Lab 5: Transistor amplifiers

5.0 Prelab

0. Determine the gain of the circuits in Figure 5.1 and Figure 5.3.

5.1 Components

Analog Discovery 2 module
Resistors: as needed
Capacitors: 1μF and 10μF
2N3904 NPN BJT

5.2 Task 1: Common emitter amplifier

1. Build the circuit in Figure 5.1. Use R_1 = 100kΩ, R_2 = 25kΩ, R_3 = 240Ω, and R_4 = 2kΩ. C_1 = 1μF and C_E = 10μF. Use the 2N3904 for the BJT. Connect the V+ and V- supplies from the AD2 as V_{CC} and V_{EE}. Connect the W1 output from the AD2 as v_i. Connect Channel 1 from the AD2 to measure v_i. Connect Channel 2 to measure v_o. The pinout for the BJT is shown in Figure 5.2.

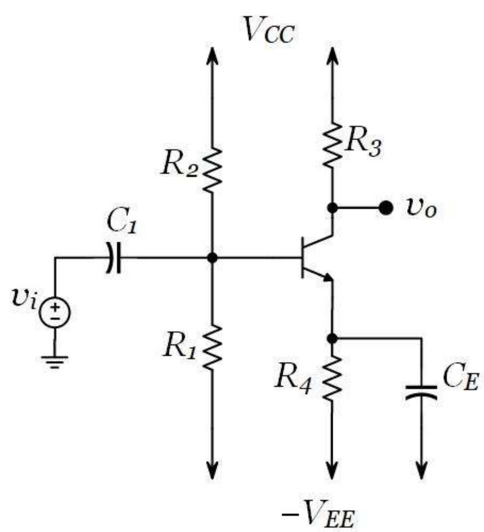

Figure 5.1. A common emitter amplifier.

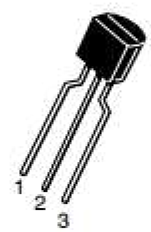

Figure 5.2. BJT pinout.

Warning: The 10 μF capacitor in your kit is an electrolytic capacitor. Electrolytic capacitors are polarized. They must be connected with the polarity shown. On your capacitor, the <u>negative</u> pole is identified with a grey band and a minus sign. This corresponds to the curved terminal in the circuit symbol. You should wear safety glasses when you use electrolytic capacitors.

2. Start Waveforms and open the supplies tab. Set V- to -5V and V+ to +5V.
3. Open the voltmeter tab. Enable the supplies and record the dc voltage at the collector (Channel 2).
4. Use the AD2 network analyzer to determine the amplifier response. If you have not used the network analyzer previously, see the Appendix at the end of these instructions.
5. Adjust the scale settings so that you can easily see the response graphs. Record the midband gain, the corner frequencies, and the phase in the midband and at the corner frequencies.

6. Stop the network analyzer and stop the supplies.
7. Open the wavegen tab and set W1 to be a sine wave with 5mV amplitude and 10kHz frequency.
8. Open the scope tab. Enable the supplies and wavegen and run the scope.
9. Adjust the time base and vertical scale so that you can see the waveforms. With a 5mV input you should expect the measured waveforms to be noisy. Automated measurements will give erroneous results. Your eyes are the best tool to judge the overall waveforms in this case. From the waveforms record the apparent peak-to-peak amplitude of input and output and their phase difference. Using these values, calculate the magnitude and phase of the gain.
10. On the wavegen tab, increase the amplitude to 20 mV.
11. Return to the scope tab and take a screenshot of the waveforms.

> A BJT amplifier circuit is linear if and only if (a) the BJT remains in the active mode over the entire range of input voltage; and (b) $|v_{be}| \le 5\text{ mV}$. In the circuit of Figure 5.1, $v_{be} = v_i$.
>
> A capacitively-coupled amplifier circuit behaves as a bandpass amplifier. The low corner frequency is determined by the capacitors in the circuit. The high corner frequency is determined by the BJT.

