EE431 Lab 6
Non-linear Circuits
Dec. 27, 2014

The purpose of this laboratory exercise is to gain experience with non-linear circuits. Use +/- 15 volt power supplies for all circuits.

1.0 Precision absolute value circuit (full-wave rectifier)

An absolute value circuit is used in situations where only the magnitude (not the polarity) of a DC type signal is needed or to measure the amplitude of an AC signal by first converting to an average DC value – a process known as full-wave rectification. Absolute value and full-wave rectification are two names for the same circuit. The circuit you will build is one of the simplest (and also best performing) ones for this function. The diodes are in the feedback path of an op-amp and high open-loop gain reduces the effect of the non-linear forward voltage drop to near zero. Thus, the circuit performs very accurately.

Build the circuit in Figure 1. Apply a 100 Hz sine wave at the following input amplitudes and observe Vo on an oscilloscope: 20, 10, 5, 2, 1, 0.5, 0.2, 0.1, 0.05, 0.02, 0.01 Volts peak-peak. At Vo you should see a full-wave rectified sine wave. Also measure the average DC voltage at Vavg. Show scope pictures of Vo in your report for the 10, 1, 0.1, and 0.01 peak-peak input signals. Make a plot of Vavg versus the applied input peak-peak voltage. The full-wave average DC average voltage for a sine wave is (2/π) times the rms voltage. If you convert your input peak-peak voltages to rms is Vavg accurately predicted?

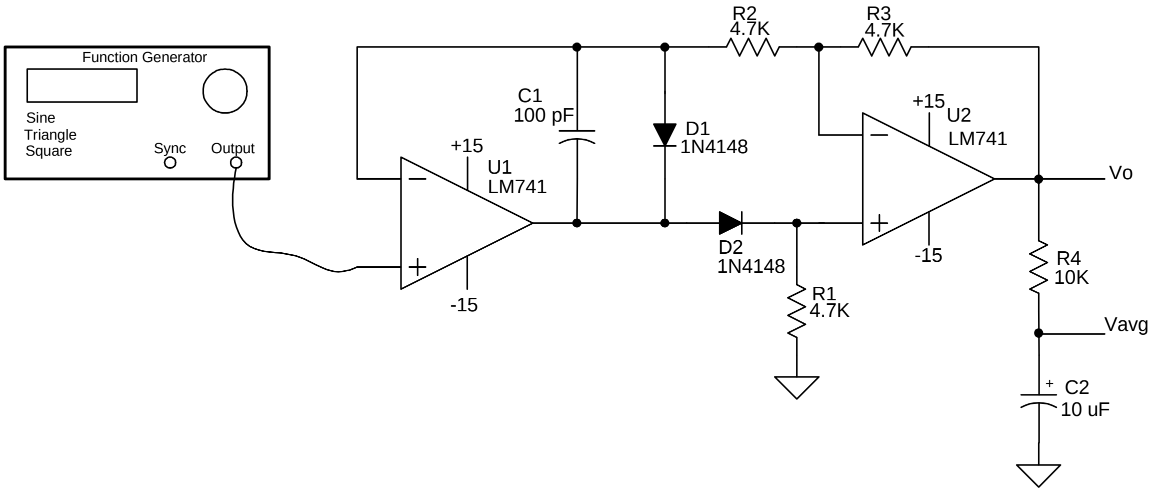

Figure 1: Absolute value circuit

This circuit has limited bandwidth over which it can work well. The limit is a function of how fast the op-amps are (the ones you are using are fairly slow). At high amplitudes the rising portion of a half cycle may become chopped off and the falling portion may even go negative. Try the following to see these effects. At low amplitudes the effects become more severe until rectification becomes useless so there is a lower limit to the input amplitude that the circuit can produce accurate output voltages.

With 10 Vpp applied, increase the frequency until there is noticeable distortion in the Vo waveform. Include a scope picture at 1 kHz, 10 kHz, and 25 kHz.

With 0.1 Vpp applied record the amplitude of Vavg at the following frequencies: 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, and 50 kHz. Plot this data. What frequency is the Vavg -3 dB below the voltage at 100 Hz.

Apply a 10 Vpp ramp wave, triangle wave, and square wave and show a picture of the Vo output and record the Vavg voltage. Some interesting things to note: For a triangle waveform the Vo output will be a triangle wave half the input peak-peak amplitude and at twice the input frequency – why? For a square wave the Vo output will be mostly a DC level with brief spikes when the waveform changes state – why? The Vavg output will be half the input peak-peak voltage – why?

2.0 Logarithmic converter

The logarithmic converter circuit uses the natural exponential characteristic of a semiconductor diode to produce a logarithmic voltage function of an input voltage. In industry it is common to use a logarithmic function to compress a signal with a high dynamic range (many orders of magnitude) to a small voltage range suitable for digitization by a relatively low resolution (i.e. economical) A/D converter.

You will first build the U1 portion of the circuit in Figure 2, take data, and then use that data to determine the required resistors in the U2 portion of the circuit to meet the given specification.

