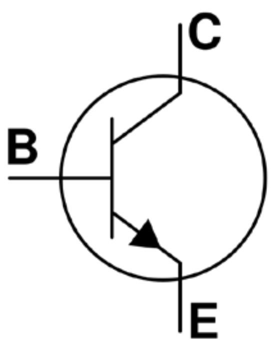
ELEC-2507

Electronics I

Laboratory Manual



By

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ELEC-2507 Lab Guidelines

- Pre-labs and Lab experiments are done individually.
- **Lab-Section**: Make sure that you go to the section (day) to which you are formally registered (or according to the section-switching arrangement made by the Head-TA). You will not be permitted to do the labs during sections to which you are not formally registered/allocated.
- **Pre-lab**: You must come prepared to the lab by carefully going through the manual and after completing the pre-lab. **You will not be allowed to do the pre-lab in lab-room**, in that case you will be asked to go out. Also, you will not be given any extra or grace-time, beyond the stipulated 3 hours of lab-time. Students must sign an attendance sheet maintained by the TAs during every lab. *Pre-lab is done individually and mandatory.*
- **Lab-Start:** Attendance at the scheduled beginning of the lab is mandatory. Any notes or review of the lab procedure begins at this time and will not be repeated. Many labs will require the full 3-hour time period to complete, and extra time will not be available.
- **Equipments**: *After the completion of the lab, you must leave the equipments in the same organized condition, as they were before you entered the lab*. Also, if you borrowed any equipment, you should return them before you leave the lab.

- **Lab-Records**: The lab-records must be submitted at the end of the lab to the TA responsible for marking for that specific day. The records will be corrected and will be given back to you during your next-lab-turn (after two weeks).

  The Lab-records can be a collection of booklets for each lab.
- **Missed Labs/PA/Quizzes**: As all the sections are already registered to their maximum-limit, it will be difficult to accommodate requests regarding any missed labs/quizzes. Students who are unable to write PA-quiz or lab in their regular session will only be permitted to do so in case of medical reasons (**with a valid medical certificate**). In such a case, please contact the head TA/PA, within 24 hours of the missed session, along with the medical certificate for making possible alternative arrangements.
- **LAB Exemptions:** No Laboratory exemptions are provided.

Note: *Arriving late, attending on the wrong day, abuse of equipment, or failure to maintain a neat lab station are grounds for reducing grades or denial of permission to do labs. Students found with other students lab manuals with data, or copies of lab reports from this year or previous years, will be assumed to have it for copying, and academic disciplinary action will be taken.*

Preparing for Lab and Lab-Records

Prepare for the lab before the session! Preparation and Execution (in lab) of the Lab should be done as follows:

Preparation (prior to coming to the lab):

- **Work-out the pre-labs individually**
- Complete all calculations (show the steps, not just the final numbers), and read the lab to establish the motivation for making the measurements you are asked for.
- **Prepare a draft Lab Report jointly, one per group**. A typical Lab Report should contain:
  - The objectives of the lab,
  - Necessary theory,
  - A brief outline of the procedure

In the lab:

