LAB II. INTRODUCTION TO LAB EQUIPMENT

1. OBJECTIVE

In this lab you will learn how to properly operate the **oscilloscope Keysight DSOX1102A,** the **Keithley Source Measure Unit (SMU) 2430,** the **function generator Agilent 33220A,** and a **bread board**.

2. OVERVIEW

This lab will take you through the basics of using all the lab equipment. The Lab procedure will test your comprehension of the background material, so be sure you have read and understood how to operate all the equipment.

Information essential to your understanding of this lab:

1. Background Material

Materials necessary for this Experiment

1. Standard testing station
2. Two resistors: 3.3 kΩ and 5.1 kΩ

3. BACKGROUND INFORMATION

3.1. BREADBOARD BASICS

Breadboards are simply a set of pre-wired interconnects that aid you in the building of your circuits. By plugging a wire of one component into a hole you will connect it to all other components in that strip or bus. Using strips, buses, and jumper wires you can construct a circuit on your breadboard. You can tell which holes are connected in one node by the black lines connecting them in Figure 1. There are the component connection strips that run up and down and buses labeled with an A or B. After examining Figure 1 the use of a breadboard should be intuitive.

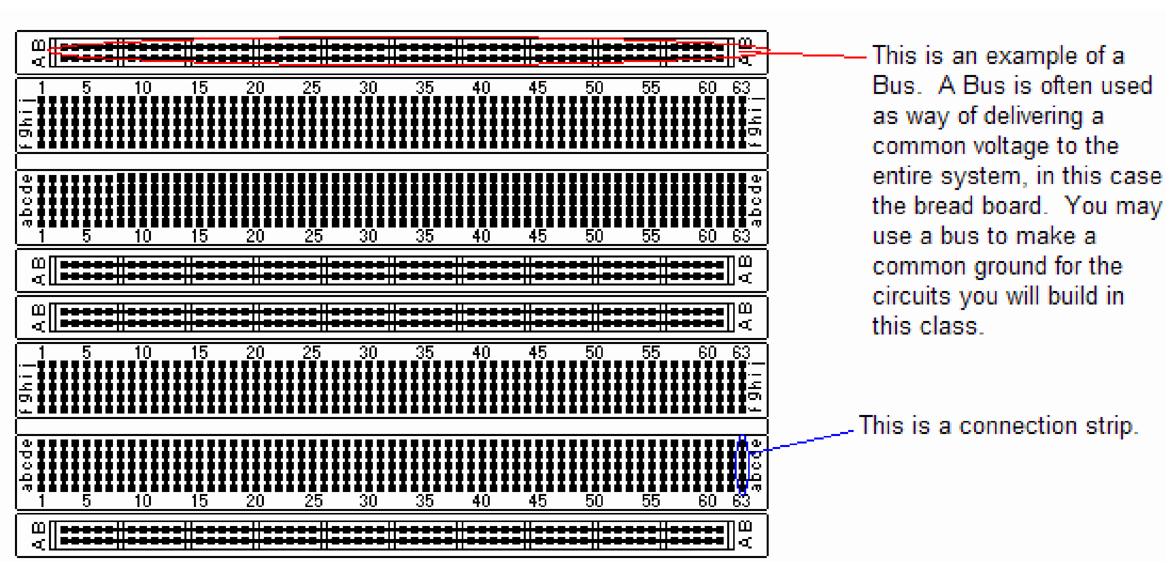


Figure 1. A schematic diagram of the breadboard showing buses and strips.

3.2. KEITHLEY SOURCE MEASURE UNIT 2400

This section will instruct you on how to use the Keithley 2430 source measure unit (SMU). The Keithley SMU can be used as **a voltage source, a current source, a voltmeter or ammeter**. Examine the figure below before moving on to studying the main functions of the Keithley SMU. (See the Link: Lab Instrument Front Panels for more detailed images of all of the front panels of the three major pieces of equipment used in this laboratory to examine these panels in more detail).

3.2.1. COMPLIANCE

In order to properly operate the Keithley SMU 2430, you must understand the concept of "compliance". Compliance is a safety feature incorporated in the Keithley SMU to protect the circuit components from unexpected high power of operation. It is a limiting factor input by the user.

There are two types of compliance issues. When the output value is above the value preset by the user, then the "CMPL" blinks. To overcome this, you need to increase the compliance value. If the units displayed on the screen blink, it means the display range is less than the actual output range. You need to press "AUTO" button to overcome this.

How to set the compliance? Press the "Edit" button twice. Use "Range" button and the "arrow" buttons to set the desired value.

