ROSE-HULMAN INSTITUTE OF TECHNOLOGY
*Department of Electrical and Computer Engineering*

EC 300 Signals and Systems — Fall 2009

# SYSTEM LINEARITY

**Lab 3**

**Mario F. Simoni, Robert Throne, and Bruce Ferguson**

## Prelab: No Prelab

## Objectives

The purpose of this lab is to gain a better understanding of what LINEARITY means in reference to a real system. You will be using a transistor amplifier circuit and measuring the input and output signals as you vary the amplitude of your input signal. You will then compare the results of your experiment to the "expected" outputs by plotting your results in Matlab.

## 1. Linearity of an amplifier

The common source amplifier, as shown in Figure 1 below, has been fabricated on a printed circuit board for you. The corresponding node names have also been printed on the PCB.

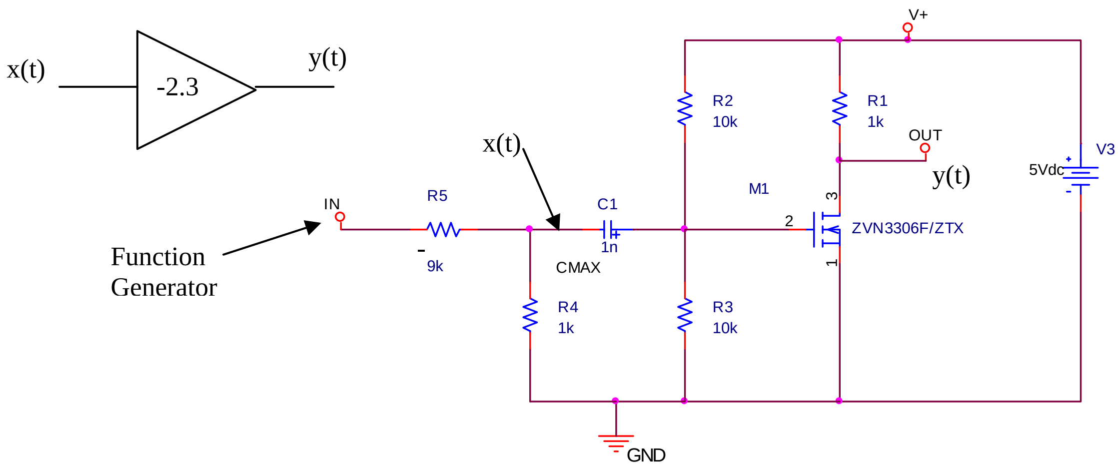



*Figure 1: Circuit Diagram of the common-source amplifier. The ideal block diagram representation for this amplifier is shown as the triangle in the upper left.*

Ideally, this amplifier should have a gain of -2.3 regardless of the input signal's amplitude. In other words, in an ideal amplifier, if the input were to go to 100 V then the output should go to -230 V. We know that this is not possible because our power supply only goes to 5 V. Saturation at the energy rails is a problem with any physical device because we cannot physically represent infinity. With transistor amplifiers the problem is even worse, because as the input gets larger, the nonlinearities of the transistors begin to affect the signal. When the input signal to the amplifier is "small", we can approximate the transistor as a linear system with its small-signal model that is composed of linear elements. As long as the input signal stays small, the amplifier behaves like a linear system. However, when the input to the amplifier is "large", the nonlinearities of the amplifier can be observed, and we have to use the nonlinear large-signal model (exponential for BJT, square-law for FETs) of the transistor to understand the operation of the amplifier. "Large" and "small" are fuzzy terms and, as system designers, we would like to have a more quantitative definition for these values. With respect to the amplitude of the input signal, the amplifier's nonlinearities decrease the gain, called gain compression, and distort the shape of the output signal, called harmonic distortion. One way to quantitatively define "small" versus "large" signal is to measure the magnitude of the input voltage at which the gain has decreased by 1dB, called the 1dB-compression point. Another is to define an acceptable level of distortion and the amplitude threshold at which this distortion level occurs. You won't understand how to measure the distortion in the signal until the end of this quarter. This lab will focus on measuring the gain compression point while simply observing the distortion that occurs in the output due to the nonlinearities of the amplifier. The goal of the first part of this lab is to:

