Lab Manual

EE3301 - Analog Electronics

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Introduction

The following material contained in this text was written with the intent to guide and assist the student in obtaining the maximum educational benefit from the module EE3301 Analog Electronics. This lab manual is intended to enhance the learning experience of the student in topics encountered in EE3301. In this lab, students are expected to gain experience in using the electronic devices used in electronic engineering and in interpreting the results of measurement operations in terms of the concepts introduced in the module. How the student performs in the lab depends on his/her preparation, participation, and teamwork. Each team member must participate in all aspects of the lab to ensure a thorough understanding of the equipment and new concepts.

The student's goals should be

To relate the laboratory experiments to theory modules and reinforce the principles learned in the classroom.

- To obtain practice and develop an interest in planning an experimental test.
- To obtain practice in interacting with the experiment and with other personnel involved in the group effort.
- To develop a proficient style in technical communication, both written and oral.
- To develop an appreciation of the open ended type of problems in research and design and the multiple paths available in the problem solution.

The overall objective is to improve the students' capabilities in these areas and thereby increase their professional competence. It is expected that students will perform and develop in laboratory modules with the same attitude and goals as in theory-oriented modules.

Responsibilities

The student, instructor and the lecturer have certain responsibilities towards successful completion of the laboratory's goals and objectives, which are listed below.

1. **Student Responsibilities**

- Read the laboratory manual and related text books before coming to the laboratory class
- Carry out any pre laboratory preparation which may include carrying out some calculations
- Consult your instructor to solve any problems that you might have encountered
- Do not wait till the last moment to consult your instructor
- Actively participate in all laboratory activities
- Understand the procedure of each laboratory session
- Stay alert and use commonsense while performing the laboratory experiment
- Keep a professional and accurate record of the experiments in the note book.
- Report any errors in the laboratory manual to the instructors.

2. **Instructor Responsibilities**

- Familiarize with each laboratory prior to the class.
- Provide the students with a syllabus and safety review during the first class.
- Provide the students with Instructor's office hours, telephone number, and the name of the lecturer in charge.
- Make sure that all the necessary equipment and other material preparations for the laboratory are available in working condition.
- Answer any questions posed by the students and supervise the students performing the laboratory experiments.
- Grade the pre-laboratories, laboratory notebooks, and reports in a fair and timely manner.
- Reports should be returned to the students in the next laboratory period following submission.
- Report any errors in the laboratory manual to the lecturer in charge.

3. **Lecturer Responsibilities**

- Insure that the laboratory is properly equipped,
- Resolve any questions or problems identified by the Instructor or the students.
- Make any necessary corrections to this manual.
- Insure that the soft copy of the manual is regularly updated and available.

Laboratory Policy and Grading

The student should understand the following policy.

Attendance

Attendance is mandatory and any absence must be for a valid excuse and must be documented or informed earlier if possible.

Laboratory records

The student must

1. Perform the Pre-Lab assignment before the initiation of each laboratory.
2. Maintain a NOTEBOOK to keep the records and perform the pre-laboratory sessions.
3. Complete and submit the lab reports to the instructors on or before the deadline.

Grading policy:

20% of the marks are being allocated for Laboratories. Grading for each laboratory class includes Pre-lab, viva, observations and discussion sections. The distribution of marks for each category is mentioned in the provided laboratory report.

Use of Laboratory Equipment

One of the major goals of this laboratory is to familiarize the student with the proper equipment and techniques for designing basic electronic circuits. Some understanding of the laboratory equipment is necessary to avoid personal or equipment damage. By understanding the device's purpose and following a few simple rules, costly mistakes can be avoided.

In general, all devices have physical limits. These limits are specified by the device manufacturer and are referred to as the device RATING. The ratings are usually expressed in terms of voltage limits, current limits, or power limits. It is up to the engineer to make sure that these ratings (limit valves) are not exceeded in device operation. The following rules provide a guideline for instrument protection.

Instrument Protection Rules

- Set instrument scales to the highest range before applying power.
- When using an oscilloscope, especially one with a cathode ray tube, do not leave a bright dot or trace on the screen for long periods of time. To avoid burning the image into the screen, reduce the intensity until the dot or trace is barely visible.
- Be sure instrument grounds are connected properly. Avoid accidental grounding of "hot" leads, i.e., those that are above ground potential.
- Check polarity markings and connections of equipment and components carefully before connecting or turning on power.
- Never connect an ammeter across a voltage source. **Only connect ammeters in series with loads.** An ammeter is a low-resistance device that, if connected in parallel, will short out most components and usually destroy the ammeter or its protecting fuse.
- Do not exceed the voltage and current ratings of equipment or other circuit elements.
- Make sure any fuse or circuit breaker is of suiTable value. When connecting electrical elements to make up a circuit, it is easy to lose track of various points in the network and accidentally connect a wire to the wrong place. A procedure to follow that helps to avoid this is to connect the main series portion of the network first, then go back and add the elements in parallel. As an element is added, place a small check (√) by it on your circuit diagram. This will help you keep track of your progress in assembling the whole circuit. Then go back and **verify all connections** before turning on the power. [One day someone's life may depend upon your making sure that all has been done correctly.]

General Laboratory Safety Rules

In addition, department of Electrical and Information Engineering is committed to provide a safe laboratory environment for all students. The students and staff are required to adhere to general laboratory safety rules in all department operated laboratories.

- Shoes shall be worn that provide full coverage of the fee, and appropriate personal clothing shall be worn in laboratories.

- Students shall be familiar with the locations and operation of safety and emergency equipment such as, emergency power off, fire extinguishers and emergency exits.

- Do not displace or remove laboratory equipment without instructor or technician authorization.

- Never open or remove cover of equipment in the laboratories without instructor authorization.

- Report all problems to the relevant technical officer.

Description of Laboratory Equipment related to EE3301 Laboratories

1. Voltmeter

A voltmeter shown in Figure 1 is an instrument that measures the difference in electrical potential between two points in an electric circuit. An analog voltmeter moves a pointer across a scale in proportion to the circuit's voltage. In order to measure a device's voltage, voltmeter must be connected in parallel to that device.

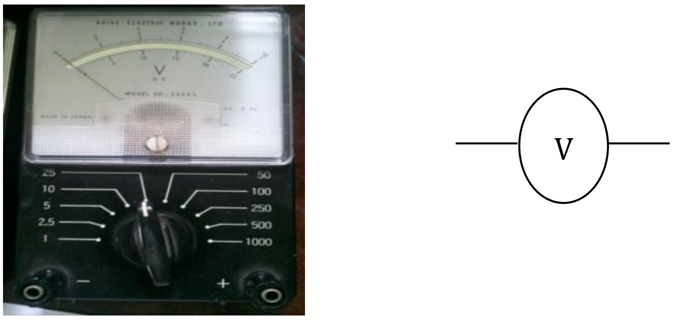


Figure 1: Voltmeter and its symbolic representation

Scale and Connection

Prior to measuring, correct voltage range should be selected from the voltmeter. To measure the potential difference across R_2, probes of the voltmeter should be placed at the end point of R_2.

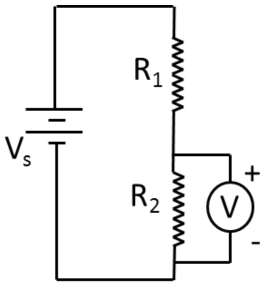


Figure 2: Connecting a Voltmeter across a Resistor

Figure 3: Probes

Way of connecting a voltmeter across a resistor is shown in Figure 2. Generally, red colour probe is the positive terminal and the black color one is the negative terminal as shown in Figure 3.

Note:

DC measurements ➔ DC voltmeter

AC measurements ➔ AC voltmeter

2. Ammeter

An ammeter measures the electric current in a circuit. In order for an ammeter to measure a device's current; it must be connected in series to that device. This is necessary because objects in series experience the same current. They must not be directly connected across a voltage source because ammeters are designed to work under a minimal burden, typically a small fraction of a volt. . Figure 4 shows a picture of an ammeter.

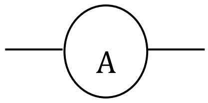


Figure 4: Ammeter and its symbolic representation

Scale and Connection

Prior to measuring, correct current range should be selected from the ammeter. To measure the current flowing through R_1, probes of the ammeter should be placed in series with R_1.

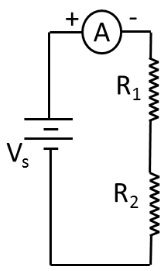


Figure 5: Connecting an Ammeter in Series with a Resistor

Way of connecting an ammeter in series with resistor is shown in Figure 5. Generally red colour probe is the positive terminal and the black color one is the negative terminal.

Note:

DC measurements ➔ DC ammeter
AC measurements ➔ AC ammeter

3. Multimeter

A multi-meter or a multi-tester, also known as a VOM (Volt-Ohm meter) shown in Figure 6, is an electronic measuring instrument that combines several measurement functions in one unit. A typical multimeter may include features such as the ability to measure voltage, current and resistance. Multimeters may use analog or digital circuits—analog multi-meters (AMM) and digital multi-meters (often abbreviated DMM or DVOM.) Analog equipment are usually based on a micro-ammeter whose pointer moves over a scale calibrated for all the different measurements that can be made; digital equipment usually display digits, but may display a bar of a length proportional to the quantity being measured.

Figure 6: Multimeter

Components

A multimeter has three parts: Display, Selection Knob, Ports.

The display usually has four digits and the ability to display a negative sign. The selection knob allows the user to set the multimeter to read different things such as milliamps (mA) of current, voltage (V) and resistance (Ω).

Two probes are plugged into two of the ports on the front of the unit. COM stands for common and is almost always connected to Ground or '-' of a circuit. The COM probe is conventionally black, but there is no difference between the red probe and black probe other than color. 10A is the special port used when measuring large currents (greater than 200mA). mAVΩ is the port that the red probe is conventionally plugged in to. This port allows the measurement of current (mA), voltage (V), and resistance (Ω).

Scale

Multi-meters generally do not feature auto ranging. You have to set the multimeter to a range that it can measure. If you set it incorrectly, you will probably see the meter screen reading as '1'.

Procedure of measuring Voltage

1. If you're measuring DC voltage you have to set the knob to DC voltage setting. For AC voltage you need to use the AC voltage setting.
2. Plug the black probe into COM and the red probe into mAVΩ as shown in Figure 7.
3. Set the multimeter to correct range.
4. Connect the black probe to the circuit's ground or '-' and the red probe to power or '+'.

Figure 7: Measuring Voltage of a Battery

Procedure of measuring Resistance

1. Set the multimeter to the 20kΩ setting.
2. Then hold the probes against the resistor legs as shown in Figure 8. The meter will read one of three things, 0.00, 1, or the actual resistor value.
3. If the meter reads 9.90, well then you've got a 9.90k Ohm (Ω) resistor (remember you are in the 20kΩ or 20,000 Ohm mode so you need to move the decimal three places to the right or 9,900 Ohms).
4. If the multimeter reads 1 or displays OL, it's overloaded. You will need to try a higher mode such as 200 kΩ mode or 2 MΩ (mega-ohm) mode. There is no harm if this happen, it simply means the range knob needs to be adjusted.
5. If the multimeter reads 0.00 or nearly zero, then you need to lower the mode to 2 kΩ or 200 Ω.

Figure 8: Measuring Resistance of a Resistor

Procedure of measuring current

1. You need to determine whether or not the circuit is AC or DC by measuring the voltage of the circuit as described in previous steps.
2. Set the multimeter to the same mode (AC or DC) amps as the voltage in the circuit, otherwise it will indicate 0.
3. Then you have to select correct range.
4. You have to measure current in series, to measure current you have to physically interrupt the flow of current and put the meter in line. Connect the black probe to the circuit's ground or '-' and the red probe to power or '+'.

Continuity test

Continuity testing is the act of testing the resistance between two points. If there is very low resistance (less than a few Ωs), the two points are connected electrically and the multi-meter will respond with a 'beep' tone. If there is more than a few Ωs of resistance, than the circuit is considered open circuited and no tone will come out. This test helps to ensure that connections are continuous between two points of a circuit.

Note: Most multi-meters will only measure currents in the ranges of μA and mA.

4. Oscilloscope

An oscilloscope is commonly used to display and analyze the waveform of electronic signals. In effect, the device draws a graph of the instantaneous signal voltage as a function of time. The vertical (Y) axis represents voltage and the horizontal (X) axis represents time.

Procedure for initializing Digital Oscilloscope

1. Power up the oscilloscope by pressing the power button as shown in Figure 9.

Figure 9: Oscilloscope Power up

2. Push and turn the probe connector until it slides on the connector. Then, turn the locking ring Clockwise to lock the connector as shown in Figure 10.