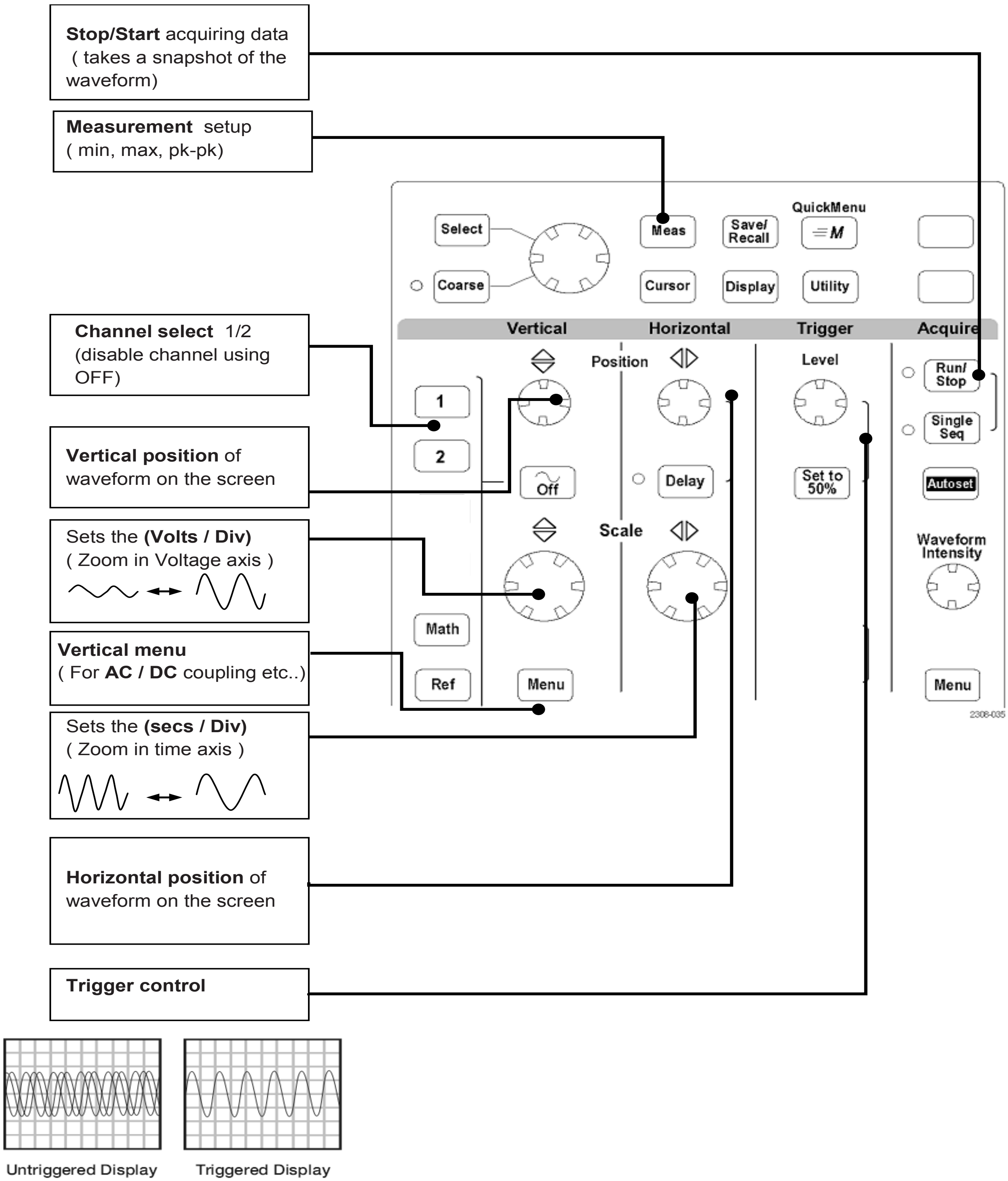
- Bring both the pre-lab and your draft lab-report and get them approved by the TAs at the beginning of the lab.
- Conduct the experiments. Note down the results. Compute/Draw necessary graphs.
- At the end of the lab, submit to the TAs your Lab Report along with results/graphs with a brief conclusion.

- Corrected pre-labs must be attached to the report.
- **Notes:** Always include clearly marked units, specifying RMS, peak, peak to peak, or DC voltage. Oscilloscope trace sketches must include vertical and horizontal scale, with units. All measurements must include the instrument used and settings. A sketch of connections should be included. Measured results should be compared with expected results. Measured values and calculations based on measurements should be clearly delineated from calculated values.
- **Keep your marked lab-records safe:** You must make sure to obtain and keep your graded reports to verify your attendance and grade in the event there is any error in recording your grades.

Keep a printed copy of the lab guidelines and manual in your possession before going to the lab and do not rely on the computers in the lab for online access.

For your benefit, a schematic diagram of commonly used oscilloscope controls and the breadboard configuration are given in the next two pages. Please familiarize yourself with them.

