EE 241 – Experiment #2: INTRODUCTION TO THE OSCILLOSCOPE

PURPOSE:

- To understand the basic operation of an oscilloscope
- To become familiar with some of the functions and limitations of the oscilloscope as a precision measuring instrument.
- To understand the advantages of using scope probes and the importance of calibrating them
- Verify Kirchhoff Voltage Law (KVL) for time-varying signals

This experiment relates to the following course learning objectives:

1. Ability to interconnect equipment and devices such as multimeters, function generators, and oscilloscopes to achieve required results.
2. Acquire practice in recording data and results and maintaining a proper engineering notebook.
3. Acquire to relate practical laboratory results with lecture theory

LAB EQUIPMENT:

1 TPS-4000 Dual DC Regulated Power Supply
1 Agilent 54621A Oscilloscope
2 Decade Resistance Box: 10/100/1KΩ step
1 Decade Capacitor: 0.01/0.1/μF step
1 Agilent 34410A Digital Multimeter
1 Agilent 33120A Function Generator (FG)
1 Small flat-head screwdriver

STUDENT PROVIDED EQUIPMENT:

2 Agilent 10074C Scope probes
4 Banana-to-banana leads
2 BNC-to-BNC
3 BNC-to-banana
1 BNC T

Overview of the Operation of an Oscilloscope

The oscilloscope is one of the most frequently used instruments in an electrical engineering laboratory. The scope displays one or two waveforms as a function of time on its display screen. In analog scope, a waveform is displayed on the fluorescent screen of the display tube by repeatedly sweeping an electron beam over the screen in a pattern resembling the desired waveform. The electron beam is deflected by a set of horizontal and vertical fields, which are called the sweep signal and the input signal, respectively. Subsystems of an oscilloscope are shown in Figure 1 below.

1 Version 6, last revised 4/14/09, EE Dept., Cal Poly
2 Adopted and edited in parts from laboratory notes of Jan Van der Spiegel of the Univ. of Penn, ESE Dept.
Digital and analog scopes

There are two types of scopes, analog and digital. Digital scopes offer more features than the analog versions. Digital scopes can process the signal and measure its amplitude, frequency, period, and rise and fall time. Some have built-in mathematical functions and can perform fast Fourier transforms in addition to capturing the display and sending it out to a printer.

Scope Probe

Scope probes are used to apply signals we wish to view to the deflection plates which control the horizontal and the vertical positions of the electron beam. Scope probes are high-quality connector cables that have been carefully designed to reject stray signals originating from radio frequency (RF) or power lines. They are used when working with low voltage signals or high-frequency signals which are susceptible to noise pick-up. Also, scope probes have high input resistance which reduces circuit loading. A probe usually attenuates the input signal by a factor of 10.

Parasitic Capacitance
The advantage of using this 10:1 attenuator is that it reduces circuit loading. By adding a resistance of 9M\(\Omega\), the input resistance (as seen by the circuit under test) increases from 1 M\(\Omega\) to 10 M\(\Omega\). As a result, the current supplied by the circuit to the scope will be roughly 10 times smaller and thus reduces circuit loading.

You will notice that the probe has a capacitor in parallel with a 9 M\(\Omega\) resistor. Compensation of the probe is obtained by adjusting this capacitor (the probe adjustment capacitor shown in Figure 3). This is done in order to ensure that high frequency signals are not distorted. This is illustrated in Figure 4 below for a square wave. When the probe is properly adjusted (compensated) a square wave will be displayed with a flat top. A poorly adjusted probe can create considerable distortion and erroneous readings of the signal’s peak-to-peak amplitude. You should get into the habit of compensating the probe every time you use it.

![Fig. 4: The effects of probe compensation: (a) correctly adjusted probe, (b) undercompensated and (c) overcompensated probe.](image)

To be clear, the compensation of the scope probe is obtained by adjusting the variable capacitor inside the probe (as shown in the Figure 3). For a times-10 probe, the compensating value will be 1/9 of the input capacitance of the oscilloscope (which is shown to be 13 pF in the Figure 3).

**Experiment Sections:**

1) Calibrating the Scope Probes  
2) The Scope Input Modes  
3) Dual Trace Measurements

**Section 1) Calibrating the Scope Probes**

In what follows, you are to connect probes to the two channels of the scope, and compensate both probes. Thus, for example, when you are told in part f to “center the trace on the display”, this is referring to the trace of the channel of interest.

a) Power-up the scope.

b) Connect the scope probe to either channel 1 or 2.

c) Connect the tip of the probe to the calibrated output socket, i.e., the Probe Comp. terminal, on the lower right corner of the scope and the ground clip of the probe to the ground of the scope.

d) Use the **Intensity** knob to ensure the trace is not too bright.

e) Press the **Auto Scale** key. Also, if necessary, press the Cursor button to turn off the cursors.

f) Use the Vertical Position knob (VERTICAL section) to center the trace on the display.
g) Adjust your probes to obtain very nice looking square waves. If necessary, press Auto Scale again to see the square wave. For the Agilent 54622A scope and associated scope probes, the adjustment screw is near the BNC connector. Use a small flat-head screwdriver to do the adjustment. Your probes may be well calibrated but they should be compensated every time the scope is used.

h) Record both the frequency and amplitude of the square wave. Record whether the probe you are using is a 10X probe or not. Note: When making your measurements, be sure that the oscilloscope indicates “Probe n:1”, where n is the appropriate value for your probe (e.g., n = 10 for a times-10 probe); if not, adjust this parameter manually. (As explained below, such manual adjustment should not be necessary; however, this particular scope is faulty! Therefore, when using this oscilloscope you must always check that it is adjusted to the proper probe setting.) Also, show your calculation of the frequency of the square wave from the period.

i) Examine the set-up and see if you can figure out how the scope knows if it is using 10X probe. See the note below.