Figure 10: Connecting the Probe

3. Use the probe slide switch to set the probe attenuation as shown in Figure 11. (if required)

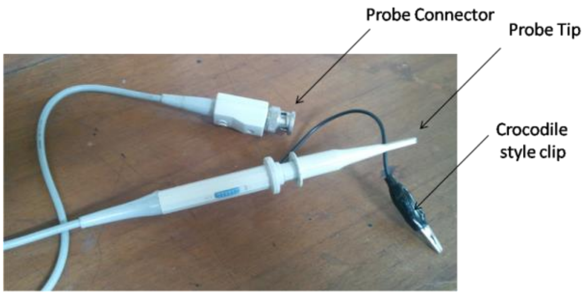


Figure 11: Oscilloscope Probe

4. Attach the probe's crocodile style clip to the ground lead as shown in Figure 12.

Figure 12: Connecting the Common Ground

5. Attach the probe tip to the square wave output located at the front face of the oscilloscope as shown in Figure 13. (This Connector outlet provides a square wave which is use to confirm the functionalities of the probe and oscilloscope)

Figure 13: Connecting the Probe Yip

6. Press the front panel setup button and select auto set (The oscilloscope automatically set the vertical, horizontal and trigger settings for a sTable display of the signal)
7. If the oscilloscope is displaying a clean square wave pattern of 1 KHz on the screen, the oscilloscope is ready to use.
8. If step 7 is ok detach the probe and connect it to your signal output and repeat step 6 (make sure that ground lead of the oscilloscope and you circuit ground are common)

Note: Use the knobs on the front face of the oscilloscope to change voltage division scale, time division scale, horizontal position, vertical position etc. .

Oscilloscope measurements

1. Press the "measure" button as shown in Figure 14.

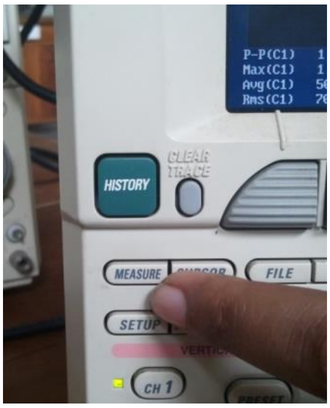


Figure 14: Measure Button

2. Select the "Item Setup" tab from the menu displayed in the bottom of the display as shown in Figure 15.

Figure 15: Item Set up

3. Select the channel of which you are going to take the measurements.
4. Select the desired measuring items from the menu displayed as shown in Figure 16. You may use the jog shuttle and rotary knob for this purpose as shown in Figure 17.

Figure 16: Selecting the Parameters

Figure 17: Jog Shuttle and Rotary Knob

5. Select “copy all to trace” when you are done.
6. Press “ESC”.

Cursor measurements

1. Press the “cursor” button as shown in Figure 18.

Figure 18: Cursor

2. Select the “Type” tab from the menu displayed in the bottom of the display as shown in Figure 19.

Figure 19: Selecting Type

3. Select the type of the required cursors (horizontal, vertical etc) from the menu displayed in the bottom of the display as shown in Figure 20.
   Note: Horizontal cursor corresponds to voltage measurements and the vertical cursor corresponds to time measurements.

Figure 20: Selecting Cursor Type

4. The position of the cursors can be varied by selecting the relevant cursor/ or both cursors using the jog shuttle and rotary knob as shown in Figure 21.

Figure 21: Toggling Between the Cursors

5. The measurements at each position of the 2 cursors and the difference of the measurements will be displayed on the screen.

5. DC Power Supply

Laboratory DC Power Supply shown in Figure 22 is used to power up the circuits during the laboratory tests. DC power supplies can be used to generate positive and negative voltages for powering electrical components such as operational amplifiers.

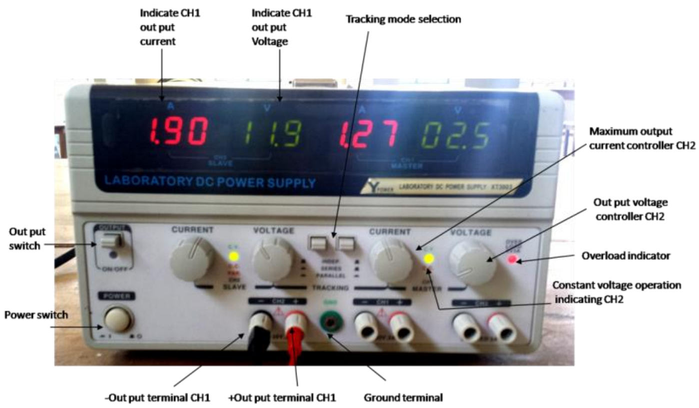


Figure 22: Typical Power Supply used in the Laboratory

Independent operation

1. Disengage both Tracking mode switches so that the power supply is in the independent operating mode.
2. Adjust “Voltage” control and “Current” control to the desired output voltage and current
3. Turn off the power supply and the equipment to be powered during hook-up
4. Connect the positive polarity of the device being powered to the red (+) terminal of the power supply as shown in Figure 23.
5. Connect the negative polarity of the device being powered to the black (-) terminal of the power supply
6. Push the output switch to power up the load

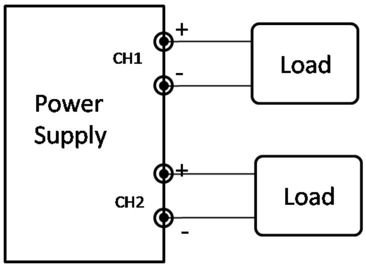


Figure 23: Connection to DC Power Supply using Channels Individually

Series tracking operation

The Series tracking mode is shown in Figure 24. In the series tracking mode, the maximum output voltage of both CH1 and CH2 supplies can be simultaneously varied with one control. The maximum CH2 supply voltage is automatically set to same as the CH1 supply by using the CH1 VOLTAGE controls.

1. Set the power supplies to the Tracking series mode by engaging the left Tracking switch and release the right tracking switch.
2. Set the CH2 CURRENT control to the full clockwise position. The maximum current is set by using the CH1 CURRENT control.
3. Adjust the output voltage to the desired level by using the CH1 VOLTAGE controls.
4. Turn off the power supply and the equipment to be powered during hook-up.
5. If “single supply” operation is desired, this allows the power supply to be used as twice the voltage and rating current simply by using the negative terminal of the CH2 supply and the positive terminal of the CH1 supply, the configuration as shown in Figure.

6. Push the output switch to power up the load.

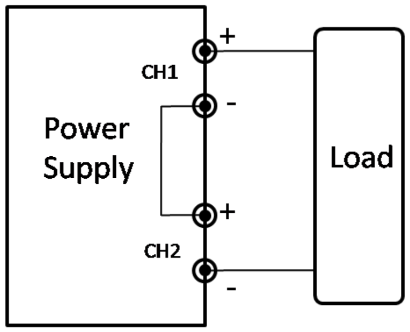


Figure 24: Series Tracking Operation

6. Function Generator

Signal/Function generator shown in Figure 25 is a device which produces simple repetitive waveforms. Such devices contain an electronic oscillator, a circuit that is capable of creating a repetitive waveform. (Modern devices may use digital signal processing to synthesize waveforms, followed by a digital to analog converter, or DAC, to produce an analog output). The most common waveform is a sine wave, but sawtooth, step (pulse), square, and triangular waveform oscillators are commonly available as are arbitrary waveform generators (AWGs). If the oscillator operates above the audio frequency range (>20 kHz), the generator will often include some sort of modulation function such as amplitude modulation (AM), frequency modulation (FM), or phase modulation (PM) as well as a second oscillator that provides an audio frequency modulation waveform.

The GFG-8200A product family offers a complete solution in generating signals at the frequency ranges of 3and5 MHz All models are embedded with standard functions such as TTL/CMOS/Ramp output, External Voltage Controlled Frequency (VCF), as well as built-in 6-digit counter (except for GFG-8215A). Further versatility of Logarithmic and Linear sweep is added into GFG-8255A/8219A/8217A, while GCV output feature and AM/FM modulation are available in GFG-8255A/8219A. All these integrated functions and user-friendly operations of the GFG-8200A series are made to accommodate the applications in audio response testing, vibration testing, servo system evaluation, ultra sound applications, etc.

Figure 25: Typical Function Generator used in the Laboratory

Figure 26: Function Generator Probe

The Silver color lead end of the probe shown in Figure 26 is connected to the output port of the function generator to get a desired signal output. According to the standard, the red color terminal is considered as positive terminal and black color terminal considered as negative terminal.

7. Basic Electronic Components

Resistors

A **resistor** is a passive two-terminal electrical component that implements electrical resistance as a circuit element. Resistors act to reduce current flow, and, at the same time, act to lower voltage levels within circuits. In electronic circuits, resistors are used to limit current flow, to adjust signal levels, bias active elements, terminate transmission lines among other uses. High-power resistors that can dissipate many watts of electrical power as heat may be used as part of motor controls, in power distribution systems, or as test loads for generators. Fixed resistors have resistances that only change slightly with temperature, time or operating voltage. Variable resistors can be used to adjust circuit elements (such as a volume control or a lamp dimmer), or as sensing devices for heat, light, humidity, force, or chemical activity. A particular fixed resistor and a variable resistor are shown in Figure 27.

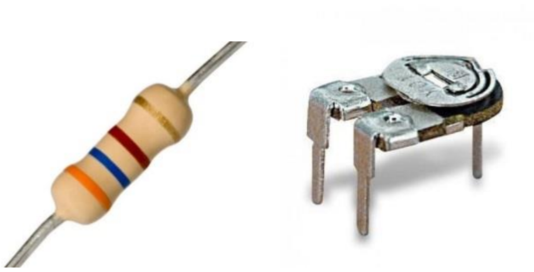


Figure 27: Fixed Resistor and a Variable Resistor

Capacitors

A **capacitor** (originally known as a condenser) is a passive two-terminal electrical component used to store energy electrostatically in an electric field. The forms of practical capacitors vary widely, but all contain at least two electrical conductors (plates) separated by a dielectric (i.e. insulator). The conductors can be thin films, foils or sintered beads of metal or conductive electrolyte, etc. The nonconducting dielectric acts to increase the capacitor's charge capacity. A dielectric can be glass, ceramic, plastic film, air, vacuums, paper, mica, oxide layer etc. Capacitors are widely used as parts of electrical circuits in many common electrical devices. Unlike a resistor, an ideal capacitor does not dissipate energy. Instead, a capacitor stores energy in the form of an electrostatic field between its plates. Several types of capacitors used in the laboratory are shown in Figure 28.

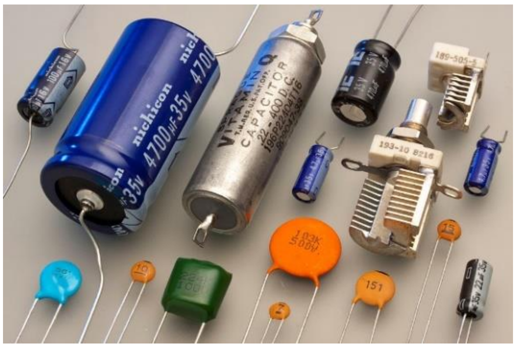


Figure 28: Various Capacitor Types used in the Laboratory

Inductors

An **inductor**, also called a coil or reactor, is a passive two-terminal electrical component which resists changes in electric current passing through it. It consists of a conductor such as a wire, usually wound into a coil. When a current flows through it, energy is stored temporarily in a magnetic field in the coil. When the current flowing through an inductor changes, the time-varying magnetic field induces a voltage in the conductor, according to Faraday’s law of electromagnetic induction, which opposes the change in current that created it. As a result, inductors always oppose a change in current, in the same way that a flywheel oppose a change in rotational velocity. Care should be taken not to confuse this with the resistance provided by a resistor.

An inductor is characterized by its inductance, the ratio of the voltage to the rate of change of current, which has units of Henries (H). Inductors have values that typically range from 1 μH (10^{-6}H) to 1 H. Many inductors have a magnetic core made of iron or ferrite inside the coil, which serves to increase the magnetic field and thus the inductance. Along with capacitors and resistors, inductors are one of the three passive linear circuit elements that make up electric circuits. Inductors are widely used in alternating current (AC) electronic equipment, particularly in radio equipment. They are used to block AC while allowing DC to pass; inductors designed for this purpose are called chokes. They are also used in electronic filters to separate signals of different frequencies, and in combination with capacitors to make tuned circuits, used to tune radio and TV receivers. Various inductor types used in the laboratory are shown in Figure 29.

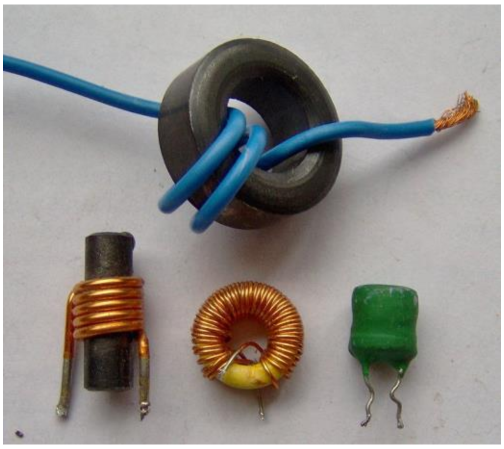


Figure 29: Various Inductor Types used in the Laboratory

Laboratory Notebooks and Reports

The Laboratory Notebook

The student records and interprets his/her experiments via the laboratory notebook and the laboratory report. The laboratory notebook is essential in recording the methodology and results of an experiment. In engineering practice, the laboratory notebook serves as an invaluable reference to the technique used in the laboratory and is essential when trying to duplicate a result or write a report. Therefore, it is important to learn to keep an accurate notebook.