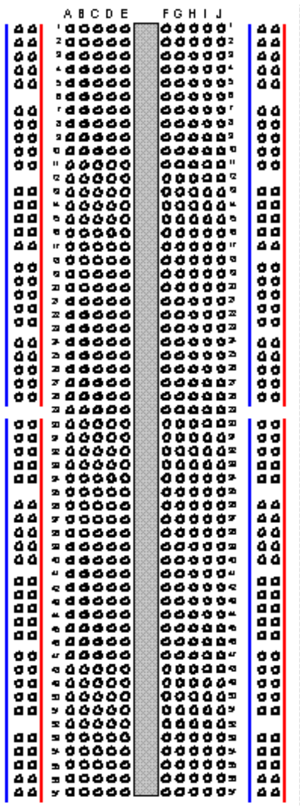
Oscilloscope controls



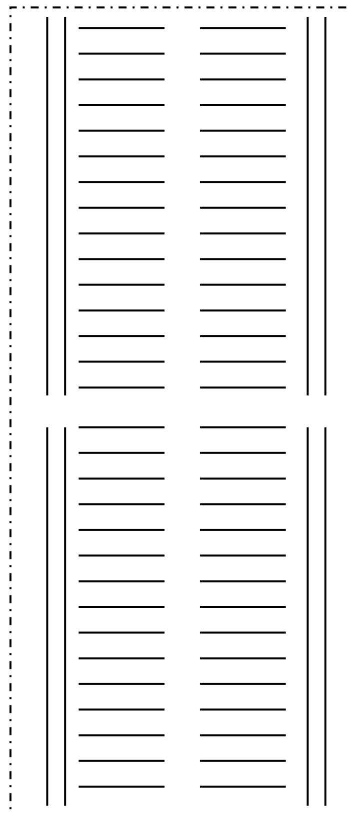
Tektronix pocket guide for oscilloscopes: http://www.tek.com/learning/oscilloscopes/
Oscilloscope (TDS3012) user Manual: http://www.tek.com/products/oscilloscopes/tds3000c/

Breadboard primer

Breadboard



How the points are connected inside



Breadboarding tips:

It is important to breadboard a circuit neatly and systematically, so that one can debug it and get it running easily and quickly. It also helps when someone else needs to understand and inspect the circuit. Here are some tips:

- Always use the side-lines for power supply connections. Power the circuit from the side-lines and not directly from the power supply.
- Keep the main component (op-amp, BJT , MOSFET etc.) near the center of the board.
- Try to use the connections of the breadboard, and if necessary use jumper wires.
- Keep the jumper wires on the board flat, so that the board does not look cluttered.

It is strongly recommended that you further read and familiarize yourself with the following reference:

Reference: http://hibp.ecse.rpi.edu/~connor/education/breadboard.pdf

Lab 1: Linear Circuits

1 Purpose

To refresh knowledge of basic linear circuit concepts including voltage dividers, equivalent circuits, transfer functions, and input and output impedances.

2 Introduction

In your previous courses, you learnt several fundamental theorems and laws of linear circuits, which would be used repeatedly in Elec2507. It is strongly recommended that you review these in details.

2.a) Thevenin's Equivalent Circuit

Thevenin equivalent models help to simplify and speed up analysis of changes in complex networks. Thevenin's theorem states that *any linear circuit can be replaced by an open circuit voltage in series with a resistor defined by the ratio of open circuit voltage and short circuit current (see Fig. 1)*.

