

ENGR 210/EEAP 240 Lab 6

Use of the Function Generator & Oscilloscope

In this laboratory you will learn to use two additional instruments in the laboratory, namely the function/arbitrary waveform generator, which produces a variety of time varying signals, and the oscilloscope, which can be used to measure and characterize these signals. This lab is in two parts: (1) a computer simulation which will show you the basic operation of the function generator and the oscilloscope, and (2) some simple laboratory measurements you will make with the oscilloscope.

A. BACKGROUND

1. Characteristics of simple time-varying signals

Up to now we have worked with DC (direct current) voltage and current sources (i.e. power supplies), whose values are constant. It is important to develop a familiarity with some common signal waveforms which are often used in testing and analyzing electrical circuits and to define some of the quantities that are used to characterize those signals. In this lab you will become familiar with sources that vary as a function of time (called AC or alternating current sources). There are many different AC waveforms. However, the most commonly encountered time-varying waveform, at least in this course, is the one whose amplitude varies sinusoidally with time, as shown in Figure 1. Such a signal, as well as any signal that varies periodically with time, can be characterized by a number of parameters, some of which are shown in the figure.

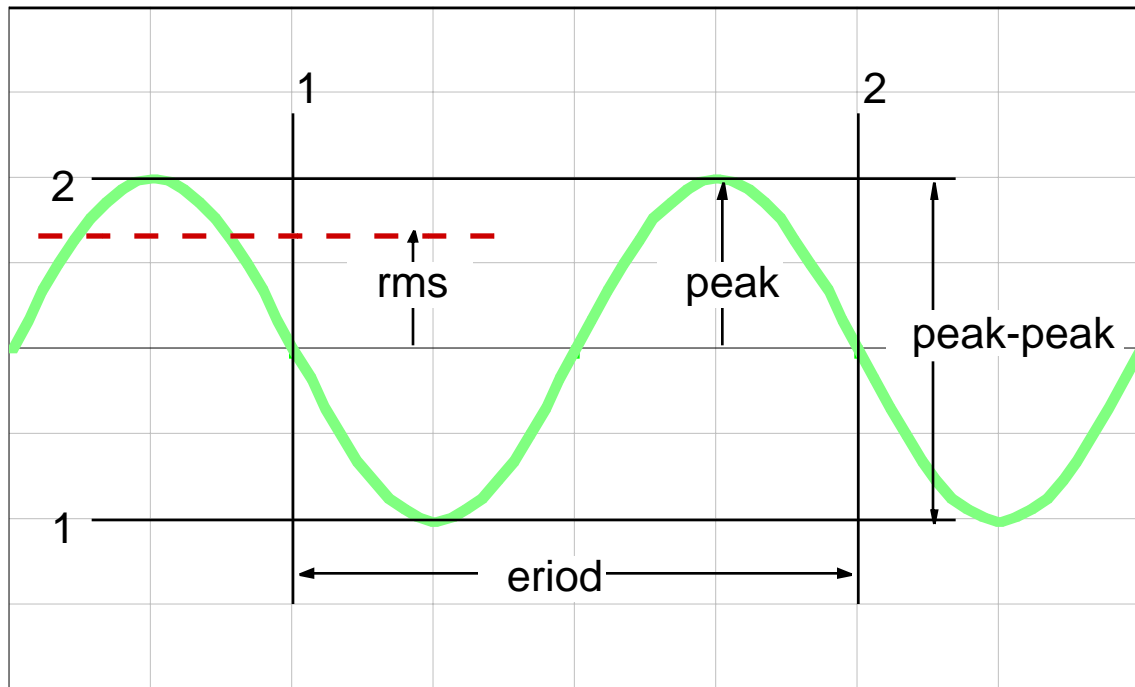


Figure 1. Characterization of sinusoidal time varying signal.

As shown in Figure 1, the period of a periodic time-varying signal is defined as the time within which the signal repeats. The frequency can be calculated from the period as

$$f(\text{Hz}) = f(\text{Hz}) = \frac{1}{T(\text{sec})}, \text{ or } \omega(\text{radians/sec}) = \frac{2\pi}{T(\text{sec})} \quad (1)$$

The amplitude of a periodic time-varying signal is characterized in one of several ways. If we describe the signal as $v(t) = V_{\text{peak}} \sin \omega t$, then the peak voltage, V_{peak} , is as shown in Figure 1. A second way to describe the signal is in terms of its peak-to-peak voltage, V_{pp} . This is the voltage difference between maximum and minimum value, or the voltage between V_1 and V_2 in Figure 1. A third way, which is most often used in characterizing voltages and currents in power systems, is based upon the ability of a source to deliver power to a resistor. The time average power delivered to a resistor by a DC source is

$$P = I^2 R \quad (2)$$

Similarly, the average power delivered to a resistor by a periodic current, $i(t)$, is

$$P = \frac{1}{T} \int_0^T i^2(t) R dt, \quad (3)$$

where T is the period. We can define an *effective current*, I_{eff} , for the AC source as the equivalent DC current that would deliver the same power to the resistor. Then equating the expressions in Eqs. 2 and 3,

$$I_{\text{eff}} = \sqrt{\frac{1}{T} \int_0^T i^2(t) dt} = I_{\text{rms}} \quad (4)$$

The right side of Eq. 4 is the square root of the average (mean) value of the square of the current, or *root mean square* (rms) current, I_{rms} . By a similar procedure we can define the rms voltage, V_{rms} , with an equation similar to Eq. 3. Thus if the voltage (or current) varies sinusoidally with time, i.e., $v(t) = V \sin(\omega t)$,

$$V_{\text{rms}} = \sqrt{\frac{1}{T} \int_0^T v^2(t) dt} = \sqrt{\frac{1}{T} \int_0^T V^2 \sin^2(\omega t) dt} = 0.707V \quad (5)$$

As an example of this, the voltage available at an electrical outlet is described by its rms voltage as 115 VAC. This means that $V_p = 115/(0.707) = 162.6\text{V}$ and $V_{\text{pp}} = 2*[115/(0.707)] = 325.2\text{V}$!

In previous labs we have used the digital multimeter (DMM) to measure DC currents and voltages. The DMM in the AC Mode can also be used to measure the RMS value of an AC waveform (root mean square) — the meaning of RMS will be covered in class when we discuss sinusoids and phasors. However, there are many other attributes of an AC signal besides the RMS value that are important such as the exact shape, frequency (or period), offset voltage, phase, etc. as is shown for a sinusoid in Figure 1 which cannot normally be measured with a meter.

Others waveforms which you may encounter are the pulse train, triangular and ramp waveforms as shown in Figure 2.

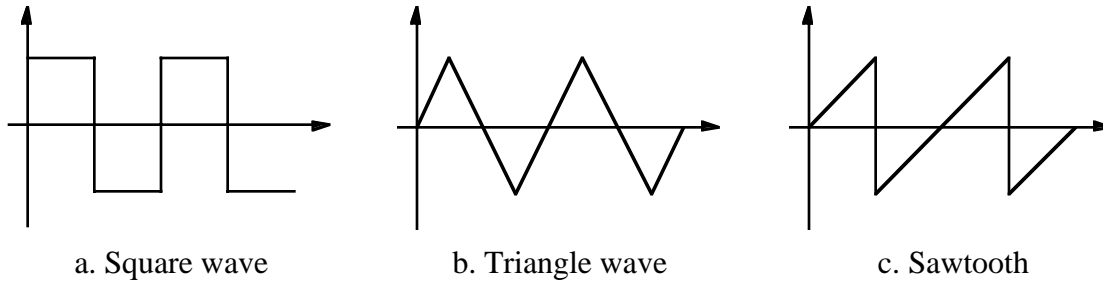


Figure 2. Sample waveforms. ($f = 1 \text{ kHz}$, $V_{PP} = 5V$.)

