# EE 351 Laboratory Exercise 6
## Frequency Response
Oct. 31, 2008, rev. Aug. 2, 2015

The purpose of this laboratory exercise is to study frequency response effects in a transistor amplifier. The cascaded effect of coupling capacitors and shunt capacitances affects both the low frequency and high frequency response of the amplifier.

It is best to use the Sync output from the signal generator connected to the External Trigger input on the oscilloscope for the most stable trigger.

**1.0     Pre lab**

1.1     Do a hand analysis of the circuit in Figure 1 to determine the bias conditions, input resistance, output resistance, and AC gain. Hint: most of this is in the example in frequency_response_notes.pdf. However, you will have to compute the net gain yourself – it will be roughly twenty percent lower than the Avl shown.

1.2     Using the results of 1.1, determine the individual low cutoff frequencies due to the input coupling capacitor, emitter bypass capacitor, and output coupling capacitor. Use the approximation method discussed in class to determine the composite low cut-off frequency.

1.3     Using the results of 1.1, determine the individual high cutoff frequencies due to the feedback capacitance and the output shunt capacitance. Use the approximation method discussed in class to determine the composite high cut-off frequency.

1.4     Do a SPICE simulation of the circuit in Figure 1 to confirm your calculations for bias conditions. Do not include the 39 and 10 ohm voltage divider (those are just a lab aid) – just connect the 1K resistor straight to the SPICE generator. Do a frequency response from 10 Hz to 100 kHz with 20 (or more) points per decade (i.e. 80 (or more) points total). Determine the composite low cut-off and composite high cut-off frequencies from the response data. By definition the cutoff frequencies are where the gain has dropped to 0.707 times the midband gain. You will have to interpolate between data points to determine the actual frequency.

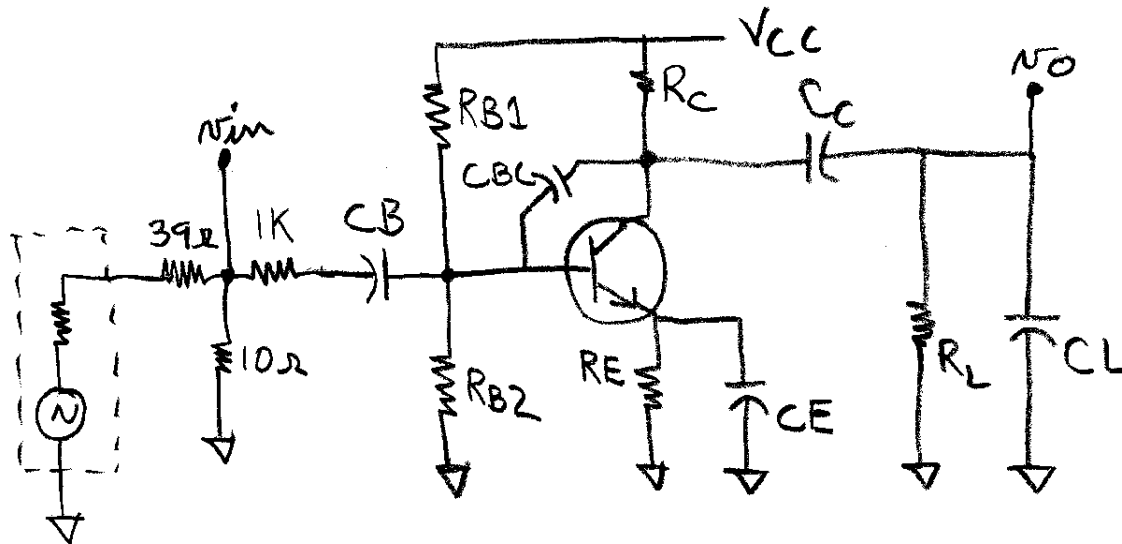# EE 351 Laboratory Exercise 6
## Frequency Response



*Figure 1: Amplifier with frequency response effects*

$V_{CC}$ = 12V, $R_S$ = 1K, $R_B1$ = 150K, $R_B2$ = 22K, $R_E$ = 1.5K, $R_C$ = 10K, $R_L$ = 10K,
$C_B$ = 1 uF, $C_E$ = 100 uF, $C_C$ = 0.1 uF, $C_{BC}$ = 22 pF, $C_L$ = 470 pF,
Not shown are: $C_{BE}$ = 25 pF (assumed internal to transistor), Cin_stray = 25 pF, and Co stray = 20 pF – these are assumed wiring capacitances.

