ENGR 210 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 can 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 . 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.

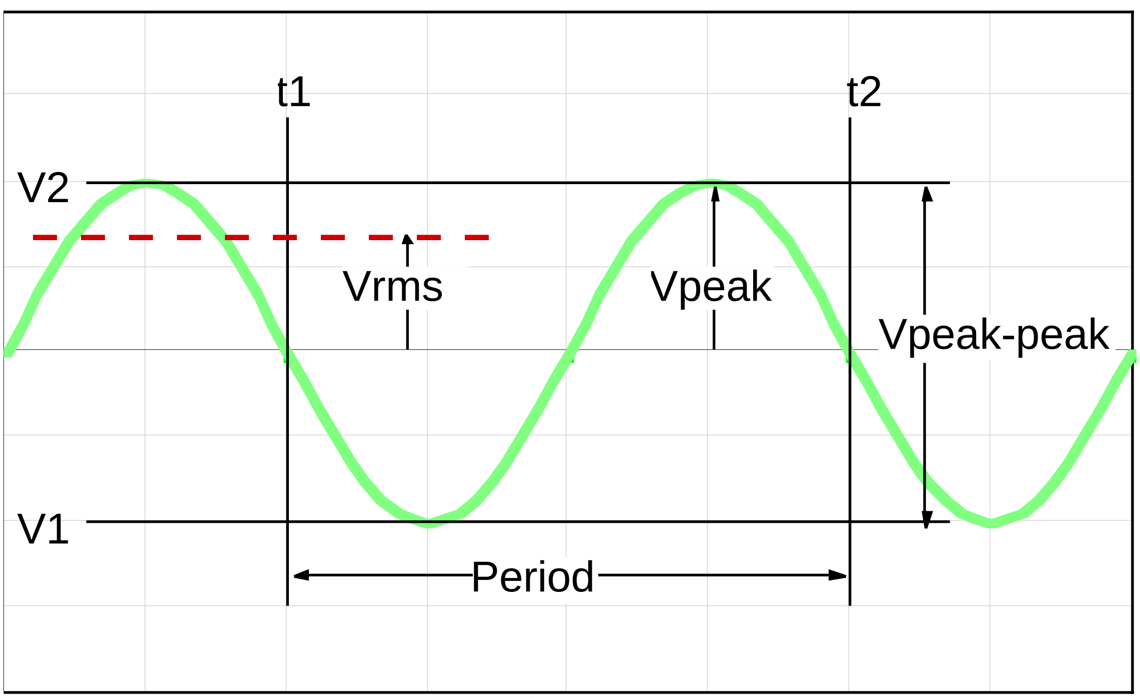


Figure . Characterization of sinusoidally time varying signal.

As shown in , 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(Hz) = $f(Hz) = \dfrac{1}{T(\sec)}$,or $\omega(radians/\sec) = \dfrac{2\pi}{T(\sec)}$ (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_{peak} sinωt, then the peak voltage, V_{peak}, is as shown in . 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 . 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

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

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

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

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,

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

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.,

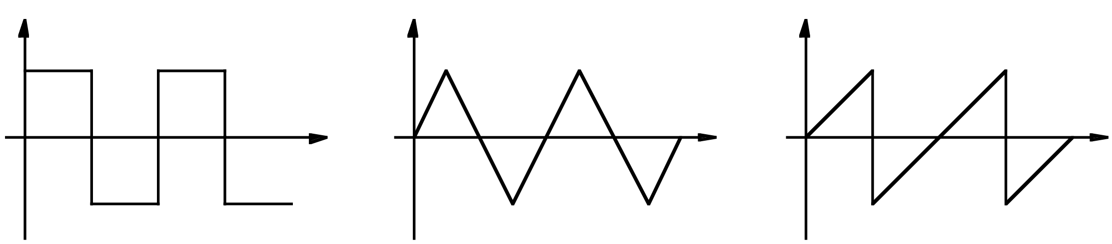
v(t) = Vsinωt,

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

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) = 162.6V and V_{PP} = 2*[115/(0.707)] = 325.2V!

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 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 .



a. Square wave b. Triangle wave c. Sawtooth

Figure . Sample waveforms. (f = 1 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.

<u>The Signal Generator</u>

The signal generator is a voltage source which can produce various time dependent signals waveforms from 0.0001 Hz to about 13 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 Vp-p) with an adjustable DC offset of up to 10 volts positive or negative. The generator has a 50 ohm output impedance (see) which can affect your selection of resistor values in several experiments.

