

# Laboratory 3 (drawn from lab text by Alciatore)

## *The Oscilloscope*

### Required Components:

- 1      10Ω resistor
- 2      100Ω resistors
- 2      1kΩ resistors
- 1      2kΩ resistor
- 2      4.7MΩ resistors
- 1      0.022μF capacitor
- 1      0.1 μF capacitor
- 1      1.0uF capacitor

### Objectives

In the previous laboratory exercise you learned about the basic operation of the oscilloscope. This laboratory exercise is designed to give you a more in-depth understanding of the proper use of the oscilloscope and its range of applications.

The oscilloscope is probably one of the most widely used electrical instruments and is one of the most misunderstood. During the course of this laboratory exercise you will become familiar with the proper methods of connecting inputs, grounding, coupling, and triggering the oscilloscope. Also during the course of this experiment you will learn the proper use of the oscilloscope attenuator probe.

### Introduction

#### AC and DC Signals

An AC signal varies with time, and its deterministic expression contains time as the independent variable. For example, Eqs. 3.1 and 3.2 are time varying signals.

$$F_1(t) = 2.0V \sin(5/s t) \quad (3.1)$$

$$F_2(t) = 3.1V \cos(5/s t) + 5.1V e^{-\frac{3.0}{s}t} \quad (3.2)$$

A DC signal on the other hand does not vary with time, hence t does not appear in its expression:

$$F_3(t) = 1.0V \quad (3.3)$$

$$F_4(t) = 5.63V \quad (3.4)$$

Now what if our signal can be written:

$$F_5(t) = 2.0V + 1.0V \sin(5/s t) \quad (3.5)$$

Is it AC or DC? Well, we say it is AC ( $1.0 \sin 5/s t$ ) with a DC offset (2.0). We can see this if we plot the signal below:

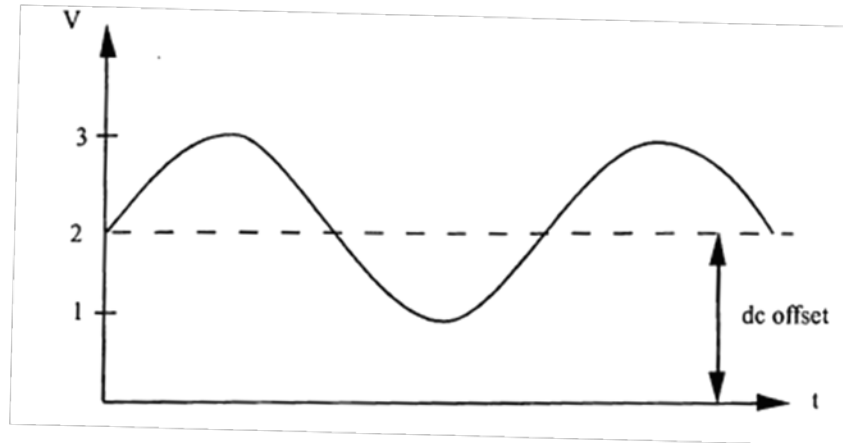


Figure 3.1AC Signal with DC offset.

This difference between an AC and DC signal is important when understanding oscilloscope coupling.

### AC and DC Coupling

Most oscilloscopes are provided with a switch to select between AC or DC coupling of a signal to the oscilloscope input amplifier. When AC coupling is selected, the DC component of the signal is blocked by a capacitor inside the oscilloscope that is connected between the input terminal and the amplifier stage. Both AC and DC coupling configurations are illustrated in Figure 3.2.  $R_{in}$  is the input resistance (impedance) and  $C_{in}$  is the input capacitance.  $C_c$  is the coupling capacitor that is present only when AC coupling is selected.

