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Audio Amplifier Lab

Introduction

In this lab, we will attempt to build a simple audio amplifier using a pair of npn transistors. We will learn about properly biasing microphones, use capacitors to block out DC voltages, learn how to properly bias transistors and use transformers to couple the amplifier's output to a low impedance speaker.

Overview and Procedure

Stage 1 - Microphone Biasing

Typical microphones used in phone headsets can be modeled as a variable resistor. The resistance of the microphone changes according to the loudness of the audio waves interacting with it. In order to convert this change in resistance to an electric signal, one can connect the microphone in series with another resistor which in turn is connected to a power source as shown in the schematic below.

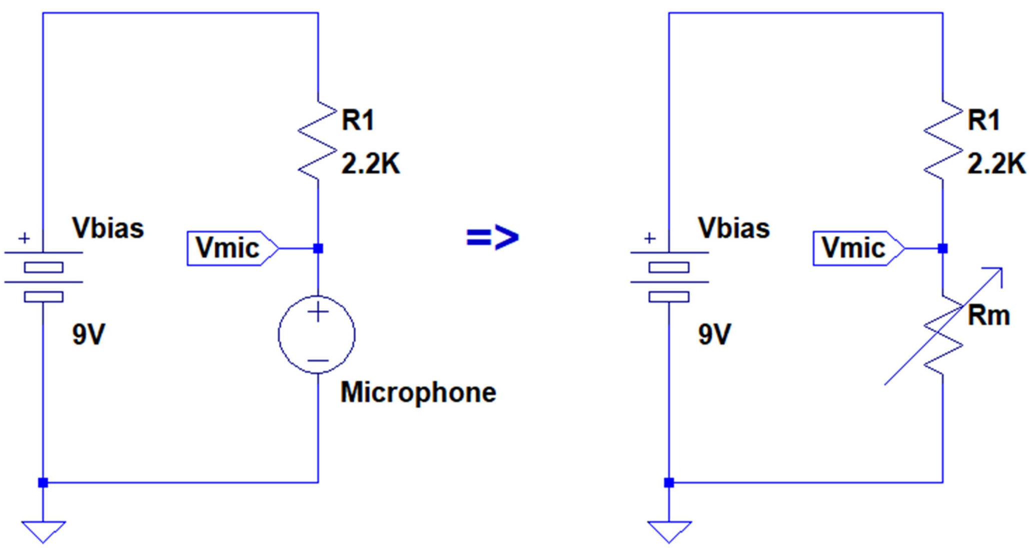

Figure 1 - Microphone Biasing

As seen above, the voltage source connected to the microphone is called the bias voltage, and the resistor connected to the microphone is called the bias resistor.

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Recall that the voltage at the top of the microphone (Labeled "V_{mic}") can be found using the "voltage divider" formula as shown below.

$$V_{mic} = V_{bias}\frac{R_m}{R_1 + R_m}$$

Therefore, as the resistance R_m changes in response to sound waves, V_{mic} changes accordingly.

Decoupling Capacitor

The signal produced by a microphone biased as shown above in Figure 1 will contain a DC bias. When the sound waves activate the microphone, the resulting signal fluctuates about the DC bias. We will use a capacitor to remove this DC bias before connecting the microphone stage to the next stage of our amplifier. Recall that capacitors act as an open circuit to DC currents; therefore, connecting a capacitor to the microphone output, as shown below, will stop the DC current while allowing the varying AC current (due to voice activities) to pass through.