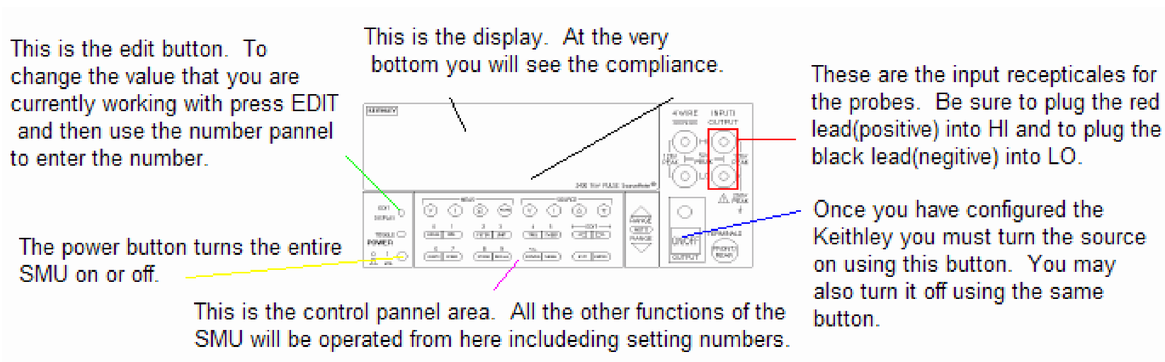


Figure 2. Front panel of the Keithley SMU 2430.

3.2.2. VOLTAGE/CURRENT SOURCE CONFIGURATION

In order to use the Keithley SMU as a voltage source or a current source, you need to follow the steps given below.

1. Press the **V/I** button in the Source group.
2. Press the **EDIT** button at the left of the front panel (see Figure 2). If you were successful, the voltage source value (V_{src}/I_{src}) will start blinking. If it is not blinking press the **EDIT** button again.
3. To change the source value, you need to use the following buttons.
   - ③ ∧ and ∨ : The **Up** and **Down** arrows in the range group (at the bottom right side of the front panel next to Output On/Off light) are used to change the range of the source value.
   - ③ ∧ and ∨ : The **Up** and **Down** arrows in the source group are used to change the digit value.
   - ③ < and > : The **Left** and **Right** arrows in the EDIT group are used to select the digit you wish to alter.
4. Once you set the value, press **Enter**.

Once you have set the Keithley SMU as a voltage or a current source you need to push the **ON/OFF** button at the bottom right corner of the front panel. Check the compliance value in the display. If something blinks, there is a problem. In order for the Keithley SMU to work as a **voltage source**, you must set the output voltage that you want and set the "compliance" for output current. Similarly, in order for the Keithley SMU to work as a **current source**, you must set the output current that you want and set the "compliance" for output voltage.

3.2.3. VOLTMETER / AMMETER CONFIGURATION

To configure the Keithley SMU as an Ammeter or a Voltmeter, use the following directions.

Voltmeter instructions

1. Set the SMU up as a current source with no output current.
2. Then from the control panel area, press the **V** button in the MEAS group under the display.

Ammeter instructions

1. Set the SMU up as a voltage source with no output voltage.
2. Then from the control panel area, press the **I** button in the MEAS group under the display.

3.2.4 Lab Exercise:

1. Connect the diode in your kit up to the Keithley SMU. Be sure to get the polarity correct. The longer lead is connected to the positive potential.
2. Set the Keithley SMU as a current source for the amount of current that your TA tells you.
3. Make sure that the compliance Voltage is set to 3 V. Make sure that the current will be less than 10 mA! If your LED burns out (and/or starts smoking), press the "output" button to turn off the output! DO NOT touch the LED or try to disconnect it with the output turned on!
4. If your current is < 100 µA, you probably have the LED connected backwards (the polarity is wrong.)
5. Turn on the Keithley SMU output and read the Voltage required to source the current. Tell your TA the value. (If you get it wrong, you will lose points.)

3.3. Keysight DSOX1102A OSCILLOSCOPE

This section will instruct you on how to operate the Keysight DSOX1102A Oscilloscope.

3.3.1 OSCILLOSCOPE FRONT PANEL CONTROL

The following is an extensive description of the controls used on the Keysight DSOX1102A Oscilloscope excerpted from the Keysight 1000X-Series Oscilloscope User's Guide. This User's Guide is also listed online for additional reference. The exact location of these controls on the front panel is shown in Figure 3 below. Please gain familiarity with the use of the Power switch, the Softkeys, the Entry knob, the [Auto Scale] key, the Horizontal and Acquisition controls, the Run Control keys, the Measure controls, the Vertical controls, and the Analog channel inputs discussed in more detail in the table below. These controls will be used repeatedly during this lab. The Cursors and Meas keys under the Measure Controls are particularly important for acquiring the data and are discussed in greater detail after the table.

