Massachusetts Institute of Technology

Department of Electrical Engineering and Computer Science

6.002 – Circuits and Electronics

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Lab Equipment Handout

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This handout is intended to provide a brief technical overview of the lab instruments which we will be using in 6.002: the oscilloscope, multimeter, and function generator. It incorporates much of the material found in the individual instrument manuals, while including some background information as to how each of the instruments work. The goal of this handout is to serve as a reference of common lab procedures and terminology, while trying to build technical intuition about each instrument's functionality and familiarizing students with their use. Students with previous lab experience might find it helpful to simply skim over the handout and focus only on unfamiliar sections and terminology.

THE OSCILLOSCOPE

The oscilloscope is an electronic instrument based on the cathode ray tube (CRT) – not unlike the picture tube of a television set – which is capable of generating a graph of an input signal versus a second variable. In most applications the vertical (Y) axis represents voltage and the horizontal (X) axis represents time (although other configurations are possible). Essentially, the oscilloscope consists of four main parts: an electron gun, a time–base generator (that serves as a clock), two sets of deflection plates used to steer the electron beam, and a phosphorescent screen which lights up when struck by electrons. The electron gun, deflection plates, and the phosphorescent screen are all enclosed by a glass envelope which has been sealed and evacuated.

The visible part of the CRT tube, the "screen", is the outside of the glass wall on whose inner surface lies the phosphorescent film. The screen is inscribed with a set of axes enclosed by a grid. As the oscilloscope operates, the electron beam traces a graph of the input voltage versus time on the phosphorescent film behind these axes. The horizontal axis is the time axis, and the vertical axis is the voltage axis.

PRINCIPLES OF OPERATION

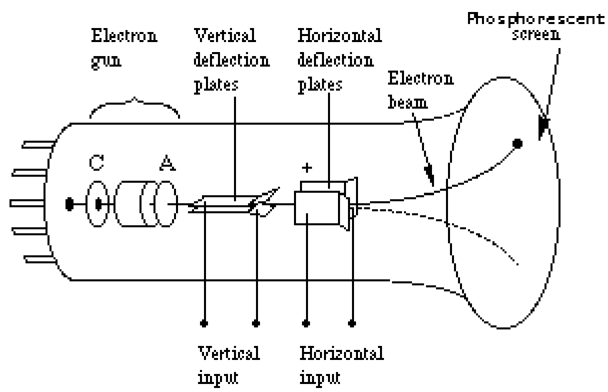

Figure 1 The internal parts of an oscilloscope

The main component of an oscilloscope is an electron gun which ejects a constant beam of electrons into the surrounding vacuum (see Figure 1). As the beam emerges from the gun, it passes through a set of parallel plates (the **Vertical deflection plates**) oriented horizontally. The voltage to be displayed is amplified and applied across these plates producing an electric field which deflects the path of the electrons vertically. The polarity of the signal of interest determines whether the deflections will be up or down and the magnitude of the signal determines the amount of vertical displacement of the electrons.

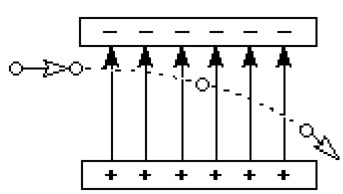

Figure 2 Deflection of an electron in a uniform electric field

After the beam has passed through the **Vertical deflection plates**, it passes through a second set of similar plates that are oriented vertically. A potential difference applied to these plates produces an electric field which deflects the electrons left or right. Under most configurations (one common exception is XY mode to be discussed later), these **Horizontal deflection plates** make the beam move sideways at a constant speed. By adjusting this speed with the **Sweep** knob, the resulting trace on the screen can be spread out or compressed.

If the two deflecting voltages were held constant, the electron beam would strike a fixed point on the phosphorescent film and a stationary point would be visible on the screen. However, most voltages of interest are time–varying and so the voltage applied to the **Horizontal deflection plates** is varied with time in such a way that the spot moves from left to right on the screen as time passes. Since the phosphorescent material has the property of emitting light for several milliseconds after the electrons have passed, the total effect is for the electrons to leave behind a visible trail – a time–varying waveform.

The horizontal deflection voltage (or "sweep" voltage) is also varied in such a way that when the beam reaches the right–hand edge of the screen, it starts over at the left–hand side. If the signal to be displayed varies periodically in time, it is possible to synchronize the sweep voltage with the signal so that the curve appears motionless on the screen. This is done with the **Trigger Level** control which sets the oscilloscope to begin a trace when the voltage it measures reaches a certain value. The (+) or (−) button lets you choose whether you want the oscilloscope to trigger on a positive or negative voltage. A trace that is running across the screen can usually be stabilized by adjusting the trigger level (as long as the waveform is periodic!).

USING THE SCOPE

Now that we have acquired a basic understanding of how the oscilloscope works, we can proceed to explore some of the most common tasks which can be accomplished with it. The oscilloscope which we will be using in 6.002 is the Tektronix 2445 – a four channel (input) scope. Since the oscilloscope has four channels, we could simultaneously graph four distinct input voltages on the CRT (although we wont get that complicated in 6.002!). Aside from the display itself, the oscilloscope consists of various control panels which give the user complete control of how the scope processes and displays its inputs. In the section that follows we will describe each of the control panels and outline the functionality of each of the settings found therein.

THE DISPLAY

The oscilloscope's display can be adjusted in various ways in order to make the displayed signals brighter and more defined on the screen. Under the display screen you will find a series of controls which will allow you to adjust the waveform brightness and focus, etc. The following are the labels of the controls along with a description of their function.