The laboratory notebook should

- Contain the experiment's title, the date, the equipment and equipment used,
- Circuit diagrams, the procedure used, the data (often in Tables when several measurements have been made), and the analysis of the results.
- Contain plots of data and sketches when these are appropriate in the recording and analysis of observations.
- Be an accurate and permanent record of the data obtained during the experiment and the analysis of the results. You will need this record when you are ready to prepare a laboratory report.

The Laboratory Report

The laboratory report is the primary means of communicating your experience and conclusions to other professionals. In this module you will use the laboratory report to inform your Instructor what you did and what you have learned from the experience. Engineering results are meaningless unless they can be communicated to others. Your laboratory report should be clear and concise.

Even though you will work with one or more laboratory partners, your report must (shall) be the result of your individual effort in order to provide you with practice in technical communication.

Laboratory 01

The Operation of Semiconductor Diodes and their Practical Applications

INTRODUCTION:

This experiment is to acquaint the student with the operation of semiconductor diodes. From current-voltage (I-V) characteristics of a silicon diode, you will determine several diode parameters including the cut-in voltage, V_γ; and the breakdown voltage, V_{BR}. You will also study the operation of half-wave and full-wave rectifiers, and the effect of smoothing filters. Furthermore, you will study the use of diodes in wave-shaping (clipper) circuits and in level-shifting (clamper) circuits. Finally, you will be able to use the knowledge gained in the diode experiments to design a dc power supply to meet certain specifications.

EDUCATIONAL OBJECTIVES:

- To understand about the operation of semiconductor diodes.
- To study about the operation of rectifiers and smoothing filters.
- To study the use of diodes in clipper and clamper circuits.
- To design a DC power supply with certain specifications.

EXPERIMENTAL OBJECTIVES:

- Determine several diode parameters by using the current-voltage (I-V) characteristics of a silicon diode.
- DC voltage (V_{dc}), the ripple factor (RF), ripple voltage (V_r), and root mean square voltages (V_{rms} and V_r (rms)) of a power supply.
- Measure and sketch the input voltage (V_{in}) and output voltage (V_o) of clipping and clamping circuits.

PRE-LAB:

Reading:

1. Read and study the Background section of this Laboratory.

.**Written**:

1. Describe the operation of P-N junction
2. What are the differences between a normal diode and a Zener diode?

EQUIPMENT NEEDED:

- Breadboard
- Variable power supply
- IN4007 Diode, Zener Diode
- Resistors – 1 kΩ, 470 Ω, 100 kΩ
- Capacitors – 10 µF, 47 µF
- 230 /6 V Transformer

- Function Generator
- Oscilloscope

BACKGROUND

Diode Structure

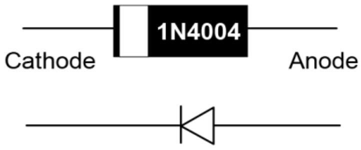


Figure 1: Diode Structure

The physical and schematic circuit symbol of the diode is shown in Figure 1. The band on the diode and the bar on the left of the circuit symbol represent the cathode (n-type material) and must be noted. The p-type material (the anode) in the diode is located to the right. The circuit symbol of the diode is an arrow showing forward bias, when the p-side is positive with respect to the n-side, and the direction of the arrow represents the direction of large current flow.

Forward and Reverse Diode I-V Characteristics

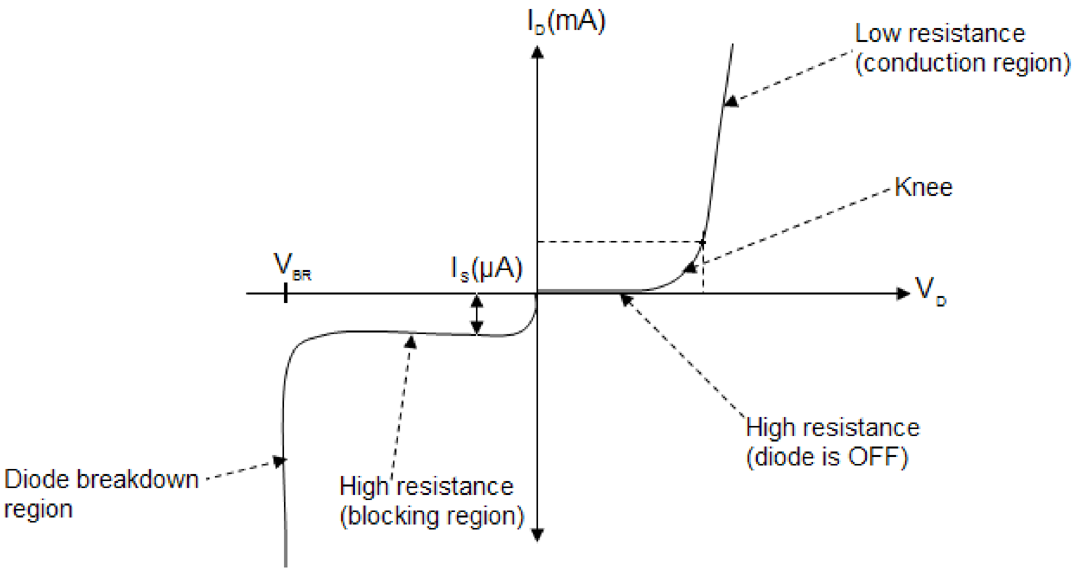


Figure 2: Forward and reverse diode I-V characteristics

The combination of the forward and reverse characteristics curve is shown in Figure 2. Appreciable conduction occurs from around 0.4 V to 0.7 V for Silicon and from around 0.2 V to 0.4 V for Germanium at room temperature. The value of cut off voltage (V_γ) is a function of the current at which V_γ is measured. If the applied voltage exceeds V_γ, the diode current increases rapidly.

If the diode is reverse-biased, only the small reverse current (the reverse saturation current or the reverse leakage current), $-I_s$, flows. This current flows as long as the applied reverse voltage does not exceed the diode breakdown voltage, V_{BR}. If the reverse voltage exceeds V_{BR}, a large amount of current flows and the diode may be destroyed if there is not enough series resistance to limit the diode current. In silicon diodes, $I_{s\ may}$ be very small and V_{BR} may be very large. Both of these values may be immeasurable on the curve tracers for diodes.

The diode can be used to change the wave shape of an incoming signal. When used as a rectifier, the asymmetrical properties of the diode's current-voltage characteristics can be used to convert an AC signal into a DC signal. The rectification can either be a half-wave or full-wave.

Half – Wave Rectifier

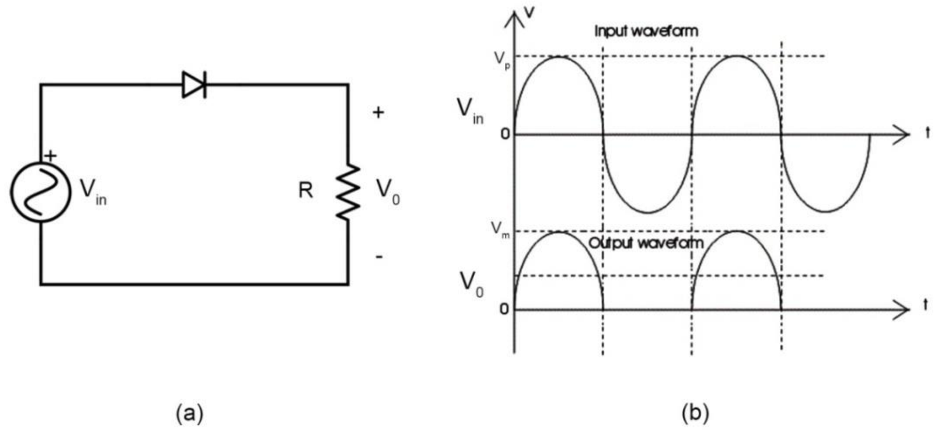


Figure 3: (a) A half-wave rectifier circuit (b) Input voltage waveform and Rectified waveform

A basic half-wave diode rectifier circuit is shown in Figure 3(a). During the positive half-cycle of the input voltage, the diode is forward-biased for all instantaneous voltages greater than the diode cut off voltage, V_γ. Current flowing through the diode during the positive half-cycle produces approximately a half sine wave of voltages across the load resistor, as shown in the lower part of Figure 3(b). To simplify our discussions, we will assume that the diode is ideal and that the peak input voltage is always much larger than the V_γ of the diode. Hence, we assume that the zero of the rectified voltage coincides with the zero of the input voltage. On the negative half-cycle of the input voltage, the diode is reverse-biased. Ignoring the reverse leakage current of the diode, the load current drops to zero, resulting in zero load voltage (output voltage), as shown in Figure 32(b). Thus, the diode circuit has rectified the input ac voltage, converting the ac voltage to a dc voltage.

The average or dc value of this simple half-wave rectified signal, V_{dc}, is given by

$$V_{dC} = \left(\frac{1}{T}\right)\int_{o}^{\frac{T}{2}} V_m sin\left(\frac{(2\pi t)}{T}\right)\mathrm{d}t = \frac{V_m}{\pi} = 0.318V_m \qquad (1)$$

V_m - the peak value of the rectified signal.

Full – wave Rectifier

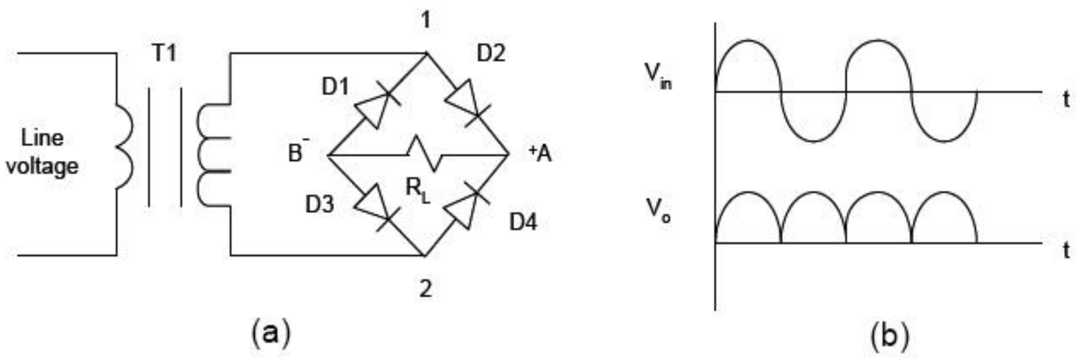


Figure 4: (a) Full wave bridge rectifier circuit (b) Input and Rectified waveforms

A full-wave bridge rectifier with a load resistor R_L and an input sine wave derived from a transformer is shown in Figure 4(a). During the positive half-cycle of the input voltage, diodes D2 and D3 are forward biased and diodes D1 and D4 are reverse biased. Therefore, terminal A is positive and terminal B is negative. During the negative half-cycle, diodes D1 and D4 conduct, and again terminal A is positive and terminal B is negative. Thus, on either half-cycle, the load voltage has the same polarity and the load current is in the same direction, no matter which pair of diodes is conducting. The full-wave rectified signal is shown in Figure 4(b), with the V_O being the output voltage.

Since the area under the curve of the full-wave rectified signal is twice that of the half-wave rectified signal, the average or dc value of the full-wave rectified signal, V_{dc}, is twice that of the half-wave rectifier.

$$V_{dc} = \frac{2V_m}{\pi} = 0.636V_m \qquad (2)$$

Filtering

The rectifier circuits discussed above provide a pulsating dc voltage at the output. These pulsations are known as "ripple". The uses for this kind of output are limited to charging batteries, running dc motors, and a few other applications where a constant dc voltage is not necessary. For most electronic circuits, however, a constant dc voltage similar to that from a battery is required. To convert a half-wave or full-wave rectified voltage with ripple into a more constant dc voltage; a smoothing filter must be used at the rectifier's output.

A popular smoothing filter is the capacitor-resistor filter, which consists of a single capacitor in parallel with the load resistor. Figure 5 shows such a filter connected to the output of a half- wave rectifier. The output wave shape of the filtered half-wave rectifier is similar to that shown in Figure 6, assuming that the time constant of the R_LC filter is comparable to the period of the input voltage.