1.	Power switch	Press once to switch power on; press again to switch power off. See "Power-On the Oscilloscope" on page 13.
2.	Softkeys	The functions of these keys change based upon the menus shown on the display next to the keys. The (Back) Back key moves back in the softkey menu hierarchy. At the top of the hierarchy, the (Back) Back key turns the menus off, and oscilloscope information is shown instead.
3.	**[Intensity]** key	Press the key to illuminate it. When illuminated, turn the Entry knob to adjust waveform intensity. You can vary the intensity control to bring out signal detail, much like an analog oscilloscope.

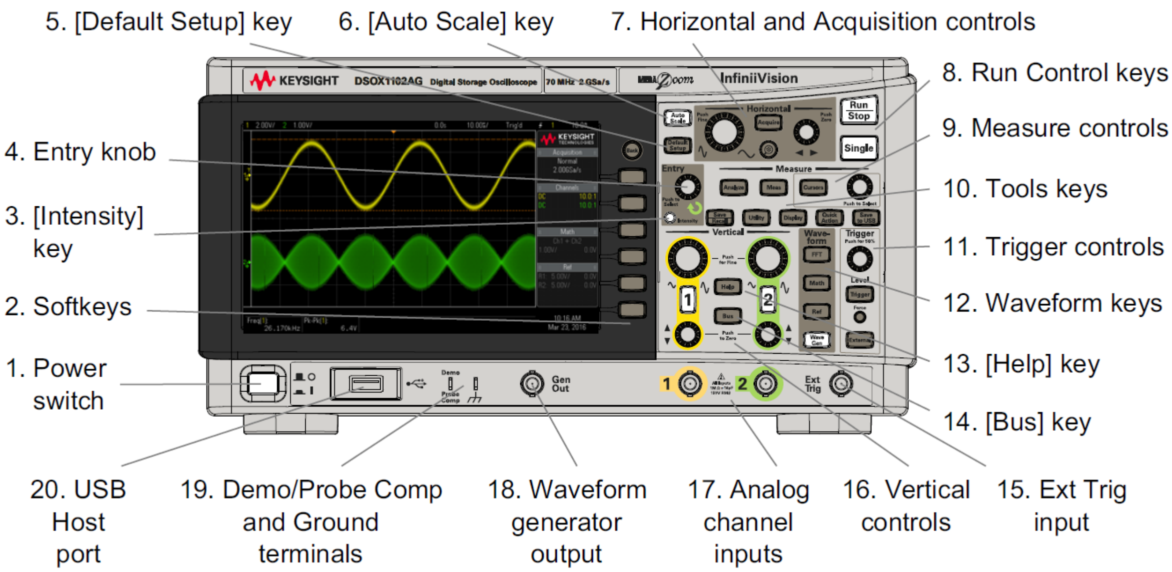


Figure 3. Front panel of the Keysight DSOX1102A Oscilloscope.

4.	Entry knob	The Entry knob is used to select items from menus and to change values. The function of the Entry knob changes based upon the current menu and softkey selections. Note that when the Entry knob ↻ symbol appears on a softkey, you can use the Entry knob, to select values. Often, rotating the Entry knob is enough to make a selection. Sometimes, you can push the Entry knob to enable or disable a selection. Also, pushing the Entry knob can also make popup menus disappear.
5.	**[Default Setup]** key	Press this key to restore the oscilloscope's default settings (details on "Recall the Default Oscilloscope Setup" on page 16).
6.	**[Auto Scale]** key	When you press the **[AutoScale]** key, the oscilloscope will quickly determine which channels have activity, and it will turn these channels on and scale them to display the input signals. See "Use Autoscale" on page 17.
7.	Horizontal and Acquisition controls	The Horizontal and Acquisition controls consist of: ▪ Horizontal scale knob – Turn the knob in the Horizontal section that is marked to adjust the time/div setting. The symbols under the knob indicate that this control has the effect of spreading out or zooming in on the waveform using the horizontal scale. Push the horizontal scale knob to toggle between fine and coarse adjustment. ▪ Horizontal position knob – Turn the knob marked ◀▶ to pan through the waveform data horizontally. You can see the captured waveform before the trigger (turn the knob clockwise) or after the trigger (turn the knob counterclockwise). If you pan through the waveform when the oscilloscope is stopped (not in Run mode) then you are looking at the waveform data from the last acquisition taken. ▪ **[Acquire]** key – Press this key to open the Acquire menu where you can select the Normal, XY, and Roll time modes, enable or disable Zoom, and select the trigger time reference point. Also you can select the Normal, Peak Detect, Averaging, or High Resolution acquisition modes and, on DSOX1000-Series models, use segmented memory (see "Selecting the Acquisition Mode" on page 54). ▪ Zoom key – Press the zoom key to split the oscilloscope display into Normal and Zoom sections without opening the Acquire menu. For more information see "Horizontal Controls" on page 33.