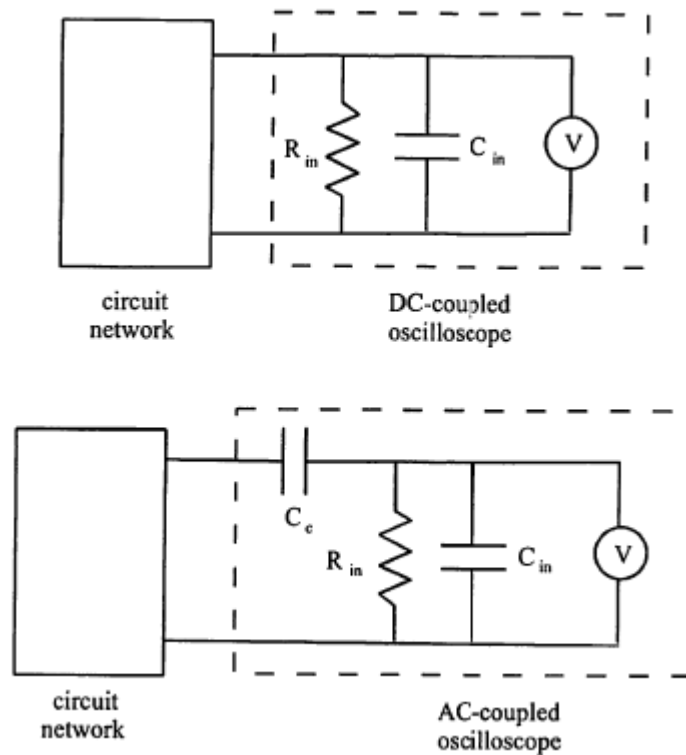


Figure 3.2 Oscilloscope Coupling

### AC Coupling

AC coupling must be selected when the intent is to block any DC component of a signal. This is important, for example, when measuring small AC spikes and transients on a 5 V TTL (transistor-transistor logic) supply voltage. However, it must be kept in mind that with AC coupling:

- One is not aware of the presence of any DC level with respect to ground.
- The lower frequency components of a signal are attenuated.
- When the oscilloscope is switched from DC to AC coupling, it takes a little time before the display stabilizes. This is due to the time required to charge the coupling capacitor  $C_c$  to the value of the DC component (average value) of the signal.
- Sometimes the input time constant ( $\tau = R_{in} C_c$ ) is quoted among the oscilloscope specifications. This number is useful, because after about five time constants ( $5\tau$ ), the displayed signal is stable.

AC coupling can be explained by considering the impedance of the coupling capacitor as a function of frequency:

$$Z = \frac{1}{j\omega C} \quad (3.6)$$

where  $j$  represents the imaginary number  $\sqrt{-1}$ . With a DC voltage ( $\omega = 0$ ) the impedance of the capacitor is infinite, and all of the DC voltage at the input terminals of the oscilloscope will appear across the capacitor. Thus, AC-coupling the oscilloscope will eliminate any DC offset present in the voltage appearing across the input terminals of the oscilloscope. For AC signals, the impedance is less than infinite, resulting in attenuation of the input signal dependent upon the frequency. As the input frequency increases the attenuation decreases to zero. The coupling mode is selected using the input selectors on the front panel of the oscilloscope. Generally, if the signal type is unknown, DC coupling is the first choice for observing the signal.

### Triggering the Oscilloscope

Triggering refers to an event at the input terminals of the oscilloscope that causes the electron beam to sweep across the screen and display the terminal voltage. The oscilloscope may be level triggered either in the AC or DC mode, and the level of the magnitude is adjustable using the trigger level control. The slope (+ or -) of the terminal voltage also affects when the beam is triggered. This slope is selected either positive or negative.

Another triggering option available is that of line triggering. Line triggering uses the AC power input to synchronize the sweep. Thus, any terminal voltage synchronized with the line frequency of 60Hz or multiples of 60Hz can be triggered in this mode. This is useful to detect if 60 Hz noise from various line related sources is superimposed on the signal.

### Grounding Source and Scope

Normally, all measurement instruments, power sources, and signal sources in a circuit must be referenced to a common ground as shown in Figure 3.3.

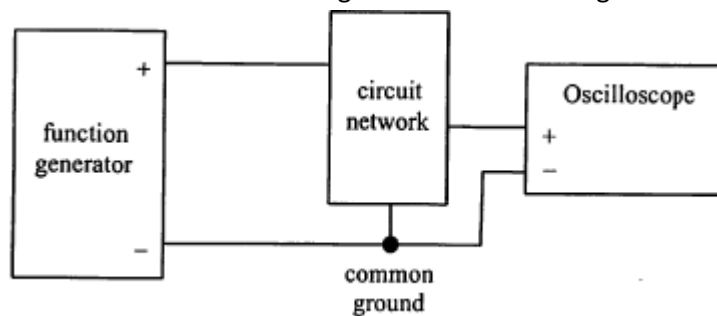


Figure 3.3 Common Ground Connection

However, as can be seen from Figure 3.4, if we wish to measure a differential voltage  $\Delta V$ , it is correct to connect the scope as shown. Note that the oscilloscope signal ground and external network ground are not common. This type of connection allows us to measure a potential difference anywhere in a circuit.

