Circuit Analysis Laboratory Manual

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List of Experiments

Laboratory Experiment Notes

1. You can easily finish your work during the scheduled lab time if you spend some time before the lab to:
    a. Read and understand the laboratory notes
    b. Practice the theoretical analysis required using the nominal component values so that you can easily redo the calculations using the measured component values to eliminate component tolerances as a source of experimental error.
    c. Set up your circuit simulations (Multisim, LTSpice, or other simulation tool) using the nominal values and confirm that you obtain the same results as calculated. You can easily edit your simulation to use the measured component values when performing the experimental procedure.
2. The lab (Bannow 133) is available (except for times that classes are meeting) for any follow0up work. Your Stagcard will provide access.
3. There are two lab instructors (Cavello / Denenberg) and your Professor (Balagi) that can assist you in understanding these experiments. Upper class and graduate EE students often can be found in the lab on weekday afternoons/evenings and they can also answer questions.
4. There will be times when the laboratory schedule gets ahead of the lecture class schedule. Do not let this be a concern as your lab instructor will go over the relevant theory as required at the start of each lab session.

Laboratory Experiment 1: Resistor Color Code and Tolerance and Ohm's Law

Objective: To become familiar with the resistor color code and the use of an ohmmeter to measure resistance and to verify Ohm's Law

Equipment:

Digital Multimeter (DMM)

Resistors: 100Ω, 1kΩ, 2.2kΩ, 10kΩ, 68kΩ, 100kΩ, 330kΩ, 1MΩ

Procedure:

1. The color code (look it up on the Internet) on each resistor defines the nominal value about which the tolerance is defined. The nominal value is that value of resistance that the resistor would have if its tolerance were 0 percent. Use the color code to determine the nominal value in each case and record them (smallest value first) in Table 1.

2. Record the tolerance. Using the tolerance and the resulting theoretical maximum and minimum values for each resistor can be calculated.

3. Using the DMM (note that it has specified accuracy as well, look it up on the Internet. Also check the "zero" by shorting the leads. If there is some residual resistance, this can noticeably affect low resistance readings.), measure and record the measured value of each resistor. Calculate the percentage deviation:
   Error = (Nominal value - Measured Value) X 100 / Nominal Value
   and record it. Check to see whether or not this value falls within the tolerance specification and record it. Be sure not to touch probes with your fingers when measuring resistance, since readings will be affected by body resistance!

Table 1: (suggestion: use Excel to create in this table and paste it into your report)

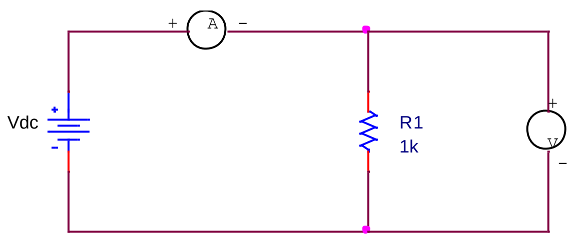
Nominal value	Tolerance	Measured value	% Deviation	Meet Spec?

Ohm's Law

1. Measure the resistance of your 1kΩ resistor using a Multimeter.

2. Connect the circuit shown in Figure 1 using 1kΩ for the resistor.

3. Adjust the Elvis variable power supply to 2V by measuring using a DMM (The Elvis virtual DVM is available). Measure the current through the resistor as shown using a second DMM (be careful not to blow the internal fuse). Record in Table 2 (again, using Excel to record data and do calculations is a better approach)



4. Adjust the power supply voltage in steps of 2V up to 12V and repeat step 3. Record in Table 2.

5. Reverse the polarity of power supply and repeat steps 3 and 4. Record in Table 2.

4. Plot I against V. What does the slope represent? Use your spreadsheet's "linear regression" analysis to get the best linear equation that represents your data.

5. Determine the resistance from the graph. How does it compare to the measured resistance.

6. Submit results and conclusions in your lab report.

Table 1:

Nominal value	Measured value

Table 2: R1=1kΩ

V in Volts	I in mA

Laboratory 2: Kirchhoff's Current and Voltage Laws

Objective: The objective of this experiment is to understand series, parallel combination of resistors and verify Kirchhoff's voltage and current laws

Equipment:

DC Power Supply

Digital Multimeter (DMM)

Resistors: 4.7kΩ, 2kΩ, 2.7KΩ, 1kΩ, 3.3KΩ

Procedure:

1. Measure the individual resistances. Calculate the equivalent resistance of the circuits shown in Figure 1 using **measured values** of resistances (show your work!).
2. Set up the circuit shown in Figure 1.
3. Measure the equivalent resistances. Record in Table 1. (Again use a spreadsheet like Excel)
4. Repeat steps 1- 4 for the circuit in Figure 2.
5. Explain the difference in values in Figures 1 and 2.

Figure 1

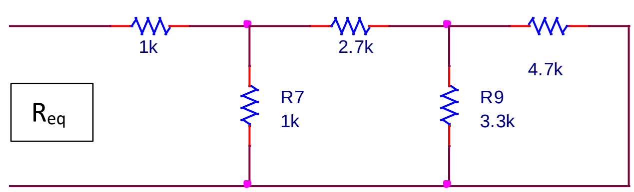


Figure 2

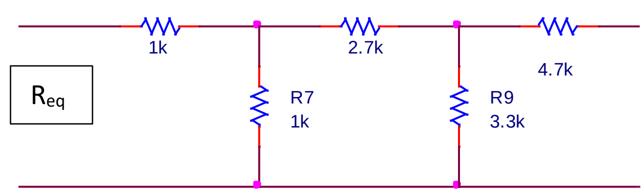


Table 1.

Figure Number	Theoretical R_{eq}	Measured R_{eq}	% Deviation

KVL and KCL

Introduction In this section of our second laboratory, two of the most important laws used to analyze circuits will be experimentally verified. Kirchhoff's Current Law states that the sum of all the currents entering a node is zero. A common mistake in applying this law is to not carefully show the direction of each current entering the node. Kirchhoff's Voltage Law states that the sum of all the voltages around a circuit loop must equal to zero. When applying this law, be sure to indicate the polarity of the voltage across each circuit element using + and - signs. Experimental results will be compared with those using hand calculations, MATLAB, and Multisim.

