School of Electrical Engineering and Telecommunications

ELEC 1111 - Electric Circuits

Laboratory Manual

Semester 2 - 2018

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Preface

How to Use and Navigate this Manual

It is advised to use this manual both in **printed version** and in **digital version** as a PDF file on Moodle.

The **printed** version will be used for marking your pre-lab exercises, submitting the results of your experiments during the lab session and getting them marked off by a lab demonstrator.

The **digital** version provides direct links to useful videos and other resources relevant to your lab.

Answer Boxes

It is important that your answers are neatly written within the provided space. Your laboratory manual and your lab books are your "professional documents" and should be treated appropriately. The answer boxes looks like a simple box, as shown below.

Demonstrator Checkpoints

When you come across the following Table, you need to ask a lab demonstrator to assess your results and record your mark in the given space in your lab manual.

	Date	Assessor	Mark

Video Resources

In the digital version of the lab manual, when you come across the icon below, you will be linked to a video that demonstrates aspects in the operation of the laboratory equipment.

Topic of the video

It is important to familiarize yourselves with the basic functions of each device before your first session so that you can spend your lab time more efficiently and become proficient with the equipment.

Key points

This icon ⚠ demonstrates important parts of your laboratory experiment. If you are unsure about the necessary steps, please consult with your lab demonstrators.

Overview

Students come into Electrical Engineering & Telecommunications from a wide range of backgrounds in laboratory experience. This is most apparent each year in ELEC1111. It is one of the course aims that all students should develop confidence at individual work in a laboratory environment. This is not difficult if electronics has been a hobby before coming to University. For the student with minimal previous laboratory experience, including those who if they are honest would say that they have rested on the ability of a laboratory partner, here are the following words of encouragement:

1) Very many students in a similar situation before have succeeded.
2) Your choice to do Electrical Engineering already indicates a desire to be successful in a laboratory environment.
3) Make life easier for yourself; read ahead and get a feel of what is required of you in each lab experiment. Remember that the equipment is used by several hundred students each year and, as such, should be robust enough for sensible use. Measurements that should not be made with any equipment will normally be clearly stated.
4) Do not be afraid to experiment. Everything should be safe at the voltages you are using. Nevertheless, there may be an occasional (non-serious) **bang** as an incorrectly connected electrolytic capacitor gets too hot, or **smoke** as an incorrectly rated resistor suffers a similar fate, much to the embarrassment of the perpetrator and to the education of all in the laboratory.
5) The demonstrators are there to help you gain a better understanding of the material. As a demonstrator, it is much more encouraging to see a student attempting to understand the situation and asking specific questions rather than getting vague questions such as "*What should I do in the laboratory today?*".

Aims of the Laboratory Sessions

This course provides the first of many electrical engineering laboratory experiences that you will encounter both here and in your future career. From now on, you will be building a sound foundation of experimental attitudes and abilities that is of utmost importance when it comes to any engineering discipline.

Your aims in the laboratory are:

- To **gain** familiarity with basic laboratory equipment and measurement techniques.
- To **reinforce** concepts that will be presented in lectures.
- To **stimulate** a scientific curiosity and help provide answers to how things work.
- To **observe** and **question**. Don't simply accept results. *Ask why that waveform has a big bump in it.*
- To **construct**, test and get working (debug) circuits.
- To **work** equally with your team member to solve the questions posed in the lab. Team work is encouraged.
- To **develop** a professional attitude to laboratory preparation, circuit design, measurement and the recording of results and finally,
- To **have some fun**!

Requirements

There are several items that are required for laboratory practices. These items are:

1) **A laboratory kit**. This kit, available from the School Electronic Workshop, includes all the expendable components as well as a prototyping board. The board will also be useful for later electronics laboratories. Resistors and capacitors will be available in all teaching lab rooms. However, you are recommended to bring a component box to keep any resistor and capacitor that you pick for your future use in each lab experiment.

2) You should also wear **safety goggles** (either your own or purchased from the School) if soldering.

3) For students continuing in Electrical Engineering & Telecommunications, it is also recommended to purchase a **small pair of wire strippers** for cutting and trimming component wires, and a **small pair of long-nose pliers** for inserting components into a prototyping board. These first two items may be purchased from most electronics or hardware stores and will be used extensively in this and future laboratory courses. Moreover, you can purchase **small jumper cables** from the School Electronic Workshop for more convenience in wiring your circuit.

Laboratory Equipment

At each bench position in the laboratory, you will find

1) **An oscilloscope**.

2) **A signal generator**, also known as a function generator.

3) **A dc power supply** with variable positive and negative voltages.

4) **Digital multimeters** with voltage, current and resistance ranges.

In addition, in each teaching laboratory room you may also find the following:

1) Soldering irons.

2) A store of preferred value resistors (1/4 W) and capacitors, together with a precision *RLC* meter (also known as LCR Bridge) to measure their values.

3) Computers with National Instruments ELVIS systems which allow prototyping of circuits and complete input signal generation and output signal measurements.

Further detailed descriptions of these equipment are provided in the Appendix section at the end of this manual, as well as in short videos available on Moodle. If necessary, other relevant laboratory hardware information will be given at the appropriate time during lab sessions.

Laboratory Record Keeping

Attendance

Your attendance, including prompt arrival and the efficient use of your laboratory periods, will be recorded by the demonstrator every week in the attendance sheet. It is essential that you complete the pre-lab exercises and any necessary laboratory preparation before coming to the lab.

⚠ You have to **attend** at least 7 of the 8 labs **AND** attain a pass assessment in labs **AND** pass the lab exam to pass the course.

Laboratory Results Recording

All students should develop the discipline necessary to record their results neatly in the lab manual. This is not academic pedantry, it is part of becoming a professional engineer.

⚠ *All results must be recorded in the Answer Boxes of your lab manual for both proper marking and record keeping purposes.*

- Keep presentation **neat** and **tidy** throughout. You need to be able to read your own notes at a later date.
- **Scraps of paper** are not allowed for recording results at the bench. Any loose sheets should be pasted into your lab book.
- All results of measurements and calculations should clearly show the **measurement units** and should be to an appropriate **precision**.
- All **circuit diagrams** should be drawn with the measurement points clearly labeled, including the Earth or common ground if appropriate.
- Use a **ruler** when drawing a straight line in any diagram or graph.
- When drawing graphs, **numerical scales** must be shown together with a label for each axis. Every graph must have a **complete title** and a statement of any special measurement conditions that apply.

Laboratory Rules for Proper Conduct

⚠ Students must complete the Moodle OH&S Safety course[1] before starting the laboratory component. If a student attends laboratory sessions without having completed the safety declaration, the marks for those labs will be zero.

⚠ The OH&S certificate must be submitted before you start work in the labs. There is a dedicated OH&S submission portal on Moodle where you can upload the certificate and submit it online.

The following **rules** need to be observed for a safe and amenable working environment:

- **Under no circumstance is 230V 50Hz mains power to be used for any purpose, other than that approved by the School of EE&T.**
- No smoking, eating or drinking in the laboratory.
- Safety regulations require that **proper enclosed footwear** must be worn at all times in the laboratory.
- Take care not to let your hair loose as it might be tangled with your circuit wires.
- Be cautious of rings, watches and necklaces. These are good conductors. Moreover, skin beneath a ring or watch is damp and lowers the body resistance.
- Leave all **water bottles, bags, umbrellas, etc.** on the space under the benches.
- Tampering with or removal of any laboratory equipment is forbidden.
- Students are expected to conduct themselves in a reserved manner at all times. Noise is to be kept to a minimum as it is a teaching environment.
- Use of lab facilities for work that is not specifically associated with a School subject requires prior approval by a member of academic staff.
- Mobile phones are not to be operated at any time within a laboratory.
- Students should clean and tidy benches up when they have finished their experiments and return any required component before they leave the laboratory. This includes equipment leads and cables, high-power resistors, and inductors. You may keep the resistors and capacitors for later use in your component box.
- As you leave the laboratory, switch off all the instruments. In particular, switch off the handheld multimeters (if there is any). Being battery powered, it is most frustrating for the next student to find an instrument not working because of flat batteries.
- Please advise the demonstrators of any equipment malfunction or issues.
- Students who fail to abide by these regulations will be told to leave the laboratory.

Acknowledgement

We would like to acknowledge and express our appreciation for the great work that Dr. Georgios Konstantinou did in preparing the initial version of this lab manual, its revision on July 2017 with the help of Dr. Harith Wickramasinghe, as well as his continuous support throughout the latest revision of it.

[1] Follow the instructions in the Moodle page of the course to complete the OH&S Safety Course

We would also like to express our deepest gratitude to the professional and technical staff managing the teaching laboratories at the School of Electrical Engineering and Telecommunications, in particular Dr. Ming Sheng, Syed Rahman, Roy Zeng, and Zhenyu Liu, for their selfless and passionate help and support in keeping the laboratories always ready for us and coming to our aid in times of need. Without their great work, we would not have been able to provide this world-class laboratories for our students.

Finally, we sincerely appreciate the feedback received from previous lab demonstrators and students , which has help immensely in improving the quality of the laboratory practices and exercises.

Dr. Arash Khatamianfar and Dr. Inmaculada Tomeo-Reyes

1 Experiment 1 - Familiarization

1.1 Aims of this Experiment

The aim of this first lab is to familiarize yourselves with

1. basic concepts of electric circuits and
2. the equipment of the laboratory and its features, functions and operation

while verifying some simple circuit laws.

1.2 Videos for Review

⚠ You are expected to familiarise yourselves with the laboratory equipment by reading the Appendix A of this manual and watching all videos before attending the first lab.

- The Prototyping Board
- Introduction to the Multimeter
- Introduction to the Power Supply
- Introduction to the Oscilloscope
- Introduction to the signal generator

1.3 Pre-lab Work

1. Read carefully Sections A.1 to A.6 of this Manual and watch the corresponding videos that explain the operation of the lab equipment.
2. What is a periodic signal / waveform?
3. What is the frequency (f) and the period (T) of a periodic waveform?
4. What is the frequency of the voltage provided by a battery? Provide necessary explanations.
5. Consider a normal power outlet. Is the supply voltage a periodic signal? If yes, what is the frequency of this voltage? If no, explain why.
6. A 12 V battery has its positive terminal connected to the earth. Draw a diagram of the connection and calculate the voltage of the two terminals relative to earth.
7. Find the value of the resistors in the following Table.

Resistor	Band 1	Band 2	Band 3	Band 4	Resistance value
R1	Blue	Grey	Gold	Gold	
R2	Yellow	Violet	Yellow	Gold	
R3	Red	Red	Red	Red	
R4	Brown	Green	Green	Silver	

8. Using a single preferred value resistor only in each case, what colour bands would you look for if your circuit design calls for the following (non-critical) resistance values?

Required Resistance	Preferred value	Band 1	Band 2	Band 3	Band 4
560 kΩ					
25 Ω					
970 Ω					
18.5 kΩ					
1.1 MΩ					
36 kΩ					

9. Calculate the equivalent input resistance between terminals a and b of Figure 1.3.1.

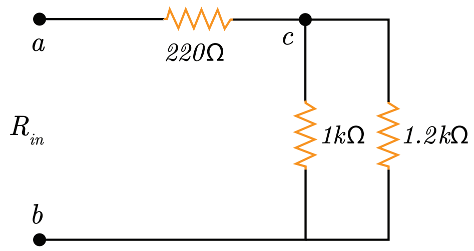


Figure 1.3.1: The resistive circuit of Experiment 1.

	Date	Assessor	Mark

1.4 Experimental Procedure

1.4.1 List of Components

In this experiment you will require:

- Your Breadboard
- 220 Ω, 1 kΩ and 1.2 kΩ resistors.

1.4.2 Resistance values

1. Select the appropriate resistors of Figure 1.3.1 from the resistor containers in the lab. Measure their resistance using the precision LCR bridge at each room and then the digital multimeter (Section A.3). Compare and comment on the results.

Resistance	Tolerance	Multimeter Value	LCR Bridge Value	Comments
220 Ω				
1 kΩ				
1.2 kΩ				

2. Calculate the input resistance of the circuit of Figure 1.3.1 using the measured values from above.

3. Build the circuit of Figure 1.3.1 in your boards and measure the input resistance using the digital multimeter. Compare its value with your pre-lab calculations and your previous calculation and comment on the results.

1.4.3 DC voltages and currents

4. Adjust the output voltage of the dc power supply to approximately 5 V (±0.1 V) and connect it to the resistive circuit of Fig. 1.3.1. Calculate the voltages at points a and c with respect to point b (using the measured resistance values from the LCR bridge) and then measure the voltages using the digital multimeter. Compare the calculated and measured values.

Voltage	Calculation	Measurement	Comments
V_{ab}			
V_{cb}			
V_{ca}			

5. Using the measured resistance values from the LCR bridge, calculate the current through each of the three resistors in Fig. 1.3.1.
6. Measure the current through each of the three resistors, using the digital multimeter (Section A.3).
7. Compare the calculated and measured values

Current	Calculation	Measurement	Comments
$I_{220\Omega}$			
$I_{1k\Omega}$			
$I_{1.2k\Omega}$			

8. What is the relation between the current through the 220 Ω resistor and the currents through the 1 kΩ and 1.2 kΩ resistors.

9. When you have finished measuring a current, please disconnect the meter and return its settings to either the **OFF** position or to a high voltage range. Why is this important?

1.4.4 AC voltages and currents

10. Set the signal generator to a sinusoidal output with a frequency of 1 kHz and at maximum amplitude. Measure the output voltage using the multimeter and record the value in the following table. Repeat the measurements for the square and the triangular waveforms. (Hint: In all the previous steps, you were measuring **dc** values but now you are measuring **ac** values. Consider this when setting up your multimeter.)

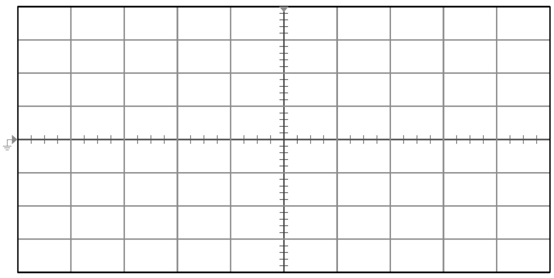
Voltage	Measurement
Sinusoidal	
Square	
Triangular	

11. Set the signal generator to a sinusoidal output with a frequency of 1 kHz and at maximum output and connect it to the resistive network of Figure 1.3.1. Measure the following two voltages (Hint: Is the digital multimeter capable of measuring peak-to-peak values? What instrument should you be using for this measurement?):

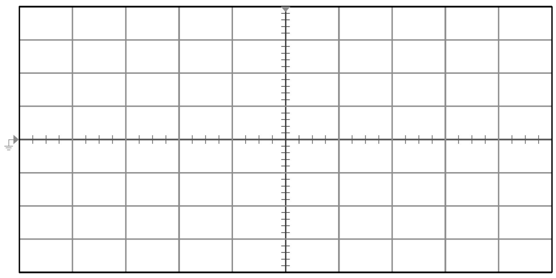
Voltage	Peak to peak value
V_{ab}	
V_{cb}	

12. Draw the two voltages in the space provided below

⚠ When drawing waveforms from the oscilloscope, it is important to clearly note the settings of the X and Y axis for your measurements (e.g. 5V/div, 10ms/div etc).



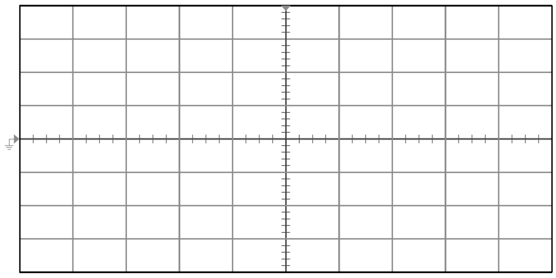
X-axis: ....
Y-axis: ....



X-axis: ....
Y-axis: ....

13. Calculate the ratio of the two voltages. Is this ratio what you expected?

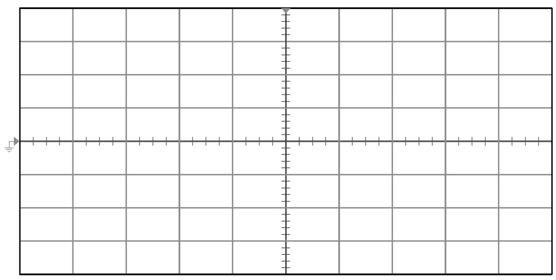
14. Adjust the timebase so that one complete period of the waveform of V_{ab} is displayed on the oscilloscope. Plot the waveform in the space below and measure the period of one cycle of the waveform. Complete the measurements using the cursors of the oscilloscope.



X-axis: ....
Y-axis: ....

15. To what accuracy do you think you can measure period on this setting of the oscilloscope?

16. Measure the voltage v_{ac} in Fig. 1.3.1 , using your oscilloscope and the cursors functions.



X-axis: ....
Y-axis: ....

17. Explain why the voltage of the resistor cannot be measured directly.

18. Explain the steps required to perform this measurement including connections of the circuit, settings of the oscilloscope and use of the oscilloscope functions.

⚠ Items 16 to 18 must be completed before Lab 5.

	Date	Assessor	Mark

2

Experiment 2 - Series and Parallel Circuits

2.1 Aims of this Experiment

The aim of this experiment is to

1. Study the properties of series and parallel combination of resistors.
2. Validate voltage and Current division laws.

2.2 Videos for Review

Please review the following videos before Experiment 2.

- The Prototyping Board
- Introduction to the power supply
- Measuring current with a multimeter
- Measuring voltage with a multimeter

2.3 Pre-lab Work

1. When are two elements connected in parallel?

2. Draw the circuit and write the equations of a current divider with resistors, R_1 and R_2.

3. Draw the circuit and write the equations of a voltage divider with resistors, R_1 and R_2.

4. Consider the circuits of the following figure. Calculate the equivalent resistance of the circuits as seen from the voltage source if all lightbulbs are of equal resistance R.

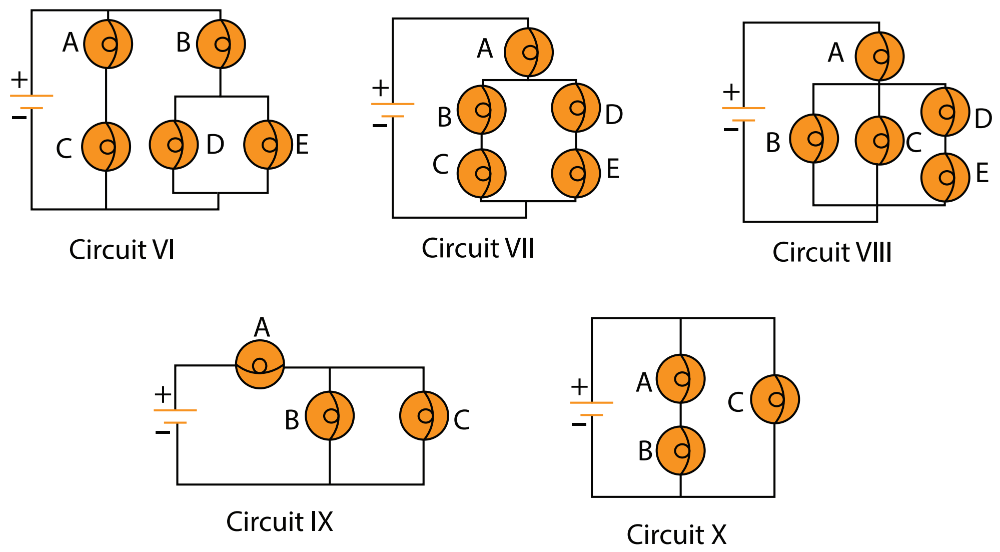


Figure 2.3.1: Circuits VI, VII, VIII, IX and X of the experiment.