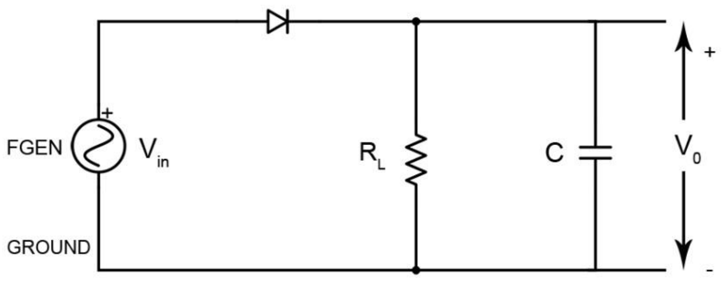


Figure 5: Rectifier circuit with an RC smoothing filer

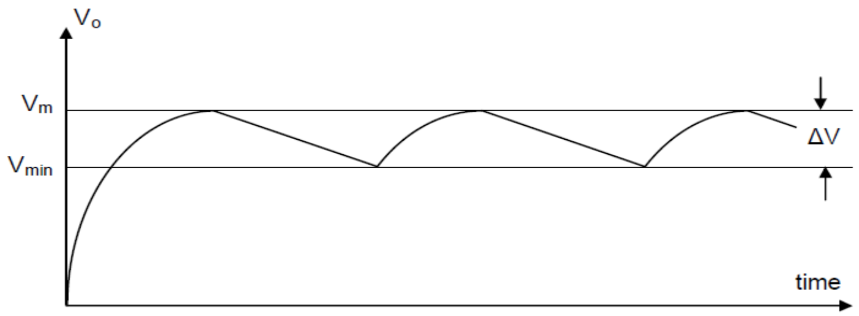


Figure 6: Output wave shape from a full-wave filtered rectifier

Notice that the output wave shape still has ripple, but the ripple is now saw-tooth or triangular shaped, and its variation is much less than that of the unfiltered pulses. The difference between the maximum and minimum of the filtered voltage is known as the Ripple Voltage (V_r).

$$V_r \equiv \Delta V = V_m - V_{min} \qquad (3)$$

where,

V_m = peak value of the rectified signal (smaller than the V_{in}, due to V_γ and R_s),

V_{min} = the minimum of the filtered voltage. V_{min} increases as the ripple voltage decreases

R_s = Source Resistance

The design equation for selecting this capacitor is

$$\frac{V_r}{V_m} = \frac{T}{R_L C} = \frac{1}{f_P R_L C} \qquad (4)$$

where,

R_L = load resistance

I_L = load current

C = filter capacitance

T = $1/f_p$ = the period of the rectified wave

For a half-wave rectifier, f_p is the frequency of the input voltage. For a full-wave rectifier, f_p is twice the frequency of the input voltage. The output of the filtered voltage for a full-wave rectifier is shown in Figure 6.

From Figure 6, the amount of ripple in the output signal is ΔV ($=V_r$) determined. From Equation 4, For the ripple voltage V_r to be small, the R_LC time constant must be large. In other words, the ripple can be reduced by increasing the discharging time constant R_LC. Hence, increasing either C or R_L will reduce the ripple voltage. It should be noted that the resistor R_L is usually inside a commercial power supply and any external load connected to the power supply is in parallel with R_L and acts both to lower the total load resistance and to increase the ripple. This is why an audible hum is often heard from power supplies when the external load resistance drops to a very low value.

Two Figures of merit for power supplies are the ripple voltage, V_r, and the ripple factor, RF. V_r has already been defined. RF is defined as

$$RF = V_r(rms) / V_{dc}. \tag{5}$$

$V_r(rms)$ is the RMS value of the ripple voltage. The value of $V_r(rms)$ can be calculated for various input wave shapes. For a complicated wave shape, such as that shown in Figure 6, the value of $V_r(rms)$ is calculated as if the filtered, rectified wave were a triangular wave, for which

$$V_{r(rms)} = \frac{V_m - V_{min}}{2\sqrt{3}} = \frac{V_r}{2\sqrt{3}} \tag{6}$$

V_r and $V_r(rms)$ are different.

For a sinusoidal input,

$V_{dc} = V_m/\pi = 0.318\ V_m$ for an unfiltered half-wave rectifier

and

$V_{dc} = 2V_m/\pi = 0.636\ V_m$ for an unfiltered full-wave rectifier

Clippers

Wave shaping is often achieved by relatively simple combinations of diodes, resistors, and voltage sources. Such circuits are called clippers, limiters, amplitude selectors, or slicers. Clipper circuits are primarily used to prevent a waveform from exceeding a particular limit, either positive or negative. For example, one may need to limit a power supply's output voltage so it does not exceed +5 V.

Figure 7 shows a positive clipper circuit. As indicated, the output voltage has the entire positive half-cycles clipped off. The circuit works as follows: During the positive half-cycle of the input voltage, the diode turns on. For an ideal diode, the output voltage is zero. For an actual diode the output voltage is equal to $V\gamma$, the cut-in voltage of the diode.

During the negative half-cycle, the diode is reverse-biased and can be approximated by an open circuit. In many clippers, the load resistor, R_L, is much larger than the series resistor, R. In which case, essentially all of the negative half-cycle voltage appears at the output through voltage-divider action. If R_L and R are comparable, then on the negative half-cycle, the output voltage would be given by

$$V_o = V_{p1} = V_p\,(R_L/(R_L+R))$$

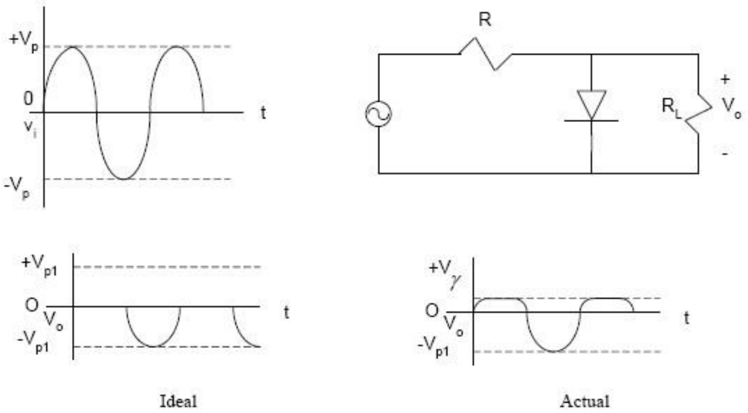
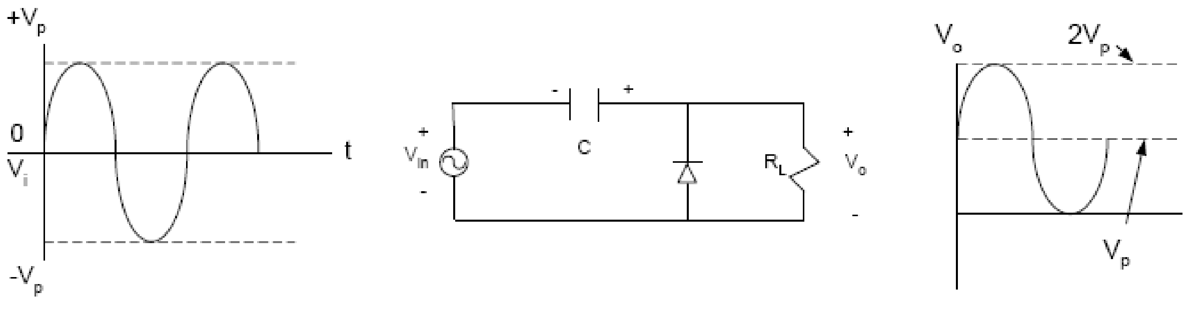


Figure 7: A positive clipper circuit: (a) Sinusoidal input to clipper circuit; (b) A positive clipper circuit; (c) Output of ideal positive clipper circuit; and (d) Output of actual positive clipper circuit

Clampers

In certain instances, it may be desirable to keep the output waveform essentially unchanged, but modify its dc level to some required value. This can be done by the use of diodes, resistors, capacitors, and voltage sources. Such circuits are known as clampers. For example, if the input voltage signal swings from -10 V to +10 V, a positive dc clamper can produce an output that keeps the signal wave shape intact but swings the voltage from 0V to +20V. TV receivers use a dc clamper to add a dc voltage to the video signal. Here the dc clamper is usually called a dc restorer.

In Figure 8(b) a positive dc clamper is shown. The clamper operates as follows: During the negative half-cycle of the input voltage, the diode turns on as illustrated in Figure 8(a). At the negative peak, the capacitor charges up to V_p with the polarity shown and the output voltage is zero. As the voltage grows beyond the negative peak, the diode shuts off as shown in Figure 8(b).



(a) (b) (c)

Figure 8: Positive dc clamper: (a) Sinusoidal input to positive dc clamper; (b) Positive dc clamper; and (c) Clamped sinusoidal output

The capacitor retains the voltage for a short time. The R_LC time constant is deliberately made much larger than the period, T, of the input signal. Hence, the capacitor remains almost fully charged during the entire off time of the diode. The capacitor thus acts like a battery of V_p volts and now only passes the ac signal, which rides on top of V_P. The output voltage signal, therefore, consists of the input signal riding on a dc voltage of $+V_p$ volts.

PROCEDURE

Part I: Simple Diode Circuits

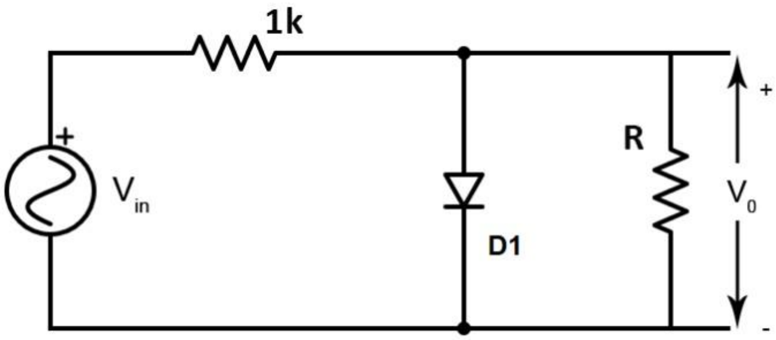


Figure 9: Simple Diode Circuit

I. Build the circuit shown in Figure 9 on the breadboard with R=1 kΩ . Use the IN4007 diode.

II. Using the Function Generator, set the frequency of the input signal to 50 Hz and vary the input voltage V_{in}(pk-pk) from 0 V to 5 V in increments of 0.5 V and record the output voltage V_o(pk-pk) using oscilloscope.

III. Sketch the observed waveforms for V_{in}=1 V and V_{in}=3 V respectively.

Table 1: Measured V_o for circuit in Figure 9

$V_{in(pk-pk)}$ (volts)	**$V_{0(pk-pk)}$ (volts)**
0.0	
0.5	
1.0	
1.5	
2.0	
2.5	
3.0	
3.5	
4.0	
4.5	
5.0	

Part II: Zener Diode Circuits

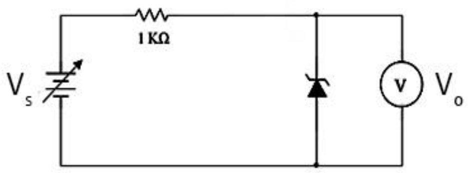


Figure 10 : Simple zener diode circuit

I. Connect the circuit as shown in Figure 10, the power supply is set to zero volts.

II. Measure and record in the Table 2, the reverse voltage (V_o) in the diode at each level of voltage (V_s).

Table 2 :

V_s (Volts)	0	2	4	6	8	10	12	14	16
V_o (Volts)									

Part III: Half-Wave Rectifier and Full-Wave Rectifier

A. Half-Wave Rectifier

I. Build the circuit shown in Figure 5 on the breadboard.
II. Select R_L and C values according to the Table 3.
III. Set the frequency of the function generator to 50 Hz. Adjust the function generator amplitude as needed to ensure that $V_{p-p} = 8$ V.
IV. Connect the oscilloscope across the resistor R_L.
V. Record the values of V_m and V_{min} in Table 3.
VI. Compute V_r, V_r(rms), V_{dc}, Ripple Factor.
VII. Draw the output voltage (V_o) waveform without capacitor and with C= 47μF capacitor.
VIII. Calculate the theoretical value of V_r and fill the Table 3.

B. Full-Wave Rectifier

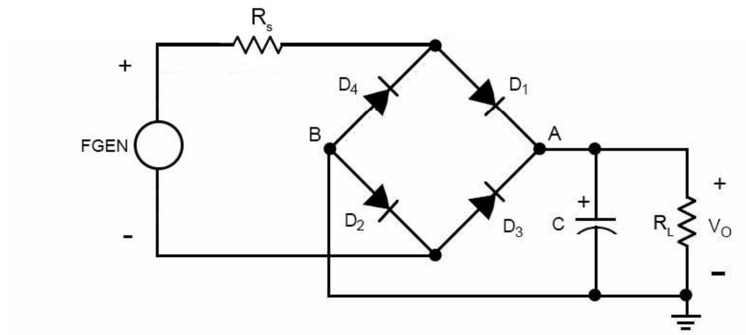


Figure 11: Full-wave rectifier with voltage-dropping series resistor R_S

I. Build the circuit shown in Figure 11 on the breadboard.
II. Select R_L and C values according to the Table 3.
III. Use the Transformer provided to set the input voltage, $V_{p-p} = 18$ V.
IV. Connect the oscilloscope across the resistor R_L.
V. Record the values of V_m and V_{min} in Table 3.
VI. Compute Vr, Vr(rms), V_{dc}, Ripple Factor.
VII. Draw the output voltage (V_o) waveform without capacitor and with C= 47μF capacitor.
VIII. Calculate the theoretical value of V_r and fill the Table 3.

