ECE Lab Manual

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1 Breadboard

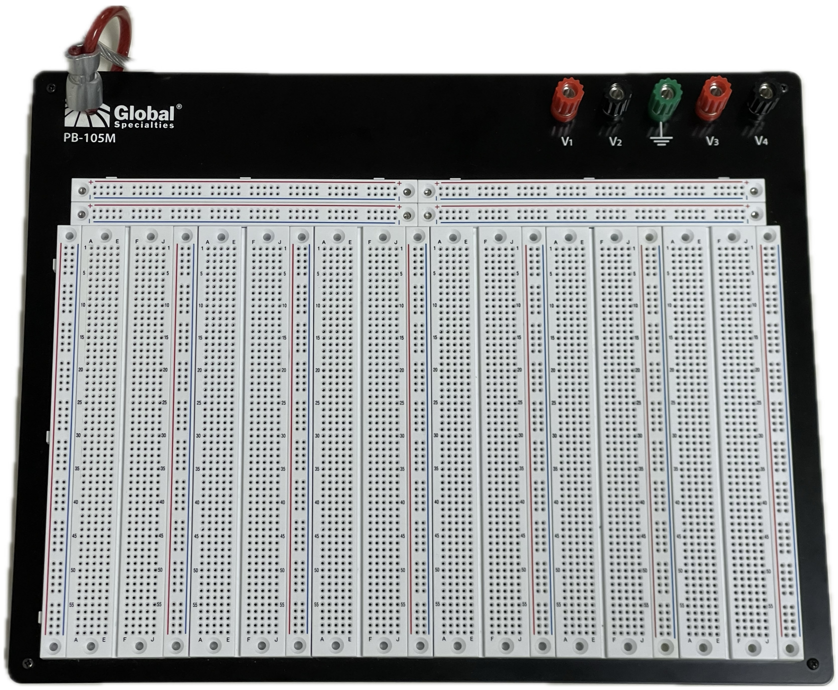

Figure 1: Breadboard

- The breadboard has many strips of metal (copper usually) which run underneath the breadboard
- There are long columns that run down the board (rails) that have a color next to them
  - These are characterized by the + and - symbols and blue and red long lines
  - The rails are useful for running various voltages (i.e. +5v or GND) down the board, while the rows are used to build your circuits
- There are short rows of 5 holes that are connected, which form a node
  - These are characterized by the letters at the top/bottom of the breadboard i.e. A-E form one node, F-J form one node
- The terminal posts on the top right of the breadboard is used to wire DC voltages to the breadboard
  - These posts can be rotated to reveal a hole in which a wire can be inserted to wire these DC voltage to the rest of the breadboard

2 Cables

2.1 DC to Breadboard Cables

Figure 2: DC to Breadboard Cables

- These cables are characterized by the banana plugs on both ends of the wire
- One end of this cable connects to the DC power supply, while the other end connects to a terminal post on the breadboard
- These cables come in either black, red, or green
  - These colors do not affect the functionality of the cable and thus can be used interchangeably
  - However, it is good to be consistent with conventions such as red: positive and black/green: negative/ground
- There is a shorter-length black DC to Breadboard Cable that can be useful for stacking grounds to tie them together

2.2 DC Shorting Bar

Figure 3: DC Shorting Bar

- The DC shorting bar is a quick way to short the negative end of one source with the positive end of an adjacent source. It is very useful when you want to work with a positive voltage source as well as a negative voltage source.
- The shorting bar is characterized by a black block with two banana plugs coming out of it
- These cables come in either black, red, or green
- Refer to the DC Power Supply section 3.4.2 for an example of a use for the shorting bar

2.3 Multimeter Clips

Figure 4: Multimeter Clips

- These cables are characterized by one banana plug on one end and a minigrabber on the other end
- The banana plug plugs into the multimeter and the clip connects to the relevant part of the circuit
- These cables come in either red or black
  - Similar to the DC to breadboard cable, these are interchangeable but it will be good to follow the convention that red: positive and black: negative
- These are not to be exchangeable with the DC to Breadboard cables due to limited supply