	Date	Assessor	Mark

2.4 Experimental Procedure

2.4.1 List of Components

In this experiment you will require:

- Your Breadboard
- Miniature Lightbulbs
- 220 Ω resistors

2.4.2 Series and Parallel Connection

1. Connect a light bulb as Circuit I of Figure 2.4.1. Supply a voltage of 2 V initially through a dc power supply. Measure the voltage across the bulb and the current through the bulb using the digital multimeter. Increase the voltage in steps of 2 V and for each voltage measure the current. Tabulate the readings. Repeat these measurements up to 10 V.

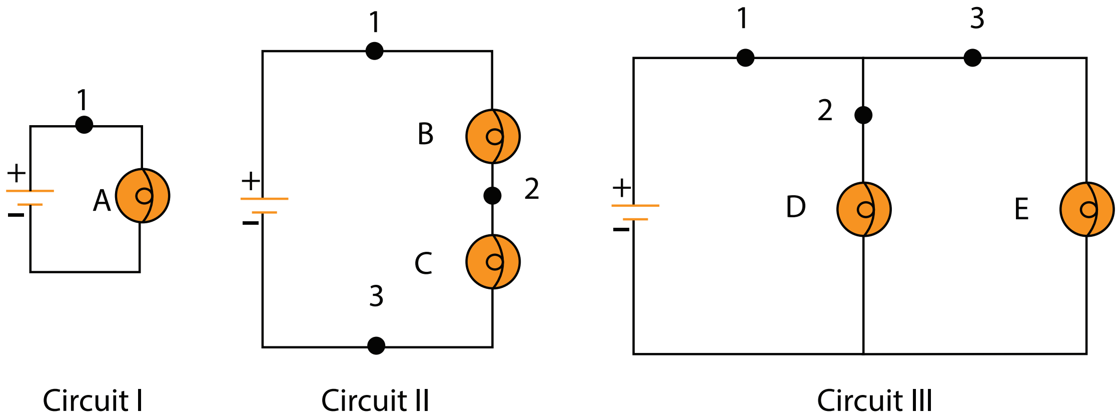


Figure 2.4.1: Three simple circuits with a battery and light-bulbs.

V	I	R
2 V		
4 V		
6 V		
8 V		
10 V		

2. Repeat the above by connecting a 220 Ω resistor in place of the light bulb. Tabulate the measurements in the following Table.

V	I	R
2 V		
4 V		
6 V		
8 V		
10 V		

3. Plot the VI curves of the light bulb and the resistor in the same graph and explain the results.

4. Calculate the resistance in the previous Table for the different sets of readings. Are they constant? Why?

5. Make the connections of Circuits II and III of Figure 2.4.1 side by side on the same prototyping board and supply with 12 V. Observe the brightness of bulbs B&C with D&E.

6. Compare the actual brightness of the bulbs. Make sure you adequately describe what you

mean in your comparisons, i.e. "the same brightness as", "brighter than", "dimmer than". Write down your reasoning.

7. Which electrical parameter impacts the brightness? Calculate this value with proper measurements and prove that your reasoning is correct.

8. Increase the voltage of circuit II to 24 V, while retaining Circuit III at 12 V. Now, compare the brightness of B&C to D&E. Record your observations and reasoning (through numerical values).

9. Add one more bulb to each of the above circuits creating Circuits IV and V as shown in Figure 2.4.2 , using a 12V supply.

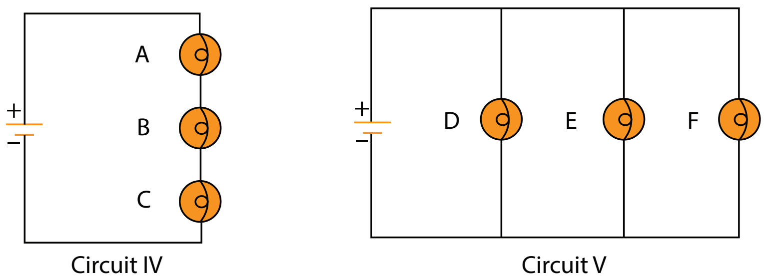


Figure 2.4.2: Circuits IV and V of the experiment.

10. Compare the brightness of Circuit IV with Circuit II and Circuit V with Circuit III. Record your observations and reasoning.

11. What happens to the overall resistance connected to the battery as you add more bulbs in series? How does it impact the brightness of the bulbs? What happens to the current through the battery as you add more bulbs in series?

12. Does the brightness of the bulbs change as you add more bulbs in parallel? What happens to the overall resistance connected to the battery as you add more bulbs in parallel?

13. Can you add unlimited number of bulbs in parallel? Why?

14. Explain why all the wirings in buildings are done in parallel.

15. Consider the circuits VI to VII shown in Figure 2.4.3. Predict the brightest bulb in each circuit. Compare the relative brightness of lightbulb A in each of the three circuits and complete the following table with the measurements.

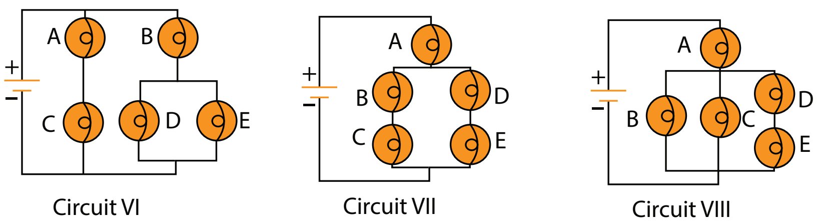


Figure 2.4.3: Circuits VI, VII and VIII of the experiment.

Lightbulb A			
Circuit	Voltage	Current	Power
VI			
VII			
VIII			

16. Observe the brightest light bulb of each of the three circuits of Fig. 2.4.3. Use the following boxes to write your measurements and do your calculations so you can provide your explanations for the brightest lightbulb in each of the three circuits.

    Circuit VI:

    Circuit VII:

    Circuit VIII:

	Date	Assessor	Mark

3

Experiment 3 - Kirchhoff's Laws

3.1 Aims of this Experiment

The aims of this experiment are to

1. investigate the properties of a simple battery and a voltage source, and
2. examine and verify Kirchhoff's Current and Voltage Laws (KCL and KVL).

3.2 Videos for Review

Please review the following videos before Experiment 3.

- Measuring resistance with a multimeter
- Measuring current with a multimeter

3.3 Introduction

A battery is a convenient way of storing electrical energy, especially in a portable form. In this experiment, the properties of a dry cell battery are examined. Such batteries should already be familiar to you as the power source for many everyday household and personal products.

3.3.1 Circuit Models for the Battery

The two battery models that will be considered are illustrated in Figure 3.3.1. Figure 3.3.1a shows the ideal model for the battery, being represented as a voltage source that is independent of all variables; eg temperature, external load, etc. This model may be used in circuit analysis where its imperfections will not affect the analysis of the circuit.

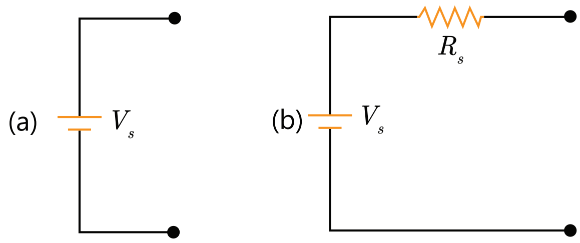


Figure 3.3.1: Equivalent Circuits of a Battery.

The addition of an internal resistor in the equivalent circuit of the battery as shown in Figure 3.3.1b accounts for the voltage drop at the terminals as current is drawn from the battery and is a significant improvement to the model. V_s and R_s will still be functions of the state of the battery (i.e. Is it nearly discharged? How old is it? etc) and even of the current being drawn from it. Therefore these equivalent circuit components will be considered at a specific operating point.

3.4 Pre-lab Work

3.4.1 Batteries

1. Consider your typical 9 V battery. What sort of information can you get from the package and what additional information would be important to know?

2. Consider the simple circuit of Figure 3.4.1. What is the current that flows in the circuit?

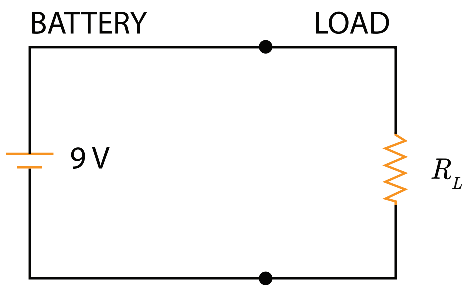


Figure 3.4.1: A simple circuit with a battery.

3. What is the power consumed by the load?

4. What is the power supplied by the battery and how does it relate to the power consumed by the load?

5. Consider the model of the practical battery shown in Figure 3.4.2. When no load is connected to the battery, the terminal voltage is measured at 8.8 V. What is the value of V_s.

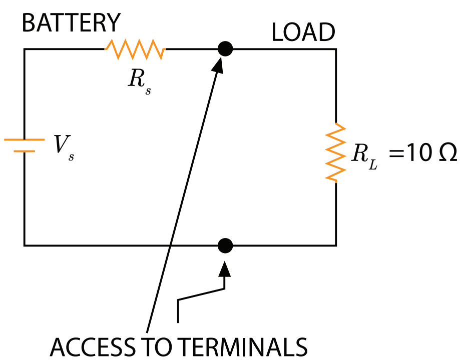


Figure 3.4.2: A non-ideal battery connected to a load.

6. When a 10 Ω Resistor is connected to the battery, the voltage at the terminals is measured at 8 V. What is the current flowing in the circuit?

7. Calculate the internal resistance of the battery R_s.

3.4.2 KCL and KVL

8. Consider the circuit of Figure 3.4.3. Calculate the resistance as seen from the terminals of the 10 V dc source.

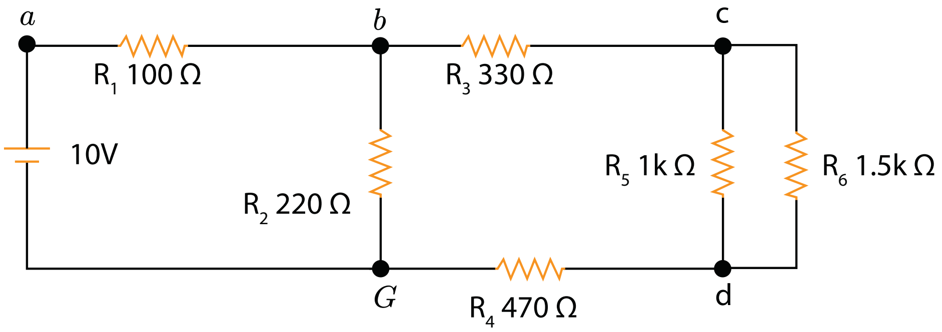


Figure 3.4.3: The resistive circuit for Experiment 3.

9. Calculate the voltages of nodes a, b, c and d with respect to node G.

10. Calculate the currents through all the resistors in the circuit.

	Date	Assessor	Mark

3.5 Experimental Procedure

3.5.1 List of Components

In this experiment you will require:

- Your Breadboard
- A 9 V Battery
- A 10 Ω, 10 W resistor (please return this resistor at the completion of the experiment)
- 100 Ω, 220 Ω, 330 Ω, 470 Ω, 1 kΩ and 1.5 kΩ resistors.

3.5.2 Batteries

1. Measure the output voltage of the battery with no external load connected using the digital multimeter.

2. Draw the circuit to illustrate how you will measure the output voltage when there is a 10 Ω resistor connected to the battery. (MAKE SURE THE RESISTOR IS OF APPROPRIATE POWER RATING!). Explain why you cannot use normal resistors for this part of the experiment.

3. Connect the circuit briefly (about 2 seconds is sufficient, even though the voltage may still be changing slowly) and measure the output voltage. Calculate the internal resistance of the battery.

4. Refering to Figure 3.3.1b, draw the circuit of the battery showing the value of the components. From the equivalent circuit values just derived for the battery, estimate the short circuit current that should be available from the battery.

3.5.3 KCL and KVL

5. Build the circuit of Figure 3.4.3 on your prototyping board, using the laboratory power supply as the 10 V source.
6. Using the digital multimeter, measure the voltages of nodes a, b, c and d with respect to node G. How do they compare with the theoretical calculations of the pre-lab work?

Voltage	Calculation	Measurement	Comments
V_{aG}			
V_{bG}			
V_{cG}			
V_{dG}			

7. Using the digital multimeter, measure the voltages V_{ab}, V_{bc}, V_{cd} and V_{ac} and comment on the results.

Voltage	Calculation	Measurement	Comments
V_{ab}			
V_{bc}			
V_{cd}			
V_{ac}			

8. Calculate the current through the 100 Ω, 220 Ω and 330 Ω resistors from the voltage drops across the resistances and record the results.

Current	Voltage	Resistance	Current Value
$I_{100\Omega}$			
$I_{220\Omega}$			
$I_{330\Omega}$			

9. Write Kirchhoff's current law for node b and verify that it is correct using the calculated current values.

10. Write Kirchhoff's voltage law for loops 1 and 2 as shown in Figure 3.5.1 (in the clockwise direction) and verify that it is correct using the measured voltage values.

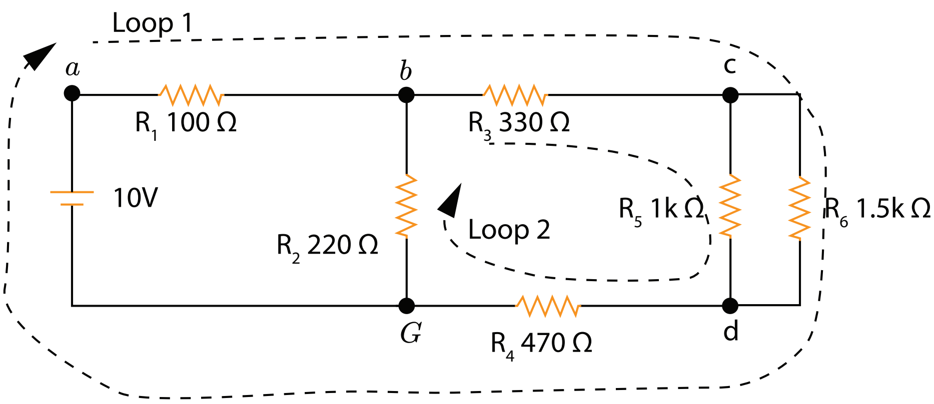


Figure 3.5.1: Loops 1 and 2 for applying KVL.

	Date	Assessor	Mark

4 Experiment 4 - Circuit Theorems

4.1 Aims of this Experiment

The aims of this experiment is to demonstrate and verify

1. Thevenin's Theorem,
2. Norton's Theorem,
3. Superposition, and
4. Maximum Power Transfer Theorem.

4.2 Videos for Review

Please review the following videos before Experiment 4.

- Introduction to the multimeter
- Measuring voltage with a multimeter
- Measuring resistance with a multimeter
- Measuring current with a multimeter

4.3 Pre-lab Work

1. Consider the circuit of Figure 4.3.1.

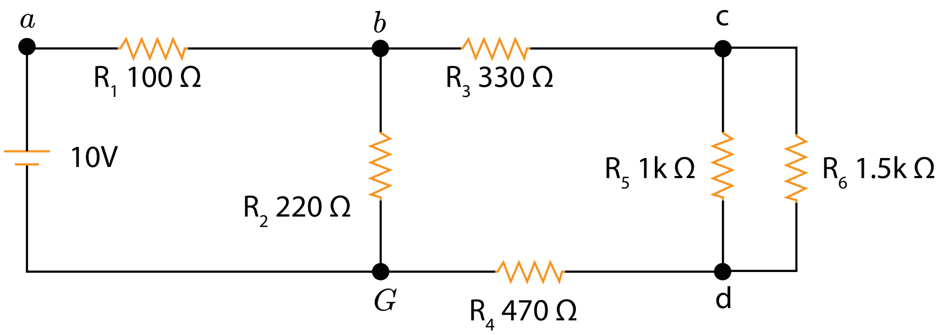


Figure 4.3.1: The resistive circuit for Experiment 4.

Assuming that the resistor R_6, 1.5 kΩ resistance represents the load resistance R_L, calculate the Thevenin and Norton equivalent circuits and draw the simplified circuit (refering to Fig. 4.3.2).

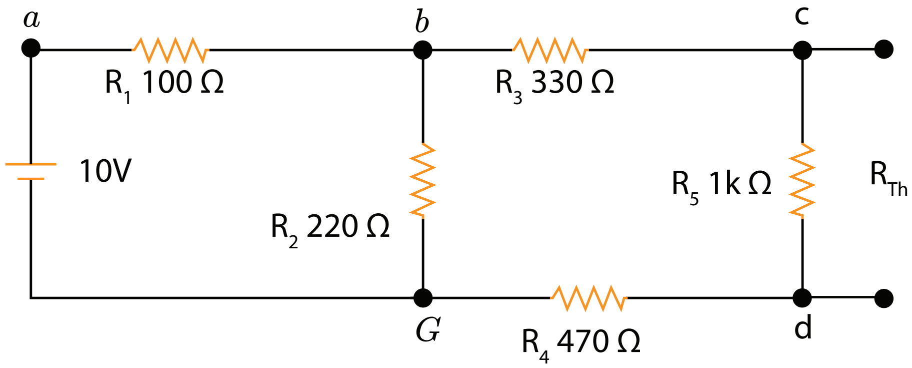


Figure 4.3.2: The equivalent circuit of Fig. 4.3.1 as seen from terminals c and d.

2. Repeat the same calculation, assuming R_3 is the load resistance, as shown in Figure 4.3.3.

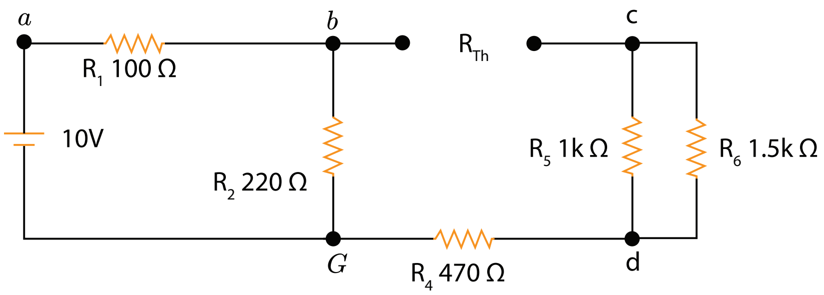


Figure 4.3.3: The equivalent circuit of Fig. 4.3.1 as seen from terminals b and c.