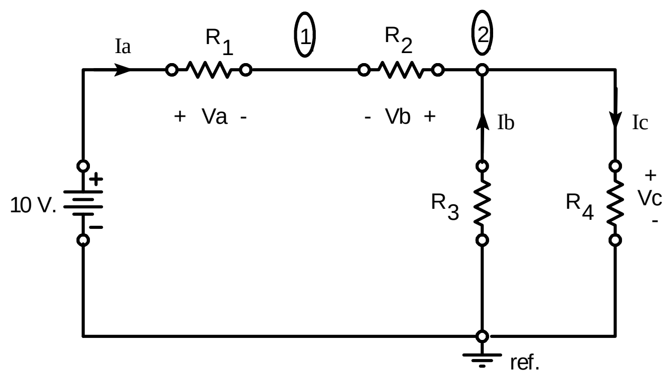


Figure 3. Circuit for Voltage and Current Measurements

Theoretical Calculations

1. Let $R_1 = 2K\Omega$, $R_2 = 4.7K\Omega$, $R_3 = 1K\Omega$, and $R_4 = 3.3K\Omega$.

2. Measure the four resistors. Record them on the circuit. Use the **measured*** resistor values to calculate the voltages across resistors and currents in the circuit. Solve for unknown node voltages V_1 and V_2 and voltages V_a, V_b, V_c by hand (show your work!). While doing so make sure to note the polarity of voltages marked in the circuit. Note: although not marked the node voltages V_1 and V_2 are considered positive with respect to the reference. Solve for unknown currents I_a, I_b, I_c making sure to observe the current directions marked in the circuit.

   ***Using measured values removes resistor tolerances as a source of error in the experiment. This is an important concept that you should apply to all hands-on engineering activities.**

Simulations

Construct a Multisim simulation of the circuit in Figure 1 using the **measured** values of the four resistors. Run the simulation so as to determine the currents and voltages indicated in Figure 3.

Laboratory Experiment

1. Construct the circuit shown in Figure 3.

2. Use the Multimeter to measure the indicated three currents (be careful not to blow the DVM fuse) along the directions marked in the circuit and five voltages with polarity shown in the circuit and record in Table 2 and Table 3.

3. Compare (calculate the percent differences) the results of Step 2 with those obtained from the theoretical calculations of Step 2 of the **Theoretical Calculations** and the **Simulation** section above.

4. Using the measured values of the three currents verify Kirchhoff's Current Law at node 2. Use your measured values of the source voltage, V_a, V_b, and V_c to verify Kirchhoff's Voltage Law. Also, verify the voltage across resistors V_a, V_b, and V_c in terms of the node voltages V_1 and V_2.

5. Submit a report with results and conclusions
Note: if you have percent errors in excess of your instrumentation tolerances, you have made mistakes in performing the laboratory.

Table 2:

Calculated					
V_a	V_b	V_c	V_1	V_2	KVL
Simulated					
V_a	V_b	V_c	V_1	V_2	KVL
Measured					
V_a	V_b	V_c	V_1	V_2	KVL

Note: The calculated and simulated results should be within round-off errors and the measured values should be within equipment tolerances.

Table 3:

Calculated			
I_a	I_b	I_c	KCL at node 2
Simulated			
I_a	I_b	I_c	KCL at node 2
Measured			
I_a	I_b	I_c	KCL at node 2

Laboratory Experiment 3: Superposition Theorem

Objective: The purpose of this experiment is to demonstrate the principle of superposition.

Equipment:

DC Power Supply

Digital Multimeter (DMM)

Resistors: 2.2kΩ, 1 kΩ, 3.3KΩ

Note: Measure each resistor and use these values in all of the following steps. This eliminates resistor tolerances as a source of experimental error.

Procedure:

1. Theoretically solve each of the networks of Figures 1 through 3 for the voltages across each of the resistors using any method of analysis known to you. Mark a polarity reference of your choice. (Note: For Figure 3 do not use superposition principle to determine the voltages but use any method of analysis known to you with both sources present in the analysis) Record the calculated values in the Table 1. Confirm that superposition is validated theoretically.
2. Set up network in Figure 1. ***Note: if using Elvis, measure the 15 volt supply voltage and adjust your calculations/simulations to use this value to eliminate that source of error.**
3. Measure the voltages across each of the resistor. Record in Table 1.
4. Repeat steps 2 and 3 for network in Figure 2 and Figure 3.
5. Verify the principle of superposition with measured voltages. Will the principle of superposition apply for currents through each of the resistors? Explain and verify this with Multisim.
6. Using voltages across each of the resistors in networks of Figures 1 2 and 3 determine the power dissipated in each of the resistor. Record in Table 2. Is the principle of superposition valid for power? Explain.

   *** You should always try to reduce sources of error in all experimental procedures.**

Table 1

	E_1 alone Present (Figure 1)		E_2 alone Present(Figure 2)		E_1 and E_2 Present (Figure 3)	
	Calculated	Measured	Calculated	Measured	Calculated	Measured
V_{R1}						
V_{R2}						
V_{R3}						

Table 2.

	E_1 alone Present (Figure 1)		E_2 alone Present(Figure 2)		E_1 and E_2 Present (Figure 3)	
	Calculated	Measured	Calculated	Measured	Calculated	Measured
P_{R1}						
P_{R2}						
P_{R3}						