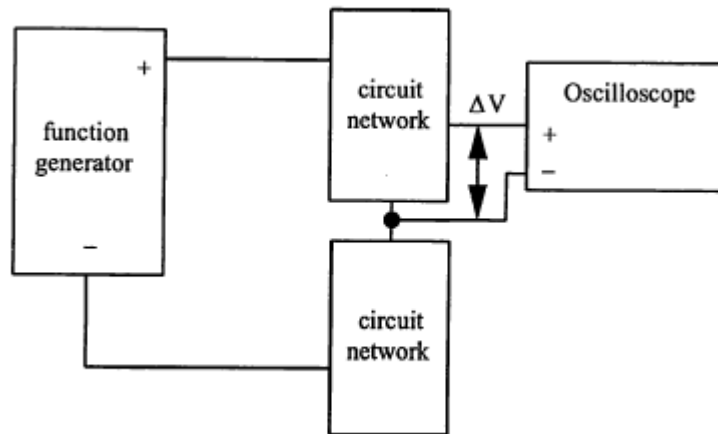


Figure 3.4 Relative Ground Connection

**NOTE** - In many oscilloscopes, including the HP54602A, each channel's "-" signal reference is attached to chassis ground, which is attached to the ac line ground. Therefore, to make a differential voltage measurement, you must use the "Ch1 - Ch2" signal difference feature, using the "+" leads of each channel. An alternative for dc circuits is to measure the voltage at each node separately, relative to ground, and then manually subtract the voltage readings.

### Properly Grounding the Oscilloscope to the Wall Socket

The laboratory the oscilloscope is equipped with a 3-pronged plug (see Figure 3.5) for safety purposes. The two flat prongs of this plug complete the circuit for alternating current to flow from the wall socket to the instrument. The round prong of the plug is connected only to the chassis and not to the signal ground. This is important to protect the operator if there is a short circuit inside the oscilloscope. Otherwise, a high voltage can occur on the chassis jeopardizing the safety of the user.

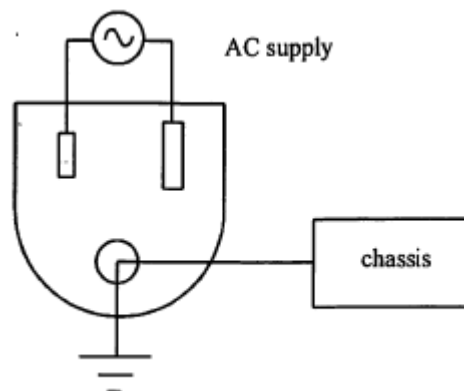


Figure 3.5 Three-prong AC power plug

## Using the Attenuator Probes

In a previous laboratory exercise you determined the input impedance of the oscilloscope, and you should have found it to be approximately  $1\text{M}\Omega$ . An input impedance of  $1\text{M}\Omega$  is large and in most cases can be considered infinite. However, when measuring the voltage drop across an element whose impedance is of an order of magnitude of  $1\text{M}\Omega$  or larger, the input impedance can induce serious error in the measurement. To avoid this problem, the input impedance of the oscilloscope must be increased. One method of increasing the oscilloscope input impedance is the use of an attenuator probe. The use of an attenuator probe will increase the input impedance by some known factor but will at the same time decrease the amplitude of the input signal by the same factor since the current into the oscilloscope is limited by the input impedance. Thus a 10X probe will increase the magnitude of the input impedance of the oscilloscope by a factor of 10, but the displayed voltage will be only 1/10 of the amplitude of the actual terminal voltage. Most oscilloscopes offer an alternative scale to be used with a 10X probe. A simple schematic of the oscilloscope input terminals with the probe attached is presented in Figure 3.6