INTENSITY:

Controls the brightness of the displayed waveform. As you increase the sweep speed of an analog oscilloscope, you need to increase the intensity level.

FOCUS:

Controls the sharpness of the displayed waveform on the screen.

READOUT INTENSITY:

Controls the intensity of the oscilloscope's on–screen measurement readouts such as frequency, period, SEC/DIV, and VOLTS/DIV.

FOCUS:

Controls the sharpness of the on–screen measurement readouts on the display.

SCALE ILLUMINATION:

Adjusts the brightness of the screen grid.

INPUT CHANNELS

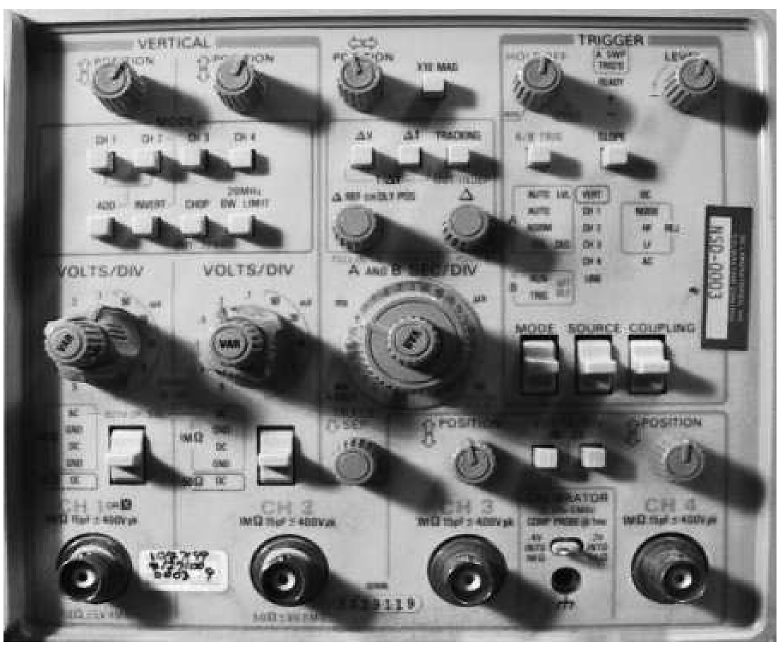

Figure 3 Control Panel for the Tektronix 2445 Oscilloscope

As mentioned previously, the Tektronix 2445 has four analog input ports for connecting to the outside world. These are labeled CH 1 – CH 4 (only CH 1 and CH 2 are full–featured) and are located horizontally along the bottom of the control panel. It is here that we will connect our probes and interface with the function generator and the circuits we build. Each channel has a variety of individual controls which affect how the channel's input will be processed and displayed on the screen. These are **input coupling**, **vertical position**, and **volts per division** (these switches are found above their corresponding input channel).

The input coupling setting affects how the input signal in processed by the oscilloscope. In the case of the Tektronix 2445, the input coupling can be set to DC, AC, or GND. The simplest of these is the GND setting which disconnects the input signal from the vertical system, letting you see where zero volts is on the screen. Switching from DC to GND and back again is a handy way of measuring signal voltage levels with respect to ground.

Before continuing with how the DC and AC settings affect the displayed signal, it is worth noting the that all signals can be broken down into two basic components: a constant component (DC) defined as the time−average of the signal, and a time−varying component (AC) defined as the original signal minus the average value. With this in mind, the DC coupling setting displays the entire input signal (time−varying plus constant components), while the AC coupling setting blocks the DC component of a signal so that only the time−varying waveform appears centered at zero volts. The AC coupling is handy when the entire signal is is too large for the VOLTS/DIV setting or the AC component is very small compared to the DC component.

Once we have selected the proper type of input coupling for the signal we will be viewing, we can select where it will be placed on the screen via the vertical position control. The vertical positioning knob is located at the top left of the control panel for CH 1−2 and at the bottom right for CH 3−4. These vertical controls are all independent, so that each channel's input can be positioned freely on the display. It is important to remember that the range of these knobs is greater than the size of the screen, so the waveform can be moved off the screen altogether!

The volts per division setting varies the size of the waveform on the screen. Think of the VOLTS/DIV setting as a scale factor (this is the factor by which the input waveform is amplified receives before it is applied to the **Vertical Deflection plates**). For example, if the VOLTS/DIV setting is 5 volts, then each of the eight vertical divisions represents 5 volts and the entire screen can show 40 volts from bottom to top. If the setting is 0.5 VOLTS/DIV, the screen can display 4 volts from bottom to top, and so on. In general, the maximum voltage that can be displayed is the VOLTS/DIV setting times the number of vertical divisions. The small knob, called a vernier knob, labeled VAR located on the VOLTS/DIV knob controls a variable gain used for scaling a displayed signal to a certain number of divisions. ***Note:*** *The vernier knob should be set full clock−wise in order for the scale settings on the VOLTS/DIV knob to be accurate.*

In a manner identical to the VOLT/DIV setting, the scale of the time axis (X−axis) can also be controlled using the **SEC/DIV knob**. For example, if the SEC/DIV setting is 1 second, then each of the 10 horizontal divisions represents 1 second and the entire screen can display 10 seconds. In essence, this setting is letting you adjust the rate at which the waveform is drawn across the screen (also known as the time−base setting or sweep speed). As with the vertical VOLTS/DIV setting, there is also a variable timing control which allows the user to set the horizontal time scale between discrete settings.