Figure 1

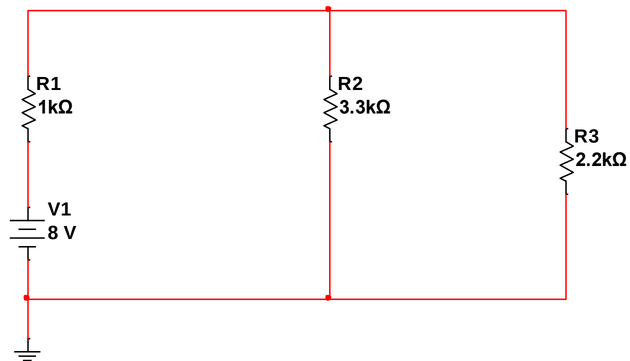


Figure 2

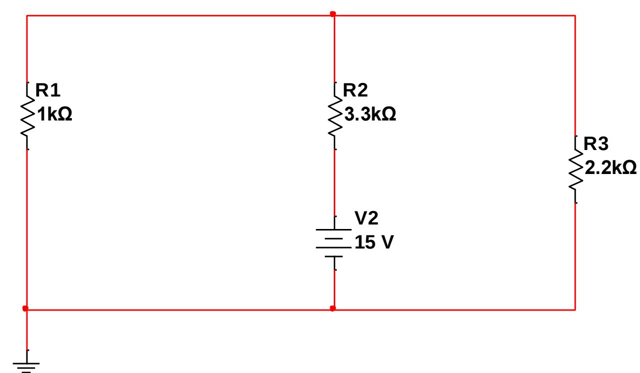
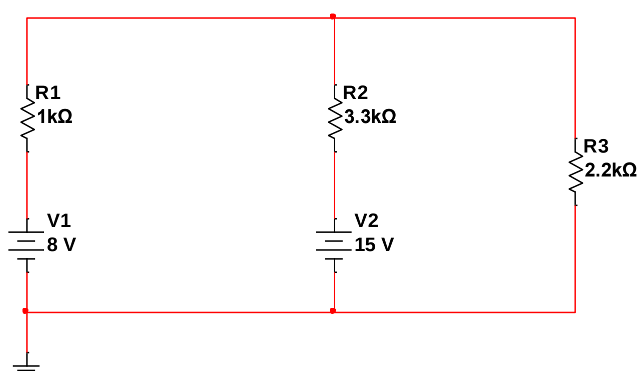


Figure 3



Laboratory Experiment 4: Thevenin's and Norton's Theorem

Objective: The purpose of this experiment is to determine the Thevenin's and Norton's equivalent circuit experimentally and theoretically for a simple network.

Equipment:

DC Power Supply

Digital Multimeter (DMM)

Resistors: 2.2kΩ, 1 kΩ, 3.3KΩ, 4.7kΩ, 6.8kΩ

Procedure:

1. Measure your actual source voltage and resistor vales and use the results in **all** subsequent steps.
2. Theoretically solve for the Thevenin's equivalent circuit (V_{TH} in series with R_{TH}) of Figure 1 between terminals a and b. Record it in the Table 1. Solve for Norton's current and record it in Table 1. Make sure to mention units for values recorded.

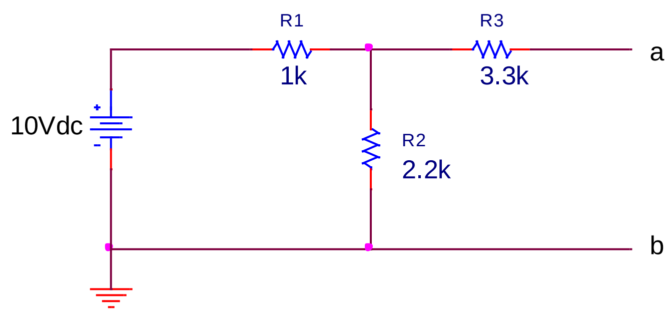


Figure 1.

3. Set up the circuit and measure the voltage between terminals a and b. What is this voltage called? Record it in Table 1.
4. Measure the current through the terminals a and b when using the current meter to short a to b.. What is this current? Record it in Table 1.
5. Remove the voltage source and replace with a short circuit. Measure the resistance between the two terminals a and b with a Multimeter. What is this resistance called? Record it in Table 1.
6. From your measurements in step 2 and step 3 calculate the Thevenin's equivalent resistance and record it in Table 1.
7. Repeat this experiment using Multisim simulations
8. Calculate the percent error between the theoretical, simulated and measured values.

Table 1

	Theory	Simulated	Measured	Percent Error
V_{TH}				
I_N				
R_{TH}				
$R_{TH} = V_{TH}/ I_N$				

9. Repeat steps 1 through 7 for Figure 2. Record theoretical and measured data in Table 2.

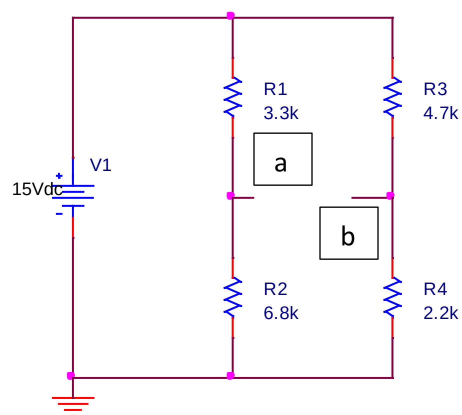


Table 2

	Theory	Simulated	Measured	Percent Error
V_{TH}				
I_N				
R_{TH}				
$R_{TH} = V_{TH}/ I_N$				

Laboratory Experiment 5: Maximum Power Transfer Theorem

Objective: The purpose of this experiment is to verify the Maximum Power Theorem.

Equipment:

DC Power Supply

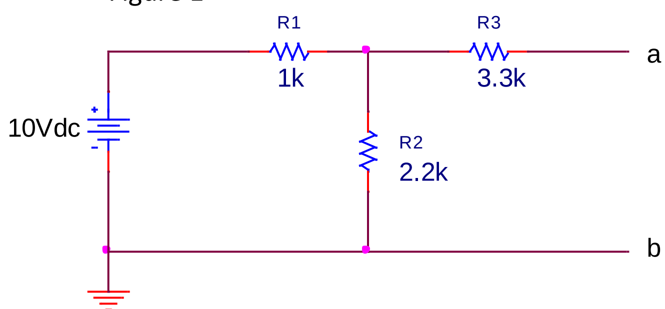
Digital Multimeter (DMM)

Resistors: 2.2kΩ, 1 kΩ, 3.3KΩ, 10kΩ Pot

Procedure: (remember to measure all component values and source voltages and use those values in all of the simulations/calculations)

1. Theoretically solve for the Thevenin's equivalent circuit (V_{TH} in series with R_{TH}) of Figure 1 between terminals a and b. Draw the Thevenin's equivalent circuit.