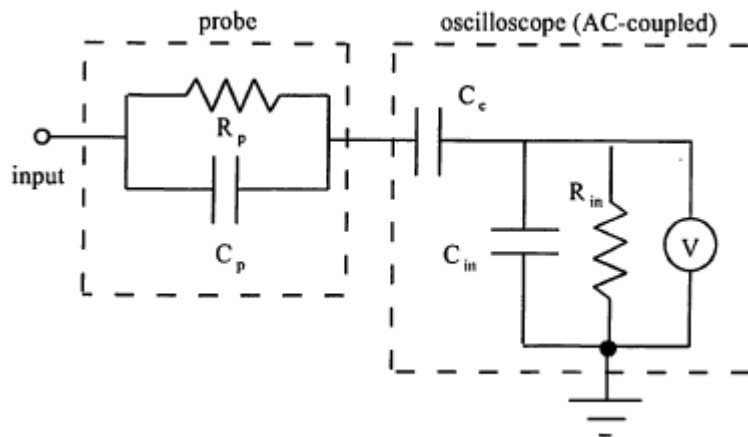


Figure 6 Simplified Model of Oscilloscope and Probe

Note that the addition of the attenuator probe to the input terminals of the oscilloscope not only changes the resistive characteristics of the terminals but the capacitive characteristics as well. A complete model for the oscilloscope, the cable connections and the attenuator probe is shown in Figure 3.7.

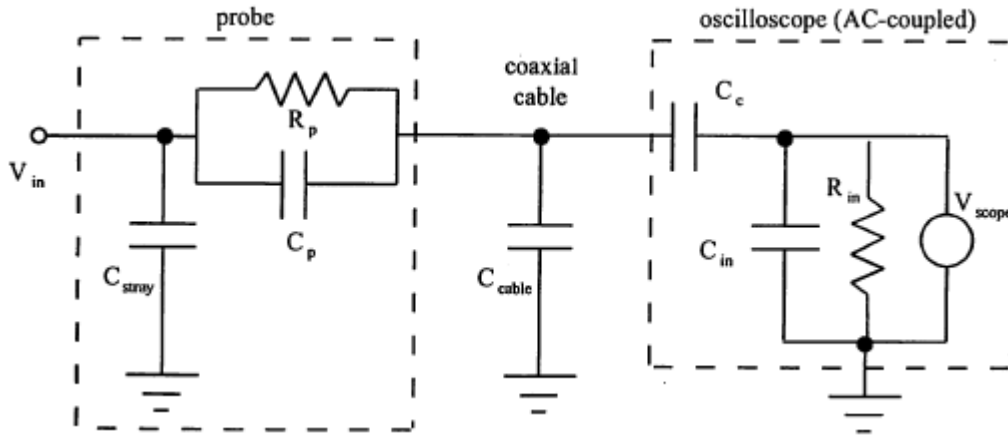


Figure 3.7 Complete Model of Oscilloscope, Probe, and Cable

Due to the collection of complex impedances between the input ( $V_{in}$ ) and the oscilloscope voltage measuring device ( $V_{scope}$ ), the voltage reading will depend on the frequency components of the input (in addition to the input voltage magnitude). However, by adjusting  $C$ , this dependence can be minimized.  $C$  can be adjusted by turning the small screw in the attenuator probe and monitoring a square wave output from the probe adjust port on the front panel of the oscilloscope. The diagram given in Figure 3.8 will help you when tuning the probe.

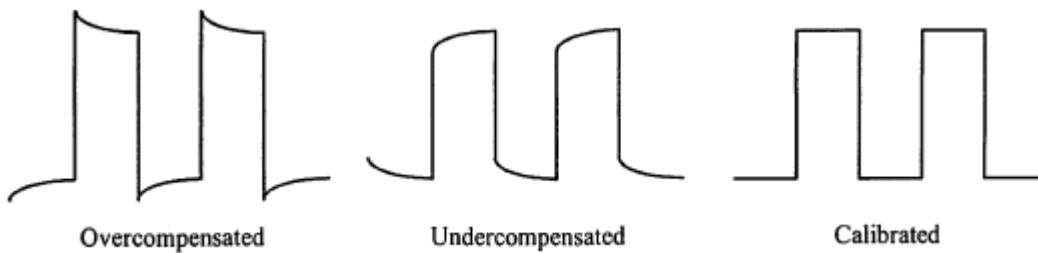


Figure 3.8 Attenuator Probe Calibration

The use of  $C_p$  to minimize the frequency dependence can be understood by looking at the impedances in the model. To simplify the analysis we will assume that the effects of  $C_{stray}$  and  $C_c$  are negligible, so the impedances of the circuit sections are

$$Z_{scope} = \frac{R_{in}}{j \omega R_{in} C_{in} + 1} \tag{3.7}$$

$$Z_{scope+cable} = \frac{R_{in}}{j \omega R_{in} (C_{in} + C_{cable}) + 1} \tag{3.8}$$

$$Z_{probe} = \frac{R_p}{j \omega R_p C_p + 1} \tag{3.9}$$

and from voltage division, the resulting voltage input-output relationship is

$$\frac{V_{scope}}{V_{in}} = \frac{Z_{scope+cable}}{Z_{probe}+Z_{scope+cable}} = \frac{\frac{R_{in}}{j\omega R_{in}(C_{in}+C_{cable})+1}}{\frac{R_p}{j\omega R_p C_p+1} + \frac{R_{in}}{j\omega R_{in}(C_{in}+C_{cable})+1}} \quad (3.10)$$

Note that if we adjust  $C_p$  so  $R_p C_p = R_{in}(C_{in} + C_{cable})$ , the frequency dependence will be eliminated.