MODE MENU

Located at the top left corner of the control panel, under the **MODE** section we find four channel select buttons along with four other buttons: **ADD**, **INVERT**, **CHOP**, and **20MHz BW (Bandwidth) LIMIT**. Not surprisingly, the four channel select buttons labeled CH 1−CH 4 are used to select the channels which will be displayed on the screen. The function of the four remaining buttons are described below:

ADD:

Displays the sum of the signals on CH1 and CH2 on the display. The individual signals are no longer displayed separately.

INVERT:

Displays the negative of the signal present on CH2.

CHOP:

Causes the oscilloscope to draw small parts of each signal by switching back and forth between them. The switching rate is too fast for you to notice, so the waveform looks whole. This mode is typically used with slow signals requiring sweep speeds of 1ms per division or less.

20MHz BW LIMIT:

Limits the input bandwidth of the oscilloscope. By limiting the bandwidth, you reduce the noise that sometimes appears on the displayed waveform yielding a more precise signal display.

TRIGGERING

The trigger controls, found at the top right of the scope, give you the ability to stabilize repeating waveforms and capture single–shot waveforms by adjusting the sweep speed in such a way that the waveform is redrawn in the same exact location during each pass. The trigger circuit acts as a comparator. You select the slope and the voltage level of one side of the comparator. When the trigger signal matches your settings, the oscilloscope generates a trigger. The slope control determines whether the trigger point is on the rising (positive slope) or falling (negative slope) edge of a signal. The level control determines where on the edge the trigger point occurs.

The oscilloscope does not necessarily have to trigger on the signal being measured. Several sources can trigger the sweep: any input channel, an external source (other than the signal applied to an input channel), or a signal internally generated by the oscilloscope. Most of the time you can leave the oscilloscope set to trigger on the channel being displayed. ***Note:*** *The oscilloscope can use an alternate trigger source whether it is being displayed or not. Be careful not to unwittingly trigger on, for example, channel 1 while displaying channel 2.*

The trigger mode determines whether or not the oscilloscope draws a waveform if it does not detect a trigger. Common trigger modes include normal and auto. In normal mode the oscilloscope only sweeps if the input signal reaches the set trigger point; otherwise the screen is left blank. Normal mode can be disorienting since you may not see the signal at first if the level control is not adjusted correctly.

Auto mode causes the oscilloscope to sweep without manual adjustment. If no signal is present, a timer inside the oscilloscope triggers the sweep. This ensures that the display will not disappear if the signal drops to small voltages. It is also the best mode to use if you are looking at many signals and do not want to bother setting the trigger each time.

In practice, you will probably use both modes: normal mode because it is more versatile and auto mode because it requires less adjustment.

The same way the AC or DC coupling can be selected for the vertical system, you can choose different types of coupling for the trigger signal. Besides AC and DC coupling, we can have high frequency rejection, low frequency rejection, and noise reduction trigger coupling. These special settings are useful for eliminating noise from the trigger signal in order to prevent false triggering.

HIGH Z (1 MEGOHM) VS. 50 OHM MODE

Ideally, we would like the oscilloscope to perfectly recreate its input signals on the display. However, once we connect the probes, the oscilloscope actually becomes part of the circuit we want to explore (possibly altering the voltages and currents we wanted to measure). This interaction between the oscilloscope and an external circuit is termed circuit loading. In an effort to minimize the amount of circuit loading for a given application, the oscilloscope provides two input impedance configurations: High Z mode and the 50 Ohm mode.

The High Z or 1 Megohm mode makes the oscilloscope's input impedance very high so that negligible current is drawn from the circuit being tested. The term High Impedance is relative however, and in the case that the circuit being observed has an output impedance greater than 1 Megohm, more current will flow through the probes and into the oscilloscope (through the path of least resistance), than through the circuit itself.

The 50 Ohm input impedance mode is used to match the 50 ohm output impedance of fast amplifiers and other devices. In such applications, failing to properly match the device's output impedance leads to signals being reflected once they reach the oscilloscope. These reflections cause the signal being viewed to be distorted by containing time–delayed versions of itself. We will not be using the 50 Ohm input impedance mode in 6.002.

XY MODE

The oscilloscope also lets you display an input signal rather than the time base on the horizontal axis. This setup is called XY mode because both the X and Y axis are tracing input voltages. As a note of interest, the waveform resulting from the XY arrangement of two periodic signals of different periods is called a Lissajous pattern. From the shape of the Lissajous pattern, you can determine information about the relative phases of the signals, as well as their frequency ratio.

For example, if you were to input the signal $\sin(\omega t)$ into both channel 1 and 2. Using the XY mode you would see a straight line of unit slope displayed on the screen (because at every instant the voltages on channel 1 and 2 are identical, ie. X=Y). Now imagine that you input the function $\sin(\omega t)$ in channel 1, but this time you decide to input $\sin(\omega t + \pi/2) = \cos(\omega t)$ into channel 2. In this case $y=\sin(\omega t)$ and $x=\cos(\omega t)$, which as you might remember from trigonometry correspond to the parametrization of the points on a circle.

BASIC MEASUREMENTS & PROCEDURES

Grounding:

Proper grounding (connecting an electrical device to an electrically neutral reference point such as earth ground) is an important step when setting up to take measurements or work on a circuit. Properly ground the oscilloscope by plugging its three–pronged power cord into an outlet protects you from a hazardous shock, while grounding yourself protects your circuits (especially small integrated circuits with memory) from damage.

Grounding the oscilloscope is necessary for safety. If a high voltage contacts the case of an ungrounded oscilloscope, any part of the case, including knobs that appear insulated, you can receive a shock. However, with a properly grounded oscilloscope, the current travels through the grounding path to earth ground rather than through you to earth ground.