2.4 Oscilloscope Probes

Figure 5: Oscilloscope Probes

- These cables are characterized by a BNC connector on one end and a set of probe and alligator clip on the other end
- The BNC connector plugs into the oscilloscope
- The probe is a clip that will be attached to the circuit, while the alligator clip will always be grounded
- These cables come in all black
- It is useful to think of oscilloscope probes as tools to measure node voltages
- There is a switch on these probes to set the attenuation factor to 10X or 1X
  - IMPORTANT: Oscilloscope probes must remain set to 10X attenuation unless the oscilloscope is also set to match this

2.5 Function Generator Cables

Figure 6: Function Generator Cables

- These cables are characterized by a BNC connector on one send and a set of red and black minigrabbers on the other end
- The BNC connector plugs into the function generator
- The red clip is the positive end of the source, while the black clip can be thought of as the negative end of the source
- These cables are not interchangeable with the oscilloscope probes, despite both having BNC connectors

3 DC Power Supply

Figure 7: DC Power Supply

3.1 Front Panel

1. Power Button
2. Screen Panel Buttons
3. Source Toggle
4. Knobs/Button to Input Voltage/Current Values
5. Output Voltages

3.2 Setting Values

Use the screen panel buttons 3 to choose which output voltage to set. Use either the voltage knob or the buttons 4 to manually set this voltage. Similarly, the same can be done for the current value.

NOTE: This current value serves as a **threshold** for overcurrent protection (OCP). Anytime the current exceeds this value, the channel will display OC, and the output will shut off to protect the source and the circuit. When this is triggered, the PS needs to be powered off, and the wiring in the circuit must be corrected to prevent OCP from recurring. Once the problem is fixed, turn on the PS and continue with the lab.

3.3 Default Values

	Voltage	Current Limit
Channel 1	5 V	500 mA
Channel 2	15 V	500 mA
Channel 3	15 V	500 mA

Note: Channels 2 and 3 are set with **Tracking: ON**. This means that both values will be synced and thus be set to the same absolute value all the time. This can be turned off using the Tracking button, if desired.

3.3.1 Full Range of Values

	Lower Limit	Upper Limit
Channel 1	0 V	5 V
Channel 2	0 V	15 V
Channel 3	-15 V	0 V

As seen in Figure 9, this power supply is capable of outputting three voltage values. V_1 and V_2 are able to output positive values, while V_3 is able to output negative voltage.

3.4 Pulling Output Voltages

3.4.1 Pulling Positive Voltages

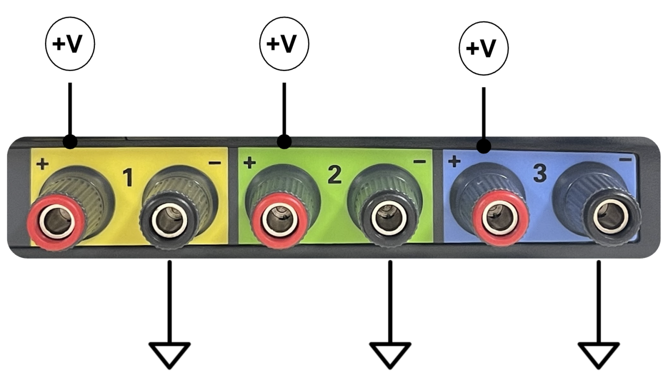

Figure 8: Power Supply Structure

This DC power supply comes with three voltage sources that have independent grounds. By default, they are all positive.

The signal ground terminals, denoted by ∇ in Figure 8, can be tied by stacking DC to Breadboard cables onto one breadboard post Plug in the DC to

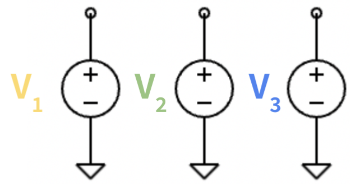

Figure 9: Power Supply Circuit Representation

Breadboard cables to connect the power supply and the breadboard and wire into the circuit appropriately

Finally, ensure that the toggle buttons are clicked and lit up.