## Specific Background Information on Using an BK Precision 2120B Oscilloscope

Looking at the front of the scope you can see that it contains a screen and a number of buttons and knobs. The screen displays the output of the oscilloscope. Just below the screen are six 'soft' buttons. The function of these buttons will change depending upon menu selections. The current function of each button is displayed directly above the button on the bottom of the screen.

### The Screen

The screen is divided into eight vertical and ten horizontal divisions. Typical information displayed on the screen includes:

- The Y-Axis Scale: The Y-Axis scale is different for each channel.
- The Time Scale: Each channel has the same time scale.
- Trigger information: The current trigger mode is in the upper right hand corner of the screen. It is displayed either as an up arrow or as a down arrow indicating positive or negative slope triggering.

### Buttons and Dials

The buttons and dials on the oscilloscope are separated into five groups: Vertical, Horizontal, Trigger, CRT and Power.

#### Vertical

The vertical group contains two columns, one for each channel. Each column contains a coaxial input port. Above the input port is a dial that controls the number of volts per division. Above this dial is a knob labeled "Position." This knob can be used to adjust the location of the ground on the screen. Beside the dial is a lever that allows you to control the coupling of the signal (AC, DC, or display ground).

Between the volt/div dial is the vertical mode lever, it allows you to control which signal(s) appear on the screen, switch to XY mode, or add the signals together.

#### Horizontal

The horizontal control group contains one large knob (Time/Div) and one small knob (Var Sweep). The large knob is used to adjust the time scale on the screen. This will allow you to zoom in on sections of the signal. The small knob labeled "Var Sweep" allows you to decalibrate the sweep frequency. You would rarely use this.



## Trigger

Triggering ensures that the display of a signal will be stable for direct observation. Triggering is the event that causes the scope to start scanning the electron beam creating the displayed signal called a trace. The scope starts the trace at the left and moves to the right at a speed determined by the time scale. For example, if the time scale is 200ms/division it will take the scope 2 ms (200ms/division times ten divisions) to complete the trace. Once the trace has reached the end of the screen the scope waits for another triggering event to initiate the trace again. The triggering event can be adjusted by the knobs and buttons in the trigger menu.

The trigger group contains two knobs and two switches and one button:

- Position: This knob allows you to shift the trace horizontally.
- Source: This switch allows you to choose which channel will be used as the trigger. In addition to the four input channels, the line can also be used as a trigger. This means the scope will trigger based on the voltage coming from the AC power source. This is useful when looking for noise caused by electrical interference.
- XY: When out this button displays voltage vs time, when in it displays voltage vs voltage.
- Coupling: This switch allows you to change how the triggering happens, this should almost always be on auto.
- Level/slope: This knob allows you to adjust the voltage level at which triggering occurs. Pulling out the knob allows you to toggle between rising and falling voltages to trigger on. This is how triggering is adjusted. For example, if you have the level set to zero and the slope set to + (up arrow) you will be triggering every time the signal goes from below zero volts to above zero volts. The level is very important when you are dealing with signals that have been rectified (by a diode). A rectified signal may never have a value of less than zero, and if you leave the level at zero, the scope may never trigger, and no signal will be displayed.

## CRT

This allows you to control how bright the traces are and their focus. You may need to adjust this when you adjust the horizontal sweep rate.

## How to Find a Signal on the Oscilloscope

Use the following procedure to display an unknown input signal on the oscilloscope:

1. Make sure the desired channel is on and set up properly.
  - Flip the Vert. Mode switch to display the channel you want to observe
  - If it is possible that your signal could have a large DC offset, select AC coupling.
2. Move the channel ground to the center of the display.
  - Adjust the ground up and down with the small, light colored, "position" knob.
3. Make sure the trigger is set up correctly.
  - Flip the source switch to select the appropriate channel
  - Adjust the level knob until the level is within the range of the signal

4. Set the Vertical scale.
  - Turn the Volts/Div knob (above Channel 1) until the vertical scale is about 1/2 of the amplitude of the signal.
5. Set the Time scale.
  - Turn the Time/Div knob until the time scale is about 1/2 of the period of the signal.