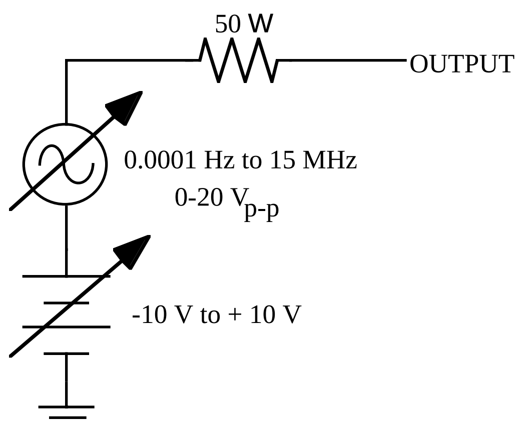


Figure - Functional circuit of a signal generator

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.

<u>The Oscilloscope</u>

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 . The <u>display system</u> 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 producing the display. The <u>vertical system</u> deflects the beam vertically and controls the amplitude axis of the display. The <u>horizontal system</u> 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.

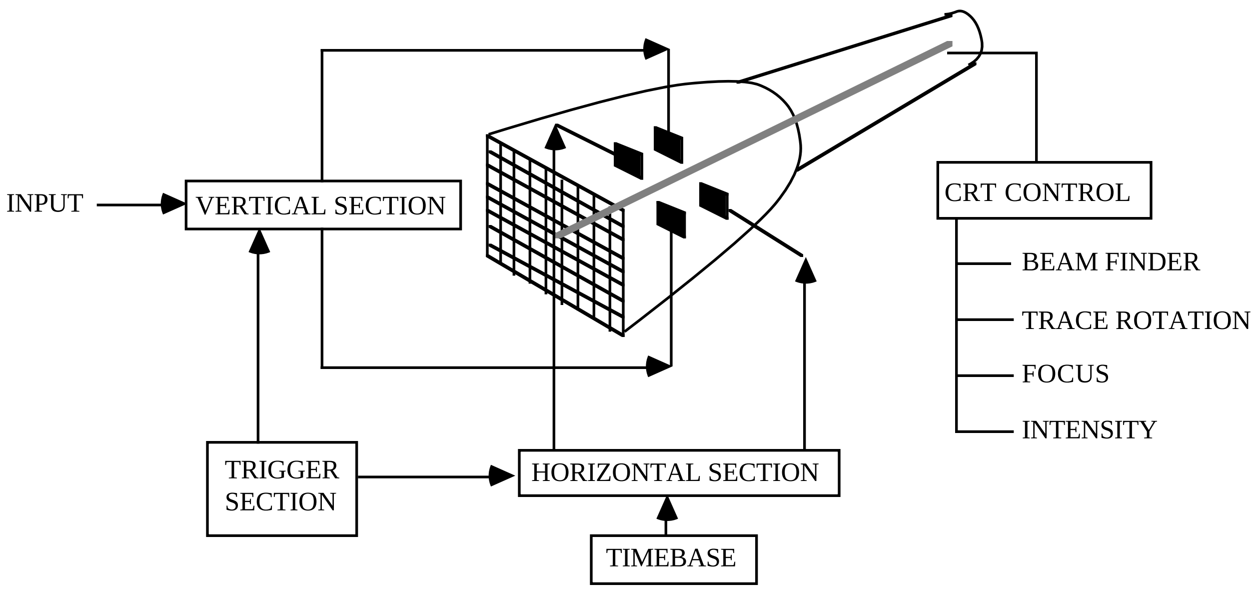


Figure - Functional diagram of oscilloscope

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. shows three consecutive displays of a waveform.

The trigger point, the point at which a sweep is started, is defined by the trigger level and whether you are triggering on a positive or negative slope. The sign of the slope determines whether the trigger point is found on the rising (+) or falling (-) slope of the signal. The level sets the voltage of the trigger point.

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 trigger mechanism is multiple inputs, called channels, to display different signals. Oscilloscopes usually have at least two channels so that one can display two waveforms simultaneously ("chop" in which the scope draws a point on channel one and then a point on channel two and then continues to “chop” back and forth while drawing two waveforms) or alternatively ("alt" in which the scope draws all of the channel one waveform and then draws all of the channel two waveform).

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 most of the above functions built-in. The goal of this lab is to learn how to use some of the different features of the digital oscilloscope.

