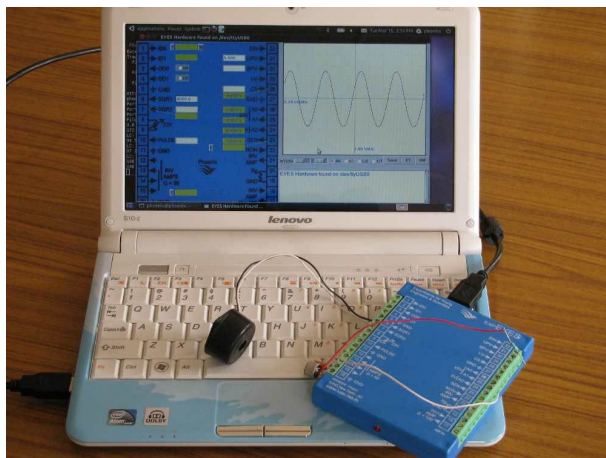


# expEYES



Experiments for  
Young Engineers and Scientists

website : [expeyes.in](http://expeyes.in)

User Manual (ver.2, Apr-2011)

with 50 Science Experiments

PHOENIX Project  
Inter-University Accelerator Centre  
(A Research Centre of UGC)  
New Delhi 110 067  
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## Preface

The PHOENIX (Physics with Home-made Equipment & Innovative Experiments) project was started in 2004 by Inter-University Accelerator Centre with the objective of improving the science education at Indian Universities. Development of low cost laboratory equipment and training teachers are the two major activities under this project. The first product was a general purpose interface, was also called Phoenix, followed by instruments like Geiger-Muller counter, Alpha spectrometer etc. The power of personal computers have been utilized for performing measurements and data analysis.

The new product, expEYES (Experiments for Young Engineers & Scientists), is meant to be a tool for learning by exploration, suitable for high school classes and above. An attempt is made to strike a balance between open ended experiments mostly meant for exploration and the conventional ones with some specific objective. We have tried optimizing the design to be simple, flexible, rugged and above all low cost. There is no need of a separate power supply since it runs on the 5 volt USB power, taking care of the long power failures common in many places. The low price makes it affordable to individuals and we hope to see students performing experiments outside the four walls of the laboratory, that closes when the bell rings.

Design of hardware developed is open and the software is released under GNU General Public License. The project has progressed due to the active participation and contributions from the user community and many other persons outside IUAC. We thank them all and also expect their continued cooperation. We are grateful to Prof. G.K.Mehta for suggesting corrections to this document. This is distributed under GNU Free Documentation License. More details and updated versions of this document are available on the website *expeyes.in*

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# Contents

|          |  |           |
|----------|--|-----------|
| <b>1</b> | <b>Getting Started</b>                                   | <b>9</b>  |
| 1.1      | Introduction . . . . .                                   | 9         |
| 1.2      | The equipment . . . . .                                  | 10        |
| 1.2.1    | External connections . . . . .                           | 10        |
| 1.3      | Software Installation . . . . .                          | 14        |
| 1.4      | The main GUI program . . . . .                           | 15        |
| 1.5      | Basic measurements using expEYES . . . . .               | 17        |
| 1.5.1    | Generate & measure voltages . . . . .                    | 17        |
| 1.5.2    | Observe voltage waveforms . . . . .                      | 18        |
| 1.5.3    | Measure frequency . . . . .                              | 18        |
| 1.5.4    | Measure duty cycle . . . . .                             | 18        |
| 1.5.5    | Setting voltage levels . . . . .                         | 18        |
| 1.6      | Experiments . . . . .                                    | 19        |
| <b>2</b> | <b>Electricity</b>                                       | <b>21</b> |
| 2.1      | Measuring voltage . . . . .                              | 22        |
| 2.2      | Voltage, current & resistance . . . . .                  | 23        |
| 2.3      | Resistances in series . . . . .                          | 25        |
| 2.4      | Resistances in parallel . . . . .                        | 26        |
| 2.5      | Measure resistance by comparison . . . . .               | 27        |
| 2.6      | Voltage of a lemon cell . . . . .                        | 29        |
| 2.7      | Voltage changing with time . . . . .                     | 31        |
| 2.8      | Alternating current (AC) . . . . .                       | 32        |
| 2.9      | AC Powerline pickup . . . . .                            | 34        |
| 2.10     | DC & AC components of a time dependent voltage . . . . . | 36        |
| 2.11     | Resistance of human body . . . . .                       | 38        |
| 2.12     | Temperature dependent resistors . . . . .                | 39        |
| 2.13     | Light dependent resistors . . . . .                      | 40        |

|          |   |           |
|----------|---|-----------|
| 2.14     | Electricity through liquids, DC & AC . . . . .          | 41        |
| 2.15     | Transient Response of RC circuits . . . . .             | 43        |
| 2.16     | Transient Response of RL circuits . . . . .             | 45        |
| 2.17     | Transient response of LCR circuits . . . . .            | 47        |
| 2.18     | Capacitor in AC circuits . . . . .                      | 49        |
| 2.19     | AC phase shift in RC circuits . . . . .                 | 51        |
| 2.20     | AC phase shift in RL circuits . . . . .                 | 53        |
| 2.21     | Ferromagnetic material inside inductor . . . . .        | 55        |
| 2.22     | RC Integration & Differentiation . . . . .              | 57        |
| 2.23     | Fourier Analysis . . . . .                              | 59        |
| 2.24     | Harmonics of a square wave . . . . .                    | 61        |
| <b>3</b> | <b>Electricity &amp; Magnetism</b>                      | <b>63</b> |
| 3.1      | Electromagnetic induction . . . . .                     | 63        |
| 3.2      | A simple AC generator . . . . .                         | 65        |
| 3.3      | Mutual induction, transformer . . . . .                 | 67        |
| 3.4      | Electromagnet, solenoid coil . . . . .                  | 69        |
| 3.5      | Eddy current braking . . . . .                          | 71        |
| <b>4</b> | <b>Sound</b>  | <b>73</b> |
| 4.1      | Generating sound . . . . .                              | 73        |
| 4.2      | Frequency of sound . . . . .                            | 75        |
| 4.3      | Velocity of sound . . . . .                             | 77        |
| 4.4      | Reflection of sound . . . . .                           | 79        |
| 4.5      | Interference of sound . . . . .                         | 80        |
| 4.6      | Analysing Music <sup>1</sup> . . . . .                  | 82        |
| 4.7      | Velocity, using ultrasound . . . . .                    | 83        |
| 4.8      | Forced Oscillations of Piezo-electric crystal . . . . . | 85        |
| <b>5</b> | <b>Electronics</b>                                      | <b>89</b> |
| 5.1      | Half wave rectifier, PN junction . . . . .              | 89        |
| 5.2      | 180° out of phase sine waves . . . . .                  | 92        |
| 5.3      | Diodes, Fullwave rectifier . . . . .                    | 93        |
| 5.4      | Diode I-V characteristic . . . . .                      | 95        |
| 5.5      | Light emitting diodes, LED . . . . .                    | 97        |
| 5.6      | Transistor CE characteristic . . . . .                  | 99        |
| 5.7      | Transistor amplifier (CE) . . . . .                     | 101       |
| 5.8      | Photo-transistor . . . . .                              | 103       |
| 5.9      | Opto-electric signal transmission . . . . .             | 104       |

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<sup>1</sup>Contributed by jithinbp at gmail.com

|          |  |            |
|----------|--|------------|
| 5.10     | Amplitude & Frequency Modulation . . . . . | 106        |
| <b>6</b> | <b>Mechanics, Optics &amp; Heat</b>        | <b>109</b> |
| 6.1      | Resonance of a driven pendulum . . . . .   | 109        |
| 6.2      | Value of 'g', Rod pendulum . . . . .       | 111        |
| 6.3      | Oscillations of a pendulum . . . . .       | 113        |
| 6.4      | Value of 'g' by time of flight . . . . .   | 115        |
| 6.5      | Temperature measurement, PT100 . . . . .   | 117        |
| 6.6      | Temperature Controller . . . . .           | 119        |
| 6.7      | Stroboscope . . . . .                      | 121        |
| 6.8      | Speed of rotation of a motor . . . . .     | 123        |
| 6.9      | Transparency Measurement . . . . .         | 125        |
| 6.10     | Standing waves on a String . . . . .       | 126        |





# Chapter 1

## Getting Started

### 1.1 Introduction

Performance of a student is often measured by the ability to memorize than the real understanding. As a result, most of them fail to apply what they learn in the classroom to things they encounter in their daily life. To some extent this can be corrected by learning based on exploration and experimenting. Experiments generally involve measuring and controlling physical parameters like temperature, pressure, velocity, acceleration, force, voltage, current etc. If the measured physical property is changing rapidly, the measurements need to be automated and a computer becomes a useful tool. For example, understanding the variation of AC mains voltage with time requires measuring it after every millisecond.

The ability to perform experiments with reasonable accuracy, opens up an entirely new path for learning science. Students can compare the experimental data with mathematical models and examine the fundamental laws governing various phenomena. Research scientists formulate hypotheses, design and perform experiments, analyze the data to check whether they agree with the theory. The objective of PHOENIX (Physics with Homemade Equipment and Innovative Experiments) project is to provide the same facilities on a smaller scale to the students. It also enables the users to develop new experiments without getting into the details of electronics or computer programming. There are several equipment and experiments developed so far. This document describes some experiments that can be done with the interface named *expEYES*.

## 1.2 The equipment

ExpEYES is interfaced and powered by the USB port of the computer. For connecting external signals, it has 32 Input/Output terminals, arranged on both sides, as shown in figure 1.1. It can monitor and control the voltages at the terminals. In order to measure other parameters (like temperature, pressure etc.), we need to convert them into electrical signals by using appropriate sensor elements. Even though our primary objective is to do experiments, you are advised to read through the brief description of the equipment given below.

*IMPORTANT : The external voltages connected to expEYES must be within  $\pm 5V$  range.*

### 1.2.1 External connections

The external connections can be grouped according to their functions.

#### Digital Inputs (ID0 and ID1)

Software can read the voltage level applied to them. Any voltage less than .8 V is treated as 0 (LOW) and anything higher than 2 V is treated as 1 (HIGH). If the voltage input is changing between HIGH and LOW, these terminals can measure the frequency and duty-cycle of the connected signal. ExpEYES is capable of measuring time interval between voltage transitions on these pins with microsecond resolution.

#### Digital Outputs (OD0 and OD1)

Using software, we can make the voltage at these terminals 0 or 5 V. OD0 is transistor buffered and can drive up to 100 mA current. OD1 can only drive only up to 5 mA.

#### Signal Generators

**SINE** Fixed frequency sine wave generator, frequency is around 100 Hz. Bipolar signal output with an amplitude of around 4 V.

**SQR1** Can generate a square wave, swings from 0 to 5 V. Frequency is programmable from 15 Hz to 1 MHz. All intermediate values of frequency are not possible.

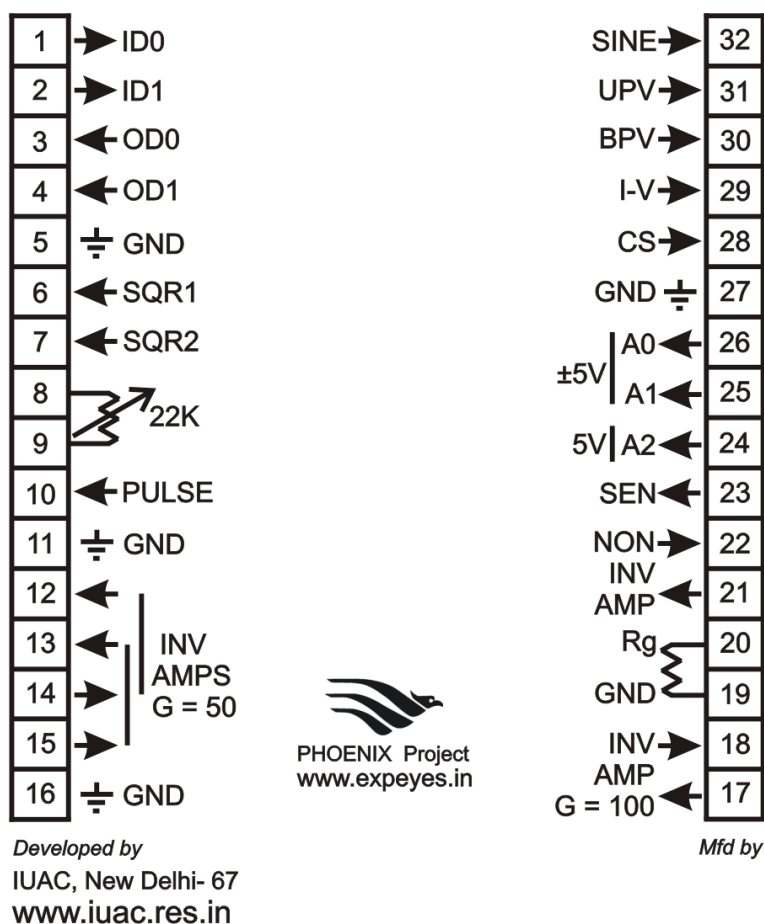


Figure 1.1: The ExpEYES top panel showing the external connections on both sides. The arrows indicates the direction of the signals..

**SQR2** Can generate a square wave, swinging from 0 to 5 V. Frequency can be set anywhere between 0.7 Hz and 90 kHz. The oscillator requires an external variable resistor, 22 k $\Omega$ , for its operation. The frequency range is controlled by software and frequency tuning within the selected range is done by adjusting the resistance. The frequency ranges are < 25 Hz, 25 to 1 kHz, 1 kHz to 10 kHz and 10 kHz to 90 kHz. Entering a frequency in a particular range selects that range. The variable resistor is then adjusted to obtain the desired frequency. The actual value of the frequency is measured and displayed during adjustment.

**PULSE** Output frequency is 488 Hz. Duty cycle can be programmed from 0 to 100 % in 255 steps. This terminal can be configured to generate a Square wave, like SQR1. This feature is used by the program demonstrating interference of sound.

### Analog Voltage Inputs

**A0 and A1** Can measure voltage within the  $\pm 5$  V range. The resolution of ADC used is 12 bits. Voltage at these terminals can be displayed as a function of time, giving the functionality of a low frequency two channel oscilloscope.

**A2** For voltage measurement. Input must be within the 0 to 5 V range. Resolution is 12 bits. Voltage can be displayed as a function of time using software.

### Analog Voltage Outputs

**BPV** Bipolar voltage output. Can be programmed to any value between -5 V to +5 V. The resolution is 12 bit, implies a minimum voltage step of around 2.5 mV.

**UPV** Unipolar voltage output. Can be programmed between 0 to +5 V. Cannot be used along with the current source output CS, since they share the same DAC output.

**IV** This is just the output BPV coming out through a 1k $\Omega$  resistor. Used for doing I-V characteristic.

### Constant Current Source (CS)

Programmable to any value from 0.05 to 2.0 mA. The load resistor should be chosen such that the the product  $IR$  is less than 2 V. Remember that CS and UPV shares the same DAC output.