Figure 1



2. Assemble the circuit in Figure 1.
3. Connect between the terminals a and b a 10Kohm potentiometer Or alternatively a set of known resistor values) which will be varied to achieve the desired Load resistance.
4. Set the potentiometer resistance to 1KΩ. Measure the current through the load and voltage across the load. Record the measurements in Table 1. Calculate the power dissipated in load.
5. Vary its resistance from 1Kohm to 8Kohm in steps of 1Kohms. While varying the resistance make sure to remove the potentiometer from the circuit. Adjust to achieve the desired value by reading the resistance on DMM. Understand why the potentiometer should be removed from the circuit in order to adjust its value. For each setting repeat the measurements in step 4 and record in Table 1.
6. Assemble the Thevenin's equivalent circuit of Figure 1. Repeat the step 3-5 and record the measurement in Table 2.
7. Compare measured values of the two circuits. Comment on it in results and conclusions section.
8. Plot the power dissipated in load as a function of load resistance. At what value of load resistance is the power dissipated in the load resistance maximum? Using the best polynomial curve fit function of your spreadsheet aids in this estimation. Comment on it in results and conclusions section.

Table 1

Load Resistance	Voltage	Current	Power

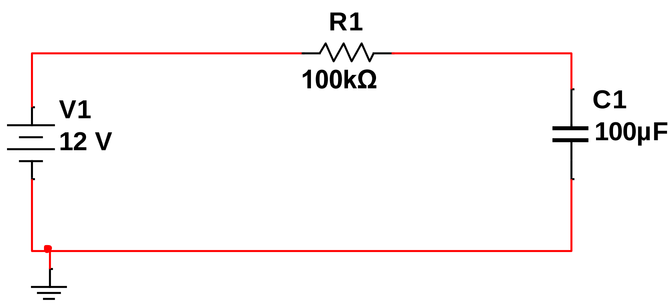
Table 2

Load Resistance	Voltage	Current	Power

Laboratory Experiment 6: Multisim Activity on Transient Analysis

Objective: The purpose of this experiment is to verify the Transient behavior of RC and RL networks using Multisim.

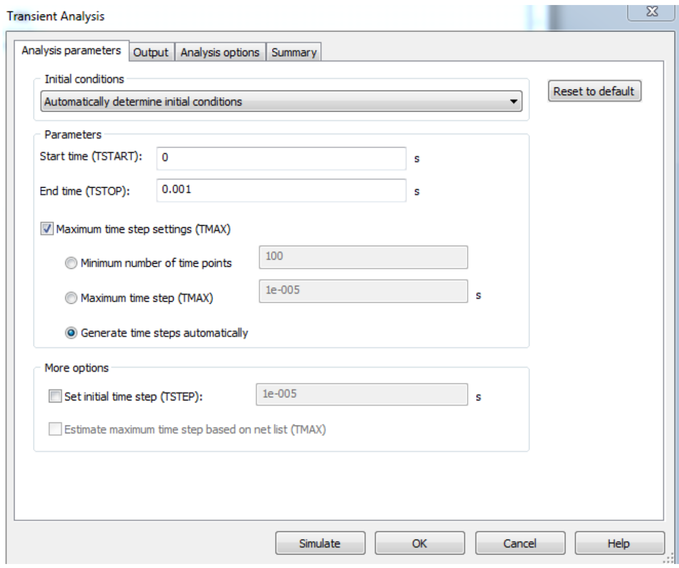
1. Assemble the following circuit in Multisim.



2. On the Analysis tab (on menu), select transient analysis.

3. A transient analysis window as below will pop up. Change the "**Initial Conditions**" to Set to Zero. Keep the "**Start time**" to 0s. Change the **End time** to 10 times the time constant (RC) of the circuit above i.e. 100s. Check m**aximum number of time points** and leave at 100. The analysis will be done at 100 points over 100s which means the circuit simulation is done every second. Click on **Output** tab and select the voltage so as to read the voltage across capacitor C1 and **add** it to the output. It will appear on the empty column on the right side when **add** has been selected (Note: From **view netlist** tab of Multisim it can be verified that the node voltage selected indeed is the capacitor voltage)

4. Click **Simulate** on the **transient analysis** window.



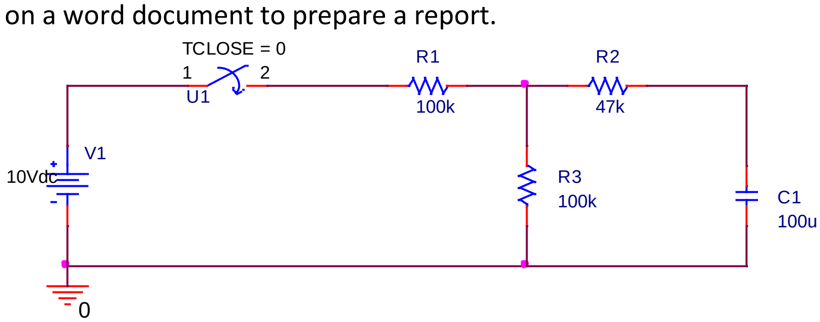
5. A graph will appear with voltage as a function of time. The window of graph will be on a black background. **Invert the graph background to white. Copy the graph and paste on a word document to prepare a report.**

6. Once again on the Analysis tab (on menu), select transient analysis. Click on **Output** tab and **Remove the selected voltage**. Then **Add** I(R1)

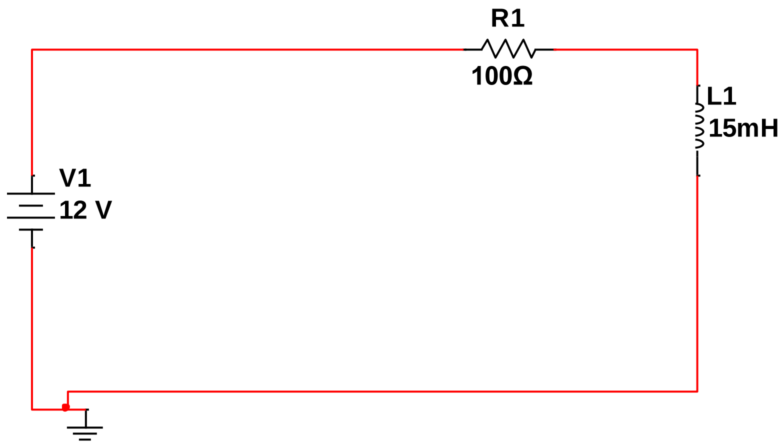
7. Once again, click **Simulate** on the **transient analysis** window. Determine the value of the time constant of the circuit analytically (RC) and verify it from simulation.

