1. Introduction to Electronics Laboratory

Learning Objectives

Electronics is the enabling technology for many tools, such as computers, cellular phones, internet, etc., that we rely on and use daily. Electronics is also embedded in many systems, such as automation, communications, consumer electronics, control, medical electronics, navigation, smart energy, etc. The main objective of this laboratory course is to provide hands-on experiences to students on instrumentation and electronic circuits. We will start with essential laboratory skills, namely, operating equipment, performing measurements, and building a simple circuit on the prototype circuit board.

Assignments Before the Laboratory Session

Read documents posted on UBLearns under Course Documents; most importantly, how to operate laboratory instruments, before you attend the first laboratory. Print out the last page of this document, "Cover and Score Sheet". Bring it with you to attend the laboratory session. Fill in your name. Get the signature of a teaching assistant when you complete the experiment as attendance record. Do the same for all experiments.

Activities During the Laboratory Session

Each bench is equipped with a function generator, a dual trace oscilloscope, a digital multimeter, and a dc power supply.

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The function generator can produce ac sinusoidal, square, and triangular waveforms with adjustable frequency and amplitude. A dc offset can be added to the output. To test analog circuits, ac signal is needed most of the time. There is no need of any offset. However, to test digital circuits, you need a clock signal, 0 for low and 5 V for high. There is an average dc voltage of 2.5 V. You need to adjust both the amplitude and the offset to generate the digital clock signal. The output of the function generator is driven by a voltage source with an output impedance of 50 Ω. The voltage decreases when you attach a load resistor because voltage is divided between the output impedance and the external load. The drop can be substantial when the load resistance is comparable to the output impedance. Do not attach any load resistor below 470 Ω to the function generator. Do not connect the output of function generator directly to any node on the circuit board with a dc voltage. You need a coupling capacitor in series to block the dc. Otherwise, you will burn the internal surface mount fuse, hence, disable the function generator.

The oscilloscope monitors the time dependence of waveforms. The dual trace oscilloscope can display two synchronized waveforms simultaneously, hence, facilitate relative timing measurements between the two waveforms. The horizontal axis is controlled by the time base. Fast sweep is needed to display high frequency waveforms or transient events. Slow sweep is used to display low frequency signals. The time base should be adjusted according to the frequency of the waveform. For sinusoidal waveforms, 5-10 cycles should be displayed across the screen. To characterize transient, transitional events, e.g., switching between logic states, the time base should be adjusted to clearly show the rise or fall time. There is one BNC-banana adapter or a probe attached to one of the two input ports of the oscilloscope. The black banana jack on the adapter or the alligator clip of the probe should be connected to the ground on the circuit board. The probe or the red jack should be connected to the signal. There is no ground connection for the second input port. You only need to connect a red jumper wire from the second input port to the signal source. Do not attach two BNC-banana adapters to the oscilloscope. You only need one ground connection. Probes can attenuate signal by a factor 10. If it does, you need to change the multiplication factor of the oscilloscope display to x10 accordingly. You will see this adjustment by pushing the channel 1 (CH1) or channel 2 (CH2) key on the oscilloscope. When a jumper wire is used to connect signal to the oscilloscope, the multiplication factor shall be set to x1.

