Mbarara University of Science & Technology
Faculty of Applied Sciences and Technology
Department of Electrical and Electronics Engineering

Laboratory Procedures, Instructions and Manual

Course Name:	Physical Electronics
Course Code:	EEE 1105
Academic Year:	2017/2018

Table of Contents

1. Laboratory Rules and Regulations

A. Accessing the Laboratories

a) Unauthorized entry into laboratories is strictly prohibited. No entry into the labs will be granted after closing hours and before opening hours

b) Entry and use of any laboratory and/or equipment is subject to availability, and timetabled practical sessions take precedence over personal work.

c) The lab technician reserves the right to refuse entry and access to the laboratory or to certain sections of the lab.

d) No equipment or furniture should be carried out of the laboratory without authorisation.

e) Vandalising and damaging lab equipment and furniture is strictly prohibited. Any such reckless activity will lead to the invocation of serious disciplinary action.

f) Strictly no food or drinks should be taken into the laboratory

g) Emergency exits should be kept clear at ALL times.

B. Laboratory Rules and Safety

1. Before the Lab Session

a) Always wait for instructions from your instructor before proceeding with the lab exercise

b) Risk assessment and identifying hazardous material: always assess the riskiness of equipment and materials by studying the danger and warning labels. Always read identification labels:
- What is it?
- What harm can it cause?
- Basic precautions for storage, handling, and use

Never handle any substance unless:

- You know what it is
- You know how to handle it

c) Compressed air
- Hoses under pressure have to be secured.
- Only use appropriate air nozzles with relief valves
- Improper nozzles can inject air into the skin
- Air can enter the blood stream, reach the heart, and cause heart failure and/or death

2. During the Lab Session

a) Turn off and unplug equipment before removing the protective cover to clear a jam, replace a part, or troubleshoot. Always ask a qualified person to open equipment if this will create exposure to energized parts operating at 50 volts or more.

b) Ensure that the power is OFF before you start connecting up a circuit. Get your circuit diagram approved by the instructor first, and then connect up the circuit strictly as per the approved circuit

c) Do not use an electrical outlet or switch if the protective cover is ajar, cracked or missing.

d) Only use DRY hands and tools and stand on a DRY surface when using electrical equipment, plugging in an electric cord.

e) Never put conductive metal objects into energized equipment. Avoid wearing metallic, loose jewellery such as rings, watches, neck chains, bracelets, etc.

f) Always pick up and carry portable equipment by the handle and/or base. Carrying equipment by the cord damages the cord's insulation.

g) Unplug cords from electrical outlets by pulling on the plug instead of pulling on the cord.

h) Re-route electrical cords or extension cords so they are not run across the floor, under rugs or through doorways, etc. Stepping on, pinching, or rolling over a cord will break down the insulation and will create shock and fire hazards.

i) Do not overload extension cords, multi-outlet strips and wall outlets.

j) Heed the warning signs, barricades and/or guards that are posted when equipment or wiring is being repaired or installed or if electrical components are exposed.

k) Always wear closed, rubber-soled flat shoes in the laboratory. Restrain long hair and refrain from wearing loose clothing.

l) Only handle volatile chemicals under a fume hood and use mechanical transfer devices for toxic chemicals.

m) In case you notice any abnormal condition in your circuit (like insulation heating up, resistor heating up, etc.) switch off the power to your circuit immediately and inform the instructor immediately

n) Always keep hot soldering irons in their holders when not in use.

3. After the Lab Session

a) Clean up all workspaces and properly dispose of waste in the waste bins

b) Return any equipment and apparatus to their designated storage positions

c) Lock/tag out any equipment found to be defective

d) Turn off:

- Water, gas, and power supplies
- Heating apparatus
- Lights

e) Lock the door upon exiting

C. Handling Emergencies

a) Ensure that you know the location of all emergency exits, and keep these clear of obstacles at all times

b) In case of a fire, exit the laboratory and building immediately. Do not attempt to put out the fire using materials other than the fire extinguisher.

c) Contact your instructor/lab technician immediately in case of any injuries or accidents

2. Laboratory Notes

All students are encouraged to purchase a Laboratory Notebook. As a part of training to be a scientist, students should maintain a personal notebook just as a research scientist does. This lab notebook will not be graded, but the student must have one and use it. A lab notebook with a sewn-together binding is preferred.

Here is a guideline for lab notebooks: a notebook should contain sufficient detail so that useful information and data can be obtained at a later time when you are writing your lab report, which will be marked. In the notebook, the student should:

- Draw a schematic diagram for every circuit that is built. Label this diagram with part numbers, pin designations, output/input designations, show the major connections to external power supplies, etc.
- List the instruments used by type and model, oscilloscope, multimeters, function generators, etc.
- Draw the appearance of the oscilloscope display, if used and indicate the vertical and horizontal scales, with units record a table of all measurements. include units (e.g. mV) for inputs and outputs.
- Always list more than one measurement as an error check

3. Lab Report Format

For each Lab, students will individually prepare a lab report for grading. This report is **not** the same as the lab notebook, and the notebook is not a substitute. Reports should be organized as a brief introduction, and then an experimental section that is organized according to the section number.

- **Preface**: a brief introductory paragraph, ≈30 words, describing the report's theme
- **Experiment**: Apparatus, Procedure (a maximum of three sentences to explain: what was **measured**, how it was measured, what was varied, how errors were estimated*
- **Results**: where it is appropriate, this should include: table and/or graph of results, label each curve and draw smooth curves through data points, label axes and indicate units, sketch or print of the oscilloscope display, if one was used.
- **Discussion**: Briefly answer the questions (if any) posed in the lab procedure. Also discuss, in a few sentences the features of the outputs to demonstrate that you understand their significance
- **Conclusions**: Draw conclusions from the results you obtained and give reasons/explanations for any discrepancies noted. Provide recommendations (if any).
- **Appendix**: In this section, attach any screenshots, photos of graphs, etc that are too long to fit in the main body of your report.