Table 3: Extreme Cases of R_L and C

	Part 1: Half Wave Rectifier		Part2: Full Wave Rectifier	
	R_L = 470 Ω C = 10 μF	R_L = 100 kΩ C = 47 μF	R_L = 470 Ω C = 10 μF	R_L = 100 kΩ C = 47 μF
Vm				
Vmin				
V_r (Experimental)				
V_r(rms)				
V_{dc}				
Ripple Factor				
V_r (Theoretical)				

Part IV: Clippers

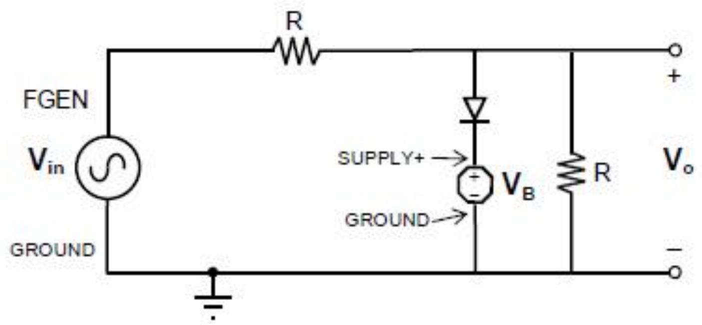


Figure 12: Clipping Circuit

I. Connect the circuit as shown in Figure 12. Select R=1 KΩ and variable power supply as V_B.

II. Set V_{in} (pk-pk)=12 V with 50 Hz frequency, V_B=0 V and observe the output waveform V_o using the oscilloscope.

III. Make an accurate sketch of the input and output waveforms on the same graph, making note of the peak values of V_o (minimum V_o and maximum V_o) and the input voltage at which clipping occurs.

IV. Set V_B (SUPPLY+) =2 V and repeat above steps.

Part V: Clampers

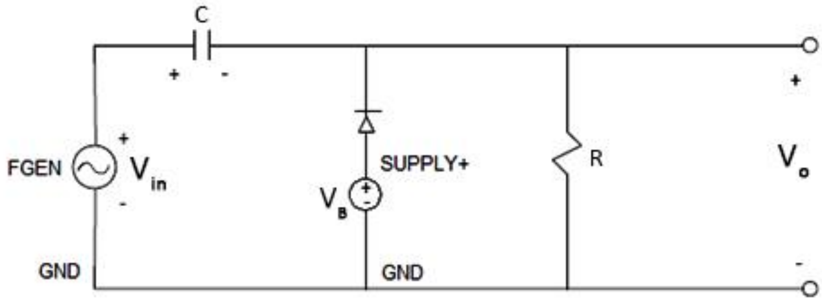


Figure 13: Clamping circuit

I. Connect the circuit as shown in Figure 13. Select R=100 KΩ, C=47 μF and variable power supply as V_B.

II. Set V_{in} (pk-pk) =12 V with 50 Hz frequency, V_B=0 V and observe the output waveform V_o using the oscilloscope.

III. Make an accurate sketch of the input and output waveforms on the same graph, making note of the peak values of V_o (minimum V_o and maximum V_o) and the input voltage at which clamping occurs.

IV. Set V_B (SUPPLY+) =2 V and repeat above steps.

Laboratory 02

Basic Amplifiers and Biasing

INTRODUCTION: The purpose of the lab is to measure the DC operating point of a single transistor amplifier, extract the most important AC parameters of an NPN bipolar transistor, examining the properties of the BJT amplifier configurations and to investigate their small signal performance. This laboratory will emphasize the measurement of the operating point (I_{BQ}, I_{CQ} and V_{CEQ}); input and output impedances and voltage gain of common-emitter and common-collector topologies.

EDUCATIONAL OBJECTIVES:

- To get familiarized with BJT characteristics.
- To get familiarized with DC analysis techniques.

EXPERIMENTAL OBJECTIVES:

- Determine the characteristics of BJT in CE configuration.
- Determine the transistor amplification background.

PRE-LAB:

Reading:

2. Read and study the Background section of this Laboratory.
3. Read the data sheet of 2N2222 and identify the transistor type and pin configuration.

Written:

1. Assume the transistor you will use has a β of 155 and V_{BE}(on)=0.65 V. For the circuit in Figure 43, calculate the overall resistance (R_B pots) such that I_C=1 mA.

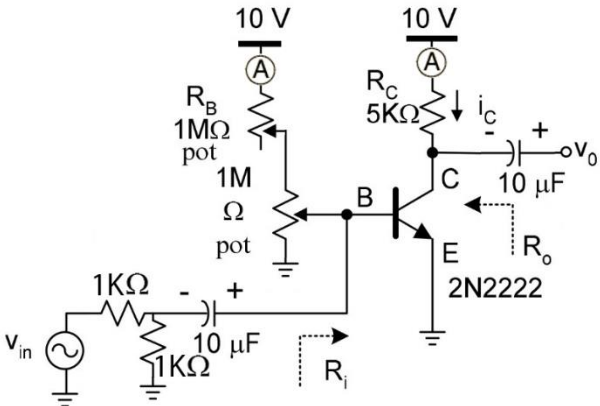


Figure 43: BJT transistor circuit 01

2. Compute the voltage V_C.
3. Find the values for the input impedance R_i, output impedance R_o
4. Find the value of the small signal voltage gain.

EQUIPMENT NEEDED:

- Dual Trace Oscilloscope
- Signal Generator
- Digital Multi-meter
- Dual Power Supply
- 2N2222 transistors
- 1 potentiometer of 1 MΩ
- Resistors
- Capacitors
- Project board
- Milli ammeter
- Micro ammeter

BACKGROUND

A Bipolar Junction Transistor (BJT) is shown in Figure 1(a) is a three-terminal semiconductor device capable of amplifying an AC signal. The three terminals are called the emitter, the base, and the collector. The device is made up three "layers" of p-type and n-type semiconductor material. BJTs consist of a thin base layer (either P- or N-type) sandwiched between two layers of the opposite type material. Thus, BJTs are either NPN or PNP. They are somewhat like two interconnected, back to back diodes, with two diode junctions.

The symbol of an NPN-BJT transistor is shown in Figure 1(b). Since the dependence of I_C on V_{BE} is exponential, the collector current varies drastically as the base-emitter voltage changes. A small current I_B flows into the base terminal because of V_{BE} variations; usually it is a small fraction of the collector current I_C. We call the ratio of I_C to I_B the current gain of the transistor that is denoted by β. The value varies significantly with temperature, and can be different between two transistors of the same type.

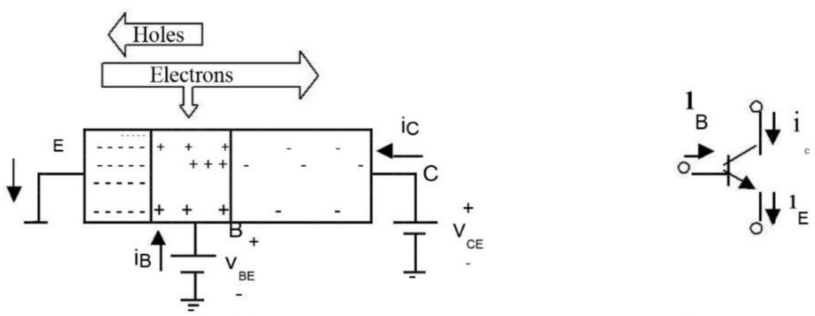


Figure 1: (a) NPN Transistor and (b) its symbol

The bipolar junction transistor (BJT) has three regions of operation:

1. Cutoff Region: If both base-emitter and base-collector junctions are reverse biased, the BJT transistor enters the cutoff region. All terminal currents are extremely small and we say the transistor is off.
2. Active Region: The base-emitter junction must be forward biased and the base-collector junction reverse biased to make a BJT transistor work in the active region. The active region is desired to design a linear amplifier.
3. Saturation Region: When both the base-emitter and collector-base junctions are forward biased, the saturation region is entered.

BJTs are used to amplify current, using a small base current to control a large current between the collector and the emitter. This amplification is so important that one of the most noted parameters of transistors is the dc current gain, β, which is the ratio of collector current to base current:

$$I_C = \beta \cdot I_B$$

In this lab you will measure several such parameters, discussed in paragraphs below.

The terminology for transistors includes a lot of subscripts. Generally, the subscripts mean:

C → Collector

E → Emitter

B → Base

Hence, V_{CE} is the collector-emitter voltage; V_{BE} is the base-emitter voltage; and I_B is the base current. One relationship to keep in mind is that I_C is always less than I_E. In fact,

$$I_E = I_C + I_B.$$

Three configurations for connecting bipolar junction transistors are common-base, common emitter, and common-collector. A large number of transistor circuits use the BJT connected in the common-emitter (CE) or grounded-emitter configuration. In the CE configuration, the input current and output voltage are the independent variables, while the input voltage and output current are the dependent variables.

In this experiment, the input and output characteristics of a transistor will be measured. The input characteristics are plots of I_B versus V_{BE} at constant values of V_{CE}. These characteristics will look like diode characteristics, particularly if the collector is shorted to the emitter and the emitter-base junction is forward biased. I_B will be plotted as a function of V_{BE}. Since the characteristics will be measured under dc conditions, the dc currents and voltages will be specified.

The output characteristics, often called the collector characteristics, are plots of I_C versus V_{CE} at constant values of I_B and have 3 basic regions of transistor operation.

These regions are the cutoff, the active, and the saturated regions. If a BJT transistor is to be used as an amplifier, it will usually be operated in the active region, where the relationship between the input current, I_B, and the output current, I_C, is nearly linear; that is, $I_C = \beta \cdot I_B$,

If the transistor is to be used in digital circuitry, it will be operated in the saturated or cutoff Conditions and will only be in the active region when switching from one condition to the other.

I_C vs V_{CE} Characteristics for BJT are shown in Figure 2.

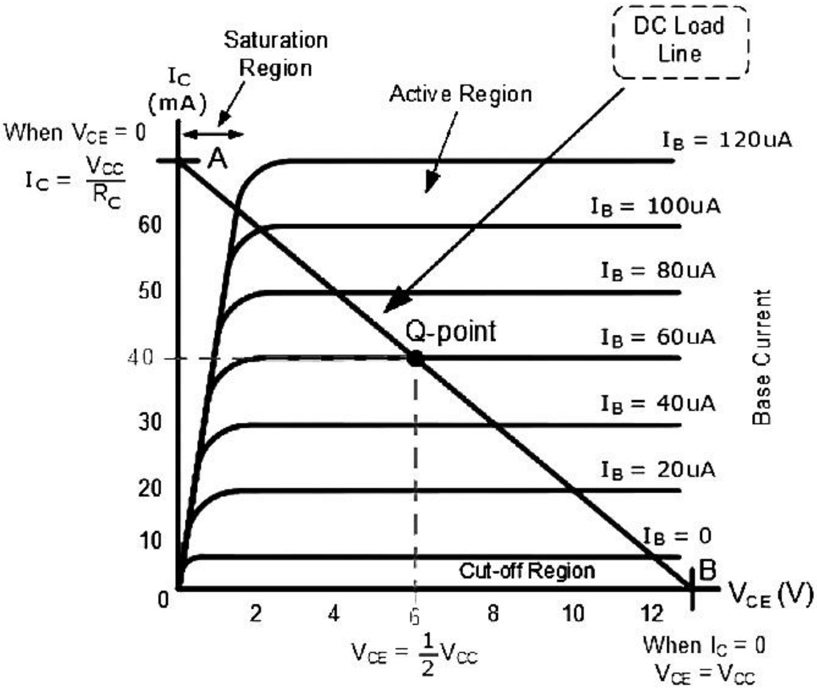


Figure 2: I_C vs V_{CE} Characteristics for BJT

Transistor basic dc analysis equations can be given as below with reference to Figure 3,

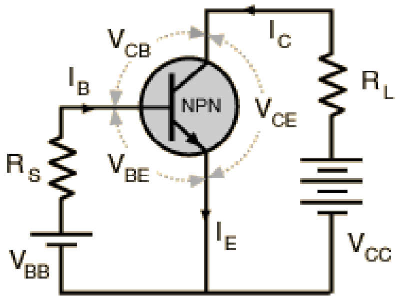


Figure 3: Basic Common Emitter BJT Circuit Diagram

$$V_{CC} = I_C.R_L + V_{CE}$$

$$V_{BB} = I_B.R_S + V_{BE}$$

$$A_V = \frac{V_{OUT}}{V_{IN}} = \frac{I_C R_{OUT}}{I_B R_{IN}}$$

PROCEDURE

1. Measure the actual values of Rc (5KΩ) and Rb (1MΩ pots) resistors that will be used in the lab.
2. Connect the circuit in Figure 43. The power supplies are 10V.
3. Adjust the potentiometer so that the voltage across Rc is 5V. Measure the voltage across Rb (remember to measure any new values for Rb if changed). Use Ohm's Law and the actual values of Rc and Rb to compute I_B and I_C.
4. Use the equation of the current gain to compute β.
5. Measure I_B and I_C using milli ammeter and micro ammeter and compute β using equation of current gain.
6. Set the potentiometers to its maximum resistance and then adjust the potentiometers so that V_{BE} in the range of 0 to 0.8V with linear increments of 0.1V (use finer increments if need be). Measure and record V_{BE}, V_C, I_B and I_C
7. Plot V_C vs V_{BE}, I_B vs V_{BE} and I_C vs I_B
8. Replace R_C by 1KΩ and adjust the potentiometers to change I_B from 0 to 100 µA with linear increments of 20µA, for each I_B measurements adjust V_{CE} from 0 to 10V with linear increments of 2V for each step measure and record I_B, I_C, and V_{CE}.
9. Plot I_C vs V_{CE} for different I_B's.
10. Replace R_C by 5KΩ and adjust potentiometer such that V_{CE}=5V and apply a sinusoidal signal of 10 KHz and amplitude of 70 mV at the input of the amplifier. And observe the output waveform from the oscilloscope.
11. Calculate voltage gain and hence calculate R_{IN} and R_{OUT}

DISCUSSION:

1. What are the reasons for the difference of two calculated β values in steps 4 and 5
2. Comment about V_C vs V_{BE}, I_B vs V_{BE} and I_C vs I_B graphs related with transistor biasing concept.
3. Comment about the input waveform and output waveform obtained in step 10 using voltage gain of the transistor.