## Laboratory Procedure / Summary Sheet-keep pages 1-10 for your notes.

Names:

1. In this step you will examine the effects of AC coupling of an oscilloscope.
  - Adjust the function generator to produce a  $5 V_{pp}$  1kHz sinusoidal output, use either a multimeter or the oscilloscope to see the output's amplitude as you are setting it.
  - Display the sinusoid on the oscilloscope with a sensitivity of 1 V/cm. Adjust the triggering level and note what you see.
  - Use the +/- trigger selector (pull/push the trigger level knob to toggle between positive and negative edge triggering) and note what happens.
  - Trigger the oscilloscope using the channel and line triggering inputs and again note what you see, in each case.
  - Refer back to Figure 3.2 for details on the impedances within the oscilloscope. We can simulate an AC coupled oscilloscope by adding an external coupling capacitor to a DC coupled oscilloscope. To do this, build the circuit shown in Figure 3.9. Adjust the function generator to add a 1 Vdc offset to the  $5V_{pp}$  1kHz signal. Be sure to select DC coupling on the oscilloscope so to properly set the offset. Use a  $0.022 \mu\text{F}$  coupling capacitor ( $C_{\text{couple}}$ ) and describe below the resulting output. **If you don't notice an effect try briefly shorting the capacitor several times while watching the oscilloscope display.** Then try a  $0.1 \mu\text{F}$  and a  $1 \mu\text{F}$  capacitor (refer back to Section 1.4 in Lab 1 for info on how to read capacitor values). **Note carefully what happens to the oscilloscope display when you first attach the scope probe to measure  $V_o$  for each case.** Make sure you discharge the coupling capacitor by shorting its leads before you attach the probe to measure the voltage. How do the results change with the capacitance value?
- What is the effect of the function generator output impedance  $R_o$  on the measured voltage  $V_o$ ?
- Now remove the coupling capacitor and toggle the oscilloscope between DC coupling and AC coupling and note what you observe in the measured voltage signal. Which of the three external coupling capacitors that you tried most closely approximates what you think the actual coupling capacitance of the oscilloscope is?