Handwritten lab reports are adequate, but typewritten reports are also welcome. Be brief, but write in clear, complete sentences.

<u>Report Grading Breakdown</u>

Executive summary	20%
Discussion of results	20%
Sample calculations	20%
Conclusions	20%
Appendix	10%
English usage, completeness, neatness	10%

4. Lab 1: DC Measurements

4.1 Aims and Objectives

The **purpose** of the experiments described here is to acquaint the student with:

a) analog & digital devices
b) design of circuits
c) instruments and procedures for electronic test and measurement.

The **aim** is to teach a practical skill that the student can use in the course of his or her own experimental research projects in physics, electronics, or another science. At the end of this laboratory session, the student should be able to:

a) design and build simple circuits of his or her own choosing.
b) use electronic test & measurement instruments such as oscilloscopes, timers, function generators, prototyping boards etc. in experimental research.

This experiment has the following **objectives**:

- Become familiar with: multimeter, prototyping board, resistor color code, reading a schematic diagram, wiring a circuit.
- Study a current source: A voltage source (Figure 1) such as a battery or power supply is inherently a device with a low internal resistance. It should provide a constant voltage for a wide range of currents. A current source (Figure 2) on the other hand should provide a constant current to a wide range of load resistances.

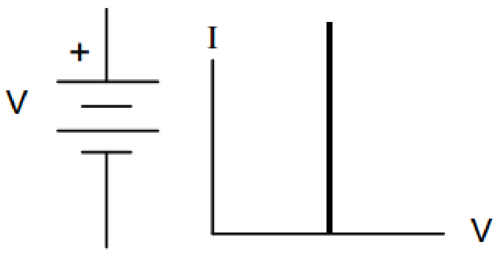


Figure 1

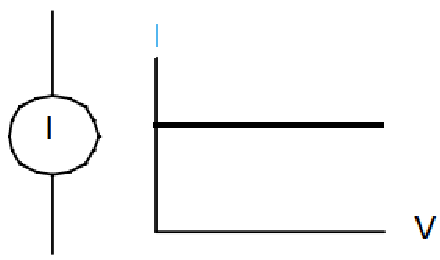
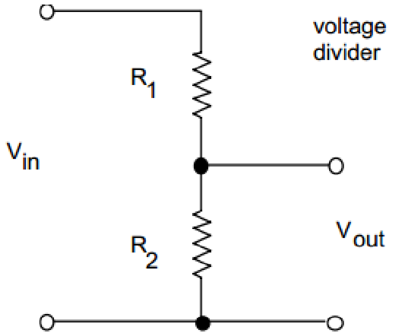


Figure 2

- Study a voltage divider: A voltage divider is two resistors connected in series (Figure 3).



$$V_{out} / V_{in} = R_2 / (R_1 + R_2)$$

Figure 3

4.2 Equipment

- Digital multimeter
- Batteries (1.5V)
- DC power supply
- Colour coded resistors
- 12V transformer
- Prototyping boards/Breadboards
- Solid-core wires
- Alligator clips

The digital multimeter: The hand-held digital multimeter is used widely to make electrical measurements of:
- Voltage DC and AC
- Current DC and AC
- Resistance
- Continuity
- Other quantities, such as frequency, depending on the meter's features

Note that the meter is connected in parallel to measure voltage or resistance, and in series to measure current.

4.3 References

This lab handout is intended for use with the following textbook:

Horowitz and Hill
The Art of Electronics
2nd Edition, 1989/1990
Cambridge University Press

4.4 Experiment Guidelines and Instructions

4.4.1 Measuring DC Voltage

- Set the function switch of the multimeter to DC volts, with a scale commensurate with the voltages expected in the circuit.
  Note: To protect the multimeter from damage, always select the maximum voltage scale to start with. Then adjust the scale downward until a meaningful reading is obtained.

a) Batteries in series

- Measure the individual voltages **V1** and **V2** of the two 1.5 V batteries.
- Then connect the batteries in series, with **forward polarity** as shown in Figure 4, and measure the total voltage **Vfmeas**. Provide an uncertainty for this measurement based on the multimeter's specifications.

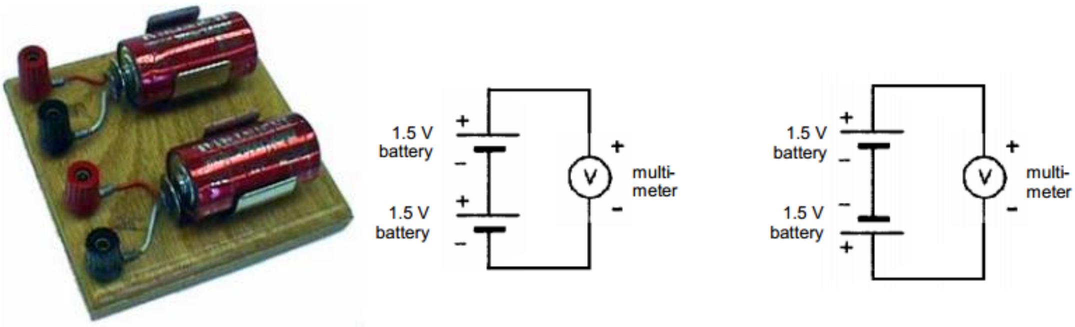


Figure 4

- Reverse the polarity of one of the batteries and measure the total voltage **Vrmeas**. Provide an uncertainty for this measurement based on the multimeter's specifications
- Calculate the expected results **Vfcalc = V1 + V2** and **Vrcalc =V1 – V2** for forward and reverse polarity of the two batteries. Note that these are calculated quantities, not measured quantities, so their uncertainty must be calculated using propagation of errors. Perform this uncertainty calculation, yielding **δVfcalc** and **δVrcalc**
- Compare these expected results **Vfcalc ± δVfcalc** and **Vrcalc ± δVfrcalc** to the corresponding measured values **Vfmeas ± δ Vfmeas** and **Vfmeas ± δVfmeas**
- In your lab notebook, draw a schematic of whatever you connect, including components and any external instruments.

b) Power supply

- A power supply is a voltage source powered by 110V-AC. You will use a "bench" power supply, which supplies an adjustable voltage. A benchtop power supply typically has two knobs: voltage and current. The way it works is that only one knob will have an effect, depending on two things: the setting of the other knob and the load resistance. For example, if you turn the current knob up to its maximum value and if you use a large resistance for a load across the power supply outputs, the voltage knob will be the one that has an effect, while the current knob merely provides an "upper limit" to how high the current is allowed to go. This will be how you will usually operate the power supply.