8.	Run Control keys	When the **[Run/Stop]** key is green, the oscilloscope is running, that is, acquiring data when trigger conditions are met. To stop acquiring data, press **[Run/Stop]**. When the **[Run/Stop]** key is red, data acquisition is stopped. To start acquiring data, press **[Run/Stop]**. To capture and display a single acquisition (whether the oscilloscope is running or stopped), press **[Single]**. The **[Single]** key is yellow until the oscilloscope triggers. For more information, see "Running, Stopping, and Making Single Acquisitions (Run Control)" on page 32.
9.	Measure controls	The measure controls consist of: ▪ **[Analyze]** key – Press this key to access analysis features like trigger level setting, measurement threshold setting, Video trigger automatic set up and display, or digital voltmeter (see "Digital Voltmeter" on page 72). ▪ **[Meas]** key – Press this key to access a set of predefined measurements. See "Measurements" on page 63. ▪ **[Cursors]** key – Press this key to open a menu that lets you select the cursors mode and source. ▪ Cursors knob – Push this knob select cursors from a popup menu. Then, after the popup menu closes (either by timeout or by pushing the knob again), rotate the knob to adjust the selected cursor position.
10.	Tools keys	The Tools keys consist of: ▪ **[Save/Recall]** key – Press this key to save oscilloscope setups, screen images, waveform data, or mask files or to recall setups, mask files or reference waveforms. See "Save/Recall (Setups, Screens, Data)" on page 82. ▪ **[Utility]** key – Press this key to access the Utility menu, which lets you configure the oscilloscope's I/O settings, use the file explorer, set preferences, access the service menu, and choose other options. See "Utility Settings" on page 86. ▪ **[Display]** key – Press this key to access the menu where you can enable persistence, adjust the display grid (graticule) intensity, label waveforms, add an annotation, and clear the display (see "Display Settings" on page 47). ▪ **[Quick Action]** key – Press this key to perform the selected quick action: measure all snapshot, print, save, recall, freeze display. and more. See "Configuring the [Quick Action] Key" on page 88. ▪ **[Save to USB]** key – Press this key to perform a quick save to a USB storage device.
11.	Trigger controls	The Trigger controls determine how the oscilloscope triggers to capture data. These controls consist of: ▪ Level knob – Turn the Level knob to adjust the trigger level for a selected analog channel. Push the knob to set the level to the waveform's 50% value. If AC coupling is used, pushing the Level knob sets the trigger level to about 0 V. The position of the trigger level for the analog channel is indicated by the trigger level icon T▸ (if the analog channel is on) at the far left side of the display. The value of the analog channel trigger level is displayed in the upper-right corner of the display. ▪ **[Trig]** key – Press this key to select the trigger type (edge, pulse width, video, etc.). See "Trigger Types" on page 50. You can also set options that affect all trigger types. See "Trigger Mode, Coupling, Reject, Holdoff" on page 51. ▪ **[Force]** key – Causes a trigger (on anything) and displays the acquisition. This key is useful in the Normal trigger mode where acquisitions are made only when the trigger condition is met. In this mode, if no triggers are occurring (that is, the "Trig'd?" indicator is displayed), you can press **[Force]** to force a trigger and see what the input signals look like. ▪ **[External]** key – Press this key to set external trigger input options. See "External Trigger Input" on page 53.