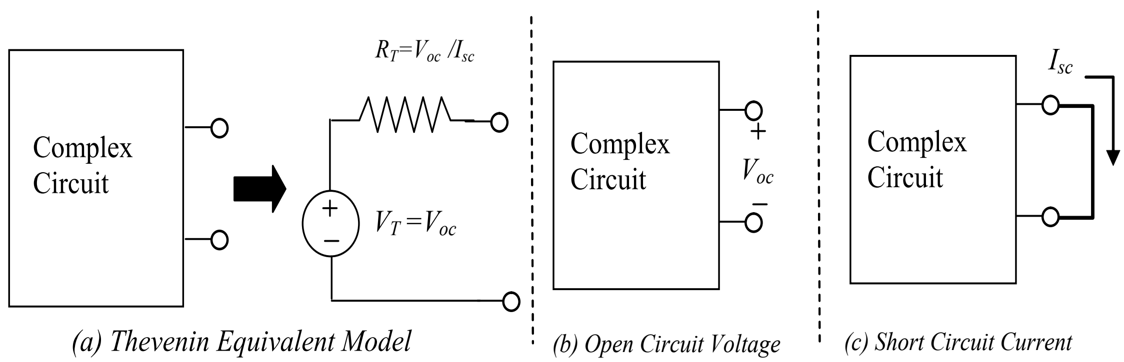
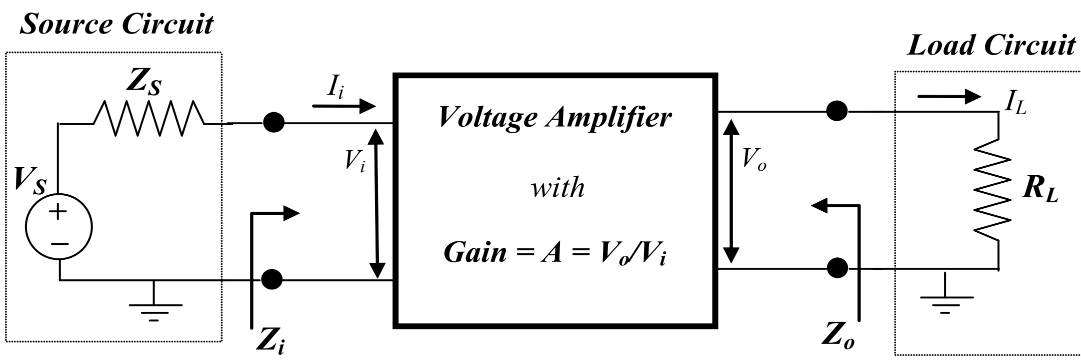


Fig. 1: Thevenin Equivalent Model of a Complex Circuit

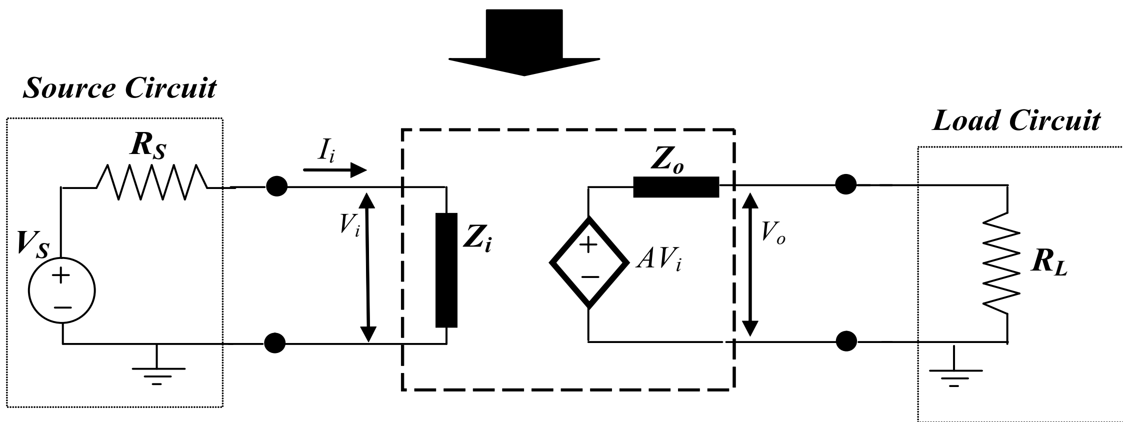
It is to be noted that even the practical signal sources can also be represented by their *Thevenin equivalents*, consisting of an ideal voltage source (V_s) and a series *source impedance* (Z_s) as shown in Fig. 2 (see the left side, marked as *Source Circuit*). For most of our measurements, the *source impedance* (Z_s) is usually small relative to the *input impedance* (Z_i) of the circuit to which it is connected and hence we can neglect Z_s (i.e., $Z_s << Z_i$). However, this may not be true when testing a circuit with low *Input Impedance*.

2.b) Concept of Amplifier Circuits

A major portion of this course will deal with amplifier circuits, which can be represented in terms of their input resistance, output resistance, and gain as shown in Fig. 2.



(a) Amplifier Circuit with Source and Load Connected



(b) Equivalent Circuit Model

Fig. 2: An Amplifier Circuit and its Equivalent Model

Input and output impedances are probably new concepts, and are very important in this course.