8. A graph will appear with current as a function of time. This concludes transient analysis of the above circuit. **Copy the inverted graph and paste on a word document to prepare a report.**

9. Assemble the following circuit in Multisim. Obtain the Thevenin's equivalent circuit to the left of the capacitor. From the Thevenin's equivalent circuit determine the time constant of the circuit. **You need NOT put the switch shown in figure.** Just connect a wire in place of switch. Simulating transient analysis takes care of the switch. Repeat steps 2 to 8 and copy the graph on a word document to prepare a report.



10. Assemble the circuit below**.** Repeat steps 2 to 8 and copy the graph on a word document to prepare a report. Note the time constant for the circuit below is 0.15ms. The END time of the analysis is 10 times the time constant.



11. Give title to each of the graph. Write Conclusion and submit the document.

Laboratory Experiment 7: The Oscilloscope

Objective: This experiment introduces period, frequency and RMS and phase measurements using oscilloscope .

Equipment:

Oscilloscope
Function Generator
DC Power Supply
Digital Multimeter (DMM)

Procedure:

A supplementary material on oscilloscope will be provided and the instructor will explain the operation and use of the oscilloscope and the function generator.

FREQUENCY MEASUREMENT

1. Adjust the zero-reference line to the middle of the screen (halfway up from the bottom of the screen) by moving the vertical position control. The zero level is now set to middle of the screen. **Do not** move the vertical position control after this because it is important the zero reference line is in the middle of the screen while making measurement of the period.

2. Set CHANNEL 1 to the AC coupling mode and connect the scope to the function generator. Set the function generator to 200Hz sinusoidal waveform. Adjust the function generator so that 4 Volts peak to peak is observed on the oscilloscope. Observe the positive half of waveform above the zero level and negative half below the zero level. Amplitude is not important parameter of measurement for this part.

3. Determine the period of waveform by measuring the length of one full cycle of the waveform and multiplying the length with the horizontal sensitivity set on the oscilloscope. In order to measure the length of one cycle move the horizontal shift position so that one of the zero crossing (positive slope)of the waveform close to the left end of screen is aligned with a vertical thick line(second one say) on the left side of the screen. Then, count the number of divisions to the next zero crossing (positive slope) to obtain the length of a cycle.

   Period= Length of cycle in division X Time/Division setting on Oscilloscope.

   Frequency = 1/T

4. Record the observation in Table 1. For the period make sure that you write the unit of period with the prefix milli or micro as necessary.

5. Repeat the period and frequency measurement for various frequency settings on the function generator as per Table 1. For each setting MAKE SURE that you adjust the time per division setting of the oscilloscope so that you observe one cycle clearly on the oscilloscope. For best results the Time/Division setting should be such that only about one to two cycles of the waveform are observed on the screen of the oscilloscope. Note that whenever the frequency setting on the function generator is changed the peak to peak amplitude also changes meaning that the function generator does not produce a constant voltage with changing frequency. Since amplitude is not a parameter of importance in this measurement it may be adjusted to about 4V peak to peak so that the waveform is observed clearly in a 1 Volt/Div scale.

6. Change the function generator setting so as to output Triangular wave.

7. Repeat period and frequency measurement for this waveform using oscilloscope using the steps outlined above and record the observations in Table 2.

8. Change the function generator setting so as to output Square wave.

9. Repeat period and frequency measurement for this waveform using oscilloscope using the steps outlined above and record the observations in Table 3.

TABLE 1. MEASUREMENT OF SINE WAVE FREQUENCY

Frequency setting (Function Generator) in Hz	Time/Division Setting	Number of Divisions per cycle	Period= Time/Div X Number of Div per cycle	Frequency= 1/T in Hz
200				
500				
2000				

TABLE 2. MEASUREMENT OF TRIANGULAR WAVE FREQUENCY

Frequency setting (Function Generator) in Hz	Time/Division Setting	Number of Divisions per cycle	Period= Time/Div X Number of Div per cycle	Frequency= 1/T in Hz
800				
4000				
10000				

TABLE 3. MEASUREMENT OF SQUARE WAVE FREQUENCY

Frequency setting (Function Generator) in Hz	Time/Division Setting	Number of Divisions per cycle	Period= Time/Div X Number of Div per cycle	Frequency= 1/T in Hz
1500				
2500				
7500				

RMS MEASUREMENT

USE CHANNEL 1 OF THE OSCILLOSCOPE

1. Set the function generator to output 1KHz frequency of sinusoidal wave.

2. Set CHANNEL 1 to the AC coupling mode and connect the scope to the function generator. Also connect a digital multimeter across the function generator and set it to measure RMS.

3. Set the vertical sensitivity and horizontal sensitivity on oscilloscope appropriately to observe the waveform clearly for each amplitude level of Table 4.

4. Derive the RMS of a sine wave with amplitude “A” using integral calculus.

5. Determine the RMS of the waveform from digital multimeter and record it in Table 4. Also record the calculated RMS value for the sine wave from the amplitude observed on the oscilloscope.

6. Derive the RMS of a Triangular wave with amplitude “A” using integral calculus.

7. Repeat RMS measurement using the same set up for Triangular waveform of frequency 1 KHz and record the observations in TABLE 5.

8. Derive the RMS of a Square wave with amplitude “A” using integral calculus.

9. Repeat RMS measurement using the same set up for Square waveform of frequency 1 KHz and record the observations in TABLE 6.