12.	Waveform keys	The additional waveform controls consist of: ▪ **[FFT]** key – provides access to FFT spectrum analysis function. See "FFT Spectral Analysis" on page 40. ▪ **[Math]** key – provides access to math (add, subtract, etc.) waveform functions. See "Math Waveforms" on page 44. ▪ **[Ref]** key – provides access to reference waveform functions. Reference waveforms are saved waveforms that can be displayed and compared against other analog channel or math waveforms. See "Reference Waveforms" on page 46. ▪ **[Wave Gen]** key – On G-suffix models that have a built-in waveform generator, press this key to access waveform generator functions. See "Waveform Generator" on page 75.
13.	**[Help]** key	Opens the Help menu where you can display overview help topics and select the Language. See also "Access the Built-In Quick Help" on page 29.
14.	**[Bus]** key	Opens the Bus menu where you can: ▪ Display a bus made up of the analog channel inputs and the external trigger input where channel 1 is the least significant bit and the external trigger input is the most significant bit. See also "Analog Bus Display" on page 39. ▪ Enable serial bus decodes. See also "Serial Bus Decode/Trigger" on page 76.
15.	Ext Trig input	External trigger input BNC connector. See "External Trigger Input" on page 53 for an explanation of this feature.
16.	Vertical controls	The Vertical controls consist of: ▪ Analog channel on/off keys – Use these keys to switch a channel on or off, or to access a channel's menu in the softkeys. There is one channel on/off key for each analog channel. ▪ Vertical scale knob – There are knobs marked for each channel. Use these knobs to change the vertical sensitivity (gain) of each analog channel. Push the channel's vertical scale knob to toggle between fine and coarse adjustment. The default mode for expanding the signal is about the ground level of the channel; however, you can change this to expand about the center of the display. ▪ Vertical position knobs – Use these knobs to change a channel's vertical position on the display. There is one Vertical Position control for each analog channel. The voltage value momentarily displayed in the upper right portion of the display represents the voltage difference between the vertical center of the display and the ground level ( ) icon. It also represents the voltage at the vertical center of the display if vertical expansion is set to expand about ground. For more information, see "Vertical Controls" on page 36.
17.	Analog channel inputs	Attach oscilloscope probes or BNC cables to these BNC connectors. In the InfiniiVision 1000 X-Series oscilloscopes, the analog channel inputs have 1 MΩ impedance. Also, there is no automatic probe detection, so you must properly set the probe attenuation for accurate measurement results. See "Setting Analog Channel Probe Options" on page 38.
18.	Waveform generator output	On G-suffix models, the built-in waveform generator can output sine, square, ramp, pulse, DC, or noise on the Gen Out BNC. Press the **[Wave Gen]** key to set up the waveform generator. See "Waveform Generator" on page 75. You can also send the trigger output signal or the mask test failure signal to the **Gen Out** BNC connector. See "Utility Settings" on page 86.
19.	Demo/Probe Comp, Ground terminals	▪ Demo terminal – This terminal outputs the Probe Comp signal which helps you match a probe's input capacitance to the oscilloscope channel to which it is connected. See "Compensate Passive Probes" on page 18. With certain licensed features, the oscilloscope can also output demo or training signals on this terminal. ▪ Ground terminal – Use the ground terminal for oscilloscope probes connected to the Demo/Probe Comp terminal.

20.	USB Host port	This port is for connecting USB mass storage devices or printers to the oscilloscope. Connect a USB compliant mass storage device (flash drive, disk drive, etc.) to save or recall oscilloscope setup files and reference waveforms or to save data and screen images. See "Save/Recall (Setups, Screens, Data)" on page 82. To print, connect a USB compliant printer. For more information about printing see "Print (Screens)" on page 85. You can also use the USB port to update the oscilloscope's system software when updates are available. You do not need to "eject" the USB mass storage device before removing it. Simply ensure that any file operation you've initiated is done, and remove the USB drive from the oscilloscope's host port. CAUTION: ⚠ **Do not connect a host computer to the oscilloscope's USB host port.** A host computer sees the oscilloscope as a device, so connect the host computer to the oscilloscope's device port (on the rear panel). See "Learn the Rear Panel Connectors" on page 26.

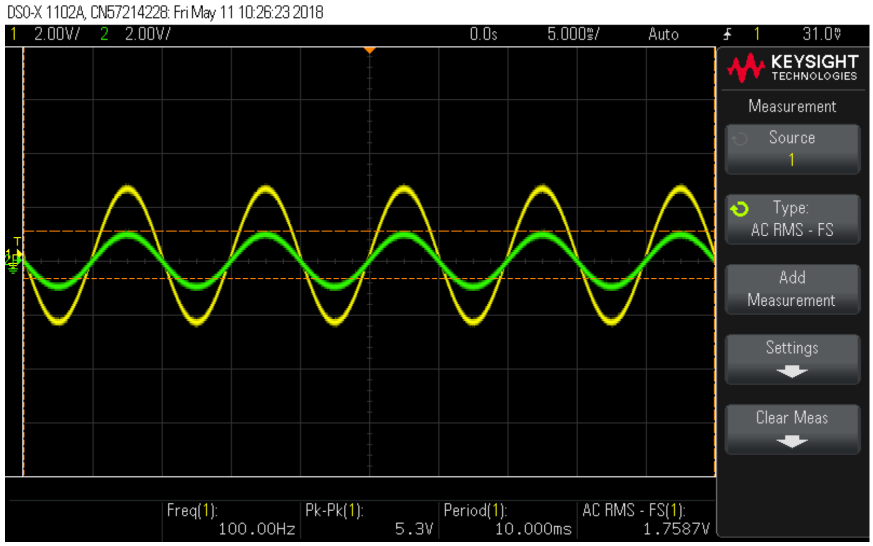
3.3.2. MEASURING VOLTAGES AND TIME-RELATED PARAMETERS

When measuring voltages with the oscilloscope, place the probes in parallel across the component where the voltage signal is being measured. Once you have the signal displayed on the screen, you can use buttons and keys to do the measurements.

