $1.6\,\mathrm{G\Omega}$ load resistance to give a $-3\,\mathrm{dB}$ frequency of $100\,\mathrm{Hz}$.

Due to this loading constraint, most electret microphones include a JFET amplifier in the capsule to buffer the signal. Figure 2 shows the standard configuration of a common-source amplifier. Also shown in the figure is the use of an external resistor (typically $500\,\Omega$ to $5\,\mathrm{k\Omega}$) to provide drain current (around $0.5\,\mathrm{mA}$) for the transistor and an impedance across which to develop the small-signal output voltage (as $v_{out} = g_m R_{\mathrm{bias}} v_{\mathrm{mic}}$). Electret condenser microphone units increasingly integrate more circuitry into the capsule enclosure for enhanced performance. See Toward More-Compact Digital Microphones from an Analog Dialog article by Analog Devices for a good perspective on these changes.

The ECM's output has a superposition of DC voltage and AC signal due to this JFET biasing arrangement. The DC component may be several volts, while the signal is only a few millivolts in magnitude. A coupling capacitor is placed in series in many circuits to block the DC bias value and pass only the small microphone signal, as shown in Figure 2. Figure 3 shows the Thevenin-equivalent circuit of a biased electret microphone signal. The output resistance of the circuit is the parallel combination of the JFET's r_o and R_{bias}, and is approximately equal to R_{bias} alone because r_o is usually much larger. When finding the frequency response of a circuit using this structure, this Thevenin-equivalent output impedance must be taken into account.

2 Procedure

> Design an amplifier system using the `LM324-N` opamp which: * Increases a microphone's output signal by a factor of about 200 at $2\,\mathrm{kHz}$ * Has a high-pass $-3\,\mathrm{dB}$ frequency of $100\,\mathrm{Hz}$. * Has a DC offset magnitude less than $10\,\mathrm{mV}$ at its output.

As part of verifying your design, also come up with a procedure for measuring your circuit's performance on these 3 metrics.

For the purposes of measurement, replace the microphone and R_{bias} resistor with the *WaveGen* signal generator output in series with the R_{bias} resistor, leaving the coupling capacitor in place. Output offset is measured with the generator turned off. Gain is measured at an input frequency of $2\,\mathrm{kHz}$. The gain at $100\,\mathrm{Hz}$ must measure no less than $-3\,\mathrm{dB}$ from the $2\,\mathrm{kHz}$ gain.

It will be necessary to deal with both the amplifier's input offset voltage and input offset current as sources of offset. Compensating for the opamp's input bias current I_B will also be necessary. See Figures 4, 5, 6, and 7 for partial circuit ideas on how to both achieve this large gain in multiple stages and to compensate for opamp offset.

Replace the signal generator with the microphone as shown in Figure 4. Monitor the amplifier output on an oscilloscope on a time scale of about 5 ms/div and speak directly into the capsule to observe the time-domain waveforms of speech. Also, use the FFT feature and display the spectrum of your speech (span/center to $5\,\mathrm{kHz}$ / $2.5\,\mathrm{kHz}$, adjust the time scale to trade-off spectral resolution with update rate).

Review formulas for reference:

1-pole RC high-pass filter:

$$f_H = \frac{1}{2\pi RC}$$

Non-inverting opamp output including V_{OS} and I_{OS}:

$$V_{out} = v_{in} \underbrace{\left(1 + \frac{R2}{R1}\right)}_{\text{gain}} + \underbrace{\left(V_{OS} + I_{OS} R_X\right) \left(1 + \frac{R2}{R1}\right)}_{\text{offset}}$$

3 Report

Use the Lab Report Guidelines document to set the content and format for your report.

The **Procedure** section should include hand calculations using values of V_{OS}, I_B, and I_{OS} to justify the resistor and capacitor values used in your design.