We will be using two different instruments in this lab: (1) the function or waveform generator and (2) the oscilloscope. Both are among the most important instruments in electronics. It is essential that you know how to use both instruments well.

The Signal Generator

The signal generator is a voltage source which can produce various time dependent signals waveforms from 0.0001 Hz to about 15 MHz. We have not used the terminology peak-to-peak in class but it means the voltage from the most positive point of a voltage waveform to its most negative point. Typically, a waveform such as a sine wave is symmetric about zero but, for various reasons, you may need to shift the entire waveform by adding a voltage in series with it. This is known as an offset voltage. The signal amplitude of the function generator is adjustable up to about 20 volts peak-to-peak (20 V_{p-p}) with an adjustable DC offset of up to 10 volts positive or negative. The generator has a 50 ohm output impedance (see Figure 3) which can affect your selection of resistor values in several experiments.

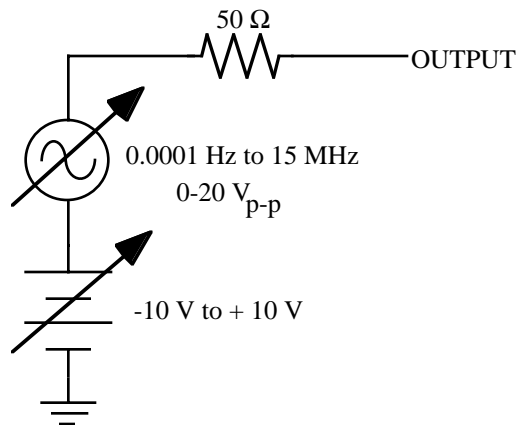


Figure 3. Functional circuit of a signal generator

The signal generator you will use is extremely versatile and can produce a variety of waveforms including common sine, square, or triangle waves as the output signal. It can also produce a simulated cardiac signal for testing biomedical instrumentation, wideband noise for testing electronic components, etc.

The Oscilloscope

The oscilloscope is often regarded as the most useful of the various electronic instruments electrical engineers typically use. The oscilloscope is used to display a plot of input voltage versus time and typically provides far more information than your DMM. The functional

blocks of the scope are illustrated in Figure 4. The display system contains a cathode-ray tube (CRT) where the plot is drawn. An electron gun at the back of the tube fires a beam of electrons at the screen similar to the way your television's picture tube works. The screen, which is covered with a phosphor coating, glows (typically green) when it is hit by the electron beam to produce the display. The vertical system deflects the beam vertically and controls the amplitude axis of the display. The horizontal system deflects the beam horizontally and controls the time axis of the display. The trigger system turns the beam on and off and synchronizes the display to the input signal. The intensity knob controls the scope's power and display brightness. The focus of the display is typically better at lower intensity levels, so the intensity should be set as low as possible for comfortable viewing. Do not set the intensity so low that the display is difficult to see. The focus knob should be adjusted after you have selected the proper intensity.

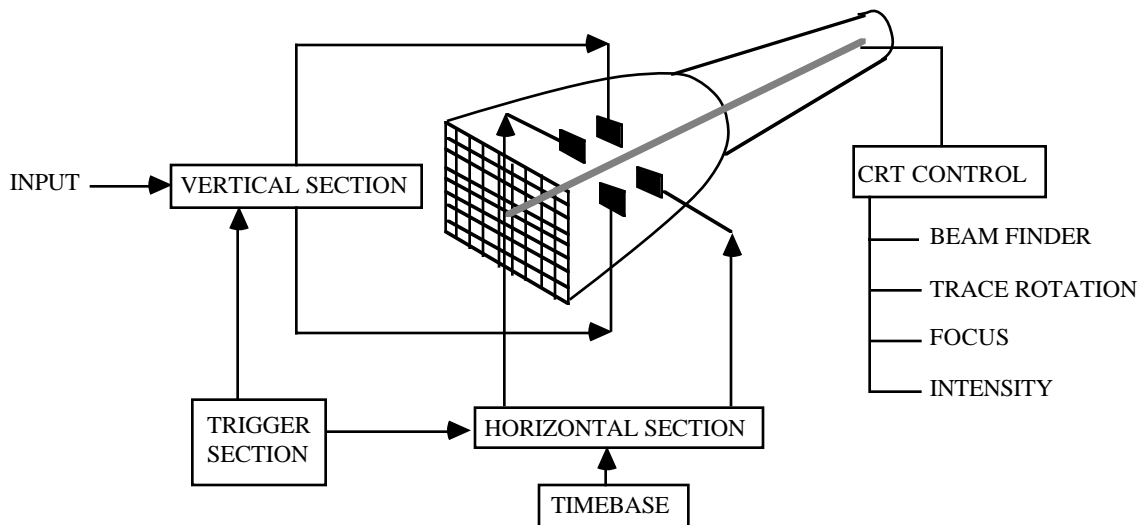


Figure 4. Functional diagram of oscilloscope

The part of the oscilloscope that students typically find the most difficult to understand and adjust is the timing and synchronization. The display on an oscilloscope looks constant because the oscilloscope repetitively sweeps across the screen, drawing new plots of the input waveform, at a rate faster than the eye can detect. The display would be a hopeless jumble of lines if each sweep did not start at exactly the same point on the waveform. The trigger system insures that the start of each sweep is synchronized to the waveform being displayed. Figure 5 shows three consecutive displays of a waveform.

The point at which a display (also called a sweep) is started is called the trigger point and is defined by the level and the sign of the slope, i.e., positive or negative. . The level sets the voltage of the trigger point. The sign of the slope determines whether the trigger point is found on the rising (+) or falling (-) slope of the signal. In Figure 5 the trigger level is shown as a constant voltage. Whenever the input voltage rises above this level the oscilloscope begins to draw the waveform on its screen. Note that the trigger level actually crosses the input waveform several times; however, the oscilloscope does not trigger a display at these points for two reasons. One, the scope is still busy drawing the current waveform, and, two, the waveform has a negative slope when it passes through the trigger level. If the scope is set to trigger on a positive slope it will wait for the next time the waveform crosses the trigger level with a positive slope as shown in Figure 5

The HP oscilloscopes you will use in the circuits lab are very smart and can typically be used to observe a waveform by simply turning the oscilloscope on and pressing the AUTO SCALE button. A microprocessor in the instrument automatically determines the settings. Another important component of the oscilloscope is its multiple inputs, called channels, to display different signals. Oscilloscopes usually have at least two channels so that one can display two waveforms simultaneously. To display two waveforms simultaneously the oscilloscope uses one of two techniques. It can "chop" the display in which the scope draws a point on the display corresponding to the channel one input, then draws a point on the display corresponding to the channel two input. By "chopping" back and forth in this manner the oscilloscope can draw what appears to be two complete waveforms corresponding to the two input channels. A simpler way of drawing two waveforms on the display is to draw all of the channel one waveform and then draw all of the channel two waveform. This technique is called alternating, or "alt".

There are also two types of scopes, analog scopes and digital ones. Digital scopes have more features than the analog scopes and work by digitizing the input signal at a VERY high rate. Because the signal waveform is then just a series of numbers digital scopes can process the signal and measure its amplitude, frequency, period, rise and fall time. Some digital scopes have built-in mathematical functions and can do Fast Fourier transforms in addition to capturing the display and sending it out to a printer or computer. The oscilloscopes in the Circuits Lab are HP 54600 digital oscilloscopes which have many built-in functions. The goal of this lab is to learn how to use some of the different features of the digital oscilloscope.

