

Testbenches for Amplifier Characterization

EE 435 Lab 5

Spring 2024

When designing amplifiers and other circuits it is important to be able to accurately characterize its behavior. As we have seen in previous labs this is typically done through the use of testbenches. While the concept of compensation is finished up in lecture, we will look at a few different testbench examples commonly used to test amplifier performance. It is important to note that there is no single test bench that can test every possible device characteristic. The testbenches outlined in this lab are a good start and can be modified or expanded upon to suit the needs of a given application.

For the purposes of this lab, we will be utilizing the basic 5 transistor amplifier previously designed for lab 2. Assume VDD is 2.5V and VSS is -2.5V.

PART 1: The common-mode input range, or input voltage swing, describes the range of input voltages such that the amplifier remains in the linear operating region. This region is always defined in relation to the power supply voltages. When this range is exceeded, the output will become non-linear and therefore not perform as desired. To obtain accurate test results for the input-common mode range there are a few methods. The most basic test is to simply sweep the input voltage across the supply range while in a unity gain configuration as shown below in figure 1.

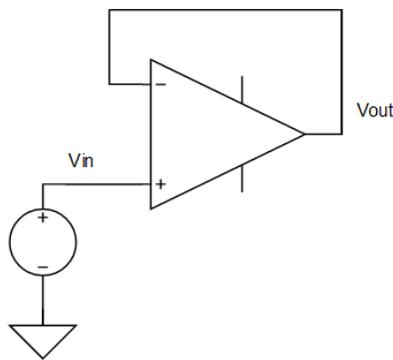


Figure 1: Amplifier in Unity Gain Configuration

Configure your simulation for a DC analysis and sweep the voltage V_{in} from -2.6V to 2.6V. Plot the output voltage and observe where the output voltage begins to curve. The start of these points represents the minimum and maximum input voltage you can have before the output voltage becomes non-linear. You may notice that it can be difficult to see where exactly the graph begins to curve. To combat this, use the calculator tool to plot the derivative of your

output voltage. This will plot the slope of the output allowing you to more clearly see where linearity decreases.

The above test was run at a nominal setting. When testing amplifiers it is important to test performance characteristics under different situations such as temperature or supply variations. Repeat the signal swing test at temperatures of -45°C and 80°C and $\pm 10\%$ of nominal supply values.

PART 2: The counterpart to the input common-mode range is the output swing. Similarly, the output voltage swing is defined as the range of output voltages such that the amplifier remains in the linear operating region. Conceptually, we should be able to test this in the same way as the input voltage swing. However, the effects of the limited input voltage range will overshadow that of the output swing. To combat this, we can configure a test bench in an inverting gain configuration as shown by figure 2 below.

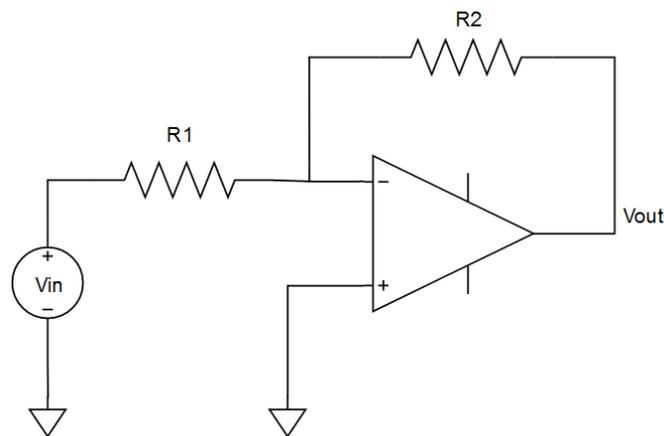


Figure 2: Inverting Gain Amplifier Configuration

Set the amplifier to have an inverting gain of -10 V/V . Use resistors on the order of megaohms to decrease the effects of loading on the amplifier. Once again, configure your simulation for a DC analysis only this time sweep your input voltage from -260mV to 260mV . By using a gain amplifier we can supply a small input voltage to remain in the input-common mode range. Observe the plot of V_{out} and its derivative to find the point where the amplifier is no longer linear. This is the output voltage swing range of your amplifier.

As with the input range, repeat the tests at temperatures -45°C and 80°C and $\pm 10\%$ of nominal supply values.

PART 3: Operational Amplifiers are inherently frequency dependent devices. It is important to be able to characterize frequency dependent parameters such as the gain bandwidth product, 3dB frequency, and also the gain itself. This is typically done by doing a frequency sweep in an AC analysis. For open loop, we can configure a testbench as shown below in figure 3.

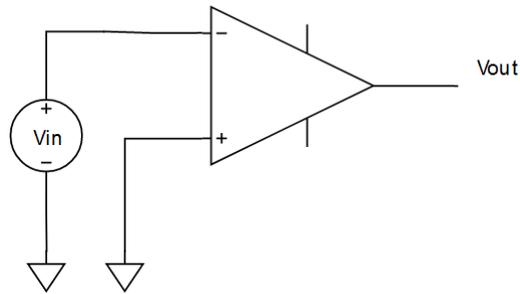


Figure 3: Open Loop AC Analysis Configuration

Here V_{in} should have a DC voltage of 0V and an AC magnitude of 1V. If using “Vsource” then check the box to enable small signal parameters and input the AC magnitude, there. Next, configure your simulation for an AC analysis with a frequency sweep from 10 Hz to 1 GHz. Change the step size to logarithmic with 10 points per decade. This value can be increased if you require more resolution on your output.