<u>For measuring peak to peak, RMS, and DC voltages along with frequencies, time periods, and other time- related parameters</u> use the following method:

1. Press the **Auto Scale** key to set the voltage and time parameters to an appropriate scale.
2. Press the **Meas** key under the **Measure** controls to take voltage and time measurements.
3. If no type of measurements have been saved to the scope at this point, then the scope will turn on an automatic frequency and V_{P-P} measurement. Otherwise the oscilloscope will make the measurements using the previously saved type of measurements.
4. The scope can save up to four continuously updated measurements. Older measurements will be rolled off the screen. These measurements will be shown at the bottom of the screen.
5. To add a new type of measurement, first press the **Type** softkey located second from the top of the softkeys and then rotate the **Entry** knob until the type of measurement is highlighted. Then press the **Entry** knob, or alternatively press the **Add Measurement** softkey, to select this measurement. The data from the measurement will be shown on the right at the bottom of the screen. Repeat this procedure to generate additional measurements.
6. To change to a second oscilloscope channel, first press the **Source** softkey at the top of the softkeys and then rotate the **Entry** knob until the second source is highlighted. Then press the **Entry** knob to choose this channel. Then choose the appropriate type of measurement. Add additional measurements as required.
7. As an example, the frequency, V_{P-P}, period, and V_{RMS} of a sinusoidal signal with a V_{P-P} of 5.3 V and a frequency of 100 Hz on Channel 1 was taken on the oscilloscope while a second sinusoidal signal was run on Channel 2 with a V_{P-P} of 2.3 V and a frequency of 100 Hz. This measurement is shown directly below. No data has been generated for Channel 2. Similar measurements could be taken on Channel 2 by

changing the source to Source 2 and adding additional measurements.



8. You can clear any measurement by pressing **Clear Meas** at the bottom of the softkeys and then pressing the appropriate softkey to clear the appropriate measurement or to clear all measurements.

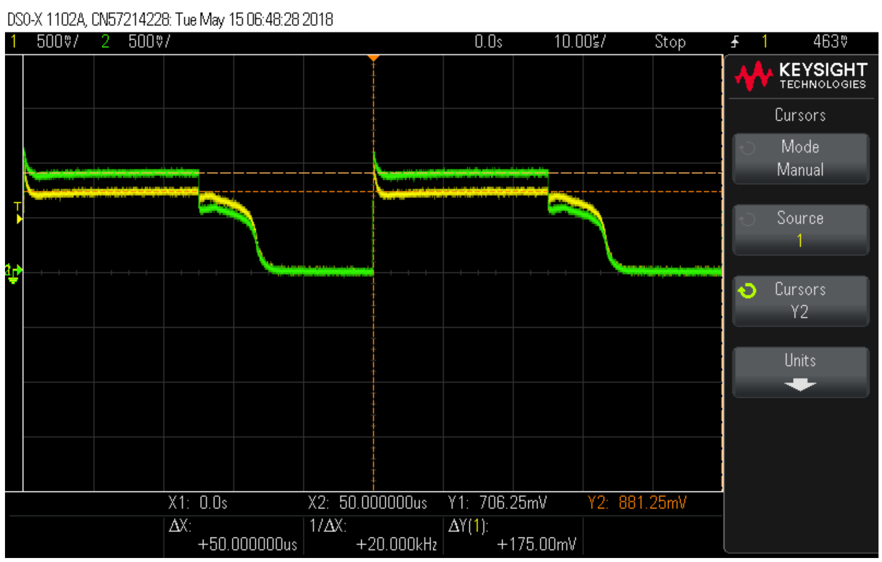
For other measurements related to the voltage and time-related parameters, we use ***cursors***. Cursors are horizontal and vertical markers that indicate X-axis values (usually time) and Y-axis values (usually voltage) on a selected waveform source. The position of these cursors can be moved by rotating the **Cursors** knob and the difference between the location of two cursors can be used to obtain either time-related parameters or voltage measurements.