12. Stop the wavegen, supplies, and scope.

5.3 Task 2: Common emitter amplifier with emitter degeneracy

13. Modify your circuit to get the circuit in Figure 5.3. Use R_e = 50Ω.

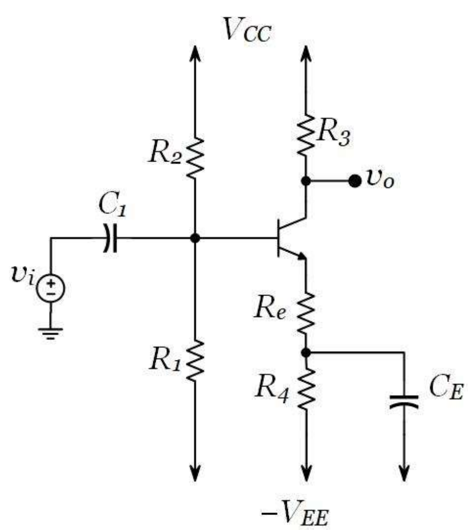

Figure 5.3. Common emitter amplifier with emitter degeneracy.

14. Use the AD2 network analyzer to determine the amplifier response.
15. Stop the supplies and close the network analyzer.
16. On the wavegen tab, set the amplitude of W1 to 20 mV (frequency still at 10kHz).
17. Go to the scope tab. Run the supplies, wavegen and scope. Record the peak-to-peak amplitude of the input and output waveforms and their phase difference. Using these values, determine the magnitude and phase of the gain.
18. Increase the amplitude of W1 to 30 mV and repeat the measurements of the last step.

19. Continue to increase the amplitude of W1 until you visually observe distortion in the output waveform. Record the amplitude of the input at which this occurs.

> The 50Ω resistor provides a feedback mechanism in the circuit. The effect of feedback is to increase the linearity of the circuit (it will remain linear for a greater range of input voltage) and the bandwidth of the circuit (the lower corner frequency decreases) in exchange for a reduction in gain.

5.4 (Optional) Task 3: The AD2 spectrum analyzer

20. The Waveforms software has a spectrum analyzer that can be used to determine the frequency content of a signal. This is the conventional method of quantifying distortion. Do this task if you would like to explore the spectrum analyzer. Do not include the measurements in your report.
21. On the wavegen tab, change the amplitude of W1 to 10 mV.
22. From the welcome tab, open the spectrum tab.
23. A spectrum analyzer determines the frequency components present in a signal. Your output should be similar to Figure 5.4. In the figure, C1 (yellow trace) is measuring the input waveform. It shows that there is a 10kHz component with magnitude approximately -40dBV, i.e. 10mV. There are no other frequency components above the noise floor of the measurement. The output also has a component at 10kHz with magnitude of -10dBV. The difference (30 dB) is the gain of the amplifier. (Note that these results were generated for a circuit with different component values – your quantitative results should be different.) Again, there are no other frequency components above the

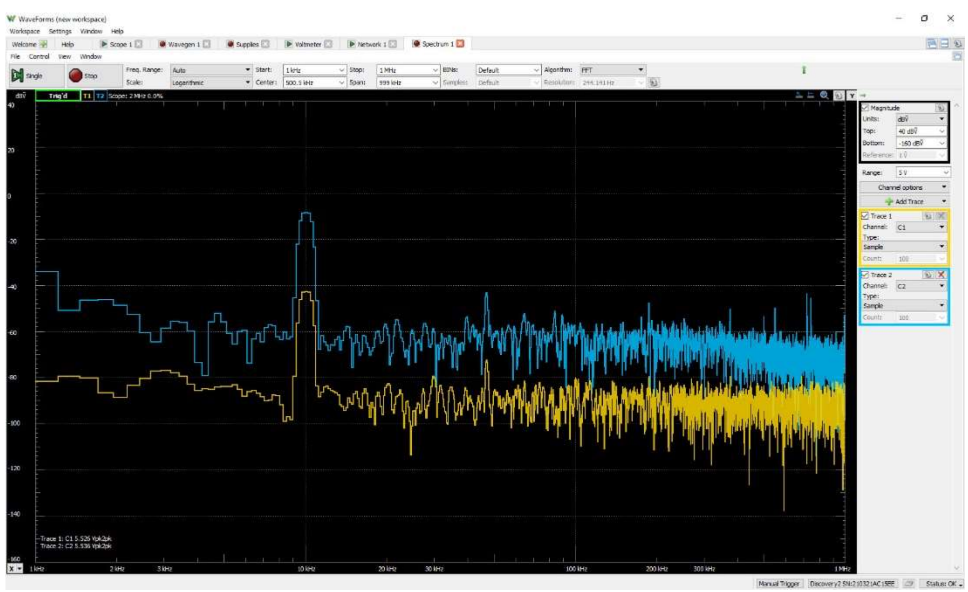

Figure 5.4. Spectrum of input and output waveforms.

noise floor of the measurement. This means that the two signals are identical in shape and only differ in magnitude.