### Inverting Amplifiers

There are three inverting amplifiers, implemented using TL084 op-amps, denoted below using their input and output terminal numbers.

**15⇒13** Input at terminal 15 and output at 13. Default Gain=50. The gain can be reduced by feeding the input through a series resistor. The gain is be governed by  $G = \frac{R_f}{(R_{ext}+1000)}$  where the internal  $R_f = 50000\Omega$ . The external series resistor is  $R_{ext}$ .

**14⇒12** Input at terminal 14 and output at 12. Similar to the one mentioned above.

**17⇒18** Input at 17 and output at 18. Default Gain=100. The gain can be reduced by feeding the input through a series resistor. The gain is be governed by  $G = \frac{R_f}{(R_{ext}+100)}$  where the internal  $R_f = 10000\Omega$  and the external series resistor is  $R_{ext}$ .

### Non-Inverting Amplifier

The input is at 21 and output at 22. The gain is decided by an external resistor  $R_g$  connected between 19 and 20 and is given by  $Gain = 1 + 10000/R_g$ . This amplifier is implemented using OP27 IC and has an offset voltage of around  $30\mu V$ .

### Sensor Input (SEN)

For connecting any sensor whose resistance varies with the measured parameter. When used with the photo-transistor. connect collector to this, and emitter to Ground. Capable of measuring the voltage and frequency.

## Frequency Counters

The terminal 15 can measure the frequency of a bipolar signal (that goes to both negative and positive values). The minimum measurable amplitude is 100 mV and the maximum is 5 V.

ID0, ID1 and SEN are capable of measuring the frequency of signals swinging from 0 to 5 V.

## 1.3 Software Installation

ExpEYES can run on any computer having a Python Interpreter and a Python module to access the Serial port. The USB interface is handled by the device driver programs that presents the USB port as an RS232 port to the application programs. The communication with expEYES is done using a library written in Python language. Programs with GUI have been written for many experiments. There are many ways to get the software running:

### The expEYES Live CD

The easiest way to get started is to boot your PC with the Phoenix Live-CD. From the PC BIOS, make the CD drive as the first boot device, insert the live CD and reboot the PC. A desktop will appear and you can start expEYES from the menu **Applications -> Science**. The expEYES live CD is made from GNU/Linux distribution Ubuntu 10.10.

### Installing on Debian or Ubuntu GNU/Linux distributions

Install python-imaging-tk from the repository of the distribution you are running. Download **expeyes.deb** from <http://expeyes.in> and install it. Also install python-scipy and grace (a 2D plotting program) for full functionality.

### For other GNU/Linux distributions

Download **expeyes.tgz** from <http://expeyes.in> and follow the instructions in the README file. It is important to give read/write permissions for all users on the USB port where expEYES is connected.

## On MSWindows

Even though expEYES is Free Software and it developed using Free and Open software, it runs on non-free platforms also. To install it on MS windows, you need the following files (given on the CD)

1. CDM20814\_Setup.exe
2. python-2.6.6.msi
3. pyserial-2.5.win32.exe
4. PIL-1.1.7.win32-py2.6.exe
5. numpy-1.6.0b2-win32-superpack-python2.6.exe
6. scipy-0.9.0-win32-superpack-python2.6.exe
7. expeyes.zip

Unzip the file **expeyes.zip**, and double click on **explore.py** inside the newly created directory named EYES.

If you have expEYES liveCD, browse inside the directory named WINEYES. All the files mentioned above are inside that directory. Double click on them in the order mentioned above to install them. The XmGrace plotting utility is not available under MSwindows. Fourier transform output will be saved to disk in text format.

## 1.4 The main GUI program

Start Applications->Science->expEYES from the menu. It will show a graphics window as shown in figure1.2, and is briefly explained below.

Clicking on the boxes showing the terminal numbers will display help messages.

Right Clicking on the left panel produces a pop-up menu of applications.

The status of Digital Inputs decides the colour of the display area against them. Pale green indicates High and Gray indicates Low. When the input voltage swings from 0 to 5 volts, this field blinks.

The display field against T15 may blink if an AC signal is given there.

The Frequency display field of SEN may blink if the input is varying between 0 and 5 volts. This will happen if the connected resistance is varying.

The Buttons marked 'F' may be used for measuring the frequency, while the display fields are blinking.

The values of output signals can be set by entering them in the nearby text box. Voltage, current, frequency and duty-cycle are set like this. Press <Enter> to set the entered value. If successful, the display will show a decimal point.

SQR2 require an external resistor to function, we use a 22k $\Omega$  variable resistor. The actual frequency is displayed just below the text field, where you set the frequency.

State of Digital Outputs, OD0 and OD1, can be changed by using the Check Buttons.

The voltages at the input terminals 23,24,25 and 26 are displayed continuously against them.

The GUI is made using a photograph of the device. Control and monitor widgets are placed on the photograph at appropriate places. Right click on the panel to get a pop-up menu of application programs for various experiments.

### **The Plot Window**

The plot window on the right side works like a low frequency oscilloscope. The maximum sampling rate is 100 kHz only. You can digitise sinewaves upto 20 kHz while using only one channel and upto 10 kHz when both are enabled. The following controls are available.

Horizontal scale Slider (ms/Sec). Set this to the minimum value and increase to view more number of cycles on the screen.

Channel selection Checkboxes for A0 and A1.

LIZ checkbox to make a Lissajous figure using A0 and A1 inputs.

FIT checkbox to enable calculating amplitude, frequency and phase by fitting the data using the equation  $V = V_0 \sin(\omega t + \theta) + C$ . The RMS value of the voltage and frequency are displayed. When both the channels are selected, the phase difference is displayed.



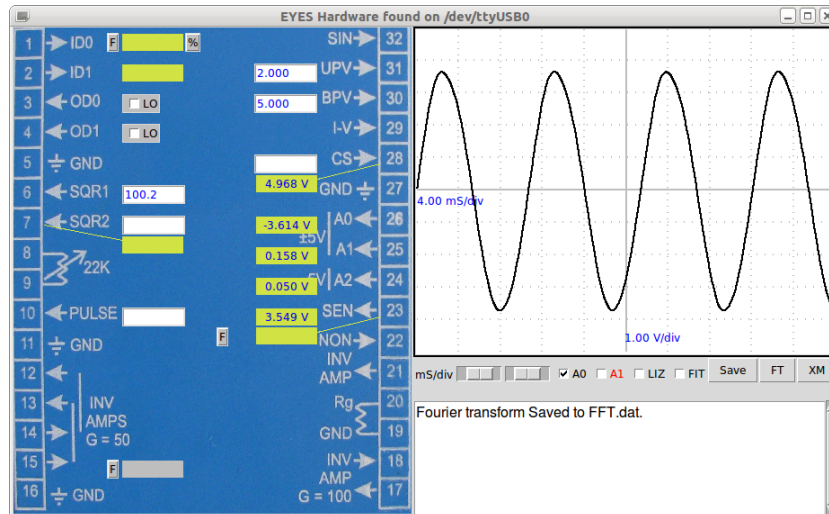


Figure 1.2: Screen shot of Explore program. Arrows indicate the signal direction. Text fields are used for setting values. Buttons are provided for frequency measurements.

SAVE button to save the data to *explore.dat* as two column text.

FT to do a Fourier Transform power spectrum of the data from enabled channels. If Xmgrace and pygrace are installed, a window is opened. Power spectrum is saved to *exploreFFT.dat* in text form.

## 1.5 Basic measurements using expEYES

Before proceeding with the experiments, let us do some simple exercises to become familiar with expEYES. Boot your computer from the LiveCD, connect expEYES to the USB port and start the expEYES program from the menu 'Applications->Science'.

### 1.5.1 Generate & measure voltages

Connect BPV to A0

Set BPV to some voltage and observe the reading at A0

Try A1 instead of A0

Repeat the same by connecting UPV to A2

### **1.5.2 Observe voltage waveforms**

Connect SQR1 to A0

Set SQR1 to 100 Hz

Adjust the horizontal scale (ms/Div) to view 4 or 5 cycles of the square wave

Repeat with other frequency values

Connect SINE to A1 and watch both traces simultaneously

Explore the FIT, XM and FT options.

### **1.5.3 Measure frequency**

Connect SQR1 to ID0

Set SQR1 to 1000

Click on the 'F' button of ID0

Connect SINE to T15 and measure the frequency.<sup>1</sup>

### **1.5.4 Measure duty cycle**

Connect PULSE to ID0

Also to A0, if you want to watch the waveform.

Set PULSE to any value from 0 to 100

Click on the '%' button of ID0, to measure the duty cycle.

### **1.5.5 Setting voltage levels**

Connect OD0 to ID0

Click on the Check button and watch ID0 display color.

---

<sup>1</sup>T15 will not measure the frequency of SQR1 or SQR2 outputs, because they do not swing below zero.

## 1.6 Experiments

A science experiment generally involves control and measurement of various physical parameters like temperature, pressure, voltage, current etc. The basic expEYES hardware can generate different kinds of electrical signals and measure electrical signals. For measuring anything other than voltage, we need to convert it using appropriate sensor elements. For example a temperature sensor will give a voltage indicating the temperature. Since experiments in electricity and magnetism does not require any sensor elements, we have more number of experiments based on electricity and magnetism.

A GUI program is provided for every experiment given in this manual. However, it is possible to do the same by writing few lines of code written in Python language. All the communication to expEYES is done using a Python library called *eyes.py*. Python libraries are used for data analysis. If you are interested in developing new experiments based on expEYES, it would be a good idea to learn Python programming language. Almost every experiment can be extended in several ways and some hints are given in this direction.

The following chapters describe experiments from different topics like electricity, magnetism, electronics, sound, heat, etc. Since the expEYES kit is meant for self learning, we have included some very trivial experiments in the beginning.



## Chapter 2

# Electricity

We start with the trivial task of measuring the voltage of a battery. Current and resistance are introduced next, followed by resistances changing with temperature and light. The concept of Alternating Current is introduced by plotting the voltage as a function of time. The behavior of circuit elements like capacitors and inductors in AC and DC circuits are explored, by measuring parameters like amplitude, frequency and phase. The transient response of a resistor and capacitor in series is used for measuring the capacitance. Inductance also is measured in the same manner. The effect of ferromagnetic materials inside an inductor is examined.

The Fourier analysis of square wave is done to study the harmonics. Integration and differentiation of a square wave using RC circuits also is explored.



Figure 2.1: Measuring the voltage of a battery

## 2.1 Measuring voltage

### Objective

Learn to measure voltage using expEYES and get some idea about the concept of Electrical Ground.

### Equipment

1.5 Volts dry cells

Battery holder with two connecting wires.

### Procedure

Connect Negative terminal of the battery to Ground.

Positive terminal of the cell to A0.

### Observation

Voltage will be displayed on the left side of A0, as shown in figure2.1.

### Discussion

We are measuring the potential difference between two points. One of them can be treated as at zero or Ground potential. The voltage measuring points of expEYES measure the voltage with respect to the terminals marked GND. We have connected the negative terminal of the cell to Ground. The positive terminal is at +3 volts with respect to the negative terminal.

Repeat the experiment by connecting the positive terminal of the cell to GND and the negative to A0. The voltage will be shown as negative. *Will it show correct voltage if Ground is not connected ?*

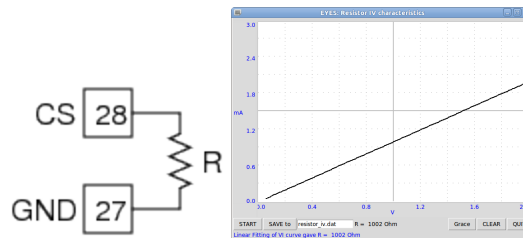


Figure 2.2: IV-characteristic of resistor

## 2.2 Voltage, current & resistance

### Objective

Learn about Current, Resistance and Ohm's law. Plot I-V curve of a resistor.

### Theory

The voltage across a conductor is directly proportional to current flowing through it. The constant of proportionality is called Resistance. This is known as Ohm's Law, expressed mathematically as

$$V \propto I ; V = IR \text{ or } R = \frac{V}{I}$$

### Equipment

A1  $k\Omega$  resistor

### Procedure

Connect resistor from CS to Ground.

Set the current to 0.5 mA and note down the voltage at CS.

Change the current in .5 mA steps. (V should not exceed 2 V at CS)

Right click on the Panel. Choose **Resistor IV** from the pop-up menu.

Draw the graph using **START** button.

## Observation

| I (mA) | V (volt) |
|--------|----------|
| 0.5    | .508     |
| 1.0    | 1.011    |
| 1.5    | 1.510    |

The current source accuracy is only 1%, due to the tolerance value of the resistor used. For applications requiring higher accuracy, you can calibrate it using a known resistance. The I-V curve is shown in figure2.2.

## Discussion

Using expEYES, we can set the current from CS (from 0.05 mA to 2 mA). The voltage at CS will depend on the resistance connected from the current source to Ground.<sup>1</sup>

The graph is a straight line since the voltage is directly proportional to current. The graph will not be a straight line for non-linear elements, like a diode.

---

<sup>1</sup>The voltage across this particular current source should not exceed 2 volts. Choose the load resistor and current values accordingly.



## 2.3 Resistances in series

### Objective

Finding the effective resistance of a series combination of resistors.

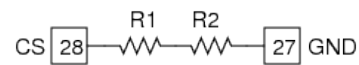
### Theory

For series combination of resistors, total resistance is given by  $R = R_1 + R_2 + \dots$

### Equipment

560  $\Omega$  and 1 k $\Omega$  resistors

### Procedure



Connect both resistors in series from CS to Ground

Set the current to 1 mA and note down the voltage displayed at CS.

### Observation

| R ( $\Omega$ ) | V (volts) |
|----------------|-----------|
| 560            | .558      |
| 1000           | 0.998     |
| 1000+560       | 1.556     |

Since the current is same, the total voltage drop gives the effective resistance. It can be seen that it is the sum of the individual values, within the measurement error.

### Discussion

Very high resistances ( $> 10^9 \Omega$ ) are often implemented using series combinations.

## 2.4 Resistances in parallel

### Objective

Find the effective resistance of parallel combination of resistors.

### Theory

For parallel combination, effective resistance is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$$

### Equipment

Two  $1k\Omega$  resistors

### Procedure



Connect  $1k\Omega$  resistor from CS to Ground.

Set the current to 1 mA (0.001 Ampere) and note down the voltage displayed at CS.

Repeat the same with two resistors connected in parallel.

### Observation

| $R_{connected}(\Omega)$ | $V_{measured}(V)$ |
|-------------------------|-------------------|
| 1000                    | 1.008             |
| $1000  1000$            | 0.503             |

Since we know the current, we can calculate the resistance from the measured voltage. As per the measured voltage the resistance of the parallel combination is  $\frac{0.503 V}{0.001 A} = 503 \Omega$

### Discussion

Why one wants to connect resistors in parallel ?

## 2.5 Measure resistance by comparison

### Objective

Learn to apply Ohm's law to find the value of an unknown resistance by comparing it with a known one.