3. What does the superposition theorem state?

4. Explain how Norton's and Thevenin's Theorems help the analysis of electric circuits.

	Date	Assessor	Mark

4.4 Experimental Procedure

4.4.1 List of Components

In this experiment you will require:

- Your Breadboard
- 100 Ω, 220 Ω, 330 Ω, 470 Ω, 1 kΩ and 1.5 kΩ resistors.

4.4.2 Thevenin's Theorem

1. Construct the circuit of Figure 4.4.1 in your prototyping board.

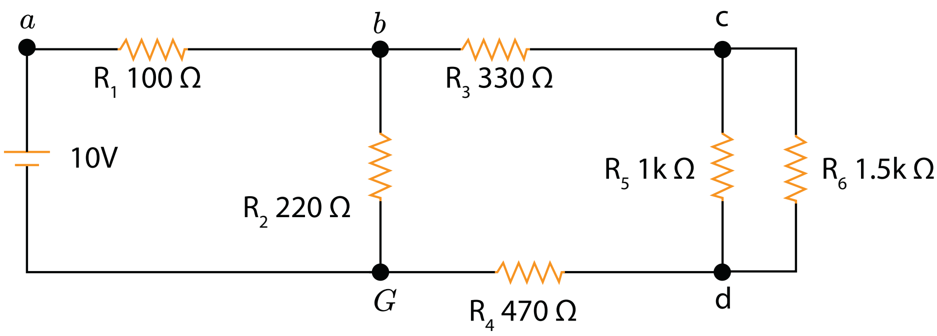


Figure 4.4.1: The resistive circuit for Experiment 4.

2. Measure the voltage across R_6 which represents the load resistor R_L (V_L), the current flowing through it (I_L) and calculate the power consumed (P_L).

3. Now remove R_6 from the terminals c and d. Obviously, the terminals become open-circuited. Measure the open-circuit voltage that appears across terminals c and d. What does this voltage represent?

4. Compare the measured voltage with the voltage of your theoretical calculations and provide explanations and comments.

5. Measure R_{Th} by setting appropriately disabling all independent sources of your circuit. Compare it to your theoretical calculations.

6. Draw the equivalent circuit, construct it in your prototyping board and connect it to the load. Measure the voltage across the load and compare it to the voltage you measured at the first step of your experiment.

4.4.3 Norton's Theorem

7. Consider the same circuit as in Figure 4.4.1. Measure I_N as the short-circuit current between terminals c and d where R_6 was connected.

8. Calculate $I_N = \frac{V_{Th}}{R_{Th}}$ and compare it to the measured value.

4.4.4 Superposition Theorem

9. Construct the circuit of Figure 4.4.2 in your prototyping board. Initially set E_1 and E_2 to be 10 V and 15 V respectively.

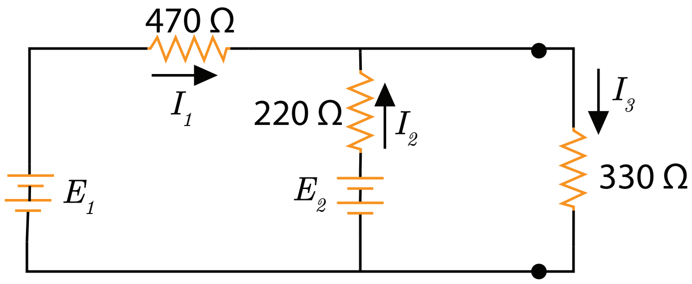


Figure 4.4.2: A circuit with two independent sources for verifying the Superposition Theorem.

10. Measure the currents I_1, I_2 and I_3.

11. Disable E_1 and measure currents as I'_1, I'_2 and I'_3.

12. Disable E_2 and measure currents as I''_1, I''_2 and I''_3.

13. Confirm the theory of superposition using your previous measurements.

4.4.5 Maximum Power Transfer Theorem

14. Construct the circuit of Figure 4.4.3 in your prototyping board.
15. Measure the voltage across R_L (V_L), current flowing through it (I_L) and the power consumed (P_L) for the different values of R_L (Hint: To complete this experiment faster, place all resistors in the breadboard and measure voltages and currents separately).

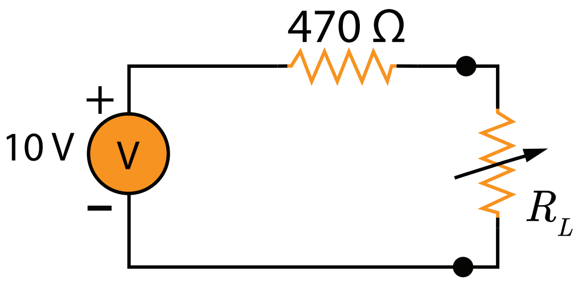
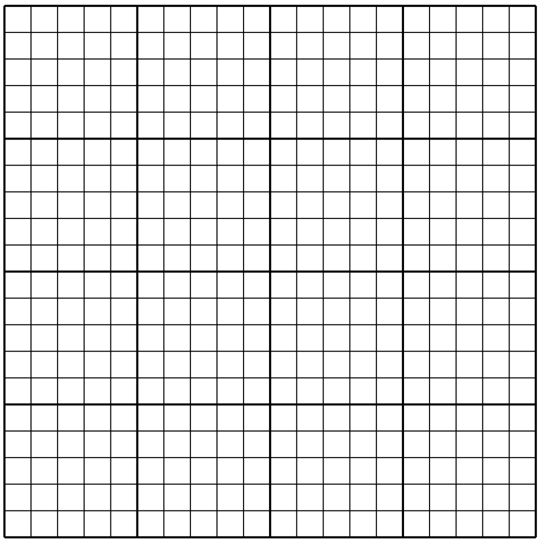


Figure 4.4.3: A simple series circuit for verifying the Maximum Power Transfer Theorem.

R_L	V_L	I_L	P_L
100 Ω			
220 Ω			
470 Ω			
560 Ω			
1200 Ω			

16. Plot the load power P_L as a function of the load resistance.



	Date	Assessor	Mark

5

Experiment 5 - Transient Behavior of First Order Circuits

5.1 Aims of this Experiment

The aims of this experiment are to examine

1. transient voltages and currents in simple RC and RL circuits with voltage step applied.
2. the response of these circuits to a square wave input.

5.2 Videos for Review

Please review the following videos before Experiment 5.

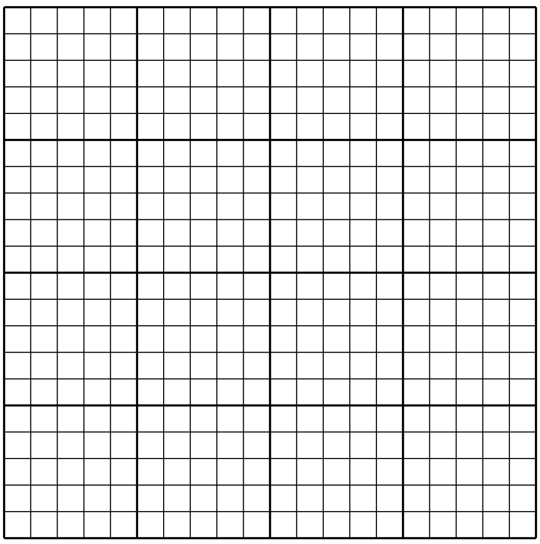
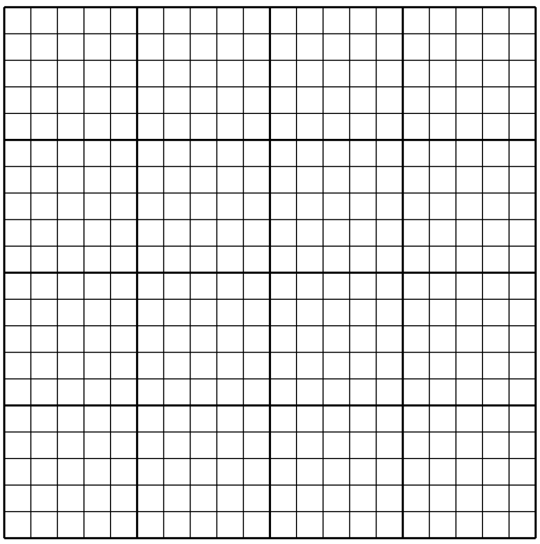
- Introduction to the Oscilloscope
- Adjusting Scales
- The Vertical Axis
- Triggering the Oscilloscope

5.3 Pre-lab Work

1. An initially charged capacitor is connected through a switch to a resistive circuit without a source. The switch is in the open position for a long time and closes at $t = 0$. Draw the circuit and calculate the steady-state voltage ($t \to \infty$) of the capacitor in this RC circuit?

2. Explain the physical meaning of the value of the voltage of the previous question. What does this mean for the energy stored in the capacitor?

3. An inductor is connected to a dc voltage source in series with a resistor. Draw the circuit. In the following graphs, plot the current through the circuit and the voltage across the inductor. Explain the waveforms.

4. An RC switching circuit has a capacitance of 100 μF and is required to have a time constant of 5 ms. What is the necessary value of resistance in the circuit? What is the inductance value required to achieve the same time constant in an RL switching circuit using the same resistor?

	Date	Assessor	Mark

5.4 Experimental Procedure

5.4.1 List of Components

In this experiment you will require:

- Your Breadboard
- 1 kΩ and 100 kΩ resistors.
- 220 μF and 220 nF capacitors
- 10 mH inductor (please return the inductor at the end of the experiment).

5.4.2 RC Transients - First Measurements

1. On your prototyping board construct the simple RC circuit shown in Figure 5.4.1. The LEDs are used to indicate the presence of current and its direction.

   ⚠ Be careful to connect the 220 μF capacitor with the $-ve$ lead connected to common which should be connected to the negative terminal of the power supply. If you connect the capacitor the wrong way it will be destroyed.

   ⚠ Be careful also to connect the leads from the capacitor to the multimeter Voltage inputs (NOT the Current inputs) Connect a long wire onto point A.

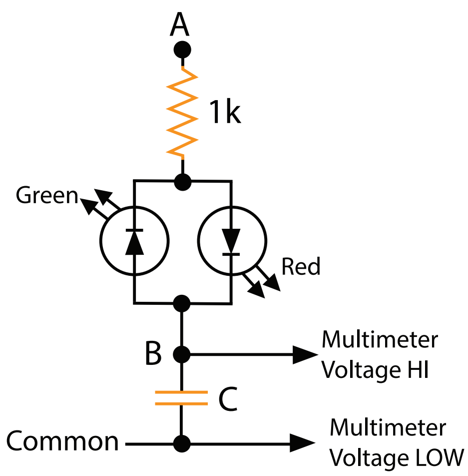


Figure 5.4.1: A circuit for observing the direction of the current during a transient event.

2. Connect point A to the +15V supply. Note that current flow is indicated by one of the LEDs lighting. Note also the voltage displayed on the multimeter. What happens to the voltage on the capacitor? Which LED lit up and approximately how long?

3. Now disconnect point A from the supply and then connect point A to ground. What happens to the voltage on the capacitor? Which LED lit up and approximately how long?

4. Why do the LEDs light up at different stages?

5.4.3 RC Transients - Waveforms

5. Now you are going to use the Oscilloscope to explore the charge and discharge of a capacitor. To allow a much shorter time to charge and discharge we are going to use a much smaller capacitor $C = 220$ nF, and a slightly bigger resistor R=100 kΩ for this part of the experiment as shown in Figure 5.4.2.

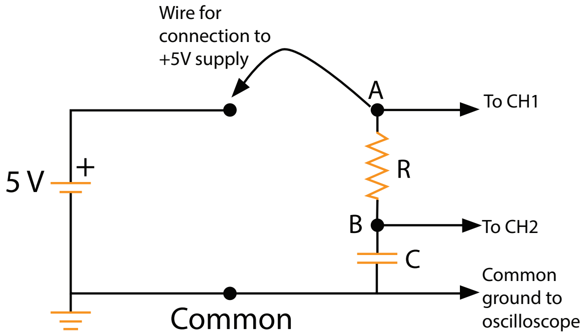


Figure 5.4.2: A circuit for observing RC transients with the oscilloscope.

6. Connect the ground terminal of the oscilloscope CH1- and CH2- to the ground terminal.

⚠ Connect CH1 of the oscilloscope to point A on the circuit and CH2 to point B on the circuit. (Note this means that CH1 is measuring the voltage V_A which is the voltage between point A and Ground and CH2 is measuring the voltage V_B which is the voltage between point B and Ground).

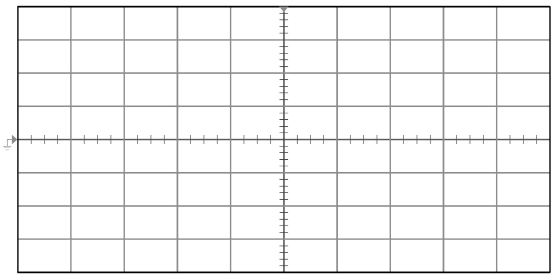
The 5 V voltage source will be taken from the 5V power supply. The switch will be implemented using a wire connected to point A. To charge the capacitor the wire (connected to point A) will be connected to the +5V supply and to discharge it will be connected to ground.

7. Set the oscilloscope to **2V/div** on both channels with DC Coupling. Also set the timebase to **20 ms/div** and the *triggering* to come from **CH1** with a trigger level of **0.5V**. Set the "sweep" setting of the oscilloscope to "Single" on the rising edge of CH1, then connect the lead from point A to the 5V supply. This should display a transient voltage for CH2 [1].

   ⚠ Explain the settings of the oscilloscope and how do they affect your measurements.

   ⚠ Refer to the "Triggering the Oscilloscope" videos. This is a very common mistake in the lab exams of the course!

8. Sketch the waveforms from the oscilloscope on the graph. Also in another colour sketch the voltage across the resistor V_{AB}



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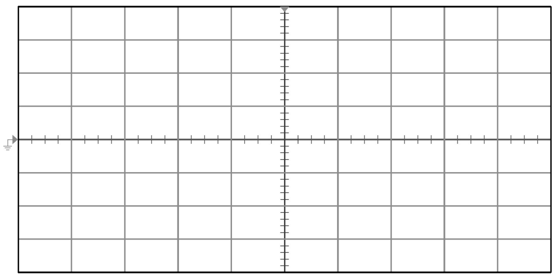


X-axis: ....
Y-axis: ....

9. The current may be determined using Ohm's law. From the waveforms calculate the peak current in the resistor.

10. This simple experiment demonstrates the first order transient response of a simple RC circuit and shows the exponential response of both the voltage and the current.

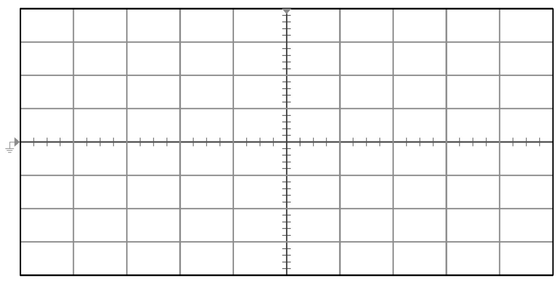
[1] If a display is not shown repeat the test after disconnecting point A from the supply and connecting it to ground, then reset the ŞSingleŤ button on the Oscilloscope before re-connecting point A to the 5V supply.

How does the current across the capacitor change? Can the voltage across the capacitor change in a similar manner? Explain your answer.

11. Would the current through the capacitor and the voltage across the capacitor be different if the R and C were swapped (ie the R connected to ground and the C connected to the supply)?

5.4.4 RC Transients - Switching RC Circuits

12. Using the signal generator, set the signal generator to maximum output voltage, a frequency of 5 Hz and a square wave output and turn it ON. Connect the output of the signal generator to point A. Set the oscilloscope to "Run" and observe the waveform displayed on the oscilloscope. Sketch the results on the graph.



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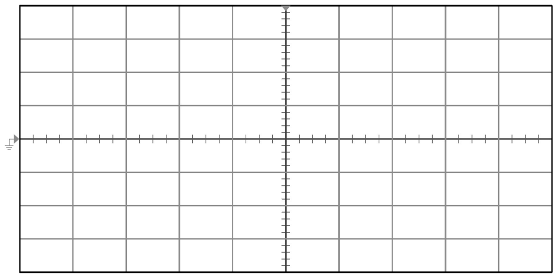
13. Change the frequency to 25 Hz and plot the new results. Explain the differences.



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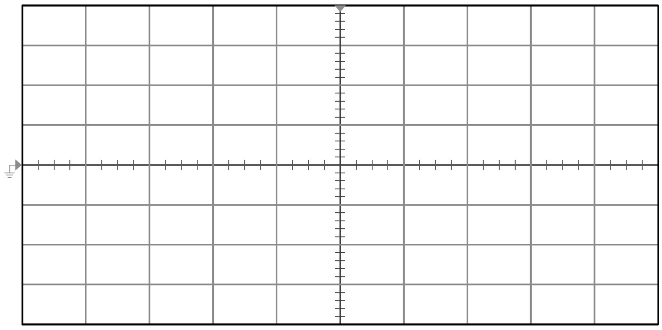
5.4.5 RL Transients

14. The transient response of an RL circuit will be observed using $L = 10$ mH and $R = 1$ kΩ. Before continuing with the experiment, measure the resistance of the inductor and note this as R_L.

15. Keeping the settings and connections of the signal generator and oscilloscope the same as your last question, replace the capacitor and resistor of Fig. 5.4.2 with the inductor and the new resistor. Calculate the time constant of your circuit. Based on your measurements of the inductor values, what is an important parameter to consider in your calculations?



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Y-axis: ....

16. How does an inductor voltage in an RL circuit, differ from the capacitor voltage in RC circuit?

	Date	Assessor	Mark

6 Experiment 6 - Operational Amplifiers

6.1 Aims of this Experiment

The aims of this experiment are to design and test the following Operational Amplifier Circuits:

1. Inverting amplifier,
2. Non-inverting amplifier,
3. Differentiator,
4. Integrator.

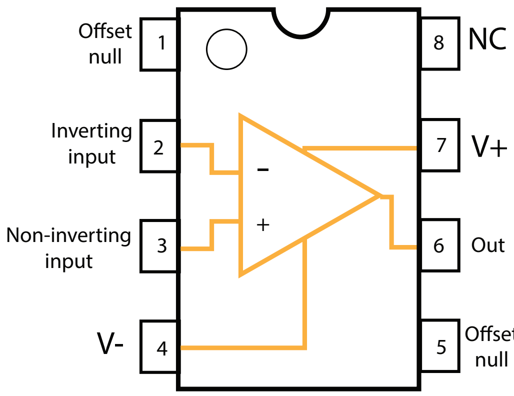


Figure 6.1.1: Connections of the LM741 Operational Amplifier.

6.2 Videos for Review

Please review the following videos before Experiment 6.