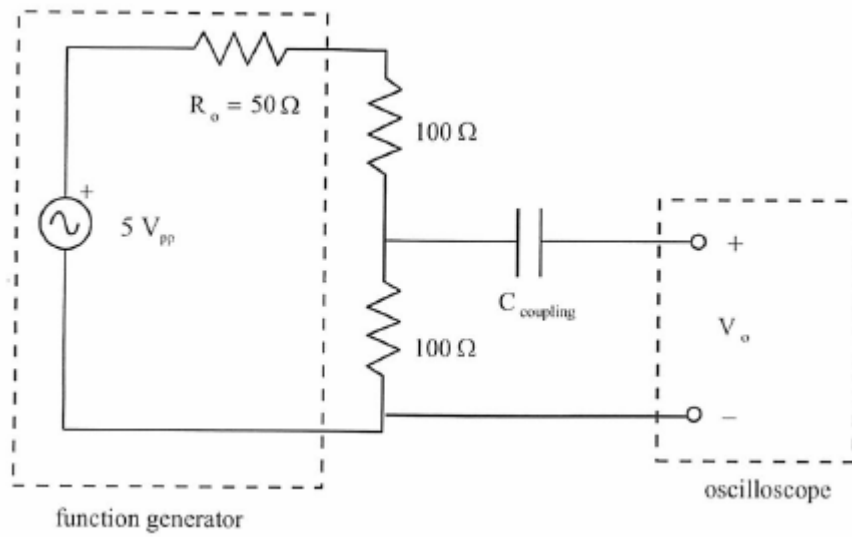


Figure 3.9 Coupling Capacitor Effects

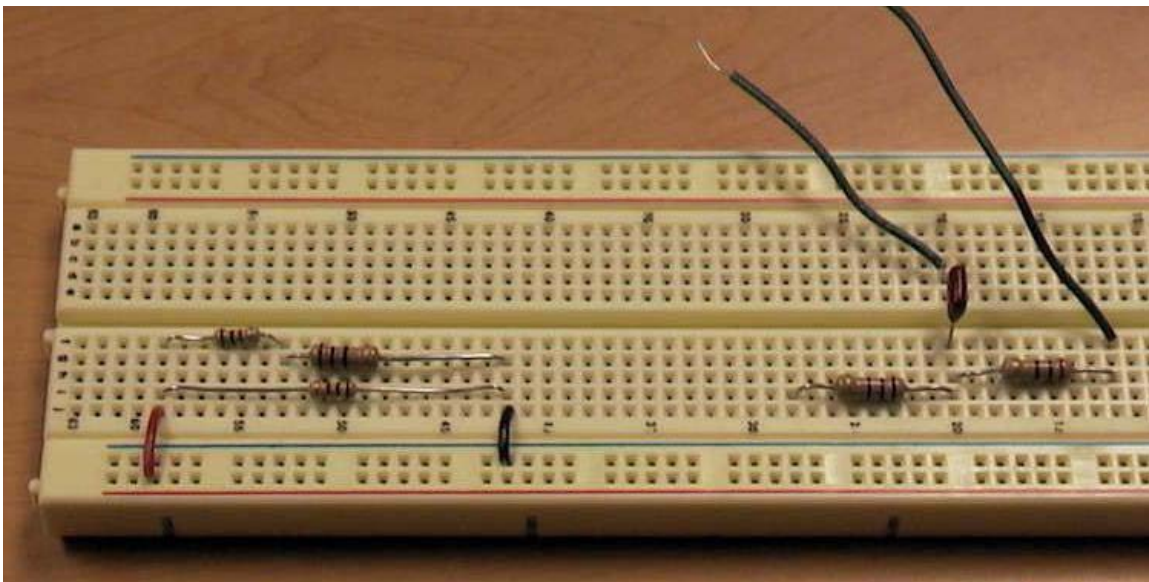


Figure 3.10 Circuits for Steps 1 (right) and 4 (left)

2. In this step and the next you will study the effects of the input impedance of the oscilloscope. Also, you will use an oscilloscope probe to increase the input impedance and note the consequences.

- Construct the circuit shown below with  $R_1 = R_2 = 1\text{ k}\Omega$  and  $V_i = 6V_{pp}$  at 1kHz

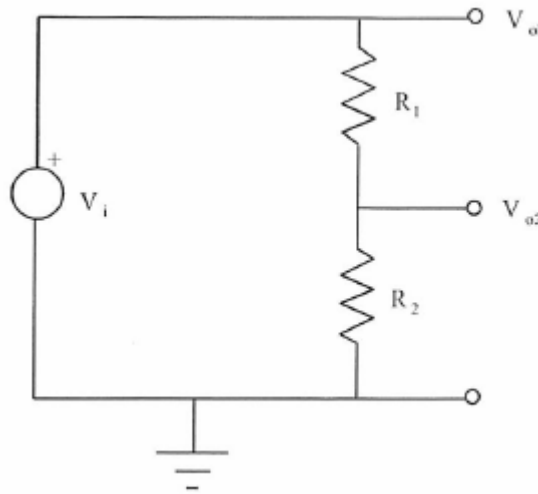


Figure 3.11 Probe Measurements

- Connect a 10X attenuator probe to channel 1 and calibrate the probe (see Section 3.3 for background info and instructions).
- Using the attenuator probe, determine each of the voltages  $V_{o1}$  and  $V_{o2}$  for the circuit above and record the peak-to-peak values in the following table. Be sure that nothing is connected to Channel 2. Note that the voltages  $V_{o1}$  and  $V_{o2}$  labeled in the figure are node voltages defined relative to ground, and not "across" voltages, so the probe ground clip should be attached to the ground of your circuit.  $V_{o2}$  happens to also be the voltage across  $R_2$ , but  $V_{o1}$  is not the voltage across  $R_1$ .

$R_1 =$

$R_2 =$

	Calculated	Measured with IX probe	% Error	Measured with 10X probe	% Error
$V_{o1}$					
$V_{o2}$					

- Replacing the resistors so that  $R_1 = R_2 = 4.7 \text{ M}\Omega$ . Measure  $V_{o1}$  and  $V_{o2}$  using the same methods as in Part 2 and record the values in the following table.

$R_1 =$

$R_2 =$

	Calculated	Measured with 1X probe	% Error	Measured with 10X probe	% Error
$V_{o1}$					
$V_{o2}$					

- Although the oscilloscope is primarily a voltage measuring instrument it can be used to indirectly measure current by inserting a small value resistor in the circuit branch of interest (unless there is a resistor in the branch already). In order to measure the current we use the oscilloscope to measure the voltage drop across this resistor and then the current through it can be calculated using Ohm's Law.
- For the network shown below determine the current  $I$  by inserting resistor  $R$  of various values (see below) and measuring the voltage drop across it in each case.