2.b.1) Input Impedance (Z_i)

Input impedance (Z_i) is the impedance found looking into the input terminals of the amplifier circuit. Input impedance (Z_i) of an amplifier is computed as the ratio of the actual voltage appearing at the input terminals of an amplifier (V_i) and the input current (I_i) entering terminals of the amplifier ($Z_i = V_i / I_i$). It can be noted from Fig. 2 that:

$$V_i = \frac{Z_i}{Z_i + Z_s} V_s \qquad (1)$$

Hence, for a good voltage amplifier, in order to transfer as much voltage as possible from the source (V_s) to the input terminals of the amplifier, we should have $Z_i >> Z_s$. If Z_s value is larger or comparable to Z_i then much of the source voltage will be unnecessarily lost across the source impedance itself (in other words such a case will result in $V_i << V_s$), as is obvious from Eq. (1). *Hence for a good voltage amplifier, its input impedance (Z_i) should be as high as possible.*

2.b.2) Output Impedance

Output impedance (Z_o) for a voltage amplifier is the Thevenin equivalent impedance of the amplifier as seen from its output terminals. You can imagine connecting a test source V_t to the output terminals, and measuring the current I_t drawn from the source (while shorting the input voltage source). Then $Z_o = V_t/I_t$.

The output impedance will determine how your circuit performs when a *load* (Z_L) is connected to the output terminals of the amplifier. As can be seen from Fig. 2, if $Z_O > Z_L$ then most of the amplified voltage, AV_i, will be lost across the output impedance (Z_O) of the amplifier and consequently the voltage available across the load (Z_L) will be considerably reduced. *Hence for a good voltage amplifier, its output impedance (Z_O) should be as small as possible.*

Practical aspects to note while measuring: It is to be noted that while doing measurements, using oscilloscope probes or meters (let the meter internal impedance be represented by Z_m) act as *loads* on a circuit whose output impedance (Z_o) is measured. In other words, Z_m of the meter becomes Z_L for the circuit. For most of our measurements, the meter impedance is large enough relative to our circuit output impedance that we can neglect the meter loading (i.e., $Z_o \ll Z_L$), but this may not be true when testing a high output impedance circuit.

Also note that, in general, parasitic capacitive/inductive impedances will depend on frequency and loading of your circuit under test.

2.b.3) Transfer Function (Gain or Attenuation)

In your previous circuit courses you should have learned to find the transfer function of a network and its frequency response. In this course you'll repeat those exercises but now the circuits may contain *active* devices, such as diodes and transistors. Primarily we'll focus on voltage gain or transfer function $A = V_o/V_i$, although we may occasionally require current gain, I_L/I_i. Note that, in general gain will depend on frequency and represented using Bode plots. Generally, in Bode plots, phase of the transfer function is represented either in degrees or radians, and the gain in terms of dBs, where

$$G = \text{gain in dBs} = \mathbf{20}\log(|V_o/V_i|)$$

As can be seen from the above expression, in case of amplification: G will be +ve, and in case of attenuation: G will be –ve.

Since we have not yet covered active devices in detail, this lab will investigate the performance of a notional 'amplifier' made of passive components, such as the one shown in Fig. 3. Since the components are passive it is not possible to achieve a voltage gain > 1, so this could be called an *attenuator*.

It is strongly recommended that you further read and familiarize yourself with the oscilloscope controls and Breadboard primer in pages 1.4-1.5 (and the further references in them), prior to the lab.

3. **<u>Pre-lab preparation</u> (in the calculations, you can ignore the effect of source-resistance R_S , i.e., you can treat it as a short).** ***Keep your prelab sheets neat.***

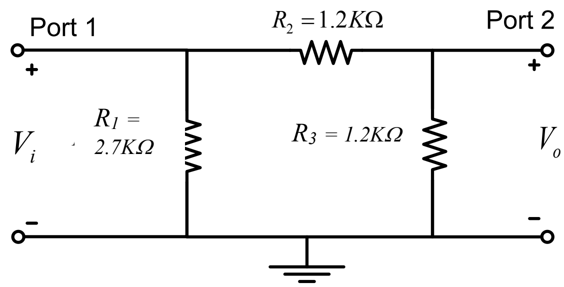


Fig. 3a: Passive Amplifier Circuit (Attenuator)