For making various voltage and time measurements with the cursors with the oscilloscope use the following method:

1. Press the **Auto Scale** key to set the voltage and time parameters to an appropriate scale.
2. Find the location of the **Cursors** knob located directly to the right of the **Cursors** key as shown below.

3. Press the **Cursors** key under the **Measure** controls to take voltage and time measurements using the cursors.
4. Press the **Cursors** knob and then rotate the knob until X1 is highlighted. Then press the Cursors knob to select this cursor.
5. Rotate the **Cursors** knob to position the cursor.
6. Then press the **Cursors** knob again and then rotate the knob until X2 is highlighted. Then press the Cursors knob to select this cursor.
7. Then rotate the **Cursors** knob again to position the the second cursor.
8. The difference in the position of these cursors can be used to determine the period and the frequency.
9. Press the **Cursors** knob and then rotate the knob until Y1 is highlighted. Then press the Cursors knob to select this cursor.

10. Rotate the **Cursors** knob to position the cursor.
11. Then press the **Cursors** knob again and then rotate the knob until Y2 is highlighted. Then press the Cursors knob to select this cursor.
12. Then rotate the **Cursors** knob again to position the the second cursor.
13. The difference in the position of these cursors can be used to determine the difference in the voltage between these two cursors
14. As an example, a signal generator was used to drive a square signal varying between 0 V and 1 V at a 20 kHz frequency across a circuit formed in series with a 10 Ω resistor and a pn junction diode. The signal was measured between the output of the signal generator and ground on Channel 2 and between the node generated between the 10 Ω resistor and the pn junction diode and ground on Channel 1. The measured output is shown below where the difference between the steady state voltage of Channel 2 and Channel 1 was 175 mV and the frequency of the oscillating circuit as determined from where the signal generator goes from 0 V to 1 V is 20 kHz with a period of 50 μs.



Cursors are not always limited to the visible display. If you pan and zoom the waveform until the cursor is off screen, its value will not be changed, and if you pan the waveform back again it will have the cursor in the original place.

3.3.3. MEASURING CURRENTS

This instrument can only measure current indirectly by reading the voltage across a resistor while it is in a circuit and then applying Ohm's Law to find the current or by using special probes using the Hall Effect to determine the current. If necessary, we will use Ohm's law to determine the current.

If you have two signals and want to find the phase between similar points select the source of measurement for cursor 1 as channel 1 and the source for cursor 2 as channel 2. The difference readout is the delay between the two signals. If you divide that delay by the period then you have the phase value as a fraction of 360°, or 2π radians. If you would like to represent that in degrees all you have to do is convert it from radians to degrees.

3.4. FUNCTION GENERATOR AGILENT 33220A

The function generator is used to generate signals for your circuits. You will need to know how to set the function generator to get sine, square, triangle or ramp signals. In addition, you will have to set up the frequency, the amplitude, offset voltage and the duty cycle.

The default settings for this instrument are a sinewave of 1 kHz, with an amplitude of 100 mV and a DC offset of 0.0 V.

Figure 4. Front panel of the Agilent 33220A function generator.

The function generator is very easy to use since each function has a specific button. If you want to select a waveform, just look for the button with the desired waveform such as a sine wave, a square wave, triangle wave, or ramp wave. Then, just press its button. All that you have to do now is set the parameters for the waveform. To set the frequency, amplitude, offset or the duty cycle you need to do the following:

1. Press the appropriate gray buttons beneath the display screen (Freq/Period, Ampl/Hi Level, Offset/Lo Level, or Duty Cycle).
2. You may enter the value one of two ways.
    a.) Turn the knob and the highlighted digit will change. You may select a different digit by using the < or the > buttons.
    b.) You can also key in the digit by using number buttons.
3. Press "Output" button on the bottom right of the front panel (right next to Sync cable) and make sure the light is "on".

IMPEDANCE MATCHING

In order to make sure you read the exact value of the amplitude output by the function generator, You should make sure the output impedance of the function generator is matched to the impedance of the connected circuits. This function generator has 50 Ω output impedance. It has been configured by the manufacturer to deliver the voltage signal when a load of 50 Ω is attached to it.

In the case of large impedance circuits the function generator may deliver up to **twice the voltage** that you have set it up to deliver. In our case, we use a series connected 5.1 kΩ resistor and 3.3 k Ω resistor, which is much higher than 50 Ω. Hence, when you set 1 V_{pp} on the function generator, you will observe twice the amplitude (2 V_{pp}) on the oscilloscope. In order to overcome this, you need to set the function generator to have "High Z" output impedance. To do this, press the "Utility" button and press the "output setup" and you can change the "output impedance" to the "High Z" output mode.