### Theory

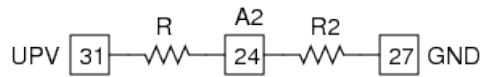
Voltage across a resistor is given by  $V = IR$ . If same amount of current is flowing through two different resistors, the ratio of voltages will be the same as the ratio of resistances.

$$I = \frac{V1}{R1} = \frac{V2}{R2}$$

### Equipment

A  $1\text{ k}\Omega$  as the reference and another resistors. (some value from  $100\ \Omega$  to  $10\text{ k}\Omega$ )

### Procedure



Connect the unknown resistor R from UPV to A2.<sup>2</sup>

Connect  $1\text{ k}\Omega$  (R2) from A2 to Ground.

Set UPV to 4 volts.

Measure voltage at A2.

### Observation

Voltage at A2 = 1.244, implies voltage across the unknown resistor is  $4 - 1.244 = 2.756$

$$\text{Current } I = \frac{1.244}{1000} = 1.244\text{mA}$$

$$\text{Unknown resistor value} = \frac{2.756}{1.244} = 2.215\text{ k}\Omega$$

---

<sup>2</sup>We use A2 when the voltage is in the 0 to 5V range.

## Discussion

What is the limitation of this method ? How do we choose the reference resistor ? suppose the unknown value is in Mega Ohms, what will be the voltage drop across a  $1k\Omega$  reference resistor ? Our voltage measurement is having a resolution of  $\frac{1}{4095}$ .

We will use this method later to measure the resistance of solutions.

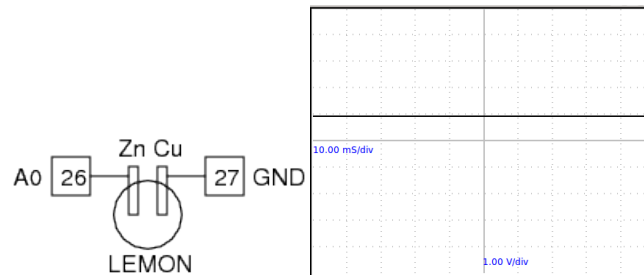


Figure 2.3: (a) Copper and Zinc plates inserted into a Lemon. (b) The DC voltage output from the cell.

## 2.6 Voltage of a lemon cell

### Objective

Make a voltage source. Learn about current capability. Concept of internal resistance.

### Equipment

Ripe Lemon (or some acid), thin Zinc and Copper plates.

A  $1\text{ k}\Omega$  resistor.

### Procedure

Insert the zinc and copper plates into the lemon.

Connect one plate to ground and another to A0, using two wires.

Connect the resistor from A0 to ground.

### Observation

Voltage across the Copper and Zinc terminals will be nearly .9 volts. Connecting the resistor reduces it to .33 volts.

What is the internal resistance of the cell ?

## Discussion

When connected, current will start flowing through the resistor. But why the voltage is going down ?

It does not happen with a new dry-cell. Why ?

Current is the flow of charges and it has to complete the path. That means, current has to flow through the cell also. Depending on the internal resistance of the cell, part of the voltage gets dropped inside the cell itself.

An ideal voltage source should have zero internal resistance.

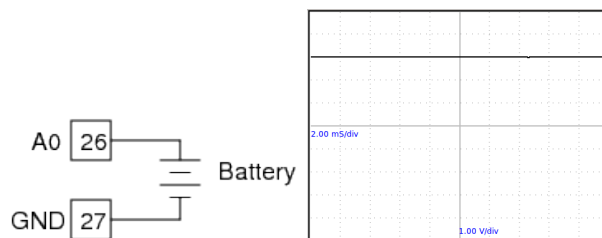


Figure 2.4: Plotting DC voltage with Time

## 2.7 Voltage changing with time

### Objective

Introduce the concept of time dependent voltages, using a  $V(t)$  graph.

### Equipment

1.5 Volts dry cells

Battery holder with leads.

### Procedure

Connect Negative of the dry cell to Ground.

Positive terminal of the cell to A0.

Observe the graph on the right side window.

### Observation

A horizontal line appears on the Graph, Time on x-axis and voltage on y-axis.

### Discussion

Voltage is constant in time. A cell is a source of Direct Current (DC). Another type of current is called Alternating Current or AC, which changes the magnitude and direction with time.

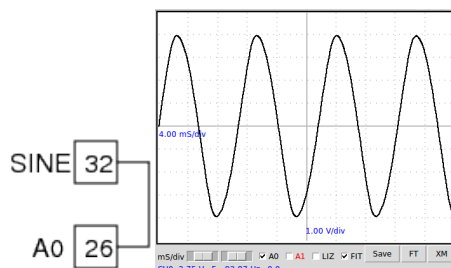


Figure 2.5: AC voltage waveform from SINE

## 2.8 Alternating current (AC)

### Objective

Learn about AC, using graphs. Get familiar with the sinusoidal voltage waveform.

### Equipment

A piece of wire.

### Procedure

Connect SINE to A0.

Adjust the horizontal scale to view 4 to 5 cycles.

Enable the Checkbox 'FIT'.

### Observation

The waveform is shown in the figure2.5. Enable the 'FIT' option to calculate the amplitude and frequency by fitting the data with the equation  $V = V_0 \sin(2\pi ft + \theta)$ , where  $V_0$  is the amplitude and  $f$  is the frequency.

### Discussion

The voltage is changing with time. It goes to both negative and positive. One full cycle takes around 12 milli seconds, ie. around 90 cycles per sec-



ond or 90 Hertz. This voltage waveform is generated by using electronic circuits.<sup>3</sup>

The AC mains supply coming to our houses has a frequency of 50 Hz. What is the significance of  $\theta$  in the equation above ?

---

<sup>3</sup>The frequency of the SIN output is around 90 Hz. It's variation is due to the 20% tolerance of the capacitors deciding the frequency.

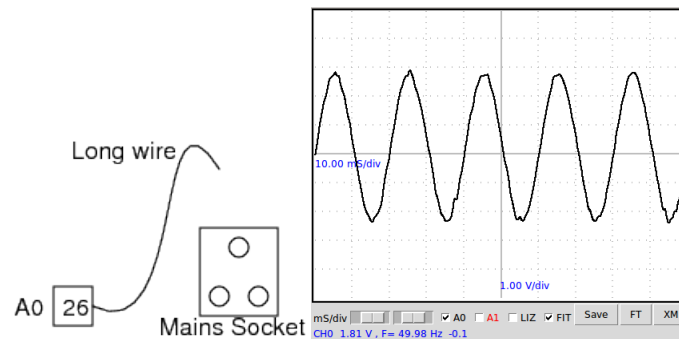


Figure 2.6: Power line pickup

## 2.9 AC Powerline pickup

### Objective

Learn about the AC mains supply. Explore the phenomenon of propagation of AC through free space.

### Equipment

A long piece of wire.

### Procedure

Connect one end of the wire to A0.

Take the other end near the power line (never touch the line) and change the orientation of the wire until you get a good signal on the screen.

Adjust the horizontal scale to 10 milliseconds per division.

Enable the Checkbox 'FIT'.

### Observation

The observed waveform is shown in figure2.6. The frequency calculated by fitting the data is 49.65 Hz

## Discussion

Without making any connection, how we are getting the AC voltage from the mains supply ? Do this experiment with a laptop computer staying far away from mains supply lines.

Is it similar to the radiation from a cell phone ?

Why the frequency is differing from 50 Hz ?

We are watching the voltage picked up by the wire, it acts as an antenna and receives the 50 Hz radiation from the power line. Touching the floating end of the wire increases the pickup, you are becoming part of the antenna. The frequency  $f$  is calculated by fitting the collected data with the equation  $V = V_0 \sin(2\pi ft + \theta)$ .

Try measuring during the daytime and at midnight to compare the measured frequencies. It depends on the total load on the grid. If the power distribution system is really good, the frequency will remain constant.

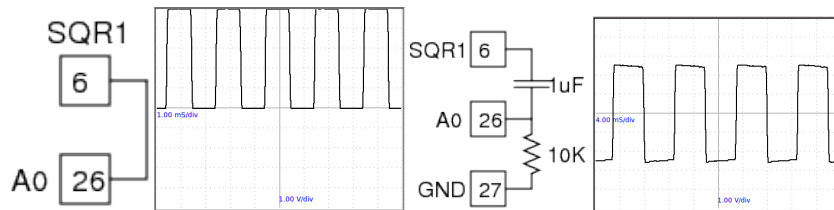


Figure 2.7: Voltage swinging between 0 and 5 volts (a) Direct connection  
(b) With a DC blocking capacitor

## 2.10 DC & AC components of a time dependent voltage

### Objective

Learn about the AC and DC components of a time dependent voltage. Separating AC and DC using a capacitor.

### Equipment

1 F capacitor, 10 k $\Omega$  resistor

### Procedure

Connect SQR1 to A0 using the wire.

Enter 500 in the Textbox of SQR1 and press Enter key.

Adjust the horizontal scale to see several cycles.

Insert a 1 F between SQR1 and A0

Connect 10 k $\Omega$  from A0 to ground.

### Observation

The observed waveforms with and without the series capacitor are shown in figure 2.7. The voltage is swinging between 0 and 5 volts. After passing through the capacitor the voltage swings from -2.5 volts to +2.5 volts.

## Discussion

What will you get if subtract a 2.5 from the y-coordinate of every point of the first graph. That is what the capacitor did. It did not allow the DC part to pass through.

This original voltage can be considered as a 5V AC superimposed on a 2.5V DC.

You may need to connect a  $10k\Omega$  resistor from A0 to Ground to see a waveform swinging between -2.5 to +2.5 volts.

Why the resistor is required?

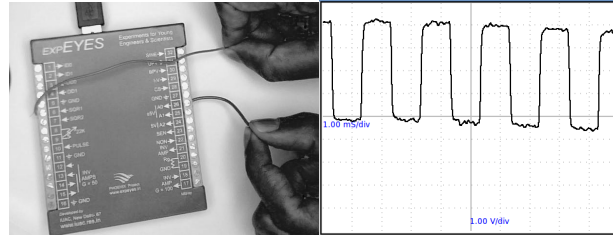


Figure 2.8: Voltage after passing through the hand.

## 2.11 Resistance of human body

### Objective

Get some idea about the resistance of the human skin and how it varies.

### Equipment

Two pieces of wire.

### Procedure

Set SQR1 to 500

make a connection from SQR1 to A0, through your body

Adjust the horizontal scale to see several cycles.

Repeat the same by using SINE instead of SQR1.

### Observation

The observed waveform is shown in figure2.8. The wave is not clean and the amplitude is reduced from 5 volts.

### Discussion

Using the method of comparison, try to calculate the resistance of the portion of the hand between the two wires, you were holding. The reference resistance is  $10M\Omega$ , internally connected from A0 to ground.

## 2.12 Temperature dependent resistors

### Objective

Show the dependence of resistance on temperature. Basic concept of a temperature sensor.

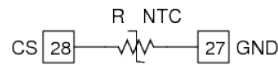
### Equipment

Thermistor (NTC)<sup>4</sup>. Resistance  $1k\Omega$  at 25 degree Celsius.

Cold water

A candle or some other heat source.

### Procedure



Connect the Thermistor (NTC) from CS to ground

Set CS to 1.0 mA

Measure the voltage across the thermistor at different temperatures

### Observation

| Setup               | $V=IR$ | $R = \frac{V}{I}$ |
|---------------------|--------|-------------------|
| Place in cold water | 1.2    | 1200              |
| Room Temperature    | 0.935  | 935               |

### Discussion

Why materials show electrical resistance ?

Why it depends on temperature ?

For metals, R increases with T. But for insulators and semiconductors it decreases. Why ?

What is the meaning of temperature at molecular level ?

---

<sup>4</sup>Negative Temperature Coefficient

## 2.13 Light dependent resistors

### Objective

Learn about LDR. Measure intensity of light and its variation with distance from the source.

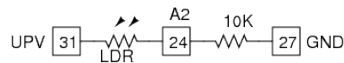
### Equipment

A Light Dependent Resistor, LDR

10k $\Omega$  resistor

A torch bulb without any reflector.

### Procedure



Connect LDR between UPV and A2

set UPV to 4 volts.

10 k $\Omega$  resistor from A2 to ground

Measure the voltage at A2, with no light on LDR.

Measure it by keeping the torch bulb at a distance<sup>5</sup>.

Change the distance and note down the voltage at A2.

Calculate the resistance by comparison as described in section 2.5

### Observation

The resistance varies from 1 k $\Omega$  to around 100 k $\Omega$  depending on the intensity of light falling on it.

### Discussion

The voltage is proportional to the resistance. The resistance decreases with intensity of light. If you use a point source of light, the resistance should increase as the square of the distance.

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<sup>5</sup>Need to be done in a dark room



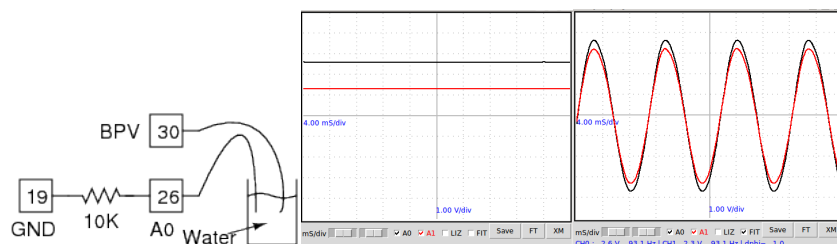


Figure 2.9: (a) Experimental setup. (b) Total DC voltage and voltage across the  $1k\Omega$  resistor. (c) Total AC voltage and voltage across  $1k\Omega$  resistor.

## 2.14 Electricity through liquids, DC & AC

### Objective

Measure the resistance of liquids. Using both DC and AC voltages.

### Equipment

- A 100 ml beaker
- Common salt
- 10k resistor

### Procedure

- Take some tap water in the beaker
- Connect a wire to BPV and place other end in water
- Another wire from A0 to water
- Connect 10k resistor from A0 to ground.
- Set 2.8 volts on BPV and watch the value of A0<sup>6</sup>
- Try changing BPV from +2.8V to -2.8V and watch the horizontal trace.
- Repeat the experiment using AC from SINE instead of DC from BPV
- Calculate the resistance as explained in section 2.5

<sup>6</sup>If the voltage is too low use a higher resistance than 10k, otherwise use a lower one.

## Observation

|    | $V_{total}$ | $V_{10k\Omega}$ | $V_{liq}$ | $I = \frac{V_{10k\Omega}}{1000}$ | $R_{liq} = \frac{V_{liq}}{I}$ |
|----|-------------|-----------------|-----------|----------------------------------|-------------------------------|
| AC | 2.6         | 2.3             | 0.3       | .23 mA                           | 1.3 k $\Omega$                |
| DC | 2.6         | 1.3             | 1.3       | .13 mA                           | 10 k $\Omega$                 |

Observed values are shown in the table<sup>7</sup>. The DC and AC resistances seems to be very different. However, when you change the polarity of BPV, the voltage across the resistor stays around the AC value for a while and then goes down. This indicates that the resistance of the liquid increases with time, may be due to some bubble formation.