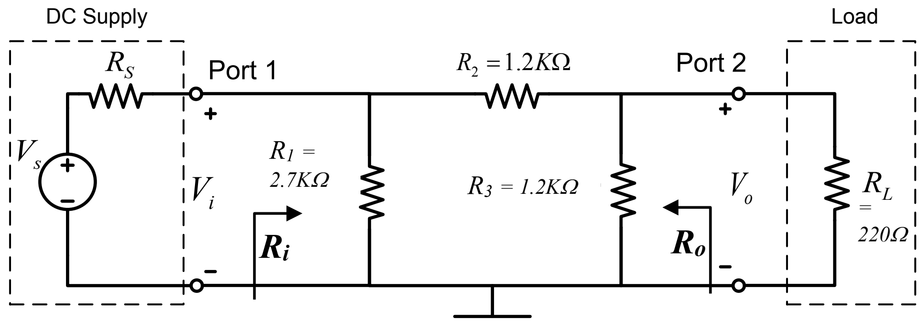


Fig. 3b: Passive Amplifier (an attenuator) with a DC Source and Load

3.1 Derive an expression (in terms of component names) for the input resistance (R_i) of the *Attenuator* in Fig. 3b. (show the steps) :

a) With the output open circuit conditions (*ie., Port 2 open*).

b) With a load R_L connected across port 2.

c) Substitute the component values and evaluate R_i for both the above conditions.

3.2 Derive an expression & also calculate the numerical value of the output resistance of the network in Fig. 3b (i.e., the resistance across port 2 looking towards the input, excluding R_L). *Note: For output resistance computations, we must set any input sources to zero, i.e., short circuit any input voltage sources and open circuit any input current sources (explain why?).*

3.3 Compute and draw the Thevenin equivalent circuit as seen by the load resistor for the network in Fig. 3b (In your calculations, use a value for V_s = 5V).

3.4 Derive an expression for the transfer function $A = V_o/V_i$ for the circuit of Fig. 3b:

a) With the output open circuit conditions (i.e., Port 2 open).

b) With a load R_L connected across Port 2.

c) Substitute the component values and evaluate A for both the above conditions.

3.5 Derive an expression for the transfer function $A=V_o/V_i$ for the circuit of Fig. 4 with the load *open circuited* and with frequency as a variable.

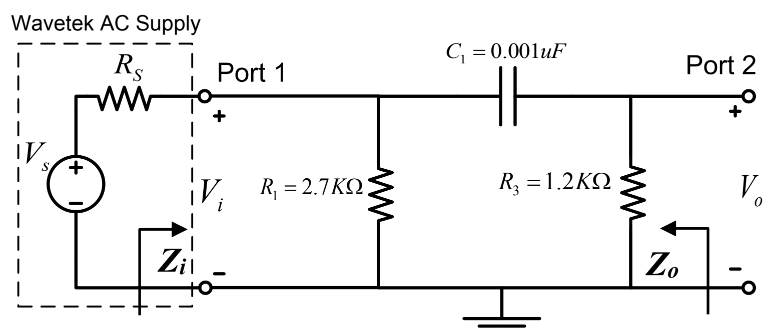


Fig. 4: Passive Amplifier with a Capacitor Component and AC Source

a) Substitute the component values and evaluate *A* and fill in the following table and draw the Bode plots (*G* v/s *w* and *phase* v/s *w*). Show the steps at frequency = 1KHz.

Frequency	***A* =|Vo/Vi|**	**G = 20log(A)**	**φ (phase angle)**
0 Hz			
1 kHz			
10 kHz			
100 kHz			
1 MHz			

b) Analytically reason the frequency related behavior of the transfer function:

3.6 For voltage amplifiers, is it desirable to have high input impedance or low input impedance? Explain clearly in your own words. What about output impedance? (Explain).

4. Experiment

Equipment :	Oscilloscope:	Tektronix TDS 3012
	Function Generator:	
	DC Power Supply:	DOE FG515
	Multimeter:	Wavetek DM15XL
Parts:	2 x 1.2kΩ, 2.7kΩ,120Ω, 220Ω resistors, 1 nF capacitor	

4.1 Input and Output Impedances

4.1.1 Measure and record the resistor values you obtained. Do they match exactly? Why or why not. You should always measure and record your resistor values. When doing calculations, always use the *measured* values.