Grounding is also necessary for taking accurate measurements with your oscilloscope. Measuring a signal requires two connections: the probe tip connection and a ground connection. Probes come with an alligator–clip attachment for grounding the probe to the circuit under test. In practice, you clip the grounding clip to a known ground in the circuit, such as the metal chassis of a stereo you are repairing, and touch the probe tip to a test point in the circuit.

MEASURING SIGNAL FREQUENCY, PERIOD AND AMPLITUDE

Measuring signal amplitude:

1) Making sure that the channel of interest is the one being displayed, adjust the SEC/DIV and VOLTS/DIV settings until the waveform is clearly visible on the display.
2) Press Δv button (located above the SEC/DIV knob).
3) Use the ΔREF knob in order to select the point which will serve as your measurement reference.
    1. For peak amplitude measurements ($\mathbf{V_p}$)place the ΔREF line along the waveform's zero crossing line.
    2. For peak–to–peak measurements ($\mathbf{V_{p\text{-}p}}$) place the ΔREF line along the waveform's minima.
4) Using the Δ knob move the second line until it reaches the top of the waveform.

5) The measured amplitude will be displayed at the top right of the display.

Measuring Signal Period:

1) With the waveform properly centered on the display, press the Δt switch (located above the SEC/DIV knob).

2) Place the ΔREF line at the wave's point of reference: minima, maxima or zero.

3) Use the delta knob to locate the corresponding point one cycle further down the wave.

4) The signal period will be displayed at the top right of the display.

Measuring Signal Frequency:

1) Follow the steps outlined for measuring the signal's period.

2) Once one period of the signal has been selected, simultaneously press Δv and Δt.

The reading at the top right of the display is the frequency of the waveform.

Note: *Make sure that the x10 button at the top of the control panel is not selected or the waveform might be too large to fit properly on the screen.*

Note: *Pressing the tracking button holds the distance between the ΔREF and Δ lines fixed. This might be helpful to make comparisons of signal period, frequency, or amplitude with a waveform present on another channel.*

BASIC TROUBLESHOOTING

Working with noisy signals:

If noise is present in the signal being observed using one of the following options might be appropriate depending on the type of noise present:

1) Enable the 20MHz Bandwidth limit option located in the MODE MENU. This option should be selected when using the oscilloscopes in lab because FM radio signals broadcast from nearby manifest themselves as high frequency noise on the scope.

2) Make sure that your circuit is wired neatly. Although this should not be a critical

issue for the circuits we build in 6.002, it is something to keep in mind while debugging (especially for more complicated circuits). Also, try to avoid using long pieces of wire on your circuit.

3) Check that the appropriate point in the circuit is properly grounded (usually accomplished through the power supply ground).

Calibrating the Scope Probes:

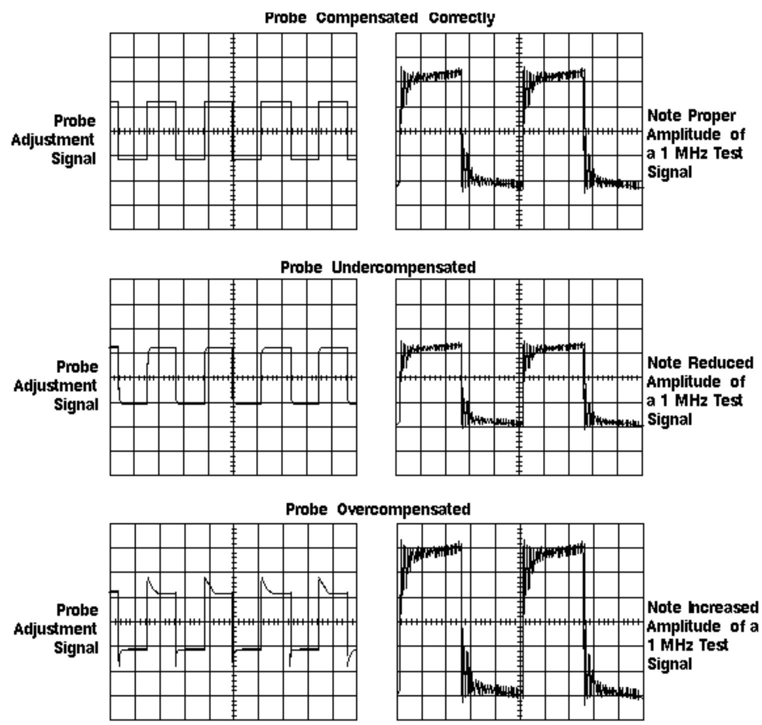

Figure 4 Oscilloscope Probe Compensation

[Image courtesy of: *XYZs of Analog and Digital Oscilloscopes* –Tektronix, pg. 26]

1) Connect an input probe to the calibration signal provided by the oscilloscope itself. This is located in–between the CH3 and CH4 input ports. ***Note:*** *If no signal is available at this port or if the oscilloscope you are using does not have this calibration signal available, a square wave generated by the function generator will suffice.*
2) Adjust the scope settings until the waveform can be clearly seen.
3) Adjust the knob on the probe until the square wave is almost perfect.

*(**Note**: This procedure works by changing changes the capacitance of the probe and hence RC time*

constant of the probe−oscilloscope circuit. It does this by varying the capacitance of the probe and hence its RC time constant.)

THE MULTIMETER

The multimeter is capable of measuring voltages, currents , resistance, waveform frequency (or period), and even short circuits (continuity). Given the wide range of measurements that are possible with this device, it is easy to see why it has become such an indispensable tool in lab. Due to the complexity of the internal circuitry which makes up the multimeter, however, we will focus mainly on learning how to perform some common measurements which will be useful throughout 6.002 (although after this course, you should hopefully have some intuition as to how some of these circuitry works). Before jumping straight into the measurement procedures, let us take a brief look at the multimeter control panel.