Turn on the computer, monitor, function generator, oscilloscope, and multimeter. If you are using a probe, verify its integrity first by connecting the spring loaded wire clip or tip of the probe to the internal square wave which appears at the upper square tab located at the lower right corner of the oscilloscope. The alligator connector of the probe is for ground connection which is located below the square wave source. You should see a square wave on the oscilloscope display. If not, the probe is not in working condition. If there is no probe, get two jumper cables, one red and one black, with banana plugs. Never pull or stretch any jumper cable. If one jumper cable is not long enough, just attach another in series. Always establish the signal ground first. If the ground connection is missing or the ground wire is broken, you will observe a 60 Hz (16.7 mSec period) background showing up in the oscilloscope display. Connect a black jumper cable between the ground tab on the function generator and the ground tab on the oscilloscope. Connect the red jumper cable from the output of the function generator directly to the channel one input of the oscilloscope or via the probe. Press the "Autoset" key or button on the oscilloscope. If the signal is weak, you may see two overlapping and possibly drifting sinusoidal waves on the oscilloscope. You can increase the amplitude of the function generator to get a stable display. Press the "ampl" key and turn the knob clockwise to increase the output voltage. Press the "Autoset" key again. With sufficient voltage, the oscilloscope should present a clean, single, stationary sinusoidal wave. In using the oscilloscope, you need to know the horizontal time scale, the vertical voltage or sensitivity scale, and where the ground or zero reference level is. Locate the readout for vertical and horizontal scales on the oscilloscope display. The readout indicates the time (horizontal) or voltage (vertical) per display unit. What is the shape of the waveform? What is its period in mSec? What is its peak-to-peak amplitude in V? Press keys on the function generator in turns to generate sine, square, and triangular waves. Observe the waveform on the oscilloscope. Switch back to the sine wave. Press the "freq" key. Then turn the knob to change the frequency. Increase the frequency by turning clockwise and decrease the frequency counterclockwise. When you reach the limit, press the right or left arrow key to change to the next digit for adjustment. Adjust the time base of the oscilloscope to display 5-10 cycles. What is the maximum frequency attainable from the function generator?

Adjust the function generator to produce a 1-kHz sine wave with peak-to-peak amplitude of 1 V. Please read the oscilloscope manual to learn how to perform automatic measurements and how to use cursors for manual measurements. On the oscilloscope, press the "Measure" key. Add a voltage measurement. Use the "Multipurpose" menu selection dial and push key to choose the root-mean-square (RMS) voltage; then the peak-to-peak voltage. What is the ratio between these two voltages? For sinusoidal wave with no dc offset, $V_{pp}=V_{RMS}*2.828$. Measure the frequency and period. Does the frequency readout agree with the function generator? Instead of relying on automatic measurements, you can measure the voltage and frequency manually by counting grids of the displayed waveform. You may also use cursors to assist you in manual measurements. Press the cursor key. Adjust the location of cursor line using the vertical position knob. You can use the difference between two vertical cursor lines to determine the period of a waveform. You can also use the difference between two horizontal cursor lines to determine the voltage of a waveform. When the waveform is noisy, don't rely on the readout. Automatic readout is meaningless because it can't discern the noise. It measures the voltage between positive noise peak and the negative noise peak. You need to perform manual measurement. Set the cursor to the middle of a noisy trace. Neither can you rely on the automatic readout when only a partial waveform is displayed. If you can't see the period or the peak-to-peak voltage of the displayed waveform, the oscilloscope can't provide a correct readout either.

Compare the voltage measured by the oscilloscope and the voltage displayed on the function generator. Is the voltage measured by the oscilloscope twice the voltage displayed on the function generator? The function generator has an output impedance of 50 Ω. It assumes that a 50 Ω load, same as its output impedance, is connected externally. The output impedance and the load form a voltage divider. Therefore, only half the voltage generated internally would appear across a 50 Ω external load. However, the input impedance of the oscilloscope is 1 MΩ; not 50 Ω. The actual voltage across the 1 MΩ load is nearly twice the value displayed on the function generator. In subsequent experiments, when you are instructed to set the function generator to produce 1 V, you should set the dial to 500 mV.

Change to square wave. Adjust the time base to much finer time scale until you can clearly observe the rise or fall time of the switching transient. Measure the rise time, i.e., the time for the waveform to traverse from 10% to 90% of the full swing Full swing is defined as the complete, 100% transition between the low and high levels in the steady state.