Laboratory 03

Operational Amplifiers and Applications

INTRODUCTION: The purpose of this experiment is to identify and analyze of application of operational amplifiers. This lab sheet gives an introduction to these amplifiers and a smattering of the various configurations that they can be used in. Apart from their most common use as amplifiers (both inverting and non-inverting), they also find applications as adders, integrators, logarithmic amplifiers, differentiators, impedance converters, filters.

EDUCATIONAL OBJECTIVES:

1. Understand the main characteristics of operational amplifiers (op-amps).
2. Analyze and implement amplifier circuits using op-amps, including inverting, non-inverting, summing, integrator, and differentiator amplifiers, Schmitt Trigger.

EXPERIMENTAL OBJECTIVES:

To sketch the following basic op-amp circuits and explains the operation of each

1. Inverting amplifier
2. Non-inverting amplifier
3. Summing amplifier
4. Integrator
5. Schmitt Trigger.

PRE-LAB:

1. A non-inverting amplifier has R_1 of 1KΩ Ω R_f of 100 KΩ. Determine V_f and β (Feedback voltage and feedback fraction), if V_O = 5V.
2. For the amplifier in Figure 1 determine the following: (a) $A_{CL(NI)}$ (b) V_O (c) V_f .

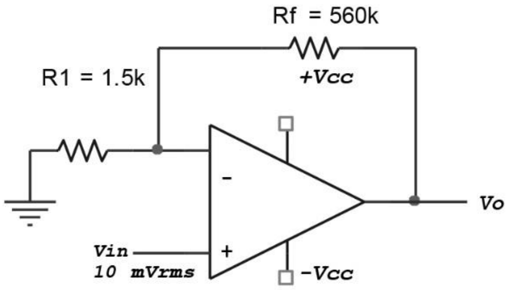


Figure 1

3. Find the value of R_f that will produce closed-loop gain of 300 in each amplifier in Figure 2.

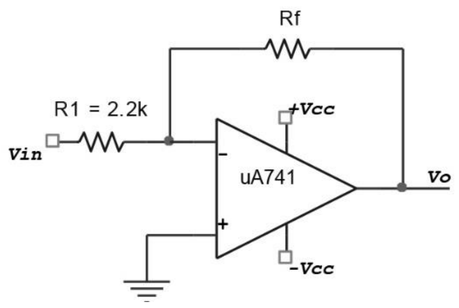


Figure 2

4. Determine the output voltage of each amplifier in Figure 3.

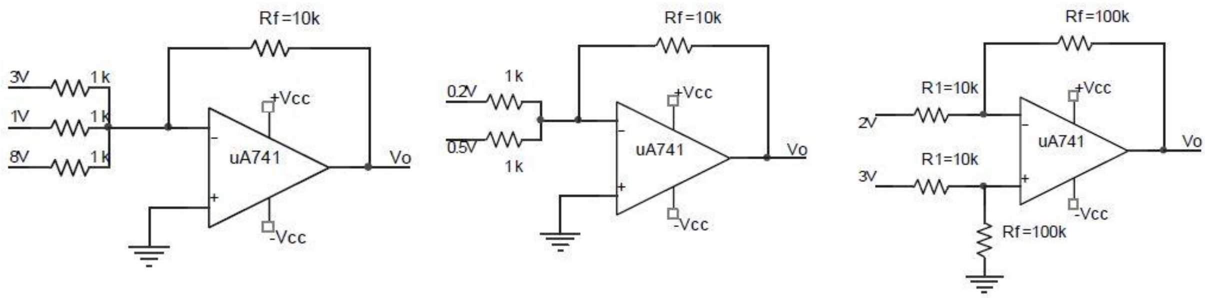


Figure 3

EQUIPMENT NEEDED:

- 741 Op-Amp
- Resistors (1K,10K,18K,1M)
- DC voltage Supply
- Capacitor (10 nF)
- Bread board, Multi-meter, and connecting wires.
- Function Generator
- Digital Storage Oscilloscope

BACKGROUND:

THEORY

In this laboratory experiment, you will learn several basic ways in which an op-amp can be connected using negative feedback to stabilize the gain and increase the frequency response. The extremely high open-loop gain of an op-amp creates an unsTable situation because a small noise voltage on the input can be amplified to a point where the amplifier in driven out of its linear region. Also unwanted oscillations can occur. In addition, the open-loop gain parameter of an op-amp can vary greatly from one device to the next. Negative feedback takes a portion of output and applies it back out of phase with the input, creating an effective reduction in gain. This closed-loop gain is usually much less than the open-loop gain and independent of it.

Closed – loop voltage gain, ACL

The closed-loop voltage gain is the voltage gain of an op-amp with external feedback. The amplifier configuration consists of the op-amp and an external negative feedback circuit that connects the output to the inverting input. The closed loop voltage gain is determined by the external component values and can be precisely controlled by them.

Non-inverting amplifier

- An op-amp connected in a closed-loop configuration as a non-inverting amplifier with a controlled amount of voltage gain is shown in Figure 4.

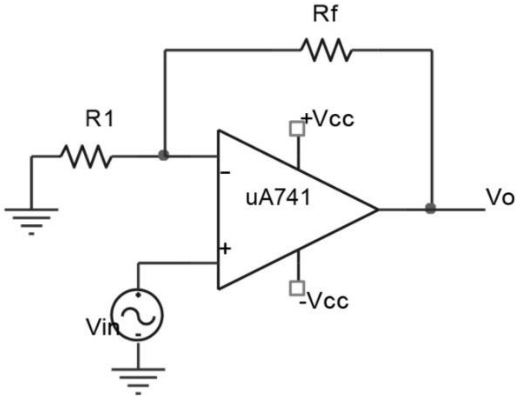


Figure 4: Non-inverting amplifier configuration of op-amp

The input signal is applied to the non-inverting (+) input. The output is applied back to the inverting (-) input through the feedback circuit (closed loop) formed by the input resistor R_1 and the feedback resistor R_f. This creates negative feedback as follows. Resistors R_1 and R_f form a voltage-divider circuit, which reduces V_0 and connects the reduced voltage V_f to the inverting input. The feedback is expressed as,

$$V_f = (\frac{R_1}{R_1 + R_f})Vo$$

The difference of the input voltage, V_{in} and the feedback voltage, V_f is the differential input of the op- amp. This differential voltage is amplified by the gain of the op-amp and produces an output voltage expressed as,

$$Vo = \left(1 + \frac{R_f}{R_1}\right) V_{in}$$

Inverting amplifier

An op-amp connected as an inverting amplifier with a controlled amount of voltage gain is shown in Figure 5.

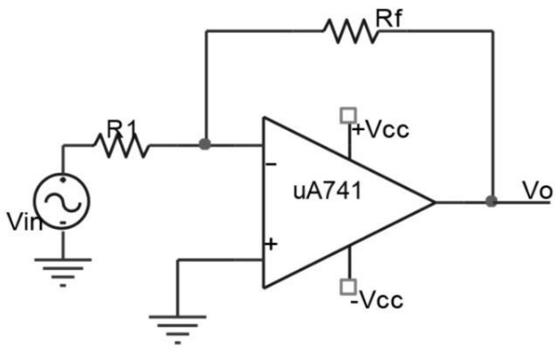


Figure 5: Inverting amplifier configuration of op-amp

The input signal is applied through a series input resistor R_1 to the inverting input. Also, the output is fed back through R_f to the same input. The non-inverting input is grounded. An expression for the output voltage of the inverting amplifier is written as

$$V_O = -\frac{R_f}{R_1} V_{in}$$

Summing amplifier

The summing amplifier is an application of the inverting op-amp configuration. The summing amplifier has two or more inputs, and its output age is proportional to the algebraic sum of its input voltages. Figure 6 shows a two-input inverting summing amplifier.

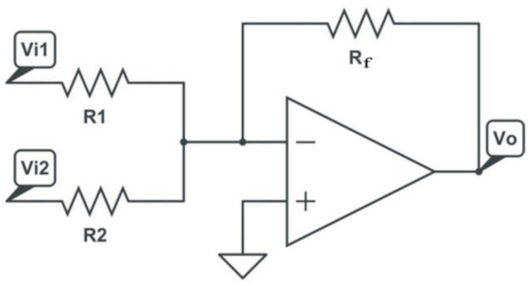


Figure 6: summing amplifier configuration of op-amp

Case-1:

If all the three resistors are equal R_1=R_2=R_f=R) then,

$$V_0 = -(V_{il} + V_{i2})$$

The above equation shows that the output voltage has the same magnitude as the sum of two input voltages but with a –ve sign indicating inversion.

Case-2:

When Rf is larger than the input resistors, the amplifier has a gain of $-R_f/R$.

where R is the value of each equal value input resistor (R1=R2=R). The general expression for the output is,

$$Vo = -\frac{R_f}{R}(V_{in1} + V_{in2})$$

The above equation shows that the output voltage has the same magnitude as the sum of all the input voltages multiplied by a constant determined by the ratio $-R_f/R$

Case-3:

By setting the ration Rf/R equal to the reciprocal of the number of inputs (n), i.e.,$\frac{R_f}{R} = \frac{1}{n}$

Summing amplifier can be made to produce the mathematical average of the input voltages.

Case-4:

A different weight can be assigned to each input of a summing amplifier by simply adjusting the values of the input resistors. In this case, the output voltage can be expressed as

$$Vo = -(\frac{R_f}{R_1}V_{in1} + \frac{R_f}{R_2}V_{in2})$$

The weight of a particular input is set by the ratio of Rf to Rx for the input (R_X= R1, R2, ….)

Integrator

An op-amp integrator simulates mathematical integration which is basically a summing process that determines the total area under the curve of a function i.e., the integrator does integration of the input voltage waveform. Here the input element is resistor and the feedback element is capacitor as shown in Figure 7.

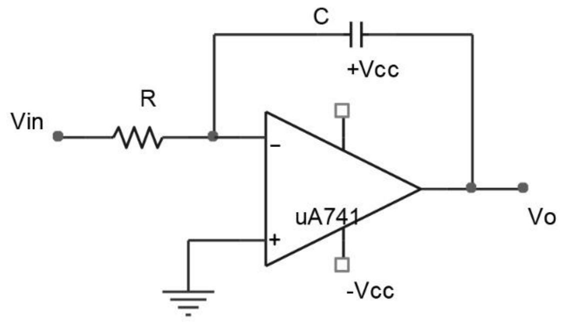


Figure 7: Basic op amps integrator

The output voltage is given by

$$V_O = -\frac{1}{RC}\int_o^t V_S dt + V_C(t=0)$$

Where V_C (t=0) is the initial voltage on the capacitor and RC is called as time constant of the integrator. For proper integration, R_C has to be much greater than the time period of the input signal.

Schmitt trigger

The Schmitt trigger is a variation of the simple comparator which has hysteresis, that is, it has a toggle action. It uses a positive feedback. When the output is high, positive feedback makes the switching level higher than it is when the output is low. A little positive feedback makes a comparator with better noise immunity. Now, to understand what causes the hysteresis let's analyze the circuit diagram of Figure 8 given below, using the same rules as in the previous section for the comparator. The key in understanding this circuit will again be in calculating the voltages that cause its output to switch. If V+ and V- are the actual voltages at the non-inverting and inverting terminals of the OPAMP, then the output will be the following, considering that V- = 0,

if V+ > 0, Vout ≈ V++

and

if V+ < 0, Vout ≈ V--

Since V_{out} changes its state whenever V+ crosses 0V, we need to find what value of V_{in} results in V+ = 0. The two values of V_{in} for which the output switches are called the trip points. V+ acts as a voltage divider formed by R1 and R2 between Vin and V_{out}. Thus the trip points of a non-inverting Schmitt trigger are:

$V_{in} = -V_{out}$ (R1/R2) (Lower trip point, LTP)

$V_{in} = + V_{out}$ (R1/R2) (Upper trip point, UTP)

Choosing suiTable ratios of R1 to R2, enough hysteresis can be created in order to prevent unwanted noise triggers. Circuit Diagram of Schmitt trigger,

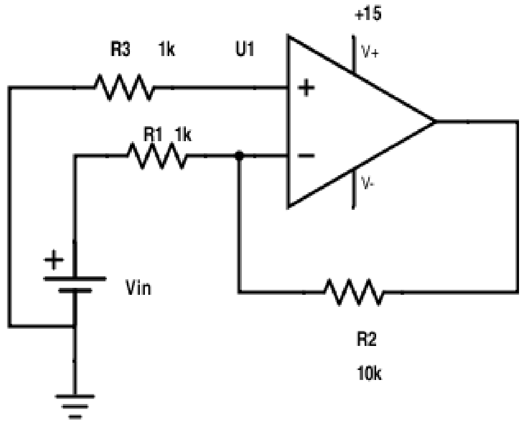


Figure 8: Inverting amplifier

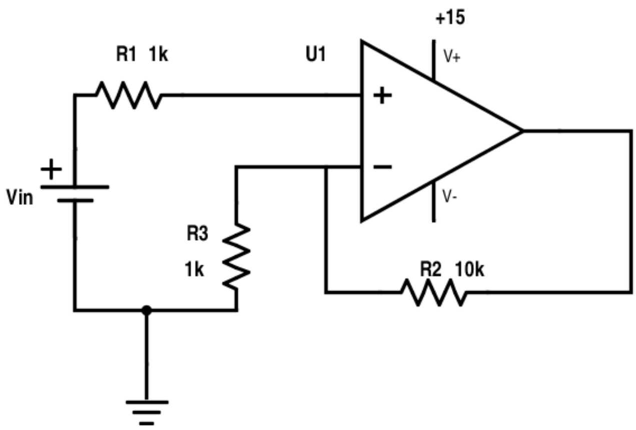


Figure 9: Non- inverting amplifier

Inverting amplifier is shown in Figure 8 and non-inverting amplifier is shown in Figure 9.