- An analog meter, with a needle, will have a measurement error due to your ability to read it. Use your own judgment of what you think is a reasonable value for the error, based on factors such as the width of the needle, the spacing between tick marks, and parallax due to viewing the meter with your head positioned at various angles.
- Set the power supply to two different voltages and measure each of these.
- Does the value on the power supply's meter agree with the value measured on the multimeter, within the error bars for the two measurements?
- As a rule, remember that meters on a power supply are usually less reliable than multimeters. Always make measurements of voltage and current with an external meter.
- As always, in both your notebook, draw the schematic for whatever you connect, including external instruments.

4.4.2 Measuring AC Voltage and Frequency

- No error measurements are required for this section.
- Set the AC/DC switch of the multimeter to AC and reset the scale to maximum voltage.
- Plug the primary of the transformer (it's labeled 8 Vrms, but you will measure this yourself) into the AC outlet and measure the AC voltage of the transformer secondary
- The wiring in a building in Uganda is nominally rated at 110 Vrms, but will vary from this value. Since this is connected to the primary of the transformer, and the voltage on the secondary is a fixed fraction of the primary voltage, you may find that your output voltage is not exactly the level printed on the transformer. The electrical generators used by utility companies produce a 50 Hz or 60 Hz voltage
- If your multimeter has a frequency (Hz) feature, use it to measure the frequency of the transformer output.
- If there is a multimeter AC/DC switch, return it to DC.

4.4.3 Resistance

- Set the function switch to Ohms.
- Check the meter by shorting the test leads. The meter should read zero ohms.
  (a) Tolerances -- **note:** if you are color blind, skip this step and inform the TA.
- For this step only, use the box of assorted resistors. Measure the resistance of ten of your resistors.
- Determine the fractional error from the nominal value (from the color code).
- Make a table with seven columns: color code, nominal value, tolerance, measured value, multimeter scale, multimeter error, multimeter error as a fraction of measured value.
- **Question:** How many of the values fall within the specified tolerance?
- As always, draw the schematic in your lab notebook.

a) Series and parallel

- Choose two resistors that are within a factor of ten of the same value. Wire them up in series and then in parallel, using the board with three terminals. Measure the series and parallel resistances.
- Calculate the expected resistances (use measured values from part a) and compare with your measurements, including error values calculated.

4.4.4 Continuity

- With the function switch set to Ohms, touch the two test leads together while watching the display.
- Now set the function switch to continuity. (This may be indicated with the diode symbol on your meter.) Touch the two test leads together and listen for the beep.
- **Question:** What does the beep signify?

!!!!!Caution: Avoid damaging your multimeter.

In the current function:

Never connect a currentmeter directly to a voltage source like 110 VAC or a battery. Without a resistor to limit the current, this would destroy the meter, or blow a fuse inside the meter.

In the resistance function:

Never connect the multimeter to a resistor that is part of a circuit. Use it only to measure the value of a loose resistor.

4.4.5 Current

a) Measured values

- Measure the actual value of one the resistors shown in Figure 5. (Throughout this course, always measure your resistor values before assembling the circuit.)

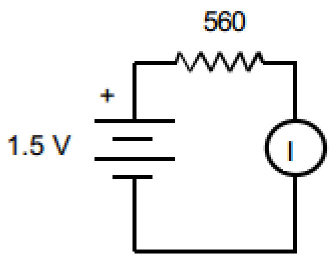


Figure 5

b) Comparison to predicted values

- Wire up the circuit in Figure 5. Set the function switch to the maximum current scale (2 A) and connect the meter into the circuit.
- Note that for current measurements the meter is in series with the other elements of the circuit. This is different from voltage measurements, where it is in parallel.
- Compare the measured value with the value of current you would calculate using the measured values of voltage and resistance.
- **Question:** Do they agree within the error value range? Explain any discrepancy.

4.4.6 Current Source

- Connect a 1.5 V battery and a large-valued resistor (10 kΩ or higher) to make a current source. For a load resistor, use the decade box (choosing values ranging from 0.1 to 2.0 times the value of the large resistor), as shown in Figure 6.

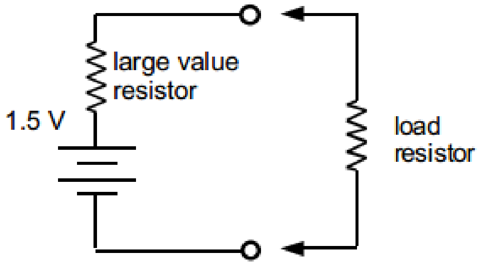


Figure 6

- This combination of a battery in series with a large resistor will act as a current source, provided the load resistance connected to the terminals is small. The current is: $I = V/(R1 + RL) = (V / R1) / (1 + RL / R1) \approx V / R1$ for $RL << R1$.
- Connect several different load resistances across the terminals and measure the current through the load resistor and the voltage across it in each case.
- **Question:** What is the most accurate way for you to use a multimeter to measure current? Is it by passing the current directly through the meter, or using the meter to measure the voltage drop across a known resistance and computing the current from Ohm's Law?
- Make a table and/or graph of current vs. load resistance.
- Compliance: Determine the range of load resistance over which the current remains constant to 10%.