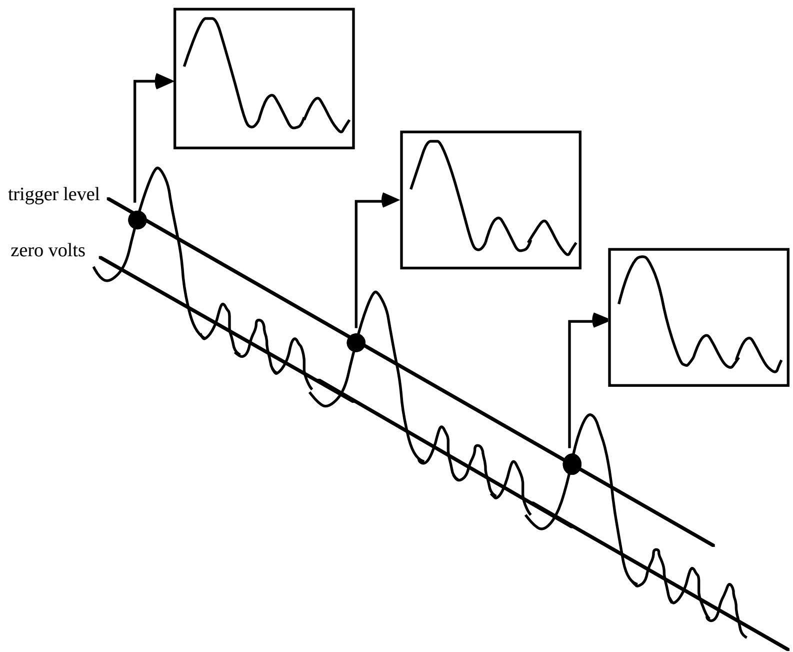


Figure - Oscilloscope waveform display

<u>The oscilloscope probe</u>

You can use simple clip leads to connect your circuit under test to the oscilloscope; however, you will typically want to use an oscilloscope probe for these connections. This 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 connected to the oscilloscope would change the circuit performance from what you wanted to measure. We will see this in future lab circuits. An oscilloscope probe has an internal large input resistance which reduces the circuit loading. A probe usually attenuates the signal by a factor of 10 although some scopes have switchable attenuators, typically X1 and X10.

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.

shows a typical probe. The probe usually has a small box connected to it which contains part of the attenuator (voltage divider) (see .) The advantage of using this 10:1 attenuator is that it reduces circuit loading. By adding a resistance of 9 MOhm the input resistance seen by the circuit under test increases from 1 MOhm to 10 MOhm. As a result, the current that needs to be supplied by the circuit will be 10 times smaller and thus reduces the circuit loading.

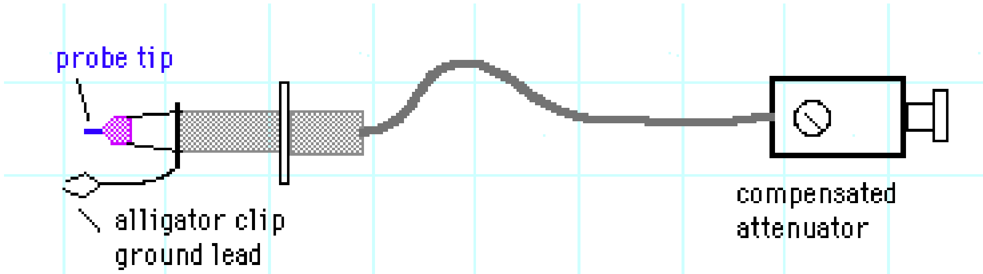


Figure . A typical oscilloscope probe

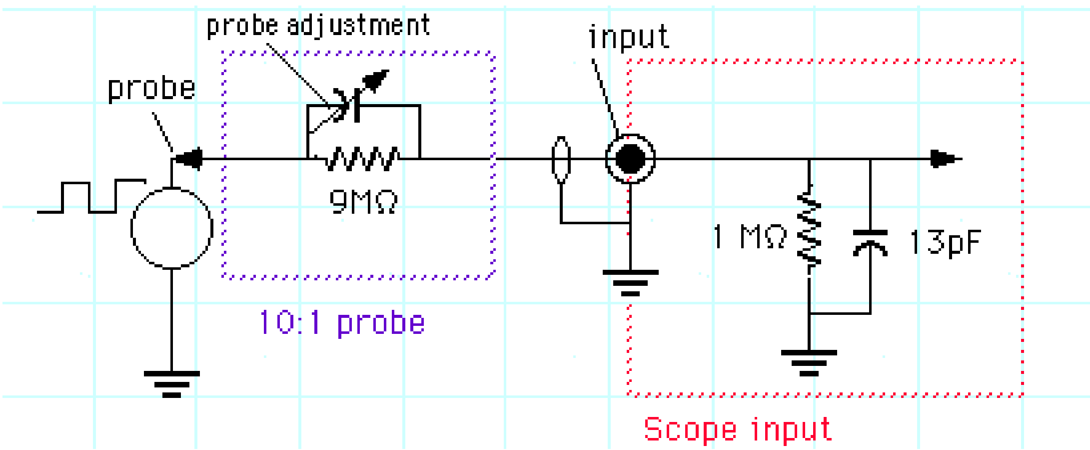


Figure . A 10:1 divider network of a typical probe.