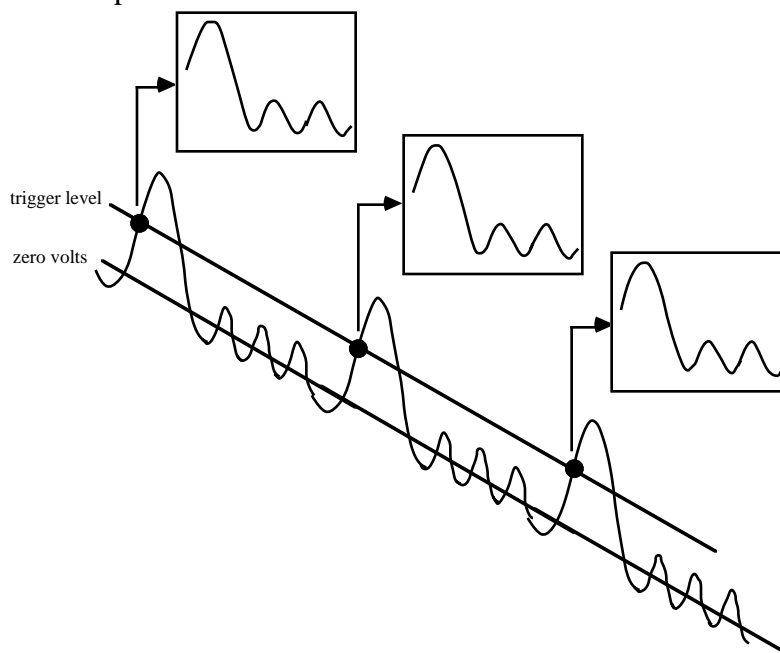


Figure 5. Oscilloscope waveform display

The oscilloscope probe

You can use simple clip leads like you used with the DMM to connect your circuit under test to the oscilloscope; however, you will typically want to use an oscilloscope probe for these connections. This is used for many reasons. One is to keep unwanted signals out of the measurement. Another reason is because a simple wire does not isolate the oscilloscope from the circuit being tested — in circuits with large resistances and small signals a simple wire running to the oscilloscope would change the circuit performance from what it was

before you connected the wire. Since you really want to measure the circuit behavior without it changing due to the measurement you use an oscilloscope probe.

Figure 6 shows a typical probe. An oscilloscope probe is a high quality connector cable that has been carefully designed not to pick up stray signals originating from radio frequency (RF) or power lines. They are especially useful when working with low voltage signals or high frequency signals which are susceptible to noise pick up. An oscilloscope probe has a large internal input resistance which reduces the circuit loading. A probe usually attenuates the signal by a factor of 10 although some probes have switchable attenuators, typically X1 and X10, as shown in Figure 6. The probe often has a small box connected to it's cable connector which contains the electronic components of the scope probe (see Figure 7). Compensated probes will have a small screwdriver adjustment in this box; some older probes will have this adjustment actually in the probe. The advantage of using a 10:1 attenuator is that it reduces circuit loading. By adding a resistance of 9MegOhm the input resistance seen by the circuit under test increases from 1 MegOhm to 10 MegOhm. As a result, the current that needs to be supplied by the circuit will be 10 times smaller and reduces the circuit loading by a factor of 10. Since very few circuits have resistance in them which are this large any current going through the scope probe is negligible compared to the other circuit components.

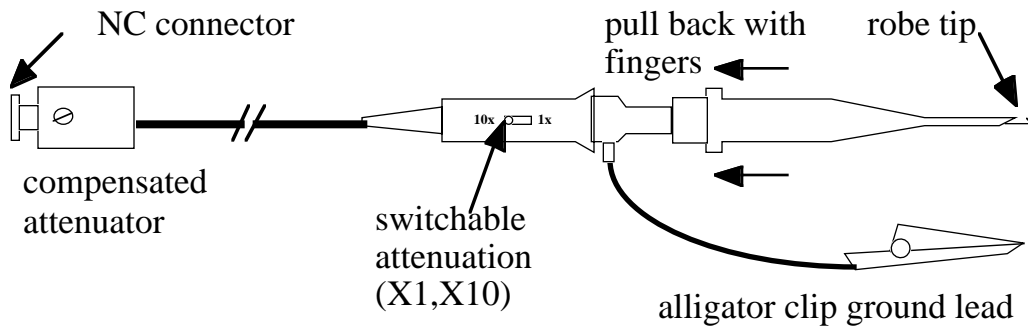


Figure 6. A typical oscilloscope probe

The probe has a fine hook at its tip which is usually retracted until you pull the probe head back with your fingers. You can use this hook to attach the probe to your circuit. It is actually pretty simple to do this with your fingers while holding the probe in the same hand.

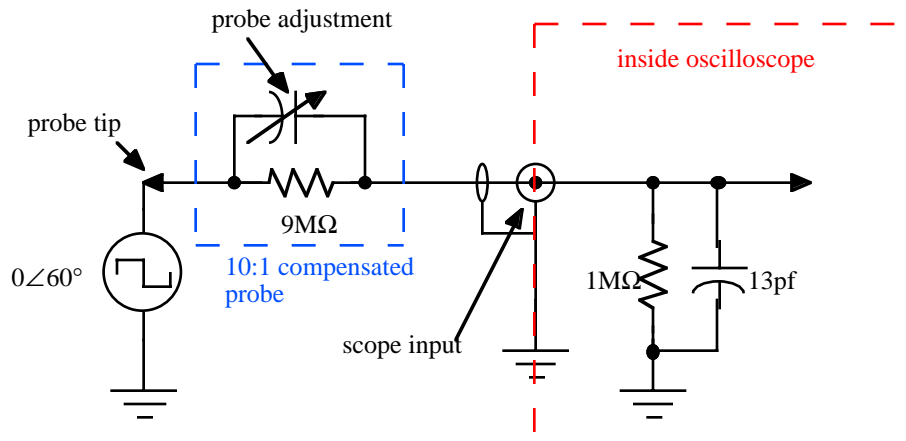


Figure 7. A 10:1 divider network of a typical probe.

Figure 7 shows a component which we have not used in the course so far, a capacitor. An important feature of an oscilloscope probe is the variable capacitor placed across the 9MegOhm resistor. This variable capacitor can be adjusted to ensure that high frequency waveforms are not distorted. The effect of adjusting this capacitor is illustrated in Figure 8 which shows the effect of the adjustment on the oscilloscope display of a square wave signal. When the probe is properly adjusted a square wave will be displayed with a flat top as shown in Figure 8(a). However, a poorly adjusted probe can give considerable distortion and erroneous readings of the peak-to-peak amplitude of the signal as shown in Figure 8(b) and Figure 8(c). Proper probe adjustment is so important that most oscilloscopes have built in means to adjust the scope compensation as you will see in this lab. You should get into the habit of checking the probe compensation with a square wave every time you use it. Note that not all square waves will produce the waveforms seen in Figure 8(b) and Figure 8(c); only square waves which have VERY vertical edges will produce these signal distortions.

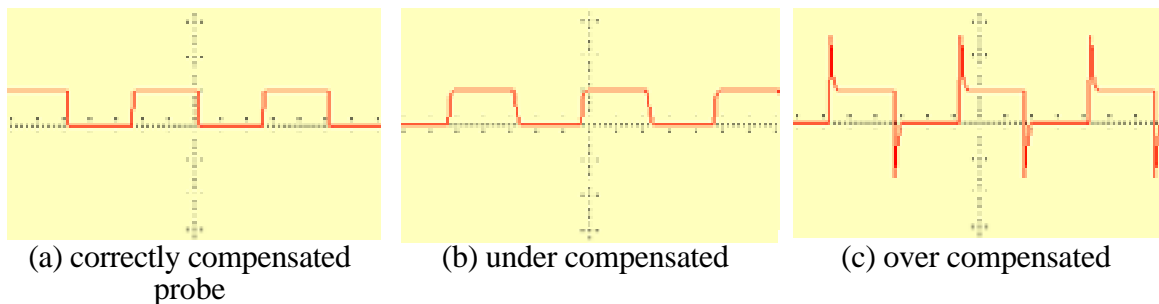


Figure 8. The effects of probe compensation.