## Discussion

Why the behavior is different for AC and DC ?

What are the charge carriers responsible for the flow of electricity through solutions ?

Is there any chemical reaction taking place ?

Try adding some common salt and repeat the measurements.

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<sup>7</sup>The values you may get could be very different depending on the ion concentration and presence of impurities in the water used.

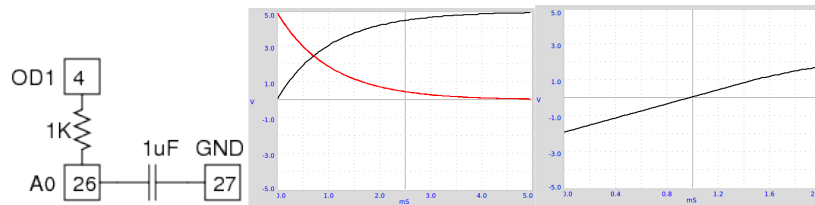


Figure 2.10: Transient response of RC circuit. The third one is the charging of a capacitor through a constant current source.

## 2.15 Transient Response of RC circuits

### Objective

In section 2.10, we have seen that a capacitor blocks DC but allows AC to pass through. In this experiment, we will explore the nature of current and voltage when a voltage step is applied. By measuring the voltage across the capacitor as a function of time, we can calculate the value of the capacitance.

### Theory

Voltage across a capacitor while charging through a resistor

$$V(t) = V_0 \left( 1 - e^{-\frac{t}{RC}} \right)$$

Voltage across a capacitor while discharging through a resistor

$$V(t) = V_0 e^{-\frac{t}{RC}}$$

### Equipment

A  $1\mu F$  capacitor and a  $1k\Omega$  resistor.

### Procedure

Connect the capacitor from A0 to Ground.

Connect the resistor from A0 to OD1.

Right click on the Panel and select **RC Circuit** from the pop-up menu

Click on 0-5V STEP and 5-0V STEP Buttons to plot the graphs

Adjust the horizontal scale, if required, and repeat.

FIT the curve to extract the time constant RC.

## Observation

Applying a 0 to 5V step makes the voltage across the capacitor to rise exponentially as shown in the figure 2.10. By fitting the graph we can extract the RC time constant and find the values of capacitance from it.

This experiment can be extended to measure dielectric constant of materials by making capacitors using them. To get the graph shown in 2.10(c), connect R from CS to A0, C from OD1 to A0, set CS to 1mA and click on 5->0V.

## Discussion

Why the graph is Exponential ?

A capacitor is made of two parallel metal plates separated by a thin layer of dielectric material. We have connected one plate (call it plate A) to ground and another plate (call it B) to OD1 via a resistor. Connection to A0 is for monitoring the voltage. Initially both plates are at zero volts. By clicking on 0->5V, we take OD1 to 5 volts. A current will start flowing through the resistor to plate B, due to the potential difference created. This current (flow of charge) will result in an accumulation of a charge on plate B. The voltage at B will be given by  $V = Q/C$ , where Q is called the capacitance. As more and more charge arrives, voltage at B also will increase. But, as per Ohm's law the current through the resistor is decided by the voltage difference across it. That means the current will gradually decrease and reach zero when the voltage at plate B becomes 5 volts. The time for this is decided by the product RC, and is given by

$$V(t) = V_0 \left( 1 - e^{-\frac{t}{RC}} \right)$$

The product RC is called the time constant of the circuit.<sup>8</sup>

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<sup>8</sup><http://hyperphysics.phy-astr.gsu.edu/hbase/electric/capchg.html>

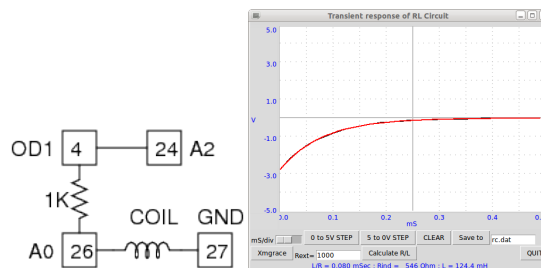


Figure 2.11: LR circuit. Voltage across the inductor after a 5 to 0V step.

## 2.16 Transient Response of RL circuits

### Objective

Explore the nature of current and voltage when a voltage step is applied to resistor and inductor in series. By measuring the voltage across the inductor as a function of time, we can calculate its value.

### Theory

In an RL circuit  $V = IR + L \frac{dI}{dt}$ . Solving this will give  $I = I_0 e^{-\frac{R}{L}t}$ . The coefficient of the exponential term  $R/L$  can be extracted from the graph of voltage across the inductor. The resistance of the inductor coil should be included in the calculations,  $R = R_{ext} + R_L$ .<sup>9</sup>

### Equipment

1k $\Omega$  resistor.

3000 turns coil, 1000 turns coil & ferrite core

### Procedure

Connect the 3000 Turns coil from A0 to Ground.

Connect the resistor from A0 to OD1.

<sup>9</sup><http://nptel.iitm.ac.in/courses/Webcourse-contents/IIT-KANPUR/esc102/node14.html>

Connect a wire from OD1 to A2 (for accurate measurement of total voltage)

Right click on the Panel and select **RL Circuit** from the pop-up menu

Click on 0-5V STEP and 5-0V STEP Buttons to plot the graphs

Adjust the horizontal scale, if required, and repeat.

Calculate the value of inductance

Repeat by inserting core. Repeat with other coils.

## Observation

The Voltage across the inductor just after a 5V to 0V step is shown in figure 2.11. The exponential curve is fitted to extract the  $L/R$  value. The resistance of the coil is measured by comparing it with the known external resistance under DC conditions. The inductances measured are tabulated below.

| Coil            | Inductance (mH) | Resistance ( $\Omega$ ) |
|-----------------|-----------------|-------------------------|
| 3000 Turns coil | 126             | 565                     |
| 1000 T          | 4.7             | 42                      |
| 1000T /ferrite  | 25              | 42                      |

## Discussion

The applied voltages are above zero, but the graph went to negative voltages. Why ?

What was the current before doing the 5->0 step ? What is back EMF ?

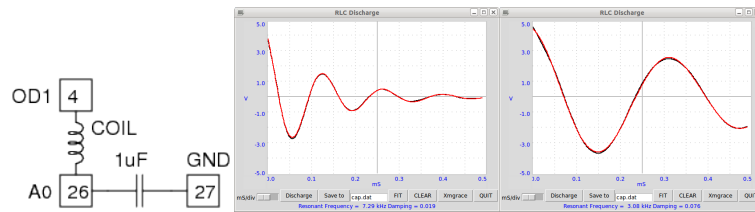


Figure 2.12: Transient response of LCR circuit. (a) Setup (b) Result with air core inductor. (c) With ferrite core

## 2.17 Transient response of LCR circuits

### Objective

The response of RL and RC circuits were done in the previous sections. Now we will explore the oscillatory nature by connecting L and C in series.

### Theory

Resonant frequency of series LC circuit  $= \omega_0 = \frac{1}{2\pi\sqrt{LC}}$ , Damping factor  $= \frac{R}{2} \sqrt{\frac{C}{L}}$ , equal to 1 for critical damping.<sup>10</sup>

### Equipment

- 0.1uF capacitor
- 3000 & 1000 Turns coil
- Ferrite core

### Procedure

- Connect Coil from OD1 to A0
- Capacitor from A0 to ground
- Right-click on Panel and select **RLC Discharge** from the menu.
- Click on Discharge. Adjust x-axis and repeat if required.

<sup>10</sup>[http://en.wikiversity.org/wiki/RLC\\_circuit](http://en.wikiversity.org/wiki/RLC_circuit)

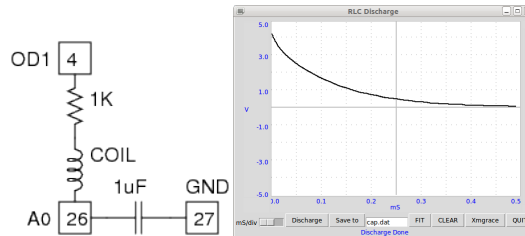


Figure 2.13: LCR with a 1k series resistor providing damping.

FIT the graph to find the resonant frequency & Damping.

Repeat the experiment with ferrite core inserted

Repeat with a  $1k\Omega$  resistor in series.

## Observation

Measurements have been done using the 1000 Turns coil, with and without ferrite core, and the 3000 Turn coil. The results are tabulated below. The capacitance and inductance were measured by an LCR meter.

| $C\mu F$ | L mH | $f = \frac{1}{2\pi} \sqrt{\frac{1}{LC}}$ | $f_{measured}(Hz)$ |
|----------|------|--|--------------------|
| .097     | 3.57 | 8552                                     | 8430               |
| .097     | 23.2 | 3354                                     | 3400               |
| .097     | 125  | 1445                                     | 1400               |

## Discussion

The under damped waveform require a resistance,  $R = \sqrt{\frac{4L}{C}} = \sqrt{\frac{4 \times 23.2e-3}{.097e-6}} = 963$  to make it critically damped. Result with a  $1k\Omega$  series resistor is shown in figure .

Why the amplitude went up after inserting the ferrite core ?





Figure 2.14: Screenshot showing the total voltage across the RC circuit and the voltage across the capacitor.  $C=1\text{ uF}$  and  $R = 560\Omega$ .

## 2.18 Capacitor in AC circuits

### Objective

Explore the effect of a series capacitor in AC circuits, under steady state conditions.

### Theory

Impedance of a Capacitor  $X_c = \frac{1}{2\pi fC}$ , where  $f$  is the frequency in Hertz and  $C$  is the capacitance in Farads. Remember the working of a capacitor explained in section 2.15.

### Equipment

1 uF capacitor

560 $\Omega$  resistor

A voltmeter, if you want to measure the voltage across the elements not directly connected to ground.

### Procedure

Connect a wire from SINE to A0

Connect the capacitor from A0 to A1

Connect resistor from A1 to Ground.

Enable A1 also. Adjust the horizontal scale to view more than 4 cycles.

Enable 'FIT' to show RMS voltage, Frequency etc.

## Observation

The input waveform and the voltage across the resistor<sup>2.14</sup>. The voltage across the capacitor is calculated using Ohm's law, you can also measure it with a volt meter.

The sum of the two voltages looks like more than the total applied voltage.

Are we violating Ohm's Law ?

What mistake we are making while adding the voltages ?

| $V_{Tot}$ | $V_{Res}$ | $I = \frac{V_{res}}{R}$ | $V_{cap} = IX_c$ | $V_R + V_c$ |
|-----------|-----------|-------------------------|------------------|-------------|
| 2.6       | .8        | 0.0014                  | 2.4              | 3.2         |

$$X_c = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 93.6 \times 1e-6} = 1712$$

$$V_c = IX_c = 1712 \times 0.0014$$

## Discussion

We need to account for the phase shift introduced by the capacitor<sup>11</sup>. Refer to the next section.

---

<sup>11</sup>[http://www.play-hookey.com/ac\\_theory/ac\\_rc\\_series.html](http://www.play-hookey.com/ac_theory/ac_rc_series.html)

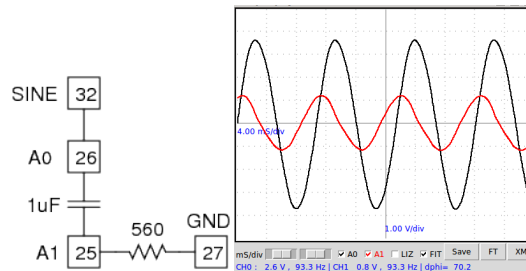


Figure 2.15: Screenshot showing phase shifts for  $R=560\Omega$  and  $C = 1\mu F$ .

## 2.19 AC phase shift in RC circuits

### Objective

Measure the AC voltage phase shift across the capacitor in an RC circuit.

### Theory

In an RC circuit, the phase shift across the inductor is given by the equation  $\Delta\Phi = \arctan\left(\frac{X_c}{R}\right)$ , where  $R$  is the resistance and  $X_c$  is the capacitive reactance.

### Equipment

1 uF capacitor

560 $\Omega$  resistor (Try other values also)

### Procedure

Connect a wire from SINE to A0

Connect the capacitor between A0 and A1

Connect Resistor from A1 to Ground.

Enable A1 also. Adjust the horizontal scale to view more than 4 cycles.

Enable 'FIT' to show RMS voltage, Frequency and Phase difference.

## Observation

The measured phase shifts are tabulated below. The connections and the voltage waveforms are shown in figure 2.15.

| C(uF) | R(k $\Omega$ ) | Freq (Hz) | $\Delta\Phi$ | $\arctan\left(\frac{X_c}{X_R}\right)$ |
|-------|----------------|-----------|--------------|---------------------------------------|
| 1     | 560            | 93        | 71.3         | 71.9                                  |

where  $X_c = \frac{1}{2\pi fC}$  is the impedance of the capacitor, Frequency is 93Hz.  $X_R$  is the resistance.

Current through a capacitor leads the voltage across it by  $90^\circ$ . Why ?

## Discussion

Why the phase of the voltage advances ? Assume we have connected the AC to plate A and at an instant  $t = t_0$  the input voltage is at zero volts. We can see that the slope of the curve is maximum there, ie. the rate of change of voltage is maximum. The capacitor gets charged very fast at this point. The plate B also gathers the same charge as plate A, that is how a capacitor works. The current to plate B is flowing from ground through the resistor and we are measuring the IR drop across the resistor, it will be already positive when plate A is at zero. This results in the phase advance.

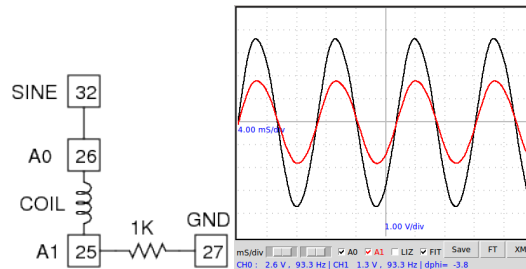


Figure 2.16: Sine wave to LR circuit. Phase shift across inductor

## 2.20 AC phase shift in RL circuits

### Objective

Measure the AC voltage phase shift in an RL circuit.

### Theory

Impedance of an Inductor  $X_L = 2\pi fL$ , where  $f$  is the frequency in Hertz and  $L$  is the inductance in Henry. In an LC circuit, the phase lag across the inductor is given by the equation  $\Delta\Phi = \arctan\left(\frac{X_L}{R}\right)$ , where  $R$  is the resistance in Ohms.

### Equipment

Inductor, use the solenoid coils supplied.

560 $\Omega$  and 1k $\Omega$  resistors

### Procedure

Connect a wire from SINE to A0

Connect the Inductor between A0 and A1

Connect the 1k $\Omega$  resistor from A1 to Ground.

Enable A1 also. Adjust the horizontal scale to view more than 4 cycles.

Enable 'FIT' to show RMS voltage, Frequency and Phase difference.