- Displaying a waveform
- The power supply in series mode

6.3 Pre-lab Work

1. What are the characteristics of an ideal OP-AMP.

2. How many and which pins of the LM741 do you have to connect in a functional OP-AMP circuit?

3. How do you have to connect the power supply in order to supply the OP-AMP?

4. When does an OP-AMP become saturated? What defines this value?

5. Derive the equation for the inverting amplifier circuit of Figure 6.4.1 using nodal analysis.

6. What equation describes the gain of a non-inverting amplifier?

7. Consider the inverting amplifier of Figure 6.4.1. How does it behave when the input resistance R_1 i) is open (removed from circuit and replaced by open circuit) (ii) is short-circuited, (iii) when the feedback resistance R_2 is open and (iv) when the feedback resistance is short-circuited.

8. What equation describes the operation of a *differentiator* circuit with OPAMPs?

9. What equation describes the operation of a *integrator* circuit with OPAMPs?

	Date	Assessor	Mark

6.4 Experimental Procedure

6.4.1 List of Components

In this experiment you will require:

- Your Breadboard
- 470 Ω, 1 kΩ, 1.5 kΩ and 1 MΩ resistors.
- 1 nF and 4.7 nF capacitors.

6.4.2 Inverting Amplifier

1. On your breadboard construct the simple circuit shown in Fig. 1, for a gain of 15.

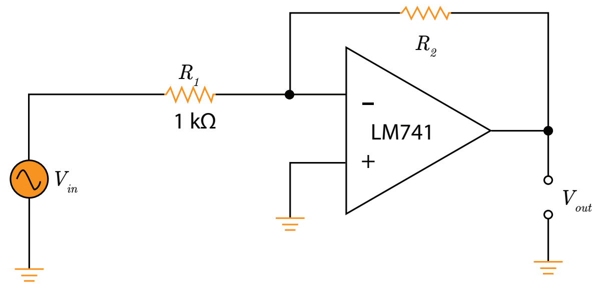


Figure 6.4.1: An inverting amplifier.

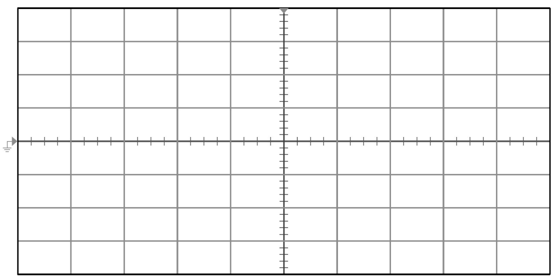
⚠ Connect the dual power supply across Pins 4 and 7. Set the power supply to $\pm 15V$. Once you have your bias connections, monitor the output current on the power-supply to be sure that there are no any inadvertent short-circuits.

⚠ Use a multimeter to probe the IC pins directly to ensure that pin 7 is at +15V and pin 4 is at -15V.

2. Use the function generator as source V_{in} to provide 0.5 V amplitude (1V peak to peak), 1 kHz sine wave excitation to the circuit.

⚠ Verify your signal before you connect it to the input.

3. Observe the input and output waveforms on the oscilloscope. Configure the scope so that the input signal is displayed on CH1 and the output signal is displayed on CH2. Make a plot of the two resulting waveforms, noting the descriptive parameters of the waveforms (peak values and the fundamental time-period or frequency).



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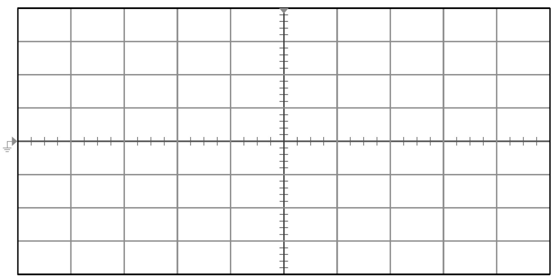

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4. Compare the experimental results with the theoretical values.

6.4.3 Non-Inverting Amplifier

5. On your breadboard construct the simple circuit shown in Figure 6.4.2, with R_2 = 15 kΩ.

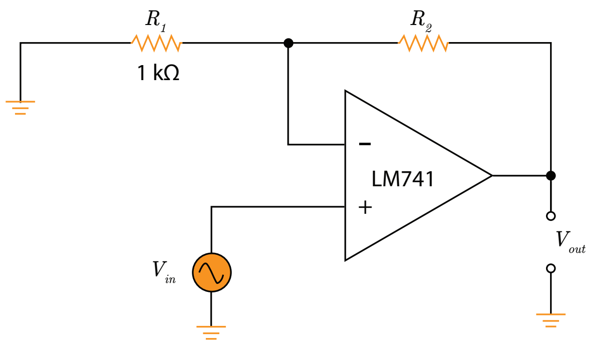
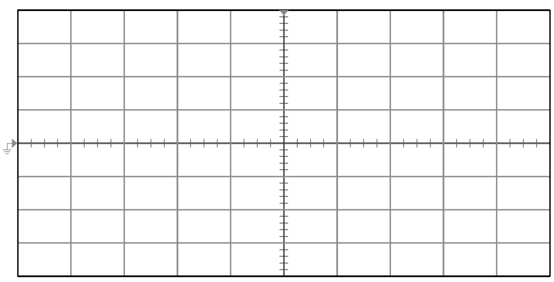


Figure 6.4.2: A non-inverting amplifier.

⚠ Similarly to the previous experiment, connect the dual power supply across Pins 4 and 7. Set the power supply to ±15V. Connect an oscilloscope in the input and the output. Don't forget to ground the scope leads.

6. Use the function generator as source Vin to provide 0.5 V amplitude (1V peak to peak), 1 kHz sine wave excitation to the circuit.

7. Observe the input and output waveforms on the oscilloscope. Configure the scope so that the input signal is displayed on CH1 and the output signal is displayed on CH2. Make a plot of the two resulting waveforms.



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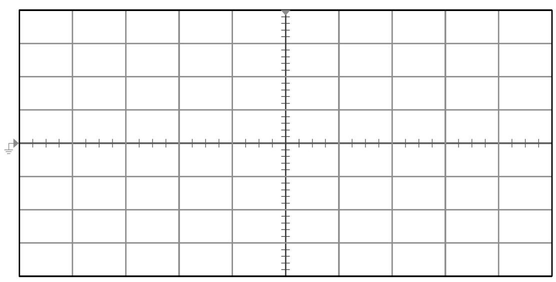


X-axis: ....
Y-axis: ....

8. Compare the experimental results with the theoretical values.

6.4.4 Differentiator

9. A practical OP-AMP differentiator is shown in Figure 6.4.3.

   ⚠ To avoid high frequency noise and stability problems it contains a resistance R_1 in series with the capacitance C.

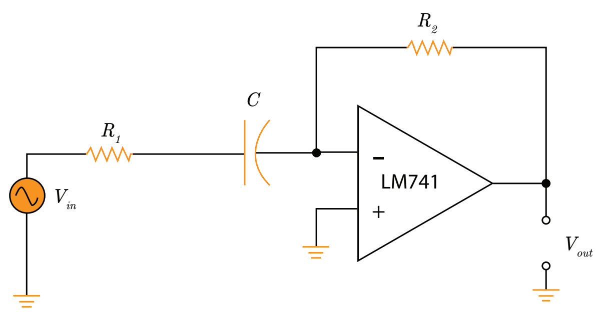
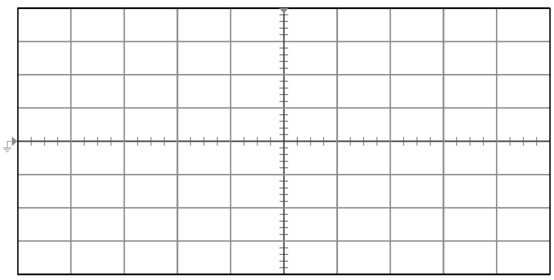


Figure 6.4.3: Configuring the operational amplifier as a differentiator.

10. On your breadboard assemble the circuit with $C = 4.7$ nF, $R_1 = 470\ \Omega$ and R2 = 10kΩ.
11. Set the function generator to provide 0.5 V amplitude (1V peak to peak), 1 kHz triangular wave input to the circuit. Set the power supply to ±15V.

    ⚠ Similarly to the previous experiment, connect the dual power supply across Pins 4 and 7. Set the power supply to $\pm 15V$. Connect an oscilloscope in the input and the output. DonŠt forget to ground the scope leads.
12. Observe the input and output waveforms on the oscilloscope. Configure the scope so that the input signal is displayed on CH1 and the output signal is displayed on CH2. Make a plot of the two resulting waveforms.
13. Repeat the measurements with a sine waveform of the same frequency and amplitude.



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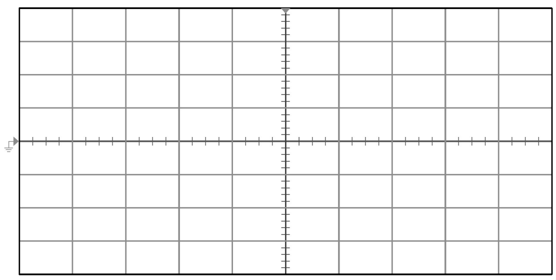


X-axis: ....
Y-axis: ....

14. Compare the experimental results with the theoretical values.

6.4.5 Integrator

15. A practical op-amp integrator is shown in Figure 6.4.4.

⚠ To limit the gain of the integrator at low frequencies, the feedback capacitor is shunted by a resistance R2 as shown.

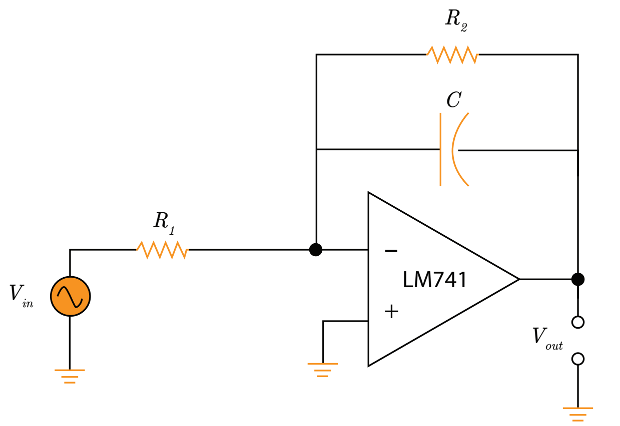
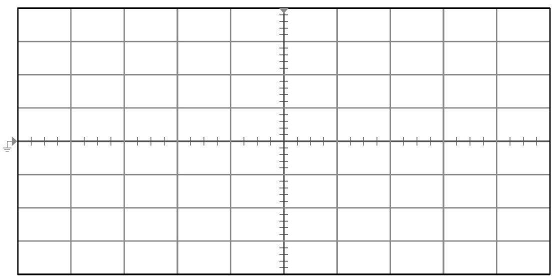


Figure 6.4.4: Configuring the operational amplifier as an integrator.

16. On your breadboard assemble the circuit with $C = 1$ nF and $R_1 = 100$ kΩ and $R_2 = 1$MΩ.
17. Set the function generator to provide 0.5 V amplitude (1V peak to peak), 1 kHz square wave input to the circuit. Set the power supply to $\pm 15V$.

⚠ Similarly to the previous experiment, connect the dual power supply across Pins 4 and 7. Set the power supply to $\pm 15V$. Connect an oscilloscope in the input and the output. DonŠt forget to ground the scope leads.

18. Observe the input and output waveforms on the oscilloscope. Configure the scope so that the input signal is displayed on CH1 and the output signal is displayed on CH2. Make a plot of the two resulting waveforms.



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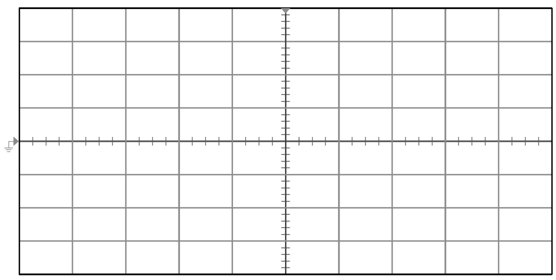

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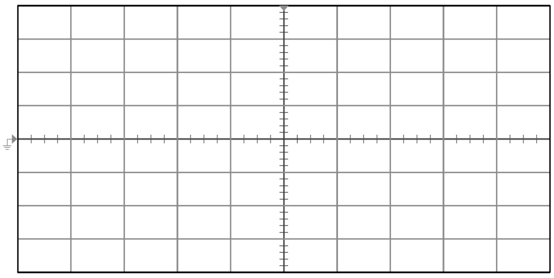
Y-axis: ....

19. Compare the experimental results with the theoretical values.

20. Change the signal generator from a square-wave to a triangular. Repeat and plot the measurements.



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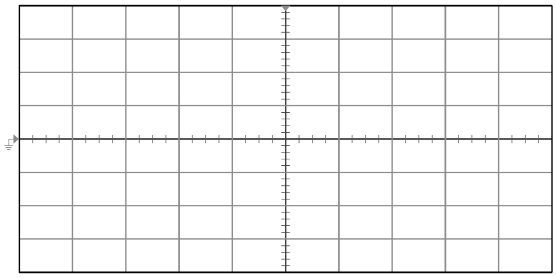


X-axis: ....
Y-axis: ....

6.4.6 Analysis of OP-AMP Circuits

21. Explain the behaviour of the integrator at low frequencies (such as DC). Refer to the answers you provided in the last question of your pre-lab . How does adding a shunt resistance prevent this problem?

22. Why is the differentiator sensitive to high frequency noise? How does adding a series resistance prevent this problem? Again refer to your answer in the last question of your pre-lab.

	Date	Assessor	Mark

7
Experiment 7 - AC circuits

7.1 Aims of this Experiment

The aims of this experiment are to:

1. investigate the frequency dependant behavior of RC circuits
2. explore the concepts of power in ac circuits

7.2 Videos for Review

Please review the following videos before Experiment 7.

- Using two channels
- Adjusting scales with 2 channels
- Triggering with 2 channels

7.3 Pre-lab Work

1. In Experiment 1, Section 1.4.4 you measured the values of a sinusoidal, triangular and square waveform using the multimeter. Explain your measurements.

2. How does frequency affect the impedance of *i)* a resistor, *ii)* an inductor and *iii)* a capacitor? Explain providing the necessary equations.

3. How much power does a 10 Ω resistor consume, when connected to a 100 V (rms), 50 Hz sinusoidal voltage source?

4. How much power does a 3 mH inductor consume, when connected to a 100 V (rms), 50 Hz sinusoidal voltage source?

5. How much power is provided by a 100 V (rms), 50 Hz sinusoidal voltage source that supplies the parallel combination of the 10 Ω resistor and 3 mH inductor?

6. What is the practical meaning of the rms value in ac analysis?

	Date	Assessor	Mark

7.4 Experimental Procedure

7.4.1 List of Components

In this experiment you will require:

- Your Breadboard
- 1.2 kΩ resistor.
- 100 nF Capacitors
- Elvis Unit (for Part B)
- Incadescent and Fluorescent (for Part B)

7.4.2 Frequency response of ac circuits

1. Consider the *RC* circuit of Figure 7.4.1

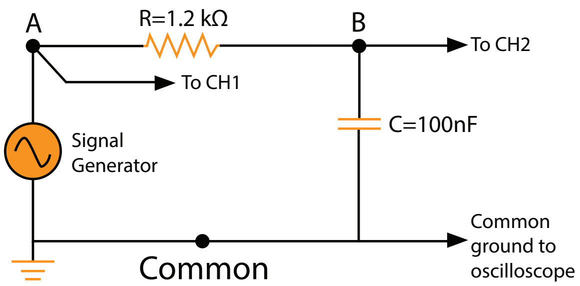
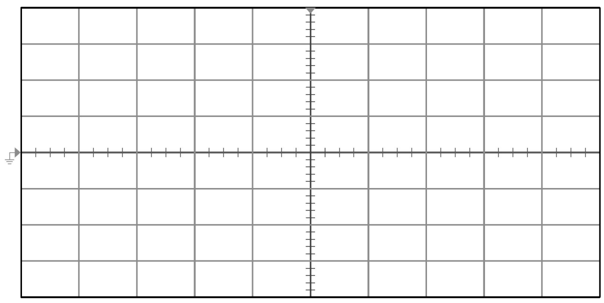


Figure 7.4.1: An RC circuit.

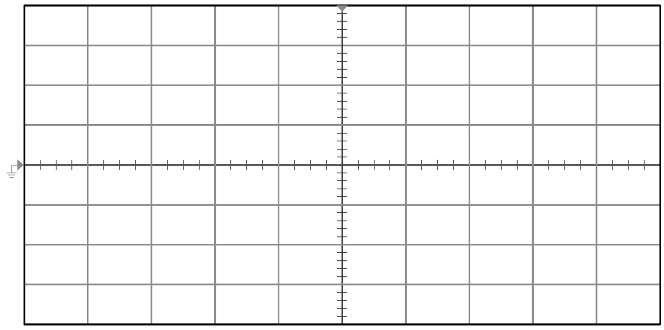
⚠ Connect CH1 of the oscilloscope to point A on the circuit and CH2 to point B on the circuit. (Note this means that CH1 is measuring the voltage V_A which is the voltage between point A and Ground and CH2 is measuring the voltage V_B which is the voltage between point B and Ground).

2. Using the signal generator, set the signal generator to 10 V peak to peak voltage, a frequency of 500 Hz and a sinusoidal output and turn it ON. Connect the output of the signal generator to point A. Set the oscilloscope to "Run" and observe the waveform displayed on the oscilloscope. Sketch the results on the graph including at least two periods of both signals.

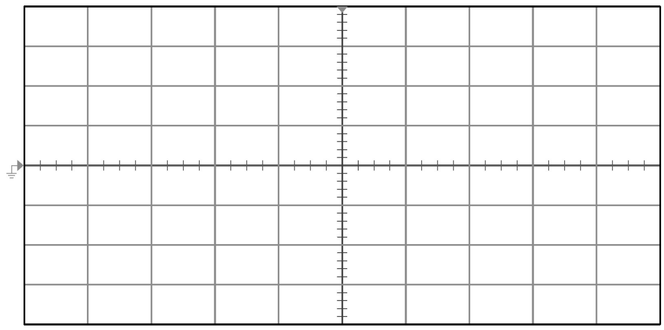


X-axis: ....
Y-axis: ....

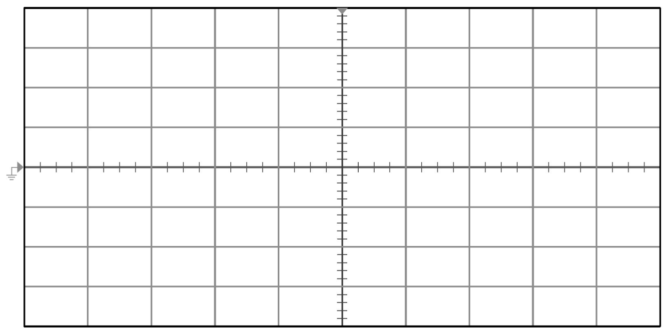
3. Increase the frequency of the signal generator with steps of 500 Hz up to 2 kHz and repeat the measurements looking at the effect on the waveforms



X-axis: ....
Y-axis: ....



X-axis: ....
Y-axis: ....