Note that the effects of under compensation are usually harder to detect than the effects of overcompensation.

Characteristics of simple time-varying signals

In previous labs you made a number of measurements on DC circuits, i.e., circuits in which the voltage and current were constant over time. However, a great number of the electrical signals that are dealt with in practice are time-varying signals, i.e., signals whose amplitude varies with time. For example, the amplitudes of the voltage and current that are available from a wall outlet, as well as most of the electrical power distribution systems, vary at the rate of 60 Hz. In addition, speech and music are encoded and broadcast through the air by means of voltage analogs of sound, and information that is stored and used in computers is in binary form, utilizing two distinct voltage levels in a time sequence.

PART A:

In this simulated lab you will use the oscilloscope and function generator to measure the time dependent voltage response of a simple resistor-capacitor circuit to a square wave voltage input.

IMPORTANT: Use the computer software labeled “LAB6” or “AC Waveforms and Circuits” for this lab - It is on the ENGR 210 Web page. If you have any problems downloading or running it please let us know!

In this simulated lab you will perform a simulated laboratory using the HP 33120A function generator and HP 54602B oscilloscope. This oscilloscope is almost identical to the HP 54601 oscilloscopes in the lab and this simulated lab will prepare you to use the lab instruments. In the first part of the simulated lab the function generator will be used to produce various waveforms which will then be viewed and measured using the oscilloscope. In the second part of the lab, you will use the function generator to generate a square wave which will be used as the input to a resistor-capacitor (RC) circuit. You will then use the oscilloscope to measure the exponential waveforms which result from this circuit. The mathematics of these waveforms are being developed in class; however, the major emphasis of this lab is to understand the operation of the function generator and oscilloscope. Future labs will examine the time-dependent behavior of circuits in more detail.

Pay careful attention to procedure for setting the output impedance of the signal generator. This does not actually change the resistance in Figure 3, but changes how the output voltage is calculated. For example, if you placed a 50Ω load on the generator and programmed the generator in 50Ω mode to output 1 volt, then you would really get 1 volt as measured by an external meter. However, if you put a 1000Ω (a high impedance) load at the output of the generator and you were still in 50Ω mode, almost all of the generator voltage would be developed across the load resistance because it is so much larger than the 50Ω resistance of the generator. Programming the generator to HIGH Z will let the generator know that all of the voltage will be developed across the high impedance load and it will adjust its scale so that the programmed output is what you will really measure.

If at any time the signal generator output and the voltages as measured by a meter or oscilloscope are different, the function generator is probably in the wrong impedance mode.

DATA AND REPORT SHEET FOR LAB 6A

Student Name (Print): _____	Student ID: _____
Student Signature: _____	Date: _____
Student Name (Print): _____	Student ID: _____
Student Signature: _____	Date: _____
Student Name (Print): _____	Student ID: _____
Student Signature: _____	Date: _____
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ANSWER THE FOLLOWING QUESTIONS:

GRADING: -2 points for each question; 30 points total for this section.

Function Generator

1. Describe how you set/adjust the output frequency of the function generator

Answer:

1. Turn the function generator on.
2. Set the frequency by
 - pressing the frequency button,
 - pressing the enter button,
 - pressing the “1” to enter a digit, and
 - pressing the up/down arrows to set the frequency units
2. Referring to Figure 3 in the lab: “If the maximum amplitude of the signal is 2.5 volts, and the minimum amplitude is -3 volts, what is the DC offset? Explain your answer.

ANSWER: The signal is symmetric about the DC offset. In this case the signal amplitude is $2.5 - (-3) = 5.5$ volts. The center (average) value of this waveform is +2.75 volts. The DC offset (the value of the DC source in Figure 3) is then +2.75 volts. Many people got the sign of the offset wrong (-1/2).

3. Explain how to set the output impedance of the function generator to “high impedance”

ANSWER:

1. Press the SHIFT button
2. Press the MENU ON/OFF button
3. Press the Right Arrow (>) to get to D: SYS MENU
4. Press the down arrow until you get the message 50 OHM.
5. Press the right arrow (>) until you get HIGH Z.
6. Press the ENTER button to select this value.
4. Using Figure 3, explain what setting the output impedance of the function generator to high impedance does.

ANSWER: You have not changed R, but you have changed how the output voltage is calculated. For example, if you placed a 50Ω load on the generator and programmed the generator in 50Ω mode to output 1 volt, then you would really get 1 volt as measured by an external meter. However, if you put a 1000Ω (a high impedance) load at the output of the generator and you were still in 50Ω mode, almost all of the generator voltage would be developed across the load resistance because it is so much larger than the 50Ω resistance of the generator. Programming the generator to HIGH Z will let the generator know that all of the voltage will be developed across the high impedance load and it will adjust its scale so that the programmed output is what you will really measure. Lots of people missed this question.

5. Describe how you program the function generator to output a specified peak-peak voltage?

ANSWER:

1. Press the AMPL button
2. Press the ENTER NUMBER button
3. Press the “5” button to set the amplitude.
4. Press the up arrow to enter the amplitude
6. Describe how you program the Function Generator to output a sine waveform?

ANSWER:

- (1) Press the \sim button
- (2) Press the ENTER NUMBER button
- (3) Press the “5” button to set the amplitude.
- (4) Press the up arrow to enter the amplitude

Oscilloscope

1. How do you adjust the oscilloscope for a 10:1 probe at its input?

Answer:

- (a) Press the channel “1” to turn on the scope menus.
- (b) Press the button underneath the “10” below PROBE.
2. Describe how to use the oscilloscope for a calibrated peak-peak voltage measurement?

Answer:

- (a) Make sure the probe adjustment is correctly set
- (b) Press the “Voltage” button on the oscilloscope.
- (c) On the scope menu, press the button underneath “Vp-p”.
3. Explain how to calculate the RMS voltage of a 5 volt peak-peak sine wave? (no theory, just the mechanics)

Answer: Multiply the peak value (2.5 volts) by $1/\sqrt{2}$ to get $2.5 \cdot .707 = 1.7675$ volts. I was expecting a value — -1 to -2 if no value

4. Describe how to use the oscilloscope for a calibrated RMS voltage measurement?

Answer:

- (a) Make sure the probe adjustment is correctly set
- (b) Press the “Voltage” button on the oscilloscope.
- (c) On the scope menu, press the button underneath “Vp-p”.
5. Describe how to use the oscilloscope for a calibrated time measurement?

Answer:

1. Press the “Time” button on the oscilloscope.
2. On the scope menu, press the button underneath “Freq”.

Exponential Waveforms:

1. What are the values of the resistor (R) and capacitor (C) you used in this simulated circuit?

Answer: $R=1\text{k}\Omega$ and $C=1\mu\text{F}$.

2. Draw a schematic of the RC circuit you examined in this lab.

3. What is the time constant (the product of R and C) for this RC circuit?

Answer: $RC=(1\times 10^3)(1\times 10^{-6})=1\times 10^{-3}=1\text{millisecond}$

4. What frequency has a period of 10 milliseconds? (The frequency is the reciprocal of the period for any waveform.)

Answer:

$$f=1/10 \text{ milliseconds} = 100 \text{ Hz}$$

5. What does the **Delay** knob on the oscilloscope do?

Answer: Delays the trigger to move the display across the oscilloscope screen.

6. Explain how to use the **Cursors** button on the oscilloscope.

Answer:

- Press the “Cursors” button on the scope.
- Pressing V1 will put a horizontal line on the display.
- The vertical position of the horizontal line can be adjusted using the “Cursor Control” knob.
- You can place vertical time lines by pressing the “t1” and “t2” buttons under the oscilloscope screen when in the cursors menu. The position of these vertical lines can be set using the “Cursor Control” knob.

PART B

This part of the lab **MUST** be done in the lab using the real laboratory equipment. The following exercises are intended to guide you through the basic functions of the oscilloscope. try out other functions and experiments with the different settings.