TABLE 4. RMS VALUE (SINE WAVE)

F=1KHz Sine Wave Amplitude in Volts	Calculated RMS value in Volts= Amplitude / √2	Measured RMS value in Volts
1		
2		
5		

TABLE 5. RMS VALUE (TRAINGULAR WAVE)

F=1KHz Sine Wave Amplitude in Volts	Calculated RMS value in Volts= Amplitude / √3	Measured RMS value in Volts
1		
2		
5		

TABLE 6. RMS VALUE (SQUARE WAVE)

F=1KHz Sine Wave Amplitude in Volts	Calculated RMS value in Volts= Amplitude	Measured RMS value in Volts
1		
2		
5		

AC WAVEFORMS WITH A DC OFFSET AND DETERMINATION OF TRUE RMS

1. Set the function generator to output sine wave of 2V amplitude in High Z mode .Also, set it to have a 2V DC offset.
2. Set the zero-reference level of Channel 1 to middle of the screen. Set the vertical sensitivity to 2 Volt/Div and horizontal sensitivity to 0.5ms/Div.
3. Set the DC power supply to 2V using a DMM across it.
4. Set the oscilloscope to AC coupling mode and adjust the function generator to read 2V amplitude (4V peak to peak) and 1KHz. Copy the waveform in Figure 1.
5. Change the channel 1 to DC coupling mode and observe the waveform.
6. Copy the waveform on to Figure 2. Explain the difference.

Laboratory Experiment 8: Operational Amplifier Circuits

Objective: The objective of the experiment is to understand the application of the operational amplifier integrated circuit as an inverting and a non-inverting amplifier.

Equipment:

DC Power supply

Function generator

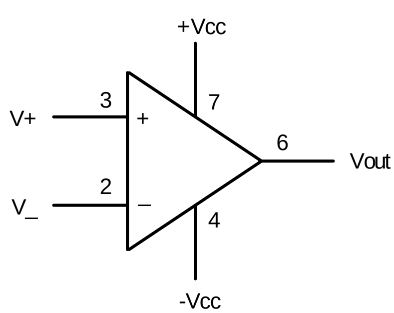
Oscilloscope

IC 741, Resistors as required

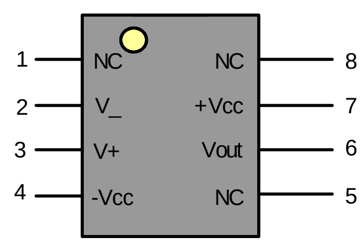
Operational Amplifier Basics

An operation amplifier can be used to perform many tasks including signal amplification, summation, integration, differentiation and filtering. This laboratory examines how to construct an inverting and a non-inverting amplifier for a required gain. For the purpose of analysis, the ideal model of operation amplifier (op-amp) is used. An ideal op-amp is an amplifier with infinite open loop gain and infinite input resistance and zero output resistance. For practical purposes, the ideal model works very well and is often used in designing amplifiers.

The LM 741 op-amp that will be used in this experiment is an eight pin device. Figure 1 shows the schematic symbol and how the pins are labeled.



LM 741 Schematic Symbol



LM 741 Pin Numbers (top view)

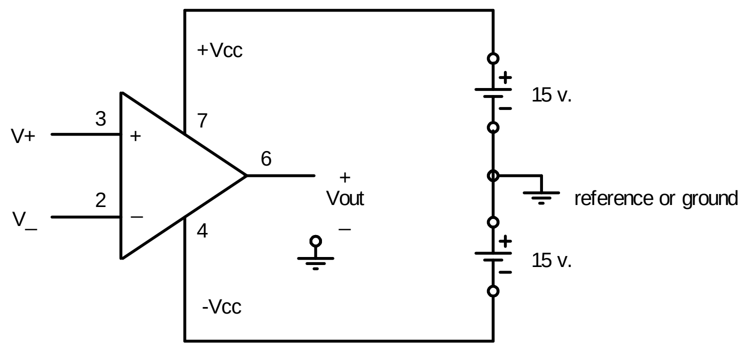


Figure 1 LM 741 Operational Amplifier Device Schematic and Labels

Circuits that include an op-amp can often be designed using two rules based on the ideal model.

1. The first rule is that the currents into pins 2 and 3 are negligibly small and can be approximated to be zero for design purposes meaning that input resistance is infinite.
2. $V_{out} = K(V_+ - V_-)$ where K is large in practice. While the value of K is typically between 25000 and 50000, its exact value is often not needed. The value of V_{out} cannot be greater than the supply voltage $+V_{cc}$ or less than the supply voltage $-V_{cc}$. Since V_{out} is limited by the supply voltage $V_{cc,}$ the expression for V_{out} implies that $|V_+ - V_-|$ is small and can be approximated to be zero for design purposes. This means K which is the open loop gain is infinite. Thus, the second rule usually assumed for op-amp design is that $V_+ = V_-$.

For this experiment two dc supplies are required as shown in Figure 2.

Figure 2 Power Supply Connections and Reference Definition

We also see that Vout is measured relative to the common point between the two power supplies. Although the connections between the integrated circuit and the power supplies are often omitted (See Figure 3) while drawing the circuit of inverting or non-inverting amplifier, but the integrated circuit will not work without them.

Pin 2 of the op-amp is referred to as the inverting input and Pin 3 is referred to as the non-inverting input.

Analysis of the inverting and non-inverting amplifier is presented below.

Inverting Amplifier Basics

Figure 3 shows the basic op-amp circuit, the inverting amplifier.

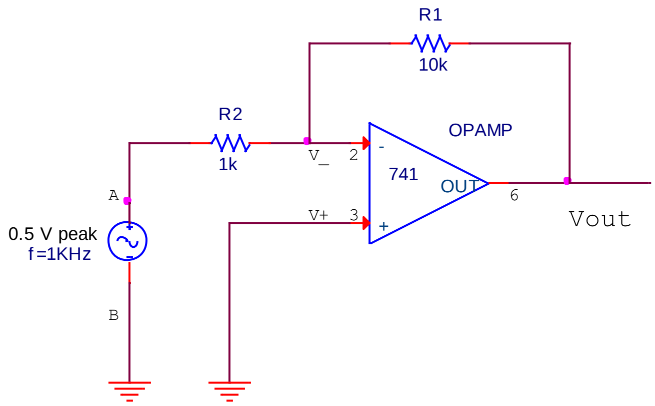


Figure 3 Inverting Amplifier Circuit

Write the node equation at the inverting input terminal of the op-amp. Refer to rule 1 which states that current into Pin 2 is zero.

$$\frac{V_{AB} - V_{-}}{R_2} = \frac{V_{-} - V_{out}}{R_1}$$

Refer to rule 2 which states that $V_+ = V_-$ and from Figure 3 it is clear that $V_+=0$. Applying rule 2 leads to $V_- = 0$. So the above equation simplifies to

$$\frac{V_{out}}{V_{AB}} = -\frac{R_1}{R_2}$$ which is the gain of the inverting amplifier.