3.4.2 Pulling Negative Voltages

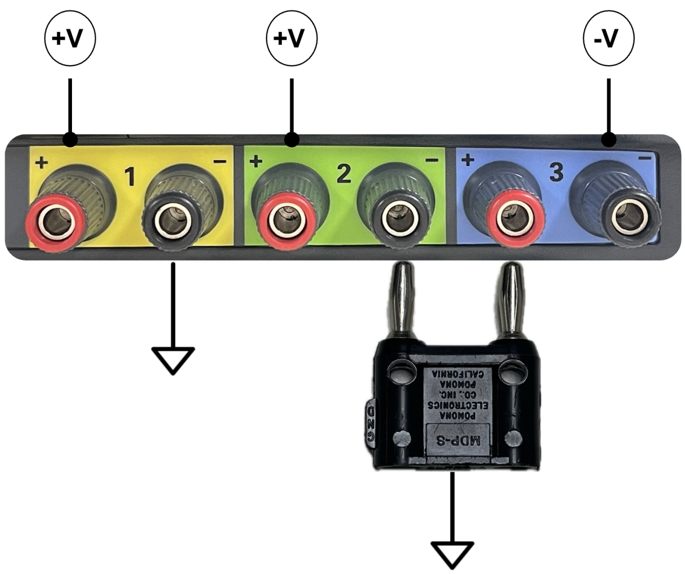

Figure 10: Power Supply Structure (with Shorting Bar)

It is possible to pull negative voltages with this DC power supply. Figure 10 shows the simplest way to achieve this configuration. You can use a DC shorting bar in order to short the negative end of one source to the positive end of another source. The source whose positive end is tied can be viewed as a negative voltage source (in this example, V_3 is negative). You pull the output from the negative terminal. Consult Figure 11 to see the circuit representation

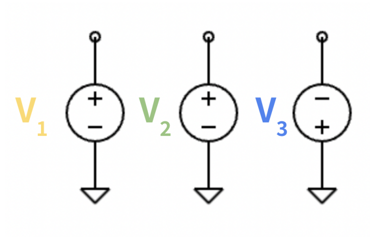

Figure 11: Power Supply Circuit Representation (with Negative Output Voltage)

for this configuration.

Note that the shorting bar can also be used for V_1 and V_2 to make V_2 negative. It is also technically possible to achieve this configuration with V_1 and V_3, but using a DC power supply cable instead.

3.5 Troubleshooting

Here are some troubleshooting tips:

1. If the voltage source appears to be outputting zero voltage
   - Check to see that the "ON" button is toggled and lit up.
   - Check to see that the DC to Breadboard cables are properly plugged in and a wire is properly inserted. Ensure that a metal-on-metal connection is made between the wire and the breadboard post.
   - Check to see that the voltage source is properly connected with the rest of the circuit. Review the section on Breadboard for clarification on how nodes are formed.

4 Multimeter

Figure 12: Multimeter

4.1 Front Panel

1. Power Button
2. Front Panel Buttons
3. Measurement Toggles
4. Cable Ports

4.2 Voltmeter

Denoted by **DCV** and **ACV** in (3), the voltmeter can be toggled on using these two buttons. Here are the key differences between the two:

- **DCV**: Intended for directly measuring DC voltages in a DC circuit
- **ACV**: Intended for measuring RMS voltages in an AC circuit

4.3 Ammeter

Denoted by **DCI** and **ACI** in (3), the ammeter can be toggled on using these two buttons. Here are the key differences between the two:

- **DCI**: Intended for directly measuring DC current in a DC circuit

- **ACI**: Intended for measuring RMS current in an AC circuit

4.4 Ohmmeter

Denoted by the Ω**2W** in ③, the ohmmeter can be toggled on using this button.