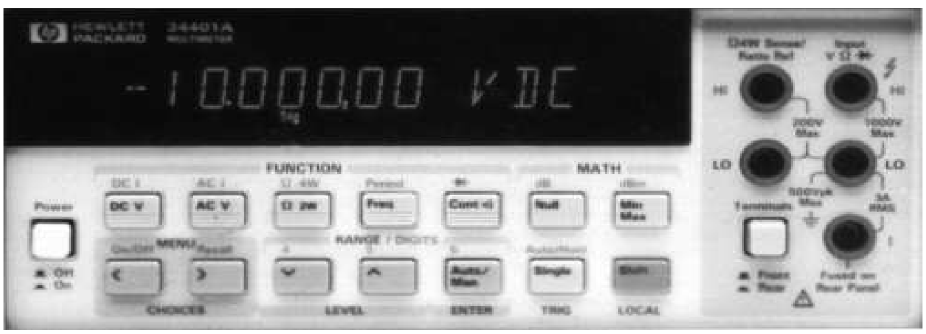

Figure 5 The HP 33120A Multimeter Control Panel

FUNCTION MENU

The function menu is the main interface for controlling the operation of the HP 33120A Multimeter. Located along the top row of the multimeter's control panel, this menu allows us to select the type of measurement which we will be performing with the device. The following is a description of the various functional configurations possible along with a description of how to select them.

Voltmeter

Configures the multimeter to measure voltages via its input ports. This configuration is selected by either pressing the **DC V** or the **AC V** buttons. *See the measurement* *procedures at the end of this section for a description of how the input probes must be connected.*

Ammeter

Configures the multimeter to measure currents via its input ports. This configuration is selected by pressing either the **DC I** (**SHIFT**, **DC V**) or **AC I** (**SHIFT**, **AC V**) buttons.

Ohmmeter

Configures the multimeter to measure the resistance seen looking into a circuit from its input ports. This configuration is selected by pressing the Ω **2W** button. For applications which require the measurement of small resistances (say a few Ohms), select the Ω **4W** (**SHIFT**, Ω **2W**) setting.

Frequency/ Period

Configures the multimeter to measure the frequency (or period) of the signal presents at its input port. This setting uses the same probe configuration as the Voltmeter. *See BASIC MEASUREMENTS & PROCEDURES for information on this configuration*.

Continuity/ Diode Checking

Configures the multimeter to check for circuit continuity. That is it checks to see if the loop formed by the positive and negative probe leads and the circuit being tested is closed. This mode is useful for detecting broken wires in circuits (open circuits), etc. If the path is closed the multimeter will produce a beep.

Why are there different probe configurations for the different types of measurements? The reason lies in how the multimeter must interact with the circuit being tested while measuring either voltage or current. To measure voltage without loading the circuit being examined, the voltmeter must be placed in parallel with the circuit and must present a very large input impedance so that negligible current flows through the probes. However, in order to measure current, the ammeter must be placed in series with the circuit and must present a very small impedance so that the flow of current through that branch is not disturbed. In order to ensure that the circuit sees a very small input impedance a different port on the multimeter is used for the ammeter configuration.

BASIC MEASUREMENTS & PROCEDURES

Multimeter self diagnostic:

The HP 34401A multimeter has a complete self routine which performs an extensive series of tests on the multimeter in order to detect if all of the internal components are working properly.

1) Turn off the multimeter.
2) Hold down SHIFT as you press the Power switch to turn on the multimeter. ***Hold down the key for more than 5 seconds.***
3) The self−test will begin when you release the key.
4) If the self−test is successful, **PASS** is displayed on the front panel, otherwise **FAIL** is displayed and the **ERROR** annunciator turns on. Consult a lab assistant for further assistance.

Measuring Signal Voltage:

1) Connect the positive signal probe into the top right input port labeled **HI**, and the negative signal probe in to the terminal directly below labeled **LO**.
2) Once the probes have been connected, press either the **DC V** or **AC V** button depending on the type of voltage being measured. ***Note:*** *The value measured under the* ***AC V*** *configuration is the RMS (root−mean square) value of the signal. The RMS value is defined to be the square root of the average value (over a period) of the square of the signal (for a sine wave* $V_{RMS} = 1 / sqrt(2) * \mathbf{V_p}$*).*
3) Connect the probes to the circuit being examined.
4) The magnitude of the voltage measured will be displayed on the screen.

Measuring resistance:

The multimeter measures the resistance seen at the terminals by injecting a test current, $\mathbf{I_{test}}$, of know magnitude into the circuit being probed and measuring the voltage seen at the terminals. The ratio $\mathbf{V_{term}/ I_{test}}$ equals the resistance seen at the terminals, $\mathbf{R_{term}}$. The following steps outline how to perform this measurement:

1) Connect the positive lead to the port labeled **HI** located at the top right of the control panel.

2) Connect the negative lead to the port labeled **LO** located immediately below the top right input port.
3) Press the button labeled *Ω* **2W** (or *Ω* **4W** for smaller resistance values) on the control panel in order to enable the Ohmmeter mode.
4) Connect the probes to the resistor being measured. ***Note:*** *The resistor must be isolated from the rest of the circuit.*
5) The magnitude of the resistance measured will be displayed on the screen.

Measuring Current:

1) Make sure the the circuit being tested is powered off before proceeding with this section.

2) Connect the positive lead into the port labeled **3A RMS (*fused on rear panel*)** located at the bottom right of the input panel.