## Observation

The measured phase shifts are shown below. Waveforms for the 125 mH inductor is shown in figure 2.16. The resistance of the inductor also should be included while calculating the phase shift.

| L(mH) | $R = R_{coil} + R_{ext}(\Omega)$ | $\Delta\Phi = \arctan\left(\frac{X_L}{X_R}\right)$ | $\Delta\Phi_{measured}$ |
|-------|----------------------------------|--|-------------------------|
| 125   | 565 + 560                        | 3.71   | -3.8                    |
| 25    | 42 + 560                         | 1.39   | -1.4                    |

Current through an inductor lags by  $90^\circ$ <sup>12</sup>.

## Discussion

If you do not know the value of an inductor, you can use this experiment to determine it from the phase shift observed with a known resistor value.

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<sup>12</sup>[http://www.play-hookey.com/ac\\_theory/ac\\_inductors.html](http://www.play-hookey.com/ac_theory/ac_inductors.html)

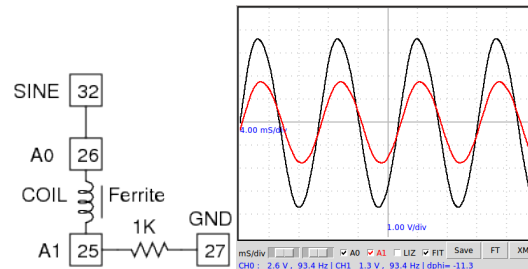


Figure 2.17: LR circuit. Effect of Ferrite core.

## 2.21 Ferromagnetic material inside inductor

### Objective

Observe the effect of ferromagnetic materials inside a solenoid coil inductor.

### Theory

Self Inductance of a solenoid is given by  $L = \frac{\mu N^2 A}{l}$ , where N is the number of turns, A is the cross sectional area,  $\mu$  is the permeability of the surrounding media and  $l$  is the length.

### Equipment

1000 turns coil

1k $\Omega$  resistor (You can use other values also)

### Procedure

Connect as explained in 2.20

Insert an iron rod into the coil and observe the changes

Repeat with the 3000 turns coil.

### Observation

The phase shift increased from 3.7 to 11.6 by inserting the ferrite core.

## Discussion

The phase shift went from 3.7 to 11.6 degrees, around 3 times increase in the Inductance. However, in this case it will be wrong to assume that the permeability of the core is 3 Why ? (look at the geometry)



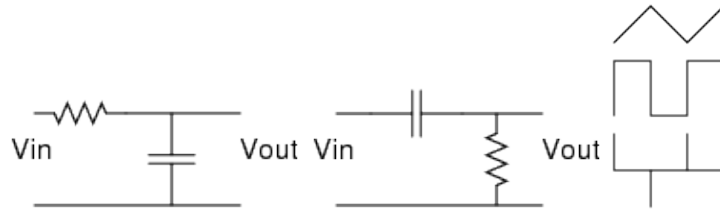


Figure 2.18: (a)RC Intergrator (b)RC Differentiator (c) Square wave, integrated and differentiated.

## 2.22 RC Integration & Differentiation

### Objective

Integrate and differentiate a squarewave using and RC circuit.

### Theory

For the circuit shown in figure2.18(a)

$$V_{out} = \frac{1}{RC} \int V_{in} dt$$

and for the one in figure2.18(b)

$$V_{out} = RC \frac{dV_{in}}{dt}$$

Figure2.18(c) shows a square wave, with it's integrated and differentiated outputs. It is easy to understand as the triangular wave differentiated twice. The constant positive slope of triangular wave gives the positive horizontal part of the square wave. Differentiating the square wave gives spikes at the rising and falling edges. These are ideal cases.

### Equipment

1uF capacitor

1kΩ resistor

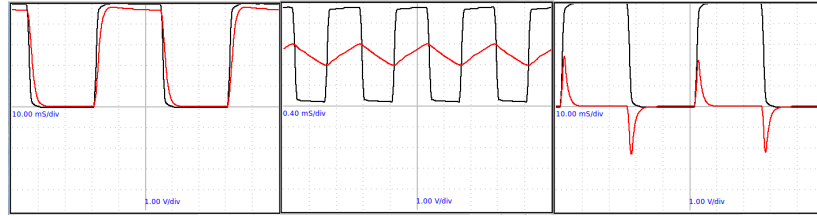


Figure 2.19: (a) Integration at 20Hz (b)Integration at 1kHz (c) Differentiation at 20Hz. For all cases  $R=1k\Omega$  and  $C=1\mu F$ .

## Procedure



Connect a wire from SQR1 to A0

Connect R from SQR1 to A1

Connect C from A1 to Ground.

Enable A1. Adjust the horizontal scale to view more than 4 cycles.

Set SQR1 to 20Hz, 100Hz and 1kHz and view the waveforms.

Interchange the positions of R and C to watch differentiation.

Click on the ButtonFT to view a Fourier Transform.

## Observation

Integration observed at 20Hz and 1kHz are shown in figure2.19, using an RC of 1 milliseconds. At 20Hz, the squarewave passes through the capacitor with a small distortion.

## Discussion

When the time period becomes comparable with the RC value, the waveform becomes triangular. The differentiation can only be shown at lower frequency since capturing the narrow spike require a fast oscilloscope.

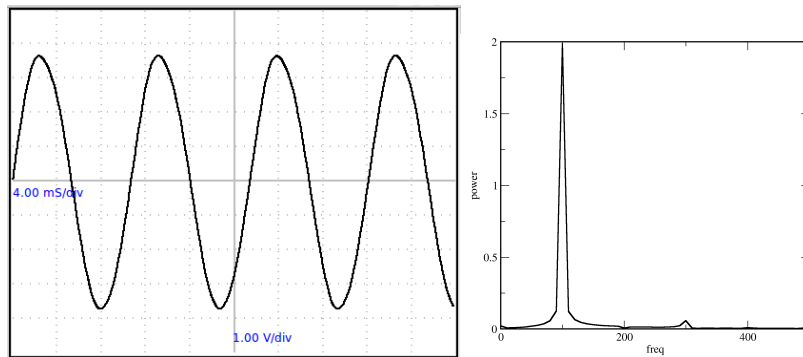


Figure 2.20: (a)Sine wave. (b) Frequency spectrum by Fourier transform.

## 2.23 Fourier Analysis

### Objective

Learn about Fourier Transform of a signal. Time and Frequency domain representations.

### Equipment

A piece of wire.

### Procedure

Connect SINE to A0

Adjust the horizontal scale to view several cycles.

Click on FT to do a Fourier transform

### Observation

The sinewave and it's Fourier transform are shown in figure2.20.

## Discussion

The original display was showing the amplitude as a function of time, and therefore is called the time domain representation of the signal. In the Fourier transform plot, frequency is on the x-axis and the y-axis shows the relative strength of the frequency components of the signal. This is called the frequency domain representation of the signal.<sup>13</sup>In this case there is only one dominant peak. The small peak at three times the fundamental frequency is a measure of distortion of our sine wave.

---

<sup>13</sup>[http://en.wikipedia.org/wiki/Fourier\\_transform](http://en.wikipedia.org/wiki/Fourier_transform)

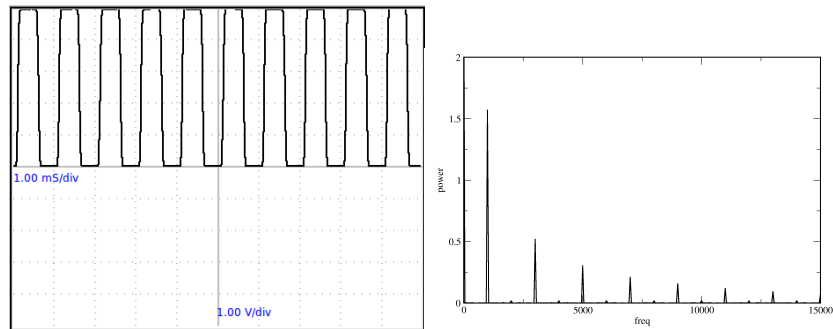


Figure 2.21: Squarewave and its Fourier transform

## 2.24 Harmonics of a square wave

### Objective

Explore the harmonic content of a square wave using Fourier Transform .

### Equipment

A piece of wire.

### Procedure

Connect terminal 6 (SQR1) to 26 (A0)

Enter 100 on the text field near SQR1 and press Enter key.

Enable the Yellow Checkbox A0 on the right side window.

Adjust the horizontal scale to 10 milliseconds per division.

Press A0-FT

### Observation

A new window opens displaying a trace as shown in figure .

## Discussion

Fourier series decomposes any periodic function or periodic signal into the sum of a set of simple oscillating functions, namely sines and cosines. A square wave function can be represented as  $f(\theta) = \sin(\theta) + \frac{\sin(3\theta)}{3} + \frac{\sin(5\theta)}{5} + \dots$ . In the Fourier transform of a square wave of frequency  $f$ , there will be a  $3f$  component (having an amplitude of one third of  $f$ ),  $5f$  component (amplitude one fifth) etc. as shown in the figure

## Chapter 3

# Electricity & Magnetism

Electromagnetic induction is demonstrated using a moving magnet and a coil powered by an AC voltage. Working of transformer is demonstrated using two coils. A simple AC generator, capable of generating multi-phase output, is made using a rotating magnet.

### 3.1 Electromagnetic induction

#### Objective

Explore the voltage induced across a coil by a changing magnetic field.

#### Equipment

Small cylindrical magnets.

3000 Turns coil and a paper tube to guide the magnet.

#### Procedure

Connect the coil from A0 to Ground.

From Panel right-click and open ***EM Induction***

Click on Start Scanning. A horizontal trace should appear

Drop the magnet through the coil until a trace is caught.

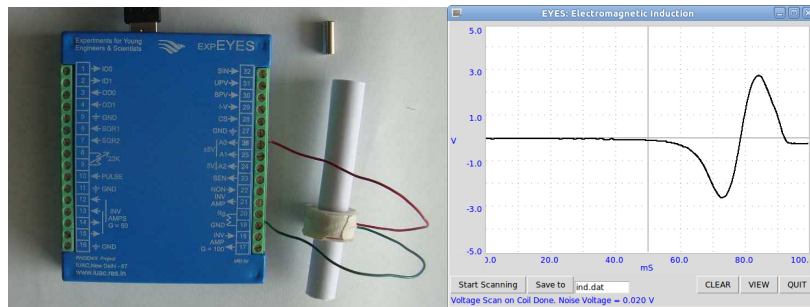


Figure 3.1: Voltage induced on a coil by a moving magnet.

Repeat the process by changing the parameters like magnet strength, speed etc.

## Observation

The result is shown in figure3.1. The amplitude increases with the speed of the magnet. From the graph, we can find the time taken by the magnet to travel through the coil.

## Discussion

The second peak is bigger than the first peak. Why ? Where will be the magnet at the zero crossing of the induced voltage?

Drop the magnet from different heights and plot the voltage vs square root of the height.



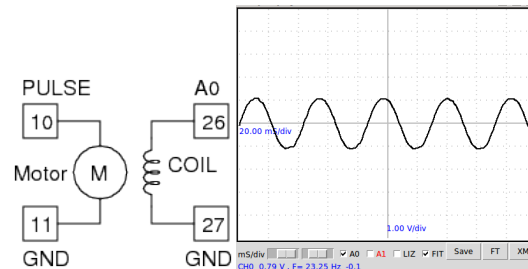


Figure 3.2: Voltage output of the AC generator with different speeds of rotation of the magnet.

## 3.2 A simple AC generator

### Objective

Measure the frequency and amplitude of the voltage induced across a solenoid coil by a rotating magnet. Gain some understanding about the AC generators by looking at the output and the drawbacks of the setup.

### Equipment

A magnet ,  $D = 10$  mm,  $L = 10$  mm

DC motor

3000 Turns coil

### Procedure

Connect the DC motor to PULSE (T10), mount the magnet horizontally.

Connect the coil from A0 to ground

Hold the coil perpendicular to the axis of rotation of the motor, close to the magnet. Be careful not to touch it.

Set PULSE to 10 (% duty cycle)

Measure the frequency & amplitude by enabling FIT.

Repeat by changing PULSE to 20 , 30 and 40 (NOT beyond that)

## Observation

The voltage output is shown in figure3.2. The speed of the motor is nearly proportional to the duty cycle (from 20% to 40%)

## Discussion

Connect another coil to A1 and bring that also near the magnet to view a two phase AC waveform. You can change the relative phase by changing the angular positions of the coils.

Bring another shorted coil near the magnet to observe the change in frequency. The shorted coil is drawing energy from the generator and the speed get reduced.

The magnetic field in this generator is very weak. The resistance of the coil is very high and trying to draw any current from it will drop most of the voltage across the coil itself.<sup>1</sup>

---

<sup>1</sup>It would be safer to power the motor from a separate variable voltage power supply (<3 volts). The PULSE output is NOT meant for this job, we are almost short circuiting an output pin of the micro-controller.

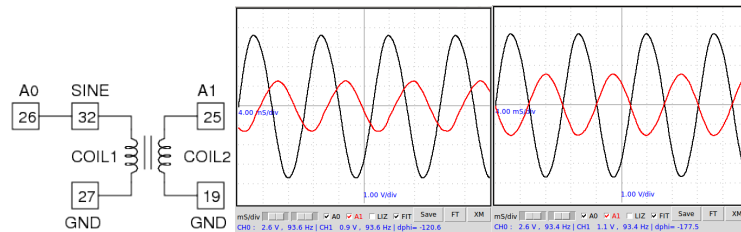


Figure 3.3: Mutual Induction between two coils.(a) Connections (b) using a ferrite rod (c) using two E shaped cores

### 3.3 Mutual induction, transformer

#### Objective

Demonstrate mutual induction between two coils, working of the transformer.

#### Equipment

Two coils, each having 3000 turns.

#### Procedure

Connect the first coil from SINE to ground.

A wire from SINE to A0, for monitoring the input wave form.

Second coil from A1 to Ground.

Align coils and insert the ferrite rod through them.

Enable A1 and FIT

#### Observation

The applied waveform and the induced waveform are shown in figure3.3. A changing magnetic field is causing the induced voltage. In the previous two experiments, the changing magnetic field is created by the movement of permanent magnets. In the present case the changing magnetic field is created by a time varying current.

## Discussion

The output should have been in phase with the input as per the theory.<sup>2</sup> However, this is not happening if the coupling is not enough.

With more ferrite material, the phase shift is as expected from the theory.

Try doing this experiment using a squarewave of 100 Hz, 1000 Hz etc. Connect a  $1\text{k}\Omega$  resistor from secondary to ground to reduce the ringing.