X-axis: ....
Y-axis: ....

4. Explain why the waveform is changing? How does the behavior of the circuit change as a function of the frequency of the input signal?

5. Using the different measurements from the previous step, plot the ratio of the output voltage (CH2) to the input voltage (CH1) as a function of frequency.

6. Explain the behaviour of the circuit. How can such a circuit be used in practical applications?

7.4.3 AC Power

7. For the circuit elements of the RC circuit shown in Figure 7.4.1, record the results of the following measurements:

Resistor		
V_{rms}	I_{rms}	P_{avg}

Capacitor		
V_{rms}	I_{rms}	P_{Avg}

	Date	Assessor	Mark

8 Experiment 8 - Digital Logic

8.1 Aims of this Experiment

The aims of this experiment are

1. To study the truth tables of various basic logic gates.,
2. To verify DeMorgan's theorem
3. To implement a circuit to control a light

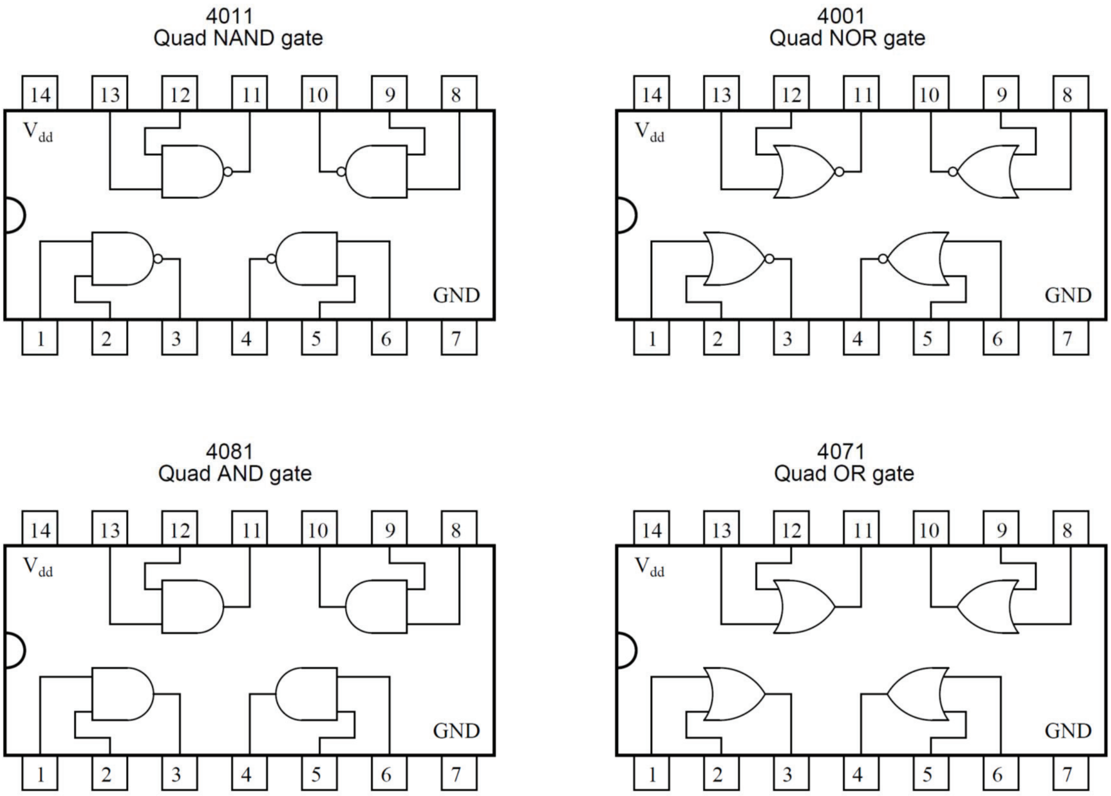


Figure 8.1.1: Examples of logical gates ICs and their pin connections.

⚠ It is important to verify the connections of the specific IC you are using with its datasheet!

8.2 Pre-lab Work

1. Calculate the Boolean expressions and write the truth tables of the logical circuits of Fig. 8.2.1.

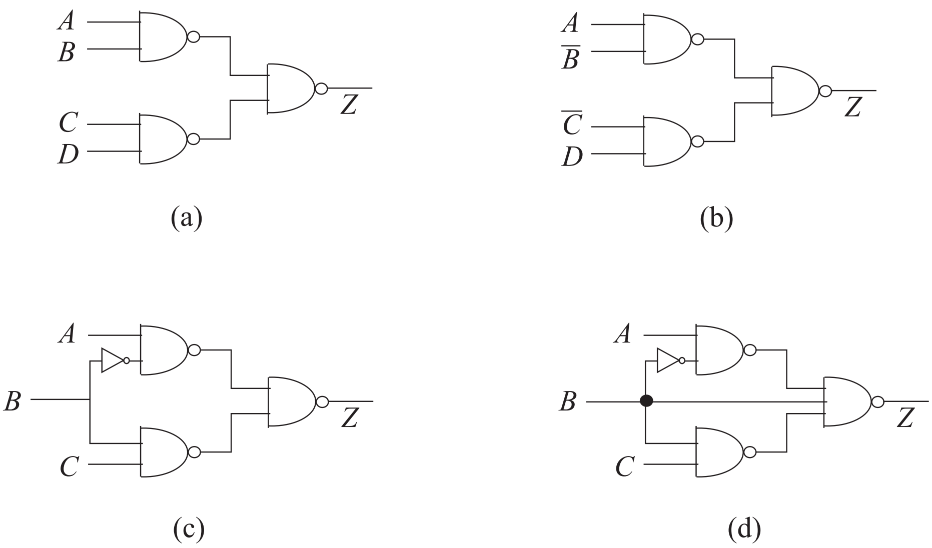


Figure 8.2.1: Logical Circuits.

2. Write the equations that define DeMorgan's Theorem.

3. Draw the logic gate equivalent circuits based on DeMorgan's Theorem.

	Date	Assessor	Mark

8.3 Experimental Procedure

8.3.1 List of Components

In this experiment you will require:

- Your Breadboard
- 7408 AND Gate
- 7432 OR Gate
- 7404 NOT Gate
- 7486 XOR Gate

8.3.2 Analysis of basic logic gates

1. Assign lines for V_{cc} and ground terminals of your breadboard and connect an IC (say 7408) in your prototyping board.

   ⚠ Connect pin 7 to ground terminal and Pin 14 to the V_{cc} terminal line.

   ⚠ Consider what defines a logical 1 and a logical 0 in a practical circuit.

2. Confirm the truth table of all logical gates.

Gate:		
A	B	Output

Gate:		
A	B	Output

Gate:		
A	B	Output

Gate:		
A	B	Output

8.3.3 Verifying DeMorgan's theorem

3. Construct the logic gate equivalent circuits based on your prelab work and verify DeMorgan's Theorem

Logical Expression:		
A	B	Output

Logical Expression:		
A	B	Output

Logical Expression:		
A	B	Output

Log. Expression:		
A	B	Output

8.3.4 Logic Circuits

4. The objective is to build and test a circuit designed to control one light. The light has three control switches A, B, and C based on the following logic:
   - If C is OFF then the light is OFF.
   - If C is ON then the light should be ON if: *i)* A is ON and B is OFF or *ii)* if A is OFF and B is ON.
   - If C is ON then, the light must be OFF if: *i)* A is ON and B is ON or *ii)* if A is OFF and B is OFF.
5. Complete the Truth Table for this logic circuit

A	B	C	Output

6. Draw a circuit to check the above logic below.

7. Implement this in the breadboard using the ICs.

   Have the lab demonstrator confirm the operation of the circuit.

	Date	Assessor	Mark

A

Appendix: Laboratory Equipment

A.1 The Prototyping Board (or breadboard)

The prototyping board gives the circuit designer a convenient base on which to construct circuits. The holes are set at 2.54mm intervals and are compatible with the pin spacings on integrated circuits. Inter-component wiring is achieved through the conductors that are already built into the layout of the board. The holes readily accept integrated circuit pins and leads from low-power diodes, 1/4 W resistors and small capacitors. However, if difficulty is experienced with larger diameter leads, solder a smaller diameter lead onto it for use instead.

Although several manufacturers make these boards, they will all have the same general characteristics and layout as illustrated in Figure A.1.1.

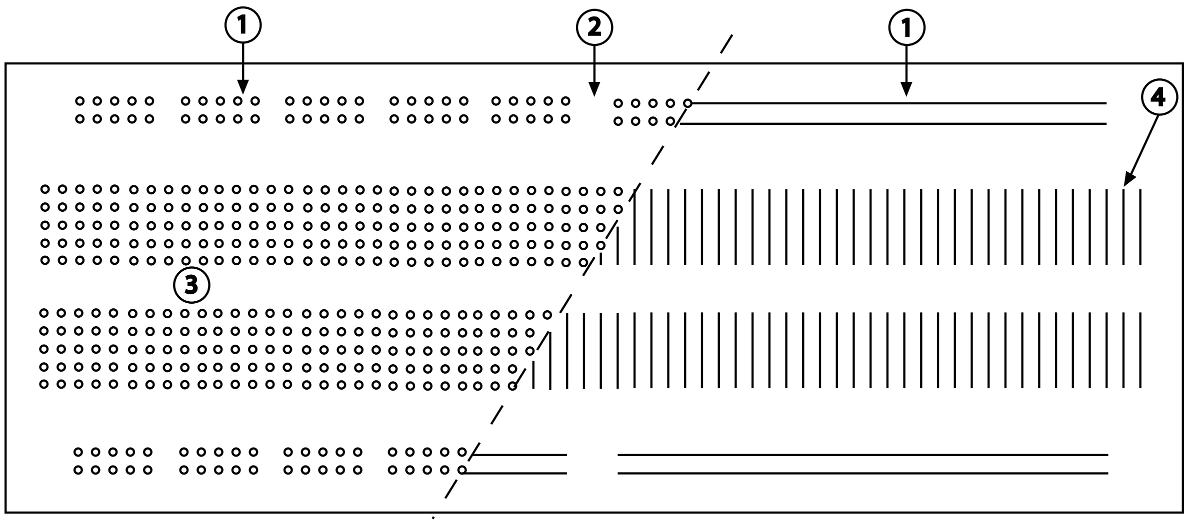


Figure A.1.1: The layout of the Prototyping Board, showing the hole placings at the left and inter-connecting conductors on the right of the figure.

A.1.1 Features of the prototyping board

These features are described in terms of the numbers shown on the board that is illustrated in Figure A.1.1.

1. There are two rows of connections ① across the top and bottom of the board. These are useful for power supply leads, earth lines and other connections that are required along the length of the board.
2. Note the gap ② at the centre of these rows of holes. Use a wire bridge if you want the line to pass right across the board.
3. The gap ③ across the centre of the board is suitable for inserting integrated circuits with the two rows of pins on opposite sides of the gap.
4. On each side of the centre gap ③, the holes are connected in groups of five at right angles to the gap ④.

The Prototyping Board

A.1.2 Suggestions for using the board

- Use the upper and lower rows of holes for power supply and earth connections.
- Keep the component leads short. Long leads may touch and give sho‘rt circuits. Circuit construction is easier to follow later if neat wiring is used in the first place.
- Insert the components gently but firmly and vertically into the holes on the board. Use **your small pair of long-nose pliers** to insert the components. A positive electrical contact must be made and maintained with the conductors beneath the holes.
- Arrange the layout of the components on your board to be similar to that of your circuit diagram, e.g.

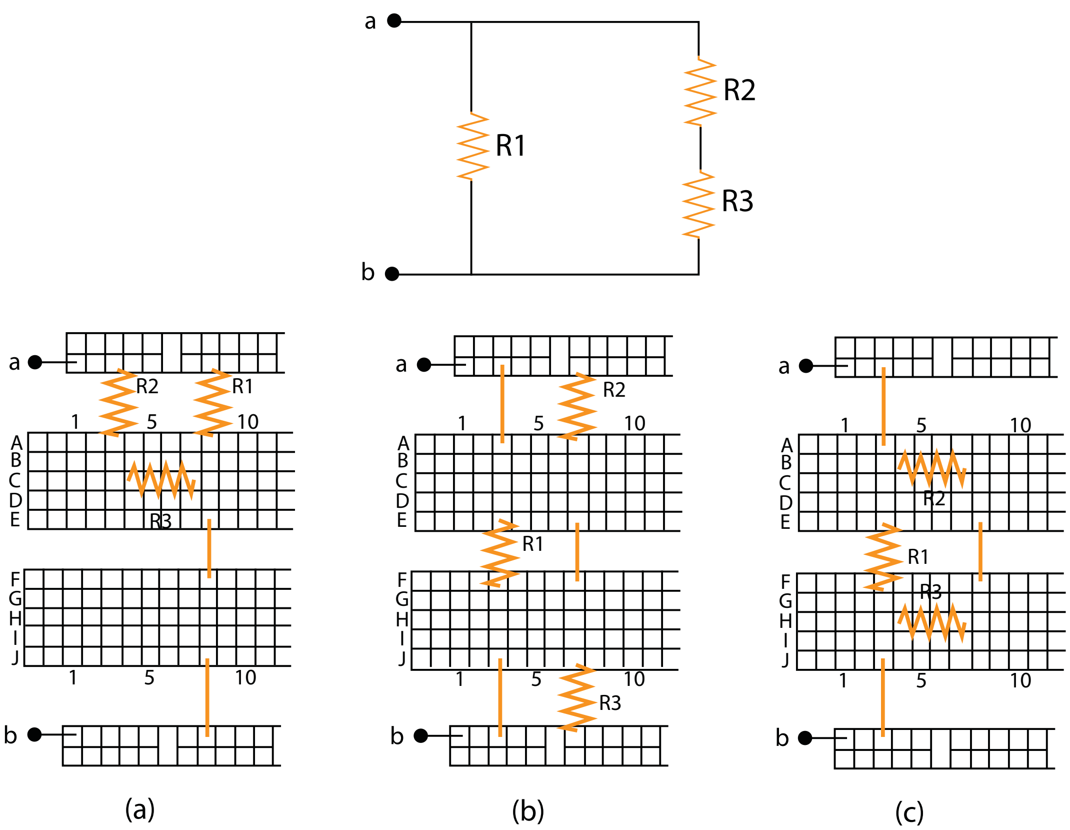


Figure A.1.2: A circuit diagram with equivalent breadboard layouts. Case (b) shows a preferred layout that reflects the circuit diagram on the board.

A.2 Resistor Colour Coding

The ordinary carbon composition fixed resistors that we use in the laboratory are characterized by three quantities

1. their **resistance** value in ohms, (Ω),
2. their **tolerance** as a percentage (%) and
3. their **power dissipation** in watts (W).

The power dissipation capability is determined mainly by the physical size of the resistor. General purpose resistors with 1/4 W dissipation will be used unless a higher power rating is required.

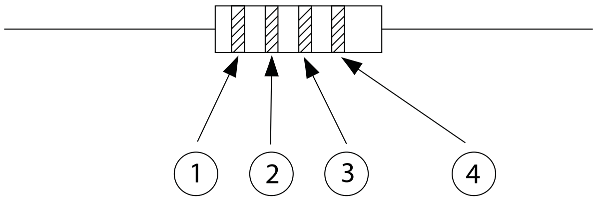


Figure A.2.1: The colour code bands on a resistor.

The nominal value for the resistor and its tolerance are described by the colour bands on the resistor. Normally, there will be four bands on each resistor placed towards one end of the resistor (if there is enough room). Commencing with the band closest to a lead of the resistor, the interpretation of each band is given in the table below.

Colour \ Band	1 First Sign. digit	2 Second Sign. digit	3 Multiplier	4 Tolerance %
Black		0	1	
Brown	1	1	10	1
Red	2	2	100	2
Orange	3	3	1 000	3
Yellow	4	4	10 000	4
Green	5	5	100 000	
Blue	6	6	1 000 000	
Violet	7	7	10 000 000	
Grey	8	8	100 000 000	
White	9	9	1 000 000 000	
Gold			0.1	5
Silver			0.01	10
No colour				20

It is important that you know how to use this table and, with practice, you should remember the numerical value assigned to each colour. The first two bands give the significant digits of the resistance value (the second digit may be zero) while the third band gives the exponent for the multiplying power of ten, i.e. the third band tells you how many additional zeroes must be added to the significant digits. The fourth band gives the tolerance or range in which an actual resistor may be found with respect to its nominal value. Most resistors used in the laboratory.

have gold (±5.%) for this tolerance band. A 20% tolerance is assumed if the fourth band is missing.

Examples

Resistor	Band 1	Band 2	Band 3	Band 4	Resistance value
R1	Brown	Red	Black	Gold	$12 \times 10^0 = 12\Omega \pm 5\%$
R2	Red	Violet	Brown	Gold	$27 \times 10^1 = 270\Omega \pm 5\%$
R3	Orange	White	Orange	Red	$39 \times 10^3 = 39k\Omega \pm 2\%$

There is a compromise in selecting the values for any store of resistors that are kept in the laboratory. It is desirable to cover all resistance values, say from 1Ω to 10MΩ, with the lowest tolerance affordable. In our laboratories the resistors generally have a tolerance of ±5%. To maintain stock at a reasonable level we don't keep all resistors from the 5% range, preferring instead to omit every second value and retaining the values that would be kept in a complete 10% range.