For sinusoidal input to the amplifier, a negative gain indicates that the phase of the output is 180 degrees relative to that of the input.

Non-Inverting Amplifier Basics

Figure 4 shows the basic op-amp circuit, the non-inverting amplifier.

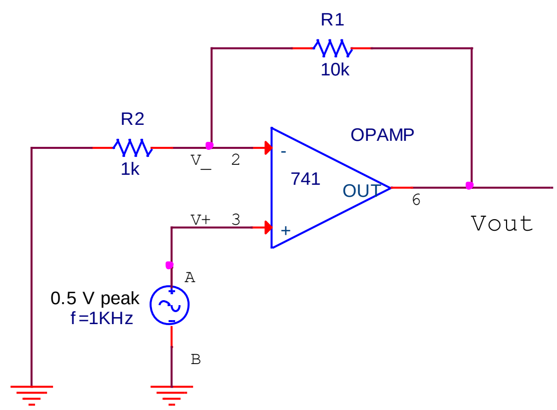


Figure 4   Non-inverting Amplifier Circuit

Write the node equation at the inverting input terminal of the op-amp. Refer to rule 1 which states that current into Pin 2 is zero.

$$\frac{0-V_{-}}{R_2}=\frac{V_{-}-V_{out}}{R_1}$$

Refer to rule 2 which states that $V_+ = V_-$ and from Figure 4 it is clear that $V_+=V_{AB}$. Applying rule 2 leads to $V_-=V_{AB}$. The above equation simplifies to

$$\frac{-V_{AB}}{R_2}=\frac{V_{AB}-V_{out}}{R_1}$$

$$\frac{V_{out}}{V_{AB}}=1+\frac{R_1}{R_2}$$ which is the gain of the non-inverting amplifier.

Procedure - Inverting Amplifier

1. Build the power supply circuit shown in Figure 2. Set the supply voltage to 15V as shown.
2. Build the inverting amplifier circuit shown in Figure 3.
3. Set the function generator to output a sine wave of amplitude 0.5V and frequency of 1 KHz.
4. Use the scope to measure the amplitude of Vout and V_{AB} and record in Table 1.
5. Also measure the phase angle of Vout relative to V_{AB} and record in Table 1.
6. Calculate the magnitude of the experimental gain **Vout/ V_{AB}.**
7. Compare the measurement values with the theoretical values.
8. Increase the amplitude of the function generator from 0.5V in steps of 0.2 V up to 1.1V and repeat steps 4 to 7.
9. Observe what happens as you increase further in steps of 0.1 for a few more times and state what happens and why does it occur.
10. Assuming you have only three resistors of values 1K, 3.3K and 4.7K given to you, how would you construct an inverting amplifier with the magnitude of gain equal to 8.

Procedure – Non-inverting Amplifier

1. Build the power supply circuit shown in Figure 2. Set the supply voltage to 15V as shown.
2. Build the non- inverting amplifier circuit shown in Figure 4.
3. Set the function generator to output a sine wave of amplitude 0.5V and frequency of 1 KHz.
4. Use the scope to measure the amplitude of Vout and V_{AB} and record in Table 2.
5. Also measure the phase angle of Vout relative to V_{AB} and record in Table 2.
6. Calculate the magnitude of the experimental gain **Vout/ V_{AB}**.
7. Compare the measurement values with the theoretical values.
8. Increase the amplitude of the function generator from 0.5V in steps of 0.2V up to 1.1V and repeat steps 4 to 7.
9. Observe what happens as you increase further in steps of 0.1 for a few more times and state what happens and why does it occur.
10. Assuming that three resistors of values 1K, 3.3K and 2.2K are given to you, how would you construct a non-inverting amplifier with the magnitude of gain equal to 6.5.

Table 1

Amplitude of V_{AB} in volts	Amplitude of Vout in volts	Phase angle of Vout relative to V_{AB}	Theoretical magnitude of Vout/ V_{AB}	Measured magnitude of Vout/ V_{AB}

Table 2

Amplitude of V_{AB} in volts	Amplitude of Vout in volts	Phase angle of Vout relative to V_{AB}	Theoretical magnitude of Vout/ V_{AB}	Measured magnitude of Vout/ V_{AB}

Laboratory 9: AC analysis of RC Circuit

Objective: To understand voltage current relationship in RC circuit for sinusoidal excitation

Introduction The first part of this experiment illustrates how to experimentally determine the value of a capacitor. The rule for combining capacitors in series will be experimentally verified in the second part of the experiment. In addition, the phase angle between voltage signals will be measured using an oscilloscope. This angle will be compared with calculations using phasors.

Experimental Determination of Capacitance

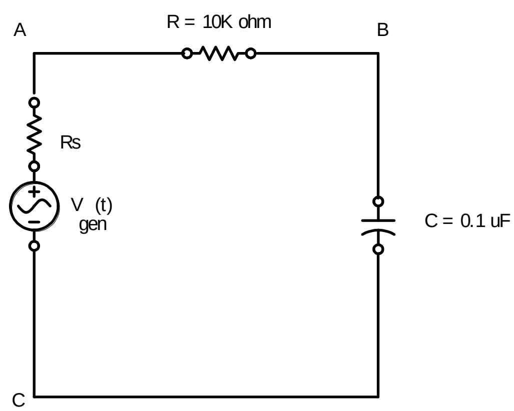
Note: Save your capacitor from this experiment to use it again in Laboratory 10 as you will have obtained a measurement of its actual value.

1. After constructing the circuit shown in Figure 1, adjust the function generator so that the voltage at node A relative to node C (reference) is given by:

   $V_{AC}(t) = 4 \sin(\omega t)$ volts

   Frequency = 2KHz

   Set the function generator to output in High Z mode so that amplitude of $V_{AC}(t)$ is indeed 4V . Assume phase angle of source is zero as it is used as the reference.