---

<sup>2</sup><http://sound.westhost.com/xfmr.htm>

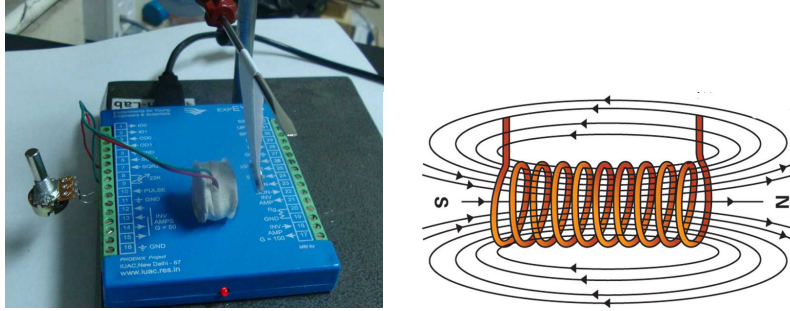


Figure 3.4: (a) Current carrying solenoid repelling a permanent magnet.  
(b) Magnetic field of a current carrying solenoid

### 3.4 Electromagnet, solenoid coil

#### Objective

Demonstrate the magnetic effect of electric current, using a solenoid coil and permanent magnet.

#### Equipment

Solenoid coil.

Two Button shaped magnets

#### Procedure

Connect the solenoid from OD0 to Ground.

Make a pendulum using a paper strip and the magnets.

Hang the pendulum near the solenoid as shown in figure 3.4

Take OD0 to HIGH and observe the force

Reverse the direction of the pendulum

Place the pendulum on the other side of the coil.

## **Observation**

The solenoid behaves just like a bar magnet. Hang the pendulum magnet near the coil and change the direction of current by interchanging the wires connected to OD0 and ground

## **Discussion**

The magnetic field of a solenoid coil is shown in figure3.4. The direction of field depends on the direction of the current.

Find the direction of winding of the solenoid from the above observations.

### **3.5 Eddy current braking**

#### **Objective**

Demonstrate the effect of eddy currents by moving a conductor perpendicular to a magnetic field.

#### **Equipment**

DC motor

Annular disc of aluminium

magnet 10mm x 10mm

#### **Procedure**

Fix the disc on the motor using a cello-tape

Connect motor between PULSE and Ground

Set PULSE to 30%

Bring the magnet close to the disc surface

#### **Observation**

The speed of rotation reduces when magnet is brought near the surface of the disc.

#### **Discussion**

Eddy currents are created when a conductor experiences changes in the magnetic field. If either the conductor is moving through a steady magnetic field, or the magnetic field is changing around a stationary conductor, eddy currents will occur in the conductor.





# Chapter 4

## Sound

Sound is generated from electrical signals and frequency of sound is measured by converting it back into electrical signal. Reflection and interference of sound are explored. Velocity of sound is measured by observing the phase shift of digitized sound with distance.

### 4.1 Generating sound

#### Objective

To find some answer to questions like:

What is a description of sound?

What are the characteristics of sound waves?

How is sound created and detected?

#### Equipment

Loudspeaker

Piezo electric disc

#### Procedure

Connect the  $150\Omega$  speaker from SQR1 to GND

Set SQR1 to 1000.

Listen to the sound.

Change the frequency to note the difference in the sound generated.

Repeat the same using Piezo disc also

Right Click and open *Music* from the menu

## Observation

The pitch of sound produced depends on the frequency.

## Discussion

How the loudspeaker is making sound? When the AC voltage is applied, the diaphragm of the speaker moves back and forth. In one forward movement, it pushes against the air in front of it and creates a compressed or high pressure region. Next it moves backward creating a low pressure region just behind the high pressure region created earlier, and completed one cycle. In the next forward movement, another high pressure region is created and it pushes the high and low pressure regions created by the last cycle. This process is repeated and the alternate high and low pressure regions travels forward. This is sound.

Generating different frequencies creates music. However the richness is provided by the right amount of harmonics for each frequency, something that we cannot control in this setup.

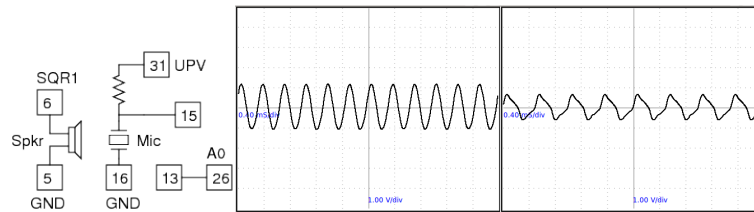


Figure 4.1: Digitizing sound.(a)Connections (b) Frequency is 3012 Hz (c) 2000 Hz.

## 4.2 Frequency of sound

### Objective

Measure the frequency of sound by converting it in to an electrical signal.

### Equipment

Microphone assembly

Piezo disc

### Procedure

Connect the microphone between T15 & T16. Bias resistor to UPV

Connect amplifier output (T13) to A0

Set 5 volts on UPV.

Connect Speaker from SQR1 to Ground.

Set SQR1 to 3000 Hz and fix the speaker facing it

Watch the waveform and adjust the timebase

Enable FIT to measure the frequency

## Observation

| freq. set | freq. measured |
|-----------|----------------|
| 3012.0    | 3011.94        |
| 2000      | 2000.46        |

By fitting the digitized data, we are able to extract the frequency information. However, the waveform looks cleaner near 3000 Hz. This is because the resonant frequency of the speaker is near 3000 Hz.

The output of 2000 Hz contains the 6000 Hz component. Click on FT to view the Power spectra and compare both.

## Discussion

Sound waves creates pressure variations in the medium through which it travels. The microphone generates a voltage is proportional to the pressure. Since this signal is very small, we amplify it 50 times before digitizing it. The voltage variations are in tune with the pressure variations. You can consider the microphone as a pressure sensor, but working only for time varying pressures.

Repeating the experiment will give results that may look strange at first sight. Powering by 100 Hz will give you a frequency of around 3900 Hz, but with a small amplitude. Resonance is again the reason.

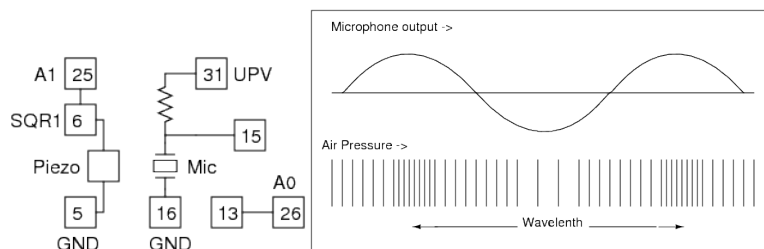


Figure 4.2: (a) Experimental setup (b) Schematic of the propagation of sound waves, and the variation of microphone output with pressure.

## 4.3 Velocity of sound

### Objective

Calculate the velocity of sound by measuring the air pressure variation with distance.

### Equipment

Piezo disc

Microphone assembly

### Procedure

Connect the Piezo from SQR1 to Ground

Connect the microphone assembly and set UPV to 5 volts.

Connect Amplifier output to A0 and SQR1 to A1

Right click and Start **Velocity of Sound** from the menu

Keep the Piezo on the edge of a piece of soft cloth, facing the microphone

Adjust the distance to make the waveforms in phase

Slide it away to make the waveform out of phase, without moving the cloth.

Measure the distance from the edge of the cloth to the current position.

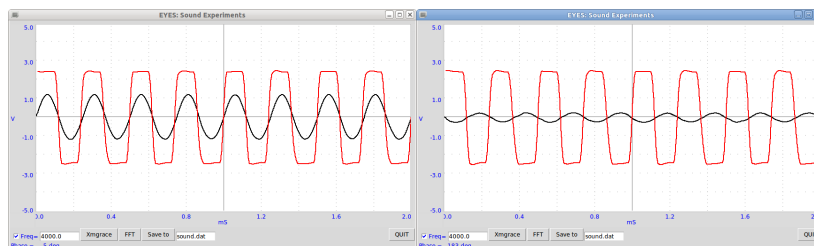


Figure 4.3: Sound amplitude captured at half wave length apart.

## Observation

The amplitude of sound captured at two points is shown in figure4.3. The squarewave is the voltage driving the piezo electric disc. To change the phase of the sinusoidal wave, the microphone output, by 180 degrees ( half wavelength) the microphone is moved by 4.3 cm. The velocity of sound is given by  $v = f\lambda = 4000 * 2 * 0.043 = 344$  meter per second.

## Discussion

Sound travels as a series of compressions and rarefactions. The lower part of figure4.2 shows the High and Low pressure regions along the direction of travel of the sound wave. The pressure as a function of time at any stationary point on the path is given by the microphone output, as shown in the upper part of figure4.2

We can display the pressure variation at any point with respect to the variation at the starting point. The relative phase of the two waveforms changes when you move the microphone. Moving by one wavelength changes the phase by 360 degrees. We have moved half wavelength to make the phase differ by 180 degrees. The velocity of sound can be calculated by multiplying the frequency and the measured wavelength.

Why use the folded soft cloth cloth ? Why not do it on a hard surface ?

## 4.4 Reflection of sound

### Objective

Study the nature of sound reflection from a hard surface

### Equipment

Microphone assembly

Piezo electric disc, powered by SQR1.

A 10cm x 10cm hard sheet, plastic or cardboard.

### Procedure

Connect the Microphone as explained in section 4.2

Connect the Piezo from SQR1 to Ground.

Fix the mic and buzzer facing the same direction

Watch the amplitude of A0.

Keep a piece of paper in front and capture again.

### Observation

Sound is getting reflected from a hard surface.

### Discussion

Change the orientation of reflector and observe the changes. How does it compare with the reflection of light from a mirror (or rather from a white sheet of paper)

Try the reflection from a soft surface like cloth or sponge.

The effect of reflection is what forced us to use the cloth surface in the previous experiment. Try placing a hard surface parallel to the direction of sound to see the effect of it on the phase difference. The sound travelling directly interfere with the part reflected from the hard surface results in phase change at the microphone.

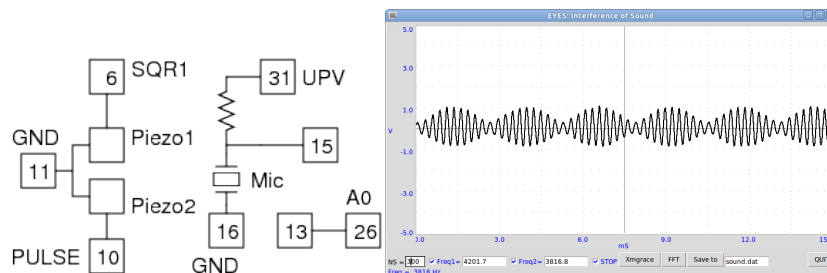


Figure 4.4: Beats created using two nearby frequencies.

## 4.5 Interference of sound

### Objective

Study the interference of sound from two individual sources

### Equipment

Condenser microphone

Two Piezo electric discs, powered by SQR1 and PULSE.

### Procedure

Make connections as shown in the figure.

Right Click and start *Interference of Sound*

Set SQR1 to 4200 Hz and PULSE to 3800 Hz

Adjust distances to get clear beat pattern.

Repeat with other values of frequencies.

### Observation

The individual frequencies are 4201.7 Hz and 3816.8, differing by 384.9 Hz. From figure 4.4 it can be seen that one wave envelope is around 2.65 ms, i.e. a frequency of around 380 Hz. Wavelength is the distance between two minimum pressure points.



## **Discussion**

The relative strength of the individual frequency components can be measured by taking a Fourier transform of the output.

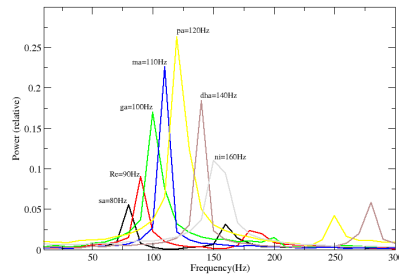


Figure 4.5: Fourier analysis of musical notes.

## 4.6 Analysing Music<sup>1</sup>

### Equipment

Guitar with someone who knows how to use it

Microphone assembly

### Procedure

Connect the microphone between T15 & T16

Bias to UPV and set it to 5 volts

Play different notes and click on FT to take the Fourier transform

### Observation

The results are shown in figure4.5. Base string E is used. Ratio between notes is given by

| Sa | Re  | Ga  | Ma  | Pa  | Dha | Ni   | Sa |
|----|-----|-----|-----|-----|-----|------|----|
| 1  | 9/8 | 5/4 | 4/3 | 3/2 | 5/3 | 15/8 | 2  |

### Discussion

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<sup>1</sup>Contributed by jithinbp at gmail.com

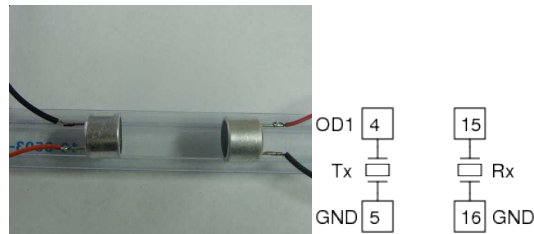


Figure 4.6: (a)Experimental setup (b) Connections

## 4.7 Velocity, using ultrasound

### Objective

Measure the velocity of sound from the time of flight of ultrasound bursts.

### Equipment

40 kHz piezo transmitter and receiver

### Procedure

Connect the Transmitter Piezo from OD1 to Ground

Receiver from T15 to Ground.

Right click and open **40 kHz Piezo TOF**

Place the Transmitter and receiver facing each other at 5 cm

Measure Time of Travel

Repeat at 6 and 7 cm also

Calculate velocity of sound from the differences in distance and time

### Observation

| Distance | Time(usec) |
|----------|------------|
| 4        | 223        |
| 5        | 253        |
| 6        | 282        |

## Discussion

In this experiment, we use a pair of 40 kHz piezo electric crystals to study the propagation of sound in air. We apply a 5 volts pulse, 13 microseconds wide, to the transmitter piezo to make it undergo mechanical vibrations to generate a 40 kHz sound wave burst. The receiver piezo kept at a distance converts this sound waves back into an electrical signal. It is amplified and the time interval between the pulse and the arrival of the waves at the receiver is measured.

To eliminate systematic errors like the response time of the transmitter, amplifier delays etc., we use the difference in time with change in distance.  $0.02/(0.000282 - 0.000223) = 338m/sec$ .

## 4.8 Forced Oscillations of Piezo-electric crystal

### Objective

Study the behavior of a Piezo-electric disc at various excitation frequencies. This is just an exploration.

### Equipment

Piezo disc

Microphone assembly

### Procedure

Connect the Piezo from SQR1 to Ground

Connect the microphone to T15, T16 and T31

Right click and open **Interference of Sound**

Place the Transmitter and receiver facing each other

Set NS (number of samples) to 800

Tick SQR1, set it to 200

Tick START

Adjust distance and click on FFT

Change SQR1 to 500, Disable and Enable START

### Observation

The resonant frequency of the Piezo crystal is around 3600 Hz, where it gives maximum amplitude as shown in figure4.7(a). When the excitation frequency is 100 Hz, the piezo gets a kick every 5 milli seconds, as shown in figure4.7(b), ie. at rising and falling edges of the exciting squarewave.