You will notice that the probe has a variable capacitor across the 9 MOhm resistor. This is done in order to ensure that high frequency signals are not distorted. The effect of adjusting this capacitor is illustrated in for measuring a square wave signal by an oscilloscope. When the probe is property adjusted (compensated) a square wave will be displayed with a flat top. However, a poorly adjusted probe can give considerable distortion and erroneous readings of the peak-to-peak amplitude of the signal. You should get into the habit of checking the probe compensation with a square wave every time you use it.

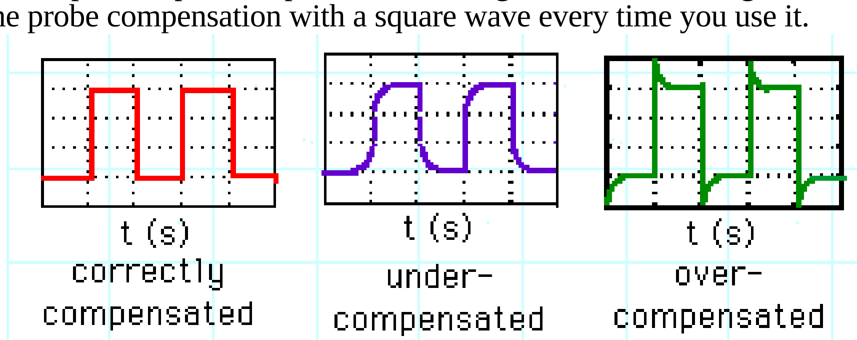


Figure . The effects of probe compensation: (a) correctly adjusted probe, (b) undercompensated and (c) overcompensated probe

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 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 , but changes how the output voltage is calculated. For example, if you placed a 50W load on the generator and programmed the generator in 50W mode to output 1 volt, then you would really get 1 volt as measured by an external meter. However, if you put a 1000W (a high impedance) load at the output of the generator and you were still in 50W mode, almost all of the generator voltage would be developed across the load resistance because it is so much larger than the 50W 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.

REPORT SHEET FOR LAB6 - PART A

Student Name (Print): ___________________ Student ID: ________________________

Student Signature: _______________________ Date: ______________________________

Student Name (Print): ___________________ Student ID: ________________________

Student Signature: _______________________ Date: ______________________________

Lab Group: ___________________

ANSWER THE FOLLOWING QUESTIONS:

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

<u>Function Generator</u>

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

Answer:
Turn the function generator on.
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 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) 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:
Press the SHIFT button
Press the MENU ON/OFF button
Press the Right Arrow (>) to get to D: SYS MENU
Press the down arrow until you get the message 50 OHM.
Press the right arrow (>) until you get HIGH Z.
Press the ENTER button to select this value.

4. Using , 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 50W load on the generator and programmed the generator in 50W mode to output 1 volt, then you would really got 1 volt as measured by an external meter. However, if you put a 1000W (a high impedance) load at the output of the generator and you were still in 50W mode, almost all of the generator voltage would be developed across the load resistance because it is so much larger than the 50W 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:
Press the AMPL button
Press the ENTER NUMBER button
Press the "5" button to set the amplitude.
Press the up arrow to enter the amplitude

6. Describe how you program the Function Generator to output a sine waveform?
ANSWER:
Press the ∿ button
Press the ENTER NUMBER button
Press the "5" button to set the amplitude.
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:
Press the channel "1" to turn on the scope menus.
Press the button underneath the "10" below PROBE.

2. Describe how to use the oscilloscope for a calibrated peak-peak voltage measurement?
Answer:
Make sure the probe adjustment is correctly set
Press the "Voltage" button on the oscilloscope.
On the scope menu, press the button underneath "Vp-p".

3. Describe how to use the oscilloscope for a calibrated RMS voltage measurement?
Answer:
Make sure the probe adjustment is correctly set
Press the "Voltage" button on the oscilloscope.
On the scope menu, press the button underneath "Vp-p".

4. 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*.707=1.7675 volts. I was expecting a value — -1 to -2 if no value

5. Describe how to use the oscilloscope for a calibrated time measurement?
Answer:
Press the "Time" button on the oscilloscope.
On the scope menu, press the button underneath "Freq".

6. What does the **Delay** knob on the oscilloscope do?
Answer: Delays the trigger to move the display across the oscilloscope screen.

7. 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.

Exponential Waveforms:

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

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

Answer:

f=1/10 milliseconds = 100 Hz

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:

Use the HP 33120A function generator to create a sinusoidal waveform with a peak-to-peak amplitude of 1 Vpp and frequency of 1 kHz. If necessary, review the tutorial on the "Function Generator/Arbitrary Waveform Generator" on the Web page.

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; then push the Off/On key underneath the display window.

Change the scale (V/div) of channel 1 (V/div KEY) (vertical panel) and note the display changes. Try out a few other settings.