PROCEDURE:

(1) Non-Inverting amplifier

1. Assume that you are asked to design an amplifier using op-amps. The input signal V_{in} should be amplified by a factor of A. The maximum swing of the input signal is 200 mV pk-pk with a frequency of 1 kHz. The maximum output limits of the Op-amp should not be exceeded. Use supply voltage +10V and -10V.
2. Choose R1= 1 kΩ and R2=18 kΩ
3. Implement the circuit and give 1 kHz, 200mV pk-pk sine wave using the signal generator.
4. Observe the input and output voltage waveforms and measure the amplitudes of the voltages on a DSO. Tabulate the reading in Table 4.
5. Calculate closed-loop gain. Tabulate the readings in Table 4.

(2) Inverting amplifier

1. Build the inverting amplifier circuit by following the same procedure as for the non-inverting amplifier.
2. Observe the input and output voltage waveforms and measure the amplitudes of the voltages on a DSO. Tabulate the reading in Table 4.
3. Calculate closed-loop gain. Tabulate the readings in Table 4.

(3) Summing amplifier

1. Assemble an adder circuit with R_f =R_1= R_2=10 kΩ .
2. Feed sinusoidal input of amplitude 200mv and frequency 1 kHz to each input.
3. Observe the input and output voltage waveforms and measure the amplitudes of the voltages on a DSO. Tabulate the reading in Table 5.
4. Find the magnitude of the output voltage and tabulate the reading in Table 5.

(4) Integrator

1. Assemble an integrator circuit with R=1KΩ and C=10nf. Connect R_f of value 1MΩ across the capacitor.
2. Feed ±300mV, 500Hz square wave input.
3. Observe the input and output voltage waveforms and measure the amplitudes of the voltages on a DSO. Tabulate the reading in Table 4.
4. Calculate closed-loop gain. Tabulate the readings in Table 4.

(5) Schmitt Trigger

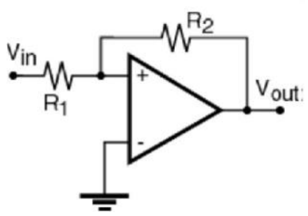


Figure 10: Schmitt Trigger

1. Construct the Schmitt trigger circuit in the above circuit diagram on the breadboard as shown in Figure 10. (R1=1K, R2=10K)
2. Connect the DC power supply at the input. Vary the input from a negative value to a positive value through 0.
3. Using the Digital Multi-meter, measure and tabulate V_{in} and V_{out}.
4. Make a plot of V_{out} vs V_{in}. Estimate the trip points from the graph (use external graph sheet and graph sheet should be attached to the lab report)
5. You can also look at the output using a DSO by coupling the output to it in DC mode.

DISCUSSION:

1. Show that $V_0 = \frac{-1}{RC}\int_0^T V_{in}\ dt$ for an integrator op amps circuit.
2. Plot the input and output voltage waveforms for following circuits on the same scale on a graph sheet. (Graph sheet should be attached to the lab report)
   - Inverting Amplifier
   - Non Inverting amplifier
   - Integrator
   - Summing Amplifier
   - Schmitt Trigger
3. A circuit known as a summing amplifier is illustrated in following Figure 11.
   i) Solve for the output voltage in terms of the input voltages and resistor values?
   ii) What is the input resistance seen by v_A?
   iii) By v_B?

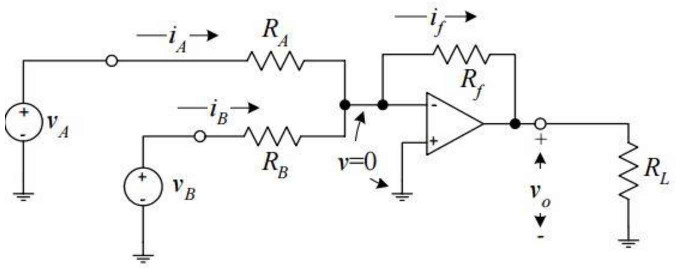


Figure 11: Example of a summing circuit

Laboratory 04

Oscillators and Analog Filters

INTRODUCTION: The purpose of the lab is to observe the characteristics of analog filters and oscillators. In this laboratory aim to design circuit, relevant to first order and second order Butterworth filters, Wein bridge oscillators and also square wave oscillators. In addition to that try to observe the behaviors of filters and oscillators by changing capacitor and resistor values.

EDUCATIONAL OBJECTIVES:

- To get familiarized with Oscillators.
- To get familiarized with Analog filters.

EXPERIMENTAL OBJECTIVES:

- Determine the characteristics of first order low pass Butterworth filter.
- Determine the characteristics of second order low pass Butterworth filter.
- Determine the characteristics of Wein bridge oscillator.
- Determine the characteristics of Square wave oscillator.

PRE-LAB:

Reading:

1. Read and study the datasheet of the LM741 op amp
2. Read and study the datasheet of the NE555.

EQUIPMENT NEEDED:

- Transistor : BC108
- Inductors : 40µH , 5.5 µH
- Potentiometer : 200k
- Capacitor : 2.2 µH(02) , 0.002 µH(02) , 0.1 µH(02) , 0.33 µH(02) , 1000pF(02) , 0.001 µH(02)
- Resistors : 1 kΩ(03) , 560 Ω , 1.2 kΩ , 56 kΩ , 10 kΩ(02) , 27 kΩ, 120 kΩ , 270 kΩ , 470 kΩ , 8.2 kΩ , 820 Ω , 5.6 kΩ , 22 kΩ(02)
- Signal Generator
- Dual trace oscilloscope
- Dual power supply
- Project board
- 741 Op-amp
- 555 timer

BACKGROUND

Part 1: Oscillators

Oscillators are a category of circuits, which produces a continuous alternating output signal without requiring an external input. There are two main types of oscillators, namely feedback oscillators and relaxation oscillators. Feedback oscillators may be further divided into resonant LC oscillators and RC oscillators.

A simple LC resonant oscillator is the Colpitts oscillator shown in Figure-1. It consists of a transistor amplifier and a LC resonant circuit. Amplifier output is fed back to its input via the LC circuit. The oscillating frequency of this oscillator is given by

$$f = \frac{\sqrt{(C1+C2)}}{2\pi\sqrt{L3C1C2}} \qquad \text{(i)}$$

A simple RC oscillator that uses an Op-amp in its circuit is shown in Figure-2. This oscillator circuit known as a Wein bridge oscillator and it's frequency given by

$$f = \frac{1}{2\pi RC} \qquad \text{(ii)}$$

Oscillations in relaxation oscillator are produced by the periodic charging and discharging of a capacitor. A square wave oscillator circuit based on the above principle is shown in Figure-3. This· circuit uses an IC commonly known as a 555 timer. The periodic time and the duty cycle of the square wave are determined by external circuit components R1, R2 and C.

$$\text{Periodic time} \qquad T = 0.693\,(R1 + 2R2)\,C \qquad \text{(iii)}$$

$$\text{Duty Cycle} \quad \frac{T_{ON}}{T} = \frac{R1+R1}{R1+2R2} \qquad \text{(iv)}$$

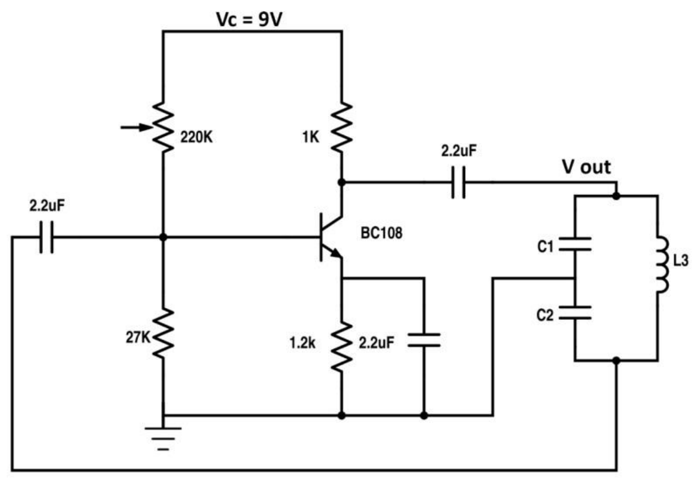


Figure 1

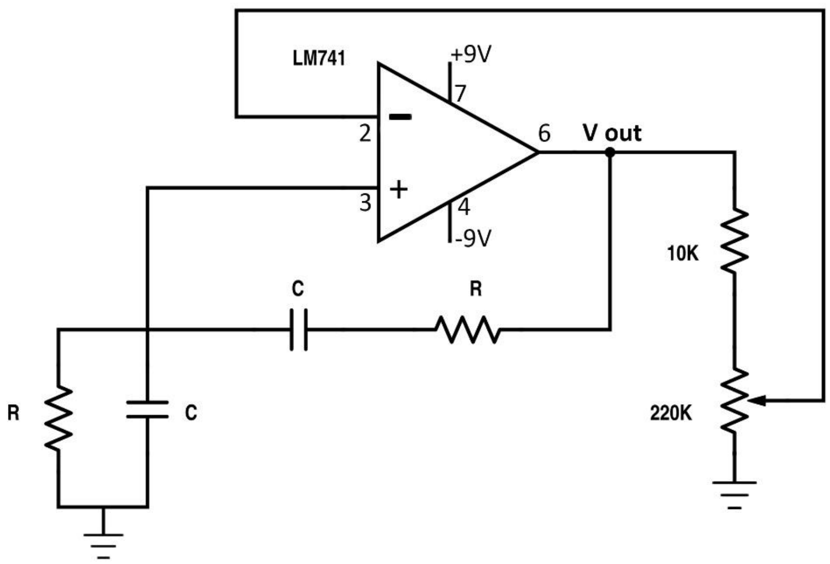


Figure 2: Wein Bridge Oscillator

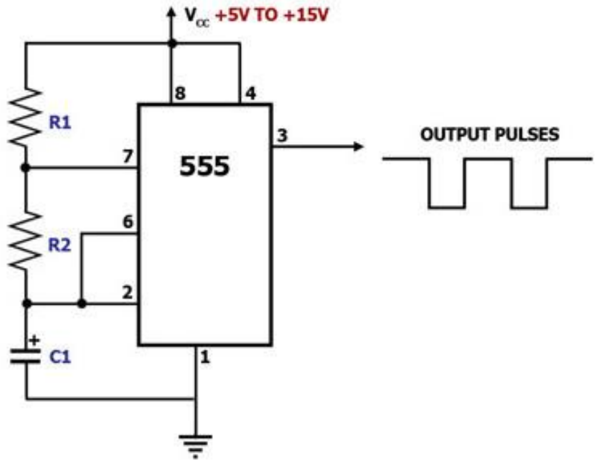


Figure 3: Square Wave Oscillator

Part 2: Analog Filters

A network designed to attenuate certain frequencies but pass others without attenuation is called a filter. A filter circuit thus possess at least one pass band, which is a band of frequencies in which the output is approximately equal to the input (attenuation is zero) and an attenuation band in which output is zero (attenuation is infinite). The frequencies that separate the various pass and attenuation bands are called the cutoff frequencies. Filters may be classified as low pass, high pass, band pass, band stop and all pass.

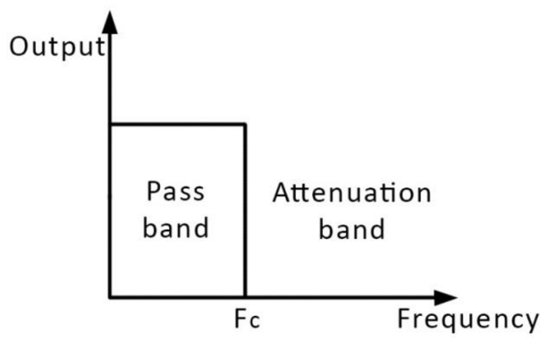


Figure 4

where Fc – cut-off frequency

The ideal response of a low pass filter is shown In Figure 4. At low frequencies, the output equals the input (i.e. Voltage gain is equal to unity). At very high frequencies output voltage is small as compared with the output voltage at low frequencies.