4.4.7 Voltage Divider - no error measurements required for this part

- A voltage divider reduces a voltage to a desired level.
- Measure the values of the resistors shown in Figure 3, then wire up the circuit. Use the breadboard. Use a 5-Volt power supply to supply Vin.

a) Without load

- Measure Vin and Vout for R1 = 3.2 k, and FOR R2 = 1.6 k. Then repeat, with R1= 1.6 k and R2 = 3.2 k. Compare Vout / Vin to the predicted values.

b) With load

- Connect a 1 kΩ load resistor across the output. Determine how much Vout is reduced (loaded), reporting the reduction of Vout as a % of the unloaded measurement of Vout. Using the rules for parallel resistances, compare to theory.
- Note that while a voltage divider is easy to build, it is a poor voltage source. Its output is not "stiff". It is easily "loaded".

5. Lab 2: AC Measurements

5.1 Aims and Objectives

The object of this lab is to learn measurement skills. You will become familiar with the oscilloscope, function generator, and pulse generator, in measuring time-varying electrical signals. You will measure:

- DC and AC voltages
- Frequency
- Phase
- Time constant of an RC circuit
- Amplitude and phase-shift responses of low-pass and high-pass RC filters.

Note: In this lab you will record a lot of data. It is recommended that you record it in columns in your lab notebook, with separate columns for:

- the reading (e.g. in mV)
- the scale on the oscilloscope (e.g. 100 mV per division)
- the estimated error for each measurement.

5.2 Equipment

- Analog oscilloscope
- Function generator
- Pulse generator
- DC power supply
- Multimeter
- 8V transformer
- Resistors (5kΩ)
- Capacitors (0.003 μF)
- BNC cables, BNC tee, BNC banana adapters

5.3 References

This lab handout is intended for use with the following textbook:

Horowitz and Hill
The Art of Electronics
2nd Edition, 1989/1990
Cambridge University Press

5.4 Experiment Guidelines and Instructions

5.4.1 Measurement of Voltages

a) <u>DC Voltages</u>

- To start, adjust the oscilloscope settings to the following:

vertical mode CH1

CH1	Volts/Div	1 Volt (use 1× indicator on dial)
	input coupling	GND
	CAL knob	fully clockwise to click
CH2	same as CH1	
	set INVERT switch to the out position	

horizontal mode A

time base	A sec/div	1 ms
	CAL knob	fully clockwise to click
var holdoff	NORM	
A trigger	P-P AUTO	
level	turn to approximately middle of knob's range	
slope	out	
A & B INT	CH1	
A source	INT	
A ext coupling	DC	

- Once you have found a trace that looks like a horizontal line, use the vertical position knob on CH1 to position the trace in the center of the display. Then change the CH1 coupling to DC.
- Connect the output of an adjustable power supply to the oscilloscope input CH1. You should see a trace at a non-zero voltage. Change the CH1 coupling back and forth, from GND to DC, to see the difference.
- Set your power supply to three different DC voltages and measure each voltage with both the oscilloscope and the digital multimeter.
- **Question:** Compare the DC voltage measurements of the oscilloscope and the digital multimeter. Report the measurement uncertainty (error) values, based on the specifications for the multimeter and the oscilloscope, and your impression of how precisely you can read the oscilloscope display. Which is more precise, the meter or the oscilloscope?

b) AC Voltages

- Connect the function generator to signal input CH1 of the oscilloscope.
- Set the function generator to produce a sine wave of about 1 to 2 Volt amplitude, a frequency of about 100 Hz, and no DC offset.
- Set a multimeter to the AC voltage function. Connect it to the function generator's output.

- **Question:** Measure the peak-to-peak AC voltage using the oscilloscope. Calculate the RMS value of the voltage.
- **Question:** Compare the AC voltage oscilloscope measurements to those on the digital multimeter. Report the measurement uncertainty (error) values. Which is more precise, the meter or the oscilloscope?

c) AC and DC coupling

- Make sure the oscilloscope coupling is set to DC.
- Set the function generator frequency to about 10 kHz.
- Turn on the offset voltage on the function generator, and twiddle the offset up and down. You should see a vertical deflection of the trace.
- Now change the oscilloscope coupling to AC and twiddle the offset voltage slowly. You should see no change.
- **Question:** Explain the difference between AC and DC coupling. Through what additional component inside the oscilloscope does the signal pass when using AC coupling?

5.4.2 Measurement of Frequency

- Use the same set-up as above. Use a digital multimeter to measure the frequency, connecting the multimeter to the function generator's SYNC output (which might be labeled TTL, depending on the model of the function generator). Determine the frequency from the measured time per cycle. Repeat for five frequencies in total, over the entire range of the function generator.
- **Question:** Make a table to compare the frequency measurements made with the oscilloscope to those with the digital multimeter. Include columns for the measurement uncertainty (error) values. Which is more accurate, the meter or the oscilloscope?
- As a practice, never trust the frequency and voltage readings shown on a function generator. Always make external measurements of the frequency and voltage.
- For the remainder of this experiment, use the multimeter for your frequency measurements.

5.4.3 Time Constant of an R-C Circuit

- The output voltage of an RC filter is

$$V(t) = V_{max}\,[1 - \exp(-t/RC)] \quad \text{........ for charging}$$

$$V(t) = V_{max}\,\exp(-t/RC) \quad \text{....... for discharging}$$

Rules of thumb:

RC: The product RC is called the "RC time constant" or simply the "RC time".

When the input voltage of an R-C circuit changes from one level to another, the output voltage will approach its final value asymptotically. RC is the time required for the output to swing by 63% toward its final value. [Because 1 – exp (-1) = 0.63.]