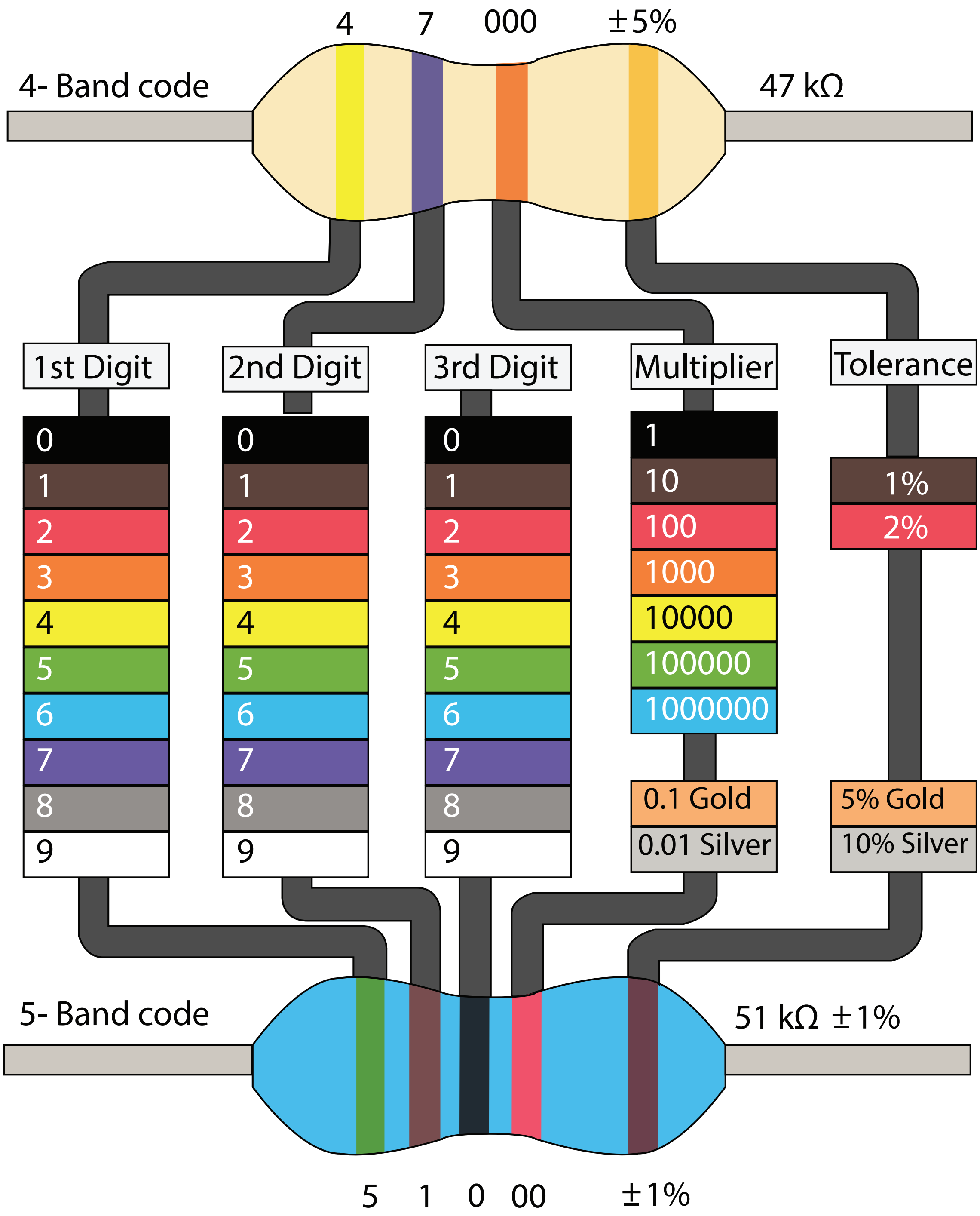
What is the 10% range of resistors?

Consider the 150 Ω resistor. If this resistor has a tolerance of ±10%, i.e. ±15Ω, then its actual value may lie anywhere within the range 135 Ω to 165 Ω.

Now consider the 180 Ω ±10% resistor which will have a value between 162 Ω and 198 Ω. You will see that any resistance value between 150 Ω and 180 Ω is within 10% of **a preferred value**.

The majority of your electronic circuit designs will use preferred value resistors given in the next table, unless a precise value of resistance is required.

PREFERRED VALUE RESISTORS, Ω												
1	1.2	1.5	1.8	2.2	2.7	3.3	3.9	4.7	5.6	6.8	8.2	10
10	12	15	18	22	27	33	39	47	56	68	82	100
100	120	150	180	220	270	330	390	470	560	680	820	1.0k
1.0k	1.2k	1.5k	1.8k	2.2k	2.7k	3.3k	3.9k	4.7k	5.6k	6.8k	8.2k	10k
10k	12k	15k	18k	22k	27k	33k	39k	47k	56k	68k	82k	100k
100k	120k	150k	180k	220k	270k	330k	390k	470k	560k	680k	820k	1.0M
1.0M	1.2M	1.5M	1.8M	2.2M	2.7M	3.3M	3.9M	4.7M	5.6M	6.8M	8.2M	10M


4 7 000 ±5%
4- Band code
47 kΩ
1st Digit
2nd Digit
3rd Digit
Multiplier
Tolerance
0
1
2
3
4
5
6
7
8
9
1
10
100
1000
10000
100000
1000000
0.1 Gold
0.01 Silver
1%
2%
5% Gold
10% Silver
5- Band code
51 kΩ ±1%
5 1 0 00 ±1%

A.3 Multimeters

A.3.1 Introduction

Multimeters are indispensable measurement tools that allow you to accurately measure currents, voltages, both AC and DC, and resistance.

A.3.2 The Digital Multimeter

There are two different models of digital multimeters in the laboratories. They are all standard units and suitable for our requirements, although there are some variations between them. In this case, the two multimeters are different models of the GWInstek GDM series. They are shown in Figures A.3.1 and A.3.2.

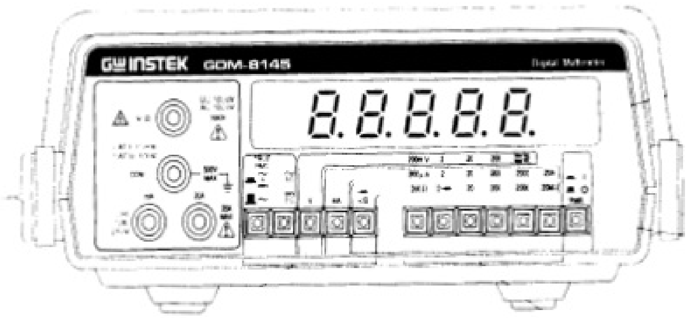


Figure A.3.1: Front panel of benchtop multimeter GWInstek GDM-8145.

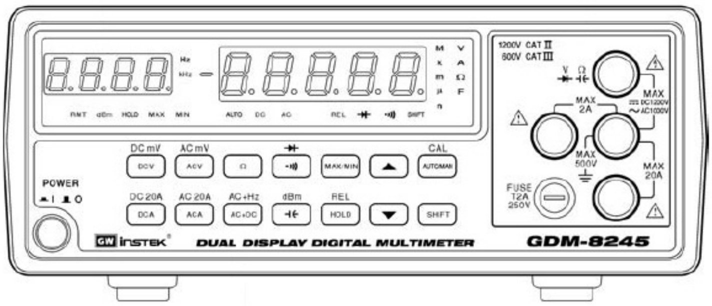


Figure A.3.2: Front panel of benchtop multimeter GWInstek GDM-8245.

The GWInstek GDM-8245 is an upgraded version of the GWInstek GDM-8145, and it includes a number of additional features, such as auto ranging. Given the similarities of the two multimeters, we will focus on the less intuitive one for our explanation, the GWInstek GDM-8145. Generalization of the procedures for using the GWInstek GDM-8245 should be trivial, and lab demonstrators can help if needed.

The multimeter connects to your circuit via banana cables, using the ports on the front panel (see Figure A.3.3). When measuring voltages and resistances, connect the multimeter across the circuit or device, using the "Voltage and Ohms" port and the black COM port.

Introduction to the multimeter

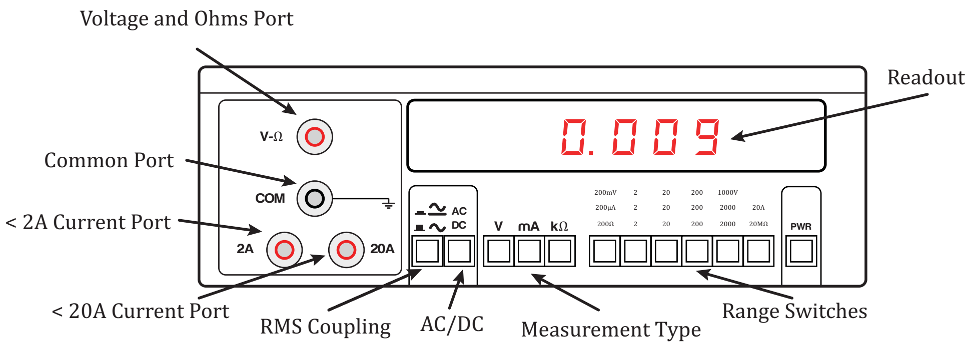


Figure A.3.3: Front panel of benchtop multimeter GWInstek GDM-8145 with functionality labelled.

A.3.2.1 Measuring Voltage

The procedure for taking a voltage measurement is as follows:

1. Plug a red banana cable into the red topmost port marked V - Ω.
2. Plug a black banana cable into the black port marked COM. Reserving black for ground connections is good practice.
3. Push the AC/DC switch if you want to take an AC measurement. Depress the switch for a DC measurement.
4. Push the voltage switch "V", and select the measurement range.
5. Connect the red cable to the positive measurement point in your circuit, and the black cable to the negative measurement point in your circuit.

Measuring voltage with a multimeter

A.3.2.2 Measuring Resistance

To measure resistance:

1. Plug a red banana cable into the red topmost port marked V - Ω.
2. Plug a black banana cable into the black port marked COM.
3. If the element you are measuring is in a circuit, take the element out.
4. Connect the cables across the element and choose an appropriate measurement range.

Measuring resistance with a multimeter

A.3.2.3 Measuring Current

To measure series current, make a break in your circuit, and bridge the gap through the multimeter. Current is measured using the current ports and the black COM port. You will not often be measuring any significant amount of current, hence you should use the leftmost current port marked "2 A".

1. Plug a red banana cable into the bottom left red port marked "mA".
2. Plug a black banana cable into the black port marked COM. Reserving black for ground connections is good practice.

3. Push the AC/DC switch if you want to take an AC measurement. Depress the switch for a DC measurement.
4. Push the current switch "mA", and select the measurement range.
5. Connect the multimeter in series with the current you need to measure. Current flowing into the multimeter through the red cable will be measured as positive.

Measuring current with a multimeter

The range switches are used to set the multimeter's measurement range, you should decide what range is suitable for your measurement before connecting your circuit to the multimeter. Treat the ranges indicated on the front of the multimeter as the maximum allowed values for that range setting. For example, if you are expecting to measure around 5 volts, select the 20V measurement range. This is particularly important for current measurements, applying a higher current than the selected range allows will blow the protection fuses in the device. The ranges are specified in volts [V], milliamps [mA], and kilo-ohms [kΩ]. If you are not sure, choose the higher measurement range first and confirm that the current or voltage can indeed be measured safely on the smaller range.

Applying an input signal that exceeds the limits of the range selected will cause all the digits on the display to flash. If you have the multimeter configured in a way that doesn't make sense, the decimal places on the display will flash. For example, selecting the 20MΩ range while measuring voltage will cause the decimal places to flash as there is range setting above 1000 V.

A.3.2.4 RMS Measurements

When you measure AC signals with the multimeter, the reading you get is the RMS value of the signal. In fact, the benchtop multimeters in the laboratories are true RMS meters, which means that the RMS value of the signal is calculated accurately from digitally sampled readings. In cheaper or older multimeters, the signal is assumed to be purely sinusoidal, and hence the RMS value is computed by multiplying the average value by a correction factor. This method works well if the signals you are measuring are sinusoidal, but produces incorrect readings for other kinds of signals, or if there is a significant amount of noise present in the signal.

The switch to the left of the AC/DC switch is used to set the AC/DC coupling of the RMS measurements. If any DC is present in the input signal, it will be included in the RMS measurement given by the multimeter. If this is important for your measurement, push the coupling switch in as the diagram above the switch indicates. Alternately, leaving the switch out AC couples the RMS measurement, giving you the RMS value of the AC component of the signal only.

A.4 The dc Power Supply

There are several types of power supply in use in the laboratories. They are all standard units and suitable for our requirements, although there are some variations between them. The purpose of this section is to point out some of the general features of a laboratory power supply.

A.4.1 Battery

A battery is a source of electricity that gives a constant dc voltage, where dc (direct current) means that the current produced by the source does not change its direction with respect to time. Remember, *a battery has two terminals, but no earth.*

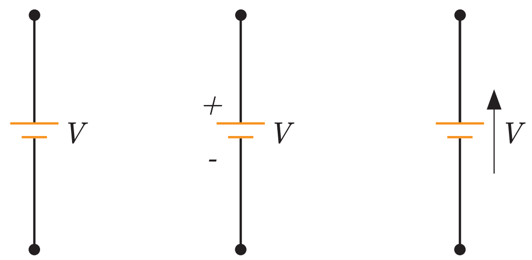


Figure A.4.1: Circuit symbols and equivalent notations for a battery.

If an earth is connected to either the negative (-) or the positive (+) terminal (but not both!) of a battery, then the battery is said to be **EARTHED**. A battery which is not earthed gives a **FLOATING** voltage and is known as a floating battery.

A.4.2 Voltage conventions

A **voltage** with a single subscript specifies the potential of the subscripted point in the circuit with respect to earth. Thus V_A specifies the potential of A with respect to earth and V_B specifies the potential of B with respect to earth. A voltage with a double subscript, for example V_{AB}, specifies the **potential difference** between A and B. The potential difference is the potential of the first subscripted point with respect to the second point. Thus $V_{AB} = V_A - V_B$.

⚠ **Floating** means not earthed, **earthed** means not floating and **"ONLY ONE EARTH"** is true for electrical circuits too!

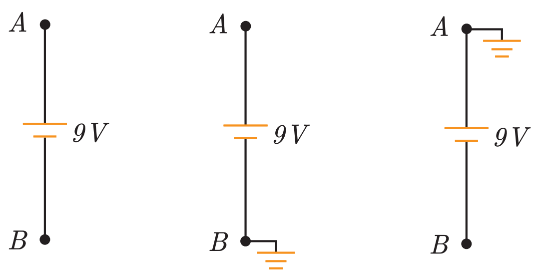


Figure A.4.2: The voltages and potential differences for three battery configurations.

	case (a)	case (b)	case (c)
V_A	?	9V	0V
V_B	?	0V	-9V
V_{AB}	9V	9V	9V

Table A.4.1: Voltage and potential table.

A.4.3 The Power Supply

This section will explain how to use the dual-output benchtop DC power supply.

There are three different models of power supplies in the laboratories. All of them are different models of the GWInstek GPC series, as shown in Figures A.4.3 - A.4.5. The only difference between the GPC-3030 and GPC-3030D models is the use of an analog or digital display. The difference of these two models and the GPC-3303 model is the use of separate GND earth connections (green connections) and the Output Enable button (which has to be pressed for the GPC-3303 to provide an output). Since the circuits you will build do not require the use of the GND earth connections, and there is no difference in the operation of the three models, we will focus on just one of them, the GPC-3303.

⚠ The green GND earth connection is physically isolated from the positive and negative output posts. This ground is connected to the metal case of the power supply, and to the building earth. The circuits you build should not require the use of this terminal.

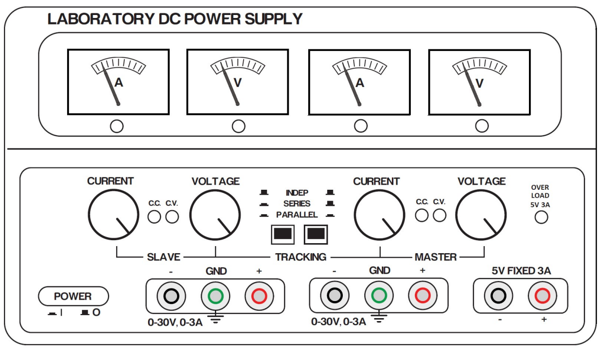


Figure A.4.3: Control panel of benchtop power supply GWInstek GPC-3030 (analog display).

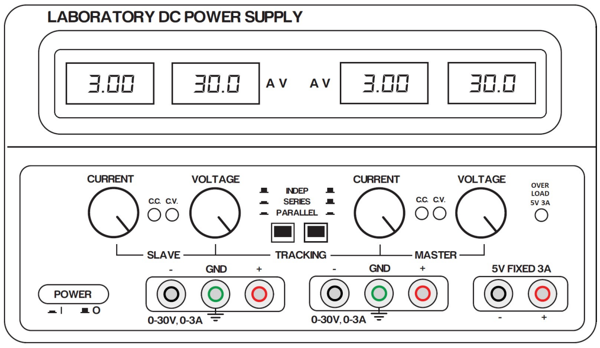


Figure A.4.4: Control panel of benchtop power supply GWInstek GPC-3030D (digital display).

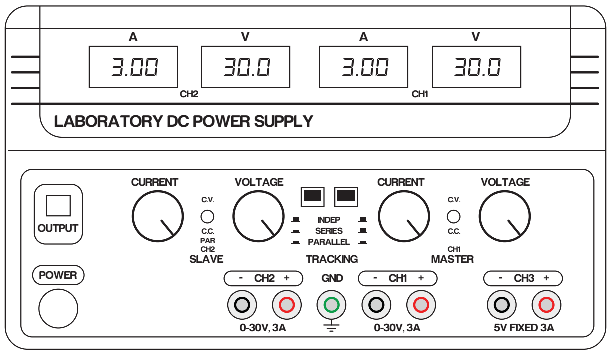


Figure A.4.5: Control panel of benchtop power supply GWInstek GPC-3303 (digital display).

The power supply has two variable outputs, Channels one (CH1) and two (CH2), as well as a third fixed 5 V output. Each output has its own set of controls, as shown in the control panel of the power supply (Figure A.4.6).

Introduction to the power supply

To set the output voltage of one of the channels, turn the corresponding 'VOLTAGE' knob and watch the voltage readout until it settles on the desired voltage. Along with this, you also need to set the maximum current by increasing the "CURRENT" knob. If too much demand is placed on the power supply, and you attempt to draw more current than what is set by the current limit knob, the supply enters constant current mode, and the CC indicator LED will come on.

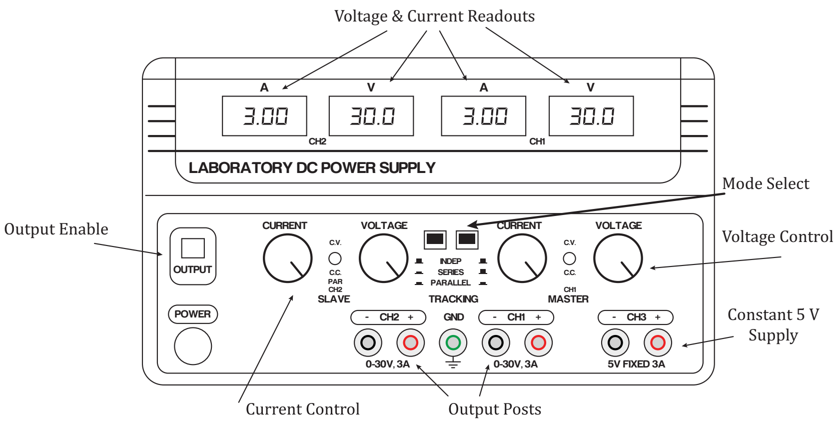


Figure A.4.6: Control panel of power supply GWInstek GPC-3303 with the important controls labelled.

The current limit feature is useful if you need to prevent a load from being supplied with too much current, however this will not be a concern in the labs, so set the limit as high you need it to be.

Current limiting

The power supply can be operated in three different modes, and each mode changes the way both channels behave. You can change the mode by using the two mode select switches indicated in Figure A.4.6.

A.4.3.1 Independent Mode

In independent mode, the two supply channels are operated completely independently. Figure 3 shows how the supply voltages are taken at the output posts. V_1 and V_2 can be set from 0 to 30 V independently. Adjusting the current knob for either channel sets the current limit for that channel alone.

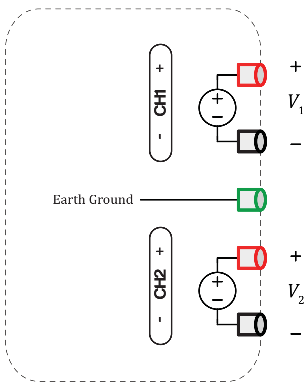


Figure A.4.7: Simplified diagram of the power supply acting in independent mode.