4.5 Wiring up Multimeter

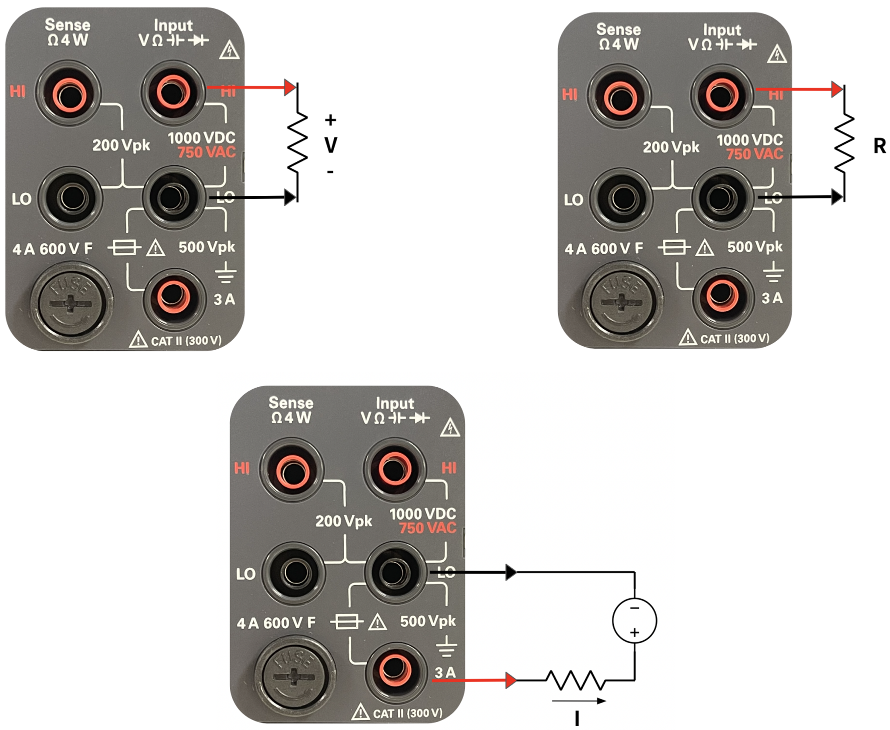

Figure 13: Voltmeter (left), Ammeter (middle), Ohmmeter (right)

1. Voltmeter
    - Attach the **positive end** of the measured voltage with the multimeter clip denoted by the **red arrow** in Figure 13
    - Attach the **negative end** of the measured voltage with the multimeter clip denoted by the **black arrow** in Figure 13
    - NOTE: This is a **parallel** connection
2. Ammeter

- Attach the multimeter clip denoted by the red arrow on the side of the circuit where the current originates in the circuit
- Attach the multimeter clip denoted by the black arrow on the other side of the circuit to complete the path in which the current travels
- NOTE: This is a **series** connection

3. Ohmmeter

    - When measuring the value of a **single resistor**, simply attach the individual multimeter clips on both legs of the resistor
    - When measuring **equivalent resistance** in a circuit, turn off independent sources and attach the multimeter clips in the desired ports from which this equivalent resistance is seen from

4.6 Troubleshooting

Here are some troubleshooting tips:

1. Common circuit building errors

    - Ensure that the ammeter is in series with the element whose current is being measured.
    - Ensure that the voltmeter is in parallel with the element whose voltage is being measured.
    - Ensure that there are no open circuits when using the ohmmeter. Otherwise, it will overload.

5 Handheld Multimeter (Legacy)

Figure 14: Handheld Multimeter

5.1 Front Panel

1. Mode Toggle Knobs
2. Cable Ports

5.2 Why Legacy?

The handheld multimeter is intended as a secondary multimeter. The multimeter in the previous section should be the primary. The handheld multimeter will be mostly useful if a lab warrants the need to measure two different measurements at the same time. Otherwise, only use the primary multimeter.

5.3 Voltmeter

Denoted by $\tilde{V}$ and $\bar{V}$ in 1, the voltmeter can be toggled on using these knob settings. Here are the key differences between the two:

- $\bar{V}$: Intended for directly measuring DC voltages in a DC circuit
- $\tilde{V}$: Intended for measuring RMS voltages in an AC circuit

5.4 Ammeter

Denoted by $\tilde{I}$ and $\bar{I}$ in 1, the ammeter can be toggled on using these knob settings. Here are the key differences between the two:

- $\bar{I}$: Intended for directly measuring DC current in a DC circuit
- $\tilde{I}$: Intended for measuring RMS current in an AC circuit

5.5 Ohmmeter

Denoted by Ω in (1), the ohmmeter can be toggled on using this knob setting.