After running the simulation there are several ways to obtain an output. The first and easiest is to simply plot V_{out} over V_{in} . This will provide you with the magnitude response of the amplifier. Use the “db20” function in the calculator to plot this in decibels. Alternatively, at the top of the Maestro page select Results → Direct Plot → Main Form to be presented with the window in figure 4. From there you can select to plot the Voltage or Current Magnitude or Phase. Click on the output net, then hit add to outputs to have the plot generated after each run.

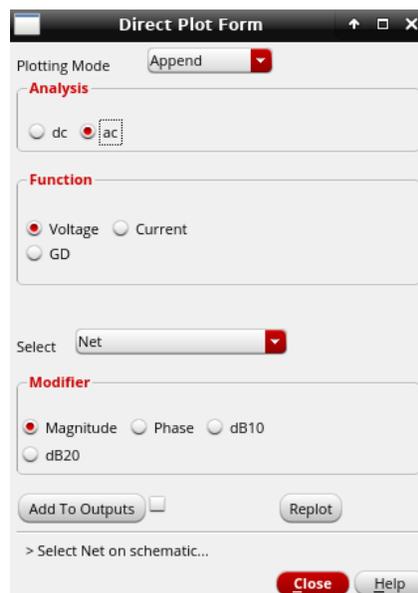


Figure 4: Direct Plot Form AC Analysis

Using the magnitude and phase plots from the AC analysis will allow you to obtain the low frequency gain, 3dB bandwidth, and gain bandwidth product. Using the phase plot, you can

obtain information such as the gain and phase margins which will be discussed later in the course.

Repeat the AC analysis with temperatures $-45\text{ }^{\circ}\text{C}$ and $80\text{ }^{\circ}\text{C}$ and $\pm 10\%$ of nominal supply values.

PART 4: In addition to the DC and AC analysis, it is important to characterize the transient performance of amplifiers as well. Some of these performance metrics include slew rate, overshoot/undershoot, settling time, and more generally the step response. In general, transient simulations can be done using a unity gain setup as shown in figure 1. Apply a step input from 0 to 100mV with a period of 25 μs . Set the rise and fall times to be small, $<1\text{ps}$. Next, configure your simulation to a transient analysis with a runtime of 100 μs . Plot your output voltage to observe the waveform.

Now, from the waveform window select measurements then transient measurements. This will open the measurements window shown in figure 5 below. From this window you will need to select settings then set the baseline values to 0 and 100mV to indicate what the min and max values of your step waveform are. The threshold can be set to 10% - 90%, then close the settings window. Once setup, the measurements window will show you the overshoot/undershoot, rise time, and slew rate for each edge.

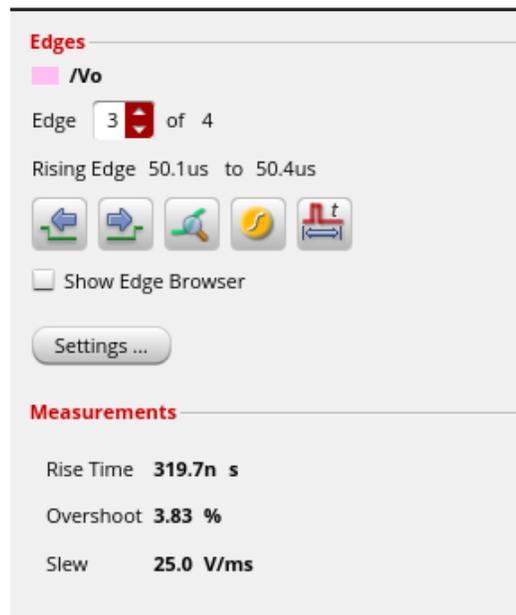


Figure 5: Transient Measurement Window

To measure the settling time, you will need to zoom in to the peak of the rising edge. From there measure the time it takes for your output to settle to an acceptable level.

Once again, you should repeat the transient measurements at temperature $-45\text{ }^{\circ}\text{C}$ and $80\text{ }^{\circ}\text{C}$ and $\pm 10\%$ of nominal supply values.

PART 5: For the final part of this lab, we will look at plotting the poles and zeros of the amplifier. The poles and zeros of an amplifier play a major role in defining the behavior so being able to observe these can be an incredible tool to use. We will start by observing the open loop poles of our amplifier. To begin, configure your testbench as shown in figure 3 with V_{in} set to DC voltage of 0V and assume a load capacitance of 10pF. Next, configure your simulation for a “pz” simulation. Select your V_{out} node for the positive output node and leave the negative output node blank. Select V_{in} as the voltage input source. You may leave the rest as default and hit okay. Run the simulation, then select Results → Main Form → Direct plot. From there you can plot the poles and zeros of the amplifier.

Note that the most basic operational amplifier is often modeled as a single pole amplifier. You should notice more than one pole in this plot as well as additional zeros. Consider what aspects of a non-ideal amplifier might cause this. Can any of these poles and zeros be neglected?

Repeat the pole zero analysis for an amplifier in unity gain configuration as shown in figure 1.