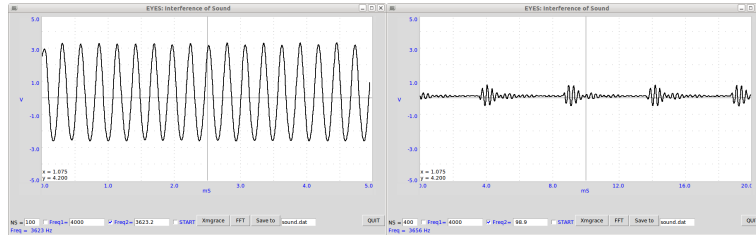


Figure 4.7: Sound output from Piezo (a)Excitation frequency 3625 Hz (b) Excitation frequency 100 Hz

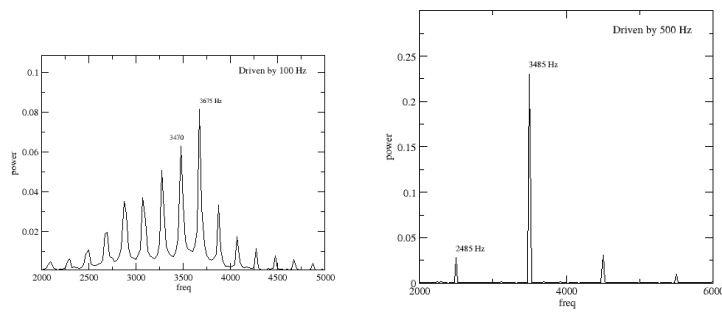


Figure 4.8: Fourier power spectrum of the sound from Piezo disk. (a)Excited by 100 Hz (b)Excited by 500 Hz.

## Discussion

The Fourier power spectrum shows that the output is amplitude modulated. The resonant frequency peak has sidebands at twice the driving frequency. This behavior is seen only at lower excitation frequencies.

It may be interesting to repeat this study using a variable frequency sine wave instead of the square wave.





# Chapter 5

## Electronics

The non-linear elements like diodes and transistors are studied by drawing their characteristic curves and making simple circuits to demonstrate their functioning. Photo-transistor is used for transparency measurements, optical signal transmission and for timing the mechanical movements. Amplitude and Frequency modulation are explored.

### 5.1 Half wave rectifier, PN junction

#### Objective

Learn the working of a PN junction diode. Making DC from a sinusoidal AC. Filtering to reduce the AC component.

#### Equipment

1N4148 diode, 1 k $\Omega$  resistor

1  $\mu$ F and 100  $\mu$ F capacitors.

#### Procedure

Connect SINE to A0

Diode from A0 to A1

Load resistor from A1 to Ground

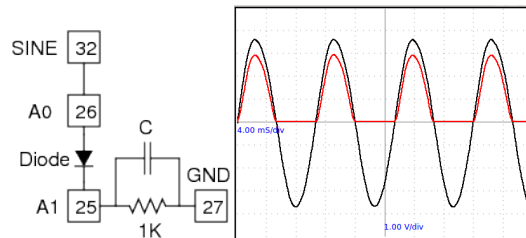


Figure 5.1: Diode as a half wave rectifier.

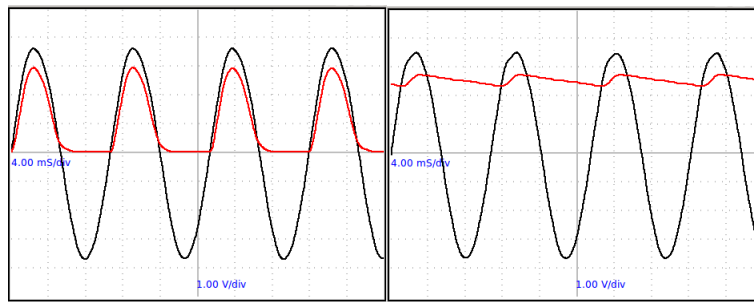


Figure 5.2: Rectifier with Filter. (a) 1  $\mu$ F (b) 100  $\mu$ F.

View the waveform on A0 and A1

Add different values of filter capacitors from A1 to ground

## Observation

The negative half is removed by the diode as shown in figure5.1. Also notice that the voltage in the positive half is reduced by around 0.7 volts, the knee voltage of a silicon diode. A load resistor is required for the proper operation of the circuit, it could be more than  $1k\Omega$  but do NOT use very low values since our AC source can drive only up to 5 mA current.

The effect of a capacitor is shown in figure5.2. We can see that the capacitor charges up and then during the missing cycle it maintains the voltage. The remaining AC component is called the ripple in the DC.

## Discussion

Can we use very large capacitance to reduce the ripple ?

During what part of the cycle current flows through the diode ?

Amount of peak current is decided by what ?

Do not get the impression that you can reduce ripple by increasing the capacitance. During the rising part of the positive half cycle, the capacitive reactance decides the current through the diode, and in practical circuits it should not exceed diode limits.

Practical circuits use full wave rectifier or bridge rectifier.

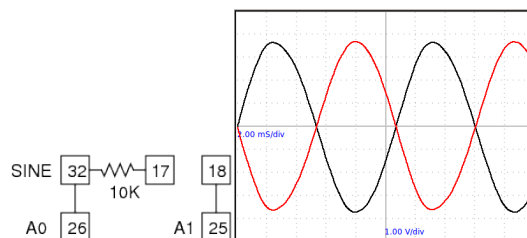


Figure 5.3: Inverting Amplifier making  $180^\circ$  out of phase sine wave.

## 5.2 $180^\circ$ out of phase sine waves

### Objective

To demonstrate the working of a fullwave rectifier using two diodes, we need two AC waveforms differing by  $180^\circ$  in phase. We do this by inverting the output of SINE using an inverting amplifier. The gain is made near unity by feeding the amplifier input through a  $10\text{k}\Omega$  series resistor.<sup>1</sup>

### Equipment

10  $\text{k}\Omega$  resistor

### Procedure

Connect as shown in the figure

View the waveforms on A0 and A1

### Observation

The result is shown in the figure 5.3.

### Discussion

The amplitudes are not exactly equal. The gain is given by  $G = \frac{10000}{10000+100}$ .

<sup>1</sup>We can also generate two out of phase waveforms by placing two coils on the opposite side of the rotating magnet, explained in section 3.2.

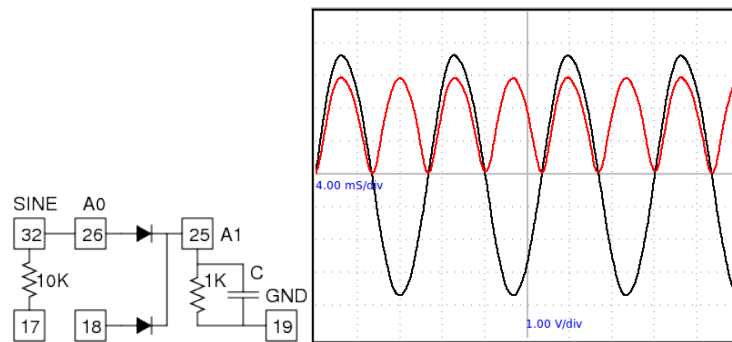


Figure 5.4: Full wave rectifier using two diodes.

## 5.3 Diodes, Fullwave rectifier

### Objective

Make a fullwave rectifier from two AC waveforms differing by 180 degree in phase.

### Equipment

Two 1N4148 diodes

1 k $\Omega$  and 10 k $\Omega$  resistors

1 uF and 100 uF capacitor.

### Procedure

Connect SINE to A0

Connect SINE to T17 through a 10k $\Omega$  resistor.

One Diode from A0 to A1

Another Diode from T18 to A1

1k $\Omega$  resistor from A1 to Ground

View the waveform on A0 and A1

Add Capacitor from A1 to ground

## **Observation**

The result is shown in the figure 5.4. Adding capacitors to reduce the ripple is left as an exercise to the user.

## **Discussion**

This is only to demonstrate the working of a full wave rectifier. You cannot draw only draw few milli amperes of current from this circuit.

Why fullwave rectifier is superior to halfwave rectifier ?

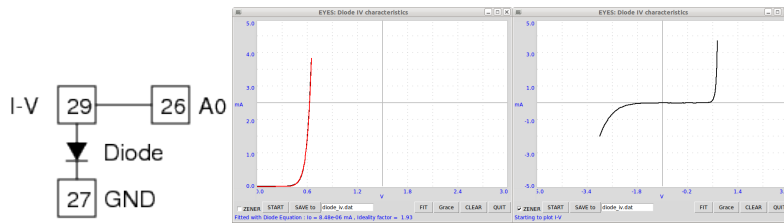


Figure 5.5: Diode IV characteristic curves for 1N4148 and a 3.3 volts zener diode.

## 5.4 Diode I-V characteristic

### Objective

Draw the I-V Characteristic of diode. Examine the Diode equation.

### Theory

The IV characteristic of an ideal PN junction diode is given by equation

$$I = I_0 \left( e^{\frac{qV}{kT}} - 1 \right)$$

$I_0$  ,Reverse saturation current

$q$  , Charge of electron

$k$ , Boltzmann constant

$T$ , Absolute temperature

For practical (non-ideal) diode, the form used is.

$$I = I_0 \left( e^{\frac{qV}{n k T}} - 1 \right)$$

where  $n = 1$  for an ideal diode. For practical diodes it varies from 1 to 2.

### Equipment

Diodes 1N4148 and a 3.3 volts Zener diode (To see the reverse biased curve).

## Procedure

Connect the 1N4148 diode from I-V to Ground. (N side to ground)

Connect IV to A0 by a wire.

Right Click and select **Diode IV** from the menu.

Click on START to draw the characteristic curve.

Click on FIT to calculate the Diode Ideality factor.

Replace 1N4148 with the Zener diode.

Enable the ZENER Checkbox and click START.

## Observation

The curves obtained are shown in figure 5.5. The value of  $n$  for 1N4148 is 1.93 and for the zener it is 1.5.

## Discussion

We have calculated the value of  $n$  by fitting the experimental data with the equation. The ideality factor of the Zener is calculated fitting the forward biased part of the data only.

Repeat the experiment by heating the diode to different temperatures.



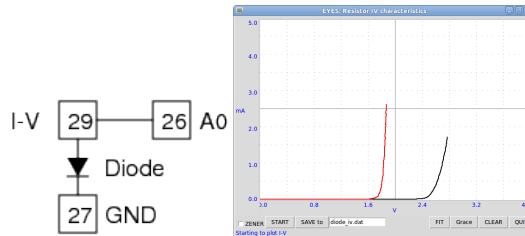


Figure 5.6: IV characteristics of Blue & Green LEDs

## 5.5 Light emitting diodes, LED

### Objective

Plot IV curves for LEDs of different wavelengths. Relate to Plank's constant.

### Theory

Energy of photon from is given by  $E = h\nu = hc/\lambda$ . This energy is equal to the energy of an electron that overcomes the junction barrier and is given by  $E = eV_0$ . So Plank's constant  $h = eV_0\lambda/c$ , where  $\lambda$  is the wavelength of light from the LED,  $e$  the charge of electron and  $c$  the velocity of light.

### Equipment

Red, Blue, Green and Yellow LEDs. All with clear glass cover, ie. not colored.

### Procedure

Right click on the Panel and open **LED IV** from the popup menu.

Connect the diodes from I-V to Ground, one by one, and plot the graph.

### Observation

The observed characteristics are shown in figure 5.6. The linear part of the curve is fitted to find the x-intercept point, and it is 1.788 for the red

LED( $\lambda = 660nm$ ), which gives

$$h = \frac{1.6e-19 \times 1.788 \times 600e-9}{3e-8} = 6.29e-34$$

## Discussion

*Note: This need to be done more accurately. Compare the ratio of voltages with wavelength to estimate the accuracy of measurements.*

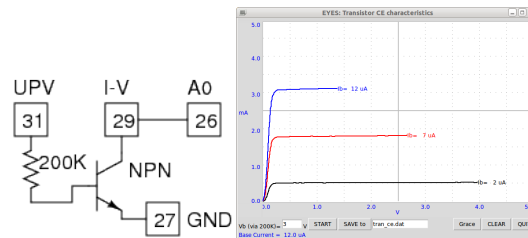


Figure 5.7: Transistor common emitter characteristics

## 5.6 Transistor CE characteristic

### Objective

Plot the CE characteristic curve of a transistor.

### Equipment

2N2222 transistor,  $200k\Omega$  resistor, wires

### Procedure

Solder two small wires to the collector.

Solder the resistor to the base.

Connect Base to UPV (0 to 5V output)

Collector to IV, and to A0 for voltage monitoring

emitter to Ground

Right-click on Panel and open **Transistor CE** from the menu

Enter the Bias supply voltage to the base and **START**. Repeat for different  $V_b$ .

### Observation

The characteristic curves for different base currents are shown in figure 5.7.

## Discussion

We are connecting the Collector to a I-V , which is connected internally to BPV. The base current is set by setting the voltage at one end of the 200 k $\Omega$  resistor, the other end is connected to the transistor base. The value of base current is calculated by

$$I_b = \frac{V_{bias} - 0.6}{200 \times 10^3} \times 10^6 \mu A$$

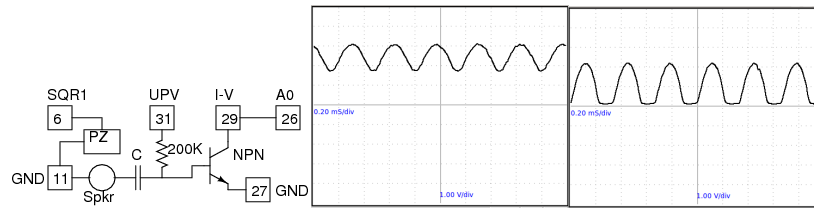


Figure 5.8: Transistor amplifier at different operating points.(a) Setup  
(b)  $Bias = 2V$  (c)  $Bias = 4V$

## 5.7 Transistor amplifier (CE)

### Objective

Demonstrate the working of a transistor amplifier in common emitter configuration. The operating point is set by changing the bias voltage, using UPV. An AC signal is generated using the loudspeaker as a microphone and this input is given to the base through DC blocking capacitor.

### Equipment

Transistor holder with  $200k\Omega$  resistor and  $1\mu F$  capacitor at the Base.

Small Loudspeaker, to be used as a microphone

Piezo disk, to generate sound.

### Procedure

Transistor Collector to IV and A0

Connect Transistor Base to UPV

Piezo Disc to SQR1 and set SQR1 to 3000 Hz

Small loudspeaker to Base through the  $0.1\mu F$  capacitor, other end Ground.

Set Bias voltage on UPV. Try values from 1V to 5V.

### Observation

The collector voltage for different base voltages are shown in figure 5.8.

## Discussion

Remember that the voltage gain is not same as the transistor  $\beta$  , but it depends on the resistance in the collector circuit. In our setup the the collector is connected to 5V through a  $1k\Omega$  resistor.

Why do we need to feed the input through a capacitor ? Why not connect the signal directly ? Try short circuiting the capacitor by a piece of wire, while observing the trace.

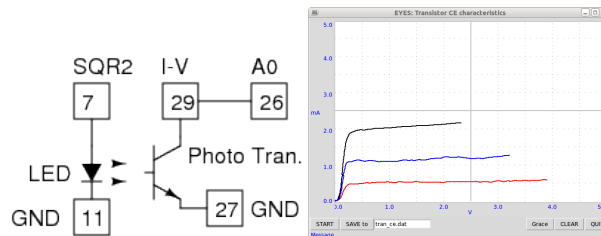


Figure 5.9: CE characteristic of photo-transistor.