On the oscilloscope, go back to the automatic setting for time and voltage. On the function generator, keep the square wave setting. Press the "offset" key of the function generator and turn the adjustment knob. This adds a dc voltage to the ac waveform. Watch the waveform move up and down on the oscilloscope while adjusting the offset voltage. Do you see a reference marker on left side of the display for ground, i.e., 0 V? Press channel 1 key on the front panel of the oscilloscope. On the oscilloscope, change from dc coupling to ac coupling. The ac coupling mode blocks the dc. Only the ac portion of the signal is displayed by the oscilloscope. Set the offset of the function generator back to zero. Adjust the function generator for 40-Hz square wave. Switch the oscilloscope between dc and ac coupling. You will notice that the ac coupling not only blocks the dc but also attenuates the low frequency signal causing drooping in the square wave. In order to see the true shape of a low frequency waveform, you need to use DC coupling. Sometimes, both low frequency and high frequency components coexist in the waveform. If you need to examine the high frequency component closely, you should set the oscilloscope to ac coupling and adjust the time base for fine resolution.

To practice measuring the frequency dependence of a signal, adjust the function generator to produce a 1-kHz sine wave with peak-to-peak amplitude of 1 V. Open a new Excel file. Fill the first column with frequencies, f (Hz): 1, 2, 4, 8; 10, 20, 40, 80; 100, 200, 400, 800; 1k, 2k, 4k, 8k; 10k, 20k, 40k, 80k, 100k, etc. Fill the second column with peak-to-peak voltages measured by the oscilloscope in ac coupling mode at those frequencies. Save the Excel file. When the signal is large, you can measure the amplitude manually or automatically by pushing the measure key on the oscilloscope. When the signal is small, noise appears. The automatic measurement doesn't differentiate noise from signal. Therefore, the automatic reading reflects the peak-to-peak noise instead of the true amplitude of signal. When large noise is present, do not rely on automatic measurement. Measure the voltage manually, i.e., from the middle of the positive noisy peak to the middle of the negative noisy peak.

In the ac coupling mode, a high-pass filter is inserted in the path of the input signal. Not only does it affect the amplitude of the signal, it also changes the phase. In order to observe the effect of filter on phase, you need to connect the sinusoidal wave generated by the function generator to both input channels of the oscilloscope. One channel operates in dc coupling mode while the other in ac coupling mode. Display waveforms of both channels. To activate the second channel, push the channel 2 key to light it up. As you reduce the frequency of the function generator to below 10 Hz, you will observe clearly a phase shift between dc and ac coupled waveforms.

Go back to dc coupling, 1 kHz sine wave, 1 V signal. Get a stable display. Learn and practice how to save the waveform and acquired data from oscilloscope to a USB drive. Read the oscilloscope manual on how to save screen image and binary data to USB drive. You can also find the procedure in the lecture. Make sure that the oscilloscope is connected to the computer via a USB cable. Run the oscilloscope program on the computer. Save the data in Excel readable format to the USB drive.

The auto-ranging digital multimeter on the bench is very easy to operate. Select voltage, current, or resistance to measure. Connect probes or test leads to the circuit. For voltage and resistance measurements connect the meter in parallel with the device. For current measurement, you must break the circuit and connect the meter in series. For ac signals, the multimeter displays the RMS voltage; not the peak-to-peak voltage. Pick up a resistor. Learn how to read its resistance by using color codes. Set a multimeter in the resistance mode. There are two leads, black for common (ground) and red for voltage and resistance. Each year, a dozen test leads are damaged by pulling and stretching. If the test lead is broken, you won't be able to perform any measurement. To test the multimeter test leads, set the multimeter in the resistance mode. Short two test leads. The resistance should be zero. If not, replace the broken test lead. Measure the resistance of the resistor. Measure your body resistance by holding one lead with each hand. What is your body resistance? When you measure a device with high resistance, you can't touch the leads because your body resistance is in parallel with the device making the reading irrelevant. If you have a diode, try to measure its resistance in the forward direction and in the reverse direction. The red lead has a positive voltage in the resistance mode. When it is connected to the anode, i.e., in the forward direction, the resistance is low. In the reverse direction, the resistance is very high beyond the measurable range. Please note that the multimeter can also operate in the manual mode. When the measurement is beyond the range of the manual setting or too large, it may display "OL" or "OVLD," i.e., overload.