5RC: is the time required to swing within 1 % of the final value. [Because exp (-5) = 0.007 ± 1%]

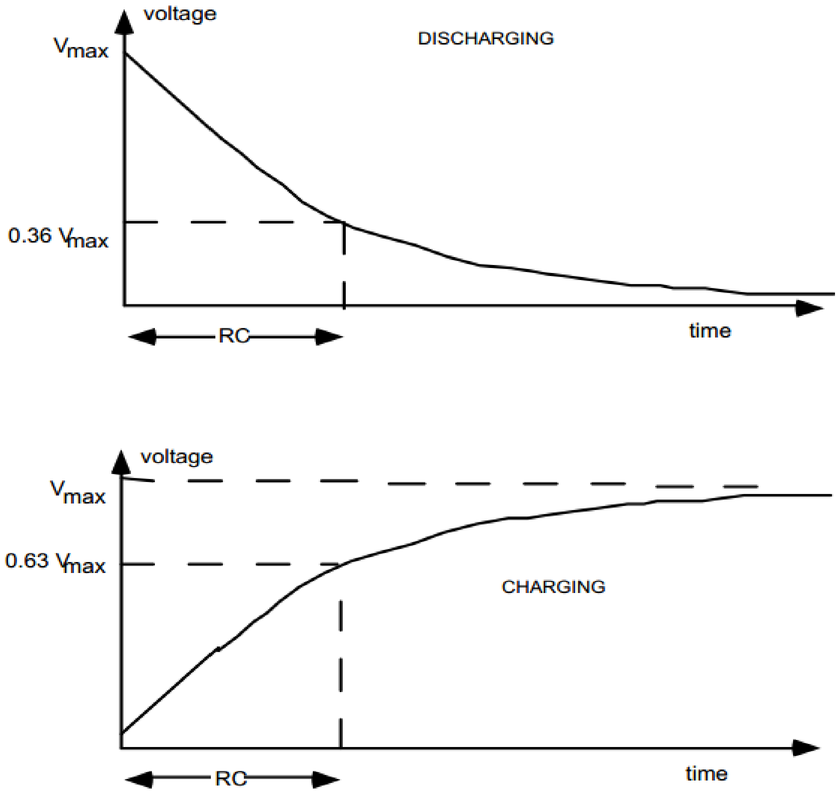


Figure 1

- Measure the actual values of a 5 k resistor and an 0.003 μF capacitor.
- Connect the series R-C circuit to a function generator and an oscilloscope, as shown in Figure2-3 a and 2-3 b. (This circuit is shown two ways to help you figure out how to wire it up.) Use a wooden board with binding posts.
- Set the multimeter to measure frequency, and connect it to the function generator.
- Set the oscilloscope for external triggering (EXT), and connect the trigger input to the SYNC output of the function generator (BNC connector labeled TTL/CMOS).
- Set the function generator to produce square waves with a peak-to-peak amplitude of about 5 Volts. Set the frequency so that it is appropriate for measuring the time response of the R-C circuit -- the period $\tau = f$-1 should be ≥ 10 RC.
- Set the oscilloscope vertical voltage scales to be the same, choosing a scale so that the trace fills a large portion of the screen. (If it fills only a small portion of the screen, your measurements will not be very precise.) Use GND input coupling to find where zero volts is, and use the vertical position to locate this on a gridline.
- If your function generator has a DC offset, adjust it so that the bottom of the waveform is at zero volts. Draw the oscilloscope display for the square wave, and indicate the voltage at both the bottom and top of the waveform.
- Adjust the oscilloscope horizontal time base so that the discharge time takes a considerable portion of the display. Use the horizontal position to locate the waveform so that the triggering time is at a convenient gridline.

(Your display should look like that in Figure 1 labeled "charging." Change the oscilloscope trigger slope between + and - to see the difference it makes.)

Charging

- **Question:** Determine the charging time constant from the oscilloscope display. Estimate your errors. Calculate the ratio of your charging time to RC.

Discharging

- Change the scope triggering slope to see the discharge portion of the trace. (Your display should look like the figure above, labeled "discharging.")
- **Question:** Determine the discharging time constant from the oscilloscope display. Estimate your errors. Calculate the ratio of your discharging time to RC.

5.4.4 R-C Low-Pass Filter

a) Amplitude Response

- Use the circuit shown in Figure 2-3 b. Set the function generator to produce a sinusoidal output with an amplitude of about 4 or 5 V peak-to-peak. Use a 1, 2, 5 frequency sequence from 500 Hz to 105 Hz (i.e., 500, 1000, 2000, 5000 Hz, ...). Also include a frequency of $f = 1 / (2 \pi RC)$ in this sequence, as calculated from measured values of R and C.
- Record a table of your data with columns for:
  - f (Hz), error bar for f
  - Vin, oscilloscope scale for Vin, error bar for Vin
  - Vout, oscilloscope scale for Vout, error bar for Vout
  - Vout / Vin
- Plot the voltage ratio Vout / Vin with log-log axes, with frequency on the horizontal scale. Make a theoretical plot of Vout / Vin on the same graph. You may use Graphical Analysis or other software to create the graph using the instructions below.
- Compare the frequency at Vout / Vin = 0.707 to $f = 1 / (2 \pi RC)$