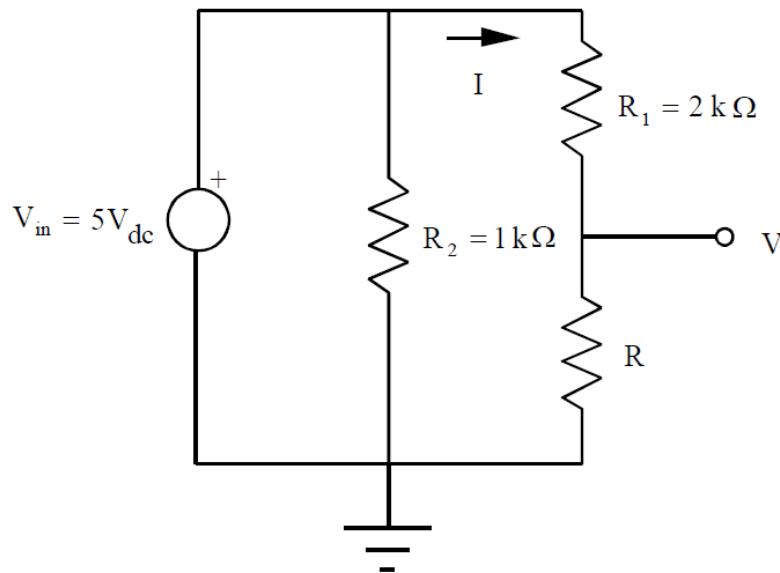


Figure 3.12 Measuring Current

- Record the exact (measured) resistance values for  $R_1$  and  $R_2$ :

$R_1 =$

$R_2 =$

- For each resistance value below, measure the voltage (V) across resistor R. **NOTE** - when measuring small voltages with the oscilloscope, you might need to adjust the voltage scale to get accurate readings.

R	Measured with 1 X probe	Measured with 10 X probe
10Ω		
100Ω		
1 KΩ		

- Record the exact (measured) resistance values for each of the three R resistors used:

$R(10\Omega) =$  \_\_\_\_\_

$R(100\Omega) =$  \_\_\_\_\_

$R(1\text{ k}) =$  \_\_\_\_\_

- Calculate the expected current through R (for each value) using the actual values for  $R_1$  and  $R_2$ . Then calculate currents from the measured voltage values above (using Ohm's Law), and compare them to the expected current values:

R	Expected (calculated) current	i via the 1X probe measurement	% Error	i via the 10X probe	% Error
10 Ω					
100Ω					
1KΩ					





4. When is it advantageous to use the oscilloscope attenuator probe?
5. You have a  $4 V_{pp}$ , 100 Hz sine wave, and I wish it to be displayed on the oscilloscope as shown below (uses the entire display). Describe how to set the oscilloscope's vertical amplifier and time base settings.

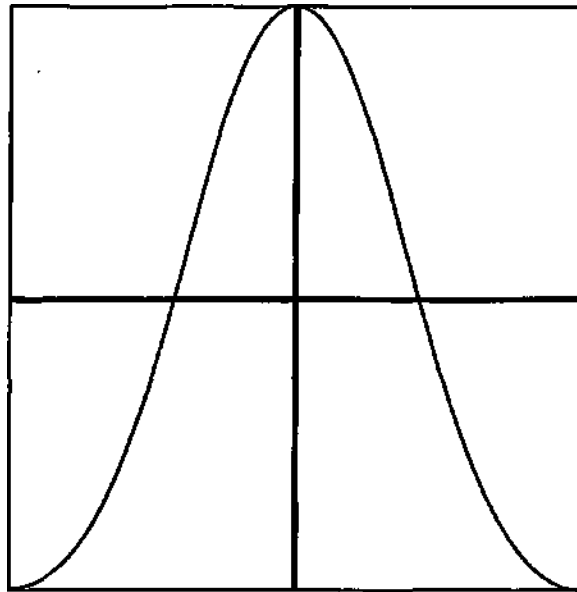


Figure 3.13 Oscilloscope Sine Wave Display

6. What is the effect of AC coupling when a signal with a DC offset is displayed on an oscilloscope?
7. In part 4, what effect does the inserted resistor have on the current measured?