1. Select, display, measure and listen to a sinusoidal waveform:

- (a) Use the HP 33120A function generator to create a sinusoidal waveform with a peak-to-peak amplitude of 1 V_{pp} and frequency of 1 kHz. If necessary, review the tutorial on the “Function Generator/Arbitrary Waveform Generator” on the Web page.
- (b) Connect the OUTPUT of the function generator to the INPUT of the oscilloscope (Channel 1). This can be done with cables — you do not need an oscilloscope probe for this. Push the AUTOSCALE button on the Measure panel. You can switch the input channel 2 off by pressing the button marked 2 on the vertical panel, or by pushing the Off/On key underneath the display window.
- (c) Change the scale (V/div) of channel 1 (V/div KEY) (vertical panel) and note the display changes. Try out a few other settings.
- (d) You can now change the time base as well (Time/div on the horizontal panel). Read the peak to peak value of the sinusoid using the scales of the scope display (shown at the top left corner in V/div). Notice the difference with the setting on the function generator.
- (e) Explain the difference if any (hint: the output impedance of the function generator is probably set to 50 Ohms - see Part A).

NOTE: In case the value of the displayed waveform is off by a factor of 10 when using a probe, check the probe setting. Push the button labeled “1” (channel 1) just above the “Position” knob. This will bring up a menu at the bottom of the screen. At the right hand side you will see Probe 1 10 and 100. Make sure that this is set to 1 (unless you use a probe).

- (f) Do only if speakers are available in the lab. Connect the output of the function generator to the input of the speaker. Use the cable with red and black clips at one end to connect the function generator output to the speaker. (It does not matter which lead is connected to which speaker terminal.) Do not turn the volume up too high (to prevent driving everyone else in the lab nuts). Vary the frequency of the signal. Record how low and high a frequency you can hear in Data Table 1.
- (g) Now disconnect the speaker for quietness.

2. Trigger Modes: These exercises will help you understand the trigger function.

- (a) Display on channel 1 a 5 kHz sinusoid of 5 V_{pp} magnitude.
- (b) Select the trigger SOURCE key (on the trigger panel); you will notice a series of choices displayed at the bottom of the screen. Push the key underneath the word Channel 2. This will select channel 2 as the trigger source. Notice and record Data Table 2 what happens. Next, select channel 1 as the trigger source.
- (c) Now change the trigger mode by pressing the MODE key and selecting Auto (with the keys at the bottom of the display). Turn the trigger LEVEL knob to change the trigger level (on the trigger panel). Record what happens in Data Table 2. Can you explain this behavior? What happens when the trigger level exceeds the peak voltage of the sinusoid? Next, select Norm trigger mode (at bottom of the display).
- (d) Select trigger Slope/Coupling key on the trigger panel. Switch between the positive and negative going slopes. Note the effect on the display.

3. Measure functions: You will learn how to use the scope to give you the amplitude and time characteristics of the waveform. This is probably the most complicated part of the lab.

- (a) Select a square wave on the function generator with an amplitude of 1 V_{pp}, offset voltage of 0.5V (so that the waveform lies between 0 and 1V), frequency of 1.25 MHz and a 25% duty cycle — this means that it is 1 volt for 25% of the waveform period and 0 for the remaining 75% of the period.
- (b) Push the VOLTAGE key on the measure panel. Select the key at the bottom of the display to measure the peak-to-peak voltage (V_{pp}). Record this measurement in Data Table 3. NOTE: These are sometimes called softkeys. In turn, press the average (V_{avg}) and RMS (V_{rms}) keys. Record these values in Data Table 3. Now, press the Next Menu soft key at the bottom of the display. Sequentially press the V_{max}, V_{top}, V_{min} and V_{base} keys. Record the displayed value for each measurement.
- (c) Using the voltage (V1-V2) cursors measure the overshoot of the displayed waveform. Record this result in Overshoot is either the voltage by which the waveform overshoots its final value, or the percentage by which the maximum voltage exceeds the final value — either is correct. In this lab we will use the voltage definition. For example, if in Figure 9 the vertical sensitivity is 1 V/cm, the waveform overshoots its final value by one centimeter; hence, the overshoot is 1 V. In terms of parameters measured by soft keys the overshoot can also be defined as V_{max}-V_{top}. Finally, some of the lab oscilloscopes even have a softkey which will directly measure overshoot

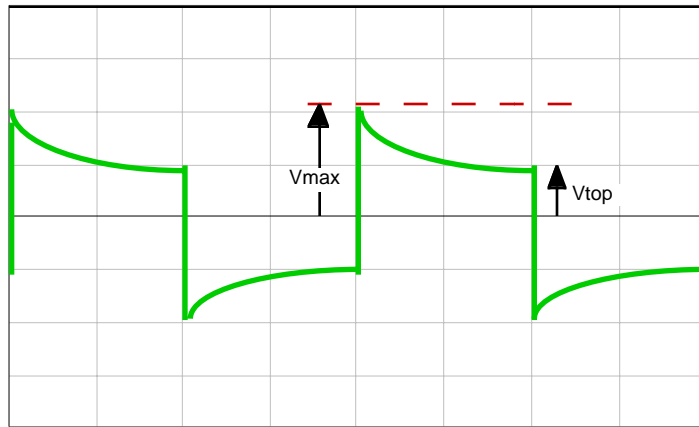


Figure 9. Overshoot definitions

- (c) Push the TIME key on the measure panel in order to measure the frequency and period. Before making any measurements adjust the oscilloscope timebase such that you see one or two periods on the screen. Press the appropriate measurement keys to measure the frequency (the should be roughly the same as the setting on the function generator), the period and duty cycle. Record these values in Data Table 5. Go to the Next Menu. Measure the rise and fall times and record these in Data Table 5.
- (d) Push the CURSOR key on the measure panel. Two vertical position-controllable cursors appear which can be used to make time measurements anywhere along the displayed waveform. Similarly, two horizontal cursors are available for precision voltage measurements. Use the cursors to measure the pulse width and pulse period. Record these values in Data Table 6
- (e) Delay function: in order to zoom in on a specific part of the waveform you can use the delay function. Experiment with this feature. Push the MAIN/DELAYED button on the horizontal panel. Next, select Delay and notice the display. Change the timebase (Time/div) to further zoom in on the rise time of the waveform. This feature is

convenient to look at the detailed structure of a waveform. You can go back to the regular display by pushing the Main display.

4. Scope Probe

A scope probe is used to display high frequency signals and to reduce noise and distortion on the signal. In the following experiments you will study the effect of using a probe.

a. Scope Probe Adjustment

The probe tips can be easily damaged or broken. Handle the probe tips with care.

Disconnect any cables from the scope inputs. Connect the probe to the Channel 1 input of the oscilloscope. You need to inform the scope that you are using a 10:1 probe. This is done by pushing the key labeled 1 on the vertical panel of the scope and then pressing the key at the bottom right side of the display until the 10:1 indicator is highlighted

Attach the tip of the scope to the square wave reference output on the front panel of the oscilloscope (underneath the display indicated by the square wave icon). View the square wave signal on the scope. If the probe is not properly adjusted the square wave won't have square corners. Use your screw driver to make adjustments on the probe so that the square wave has a flat top. Do this carefully and do not turn the screw too much as this can damage the probe. The probe is now ready to be used.

b. Measuring a square wave

Remove the scope probe. Connect the Channel 1 input to the waveform generator using a coax cable (black cable) or any other lab connectors. Adjust the signal generator to produce a square wave with a frequency of 2 MHz and amplitude of 2 Vpp. Display the square wave on the oscilloscope. Notice that the square wave may not be very clean and that it may have considerable amount of ringing. Make a sketch of the screen and record it in Data Table 7. Also record the scope voltage sensitivity and time base settings. (We will cover how to get a bit map image of the screen in the near future.) Remove the cable, and connect the probe input to the output of the function generator. You can just touch it to the generator output. **Be extra careful not to bend the probe pin (it is easily damaged).** You must also connect the ground of the function generator to the ground connector of the probe. Adjust the vertical scale of the scope and record the waveform. It should be very clean with no noise or ringing. Make a sketch in Data Table 8. Record the scope's voltage sensitivity and time base settings in Data Table 8.

c. Effects of a poorly adjusted probe

Connect the probe input back to the square wave reference output from the oscilloscope. Use the cursors on the scope to measure the waveform's characteristics, i.e. Vpeak-to-peak, Vtop, Vmax. Record the values in Data Table 9. Now mis-adjust the scope probe by turning the screw in the scope compensation box by about a quarter turn. Notice what happens to the square wave output. Do the same measurements as before and record them in Data Table 9. How do these measurements compare with the measurements for a compensated (properly adjusted) probe? Now readjust the probe carefully using this reference square wave signal at the scope terminal.