A.4.3.2 Series Mode

When in series mode, the positive (red) terminal of channel two is connected to the negative (black) terminal of channel one, shown in Figure A.4.8. In this mode, the voltage setting for channel two (the slave) will mimic the setting for channel one (the master). This means that the voltage V_1 appears on both channels, creating a virtual ground in the middle. The voltage at the positive terminal of channel one will be at V_1 V, whilst the voltage at the negative terminal of channel two is $-V_1$ V.

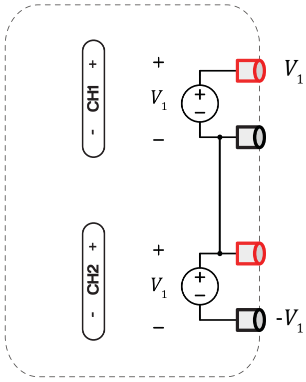


Figure A.4.8: Simplified diagram of the power supply whilst acting in series mode. Earth GND has been omitted.

⚠ Series mode is useful when you need to power an op-amp with both positive and negative supplies, and also provide the circuit with a ground (0 V). The overall output current will be limited by the lowest set current knob.

The power supply in series mode

A.4.3.3 Parallel Mode

While in parallel mode, both positive terminals, and both negative terminals, are connected together. This allows you to supply twice the maximum current to your circuit, for a total of 6 amps of current.

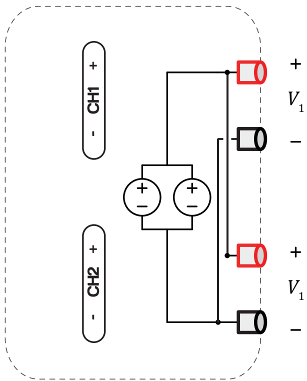


Figure A.4.9: Simplified diagram of the power supply when it is acting in parallel mode. Earth GND has been omitted.

The power supply in parallel mode

A.5 The Signal Generator

The signal generators in the labs are capable of providing sine, triangle and square waves at frequencies from 0.5Hz to 5MHz.

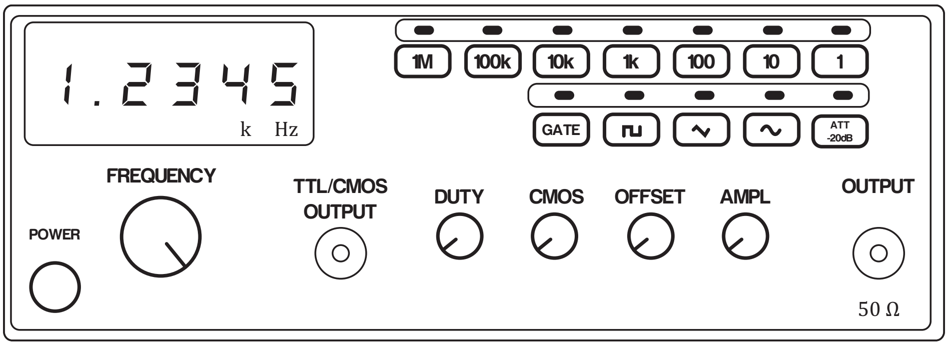


Figure A.5.1: The interface of the signal generator.

Introduction to the signal generator

A.5.1 Using the Signal Generator

The frequency of the output signal is displayed on the six digit LED display on the top left of the control panel. To adjust the frequency, first press the frequency decade selection button corresponding to the order of magnitude required. Then use the frequency adjustment knob to tune the generator to the desired frequency. You can change the function type using the buttons indicated by "Function Type" in Figure A.5.2.

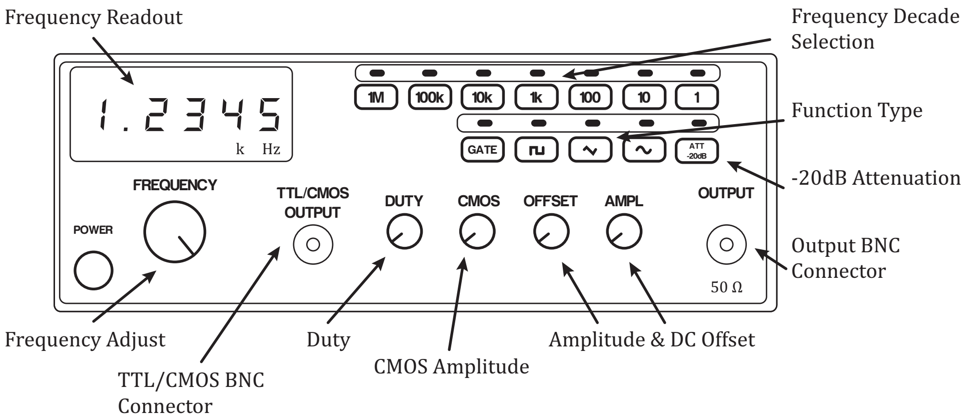


Figure A.5.2: The control panel with the functionality of each control labelled.

There are four smaller knobs used to further adjust the output signal, labelled "DUTY", "CMOS", "OFFSET" and "AMPL". The black text next to these adjustment is applicable when the knobs are in the pushed-in position, and the orange text is applicable when the knobs have been pulled outwards. The amplitude knob changes the amplitude of the output signal, the maximum amplitude the function generator can provide is 10 V. If you need a very low voltage signal, you can use the -20dB button to attenuate the signal further. If you require a DC offset in your signal, pull out the DC offset knob and adjust accordingly. To adjust the duty cycle of the waveform, pull out the "DUTY" knob and adjust accordingly.

The signal generator connects to your circuit from the output connector on the right side of the control panel using a BNC cable. The other BNC connector is used for the TTL/CMOS output.

⚠ Using the wrong BNC connector is a common mistake in the labs.

Displaying a waveform

Amplitude Attenuation

Duty Cycle

Offset

A.5.2 TTL/CMOS Output

The other BNC connector labelled "TTL/CMOS OUTPUT" provides a clock (square wave) output at the currently selected frequency, for circuits containing TTL or CMOS family logic. If the "CMOS" knob is pushed in, the function generator is set to output a TTL compatable clock signal. TTL Logic operates on 0/+5V, so when the output is set to TTL, a 0-5V square wave is provided. If the knob labelled "CMOS" is pulled out, it can be adjusted from 0 to +15V; as a range of logic voltage levels can be used with CMOS logic.

The CMOS and TTL Terminal

A.6 The Oscilloscope

The oscilloscope is one of the most important tools you will use in these labs, and your career as an electrical engineer. Oscilloscopes allow you to inspect circuit voltages as they vary over time, and measure just about everything you wanted to know about them, from their average value to their frequency. Almost all oscilloscopes have two input channels, allowing you plot two signals together so that you can compare them. The oscilloscope display is broken up into a number of horizontal and vertical divisions, marked by the dotted lines on the display.

There are several types of oscilloscope which are used in our laboratories, but these notes relate in particular to two models, the Rigol DS1102CA and the Keysight DSOX1102A. Please note that while the videos have been recorded using the Rigol DS1102CA, they are also very useful to understand the Keysight DSOX1102A, since the operation is essentially the same.

The oscilloscope, as with any piece of measuring equipment, should not change the operation of your circuit or any of the voltages in it.

⚠ The oscilloscope can only measure directly the *potentials* of the signals with respect to earth and **not the potential difference** between any two general points in a circuit. It is however capable of monitoring two signals at the same time and, by subtracting one signal from the other, a potential difference can be measured.

A.6.1 Using the Rigol DS1102CA

The DS1102CA is a dual-trace oscilloscope that is capable of displaying two independent voltage waveforms as a function of time.

Introduction to the Oscilloscope

A.6.1.1 The Oscilloscope Layout

The DS1102CA oscilloscope front panel is shown in Figure A.6.1.

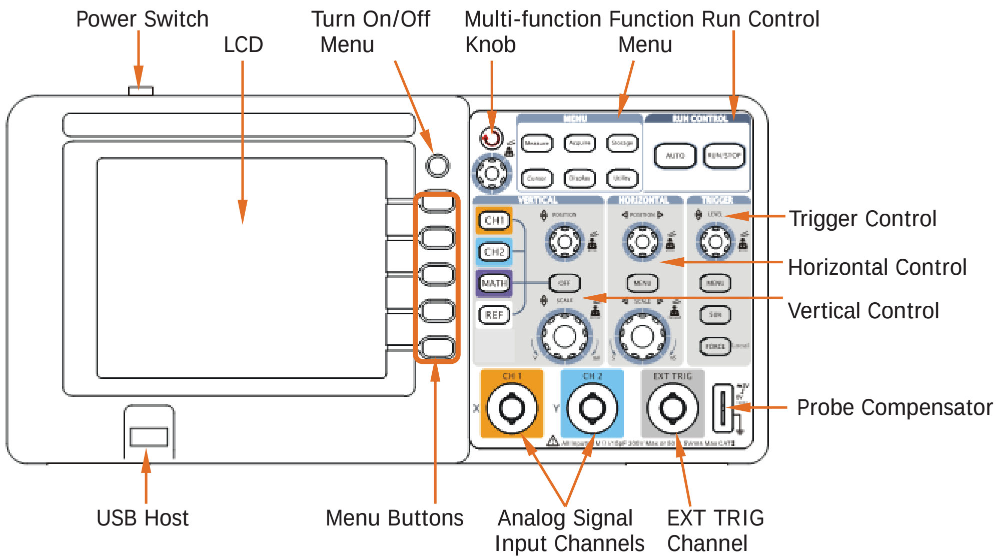


Figure A.6.1: The DS1102CA oscilloscope front side.

A.6.1.2 Functions of Oscilloscope Knobs

Carefully examine the front panel of the oscilloscope and make sure you identify all the knobs and their functions:

Horizontal	Large knob	Horizontal time scale - Timebase
	Small knob	Horizontal position
Vertical	Large knob 1	Vertical scale CH 1
	Small knob 1	Vertical position CH1
	Large knob 2	Vertical scale CH 2
	Small knob 2	Vertical position CH2
Trigger	Small Knob	Trigger Level
↻	Small Knob	Cursor Control

A.6.1.3 Horizontal Controls

The Horizontal Position knob controls the horizontal (or X) position of the waveform on the screen and may be used to align the waveform as you wish with the screen graticule. Turn it left and right to see its effects, but initially leave it near the centre of its travel.

The Horizontal Scale - Time Base (TIME/DIV) knob determines the sweep rate across the screen and is given as a time per division for the horizontal display. For example: a waveform is displayed on the oscilloscope with a scale set at 0.5ms/div. If the period of the waveform is found to be 4 divisions, then the period is $4 \times 0.5 = 2.0$ ms. The frequency of the waveform is given by the reciprocal of the period, that is frequency = 1 / 0.002 = 500Hz. As mentioned previously, the oscilloscope should not affect your circuit and does not change the time or voltage of the signal that it measures. If the switch is changed from 0.5ms/div to 1ms/div, the waveform will now be 2div long (2div $\times$ 1ms/div = 2ms).

Clicking either offset knob inwards sets the offsets back to zero.

Adjusting Scales

A.6.1.4 Vertical Controls

The Vertical Position knob controls the vertical (or Y) position of the waveform.

The Vertical Scale - (VOLTS/DIV) knob determines volts/div for the vertical axis of the display.

Clicking either offset knob inwards sets the offsets back to zero.

The Vertical Axis

AC - DC - GND Input Coupling Menu

Push the "CH1" button in the vertical control area. This will display the menu for the vertical amplifier. The top menu button has three possible states **AC - DC - GND**. This menu determines whether the dc component of the signal will be displayed on the screen. It also allows you to determine the **GND** (zero-volt input) level of the display.

DC: The input signal is amplified directly. All components of the signal (that is, dc and ac) are displayed on screen. Note that **DC** does not mean that this position is to measure dc only. *Generally, this is the setting to use.*

AC: The dc component of the input signal is decoupled (that is, blocked off) by a large internal capacitor, leaving the signal ac component only. Also, signals slower than 10Hz are attenuated. AC coupling is sometimes called capacitive coupling, because a capacitor is added in series with the measurement to achieve the DC blocking required. AC coupling is useful when you need to study a small AC signal superimposed on a large DC voltage.

GND: The input signal is disconnected and the display reads a zero-volt signal. Note that in this position the examined node on the circuit is not earthed.

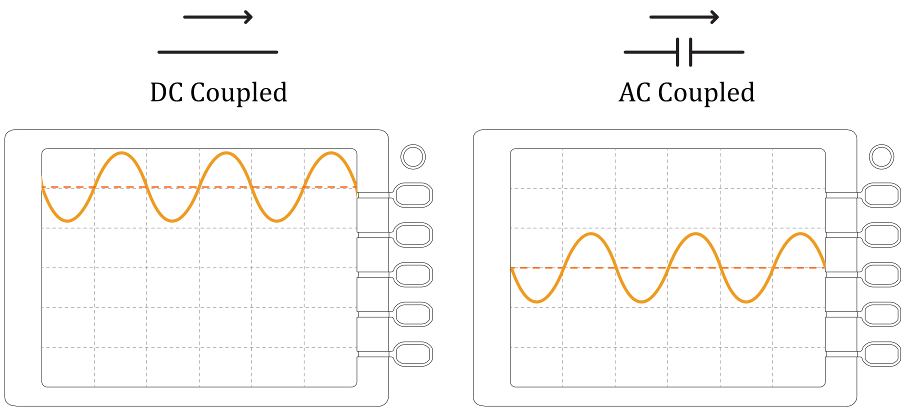


Figure A.6.2: The same signal viewed with DC and AC coupling respectively.

Coupling Modes

A.6.1.5 Input Channels

The oscilloscope resistance at the input socket is 1 MΩ. This is in parallel with ≈15 pF input capacitance for the oscilloscope. Depending on the magnitude of the circuit components, either or both the resistance and capacitance may affect the circuit being examined. The maximum allowable input voltage is 300 V RMS. For any high voltage measurements, be sure about your equipment capabilities *AND your safety procedures.*

A.6.1.6 Triggering the Oscilloscope

There are three different modes (sweep modes) the trigger can operate in. Each mode changes what the oscilloscope does once a trigger condition occurs.

Normal Mode: Once a trigger condition is met, the oscilloscope graphs a single time period and leaves this on the display until another trigger condition is met. Once the new trigger event occurs, the oscilloscope graphs the signal again. Periodic waveforms will appear stationary, because they will cross the trigger level at routine intervals.

Auto Mode: Operates the same way as normal mode, however the oscilloscope will automatically trigger if no triggers events have occurred recently. This is useful in situations where the input waveform has stopped crossing the trigger level for whatever reason.

Single Mode: Waits for a trigger event, graphs one time period and freezes until you hit the RUN/STOP button. This is useful for catching infrequent or non-periodic events.

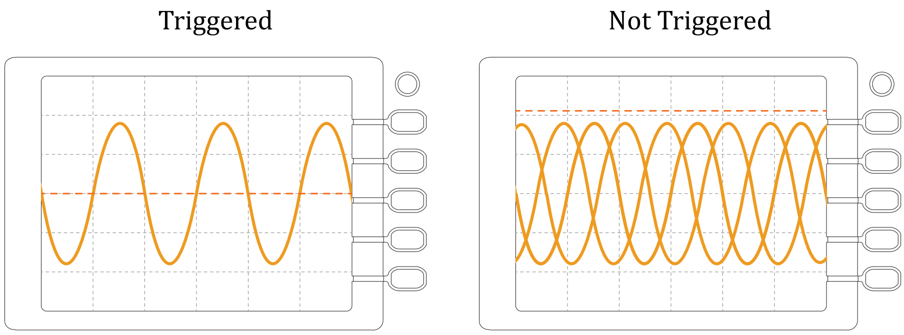


Figure A.6.3: A correctly triggered sine wave, and an untriggered sine wave.

On the Rigol oscilloscopes, the trigger level is simply adjusted with the trigger level knob indicated in Figure A.6.4. Opening the trigger menu allows you to:

- Select which channel to trigger from, either channel one or channel two .
- Change the trigger to look for rising, falling edges, or both.
- Under 'Sweep', you can change the mode the oscilloscope triggers in, described above.

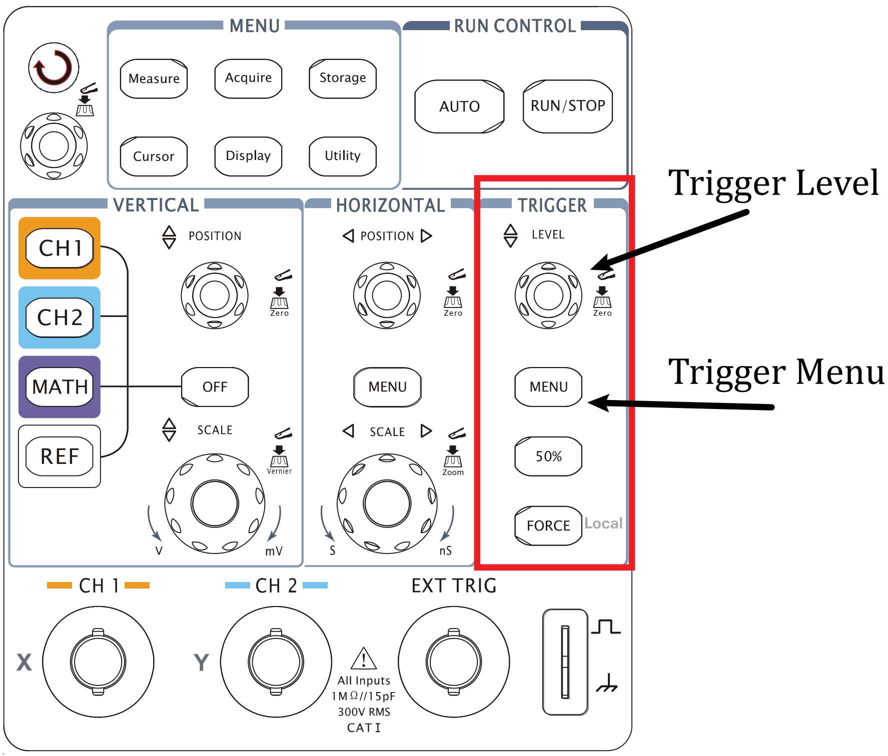


Figure A.6.4: The trigger control panel.

Triggering the Oscilloscope

A.6.1.7 Using Two Channels

Using two channels

Adjusting scales with 2 channels

Triggering with 2 channels

A.6.1.8 Measuring Waveforms

Once your waveforms are scaled and triggered appropriately, you can configure the oscilloscope to perform measurements using the 'Measure' button at the top of the Oscilloscope. You can change the source you are measuring by pressing the 'Source' option when the measure menu opens. Selecting 'Voltage' allows you to display peak voltages, RMS and average values, percentage overshoot and more. Selecting 'Time' allows you to measure the frequency, duty cycle and many other time-related properties of the waveform. Once an option is selected, it remains on the screen until you clear it away by pressing 'Clear' on the measure menu.