The practical response of a low pass filter is shown in Figure 5.

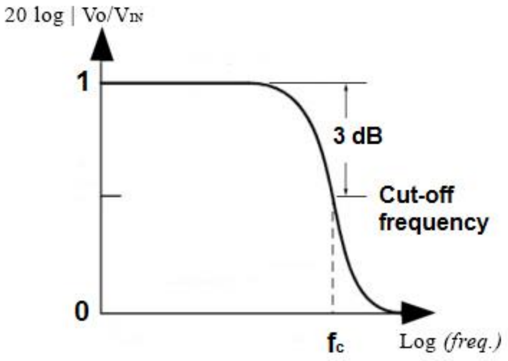


Figure 5

where Vo – Output voltage of the filter

V_{IN} – Input voltage of the filter

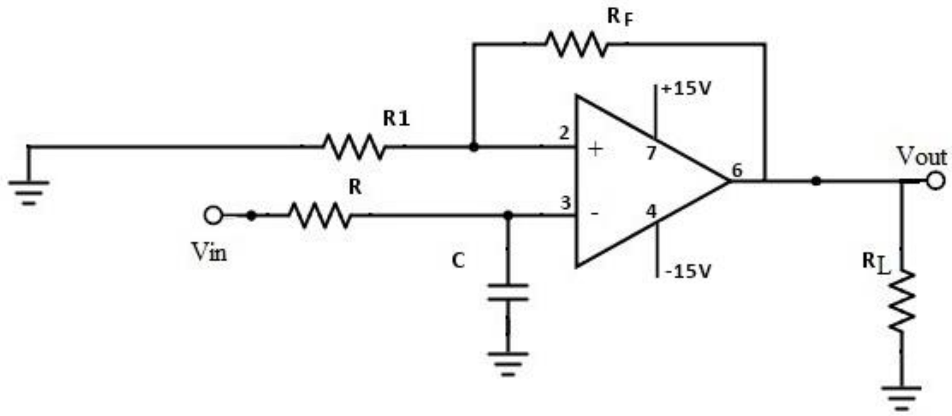


Figure 6: First order low pass Butterworth filter circuit

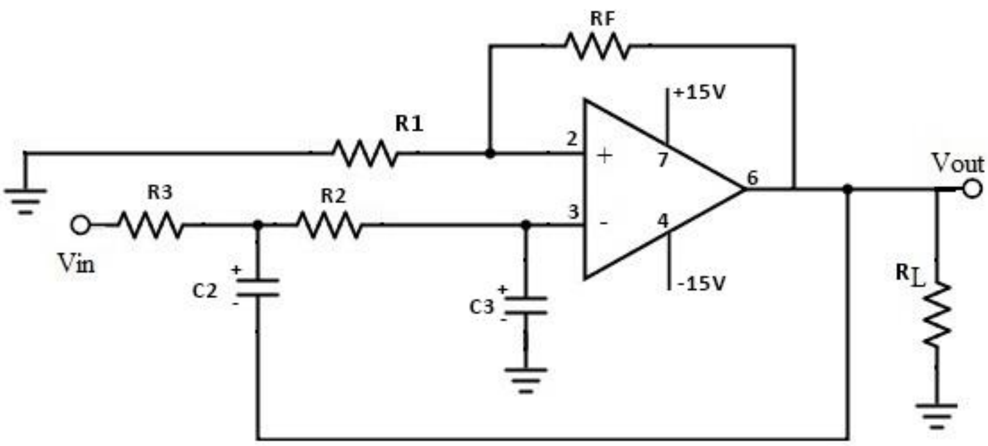


Figure 7: second order low pass Butterworth filter circuit

In this case, Fc is defined as that frequency of V_{IN} where it is reduced by -3dB from its low frequency value. A first order low pass Butterworth active filter circuit is shown in Figure 6. It consists of an operational amplifier. Its output voltage is given by the following equations.

$$\frac{V_o}{V_{IN}} = \frac{A_f}{1+j[f/f_c]} \qquad \text{(v)}$$

where V_o/V_{IN} - Gain of the filter

$A_f = l + R_F/R_1$ - Pass band gain

$f_c = 1/(2\pi RC)$ - Cutoff frequency

A second order low pass Butterworth active filter circuit is shown in Figure 7. The cutoff frequency of filter is given by

$$F_c = \frac{1}{2\pi RC} \qquad \text{(vi)}$$

where $R = R_2 = R_3$ and

$C = C_2 = C_3$

PROCEDURE

Part 1: Oscillators

(a) LC resonant oscillators

1. Connect the Colpitts oscillator as shown in Figure 1. Observe the variation of the shape of the output waveform when the potentiometer is varied. Record the output waveform and measure the periodic time of oscillations using the oscilloscope for the following combinations of C_1, C_2 and L_3.

$C_1 = 0.1\mu F$	$C_2 = 0.1\ \mu F$	$L_3 = 1.55mH$
$C_1 = 0.002\mu F$	$C_2 = 0.002\ \mu F$	$L_3 = 1.55mH$

2. Compute the theoretical frequencies using (i) and compare with the frequencies estimated from the measured periodic times.
3. LC oscillators are not generally used for producing very low frequencies.
   Explain why?

(b) RC Oscillators

1. Connect the Wein bridge oscillator circuit shown in Figure 2. Observe the variation of the shape of the output waveform when the potentiometer is varied. Adjust the potentiometer until a sinusoidal output signal is achieved. Record the output waveform and measure the periodic time for the following two cases.

   $R = 1k\Omega$ $\quad$ $C = 0.33\mu F$

   $R = 10k\Omega$ $\quad$ $C = 1000pF$

2. Compute the theoretical frequencies using (ii) and compare with the frequencies estimated from the measured periodic times.

(c) Relaxation oscillator

1. Connect the relaxation oscillator circuit shown in Figure 3 with $R_1 = 1k\Omega$, $R_2 = 1k\Omega$ and
   $C =0.1\ \mu F$.

   Record the output waveform and measure the periodic time T, and on time, T_{ON}.

2. Change the value of C to 0.33µF and 2.2 µF and tabulate the corresponding values of T and T_{ON} and the frequency f.

Part 2: Analog Filters

(a) First order low pass filter

1. Connect the first order low pass Butterworth filter circuit as shown in Figure-6 with the following resistors and capacitors.

   $R_1 = R_F = 10k\Omega$ $\quad$ $R = 820\Omega$

   $C = 0.1\mu F$ $\quad$ $R_L = 8.2k\Omega$

2. Connect a signal generator to the circuit and set its output voltage to 2V pk-pk. Measure the output voltage of the circuit using an oscilloscope while varying the frequency of the signal and fill the Table.

Table 6:

Frequency (kHz)	V_{OUT}
0.10	
0.40	
0.60	
0.80	
1.00	
1.25	
1.50	
1.75	
2.00	
3.00	
4.00	
5.00	
6.00	
7.00	
8.00	
9.00	
10.00	

3. Plot a graph, gain 20log | V_O / V_{IN} | vs log (freq).
4. Obtain the cutoff frequency of the filter from the graph and compare it with the theoretical cutoff frequency.
5. Find the Slope of the graph in the stop band.

(b) Second order low pass filter

1. Connect the second order low pass Butterworth filter circuit as shown in Figure 7 with the following resistors and capacitors.
   R1 = 10kΩ RL = 8.2kΩ C = 0.1 μF
   R2 = R3 = 22kΩ RF = 5.6kΩ
2. Connect a signal generator to the circuit and set its output voltage to 2V pk-pk. Measure the output voltage of the circuit using an oscilloscope while varying the frequency of the signal and fill the Table 7.

Table 7:

Frequency (Hz)	**V_{OUT}**
45	
50	
55	
60	
65	
70	
75	
80	
85	
90	
95	
100	
105	
110	
115	
120	

3. Plot a graph, gain 20log | V_O/V_{IN} | Vs log (freq).
4. Obtain the cutoff frequency of the filter from the graph and compare it with the theoretical cutoff frequency.
5. Find the slope of the graph in the stop band.
6. Compare the result of (a) 5 and what you can conclude from it.

Pre-Lab writing :

1. Describe the operation of P-N junction

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2. What are the differences between a normal diode and a Zener diode?

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Observations :

Part I: Simple Diode Circuits

Table 1: Measured V_o for circuit in Figure 9

$V_{in(pk\text{-}pk)}$ (volts)	$V_{0(pk\text{-}pk)}$ (volts)
0.0	
0.5	
1.0	
1.5	
2.0	
2.5	
3.0	
3.5	
4.0	
4.5	
5.0	

1. Observed Output Voltage (V_o) waveform when V_{in} = 1 V

2. Observed Output Voltage (V_o) waveform when V_{in} = 3 V

Part II: Zener Diode Circuits

Table 2

V_s (Volts)	0	2	4	6	8	10	12	14	16
V_o (Volts)									

Part III: Half-Wave Rectifier and Full-Wave Rectifier

Table 3: Extreme Cases of R_L and C

	Part 1: Half Wave Rectifier		Part 2: Full Wave Rectifier	
	R_L = 470 Ω C = 10 μF	R_L = 100 kΩ C = 47 μF	R_L = 470 Ω C = 10 μF	R_L = 100 kΩ C = 47 μF
V_m				
V_{min}				
V_r (Experimental)				
V_r(rms)				
V_{dc}				
Ripple Factor				
V_r (Theoretical)				

A. Half-Wave Rectifier

1. Output voltage (V_o) waveform without capacitor and with C= 47μF capacitor

B. Full-Wave Rectifier

1. Output voltage (V_o) waveform without capacitor and with C= 47μF capacitor

Part IV: Clippers

1. Input and Output waveforms when V_B = 0 V

2. Input and Output waveforms when V_B = 2 V

Part V: Clampers

1. Input and Output waveforms when $V_B = 0$ V

2. Input and Output waveforms when $V_B = 2$ V

Discussion :

1. Describe the working principle of a biased diode clipper circuit for both positive and negative.

2. Find out practical applications where clamping circuits are used.

3. Using the equation provided, Design a bridge-type, full-wave rectified, dc power supply using a filter capacitor (either 22μF or 47μF). The maximum output voltage V_m of the rectifier is to be at least V_{in} - $2V_\gamma$, with a ripple factor, RF, less than 0.05. The voltage, V_{in}, is the voltage supplied to your rectifier circuit after the voltage drop across the resistor R_S

$$RF = \frac{1}{\sqrt{3}} \cdot \frac{1}{(2f_P R_L C - 1)}$$

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Pre Lab :

Observations :

Actual values of resistors

Voltage across R_B =

Measured values of I_B and I_C

Table 1:

V_{BE} (V)	V_C (V)	I_B (μA)	I_C (mA)
0			
0.1			
0.2			
0.3			
0.4			
0.5			
0.6			
0.7			
0.8			

Table 2:

I_B (μA)	V_{CE} (V)	I_C (mA)
	0	
	2	
	4	
	6	
	8	
	10	
20	0	
20	2	
20	4	
20	6	
20	8	
20	10	
40	0	
40	2	
40	4	
40	6	
40	8	
40	10	
60	0	
60	2	
60	4	

60	6	
60	8	
60	10	
80	0	
80	2	
80	4	
80	6	
80	8	
80	10	
100	0	
100	2	
100	4	
100	6	
100	8	
100	10	

Observed input and output waveforms.

Calculations :

Discussion :

1.

2.

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Pre-Lab writing:

2. A non-inverting amplifier has R1 of 1KΩ & R_f of 100 KΩ. Determine V_f and β (Feedback voltage and feedback fraction), if V_O = 5V.

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2. For the amplifier in Fig.(a) in your lab sheet determine the following: (a) A_{CL} (b) V_O (c) V_f

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3. Find the value of R_f that will produce closed-loop gain of 300 in each amplifier in fig.(b)

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4. Determine the output voltage of each amplifier in Fig (c)

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Observations :

Table 1 : The Calculated and Measured amplitude, voltage gain Values

op-amp configuration / circuit	**Input Signal**	**Output Signal**	**Voltage gain**	
	Amplitude	**Amplitude**	**Designed value**	**Actual Value**
Non-inverting amplifier				
Inverting amplifier				
Integrator				

Table 2: The Calculated and Measured amplitude Values of input and output waveforms

op-amp circuit	**Input signal (volts)**		**Output signal, VO (volts)**	
	V1	**V2**	**Designed value**	**Actual Value**
Summing amplifier				

Table 3: Measured values of input and output of Schmitt trigger

Obs. No	Vi (V)	Vo (V)
1		
2		
3		
4		
5		
6		
7		

Discussion :

(1) Show that $V_0 = \frac{-1}{RC} \int_0^T V_{in}\ dt$ for an integrator op amps circuit.

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(2) Plot the input and output voltage waveforms for following circuits on the same scale on a graph sheet. (Graph sheet should be attached to the lab report)

- Inverting Amplifier
- Non Inverting amplifier
- Integrator
- Summing

(3) A circuit known as a summing amplifier is illustrated in Figure 7.

i) Solve for the output voltage in terms of the input voltages and resistor values?

ii) What is the input resistance seen by V_A?

iii) By V_B?