The power supply can produce two independently adjustable voltages up to ±30 V and one fixed voltage at 5 V. The red receptacle is positive in reference to the black receptacle. You can choose either the black or the red receptacle as the signal ground. If the black receptacle is the ground, the red receptacle provides a positive voltage. If the red receptacle is the ground, the black receptacle provides a negative voltage. To power circuits requiring both positive and negative voltages, one can tie the black receptacle of voltage supply A and the red receptacle of voltage supply B together to form the common signal ground. Power supply A provides a positive voltage while power supply B provides a negative voltage. Do not use the earth ground.

You can only set the current limit of the adjustable voltage power supply. There is no current limit adjustment for the 5-V power supply. Turn the current limiting knob on the power supply to 0.18 A. Set the voltage at 10 V. Press in the output key to activate the power supply. Measure the output voltage with a multimeter in dc voltage mode. The measured voltage shall be very close to 10 V. Deactivate the power supply. Connect a wire to short the output of the power supply. Activate it again. The current flowing in the short circuit is indicated by current readout. The output voltage drops down to 0. It is no longer at the previously set value and the red LED turns on to indicate that the power supply is operating in the current limiting mode. You need to use the current limiting feature all the time to prevent damaging devices in circuits. Set the current limit to 0.18 A before activating the power supply. In normal operation, the power supply should not be in the current limiting mode.

If you have gotten the kit for parts, assemble the prototype circuit board. Align the tab on the insulating post to the flat side of the opening on the prototype board. Tighten the nut securely, preferably with a wrench. Make sure that banana jacks will never become loose, hence, shift and rotate in the socket. A wire with exposed metal contacts on both ends connects the banana jack to the power bus on the board. Do not let the wire insulation slip under the jack preventing metal-to-metal contact. Between you and your partner, discuss how sockets of the prototype board are internally connected. Identify bus lines on the prototype circuit board. The bus lines on the prototype board are reserved for power supply and ground connections. You can use bus lines to make connections to multiple nodes in the circuit for power or ground. The input signal often gets connected only to one node in the circuit. You don't need a bus line for connecting the input signal.

The next task is to build a very simple circuit, namely, a voltage divider, on the prototype circuit board. The amplitude of the function generator may be too large for testing high gain circuits even when it is set to the minimum. In such a case, a voltage divider at the source end is needed. A voltage divider consists of two resistors in series, for example, 1 kΩ and 47 Ω. The output of the function generator is connected to one end of the 1-kΩ resistor. The ground is connected to one end of the 47-Ω resistor. The common node of the 1 kΩ and 47 Ω resistors provides the output. The signal is attenuated to approximately 1/20; more precisely, 47/1047 if resistances are exact. Like the function generator, the voltage divider at the source end should also have low output impedance, e.g., 47 Ω. Do not use resistors of large resistances, e.g., 100 kΩ and 4.7 kΩ in forming the voltage divider. The input resistance of the circuit driven by the divider is in parallel with the output resistor of the divider. ***The dividing ratio changes once you connect the output to the circuit because of loading***. The 1-kΩ resistor in the front prevents the divider from loading down the function generator.

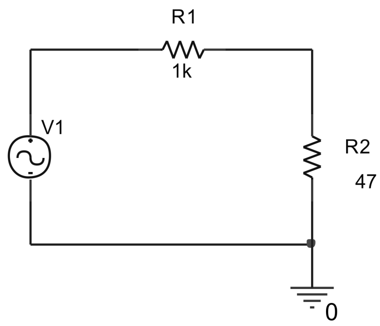

Fig. 1. The voltage divider circuit. The output voltage is taken across the 47-Ω resistor. The front resistor is 1 kΩ so that it won't load down the function generator.