3) Connect the negative lead to the port labeled **LO** located second from the bottom on the right side of the input panel.
4) Select either to measure **DC I** or **AC I** in order to place the multimeter in Ammeter configuration. ***Note:*** *The value measured under the* ***AC V*** *configuration is the RMS (root−mean square) value of the signal. The RMS value is defined to be the square root of the average value (over a period) of the square of the signal (for a sine wave* $I_{RMS} = 1 / sqrt(2) * I_p$*).*
5) Break the circuit where is the current is to be measured and connect the probes. Be careful about polarity!
6) Power on the circuit being tested.
7) The magnitude of the current measured will be displayed on the screen.

   Note: *If the ammeter is not working even though it has been setup properly, the current−limiting fuse located on the back of the multimeter should be checked. If the fuse has burned out, no current will flow into the ammeter.*

THE FUNCTION GENERATOR

In 6.002 we will be using the HP 33120A Function Generator in order to generate most of the waveforms that we will be using to test the circuits we build. Although the circuitry which actually generates the waveforms inside the function generator is quite complex, its use should be quite intuitive. In the same manner that we require a variety of waveforms in order to analyze and understand circuits analytically, we need a way to recreate those mathematical waveforms in lab to verify that our analytical design actually works as we had anticipated. As done previously for the oscilloscope and multimeter, we will review all of the main features of the HP 33120A and then proceed to describe some basic procedures for its use.

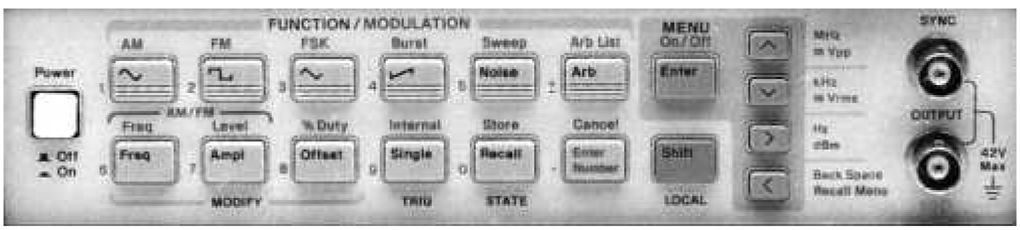

Figure 6 The HP33120A Function Generator Control Panel

The function generator provides various methods for entering numerical values to the device. The greater than and less than keys (**>** , **<**) are used to select the digit which will be modified, and the knob and up−down arrow keys are used to increment or decrement the value of the selected digit. Use the **Enter Number** mode to enter the number with the appropriate units. The type of units to be used are also selected with the arrow keys.

FUNCTION/MODULATION MENU

The **FUNCTION/MODULATION** control panel on the function generator presents the main interface for controlling wave shape, frequency, amplitude, and offset. By combining all of these features it is possible to recreate almost any necessary test waveform. The sine wave, square wave, triangle wave, and ramp buttons generate the respective waveforms at the output of the function generator. The frequency (default is 1kHz) and amplitude (default is 100mV) values for these waveforms will be those currently selected by the user. The MODULATION settings which can be selected with the SHIFT key will not be used in 6.002. These allow the user to generate an output using one of the following signal modulation schemes: Amplitude, Frequency, Frequency−Skip

Keying, Burst, and Frequency Shift.

The function generator also includes a set of predefined waveforms which might be interesting to play around with. These range from an exponential rise waveform to a test cardiac signal. They can be selected by selecting the **Arb List** (**SHIFT, Arb**) setting. Once one of these waveforms has been selected, it will be assigned to the ARB key and can be retrieved at any time by pressing this key. As with all other waveforms, the amplitude and frequency can be modified as described at the end of this section.

FUNCTION GENERATOR OUTPUTS

At its output terminals, the function generator presents an impedance of 50 Ohms to any circuit which is being examined. When the function generator interacts with an outside circuit, it can be set to operate either one of two modes: **50 Ohm** (the 50 Ohm mode will not be used in 6.002) and **High−Z** mode. Selecting these options does not change to the output impedance of the function generator, rather it informs the generator of the type of impedance to expect from the circuit being measured. Knowing the type of circuit with which it is interfacing allows the generator to modify its output so that the user−selected waveform properties are those seen at the input terminals of the circuit.

The necessity of these controls can be seen from the following expression for the input voltage of the any circuit being interfaced with the function generator: $\mathbf{V}_{circuit} = \mathbf{V}_{generator} * \mathbf{R}_{circuit} / (\mathbf{R}_{generator} + \mathbf{R}_{circuit})$. If the input impedance of the circuit, $\mathbf{R}_{circuit}$, is 50 Ohms we see that the voltage seen at the input terminals of the device is just half the voltage being provided by the function generator, $\mathbf{V}_{circuit} = \mathbf{V}_{generator} / 2$. Conversely, if the circuit's input impedance is very large ($\mathbf{R}_{generator} << \mathbf{R}_{circuit}$) , then we see that the voltage seen at the input terminals of the device is exactly that which is being output from the function generator, $\mathbf{V}_{circuit} = \mathbf{V}_{circuit}$. Knowing the approximate input impedance of the circuit of interest therefore allows the function generator to compensate for these differences.

Note: *If the function generator is operating in 50 Ohm mode and a high impedance circuit is connected to it, the voltage present at its terminals will be two times larger than expected.*

BASIC MEASUREMENTS & PROCEDURES

Function Generator self diagnostic:

The HP 33120A has a complete self routine which performs an extensive series of tests on the function generator in order to detect if all of the internal components are working properly.