5.6 Wiring up the Handheld Multimeter

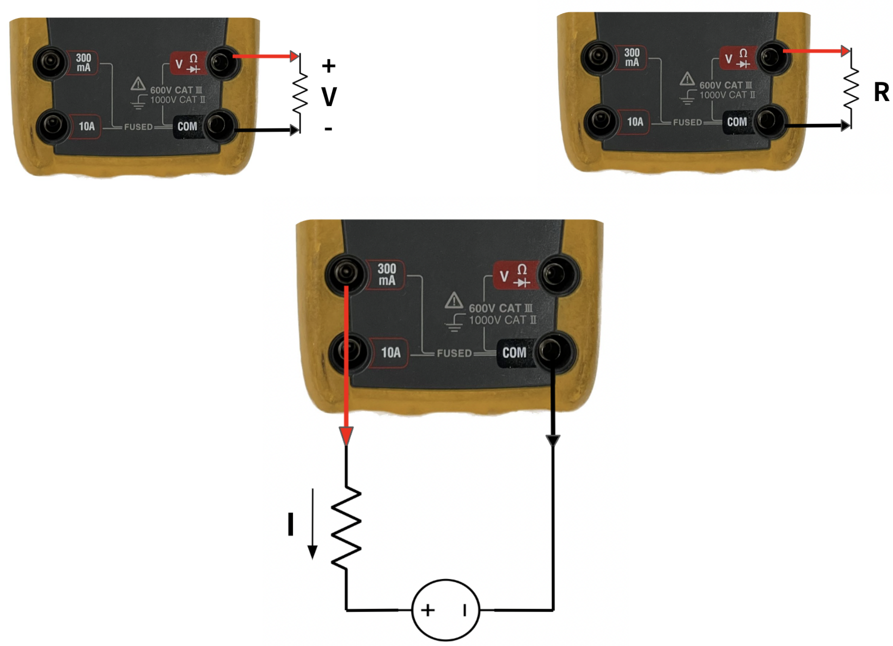

Figure 15: Voltmeter (left), Ammeter (middle), Ohmmeter (right)

1. Voltmeter
   - Attach the **positive end** of the measured voltage with the multimeter clip denoted by the **red arrow** in Figure 15
   - Attach the **negative end** of the measured voltage with the multimeter clip denoted by the **black arrow** in Figure 15
   - NOTE: This is a **parallel** connection
2. Ammeter
   - Attach the multimeter clip denoted by the red arrow on the side of the circuit where the current originates in the circuit

- Attach the multimeter clip denoted by the black arrow on the other side of the circuit to complete the path in which the current travels
- NOTE: This is a **series** connection

3. Ohmmeter

    - When measuring the value of a **single resistor**, simply attach the individual multimeter clips on both legs of the resistor
    - When measuring **equivalent resistance** in a circuit, turn off independent sources and attach the multimeter clips in the desired ports from which this equivalent resistance is seen from

5.7 Troubleshooting

Here are some troubleshooting tips

1. If the current appears to be zero, but you are expecting some nonzero current

    - Check to see that you are plugged into the **300mA** as opposed to the **10A** port. Typically, the currents in the lab will be small, and thus, a mA range will be more appropriate.

2. Circuit building errors

    - See the previous troubleshooting section (4.6)