1. Estimate the 1-dB compression point for the amplifier
2. Record the output of the amplifier on the oscilloscope for both a "large" and "small" signal input to observe the distortion.

a) Connect the power supply, function generator, and oscilloscope to the amplifier as shown in the figure above. Of special note when testing the amplifier:

1. Make sure you connect your power supply with the right polarities and that it doesn't exceed 5 V.

2. The voltage divider connected to the function generator reduces the amplitude of the function generator by a factor of approximately 10. When doing your experiments, make sure you measure the input to the amplifier on the negative node of the capacitor (as indicated by the x(t) signal in the schematic above) not the output of the function generator.

3. Set the coupling of the oscilloscope to AC and the probe gains to 10:1 for each channel. Do not use autoscale because it will change your coupling back to DC.

4. Set the trigger to use the output signal as its source. Use the Mode/Coupling button on the trigger to set HF Reject and Noise Reject for the trigger. THIS IS VERY IMPORTANT, YOU WILL NOT BE ABLE TO TAKE MEASUREMENTS OTHERWISE!!!

5. Turn on averaging (with at least 8 samples) in the oscilloscope to reduce the noise of the function generator.

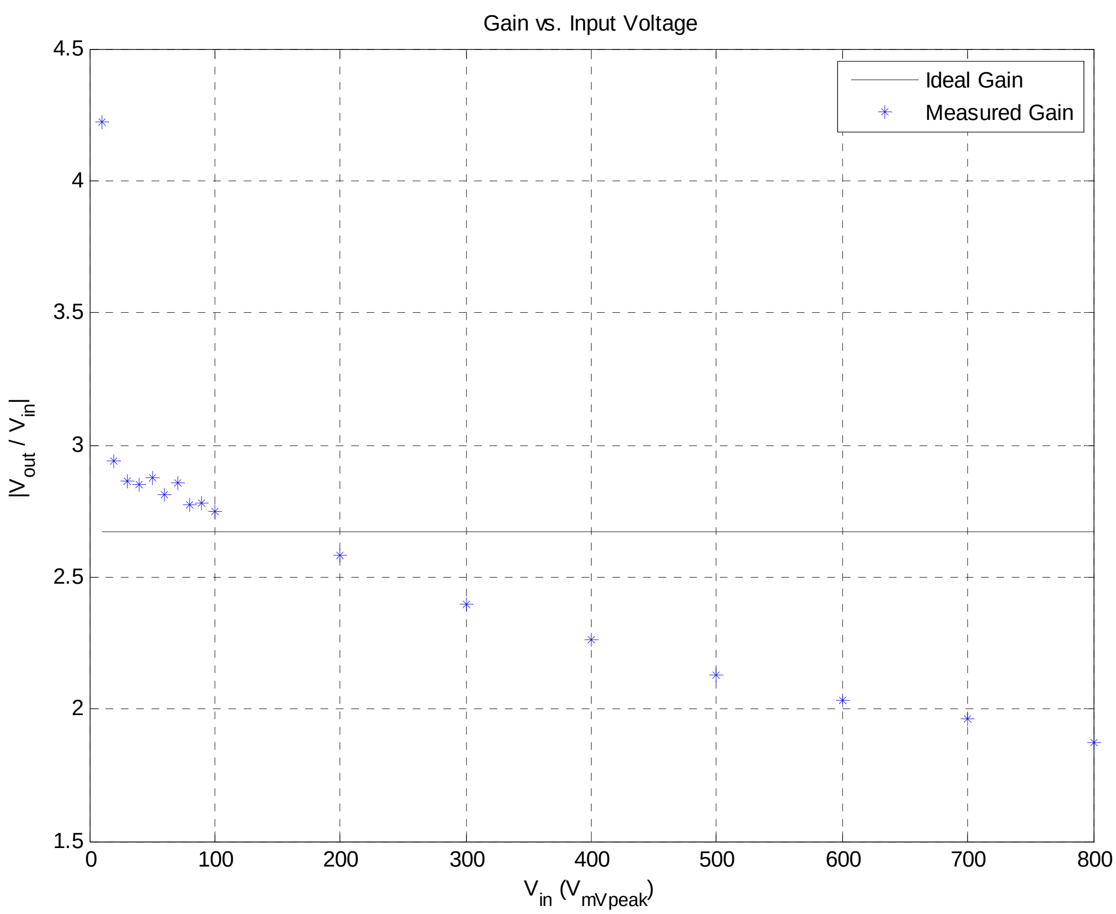
6. Set both channels to have their "gnd" level at the exact center of the scope screen.