4.1.2 Construct the circuit as shown in Fig. 3b, but do not yet connect the DC supply.

4.1.3 Using the Multimeter, measure the input resistance at port 1.

4.1.4 Remove R_L and short the input terminals together. Using the Multimeter, measure the output resistance as seen from port 2. What does this measurement correspond to (refer to your prelab calculations)?

4.2.1 Explain any difference between the measured values and corresponding pre-lab exercises.

4.2 Transfer Function

4.2.2 Turn on the DC power supply and set the variable output voltage to 5V. Check the voltage with the Multimeter. Connect the DC power supply to port 1, as shown in Fig. 3b (note that load is not connected yet, i.e., open circuit load conditions).

4.2.3 Using the Multimeter, measure the voltage at both ports. Find the transfer function V_o/V_i (also called the voltage gain). What does this measurement correspond to (refer to your prelab calculations)?

4.2.4 Connect a load 220Ω resistor as shown in Fig. 3b. Measure the voltage at port 2.

4.2.5 Find again the voltage gain. Explain why the gain is lower than the measurement in 4.2.2.

4.2.6 Repeat 4.2.5 and 4.2.4 using a 120 Ω load resistor.

4.2.7 V_o measured in 4.2.3 is approximately the open circuit voltage (since the meter input resistance is >> the circuit output resistance). Measure the short circuit current by connecting Vo to ground and measuring the voltage drop across R_2, and calculating I_{SC}. Calculate the value of the Thevenin resistance based on your measurements.

4.2.8 Explain any difference between the measured and corresponding pre-lab exercises.

4.3 Thevenin Equivalent

4.3.1 Turn off the DC power supply. Disassemble your circuit and build the Thevenin equivalent as shown in Fig. 1, using the closest available resistor to your calculated value from 4.2.7.

4.3.2 Connect the 220 Ω load resistor. Turn on the DC supply and use the Multimeter to measure the voltage at port 2 (be careful here about the voltage value of the DC supply).

4.3.3 Repeat 4.3.2 replacing the 220Ω load with a 120Ω load.

4.3.4 Compare the voltages in 4.3.2 and 4.3.3 to that found in 4.2.5 and 4.2.6. Explain any differences in terms of the output impedance and load.

4.4 AC Response & Bode Plots

4.4.1 Turn off the DC power supply. Build the circuit shown in Fig. 4. Note that we are not attaching a load resistance to the amplifier in this experiment. In other words, the amplifier is *unloaded* (i. e., output is open circuited).

4.4.2 Turn on the DC power supply and set it to 5V. Measure the transfer function. Is this result expected? Explain why.

4.4.3 Turn off the DC power supply and disconnect it from the circuit. Connect the function generator to the circuit and turn it on. Adjust the frequency to 1 kHz. Using the Multimeter (set to measure AC volts!) adjust the output of the function generator (input to your circuit) to 2V RMS (not peak!; note that $V_{rms} = V_{peak}/\sqrt{2}$))

4.4.4 Using the oscilloscope display the input and output voltage waveforms on different channels. Find the gain V_o/V_i and phase difference between the two signals.

4.4.5 Repeat the measurements in 4.4.4 at 10kHz, 100kHz, and 1MHz. Also record the RMS value of the input voltage at each frequency. Put all values in a table as shown below and sketch the Bode plots (*G* v/s *w* and *phase* v/s *w*).

Frequency	Vi (RMS)	Vo (RMS)	φ (phase angle)	*A* =Vo/Vi	G = 20log(A)
0 Hz					
1 kHz					
10 kHz					
100 kHz					
1 MHz					

4.4.6 Disconnect the oscilloscope, and use the Multimeter to measure the value of the input voltage at 1kHz, 10kHz, 100kHz, and 1MHz.

4.4.7 Is there a difference between the input voltage measured using the Multimeter and the Oscilloscope? At what frequencies? What can you conclude from the two devices based on your observation?

4.5 Breadboard, Panel and Display Buttons

4.5.1 Demonstrate to your TAs and answer any quizzes that may be asked while operating an Breadboard, Oscilloscope, a Function Generator, a DC Power Supply and a Multimeter. Prepare as part of your report, a summary of various panel and Buttons that are available to you to use with an Oscilloscope, Function Generator, DC Power Supply and Multimeter.