You can use the voltage dividing concept to measure the output impedance of the function generator. R1 in Fig. 1 represents the output impedance. R2 is the externally attached load resistor. You need to measure the output voltage twice, once without any load resistor and the second time with a load resistor. The resistance of the load resistor can be anywhere from 47 Ω to 220 Ω. Can you determine the output impedance of the function generator by applying the voltage divider formula?

To obtain a stable display of a weak signal on the oscilloscope, you need to control the trigger. The trigger signal can be one of the input signals, channel 1 or 2, an external trigger input, or the ac power line signal. It can be filtered by selecting the coupling mode: dc, ac; low frequency (LF) or high frequency (HF) filter. It is difficult to obtain a stable trace if the signal is very small. Therefore, you should always select the stronger signal as the trigger if there is one.

To practice trigger adjustment, set the function generator at the lowest possible voltage. Connect the output of the function generator to the input of the voltage divider. Connect the output of the voltage divider to the oscilloscope, channel one. The signal is in mV range. You can practice manual adjustment. Read and follow instructions in the oscilloscope manual. You can apply a filter to suppress the high frequency noise by pushing the menu key of trigger control. Press coupling. Select HF for high frequency noise rejection. Alternatively, you can connect a strong signal, i.e., the signal before the divider, as the external trigger. If the signal under examination is in synchronism with the ac power line, use the line trigger mode. You will use the line trigger in the dc power supply experiment.

You need to get a stable display on the oscilloscope first before performing any measurement or data acquisition. If the waveform is not stable, adjust the trigger control. Measure the peak-to-peak voltage at the output of the divider manually. Since noise is present, the automatic measurement is not accurate. It measures the peak-to-peak noise instead of the signal. When the signal is weak and trace is noisy, with proper synchronization, averaging can be performed. Press the acquire key. You can average 4, 8, 64, or 128 traces. Without a stable display, you can't do averaging. Follow instructions on the oscilloscope manual. Practice averaging on the weak signal from the voltage divider. Measure the peak-to-peak voltage manually and automatically after averaging. Do measurements match?

At the end of laboratory session, turn off all equipment. Instead of logging out, shut down the computer. Turn off the monitor.

Activities After the Laboratory Session

Search the web for information on “semi log Excel” or “Bode plot Excel.” Learn how to plot the frequency dependence of measured voltage using $\log_{10}$(frequency) as the horizontal axis. Plot the data taken from the oscilloscope in the ac coupling mode and recorded in the Excel file. Incorporate the “Cover and Score Sheet” of Exp. 1 along with the semilog plot in one Word file. Read “How to Submit Report” posted under Assignments. Practice report submission to UBlearns by submitting the Word file. Please note that no score will be assigned. It is for practice only.

Read “Writing Report” posted on UBLearns under Course Documents. In it, you will find how to submit report as a team.

Browse and read: http://www.plagiarism.org/plagiarism-101/what-is-plagiarism.

Memorize the color coding scheme for resistors. Sort resistors and place them in different bins or compartments. Do the same for capacitors.

Self Study

Answer following questions as a self study. You don’t need to submit answers in the report.

1. Are you familiar with basic operations of all laboratory equipment? Do you know how to operate the oscilloscope?
2. What is the difference between ac coupling and dc coupling at the input of the oscilloscope? Under what condition, one should use ac coupling? How about dc coupling?
3. How do you get a stable waveform displayed on the oscilloscope if the signal is in the mV range?
4. What is a voltage divider? When do you need it? Can you simulate a voltage divider? What is the output impedance of the voltage divider? Why should the output impedance be kept low?
5. Why is the readout of the function generator different from the oscilloscope display, by what factor?
6. Can you digitize a waveform and interpret the recorded data?
7. Memorize the color code. What is a resistor labeled with brown, black, and orange? How about a capacitor with a code of 104?

Cover and Score Sheet

Experiment 1 – Introduction to Electronics Laboratory

Author:______________________________ Partner:_________________________

Score

Item	Credit	Score
Bode Plot		

TA Signature:________________________ Date:______________________________