6 Oscilloscope

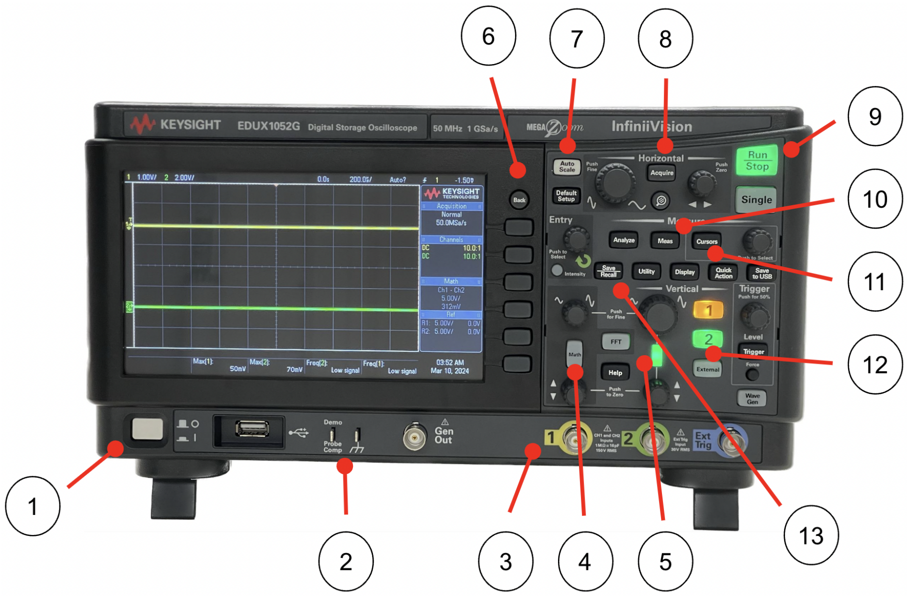

Figure 16: Oscilloscope

6.1 Front Panel

1. Power Button
2. Probe Tester
3. Input Ports
4. Math
5. Vertical Scaling
6. Front Panel Buttons
7. Auto Scale
8. Horizontal Scaling
9. Run/Stop/Single
10. Measure
11. Cursor
12. Waveform Toggle
13. Save/Recall

6.2 Quick Guide

By default, the oscilloscope channels and probes are set to 1:1 ratio.

1. Connect BNC oscilloscope probes to the input ports 3.
2. Turn on an input channel by pressing the **Waveform Toggles** 12. It should now be glowing.
3. Connect both ends of the probe to the circuit in order to see the voltage difference between two nodes.
4. Press **Auto Scale** 7 and the device will compute vertical and horizontal scaling for each input.
5. Further adjust horizontal and vertical scaling using their respective knobs 8 and 4.
6. Shift the signal in time and offset using the knobs adjacent to the scaling knobs.
7. Press the cursor 11 key, then press the menu key for **Mode**. Press **Manual** then X or Y, for horizontal and vertical cursors respectively. This allows for manual data collection.
8. Press **Measure** and select the mode for the desired measurement type i.e., Pk-Pk, Max, Min, Phase, etc.

This will allow for the measurement and analysis of most simplest use cases in the lab. More details on each of these steps are discussed below.

6.3 Input Channels

Using an oscilloscope probe discussed in the cables section of this manual, connect the probes via **input ports** 3. In order to read an input signal, connect the retractable hook tip of the probe to the circuit and the alligator clip to ground or another terminal. The device will display the voltage difference between the nodes connected via the probes. The corresponding input channels can be turned on and off using the **waveform toggles** 12. If the waveform toggles are illuminated by the button's back light, the corresponding channel is being displayed.

6.4 Auto Scale

By pressing the button labelled **Auto Scale** 7, the oscilloscope will compute suitable settings to display the input waveform. However, these settings may likely need to be changed in order to accommodate the measurements that need to be taken. The output window scaling can be further adjusted using the horizontal and vertical scaling.

6.5 Horizontal and Vertical Adjustment

In order to make further adjustments to the waveform display, the **sweep speed** (8) and **horizontal delay** (8) knobs can be used. The sweep speed knob seen on the left of the horizontal controls, adjusts the timescale of the waveform. The horizontal delay knob can shift the waveform to the left or right, i.e. adding a positive or negative time delay.

The vertical controls are similar, with **vertical scale** (5) and **vertical position** (5). These work in a similar manner by adjusting the volts per division and vertical offset to the waveform, respectively.

6.6 Acquisition Mode

The acquisition mode can be selected via the **Acquire button** (8). This opens the acquire menu on the display. This display can be navigated via the **front panel buttons** (6). This menu holds two important settings: time mode and acquisition mode.

Time Mode

- **Normal:** The normal view mode for the oscilloscope. In this mode the device displays volts versus time.
- **XY:** Shows volts-versus-volts plotting the amplitude of channel 1 on the x-axis and amplitude of channel 2 on the y-axis. This mode is useful for analyzing phase differences between waveforms, and in conjunction with math mode, displaying the i-v characteristics for a given device.
- **Roll:** Most likely will not be used in most ECE coursework, however, this time mode causes the input waveform to scroll laterally across the display. This is only usable for low frequency input waveforms.