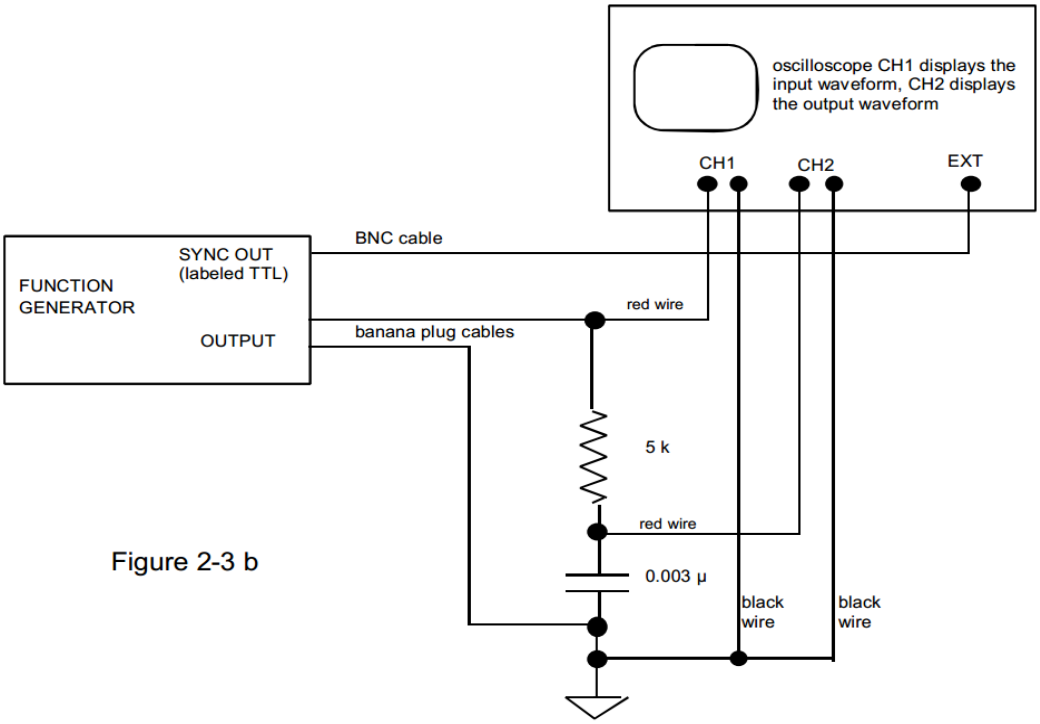


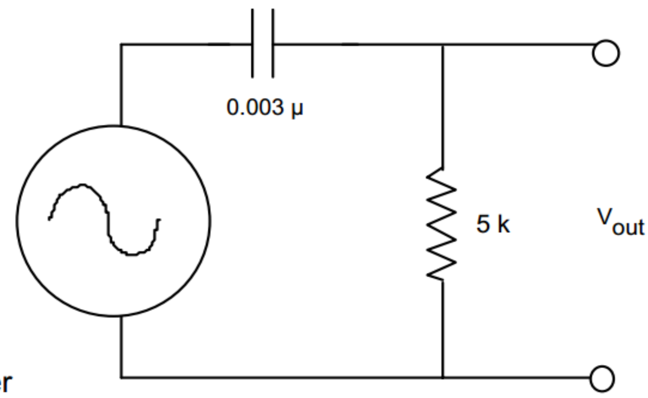
Figure 2-3 b

b) Phase Response

- Use the same circuit as in Figure 2-3 b above.
- Measure the phase shift of the voltage across the capacitor relative to the input voltage from the oscillator, for the same frequency sequence as for the amplitude response above.
- Record your data with columns for: f (Hz), error bar for f delay in msec, error bar for delay in msec phase in degrees, error bar for phase in degrees.
- Plot the phase curve on a graph with a semi-log scale (θ linear, f log). Compare with a theoretical plot of the phase shift on the same graph.
- What is the phase angle, measured and theoretical, at $f = 1/(2\pi RC)$?

5.4.5 R-C High-Pass Filter

- Use the same 5 kΩ resistor and 0.003 µF capacitor as in the R-C low-pass filter, above, but swap them to make a high-pass filter.



High Pass Filter

- Make the same amplitude response measurements and plots as for the lowpass filter, above, but omit the error values. To save time, do not record error values here; record them only for the low-pass filter. Use the following frequencies: 100 kHz, 50, 20, 10, 3, 1 0.3 0.1 kHz; also include a frequency of $f = 1 / (2\pi RC)$ in this sequence, as calculated from measured values of R and C.

6. Lab 3: Diodes, Power Supplies and SCRs

6.1 Aims and Objectives

In this lab we examine the properties of diodes and their applications for power supplies and signals:

- Diode rectification in 1/2 wave and full wave bridge circuits
- Filtering in power-supply circuits
- 3-terminal voltage regulator
- Zener diode and its use as a voltage regulator
- Diode clamp circuit
- Silicon controlled rectifier (SCR)

We will also build our measurement skills, learning to use a digital oscilloscope

6.2 Equipment

- Digital oscilloscope
- Signal diodes, Power diodes, Zener diodes
- Prototyping board/Breadboard
- Potentiometer
- 6 V Lamp/ bulb
- 3 terminal regulator
- 8V center-tapped transformer
- Function generator
- 0 – 30 V DC power supply
- Resistors
- Capacitors
- Decade box

6.3 References

This lab handout is intended for use with the following textbook:

Horowitz and Hill
The Art of Electronics
2nd Edition, 1989/1990
Cambridge University Press

6.4 Experiment Guidelines and Instructions

Caution: In this lab it is possible to burn up components if you are not careful to make sure everything is correct before turning on the power. Please note all caution statements in these instructions. Double-check before turning power on! When using the decade box, do not set the load resistance below 50 Ω.

Ohmmeter Check of Diode

- You will need a multimeter to confirm the polarity of a diode. You don't need to report your results here in your lab report.
- Use your oscilloscope (or a second multimeter) to determine which of the multimeter leads has a + voltage and which is.
- Look at your multimeter to see what special features it has. You can do a diode check with the resistance function, on the 200 Ω scale. Even better, try the continuity or diode-check feature, as shown by the symbol, if your multimeter has one. The diode-check function will display the diode's voltage drop across the PN junction.
- Confirm the PN polarity of a signal diode (these are smaller than the power diodes). Look at the markings on the diode to see how they show the polarity.
- Repeat the diode tests above, using a power diode.
- Note that for a multimeter check to work, the multimeter must apply a voltage of at least 0.5 Volt between its two leads to bring the "diode" into conduction when it is forward biased.