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.

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, 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).

Do only if speakers are available in the lab. Connect the output of the function generator to the input of the speaker. Use alligator clips to connect the function generator output to the speaker. Do not turn the volume up too high (to prevent a cacophony of sounds in the lab). Change the frequency of the signal and record how low and high a frequency you can hear in your data report (end of this lab).

Now disconnect the speaker for quietness.

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

Display on channel 1 a sinusoid of a few kilohertz and a few Vpp in magnitude.

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 in the data table what happens. Next, select channel 1 as the trigger source.

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) and notice what happens. Can you explain it? What happens when the trigger level exceeds the peak voltage of the sinusoid? Next, select Norm trigger mode (at bottom of the display).

Select trigger Slope/Coupling key on the trigger panel. Switch between the positive and negative going slopes. Note the effect on the display.

4. 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.

Select a square wave on the function generator with an amplitude of 1 Vpp, 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.

Push the VOLTAGE key on the measure panel. Select one of the keys at the bottom of the display to measure the peak-to-peak voltage (Vpp), average (Vavg) and RMS (Vrms) voltage. Compare and record the Vpp to the RMS values. What is the relationship between both? Now, push the Next Menu button at the bottom of the display. You can now measure the Vmax, Vtop, Vmin and Vbase values. Record these values. The overshoot is how much the leading edge of the square wave exceeds the final value of the square wave. Display and measure the overshoot of the signal.

Push the TIME key on the measure panel in order to measure the frequency and period,. Vary the timebase such that you see one or two periods on the screen. Select the appropriate keys to measure the frequency (compare with the setting on the function generator), the period and duty cycle. Record these values. Then go to the Next Menu to measure the rise and fall times.

Use the cursors to measure time or voltage differences. Push the CURSOR key on the measure panel. Two vertical position-controllable cursors appear and can be used to make time measurements anywhere along the displayed waveform. Use the cursors to measure the pulse width and pulse period. Experiment on your own. Similarly, two horizontal cursors are available for precision voltage measurements.

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.

5. Scope Probe

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

Scope Probe Adjustment

Probe pins can be easily damaged or broken. Handle the probe with care.

Connect the probe to one of the input channels 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 or 2 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 signal at the terminal on the front panel (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.

Measuring a square wave

Set the waveform generator to a square wave with a frequency of 2 MHz and 2 Vpp. Also display the square wave on the oscilloscope using a coax cable (black cable) or any other lab connectors. Notice that the square wave is not very clean and that it has a considerable amount of ringing. Make a sketch of the screen (we will cover how to get a file of the screen data in a future lab). Next use the probe scope to display the signal. 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).** Also, you must connect the ground of the function generator to the ground connector of the probe. Adjust the vertical scale of the scope and notice the waveform. It should be much cleaner with less ringing. Make a sketch for your report.

Effects of a poorly adjusted probe

Connect the probe input to the output of the function generator (make sure that the ground of the function generator is connected to the probe ground). Select a 2 MHz square wave of 10 Vpp and display it on the scope. Use the cursors on the scope to measure the waveform characteristic: peak-to-peak value, Vtop, Vmax. Record the values. 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 measurement as before, recording them. How does it compare with the measurement of a compensated probe? Now readjust the probe carefully, using the reference square wave signal at the scope terminal.

This only works using the reference signal from the scope. The signal generator output does not change fast enough to cause problems with the scope probe.

test

6. Bad 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 the sordid truth about op amps: *they're not as good as we keep saying they are in class!* Sorry about that but you're now ready for the real truth. Let's start by looking at one way that op amps depart from the ideal model.

Op-amp Limitations: *Slew Rate*

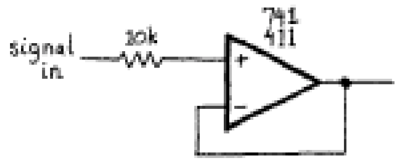


Figure . Slew rate measuring circuit

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)

a) Square wave input

Build the circuit shown in Figure 9. Drive the input with a square wave in the neighborhood of 1 kHz, and look at the output with a scope. Measure the slew rate by observing and measuring the slope of the transitions. You will need to zoom in on a rising or falling edge of the square wave and will probably want to use the cursors for a good measurement.

Suggestions:
Find a straight central section of the square wave; avoid the regions near "saturation', i.e.,. near the maximum or minimum limits of output swing.
Full slew rate is achieved only for strong "overdrive:" a large difference signal 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. See what happens as the input amplitude is varied.
The rates for slewing up and down may differ.

b) *Sine input*

Switch to a sine wave keeping everything else the same as for the above measurements. Be sure to record the initial amplitude of the sine wave as you will need this for your write-up. Vary the frequency and measure the frequency at which the output amplitude begins to drop. Again this must be a large signal measurement with Vin on the order of 10 Volts or more peak.