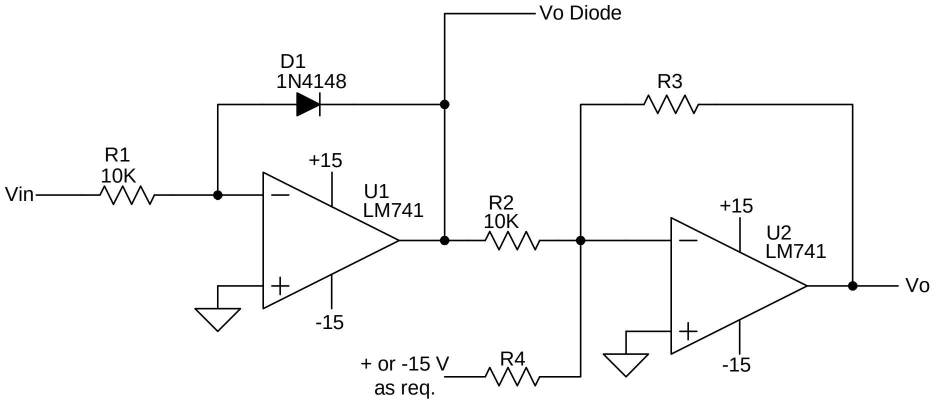

Figure 2: Logarithmic circuit

Because the input voltage must be adjusted over a wide range from 5 volts down to 10 mV the voltage divider shown in Figure 3 is used for better resolution when setting input voltages lower than about 200 mV. **The applied voltage to R1 will always be directly measured at R1 with the DVM**.

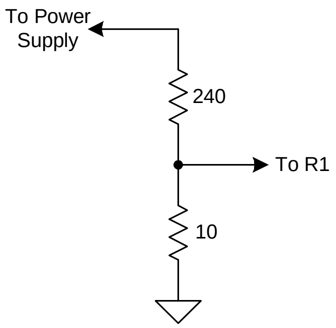

Figure 3: Voltage divider
for use to input voltage < ~200 mV

Apply nominal input voltages to R1: 0.01, 0.02, 0.05, 0.10, 0.20, 0.5, 1, 2, and 5. The operative word is nominal – you do not need to waste time setting the input voltage to exactly the given value – just anything reasonably (with about 10 percent) close. Record the actual voltage you apply and the corresponding output voltage of U1 (Vo diode).

Enter this data into Excel and make a plot – use a linear axis for Y (output of U1 – Vo_Diode) and a logarithmic axis for X (Vin applied voltage to R1). The plot should be a fairly straight line with a negative slope from negative a few tenths of a volt to about negative 0.6 volts except that data for the first two or three points may deviate a bit because the bias current of the op-amp corrupts the low-current measurement. That is fine – there is nothing you can do about it – it is a good illustration of the errors that can be caused by op-amp bias current and why more expensive op-amps are used for precision applications.

Determine a best fit equation of the form Vo_Diode = K_A*$\log_{10}$(Vin) + K_B for the data points that are on a general straight line – do not use outlier data points as those will only cause errors. You don't need to get involved with linear regression – although that would be the preferred method in real engineering. All you need are two good points widely spaced and you can easily develop the y=mx+b equation from those as follows. The key to this working is picking two widely spaced points from your plot that are good representatives of the ultimate straight line. As an example the points for nominal Vin = 5 and Vin = 0.05 will be used. You may need to pick different points depending on your data. We write two equations with two unknowns, K_A and K_B.

Vo_Diode_ Vin_5.0 nominal = K_A*$\log_{10}$(Vin_5.0_actual) + K_B (1)
Vo_Diode_Vin_0.05 nominal = K_A*$\log_{10}$(Vin_0.05_actual) + K_B (2)

Substituting actual example measured values:

$$-0.573 = K_A*\log_{10}(5.13) + K_B \tag{3}$$
$$-0.357 = K_A*\log_{10}(0.0482) + K_B \tag{4}$$

The student can easily solve this for K_A and K_B.

Overlay a plot of the equation

$$Vo\_Diode = K_A*\log_{10}(Vin)+K_B \tag{5}$$

on your first plot to prove that the fit is good. Only proceed if the fit is really good. If the fit is poor then something is wrong – fix it first or you will be wasting time in subsequent steps. As a check, K_A should be around -0.1 and K_B should be around -0.5 – depending on the specific characteristics of your diode. The proof is when a plot of your equation fits accurately over your measured data.

Your job is now to calculate the require resistors so that the output voltage of U2 is per the following table. Note that the output voltages changes by 2 volts for each decade of input voltage.

Vin **to R1**	**Vo** **from U2**
5.000 volts	10.00 volts
0.500 volts	8.00 volts
0.050 volts	6.00 volts

Determine the equation of the above table in the form:

$$Vo = K_1*\log_{10}(Vin) + K_2 \tag{6}$$

Hint: use the same method as used for calculating K_A and K_B. As a check, K_1 should compute to be 2.0 and K_2 should compute to be 8.6 – be sure to show your calculations. Equations 5 and 6 can be combined as follows in the transfer function of U2 noting that the equation in the brackets represents the output of U1:

$$Vo = U2\_gain*[K_A*\log_{10}(Vin)+K_B] + U2\_offset \tag{7}$$

Equating terms of Equations 6 and 7:

$$U2\_gain = K_1/K_A \tag{8}$$
$$U2\_offset = K_2 - U2\_gain*K_B \tag{9}$$

R3 is calculated knowing R2 and the required U2_gain. R4 is calculated knowing the required offset voltage and the available offset voltage source (+15 or -15 volts – if U2_offset computes to be a negative value then use +15 volts, or use -15 volts if U2_offset computes to be positive). Solve the following equation (use the appropriate polarity for 15) for R4.

$$U2\_offset = -(15*(R3/R4)) \qquad (10)$$

Apply the same sequence of input voltages as in the first part and now measure the output voltage of U2. Plot the data as you did in the first part. Don’t expect your output to exactly meet the specification as you had to do some rounding in the resistor values. However, the result should generally be reasonable. Determine the actual K_1 and K_2 of your circuit – if all went well then your actual K_1 should be between about 1.8 and 2.2 and your actual K_2 should be within a volt of the target value.

The circuit you built is a simple demonstration of what can be done. Your circuit barely operates accurately over two to three decades of input voltage. Improved circuits used in the commercial world operate very accurately over six to seven decades of input voltage!