EE 388 LAB 6
Low Frequency Response of an Amplifier

6.1 Prelab Calculations

The amplifier in Figure 6-1 is designed to have a collector current between 15 mA and 30 mA. For the 2N3904 transistor, $50 \leq \beta \leq 350$. Make the following calculations. For minimum and maximum calculations, use resistor tolerances, capacitor tolerances (+80%, -20% for electrolytic capacitors), and variations in $\beta$. For calculations, you may need to know that $I_{\text{C min}}, r_{\pi \text{ min}}, \beta_{\text{min}},$ and $g_{m_{\text{min}}}$ occur together and $I_{\text{C max}}, r_{\pi \text{ max}}, \beta_{\text{max}},$ and $g_{m_{\text{max}}}$ occur together.

1. Find an expression for the pole due to $C_S$ in Figure 6-2.
2. Find the minimum and maximum frequencies of the pole due to $C_S$ in Figure 6-2. Fill in Table 6-1.
3. Find an expression for the pole due to $C_E$ in Figure 6-3. Assume that $C_S$ is a short.
4. Find the minimum and maximum frequencies of the pole due to $C_E$ in Figure 6-3. Fill in Table 6-2.
5. Find an expression for the pole due to $C_L$ in Figure 6-5. Assume that $C_S$ is a short.
6. Find the minimum and maximum frequencies of the pole due to $C_L$ in Figure 6-5. Fill in Table 6-3.
7. Find the overall lower 3 dB frequency of the amplifier of Figure 6-6. Note that the pole due to $C_S$ in the circuit of Figure 6-6 is not at the same frequency as the pole due to $C_S$ in the circuit of Figure 6-2. In Figure 6-6 the pole due to $C_S$ is at:

$$\omega_{C_S} = \frac{1}{C_S(R_S + R\|R_2\|r_\pi)}$$

Find the maximum value of this new value of $\omega_{C_S}$. To find the maximum value of the overall lower 3 dB frequency, $\omega_L$, use the approximation

$$\omega_L = \omega_{C_S} + \omega_{C_E} + \omega_{C_L}$$

If you use the maximum values of $\omega_{C_S}, \omega_{C_E},$ and $\omega_{C_L}$, the measured overall 3 dB frequency will always be less than the calculated approximation. Since we are always concerned with the lower 3 dB frequency being less than a specified value, if the approximation is less than the specification then the actual value will be less. Since all we know is that $\omega_L (Actual) \leq \omega_L (Calculated)$, it only makes to calculate the maximum value of $\omega_L$. Calculate the maximum value of $\omega_L$ and enter the value in Table 6-4.

8. Use PSpice to obtain a Bode plot of $V_o/V_s$ for the amplifier in Figure 6-6.

6.2 Laboratory Procedure

6.2.1 Bias Measurements

Wire the circuit of Figure 6-1 without the capacitors. With $V_S$ set to zero measure the polarity of the voltages which will appear across the bias capacitors. Check to see if the voltage polarity across the capacitors is as indicated in Figure 6-1. Due to device tolerances your circuit may have different voltage polarities across the capacitors. If so, wire the capacitors according to your bias measurements.
6.2.2 Frequency Response Due to $C_S$

Wire the circuit shown in Figure 6-2. Wire $C_S$ so that it is consistent with the voltage polarity measured in the bias measurement. This amplifier will have a voltage gain of approximately 5. Fill in the results in Table 6-1. Use the measurement technique given below to measure the 3 dB frequency.

<table>
<thead>
<tr>
<th>Table 6-1: Measured data for the circuit of Figure 6-2.</th>
<th>(rad/sec)</th>
<th>Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega_{C_S}$ (max)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\omega_{C_S}$ (min)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\omega_{C_S}$ (measured)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Set the scope to external triggering. With a BNC cable, hook the “SYNC OUT” of the function generator to the “EXT IN” of the oscilloscope.
2. Set the function generator to a 1 kHz sine wave. This frequency is approximately mid-band for this amplifier.
3. Use the “LOW” output of the function generator as your signal source. Set the amplitude of the function generator so that $V_o$ is an undistorted sine wave. Usually 1 V peak-peak is a good amplitude.
4. Measure the mid-band gain $\frac{V_o}{V_s}$ at 1 kHz.
5. Find the lower 3 dB frequency of this amplifier. The 3 dB frequency occurs when the gain has been reduced to 0.707 of the mid-band gain. Assuming that the amplitude of $V_s$ remains constant, the 3 dB frequency occurs when the amplitude of $V_o$ has been reduced to 0.707 of its mid-band value. Since the lower 3 dB frequency of this amplifier is very low, the following procedure is recommended:
   - Set the scope to display $V_o$ only.
   - Let $V_s$ have a frequency of 1 kHz. Set the amplitude of $V_s$ so that $V_o$ is a 1 V peak-peak sine wave.
   - Select the gain of the scope so that $V_o$ fills as much of the display screen as possible.
   - Select digital memory on the scope.
   - Use the cursors to measure the peak-to-peak voltage of $V_o$.
   - This is shown on the display screen as $\Delta V$.
   - Multiply the your value of $\Delta V$ by 0.707 and then move the cursors to set $\Delta V$ to this value. When the peak-to-peak voltage of $V_o$ fits between the cursors you will be at the 3 dB frequency.
   - Slowly decrease the frequency and adjust the sweep rate of the scope appropriately.
   - When the $V_o$ sine wave fits between the cursor press the “LOCK” button on the oscilloscope. This will allow you to see the low frequency sine wave on the scope more accurately.
   - Move the cursors to measure the frequency of the sine wave. Compare the measured 3 dB frequency to the calculated 3 dB frequency.
   - Obtain a hard copy of the scope display.