Acquisition Mode

- **Normal:** This is the standard acquisition mode for the oscilloscope. The signal is shown on the display as it is read by the device. Due to this there is decimation of the input signal due to the sampling rate of the device.
- **Peak Detect:** This mode stores the maximum and minimum for a given sampling interval and displays the peaks. This causes the signal to appear noisier, but it can be used in order to identify glitches in oscilloscope readings.
- **Averaging:** As described, this mode takes the average of multiple acquisitions. This decreases noise and increases signal resolution. The number of averages can be changed by pressing the **#Avgs** key in the **Acquire** menu.

- **High Resolution:** Similar to the averaging mode, except the number of averaged samples is dependent on the sweep speed setting on the oscilloscope. This has the effect of reducing the oscilloscope's bandwidth.

6.7 Cursor Controls

Cursors are a very useful analysis tool and can be used to manually calculate time constants, phase differences, and other useful values. Press the **Cursors** 11 key to open the display menu. Press **Mode** and choose between:

- **Manual:** In this mode one can move 2 horizontal cursors and 2 vertical cursors, labelled X1, X2, Y1, and Y2. ΔX and ΔY show the differences in time and voltage, respectively.
- **Track Waveform:** Select a source, and as the cursor moves horizontally it will track the vertical amplitude of the waveform and show the same ΔX and ΔY terms as manual mode.
- **Binary:** In this mode, a trigger level must be set. When the cursor value goes above the trigger it will read 1 and 0 when it is below the trigger.
- **Hex:** This is very similar to binary mode except logic levels are displayed in hexadecimal.

Once mode is selected the cursors can be moved via the **Cursor Knob** near the cursor key. Units can be changed by pressing the **Units** menu key.

6.8 Measure Function

The measurement function on the oscilloscope is an invaluable tool for data collection. The oscilloscope can take a variety of different measurements including, pk-pk voltage, max, min, phase, rise-time, RMS, etc. To begin to taking measurements press the **measure key** 10. The measurement menu necessitates the selection of a source and measurement type. These settings are navigated via the front panel buttons and entry knob. Once a source channel and measurement type are selected, press **add measurement** in order to add the data to the waveform display. Some measurement types allow for the selection of additional settings which can be accessed via the **settings** section of the measurement menu.

6.9 Math Function

Using the math function one can apply arithmetic operations on the input channels, resulting in a third math waveform. Transforms and filters can also be applied in this mode. Such as a low pass filter or FFT, which will be described in greater depth.

1. To enter this mode press the **Math** 4 key

2. Display the waveform by toggling the **Function** menu key
3. Press the **Operator** menu key to choose the operation, transform, or filter to be applied
4. Use the **Source 1 & 2** menu keys to select the channels the operation will be applied to
5. The waveform can then be resized and adjusted using the scaling and shifting knobs adjacent to the math key.

These operations can be used to determine things like the i-v characteristics of non-linear components.

NOTE: Tools like the cursor and XY mode can be used on a math waveform.

6.10 FFT/Frequency Analysis

An FFT can be taken by navigating to the **Operator** tab in the math menu and then selecting FFT. This can be selected for magnitude or phase. Pressing **Auto Setup** will then compute frequency span and center values to maximize the frequency spectrum displayed. The **More** menu key allows for the manual selection of the transform parameters.

- **Span:** Changes the overall width of the FFT spectrum. The Hertz per division is computed by dividing the span by 10.
- **Center:** Changes the center frequency on the display.
- **Window:** Allows for selection between Hanning, Flat Top, Rectangular, and Blackman Harris window functions. These window functions serve to address leakage occurring as a result of taking the FFT. This is out of scope for most lower-level ECE coursework.
- **Vertical Units:** For the magnitude FFT, this toggles between **Decibels** and **V RMS**. For the phase FFT, this toggles between **Degrees** and **Radians**.

NOTE: The offset and vertical scale of the FFT display can be adjusted via the **Math** 4 knobs.