1) Turn off the function generator.
2) Hold down **SHIFT** as you press the Power switch to turn on the function generator. ***Hold down the key for more than 5 seconds.***
3) The self–test will begin when you release the key.
4) If the self–test is successful, **PASS** is displayed on the front panel, otherwise **FAIL** is displayed and the **ERROR** annunciator turns on. Consult a lab assistant for further assistance.

To set the function generator to High−Z mode:

1) Press **SHIFT** and then **ENTER** in order to access the *MODE MENU*.
2) Scroll through the menu until the *D: SYS MENU* item appears on the screen.
3) Press the down arrow twice in order to enter the input impedance mode selection submenu.
4) Press the left or right arrow keys (**<**, **>**) until the words *HIGH−Z* appear on the display.
5) Once *HIGH−Z* has been selected press the **RETURN** key to accept the selection and return to the measurement display.

   Note: *If the function generator is in 50 Ohm Mode the voltages generated will be 2 times larger than expected for the circuits we will be using. See the previous section on the function generator outputs for more details.*

To set the output frequency of a selected waveform:

1) Enable the *frequency modify* mode by pressing the **FREQ** key.
2) Enter the magnitude of the desired frequency using either the dial, arrow keys, or the Enter Number function. Notice that the Num annunciator turns on and "ENTER NUM" flashed on the display, indicating that the number mode is enabled. *To cancel the number mode, press **SHIFT** and **CANCEL**.*
3) Set the units to the desired value. As soon as you select the units, the function generator outputs the waveform with the displayed frequency. *To turn off the*

flashing digit, move the cursor to the left of the display using the arrow keys.

To set the output amplitude:

1) Enable the *amplitude modify* mode by pressing the **AMPL** key.
2) Enter the magnitude of the desired amplitude.
3) Set the units of the desired value.

To set a DC Offset Voltage:

1) Enable the *offset modify* mode by pressing the **OFFSET** key.
2) Enter the magnitude of the desired offset.
3) Set the units to the desired value.

   Note: *Notice that the Offset annunciator turns on, indicating that the waveform has an added offset. The annunciator will turn on when the offset is any value other than 0 volts.*

Outputting a DC Voltage:

In addition to generating waveforms, you can also output a dc voltage in the range of +/− 5 Volts DC.

1) Press the OFFSET key and hold it down for more than 2 seconds.
2) Enter the magnitude of the desired voltage.
3) Set the units of the desired value.

   Note: *Notice that the Offset annunciator turns on (all other annunciators are off), indicating that a dc voltage is being output.*

THE PROTOBOARD

In 6.002 we will be making use a protoboard for constructing our lab circuits. The layout of the protoboard allows us to quickly construct and test circuits without the need for complicated wiring or soldering. **Figure 7** illustrates the internal wiring of the protoboard. ***Note:*** *The dark center strip indicates that the five columns to the left are electrically isolated from the five columns two the right. That is, no physical connection exists between them.*