Note that the lower 3 dB frequency will be around 10 Hz.

6.2.3 Frequency Response Due to $C_E$

Wire the circuit shown in Figure 6-3. $C_E$ is an emitter bypass capacitor and makes the gain $\frac{V_o}{V_s}$ large at midband. Note that $C_S$ has been changed to 1000 $\mu F$. This places the pole due to $C_S$ at a much lower frequency than the pole due to $C_E$, making the pole due to $C_E$ the dominant pole. Since the pole due to $C_S$ is at such a low frequency, $C_S$ can be considered a short at frequencies where $C_E$ will be affecting the gain of the amplifier.

Since the gain of this amplifier is so high you may not be able to make $V_s$ small enough to keep $V_o$ from saturating or clipping. To avoid saturating or clipping use the circuit of Figure 6-4. The gain of this amplifier is
still $\frac{V_o}{V_s}$. Since it is easier to measure larger signals, the gain $\frac{V_o}{V_{\text{sig}}}$ should be measured and multiplied by the voltage divider ratio to obtain the gain $\frac{V_o}{V_s}$:

$$
\frac{V_o}{V_s} = \frac{V_o}{V_{\text{sig}}} \left( \frac{100 + 1}{1} \right)
$$

Measure the lower 3 dB frequency using the same method as used in section 6.2.2. Fill in the result in Table 6-2.

| Table 6-2: Measured data for the circuit of Figure 6-3. |
|------------|------|
| $\omega_{C_e}$ (max) | (rad/sec) |
| $\omega_{C_L}$ (min) | (rad/sec) |
| $\omega_{C_L}$ (measured) | Hz |

### 6.2.4 Frequency Response Due to $C_L$

Wire the circuit shown in Figure 6-5. As in section 6.2.3, $C_L$ is large to make the pole due to $C_L$ the dominant pole. Measure the lower 3 dB frequency using the same method as used in section 6.2.2. Enter the result in Table 6-3.

| Table 6-3: Measured data for the circuit of Figure 6-5. |
|------------|------|
| $\omega_{C_L}$ (max) | (rad/sec) |
| $\omega_{C_L}$ (min) | (rad/sec) |
| $\omega_{C_L}$ (measured) | Hz |

### 6.2.5 Overall Frequency Response

Wire the circuit shown in Figure 6-6.

1. Measure the 3 dB frequency of $\frac{V_o}{V_s}$ and enter the result in Table 6-4.

2. Measure $\frac{V_o}{V_s}$ at several frequencies. Enter the measured data in Table 6-5 and then use MATLAB to generate a Bode plot of $\frac{V_o}{V_s}$.

3. Compare this Bode plot to the one obtained from PSpice. Since you are interested in the low frequency response of this amplifier, your Bode plot should include the mid-band gain and all poles of interest. In other words, your Bode plot should include frequencies from 1 Hz up to 100 kHz.

<p>| Table 6-4: Measured data for the circuit of Figure 6-6. |
|------------|------|
| $\omega_{3dB}$ (max — calculated) | (rad/sec) |
| $\omega_{3dB}$ (measured) | Hz |</p>
<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>$\omega \left( \frac{r}{s} \right)$</th>
<th>$v_s$</th>
<th>$v_o$</th>
<th>Gain $\left( \frac{v_o}{v_s} \right)$</th>
<th>Gain in Decibels $20 \log_{10} \left( \frac{v_o}{v_s} \right)$</th>
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</table>
Figure 6-1: Single stage amplifier.

Figure 6-2: Single stage amplifier for finding the pole due to $C_s$.

Figure 6-3: High gain amplifier.
Figure 6-4: Circuit for finding the pole due to $C_E$.

Figure 6-5: Circuit for finding the pole due to $C_L$.

Figure 6-6: Circuit to find the overall lower 3 dB Frequency.