7. You can use the quick-measure feature of the scope to measure the pk-pk amplitude of the INPUT, x(t), and divide by 2 to get the peak value. **For the OUTPUT, y(t), use the y-cursors to measure ONLY the positive peak amplitude of the signal.**

Instructor Verification (see last page)

b) Set the function generator to be a sinusoid with frequency of 1 kHz. Start with the peak amplitude of **x(t)**=10 mV as measured on the scope. Measure the positive peak voltage of both **x(t)** and **y(t)** as you sweep the amplitude of **x(t)** as shown on the data recording table at the end of this handout. NOTE: The the peak amplitude of **x(t)** is different from the function generator because of the voltage divider. You will need to sweep the function generator's amplitude from **approximately** 100mV to 10V, use the scope measurement to ensure the proper amplitude of x(t). Record your data in the table at the end of this handout and then enter the vectors into a Matlab m-file.

c) In the same m-file, plot the gain of the amplifier (|vout/vin|) for each input voltage amplitude. Your plot should look like the following figure. Include in your plot a line that indicates the ideal gain of your amplifier. The ideal gain can be found by averaging the measured gain for the first few "small-signal" data points. Using the "debugging" data points at the end of this lab, you should get the following plot:




d) You can get a rough estimate of the gain compression point by looking at your plot. This point is defined as the input voltage at which the gain begins to decrease rapidly. You should indicate your gain compression point in your plot. Use the menu commands in the figure window to insert an ellipse.

e) In the same m-file, use the *polyfit* command in Matlab to fit a line to only the data **below** the gain compression point using x(t) as your x-coordinates and y(t) as your y-coordinates for the *polyfit* command.

f) Use the *figure* command to start a new figure. In this new figure window, plot the measured output voltage versus the measured input voltages and the line that you generated from the previous step. You should get a figure that looks like the one below. This figure shows how your data compares to a purely linear amplifier. If done correctly, your data should deviate from the ideal line at the gain compression point. This figure is how the gain compression is typically displayed. Add axes labels and title to this figure and print it out to turn in. Using the "debugging" data points at the end of this lab, you should get the following plot:

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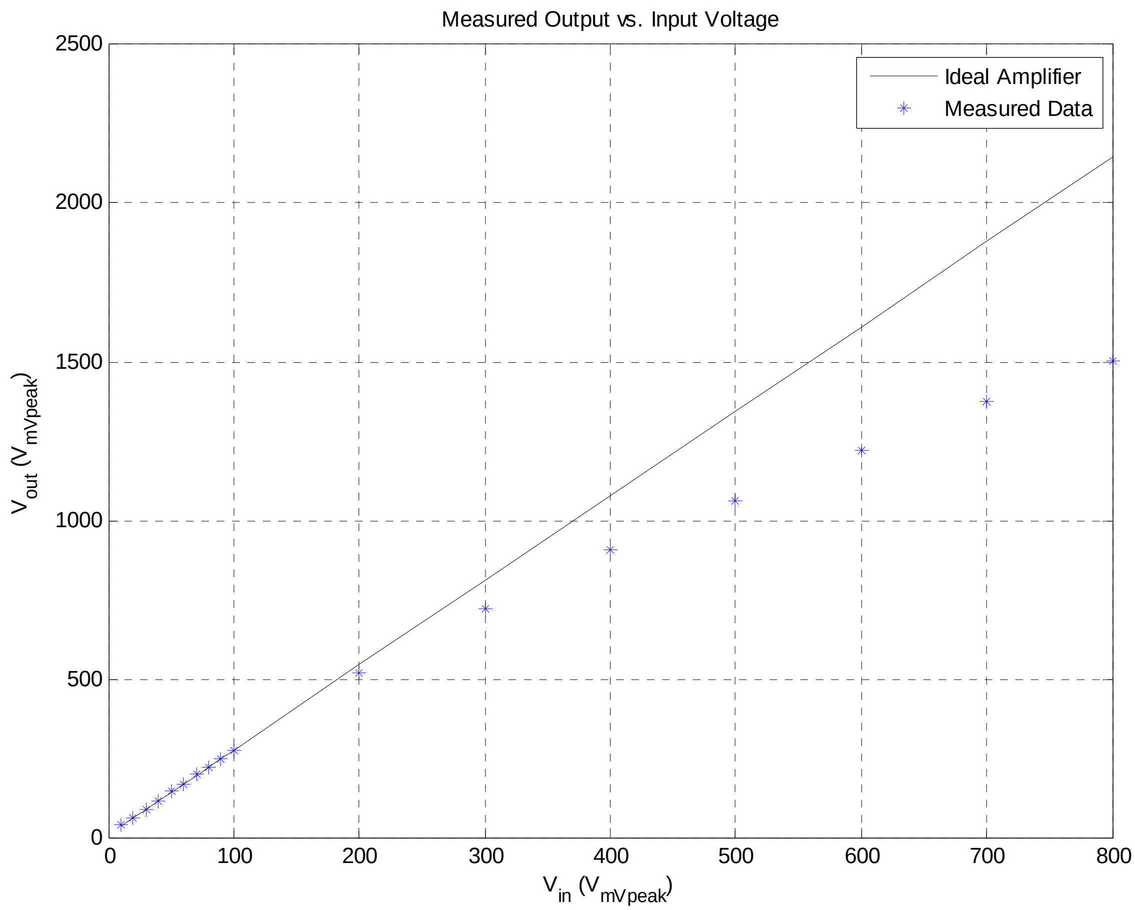


g) Now that you've found the gain compression point, you can quantitatively define "small" and "large" signal. Record a screen capture from the oscilloscope showing the output traces for the input and output voltages for both a "small-signal" value of x(t) and a "large-signal" value of x(t). Print out these screen captures to hand in with your lab. Indicate on the printouts where the nonlinearities of the amplifier cause distortion.

i) Also hand in your table with the recorded data files and the final m-file that includes your code for data analysis

Instructor Verification (see last page)

## Report

For this lab, turn in all of your Matlab code and plots in addition to this verification sheet.

Lab 03 System Linearity
Instructor Verification Sheet

Name _______________________________________ Date of Lab: ________________

Part 1(a) Demonstrate that your circuit works appropriately.

Verified: _______________________________________ Date/Time: ________________

Part 1(f) Present your plots.

Verified: _______________________________________ Date/Time: ________________

Part 1(g) Present your plots.

Verified: _______________________________________ Date/Time: ________________

| x(t) (mVp) | Debugging y(t) (mVp) | Your Measured y(t) (mVp) |
|---|---|---|
| 10 | 42.2 | |
| 20 | 58.8 | |
| 30 | 85.9 | |
| 40 | 114.1 | |
| 50 | 143.8 | |
| 60 | 168.8 | |
| 70 | 200 | |
| 80 | 221.9 | |
| 90 | 250 | |
| 100 | 275 | |
| 200 | 516 | |
| 300 | 719 | |
| 400 | 906 | |
| 500 | 1063 | |
| 600 | 1219 | |
| 700 | 1375 | |
| 800 | 1500 | |
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