* Note: You have now calibrated the scope probes to work optimally with the scope. The probes should always be calibrated every time measurements are taken with the scope. Also, for the Agilent scope and accompanying scope probes, though the probes are 10X probes, your reading will come out “normal” due to the design of the scope and probes. This means that the scope is designed to detect that a times-n probe is being used, and then automatically adjust its readout to account for the voltage divider that is shown in the figure 3. That is, the voltage displayed by the scope is not the voltage being applied directly to its jack; rather, it is the voltage being applied to scope probe (which is n =10 times larger).

Questions: Section 1

1) What are two possible advantages of using 10X probes when taking scope measurements?

2) From step i, how did the scope know the Philips 10X probes were connected?

Section 2) The Scope Input Modes

a) Using a BNC-to-BNC cable and a BNC T (at either end of the cable), connect the Agilent 33120A function generator output (not Sync) directly to Channel 1 of the oscilloscope. (Thus, here you are not using a scope probe.) If necessary, turn off Channel 2 by pressing the “2” until the light turns off.

b) Connect the other end of the T to the Agilent 34401A multimeter thru a BNC-to-banana cable. Set the meter to “DC V” and manually set the range to 10V.

c) Set the output termination of the function generator to high impedance, by applying the following keystrokes: Shift, Menu On/Off, >, >, >, ∨, ∨, and > (as necessary to select High Z), then Enter. (If the 50-ohm output termination is chosen instead, then for high-impedance loads—i.e., loads much greater than 50 ohms, as are typical in this lab—the actual output voltage would differ from the displayed voltage by a factor of 2.) Perform this adjustment in future experiments too.

d) Set the output of the generator to a 5.0V peak-to-peak sinusoid (a.k.a. “sine wave”) at 500Hz, with a 0V DC offset. Then, press Auto Scale on the scope.

e) Observe the effect on the displayed waveform of switching between AC and DC coupling on the oscilloscope input (Press the Channel 1 button, then the left “soft key” below the display). For each type of coupling, use the multimeter to measure the AC and DC components of the sinusoid.
f) For DC coupling, import the scope image into report by following the instructions given in the box on the right. Also, use the Cursors feature of the scope to measure the DC offset of the displayed waveform; specifically, measure the maximum and minimum values of the waveform, and divide their sum by 2.

g) Now, set the output of the generator to a 5.0V peak-to-peak sinusoid at 500Hz with a 2V DC offset; then, repeat parts e and f.

Questions: Section 2

1) Would you expect the multimeter measurement to change when transitioning from AC to DC coupling on the scope? Why?

2) In parts f and g, was the DC component measured by the multimeter close to the DC offset set on the function generator? Also, was the AC component measured by the multimeter closer to the peak-to-peak value of the sinusoid or its RMS value? Report values.

3) Under what conditions would the waveform shift up or down on the scope display as the setting was switched from AC to DC coupling?

Section 3) Dual Trace Measurements

a) Construct the circuit shown below with $V_s = 3.0\, \text{V}_{\text{pp}}$ sine wave @ 1300 Hz with no DC offset.

b) Display the function generator (FG) voltage $V_s$ on channel 1 and the voltage $V_2$ across $R_2$ on channel 2. Measure peak-to-peak voltage of both signals using scope’s Quick Meas: Source 1, Peak-to-Peak, Source 2, Peak-to-Peak.

c) Noting that $V_1 = V_s - V_2$, use the math key on the scope to display $V_1$ by pressing the (1-2) softkey. Note that Kirchhoff’s laws apply for any instant in time; this means that the measurements of voltage at any time around a closed path should sum to zero. As an example, use Quick Meas with Math selected to measure peak-to-peak of $V_1$, $V_s$, and $V_2$, and verify that $V_1 = V_s - V_2$. Before capturing the scope image, simultaneously display all three waveforms—$V_s$, $V_1$, and $V_2$—from top to bottom, and without overlap—by making the following adjustments manually:

− Adjust the vertical sensitivities of both scope channels and difference display (via the Math feature) to the same value, to obtain the appropriate vertical scaling.
— For each channel, using the Ground feature under Coupling, adjust the vertical position of V_s or V_2 to make 0 V correspond exactly to a horizontal grid line, then set the coupling to DC. Capture and record the scope image including appropriate description/labels.

— Make all three vertical sensitivities visible when capturing the scope image.

d) Replace R_2 with a decade capacitor set to 0.1 \(\mu\)F and display the supply voltage on channel 1 and the voltage across the capacitor on channel 2. Set Math/Setting/Offset to 0V and adjust all three waveforms to fit inside the display. Capture and record the scope image including appropriate description/labels.

**Questions: Section 3**

1) Did KVL apply to the resistive circuit? Show explicitly that it did or did not apply.

2) For the RC circuit (step d), draw 2 vertical lines (one at V_s=0, and another at V_s=max) and show that KVL holds.

3) What would have happened to the scope display if the two probe grounds were connected to points with different potentials in the circuit?