DATA SHEET FOR LAB6 - PART B

Student Name (Print): ____________________ Student ID: ________________________

Student Signature: _______________________ Date: ______________________________

Student Name (Print): ____________________ Student ID: ________________________

Student Signature: _______________________ Date: ______________________________

Lab Group: ____________________

DATA:

1. f) f_{LO}= __________ Hz; f_{HI}=__________ kHz.

RECORD ONLY IF SPEAKERS WERE AVAILABLE IN LAB

3. b) What happened?

3. c) What happened?

4. b) V_{MAX} = __________ Volts

V_{TOP} = __________ Volts

V_{MIN} = __________ Volts

V_{BOTTOM} = __________ Volts

Overshoot:

t_{RISE} = __________ Seconds

t_{FALL} = __________ Seconds

4. c) frequency = __________ Hz

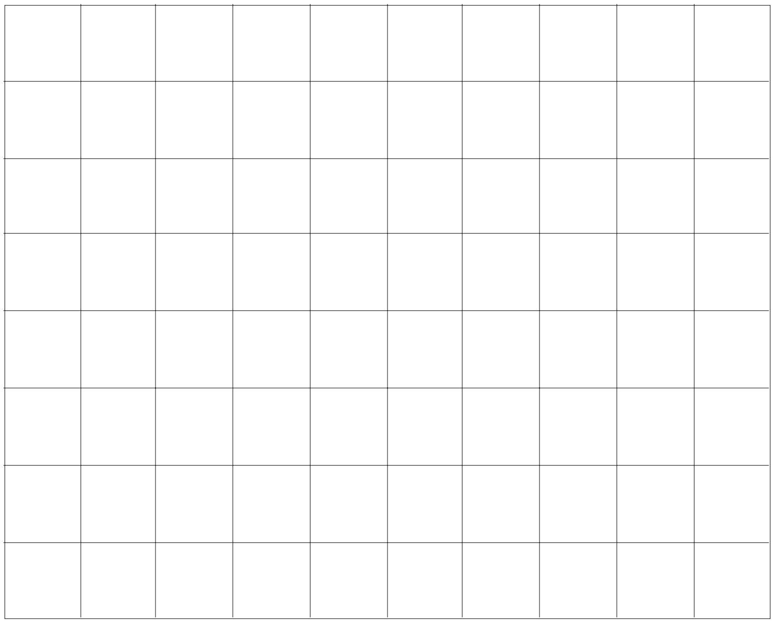
period = __________ seconds

duty cycle = __________ %

4. d) pulse width = __________ Hz

pulse period = __________ seconds

5. b) Sketch of square wave measurement w/o using scope probe.



Volts/div:

____

Time/div

____

Sketch of square wave measurement using scope probe.

Volts/div:

____

Time/div

____

5. c) Measurements with correctly adjusted scope probe.

V_{MAX} = _________ Volts

V_{TOP} = _________ Volts

V_{P-P} = _________ Volts

Measurements with mis-adjusted scope probe.

V_{MAX} = _________ Volts

V_{TOP} = _________ Volts

V_{P-P} = _________ Volts

6. a) Measured slew rate of 741 op-amp: ___________ V/µs

6. b) Frequency at which 741 output begins to drop: ______ Hz

REPORT SHEET
FOR LAB6 - PART B

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 3(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 3(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 Vtop and Vmax in 4(b)?
ANSWER: Vtop is some sort of average; even the manual is not clear on this. However, Vmax 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.

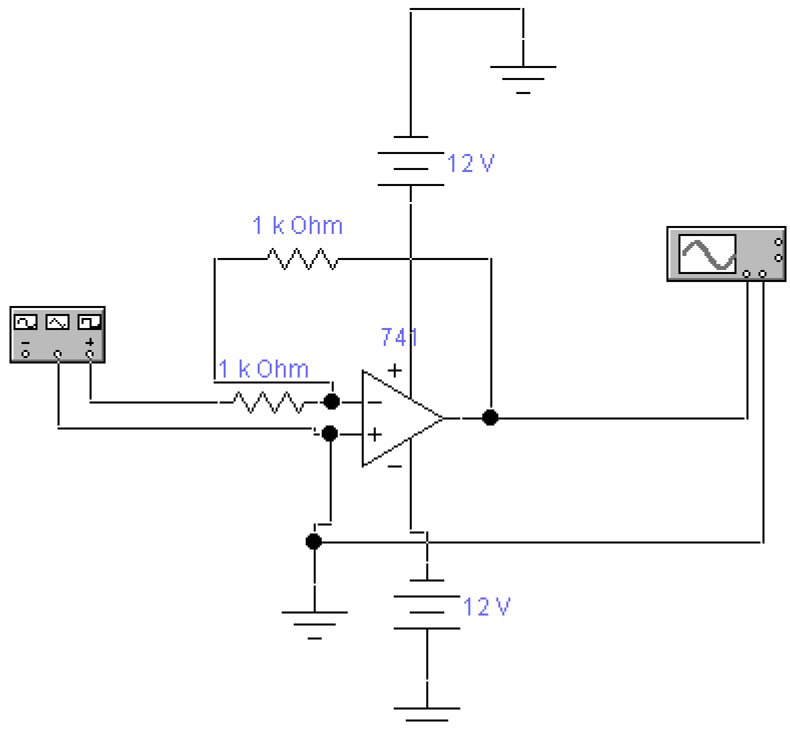
4. Describe how you measured the overshoot in 4(b).
ANSWER: The most elegant way was to compute Vmax - Vtop. Overshoot is not a time; it is the amount by which the voltage waveform exceeds the expected value.