This step only works well using the reference signal from the scope. The signal generator output does not change fast enough to cause problems with the scope probe. However, if you were working with digital signals or with a fast signal generator adjusting the scope probes would be very important.

5. Slew Rate Limitations of Real Op-Amps

We are now going to use a scope and function generator to make a measurement that you could not otherwise make. We are also going to expose you to real op amps: *they're not as good as we keep saying they are in class*. Let's start by looking at one way that op amps depart from the ideal model.

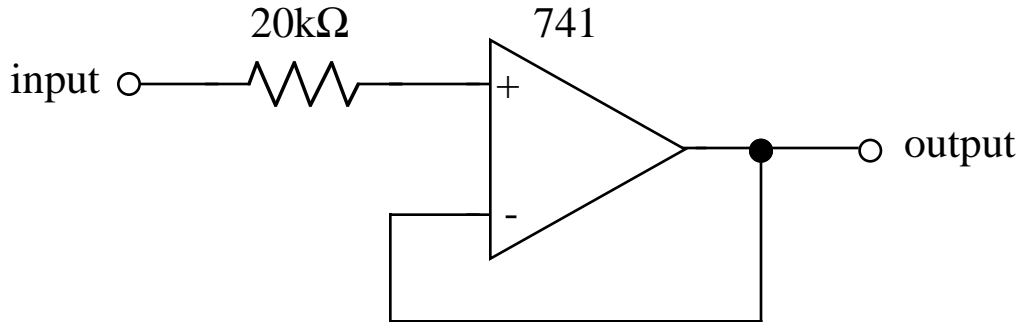


Figure 10. Slew rate measuring circuit

NOTE: A gain of 1 inverting op amp circuit works just as well as the above circuit. The series resistor prevents damage if the input is driven beyond the supply voltages by the function generator - it's exact value is not critical but should be $>10k\Omega$)

The slew rate of an op amp is defined as the fastest rate at which the output can change. This is a very important measurement if you are working with high-frequency circuits.

(a) Square wave input

Build the circuit shown in Figure 10. Drive the input with a 1 kHz square wave from your function generator, and look at the output waveform on your oscilloscope. For this measurement to work you should use an input signal of about 10 volts PEAK amplitude. Measure the slew rate by measuring the slope of the nearly vertical voltage transitions at the op amp output. You will need to zoom in on a rising or falling edge of the square wave and use the cursors for a good measurement. Record this value in Data Table 10.

Hints:

- Find a straight central section of the square wave's voltage swing; avoid the regions near "saturation", i.e., near the maximum or minimum limits of the output signal.
- Accurate slew rate measurements are achieved only for large difference signals seen at the input of the amplifier. You need to drive the op-amp circuit with something on the order of 10 Volts PEAK to get good results. Reduce the input signal and note what happens.
- The rates for slewing up and down are typically different.

(b) Sine input

Switch the function generator output to a sine wave. Keep everything else the same as for the above measurements. V_{in} must be 10 Volts or more PEAK for this experiment to work. Record the initial amplitude of the sine wave in Data Table 10. Increase the frequency of the signal generator until the output amplitude begins to drop and/or the waveform begins to look triangular (See Appendix 1). Record this frequency in Data Table 10.

DATA SHEET FOR LAB 6B

Student Name (Print): _____ Student ID: _____

Student Signature: _____ Date: _____

Student Name (Print): _____ Student ID: _____

Student Signature: _____ Date: _____

Student Name (Print): _____ Student ID: _____

Student Signature: _____ Date: _____

Lab Group: _____

f_{LO}		Hz
f_{HI}		kHz

**Data Table 1. High and low audible sinusoidal frequencies
(RECORD ONLY IF SPEAKERS WERE AVAILABLE IN LAB)**

Event	Observation
2(b) Channel 2 used as trigger source	
2(c) Varying trigger level	

Data Table 2. Effects of triggering controls

Peak-to-peak voltage (Vpp)	1.047	Volts
Average voltage (Vavg)	0.245	Volts
RMS voltage (VRMS)	0.500	Volts
Maximum voltage (Vmax)	1.016	Volts
Top voltage (Vtop)	1.000	Volts
Minimum voltage (Vmin)	-0.53milli	Volts
Base voltage (Vbase)		Volts
Overshoot (Vovr)	1.562	%

Data Table 3. Waveform voltage measurements using scope functions

V1	Volts
V2	Volts
V2-V1 (Overshoot)	Volts
Vmax-Vmin	Volts

Data Table 4. Overshoot measurements

frequency	1.250kHz	Hz
period	800μsec	seconds
Duty cycle	24.8	%
Rise time		seconds
Fall time		seconds

Data Table 5. Waveform time and frequency measurements using scope functions

Pulse width	200μsec	Seconds
Pulse period		Seconds

Data Table 6. Cursor based measurements

Volts/div:

 Time/div

Data Table 7. Sketch of square wave measurement w/o using scope probe

Volts/div:

Time/div

Data Table 8. Sketch of square wave measurement using scope probe.

With correctly adjusted scope probe	Vmax	Volts
	Vtop	Volts
	Vpp	Volts
With incorrectly adjusted scope probe	Vmax	Volts
	Vtop	Volts
	Vpp	Volts

Data Table 9. Effects of probe adjustment upon measurements.

Measured slew rate	V/ μ s
Signal generator output amplitude	V Peak
Frequency at which op amp output begins to drop	Hz

Data Table 10. Slew rate measurements of 741 op amp

REPORT SHEET FOR LAB 6

Student Name (Print): _____ Student ID: _____

Student Signature: _____ Date: _____

Student Name (Print): _____ Student ID: _____

Student Signature: _____ Date: _____

Student Name (Print): _____ Student ID: _____

Student Signature: _____ Date: _____

Lab Group: _____

ANSWER THE FOLLOWING QUESTIONS:

1. Explain what happened in 2(b) when you selected Channel 2 as the signal source?

ANSWER: should have gone out of sync since you were triggering on another, in this case non-existent, signal.

2. Explain what happened in 2(c) when you varied the TRIGGER level. What happens when the trigger level exceeds the peak voltage of the sinusoid?

ANSWER: The display again goes out of sync. When the voltage is below the peak level, this trigger voltage corresponds to the waveform voltage at the left side of the display. You can actually see the waveform move to the left or right as you vary the trigger level.

3. What is the difference between V_{top} and V_{max} in 3(b)?

ANSWER: V_{top} is some sort of average; even the manual is not clear on this. However, V_{max} is the maximum value of the waveform. Any reasonable explanation was accepted; a numerical value was not what was asked for and two points (-2) were taken off for a numerical answer.

4. Describe how you measured the overshoot in 3(b).

ANSWER: The most elegant way was to compute $V_{max} - V_{top}$. Overshoot is not a time; it is the amount by which the voltage waveform exceeds the expected value.