Learn to use the digital oscilloscope and scope probe

- Connect a scope probe to the digital oscilloscope as shown in the photos below.
- A scope probe has two settings: 1X and 10X (photo shows 10X setting). This notation might be confusing: the 10X setting has the effect of dividing, not multiplying, the signal by a factor of ten. An advantage of a 10X probe is that it has a higher frequency response, so that if you need to view signals > 1MHz, you should use a 10X probe. In most of this course you will view slower signals, and a 1X probe is adequate.
- Press the AUTOSET button to see the display of a square wave
- Push the CH2 MENU button twice, to see how this turns the display for that channel off and on. The two channels are distinguished by their color.
- To see their effect, adjust these knobs: VOLTS/DIV, SEC/DIV, VERTICAL POSITION, HORIZONTAL POSITION. Look for the arrow at the top that indicates the trigger time, and the arrow at the right that indicates zero voltage.
- Push the CH1 MENU button to see the display. Toggle the "Probe" setting so that it indicates the same setting as on your probe (1X, not 10X or 100X).You must always check this, before using the scope, to avoid X10 errors in your voltage measurements.
- Push the TRIG MENU button and view the menu. Sometimes in this course you will be asked to use EXT TRIG, which you can accomplish with the digital

oscilloscope by toggling "Source" to the "Ext" setting. At other times, you might wish to use CH1 as the "Source."

Build your triggering skills

- First, choose "AUTO" trigger, with the source specified as the same channel (1 or 2) as your probe. While viewing the square wave from the probe, adjust the trigger level knob up and down while watching the display. Observe that when the trigger level is adjusted too high or too low, there is a loss of triggering, and this can casuse the displayed waveform to be unstable in the horizontal direction.
- Next, repeat with "NORM" rather than "AUTO" trigger. In this mode the scope will not update the display unless there is a valid trigger event, unlike the "AUTO" mode which will trigger occasionally even when there's no valid trigger event, just so that you can see at least something on the display.
- Push the MEASURE button and view the menu. Toggle the "Type" setting to measure the peak-to-peak voltage and the frequency of the waveform. Then adjust the TIME/DIV knob so that less than one full oscillation is shown, and notice how the scope is unable to measure frequency.

Digital Oscilloscope Skills

- Use the function generator to apply a sine wave of approximately 1.2 – 1.8 volts amplitude and approximately 1 kHz frequency to one of the oscilloscope inputs. Using the MEASURE button, measure the amplitude and period of the waveform.
- Compute the uncertainty of the amplitude, and the uncertainty of the period. Do this using specifications from the oscilloscope's manufacturer's user manual. For the TEDS 1000 or 2000 seies oscilloscope, see pp. 155-156. To compute the uncertainty of the period, you will require the sampling period, which is the reciprocal of the sampling rate; this parameter depends on the tim/div setting – see the table on pp. 22-23. (Note: this exercise is intended to train you to look up manufacturer's specifications for an instrument, which is a routine all physics experimenters should follow in their research.)

6.4.1 Diode Limiter

- Diode limiters could be used at the inputs of small-signal instruments to protect against accidental application of large input signals.
- This is a low-current application, so you use signal diodes, not current diodes.
- Using signal diodes, connect the input of the circuit shown below to the function generator, set to about 1 kHz. Check that the –20 dB attenuator switch on the function generator is not activated. Try sines, triangles, and square waves of various amplitudes. Try a low amplitude for the oscillation, and adjust the function generator's dc offset to observe the effect of clipping.
- Print the output of the clamp circuit for sine wave inputs two ways:
  i) With an output waveform that is severely clipped.
  ii) With an output waveform that is only slightly clipped.

- Comment quantitatively on the output amplitude where clipping is strongly observed and explaining what parameter for a diode determines this clipping amplitude.

6.4.2 Diode Clamp

- Connect the clamp circuit in the figure. Use the +5V power supply built into your prototyping board. This is a low-current application, so you use signal diodes, not current diodes.
- Connect the input of this circuit to the function generator with a sine wave at 10 kHz. Check that the –20 dB attenuator switch on the function generator is not activated.
- Set up the oscilloscope to show the input and output waveforms. Use DC input coupling on the oscilloscope,
- Connect three grounds together: the ground of the 5 V power supply, the ground of the function generator, and the ground of the oscilloscope.
- Adjust the sine wave amplitude so that you can see a "clamped" output.
- Print the waveforms for the input and output of the clamp circuit. (If you can see that the clamped voltage is not quite flat, then you can see the effect of the diode's non-zero impedance in conduction.) From your observation explain in one or two sentences what the clamp circuit is useful for

6.4.3 Power Supply Rectifying Circuits

<u>(a) Half Wave Rectification</u>

- Set up the circuit as sketched here. (For this part, ignore the center-tap (CT) terminal on the transformer, if any.) You are building a power supply, so use power diodes rated at 1 W, not the little signal diodes. Use the decade box, set at 1 kΩ, for the load resistor.
  Caution: do not use the insulated "mini grabber clips" to connect the transformer to power diodes; they can melt and they are costly. Use alligator clips, and arrange the components on your prototyping board so that the alligator clips will be separate by > 2 inches so that they don't short. If using an analog scope, set the oscilloscope as follows: input coupling DC (CH1 and CH2) vertical mode BOTH and either ALT or CHOP (this is the dual trace feature)
- In the figure below, the waveforms are shown as they would look if the input voltage had a 1 V amplitude. Notice the 0.5 V diode drop. Also notice the time interval shown between the dashed lines, when the input voltage is positive but not large enough for the diode to conduct.
- Adjust the variac to indicate 10 VAC output.
- Measure the P-P amplitude of:
  a) the input voltage Vi from the transformer
  b) the rectified sine wave output voltage Vo across the 1 kΩ "load resistor" RL.
- Print the input and output waveforms and compare the peak output voltage with half of the PP input voltage. **Question:** Explain the difference.

- Repeat without the variac, i.e., with the transformer powered directly from a 110 VAC outlet, so that the waveform from the transformer has a larger output.

(b) Full Wave Rectification

- CAUTION: In this part, carefully check the polarity of your diodes before turning on the 110 VAC power-- otherwise you may burn up the diodes.
- Measure the output waveform of the full-wave bridge circuit in Figure 3-3. Do not attempt to measure the input waveform. Use a 1 kΩ load resistor.
- Print the output waveform. Compare to the half-wave rectifier.