It is important to realise that the measurements and their accuracy depend on the degree to which the signal is present on the screen. If you wanted to measure the amplitude of a sine wave accurately, you should scale the waveform so that it fills the display, without clipping at the top.

You can measure a waveform quickly using the *Volts/div* setting of the X and Y Axis and the boxes in the screen of the Oscilloscope. However, to achieve accurate measurements, the Oscilloscope provides cursors, which are enabled by pressing the "Cursor" button at the top of the Oscilloscope.

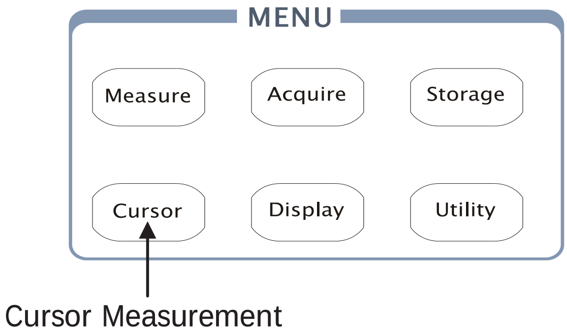


Figure A.6.5: The Cursor button in the DS1102CA oscilloscope front side.

Cursors are horizontal and vertical markers that indicate X-axis values (usually time) and Y-axis values (your voltages or currents) on a selected waveform source.

Cursors are not always limited to the visible display. If you set a cursor, then pan and zoom the waveform until the cursor is off screen, its value will not be changed, and if you pan the waveform back again it will have the cursor in the original place.

The cursor measurement has three modes: Manual, Track and Auto Measure.

- **Manual**
  In this mode, the screen displays two parallel cursors. Move the cursors to make custom voltage or time measurements of the signal. The values are displayed on the boxes below

the menu. Before using cursors, make sure to set the Signal Source as the channel for measuring.

- **Track**
  In this mode, the screen displays two cross cursors. The cross cursor sets the position on the waveform automatically. Adjust cursor horizontal position on the waveform by rotating the multifunction knob (See Fig. A.6.1). The oscilloscope displays the values of the coordinates on the boxes below the menu.

- **Auto Measure**
  This mode will take effect with Automatic Measurements. The instruments will display cursors while measuring parameters automatically. These cursors demonstrate the electrical meanings of these measurements.

When using the **Track** option, you can get measurements by

- Position of Cursor A (Time cursor centered on the midpoint of screen; Voltage cursor centered on channel ground level).

- Position of Cursor B (Time cursor centered on the midpoint of screen; Voltage cursor centered on channel ground level).

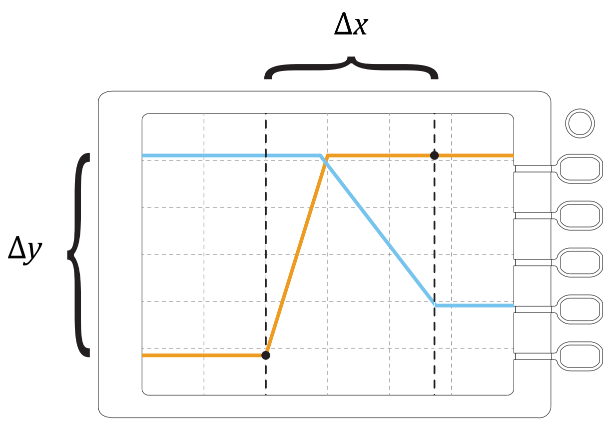


Figure A.6.6: Two cursors tracking channel one, with Δx and Δy indicated.

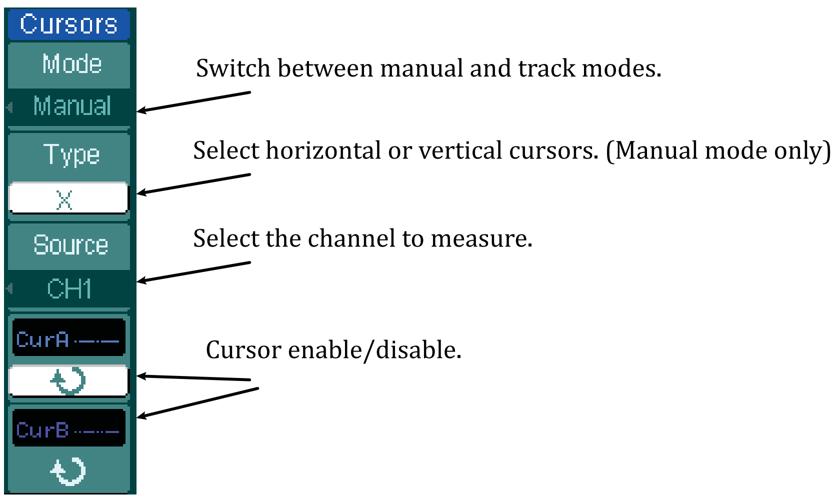


Figure A.6.7: The cursor menu. Currently, only cursor A is adjustable with the multi-function knob.

- Read the horizontal space between Cursor A and B (ΔX): Time between cursors, units in seconds.
- ($1/\Delta X$), units in Hz, kHz, MHz, GHz.
- Vertical space between cursor A and B (ΔY): Voltage between cursors, units in V.

A.6.1.9 Some Other Facilities

Calibrate Output (CAL)

How do you know that your oscilloscope is not faulty? You could

(a) ask the tutor;

(b) try another oscilloscope;

(c) test it;

(d) none of the above.

On each occasion that you use an oscilloscope, **the answer must be (c)**. This can be done, because in most oscilloscopes there is a "Calibrator Waveform" socket or terminal which generates a known waveform at a specified voltage and frequency. If you observe your oscilloscope carefully, you would find the peak-to-peak value of the voltage for a square wave. You can use this signal to test your oscilloscope, both Channel 1 and Channel 2. Should your oscilloscope not read the voltage specified by the calibrate output, it is out of calibration and it needs to be calibrated.

⚠ It is a good habit to test your oscilloscope before taking your measurements, otherwise you may have to repeat all your measurements should your oscilloscope be out of calibration.

This signal may also be used to adjust the tuning of some probes.

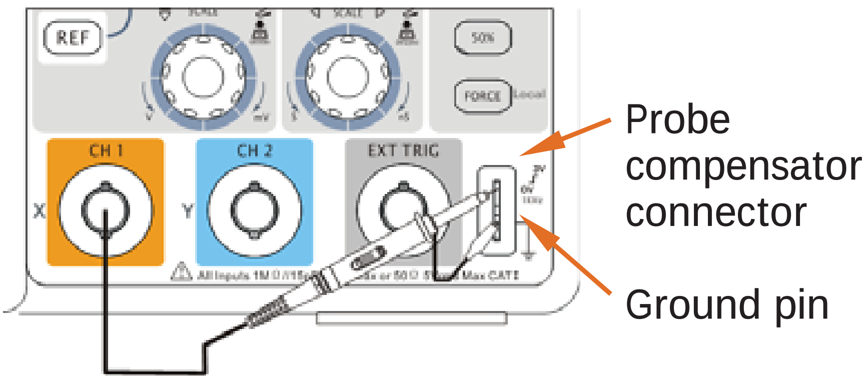


Figure A.6.8: Calibrating the probes.

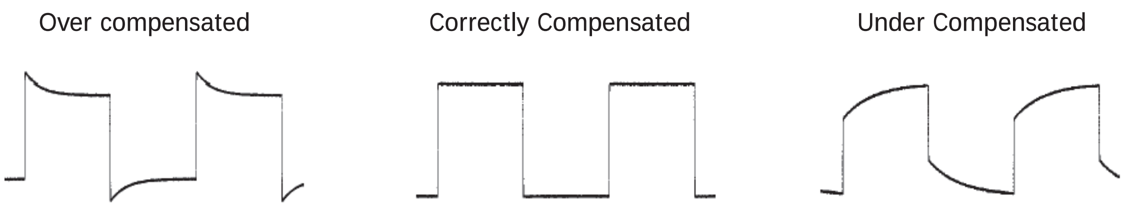


Figure A.6.9: Proper Calibration.

Mains Ground Input

The oscilloscope amplifiers are CONNECTED INTERNALLY to the mains earth of the power point, as is the chassis-frame of the oscilloscope. When the oscilloscope leads are plugged into the Channel 1 and Channel 2 sockets, all the black crocodile clips or hooks, but not the probe, are also connected internally to earth.

⚠ **Important: There must be only one earth in your circuit.**

All the earth leads from the oscilloscope must be connected to the one point in your circuit, where the earth symbol is shown. The terms "Floating" and "Earthed" may be confusing and should be clearly understood. Refer to the notes on Section A.4, for more information.

A.6.2 Using the Keysight DSOX1102A

The DSOX1102A is a dual-trace oscilloscope that is capable of displaying two independent voltage waveforms as a function of time.

A.6.2.1 The Oscilloscope Layout

The DSOX1102A oscilloscope front panel is shown in Figure A.6.10.

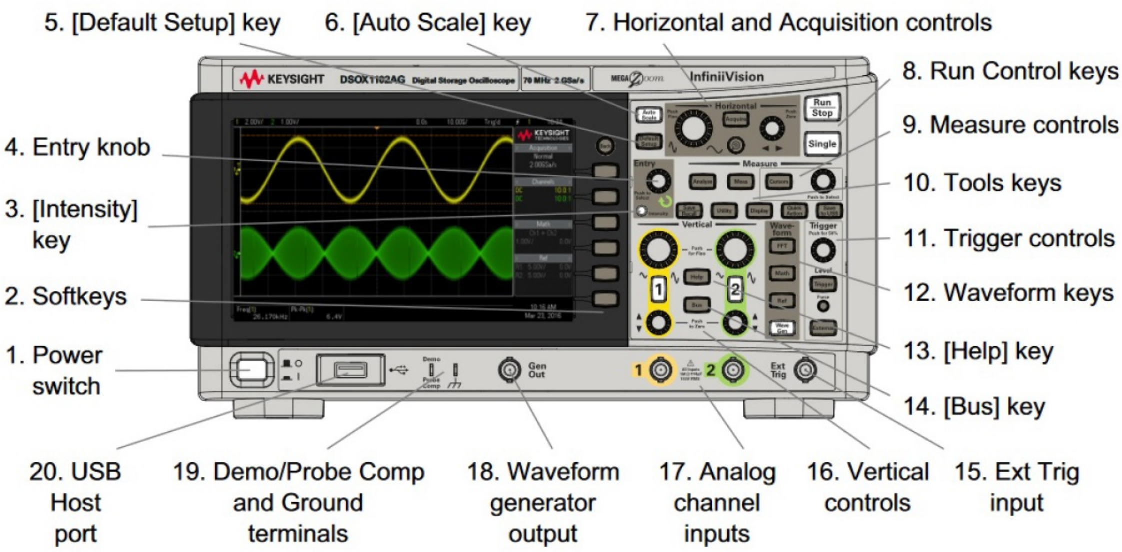


Figure A.6.10: The DSOX1102A oscilloscope front side.

A.6.2.2 Functions of Oscilloscope Knobs

Carefully examine the front panel of the oscilloscope and make sure you identify all the knobs and their functions:

Horizontal	Large knob	Horizontal time scale - Timebase
	Small knob	Horizontal position
Vertical	Large knob 1	Vertical scale CH 1
	Small knob 1	Vertical position CH1
	Large knob 2	Vertical scale CH 2
	Small knob 2	Vertical position CH2
Trigger	Small Knob	Trigger Level
↻	Entry Knob	Value selection

A.6.2.3 Horizontal Controls

The Horizontal Position knob controls the horizontal (or X) position of the waveform on the screen and may be used to align the waveform as you wish with the screen graticule. Turn it left and right to see its effects, but initially leave it near the centre of its travel. Clicking the offset knob inwards sets the offset back to zero.

The Horizontal Scale - Time Base (TIME/DIV) knob determines the sweep rate across the screen and is given as a time per division for the horizontal display. For example: a waveform is displayed on the oscilloscope with a scale set at 0.5ms/div. If the period of the waveform is found to be 4 divisions, then the period is $4 \times 0.5 = 2.0$ ms. The frequency of the waveform is given by the reciprocal of the period, that is frequency = 1 / 0.002 = 500Hz. As mentioned previously, the oscilloscope should not affect your circuit and does not change the time or voltage of the signal that it measures. If the switch is changed from 0.5ms/div to 1ms/div, the waveform will now be 2div long (2div $\times$ 1ms/div = 2ms). The symbols under the knob indicate that this control has the effect of spreading out or zooming in on the waveform using the horizontal scale. Push the channel's horizontal scale knob to toggle between fine and coarse adjustment.

A.6.2.4 Vertical Controls

The Vertical Position knob controls the vertical (or Y) position of the waveform. Clicking the offset knob inwards sets the offset back to zero.

The Vertical Scale - (VOLTS/DIV) knob determines volts/div for the vertical axis of the display. Push the channel's vertical scale knob to toggle between fine and coarse adjustment.

Channel Coupling

Push the "1" button under the vertical scale knob. This will display the menu for Coupling, Channel bandwidth limit, Vertical scale fine adjustment, Channel Invert and Channel Probe. The coupling menu determines whether the dc component of the signal will be displayed on the screen.

DC: All components of the signal (that is, dc and ac) are displayed on screen. Note that **DC** does not mean that this position is to measure dc only. *Generally, this is the setting to use.*

AC: The dc component of the input signal is decoupled (that is, blocked off) by a large internal capacitor, leaving the signal ac component only. Also, signals slower than

10Hz are attenuated. AC coupling is sometimes called capacitive coupling, because a capacitor is added in series with the measurement to achieve the DC blocking required. AC coupling is useful when you need to study a small AC signal superimposed on a large DC voltage.

A.6.2.5 Channels Inputs

The oscilloscope resistance at the input socket is 1 MΩ. This is in parallel with ≈16 pF input capacitance for the oscilloscope. Depending on the magnitude of the circuit components, either or both the resistance and capacitance may affect the circuit being examined. The maximum allowable input voltage is 150 V RMS. For any high voltage measurements, be sure about your equipment capabilities *AND your safety procedures.*

A.6.2.6 Triggering the Oscilloscope

The trigger level is simply adjusted with the trigger level knob. There are two different modes (sweep modes) the trigger can operate in. Each mode changes what the oscilloscope does once a trigger condition occurs.

Normal Mode: Triggers and acquisitions only occur when the specified trigger conditions are found. Once a trigger condition is met, the oscilloscope graphs a single time period and leaves this on the display until another trigger condition is met. Once the new trigger event occurs, the oscilloscope graphs the signal again. Periodic waveforms will appear stationary, because they will cross the trigger level at routine intervals.

Auto Mode: If the specified trigger conditions are not found, triggers are forced and acquisitions are made so that signal activity is displayed on the oscilloscope.

A.6.2.7 Measuring Waveforms

Once your waveforms are scaled and triggered appropriately, you can configure the oscilloscope to perform measurements using the 'Meas' button in the Measure control. You can change the source you are measuring by pressing the 'Type' option when the measure menu opens. Selecting 'Voltage' allows you to display peak voltages, RMS and average values, percentage overshoot and more. Selecting 'Time' allows you to measure the frequency, duty cycle and many other time-related properties of the waveform.

It is important to realise that the measurements and their accuracy depend on the degree to which the signal is present on the screen. If you wanted to measure the amplitude of a sine wave accurately, you should scale the waveform so that it fills the display, without clipping at the top.

You can measure a waveform quickly using the *Volts/div* setting of the X and Y Axis and the boxes in the screen of the Oscilloscope. However, to achieve accurate measurements, the Oscilloscope provides cursors, which are enabled by pressing the "Cursors" button in the Measure control.

Cursors are horizontal and vertical markers that indicate X-axis values (usually time) and Y-axis values (your voltages or currents) on a selected waveform source.

The cursor measurement has three modes: Manual, Track Waveform and Measure.

- **Manual**
  In this mode, the screen displays two parallel cursors. Move the cursors to make custom voltage or time measurements of the signal. Use Cursors knob to select and adjust.
- **Track Waveform**
  In this mode, the screen displays two cross cursors. The cross cursor sets the position on the waveform automatically.
- **Measure**
  In this mode, cursors show locations used for the most recently added measurement.

When using the cursors, you can get measurements by:

- Position of Cursor A (Time cursor centered on the midpoint of screen; Voltage cursor centered on channel ground level).
- Position of Cursor B (Time cursor centered on the midpoint of screen; Voltage cursor centered on channel ground level).
- Read the horizontal space between Cursor A and B (ΔX): Time between cursors, units in seconds.
- ($1/\Delta X$), units in Hz, kHz, MHz, GHz.
- Vertical space between cursor A and B (ΔY): Voltage between cursors, units in V.

A.6.2.8 Some Other Facilities

Compensate Passive Probes

How do you know that your oscilloscope is not faulty? You could

(a) ask the tutor;

(b) try another oscilloscope;

(c) test it;

(d) none of the above.

On each occasion that you use an oscilloscope, **the answer must be (c)**. This can be done, because in most oscilloscopes there is a probe compensation socket or terminal (see number 19 in Figure A.6.10) which generates a known waveform at a specified voltage and frequency. If you observe your oscilloscope carefully, you would find the peak-to-peak value of the voltage for a square wave. You can use this signal to test your oscilloscope, both Channel 1 and Channel 2. Should your oscilloscope not read the voltage specified by the compensation output, it is out of calibration and it needs to be calibrated (see Figure A.6.11).

⚠ It is a good habit to test your oscilloscope before taking your measurements, otherwise you may have to repeat all your measurements should your oscilloscope be out of calibration.

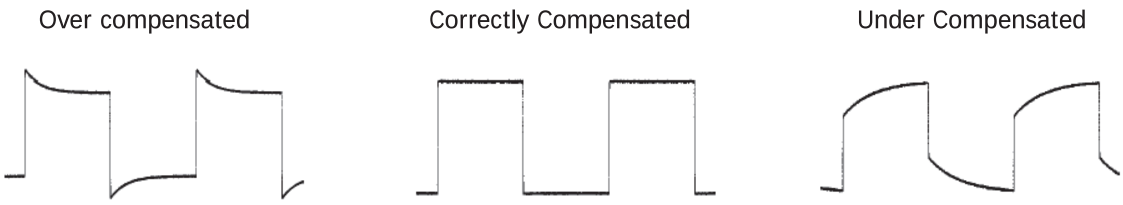


Figure A.6.11: Proper Calibration.

Mains Ground Input

The oscilloscope amplifiers are CONNECTED INTERNALLY to the mains earth of the power point, as is the chassis-frame of the oscilloscope. When the oscilloscope leads are plugged into the Channel 1 and Channel 2 sockets, all the black crocodile clips or hooks, but not the probe, are also connected internally to earth.

⚠ **Important: There must be only one earth in your circuit.**

All the earth leads from the oscilloscope must be connected to the one point in your circuit, where the earth symbol is shown. The terms "Floating" and "Earthed" may be confusing and should be clearly understood. Refer to the notes on Section A.4, for more information.