5. Calculate the duty cycle from your measurements in 3(d) and compare with the measurement result in 3(c).

ANSWER:

6. Why were your measurements different using a correctly and then a mis-adjusted scope probe in 4(c)?

ANSWER: The probe cannot respond correctly to quickly changing waveforms unless it is properly adjusted.

7. Compare your measurements for 5(a) and 5(b) using the results from Appendix 1. First, determine the frequency of a sine wave with the equivalent slew rate that you measured in 5(a). Second, using this same relationship compute the effective rise time of the sinusoidal cutoff frequency you measured in 5(b).

Comments on grading:

Part A:

This part is 30 points total; 2 points per question.

Function Generator

4. The generator will not change the output impedance; instead, it changes how it calculates it so that the programmed voltage will be correct.

Oscilloscope: The cursors are not used simply to measure time constant. There are two of them and they can be used to measure voltage and time differences. If you get this confused or do not know that there are multiple cursors points will be taken off.

Part B: Data

This part is 35 points total. Most of the data collected seemed to be pretty good. There were some problems with the oscilloscope probe measurements and no points were taken off there. However, many people were off in the slew rate measurements by many orders of magnitude. The major problem seemed to be that people were using input voltages that were too small.

Very few points were taken off elsewhere.

Part B: questions

This part is 35 points total; 5 points per question. Show your calculations and procedures. If you do not show your procedures we will have no choice but to take off points for data that is completely unreasonable. This part can cost you 1-5 points depending upon how unbelievable or how undocumented your answer is.

APPENDIX 1. Slew Rate Limiting

Background

Slew rate is a natural inability of the operational amplifier to change voltage faster than some specified rate. This is controlled by a capacitance inside the op amp which you may study in later courses. However, the simple picture is that a real op amp has a limited maximum slope of any input waveform which it can reproduce. Any slopes larger than this limit will be replaced by the slower limit. The actual mathematics is complex and we don't really want to get into it here.

Simulation

We can use the circuit shown below to measure the effects of maximum slew rate upon a sine wave for a 741 operational amplifier.

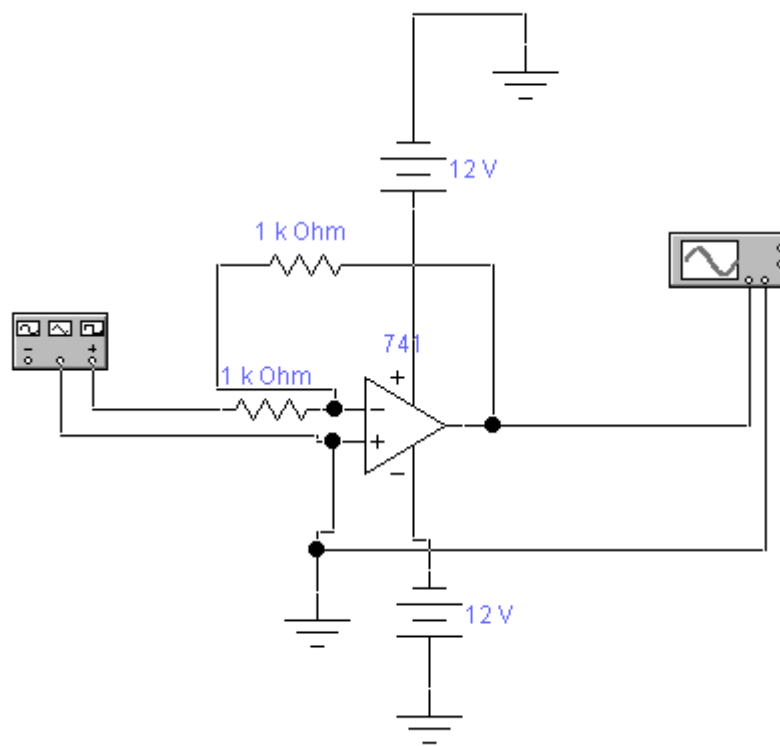


Figure 11. Op Amp circuit in EWB to demonstrate slew-rate limiting.

This analysis was done in Electronics Workbench using their 741 op amp model which is pretty accurate. The circuit shown in Figure 11 has a gain of 1 (the exact gain is not important for this analysis), and is initially being driven by a 1 kHz sine wave of 10 volts peak amplitude. Under these conditions the output sine wave is very well formed and looks sinusoidal as shown below.

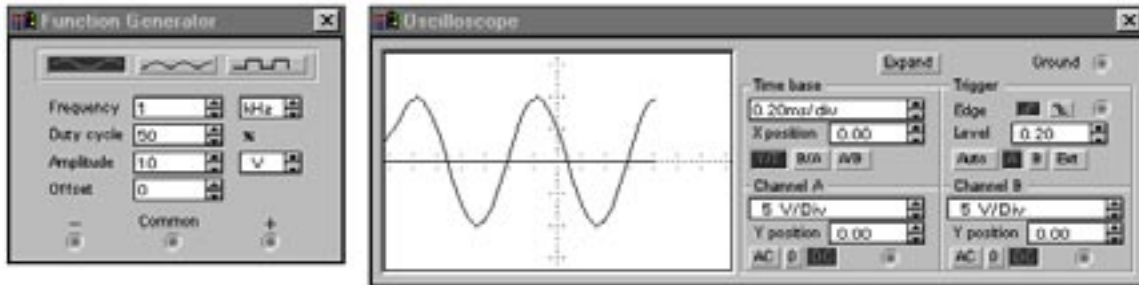


Figure 12. Op Amp Output ($V_{in}=10V$, $f=1kHz$)

The effect of increasing the frequency of the sine wave to about 9 kHz is shown in Figure 13. The output still appears very sinusoidal.

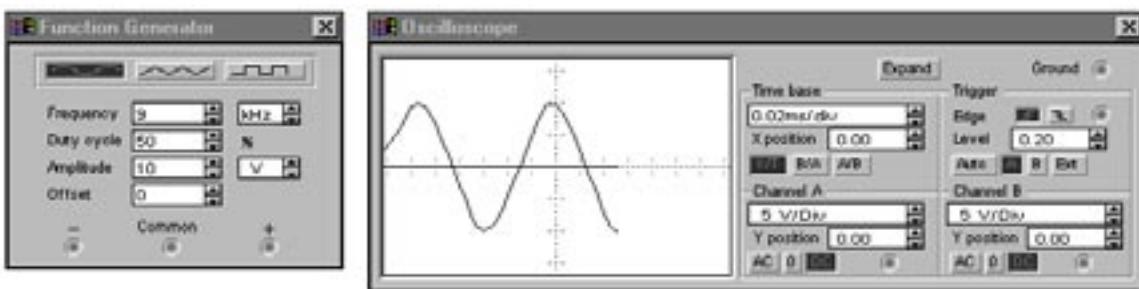


Figure 13. Op Amp Output ($V_{in}=10V$, $f=9kHz$)

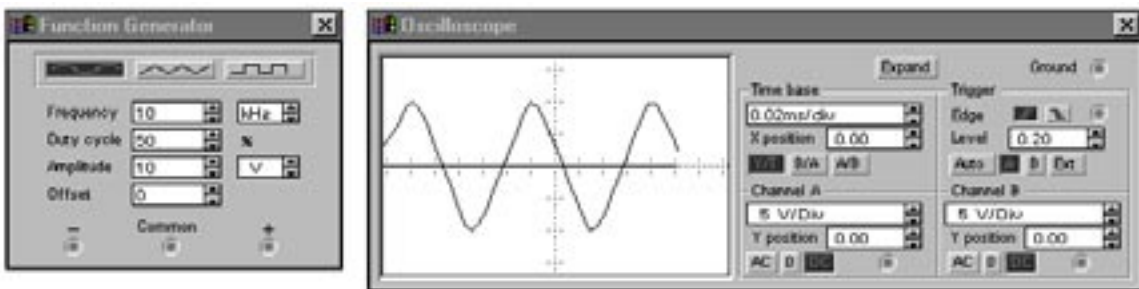


Figure 14. Op Amp Output ($V_{in}=10V$, $f=10kHz$)

At 10 kHz the output waveform shown in Figure 14 is definitely triangular and is starting to show slew rate limiting.