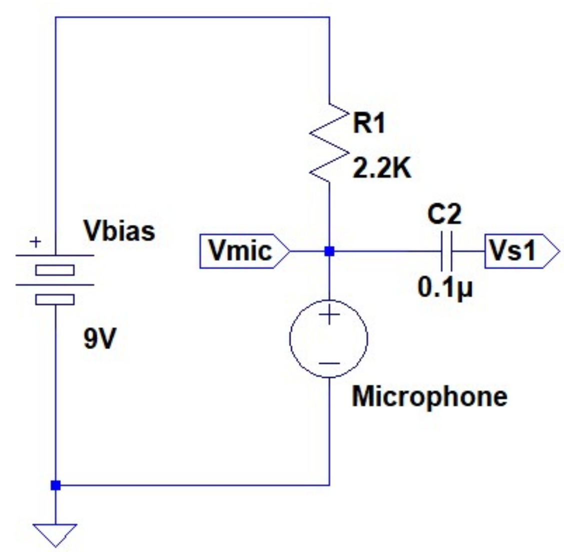

Figure 2 - Stage 1 with Decoupling Capacitor

Stage 1 Construction

Construct the circuit shown in Figure 2 above. Use a power supply set to 5V output as the power source. Using an oscilloscope, monitor the following voltages:

1. Probe the signal at "V_{mic}".
    a. How does it change in response to your voice?
    b. What is the value of DC bias? V_{mic} = ______________ V
    (Note: Measure the voltage at V_{mic} when there are no audio waves exciting the microphone.)

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2. Probe the signal at “V_{s1}”.
    a. How does the signal change in response to your voice?
    b. What is the value of DC bias at this point? V_{s1} = _____________ V

Stage 2 - Transistor Biasing

The second stage of our amplifier uses an NPN bipolar transistor for voltage amplification. However, before we set out to analyze the amplification process, we need to study the effect of the biasing circuit (shown in the dotted box below) on the first stage.

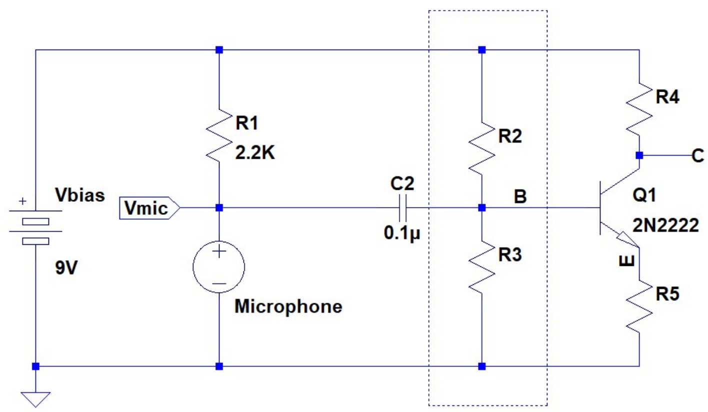

Figure 3 - Transistor Biasing

As previously discussed, the base-emitter pair forms a diode which requires proper biasing to turn on. Similar to other diodes, the bias voltage is normally in ~0.6-0.7V range. Therefore, in order for our transistor to operate correctly over the entire range of our input signal, we need to ensure that the VBE remains above 0.7 volts for the minimum input voltage, $min(Vmic)$.

The biasing requirement is illustrated in the diagram below where we have used a simple sinusoidal wave to represent the input voice signal.

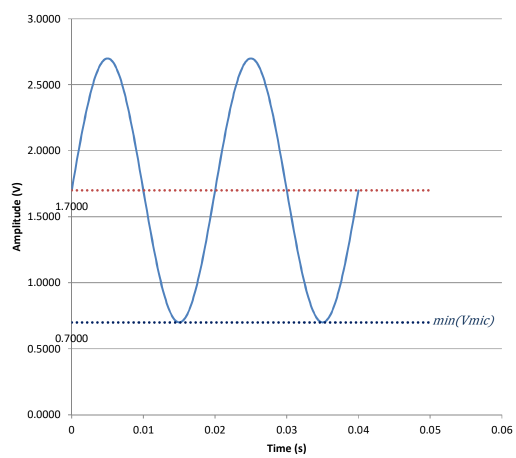

Figure 4 - Input Signal Biasing

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With the above biasing, we are making sure that the voltage at the emitter always stays above ground (0V).

Once the biasing resistors have been identified, we can analyze the effect of the biasing resistor network on the decoupling capacitor C2.