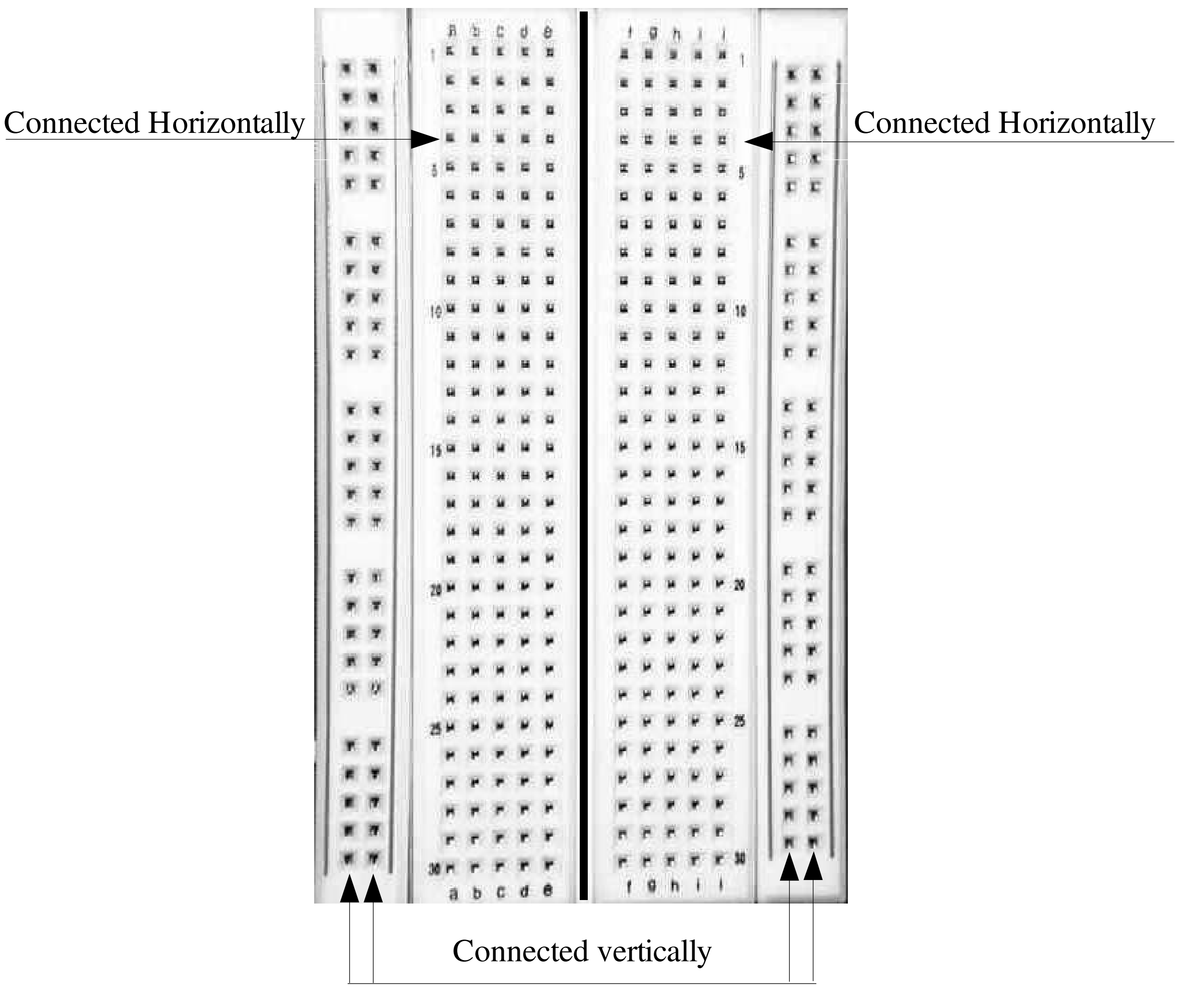

Figure 7 Internal connections of a protoboard.

As shown in **Figure 7**, there are 4 columns which are connected vertically. That is, a voltage applied to any point in that column will be available at any other point along the same column. These columns are typically used to supply $\mathbf{V_{cc}}$ and **GND** to the circuit being constructed. The remaining sockets of the protoboard are connected horizontally, so that a voltage applied to any point in a row is availble at all other points of the row. Since rows on different sides of the center isolator are unconnected, the center region is most commonly used to place integrated circuits (such as op−amps, etc.) so that each pin of the IC has an entire row for possible connections.

This wiring configuration applies, not only to the protoboards which we will use in 6.002, but in general to most protoboards.

REFERENCES

OSCILLOSCOPE REFERENCES

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   Web Reference: http://www.tektronix.com/Measurement/App_Notes/XYZs/scope.html
2) Oscilloscope web references:
   http://progdev.sait.ab.ca/cmph200/oscillos.htm#Objective%204
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MULTIMETER REFERENCES

1) HP 34401A Multimeter: User’s Guide; Hewlett−Packard Company, Copyright 1991−1996.

FUNCTION GENERATOR REFERENCES

1) HP 33120A / Arbitrary Waveform Generator: User’s Guide; Hewlett−Packard Company, Copyright 1994,1996, 1997.

NOTE: The manuals for the Tektronix 2445 Oscilloscope, HP 34401A Multimeter, and the HP 33120A Function Generator are available at the front desk of the 5th floor lab.

GLOSSARY

AC – (Alternating Current) Used to refer to any waveform that varies in a repeating pattern over time.

ADC – (Analog–to–Digital–Converter) A digital electronic component that converts an electric signal into discrete binary values.

AM – Modulation in which the amplitude of a carrier wave is varied in accordance with some characteristic of the modulating signal.

Bandwidth – A range of frequencies.

Circuit Loading – The unintentional interaction of the probe and oscilloscope with the circuit being tested, distorting the signal.

Coupling –The method of connecting two circuits together. Circuits connected with a wire are directly coupled; circuits connected through a capacitor or a transformer are indirectly (or AC) coupled.

CRT (Cathode–Ray Tube) – An electron–beam tube in which the beam can be focused on a luminescent screen and varied in both position and intensity to produce a visible pattern. A television picture tube is a CRT.

DC (Direct Current) – A signal with a constant voltage or current.

FM (Frequency Modulation) – Modulation in which the instantaneous frequency of a sine wave carrier is caused to depart from the center frequency by an amount proportional to the instantaneous value of the modulating signal.

Ground – 1. The voltage reference point in a circuit. 2. A conducting connection by which an electric circuit or equipment is connected to the earth to establish and maintain a reference voltage level.

Hertz (Hz) – One cycle per second; the unit of frequency. The waveforms frequency equals 1/Period.

Impedance (Z) – The ratio of voltage to current at the terminals of an element or circuit under sinusoidal steady state conditions.

Modulation – The process, or result of the process, of varying a characteristic of a carrier, in accordance with an information–bearing signal.

Peak (Vp) – The maximum voltage measured from a zero reference point (ie. Ground).

Peak–to–Peak (Vp–p) – The voltage measured from the maximum point of a signal to its minimum point. For symmetric waveforms, usually equal to 2 times Vp.

Period – The amount of time it takes a waveform to complete one cycle. The period equals 1/Frequency.

Rise Time –The time taken for the leading edge of a pulse to rise from its minimum to its maximum value.

Root Mean Square (RMS) – the RMS value of a periodic signal is defined to be the square root of the average value (over one period) of the square of the signal. For a sine wave of unit amplitude, the RMS voltage is 1/ sqrt(2) $\simeq$ .707 of the peak value; for a square wave it is equal to the peak value; for a triangle wave it is less that .707.

Signal Generator – A test device for injecting a signal into a circuit input; the circuit's output can then be read by an oscilloscope.

Sweep – One pass of an oscilloscope's electron beam from left to right across the CRT screen.

Transducer – A device that converts a specific physical quantity such as sound, pressure, strain, or light intensity into an electric signal or vice versa.

Transient – A signal typically generated when a circuit is powered on and before it settles into its steady state behavior.

Trigger – The circuit that initiates a horizontal sweep on an oscilloscope and determines the beginning of a waveform.

Trigger Holdoff – A control that inhibits the trigger circuit from looking for a trigger level for some specified time.

Trigger Level – The voltage level that a trigger source signal must reach before the trigger circuit initiates a sweep.

Z–Axis – The signal in an oscilloscope that controls electron–beam brightness as the trace is formed.