4. PREPARATION

There is no preparation for this lab except for reading and learning the background material.

5. PROCEDURE

5.1. FUNCTION GENERATOR AND OSCILLOSCOPE

Turn on the function generator and the oscilloscope and perform the following tasks.

1. Build the circuit shown below in Figure 5.
2. Use the function generator to generate a signal with a frequency of 100 Hz and amplitude of 5 V.
3. Measure all voltages and all the time-related parameters (see section 3.3.2) across R_1. Since this is a single ended oscilloscope you cannot simply use one oscilloscope probe to measure the voltage across R1. You must make sure you use two oscilloscope probes with one used to measure the voltage between the positive side of R1 and ground (Channel 1) and the other used to measure the voltage between the positive side of R2 and ground (Channel 2) and then to subtract the Channel 2 signal from the Channel 1 signal in order to get the voltage across R1.

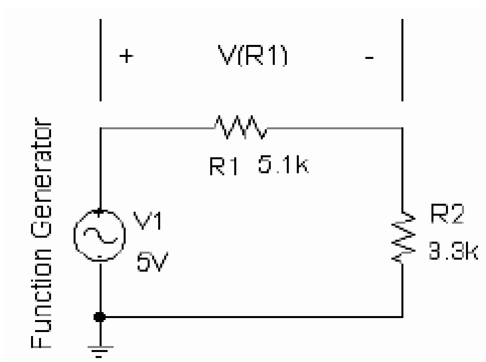


Figure 5. Circuit being used for measuring the voltages and time parameters generated by the function generator with the oscilloscope.

5.2. KEITHLEY SMU

This part of the lab experience will focus on the Keithley SMU. Notice that Figure 6 a) and b) are source transforms of each other. You should be able to compare and contrast the voltage and current measurements. Do all of the following.

1. Using the circuit of Figure 6 a), set up a Keithley SMU as a voltage source of 10 V DC. Use the second Keithley SMU to measure the voltages in R_1 and R_2. Measure the current in the circuit directly from the Keithley SMU used as the voltage source.
2. Using the circuit of Figure 6 b), set up a Keithley SMU as a current source of 5 mA DC. Set up the other Keithley to measure the current in R_3 and in R_4.

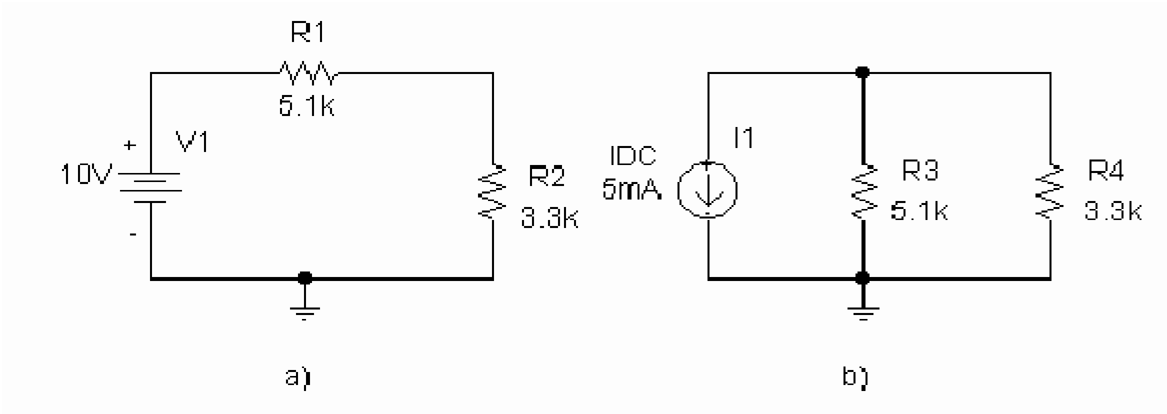


Figure 6. Circuits for Keithley SMU to measure voltages and currents.

3. Measure the impedance of your two resistors using the Keithley SMU. Record the values and use these values to determine if your measurements were actually correct.

6. LAB REPORT

Type a lab report with a cover sheet containing your name, class (including section number), date of the lab, and the report due date. Use the following outline to draft your lab report.

- Introduction: type a summary of the key features of the equipments used in this lab.
- Lab report:
  - Report all the measured data collected from this lab. (Make sure it is easily discernable which values are from a particular section of the procedure.)
  - Give theoretical descriptions for each section of the procedure and describe how the theory compared with the measured results. Include the circuit diagrams in your descriptions as necessary. Use the measured values for your resistors in finding the theoretical values.
- Conclusions: write up your conclusions for this lab.