5. Calculate the duty cycle from your measurements in 4(d) and compare with the measurement result in 4(c).
ANSWER:

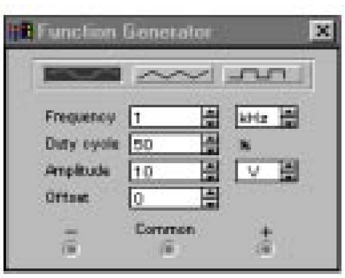
6. Why were your measurements different using a correctly and then a mis-adjusted scope probe in 5(c)?
ANSWER: The probe cannot respond correctly to quickly changing waveforms unless it is properly adjusted.

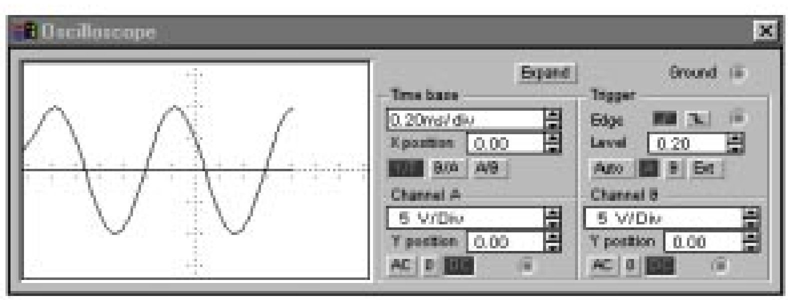
7. Compare your measurements for 6(a) and 6(b). HINT: What is the maximum slew rate of a sine wave of frequency w? Using this relationship determine the frequency of an equivalent sine wave with the slew rate you measured in 6(a). Also using this relationship compute the frequency of a sine wave with the slew rate you measured in 6(a).

ANSWER: Let's consider the circuit shown below and use it to measure the effects of maximum slew rate upon a sine wave.



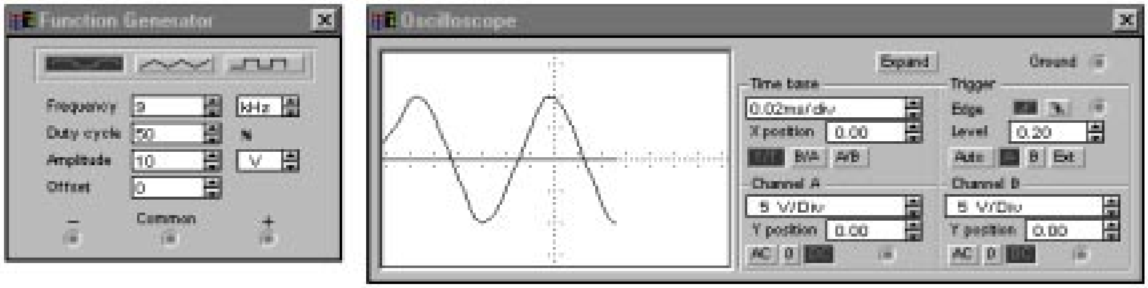
This analysis was done in Electronics Workbench using their 741 op-amp model which is pretty accurate. The circuit shown above has a gain of 1 (the exact gain is not important for this analysis), and is initially being driven by a 1 kHz sine wave of 10 volts peak amplitude. Under these conditions the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