6.11 Save/Recall

The oscilloscope allows for the export of settings, waveform data, and display output images. This functionality is particularly valuable when generating lab reports and homework. In order to export data, press the **Save/Recall button** 13. This will open the Save/Recall menu. Press the front panel button associated with **save** on the display menu. This will then allow for the selection of format, which roughly speaking includes setup files, data files, and image files.

After selecting the file type navigate to the storage location of choice. This can be an external USB storage device or the device's onboard storage. However, it is recommended to use external storage for the purpose of data export.
In summary:

1. Press the **Save/Recall** button 13
2. Use the front panel buttons to select save from the save/recall menu
3. Select data format
4. Navigate to the desired storage location
5. Use the **Press to save** softkey

6.12 Troubleshooting

1. If the displayed amplitude is a fraction or a large factor of the analytical value.
   - Double check the probe attenuation factor. To do this press the **Channel** key, then **Probe** menu key. continually pressing this key will switch the probe between **decibels** and **ratio**.
   - Turning the **entry knob** will then change the attenuation factor. Verify that the attenuation setting on the oscilloscope matches the physical probe.
2. Missing DC offset.
   - Verify that the channel is set to DC coupling. Press the desired **Channel** key, then the **Coupling** menu key. Here you can toggle between AC and DC coupling.

7 Function Generator

Figure 17: Function Generator

7.1 Front Panel

1. Power Button
2. Front Panel Buttons
3. Waveform Generator
4. Knob/Buttons to Input Values
5. Output Ports and Toggles

7.2 Output Channels

The EDU3321A function generator has two output channels. This device uses different cables from the oscilloscope discussed in the previous section. Once a BNC cable is attached to the output channel, press the associated **channel toggle** 5. This will turn on the respective output channel.

IMPORTANT: By default, the function generator will be set with fixed series output impedance of 50Ω. This value may seem familiar depending on how familiar one is with impedance matching, as this is a common characteristic impedance for many transmission lines. However, if this is not a familiar concept, one should change the output termination to High Z. This will set a large output impedance for the desired channel, allowing a larger percentage of the input voltage to be seen at the load. This can be achieved by:

1. Press the **Setup** 5 softkey
2. Then press the menu softkey labelled on screen as **Output** 2
3. Next, select **High Z** as the output load using the menu softkeys
4. **NOTE:** If necessary this is also where one can select 50Ω or custom output impedance

7.3 Waveform Types

The EDU33212A is capable of outputting a large number of output waveforms. However, in most use cases within ECE coursework, standard waveforms such as, sine, square, ramp, and pulse functions. These can be navigated to via the **Waveform** 3 softkey. The menu keys can then be used to select the desired output waveform type.

- Sine
- Square
- Ramp
- Triangle
- Pulse
- PRBS (Pseudo-Random Binary Sequence)
- DC
- Gaussian noise

Additionally, the function generator can output a 9 of arbitrary waveforms and allows for the use of 6 modulation types. However, these are outside of the scope of this guide. For information on these functions refer to the device manual.

7.4 Adjusting Waveform Parameters

The most important settings after the output function type are the waveform parameters. The parameters available to change will differ between the types of output functions, but can all be navigated to using the **Parameters** 3 key. This will show a list of waveform parameters such as

- **Frequency:** Sets the frequency in Hertz of the output function. This can also be set by period length.
- **Amplitude:** Changes the magnitude of the function. It can also be set using high-level and low-level, where the max and min of a function are input, and the offset is calculated to generate the waveform.
- **Offset:** Applies a DC offset to the output waveform. This will be applied automatically if using high-level and low-level.
- **Phase:** Applies a phase shift in degrees. This only has a noticeable effect given a reference waveform.
- **Duty Cycle:** Changes the percentage of time a pulse is high relative to the period of the waveform.

NOTE: The way in which these parameters are displayed will vary based on the units selected in the function generator settings. For example, one can either display amplitude and offset, or high and low levels. This can be changed by pressing the **Units** key and toggling between these different modes.

To change a given parameter press its associated menu key, then input a numerical value using the number pad or input knob 4. Then press the menu key showing the desired unit for the input value i.e. mV vs V.

7.5 Troubleshooting

1. If the amplitude of the output signal appears substantially lower than the analytical solution, and the cause is undesirable and unknown.
   - Verify that the output termination is in high Z mode.