## 2.0    Circuit measurements

2.1    Build the circuit in Figure 1.  If the exact capacitor values as shown in the circuit are not available then use combinations of what is available to achieve something close (say within +-25%) and then adjust your calculations for frequency response in 1.2 – 1.4 to use the same capacitance values you actually used.

2.2    Confirm that the bias conditions, $V_B$ and $V_C$, are in reasonable agreement with your hand calculations and SPICE simulation.  Fix any problems before proceeding.  There is no point taking data on an amplifier that is not working.

2.3    Confirm that the net AC gain at 2 kHz is in reasonable agreement with your hand calculations and SPICE simulation.  If not then correct whatever is wrong.  Try a quick test run over the frequency range in 2.5 to see that the circuit generally behaves as you expect – a flat mid-band gain from several hundred Hz to several kHz and dropping significantly towards the upper and lower frequency extremes.  If this looks good then continue.  If not then correct whatever is wrong.

2.4    Set the sine wave output from the signal generator as measured at vin with an oscilloscope at 20 mVpp for the following measurements.  The voltage divider is included to make it easier to set this value and to insure that the source impedance on the generator side of the 1K resistor is very small.  Once this is set then do not adjust the output amplitude of the generator.  You do not have to check this again

at any frequency unless you suspect a problem because it will not change over the course of the experiment. If you find it different then someone changed the generator output level.

2.5.1   Use the oscilloscope to measure the peak to peak signal amplitudes. You may have to change vertical amplitude scales at various portions of the experiment to keep the signal from being too large to show on screen but larger than one major division on the vertical scale. For measuring the peak-peak values, use either your eye to make on-screen measurements or use the oscilloscope's cursors and measure the sine wave amplitude ignoring any other extraneous noise. The scope's automatic measurement feature measures everything and can provide wrong results if other signals are present – trust your eyes and use common sense.

2.5.2   Measure the amplitude across the load resistor and compute the net gain (i.e. output signal divided by 20 mVpp) at the following frequencies: 20, 30, 40, 50, 60, 80, 100, 120, 150, 200, 300, 500, 800, 1000, 1500, 2000, 3000, 5000, 8000, 10,000, 12,000, 15,000, 20,000, 25,000, 30,000, 40,000, 50,000, 60,000, 80,000, and 100,000 Hz.

2.6   Plot the data measured in 2.5 on a log-log plot with frequency on the horizontal axis and net gain on the vertical axis. A log-log axis set is appropriate because the numerical values will have a very wide range. Excel is good for this.

2.7   From the plot, interpolate the low cut-off frequency and high cut-off frequency where the response has dropped to 0.707 times the level at around 3 kHz.

2.8   Compare the measured cut-off frequencies with your calculated data and SPICE simulation.

**3.0   Square wave testing**

3.1   Change the generator waveform selection to square wave and keep the output set at 20 mVpp as measured at vin – use this amplitude for all parts below. Set the frequency to 2 kHz. Square wave testing applies a whole spectrum of signals and can be used to show frequency response effects by noting the distortion in the output square wave – which may not even resemble a square wave.

3.2   Observe the output signal across the load resistor. Note that the top and bottom portions are the square wave are tilted instead of flat. This is due to the finite low cut-off frequency. The tilt becomes greater as the frequency is lowered. Make the measurements as described in the note, square_wave_testing.pdf and compute the low cutoff frequency. Compare this with the measured low cut-off frequency.

3.3   Measure the rise time of the square wave at the load resistor as described in the note, square_wave_testing.pdf. This is the time to traverse from 10% to 90% of

the peak-peak amplitude.  Be sure to set the scope so that the rise time occupies most of the horizontal part of the screen so you have good time resolution.  Use this value to compute the high cutoff frequency. Compare this result with the measured high cut-off frequency.  This is an approximation.

3.4     Set the frequency of the square wave signal generator to 20 Hz and observe the waveform across the load resistor.  You should see only a positive and negative pulse – almost like the derivative of a square wave.  This shows that the lower frequency components of the square wave are attenuated as they are below the cutoff frequency of the AC coupling.

3.5     Set the frequency of the square wave signal generator to 50 kHz and observe the waveform across the load resistor.  The waveform should be close to a sine wave since harmonics of the signal are above the high cutoff frequency of the amplifier and harmonics are highly reduced relative to the fundamental.