

SYSTEM LINEARITY

Lab 3

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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.

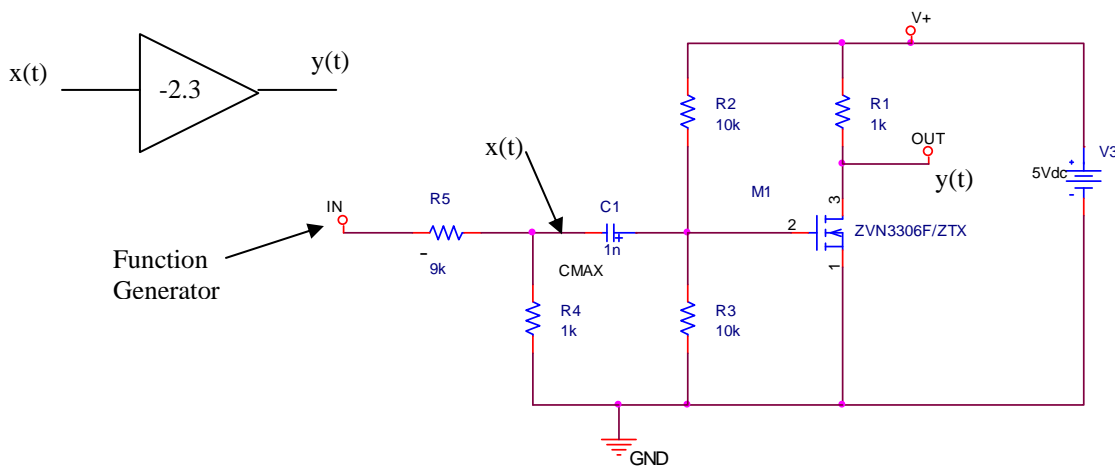


Figure 1: Circuit Diagram of the common-source amplifier. The ideal block diagram representation for this amplifier is shown as the triangle in the upper left.

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. Measure 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 $\mathbf{x}(t)$ 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 $\mathbf{x}(t)$. 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 ($|v_{out}|^2/|v_{in}|^2$) in dB vs. the Power of the input signal into a 1 Ohm resistor in dB for each input voltage amplitude. Your plot should look like the Figure 1 below. 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 (i.e. those data that lie to the left of the 1-dB compression point).

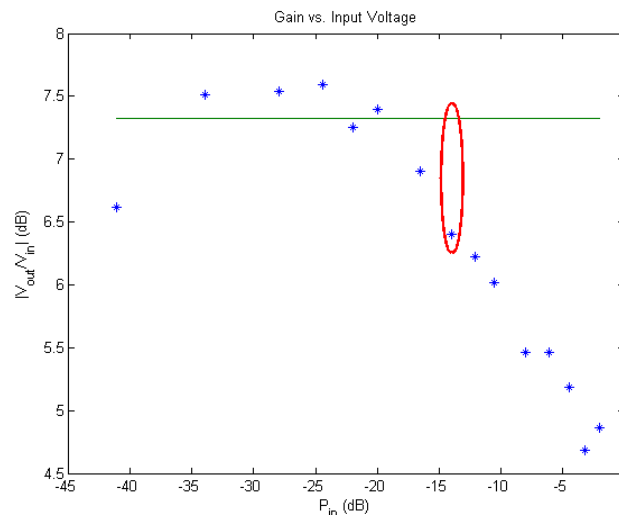


Figure 1: Plot of Voltage Gain (dB) vs. Input Signal Power (dB)

d) You can get a rough estimate of the gain compression point by looking at your plot. This point is defined as the input power at which the gain is reduced by 1dB. You should indicate your gain compression point in your plot similar to the red ellipse shown above. Shapes can be added to your plot using the menu options in the figure window.

e) In the same m-file, use the *figure()* command to assign figure(1) to the plot above and figure(2) for a new plot. The new plot will look like Figure 2 below and will plot the output signal power vs. the input signal power, both in dB relative to a 1 Ohm resistor.

f) To create the new plot you will:

- First use the *polyfit* command in Matlab to fit a line to only the data **that are to the left of** the 1-dB compression point (as these are considered the "small-signal" inputs so that the amplifier is behaving linearly). This line will become the green line shown in Figure 2 below. For the *polyfit* command, use $|v_{in}|$ (in units of Volts) as your x-coordinates and $|v_{out}|$ (in units of Volts) as your y-coordinates. *Polyfit* returns the coefficients of a 1st order polynomial (i.e. a line).

- You must then use the coefficients from *polyfit* to **create a matrix of data points that represents your best fit line**. This is how the amplifier would behave if it was linear for all amplitudes of the input.
- Note that the line that you just created has units of Volts. You must convert the x- and y- coordinates of this line to units of dB so that it can be displayed with the input and output signal power data that you collected.
- In your *figure(2)* window, plot the measured input and output signal powers relative to 1 Ohm in dB 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 fall 1dB below the ideal line at the compression point. This figure illustrates how the gain compression is typically displayed. Add axes labels and title to this figure and print it out to turn in.

Instructor Verification (see last page)

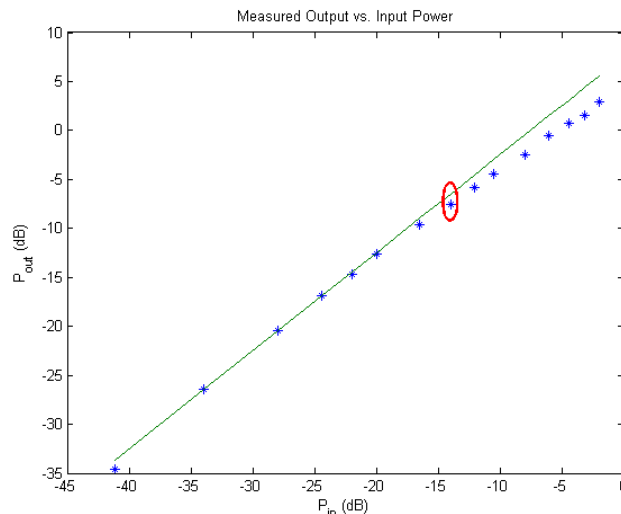


Figure 2: Plot of Output Signal Power (dB) vs. Input Signal Power (dB)

g) Now that you've found the gain compression point, you can quantitatively define "small" and "large" signal. Indicate the peak input voltage and input signal power relative to 1 Ohm in dB on the instructor verification page. Record a screen capture from the oscilloscope showing the 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 the screen captures to hand in with your lab. For the "large-signal" case, highlight on the printout the distortion that is caused by the nonlinearity of the amplifier.

h) Also hand in your table with the recorded data and the final m-file in which you did the data analysis and created the two figures.

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(h) Present your plots.

Verified: _____ Date/Time: _____

1-dB Compression Point:

In dB relative to 1 Ohm _____ In peak voltage _____

$x(t)$ (mVp)	$y(t)$ (mVp)
10	
20	
30	
40	
50	
60	
70	
80	
90	
100	
200	
300	
400	
500	
600	
700	
800	