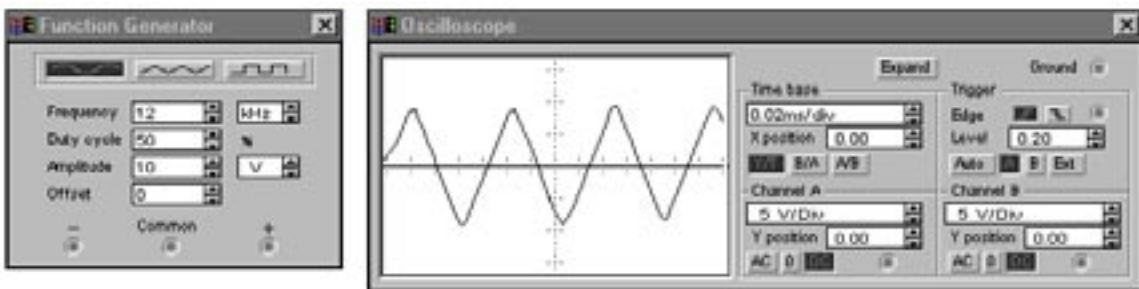


Figure 15. Op Amp Output ($V_{in}=10V$, $f=12kHz$)

At 12 kHz the wave is very obviously triangular as shown in Figure 15. Notice also that the amplitude of the output waveform has also started to drop. This is approximately the limiting frequency you should have measured in the lab.

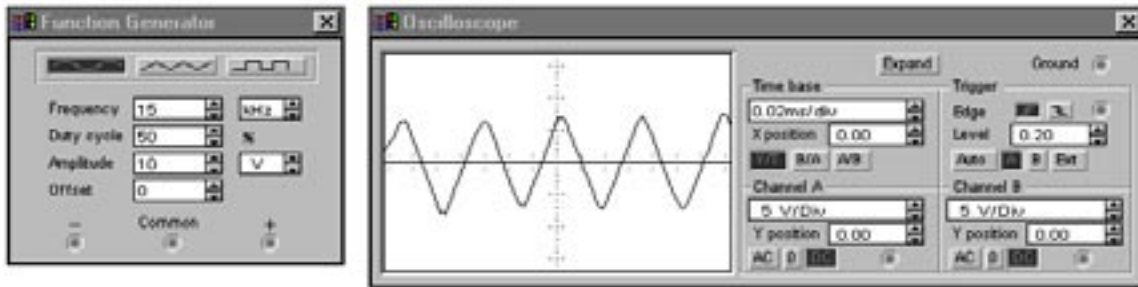


Figure 16. Op Amp Output ($V_{in}=10V$, $f=15kHz$)

At 15 kHz the drop in the amplitude of the output waveform is very obvious as seen in Figure 16.

Calculations

The slope of a sine wave is zero near the peak value of the waveform, and a maximum when the waveform crosses zero. Since a slope is a slope irregardless of the shape of the waveform consider the slope of a sine wave as it crosses zero. Assuming the amplitude of the input sine wave remains constant as you change the frequency you will eventually reach a frequency at which the op amp cannot change voltage any faster, i.e. it will have reached its maximum slope (or slew rate). As you increase the frequency at the input above this frequency the output waveform will start behaving funny and will decrease in amplitude.

Figure 14, Figure 15, and Figure 16 show these effects. This effect will be very important whenever you deal with sensors in the future. Although a slew rate is a slope it also translates into a maximum frequency that the op amp can amplify accurately. Basically, $\frac{dv(t)}{dt} = \text{slew_rate}$. For a sine wave this can be evaluated as $\frac{d(A \cos \omega t)}{dt} = A \omega \sin \omega t$.

We can ignore the $\sin \omega t$ part of this expression and just consider the waveform at its peak amplitude. Slew rate limiting of a sine wave occurs when the op-amp's slew rate equals $A\omega$ for a given sine wave. The published slew rate for the 741 op-amp is about 0.5 volts/ μ second, or $0.5 \times 10^6 \frac{\text{volts}}{\text{sec}}$.

We can use this published slew rate to determine the corresponding frequency at which the input sine wave should become triangular. Let's solve for the corresponding slew rate frequency. The amplitude of the sine wave used in the simulation was 10 volts peak. Equating the published slew rate to the maximum derivative of the sine wave one gets

$0.5 \times 10^6 \frac{\text{volts}}{\text{sec}} = A \omega = (10V)2\pi f$, or $f=7958$ Hz. This is frequency which corresponds to the nominal slew rate of 0.5 volts/ μ second and is close to the frequency at which we first saw distortion of the sine wave. The actual amplitude did not noticeably drop until about 12 kHz which corresponds to an estimated slew rate of $\text{slew_rate} = (10V)2\pi(12 \times 10^3) = 753,982 \frac{V}{\text{sec}} \approx 0.75 \frac{V}{\mu\text{sec}}$ which is not a bad estimate of the slew rate for the 741 op amp.

APPENDIX 2. H-P Oscilloscope Voltage Measurements

Once the top and base calculations are completed, most of the voltage measurements can be made.

V_{min} = voltage of the absolute minimum level
 V_{max} = voltage of the absolute maximum level
 V_{p-p} = $V_{max} - V_{min}$
 V_{base} = voltage of the statistical minimum level
 V_{top} = voltage of the statistical maximum level
 V_{amp} = $V_{top} - V_{base}$

V_{base} may be equal to V_{min} for many waveforms, such as triangle waveforms. Likewise, V_{top} may be equal to V_{max} . Figure 13-9 shows where these waveform definitions occur.

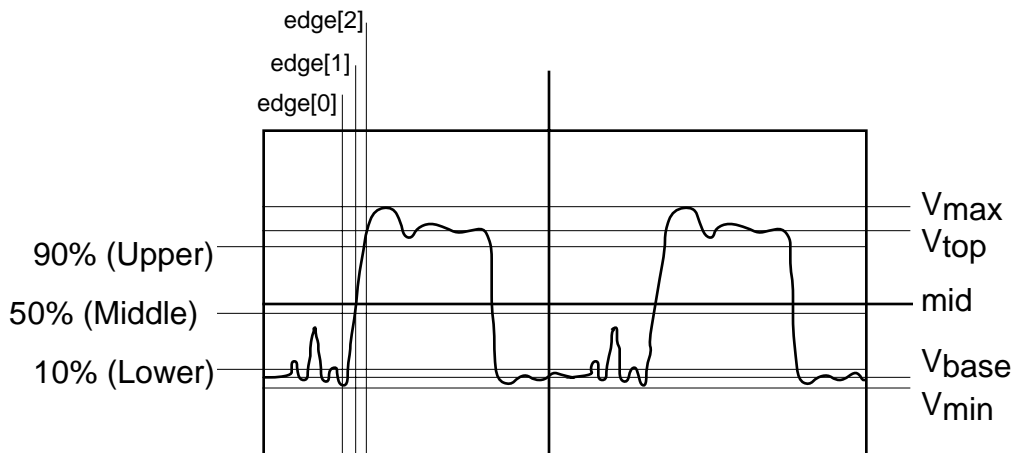


Figure 13-9. **Waveform definitions used to make voltage measurements**

Several of the voltage measurements require threshold and edge information before they can be made.

V_{avg} = average voltage of the first cycle of the signal

Overshoot = a distortion which follows a major transition. If first edge is rising
then overshoot = local max - top
else overshoot = base - local min

Preshoot = a distortion which precedes a major transition

If first edge is falling then preshoot = base - local min
else preshoot = local max - top