6.4.4 Power Supply Filtering

- CAUTION: In this part, carefully check the polarity of your capacitor before turning on the 110 VAC power.
- Starting with the full wave rectifier circuits in Figure 3-3, add a capacitor C = 100 μF across the load resistor as shown in Figure 3-4. Note that capacitors of such a large value are polarized: one of the capacitor's two leads is marked – or +.
- Measure the DC output voltage.
- Measure the PP AC ripple using the oscilloscope.
- [Try this two ways: i) first with DC input coupling ii) repeat with AC input coupling.
- You should find that AC coupling allows you to use a smaller scale in Volts/div and thereby make a more accurate measurement.]
- Print the output waveform. **Question:** Discuss in one sentence how the filter capacitor improves the performance of a power supply.
- Repeat with a capacitance of 1000 μF.
- Using the capacitance of 100 μF, try a smaller load resistance (CAUTION: do not set the load resistance below 50 Ω).
- List your results. Compare with the calculated values of the DC output and ripple voltages.
- **Question:** Discuss (in two of three sentences) two factors that cause ripple to become worse.
- Note that in a power supply, a bigger capacitance gives better filtering, but with the tradeoff that the component is costlier, larger and heavier.
- Note that the smaller the load resistance, i.e. the larger the current that the power supply must deliver, the worse the ripple. Do not disassemble the full-wave rectifier yet.

6.4.5 Voltage regulation with 3-terminal regulator

3-terminal voltage regulators are easy to use. From the outside it looks like a transistor, but on the inside there is a good regulator that makes use of negative feedback. It features thermal protection so that it is hard to burn up.

(a) Simple test

- Connect the 78L05 regulator on your prototyping board. For an input, use the +12 Volt power supply that is built into your prototyping board, or an external power supply set to about +10 V.
- Confirm that the output is +5 Volts.
- An ideal voltage regulator supplies the same output voltage, regardless of the input voltage, regardless of the output load.

(b) Use as a power supply regulator

- Now connect the input of the 78L05 regulator, as shown below, to the output of the power supply you built in step 3. Include a 1 kΩ load resistor.
- Turn on the power supply, and observe the output voltage.
- Compare to the filtered output without regulation, as measured in step 2.

(c) Regulation as the input voltage is varied

- Now plug the transformer of your power supply into a variac instead of into 110 VAC. Connect a multimeter to measure the Volts ac from the variac Set RL to 1 kΩ.
- Adjust the variac output voltage, beginning at110 VAC and going downward, using the printed scale on the top of the variac. (Caution: Do not operate the variac at voltages above 110 V)
- Confirm that the regulator maintains the same +5 Volt output over a wide range of AC voltage (typically from 80 to 110 VAC).

(d) Regulation as the load is varied

- Disconnect the variac. Connect your multimeter to measure current through the load.
- CAUTION: In this step, to protect the decade box, always keep 50 or 100 Ω switched in while you adjust the other scales. This precaution will keep you from accidentally setting the decade box to zero resistance.
- CAUTION: As always, measure current beginning with the meter set to the highest scale.
- Set RL to about 10 kΩ, and vary it downward.
- Note the load resistance at which ripple begins to appear. What current value does this correspond to? (This is the maximum regulated current.)

(e) Thermal protection

- Continue to decrease the load resistance. Does the output of the regulator shut down when the current exceeds a certain threshold? This is the current limit of your regulator.

- [To work, this shut-down test requires using a regulator in the TO-92 package; don't use a larger package like TO-220 (LM78M05CT) for this lab -- it won't shut down under these conditions.]
- An advantage of these three-terminal regulators is the shutdown feature. Another alternative for voltage regulation is the zener diode in the next experiment, but zeners do not have thermal protection, so you must be careful to select the right one and use it within its design parameters.

6.4.6 Voltage Regulation with Zener Diodes

Zener diodes can be used as a simple voltage regulator to establish a reference voltage source for non-critical applications. **CAUTION**: Zener diodes are very easy to burn up if you do not wire them up correctly.

- Remove the 3-terminal regulator and its accompanying two capacitors.
- Select an appropriate Zener, depending on your transformer (5V for a 6.3 V transformer or 12 V for a 12.6 V transformer). Assume the Zener has a power rating of 0.4 W in either case.
- Add a Zener diode across the output of the PI filtered power supply you built in part 3b, as shown in Figure 3-6.

(a) Calculations

- Before you power up your circuit, do the following:
  Determine the maximum Zener current IZ max from the power rating.
  (ii) Determine the total current through the 91 Ω resistor:
  Itot = (Vin - VZ) / 91.0 Ω
  This current is the sum of the Zener current IZ and the load current IL. Check whether it exceeds IZ max because there must then be a minimum load current to prevent overloading the Zener. This will imply a maximum load resistance.

(b) Measurements

Output voltage:

- Power up your circuit.
- Measure the voltage across the load resistance.
- **CAUTION**: in the next step, to protect the decade box, always keep 100 Ω switched in while you adjust the other scales. This precaution will keep you from accidentally setting the decade box to zero resistance.
  Regulation:
- Vary RL beginning at 10.1 kΩ and stepping downward to 500 Ω.
- Note the load resistance above which the voltage stays approximately constant. **Question**: To what current does this correspond?

6.4.7 SCR Circuits

(a) DC Control – RC Timer

- The circuit in Figure 3-8 switches on a voltage across the load after a delay. The SCR switches on when the gate voltage (G) exceeds the cathode voltage (C). The gate voltage is developed across the capacitor C1 by the R-C combination. Short C1 to remove all charge.

(i) Switching time

- Turn on the supply and determine the time for the voltage to be switched across the load.

(ii) Gate voltage

- Short C1 again and repeat with each of the resistors in the time constant portion of the circuit.
- Determine the gate voltage necessary for firing.

(b) AC Control -- Lamp Dimmer

- In the circuit in Figure 3-9, the R-C combination acts as a phase shifter for the 60 Hz AC voltage. As R is increased, the phase is shifted from 0° to -90 °. With this circuit it is possible to control the output half wave from completely on to completely off.
- Use the input from the transformer secondary as a reference signal for the oscilloscope. Observe the phase shifted wave across C and the output wave across RL. **Question:** Explain why the lamp dims.