Stage 2 Construction

Determine suitable values for R2 and R3 to properly bias Q1's base. (Please show your work!)

R_2 = ________________ Ω

R_3 = ________________ Ω

Stage 2 "Small Signal" Analysis

In order to now analyze the effect of the biasing resistors on stage 1 of our amplifier, we need to learn about the concept of "Linear Time Invariant" (LTI) systems. Linear Time Invariant systems are a class of circuits whose responses to input signals do not vary over time. In other words, applying the same input signal to the circuit at different times produce the same output.

The Linear property of LTI circuits implies that the output of such a circuit to a sum of different input signals is the same as the sum of the outputs in response to each input applied individually. For example, if the input signal is comprised of a DC bias (offset) of 2V plus a sinusoidal signal such that the resulting input signal is given by

$v_i(t) = 2 + 1.5sin(120\pi t)$,

the output of an LTI circuit can be found by summing the output of the circuit in response to the two individual signals below.

$v_{i1}(t) = 2$

$v_{i2}(t) = 1.5sin(120\pi t)$

The linear property of circuits greatly simplifies the process of circuit analysis. In the case of our audio amplifier circuit, for example, we know the response of the decoupling capacitor to a DC bias is to block it; hence, the output is 0V. Therefore, we can concentrate on analyzing the response of the circuit to the sinusoidal input alone.

The analysis of a circuit to a sinusoidal input alone is sometimes called "small signal" analysis. When performing small signal analysis, we set all the DC biases, including DC input sources, to 0V and analyze the resulting circuit.

For stage 1 and 2 of our amplifier circuit, the small signal equivalent circuit is as shown below.

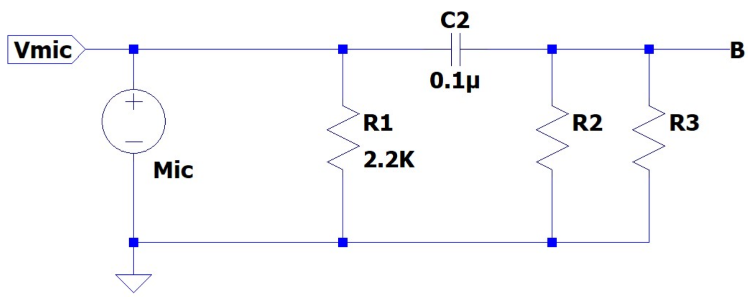

Figure 5 - Small Signal Equivalent Circuit

As seen in the circuit above, $R2$ and $R3$ are now in parallel, and the combination is in series with $C2$. In order to find the voltage at B, therefore, we can apply the voltage divider rule to the equivalent circuit below where the impedance of the capacitor $C2$ is given by $z_{C2} = \frac{1}{sC_2}$.

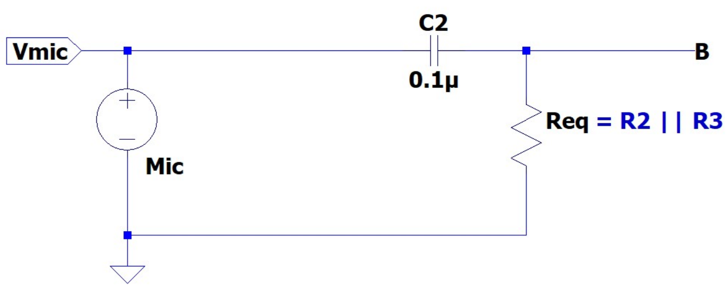

Figure 6 - Equivalent Small Signal Circuit

Therefore, the voltage at point B is given by

$$V_B = V_{mic}\frac{R_{eq}}{Z_{c2} + R_{eq}} = V_{mic}\frac{R_{eq}}{\frac{1}{sC_2} + R_{eq}}$$

Which after some simplification is

$$V_B = V_{mic}\frac{sC_2R_{eq}}{1 + sC_2R_{eq}}$$

Where $s = \delta + j\omega$.