24. On the wavegen tab, change the amplitude of W1 to 30 mV. Return to the spectrum tab and record the frequency components present in input and output and their magnitudes.
25. On the wavegen tab, change the amplitude of W1 to 50 mV. Return to the spectrum tab and record the frequency components present in input and output and their magnitudes.
26. Stop the supplies. Stop and close all other tabs.

27. In the above results, the presence of significant frequency components other than 10kHz indicates distortion in the signal. None of your changes should cause a change in the spectrum of Ch2 but not of Ch1. The magnitude of output frequency components not present in the input is a quantitative measure of distortion. You will study more on distortion in future courses.

5.5 Appendix: Using the AD2 network analyzer

28. Waveforms has a network analyzer function that can be used to generate the Bode plots for a given circuit. The network analyzer function is accessed by opening the Network tab. This will open the window for the network analyzer of the AD2. You should see a screen similar to that shown in Figure 5.5.

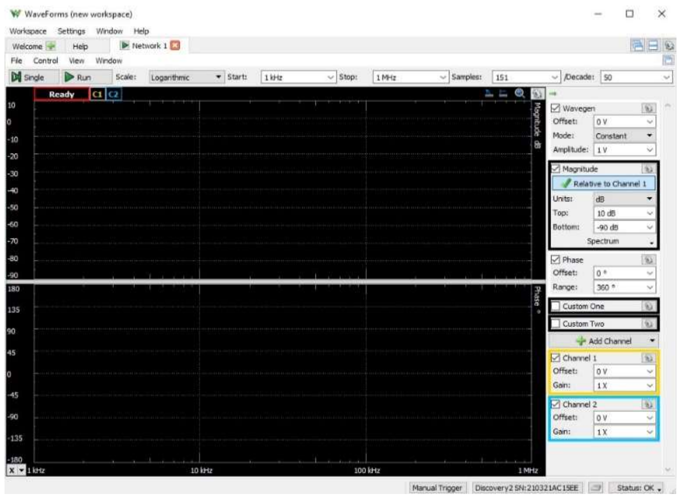

Figure 5.5. The Network Analyzer in the AD2.

29. Adjust the settings across the top of the screen as follows, Scale: Logarithmic; Start: 10 Hz; Stop: 5 MHz; Samples: 2.001k. (The last setting, "/Decade:" will be adjusted automatically.)
30. On the righthand side, there should be five boxes already selected as shown in Figure 5.5: Wavegen, Magnitude, Phase, Channel 1, and Channel 2. Check that these are the boxes selected then adjust the remaining settings as follows:
    a. Wavegen – Offset: 0V; Mode: constant; Amplitude: 10mV
    b. Magnitude – "Relative to Channel 1" checked; Units: dB; Top: 10dB; Bottom: -50dB
    c. Offset: -45°; Range: 180°

Logarithmic scale is needed for Bode plots. Start and Stop determine the range of the frequency sweep. Samples is the number of measurements per frequency decade. More samples result in a slower scan but a smoother output.

31. At the top of the screen select Single. The network analyzer will now plot the magnitude and phase responses of the circuit. The measurement will be slow because we have selected a large number of samples.
32. In the resulting magnitude plot, there will be a plot for Ch1. This will show you the actual amplitude of Ch1 in dB (normalized to the 20 mVpp that we defined). Ideally, this should be a flat line at 0 dB. However, with capacitive circuits the AD2 cannot always produce the desired value of output from the wave generator. The plot for Ch2 is normalized relative to Ch1 so it is actually the plot of the gain in dB. The phase response is the phase of the gain. For an inverting amplifier, it should be 180° in the midband.