2. Use the scope to find the peak voltage across the capacitor.

3. Observe both V_{AC} and V_{BC} on the oscilloscope. Are they in time phase? Measure the phase difference between them. Use this information to determine the phase angle of the current through the circuit. From the observation on oscilloscope what will you conclude about the sum of peak voltages across each element of the loop. Will the sum of peak voltages around the loop satisfy KVL? Do NOT measure to conclude this.

4. Use mulitimeter to determine the rms voltage across R. Determine the rms current through the resistor and hence through the series circuit. Determine the peak current value and the current phasor using the information obtained from step 3. Determine the voltage phasor across R. Use the multimeter to determine the rms voltage across the capacitor. Determine the peak voltage (V_{BC}) to

rms voltage ratio across the capacitor. Does it validate theory? Determine voltage phasors across C. Verify KVL with phasor values voltage across all the elements in the circuit.

5. Calculate the magnitude of the capacitor impedance, $|Z_c|$ using measurements from Step 4.

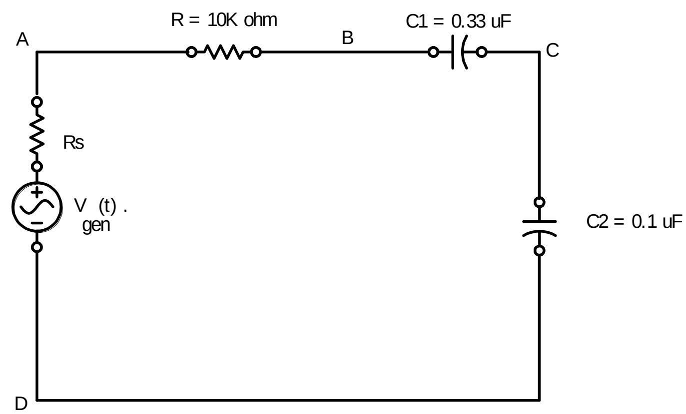
6. Calculate the capacitance C using the expression, $$C = \frac{1}{2\pi f |Z_C|}.$$

7. Measure the value of C using the capacitance meter in the lab. Using the capacitance meter value of C as the reference, calculate the % error of the nominal value of C, and the % error of the value of C obtained from Step 6.

8. Record all the measured values and calculated values. Record the voltage and current phasors and the verification of KVL. Submit a report with results and conclusions.

Series Capacitors in a Circuit

1. Construct the circuit in Figure 2. Set the function generator in High Z mode to give $V_{AD}(t)$= 4sin(ωt) volts and Frequency = 2KHz



2. Measure the rms value of V_{BD} using multimeter and the rms current through the capacitors.
3. Using measurements in step 2. Determine the impedance of equivalent capacitance of two capacitors in series which is $|Z_{CEQ}|$. Find the equivalent capacitance of the two capacitors in series from $|Z_{CEQ}|$.
4. Compare with the theoretical value of the equivalent capacitance.

Laboratory Experiment 10: RC FILTERS

OBJECTIVE:

The objective of this experiment is to study the frequency response of simple LOW PASS and HIGH PASS RC filters and determine the cut-off frequency experimentally. Both amplitude and phase measurements are made and both the response of the two filters will be plotted on a semi-log graph.

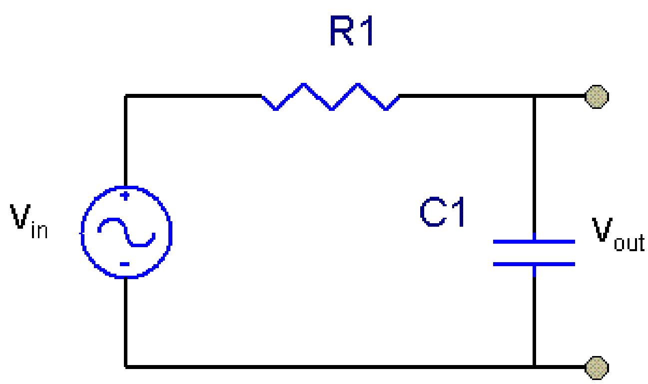
EQUIPMENT:

Oscilloscope
Function Generator
Resistors
Capacitors

PROCEDURE:

PART A: LOW PASS RC FILTER

1. Set up the circuit shown in the figure below with R1 value of 8.2KΩ and C1 value of 0.01µF. The output voltage is measured across the capacitor.



2. At each frequency calculate the magnitude of voltage gain $|V_o / V_i|$ and the phase angle (θ) between the input voltage and the output voltage using the formulae below. Record these values in the data table.

$$f_c = \frac{1}{2\pi RC}$$

$$\left|\frac{V_o}{V_i}\right| = \frac{1}{\sqrt{1+\left(\frac{f}{f_c}\right)^2}}$$

$$\theta = -\tan^{-1}\left(\frac{f}{f_c}\right)$$

3. Adjust the input sinusoidal signal voltage at the input to the filter as10 Volts peak to peak. Set the function generator in High Z mode for the output.

4. Vary the frequency of the input from 100 Hz to 10KHz in steps listed in the Table 1. For every frequency make sure the input voltage is 10 Volts peak to peak.

5. At each frequency measure the output voltage (V_o) across the capacitor and the phase angle difference (θ) between the output V_o and the input V_I and record these values in Table 1.

6. Plot a graph of the voltage gain vs. frequency for both calculated data and measured data on the same graph. Determine the measured cut-off frequency from the graph as the frequency corresponding to a gain of 0.707on the experimental curve. Make sure you use a semi-log graph paper with frequency on the log axis or use Microsoft Excel to plot with x-axis in logarithmic scale

7. Plot a graph of the phase angle vs. frequency for both calculated data and measured data on the same graph. Observe what happens to the phase angle at the cut-off frequency. Use a semi-log graph paper with frequency plotted on log axis or use Microsoft Excel to plotwith x-axis in logarithmic scale.

8. Compare the theoretical and measured graphs.

Table 1: RC LOW PASS FILTER

Input Voltage at all Frequency = $10V_{p-p}$

Calculated Cut-off Frequency f_c =

Frequency Hz	Calculated Voltage Gain $\|V_o / V_i\|$	Calculated Phase Angle	Measured Output Voltage in Volts	Measured Voltage Gain $\|V_o / V_i\|$	Measured Phase Angle
100					
400					
800					
1000					
1600					
2000					
3000					
4000					
6000					
10000					