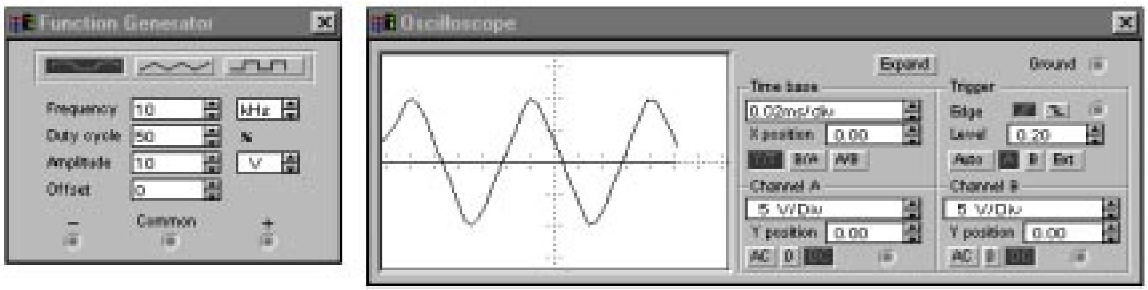


Lets look at what happens when we increase the frequency of the sine wave to about 8 kHz as shown below. The output still appears very sinusoidal.

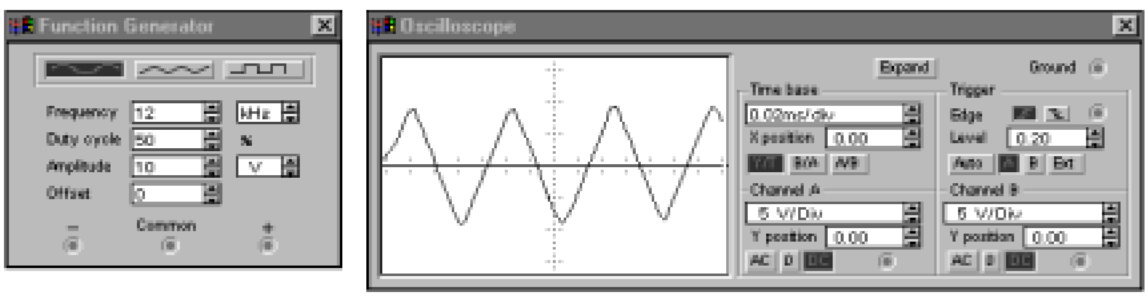
This still looks fine. So, let's increase it to 9 kHz.



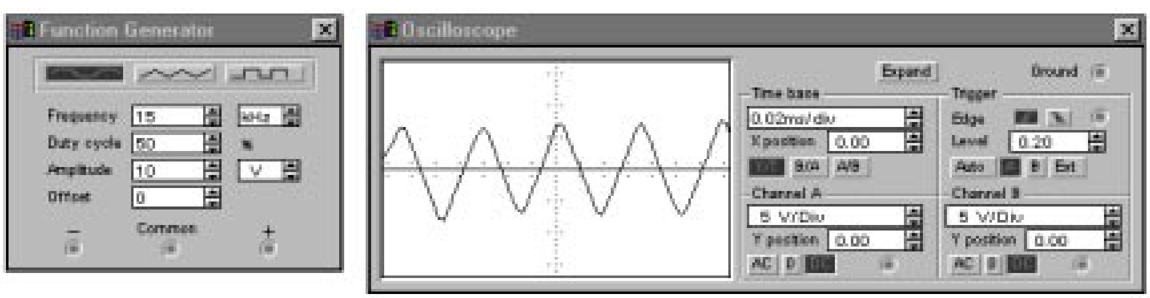
Let’s increase the generator frequency to 10 kHz.



At 10 kHz the output waveform shown above is definitely triangular and is slew rate limited. Let’s go to 12 kHz.



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



At 15 kHz the drop in the ampltude of the output waveform is very obvious. The relationship between slew rate and the frequency of a sinusoid was discussed in an e-mail. Basically, dv(t)/dt=slew rate and for a sinusoid, $d/dt(A\cos\omega t)=A\omega\sin\omega t$. We can ignore the sinwt and just consider the waveform at its peak amplitude. Skew 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/microsecond, or 0.5x10^6 volts/sec. The amplitude of the sine wave used in the simulation was 10 volts peak. Let's solve for the corresponding slew rate frequency.

0.5x10^6=(10 volts)*2*p*f, or f=7958 Hz. This is about the frequency at which we first saw distortion of the sine wave and has a computed slew rate of 0.5 volts/microsecond. The actual amplitude did not noticably drop until about 12 kHz which corresponds to a slew rate of Aw=(10volts)*(2*p*12x10^3)=753,982 volts/second=0.75 volts/microsecond. This is not a bad estimate of the slew rate.

Comments on grading:
Part A:
This part was 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
7. 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 got these points confused or did not know that there were multiple cursors points were taken off.

Part B:
This part was 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 m,agnitude. The major problem seemed to be that people were using input voltages that were too small. Since no calculations or procedures were shown on most papers I had no choice but to take off points for data that was completely unreasonable. This part cost many people 1-5 points depending upon how unbelieveable or how undocumented the answer was. Very few points were taken off elsewhere.

Part C:
This part was 35 points total. Each question was 5 points.