## 5.8 Photo-transistor

### Objective

Understand the photo transistor. Draw the CE characteristic

### Equipment

Photo transistor (base lead removed) and wires  
white LED

### Procedure

Transistor Emitter to ground and Collector to IV and A0  
LED from SQR2 to ground  
Right-click on Panel and open **Photo-Transistor CE** from the menu  
Place a light source 5 cm away from the Transistor  
Click on START, to draw the CE curve  
Repeat by changing the distance between light source and transistor

### Observation

The characteristic curves for different light intensities are shown in figure.

### Discussion

The base current is decided by the intensity of light.

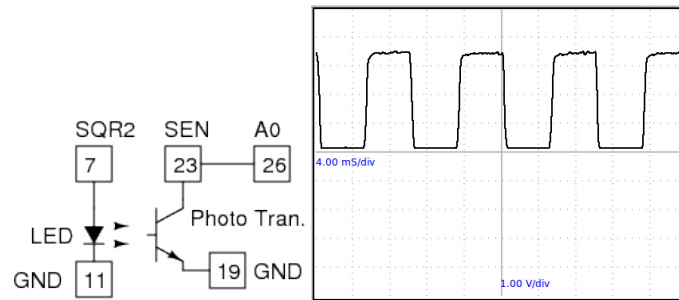


Figure 5.10: The waveform at the photo-transistor collector

## 5.9 Opto-electric signal transmission

### Objective

Demonstrate the transmission of signals through optical media. Electrical signals are connected into light at the transmitter and converted back into electrical signals at the receiver.

### Equipment

LED and Photo transistor.

Fiber optic cable.

### Procedure

Connect LED from SQR2 to ground.

Connect the 22k resistor of SQR2

Phototransistor emitter to ground and collector to SEN (T23)

Connect SEN to A0

Set SQR2 to 100 Hz

Place the LED facing the phototransistor and adjust the waveform

Enable FIT option to calculate the frequency by fitting the data.



Get a more accurate frequency measurement by clicking on 'Measure Freq'

Repeat the experiment by changing the frequency.

Use the Fiber Optic cable to guide the light from LED to the transistor.

### **Observation**

The output of the phototransistor for 500 Hz signal to the LED is shown in figure5.10. The frequency calculated by curve fitting is very close to 500. The frequency measurement done internally gives the correct value.

### **Discussion**

The electrical signal is converted into light signal by the LED. Light is transmitted to the photo-transistor and it is converted back into the electrical signal. It can be seen that, the shape of the waveform is slightly rounded but the frequency information is preserved. This demonstrates the advantage of digital signal transmission over the analog.

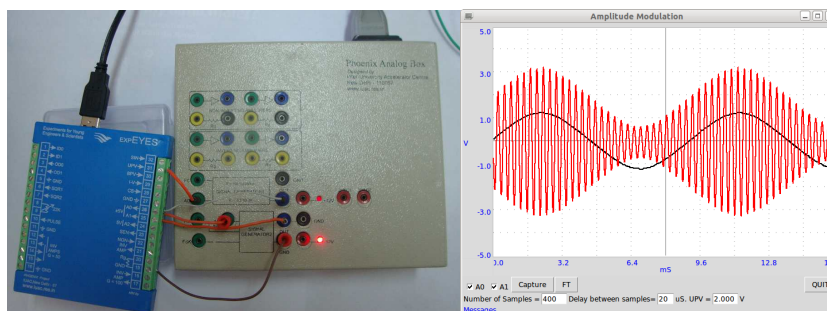


Figure 5.11: Amplitude modulation. (a) Experimental setup (b) Modulating signal along with the modulated output.

## 5.10 Amplitude & Frequency Modulation

### Objective

Study amplitude and frequency modulation of a signal. Analyse the AM output mathematically to see the sidebands.

### Equipment

Phoenix Analog Box. It has a sine wave generator (around 100 Hz) whose amplitude can be controlled using a DC control voltage. It also has a 4kHz sine wave generator that has Amplitude and Frequency controls. We use the UPV output of expEYES to control the amplitude of the 100 Hz generator. Its output is monitored on A0 and also given to the Amplitude Modulating input of the second oscillator. The amplitude of the second oscillator is given to A1.

You can capture these waveforms, separately or together. The number of samples and the time gap between samples can be specified by the user. The depth of modulation is decided by the amplitude of the modulating signal.

Analog box also allows you to set the frequency of the modulating signal between 100 to 300Hz but we are not using this feature here.

### Procedure

Connect the Grounds of Analog Box and expEYES

UPV to AC of the 100 Hz oscillator  
100 Hz output to A0 and AM input  
Modulated output to A1  
Select A0 and A1  
Capture 400 samples with 20 microsecond interval  
Select A1 only  
Capture 1800 samples with 40 usec interval  
Click on Power Spectrum to do a Fourier transform  
To do FM connect 100 Hz output to the FM input of the other generator.

### Observation

A carrier signal having a frequency of around 4kHz is modulated by a sinewave of around 100 Hz. A small portion of the output (400 points with 20 usec gap) along with the modulating signal is shown in figure 5.11(b). Power spectrum is calculated using Fourier transform. To get better results a larger sample (1800 samples with 40 usec gap) is taken for this purpose.

Frequency modulation also done, just changing the signal connection from AM to FM input. The FM output is shown in figure

### Discussion

The two sidebands are clearly obtained on both sides of the carrier peak, separated by the modulating frequency.

The AM output looks similar to the sound beats we obtained in section 4.5, but taking a power spectrum of beats gives two peaks corresponding to the individual frequencies. How do they differ in spite of the similar looks ?

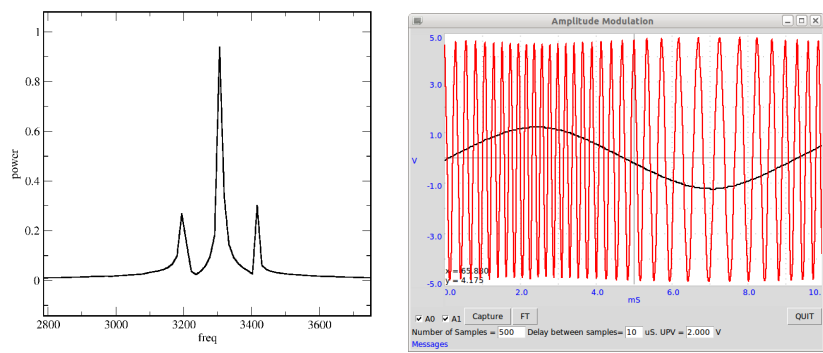


Figure 5.12: (1)Power spectrum of AM output. Generated from 1800 data points with 40 microseconds time interval in between.(2) The FM output

## Chapter 6

# Mechanics, Optics & Heat

Resonance phenomena is studied using a driven pendulum. Value of acceleration due to gravity is measured using time of flight method and also by using a pendulum.

### 6.1 Resonance of a driven pendulum

#### Objective

Demonstrate the resonance of a driven pendulum.

#### Equipment

Solenoid and pendulum made of button magnets, same as in section 3.4

22 k $\Omega$  potentiometer

#### Procedure

Connect solenoid from SQR2 to Ground.

Connect the 22K variable resistor of SQR2.

Hang the pendulum near the solenoid as shown in figure 3.4

Set SQR2 to 10 Hz, and adjust the resistor to reduce frequency until the pendulum amplitude goes up .

## Observation

When SQR2 reaches the resonant frequency of the pendulum, the amplitude goes up due to resonance. A 5.2 cm (from the center of the magnet to the axis of oscillation) long pendulum resonated at around 2.3 Hz, almost tallying with its calculated natural frequency.

## Discussion

The resonant frequency of the pendulum can be calculated by assuming it as a simple pendulum and using

$$f = \frac{1}{T} \quad \text{where} \quad T = 2\pi\sqrt{\frac{\ell}{g}}$$

where  $\ell$  is the distance from the center of the magnet to the point of suspension and  $g$  is the acceleration due to gravity.

Repeat the experiment by changing the length of the pendulum.<sup>1</sup>

---

<sup>1</sup>SQR2 cannot go below 0.7 Hz

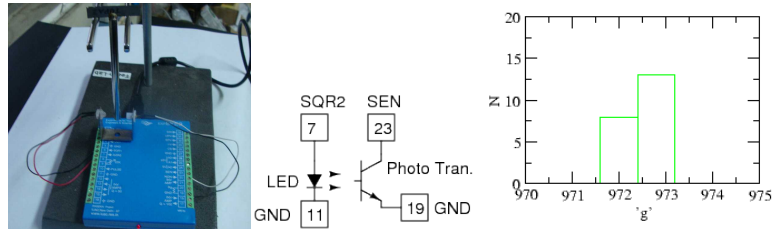


Figure 6.1: Measuring the period of a rod pendulum using Light Barrier, to calculate the value of 'g'.

## 6.2 Value of 'g', Rod pendulum

### Objective

Measure the period of oscillations of a rod pendulum using a light barrier and calculate the value of acceleration due to gravity.

### Theory

Period of oscillation of a uniform rod about one end is given by

$$T = 2\pi\sqrt{\frac{2\ell}{3g}}$$

### Equipment

Light Barrier, made of LED and photo-transistor

Rod Pendulum

### Procedure

Connect the LED from SQR2 to Ground

Photo-transistor collector to SEN and emitter to ground

Right click on the panel and start **Rod Pendulum** from the popup menu

Measure and enter the length of the pendulum

Oscillate the pendulum and click on START

Can make a histogram using XmGrace.

## Observation

The time period (in milli seconds to match the vertical range with value of 'g') and the calculated value of 'g' are plotted, as shown in figure 6.1. It also shows a histogram of the 20 readings.

## Discussion

The calculated value of 'g' is around  $972.5 \text{ cm/sec}^2$ , showing a systematic error of around 8.5%. The random error is less than 0.1%. The reason for the systematic error could be due to the following reasons. The length is measured from the knife edge to the bottom and used in the formula. But there is a small mass projecting above the knife edge that is not included in the calculation. Another reason is that the pendulum may not be exactly vertical in the resting position.



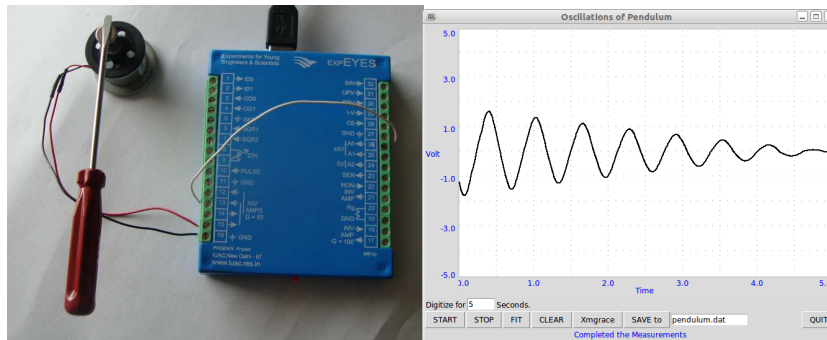


Figure 6.2: Nature of oscillations of a pendulum.

## 6.3 Oscillations of a pendulum

### Objective

To study the nature of oscillations of a pendulum. An angle encoder is required for measuring the angular displacement as a function of time. We will try to measure the angular velocity as a function of time, since it can be done using an inexpensive DC motor.

### Equipment

A small DC motor with a pendulum attached to its axis.

### Procedure

Attach some sort of rigid pendulum to the axis of the motor.

Connect the terminal of the DC motor between T17 and Ground

Connect T18 to A0

Right click and start *Pendulum Waveform* from the menu.

Oscillate the pendulum and START digitizing

## Observation

The observed waveform is shown in figure. Fitting it with equation  $A = A_0 \sin(\omega t + \theta) * \exp(-dt) + C$ , using Xmgrace gave an angular frequency of 10 Hz.

## Discussion

The pendulum should be made with a heavy bob and a light weight rod connecting it to the axis of the motor. I was in a hurry to finish this writeup and just used a screwdriver and a magnet to attach it to the motor axis. The DC motor acts like a generator in this case.

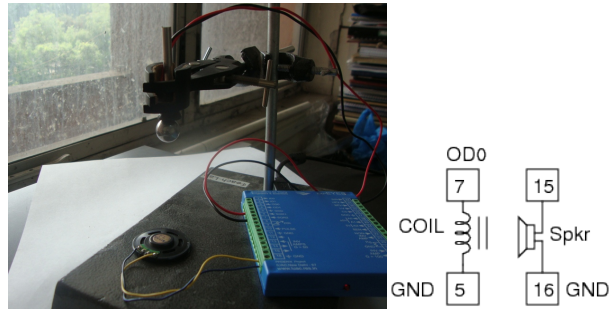


Figure 6.3: Gravity by measuring the time of flight. The iron ball is held by the electromagnet.

## 6.4 Value of 'g' by time of flight

### Objective

Measure the time of flight of a body falling under gravity from a known height and calculate the value of acceleration due to gravity.

### Equipment

Electromagnet (1000 Turns coil with iron core)

150Ω Loudspeaker

### Procedure

Fix the Electromagnet on a stand

Connect it to OD0 and Ground

Connect speaker between T15 & T16

Right Click and start **Gravity TOF** from the menu.

Click on *Attach the Ball* to energize the magnet.

Enter the height from the bottom side of the ball to the floor

Click on Measure TOF

## Observation

| Height | Time $t$ | $g = \frac{2h}{t^2}$ |
|--------|----------|----------------------|
| 35     | .269     | 967.4                |
| 25     | .228     | 961.8                |

## Discussion

The calculated values is less than the actual value. Why ?

We measure the time from making a 5->0 volts transition at OD0 to the appearance of few millivolts at the loudspeaker output. The magnetic effect will not vanish instantly and the circuit delays are also need to be accounted.

If you apply a correction of 2 milliseconds to the first reading, the result is  $70/.267^2 = 981.9$ . This shows the accuracy required for measuring the time of flight.

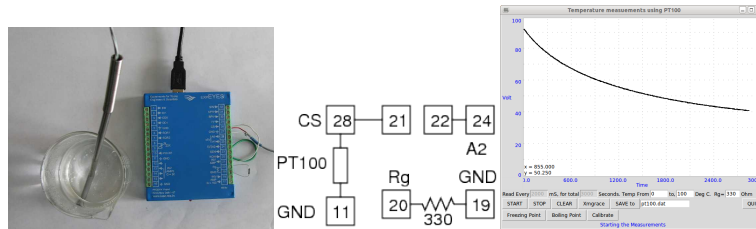


Figure 6.4: Cooling curve of water measured using PT100 sensor.

## 6.5 Temperature measurement, PT100

### Objective

Record the temperature of a liquid by using a Platinum Resistance Thermometer

### Theory

Resistance of a PT100 element is related to the temperature by the equation

$$R_T = R_0 [1 + AT + BT^2]$$

where  $A = 3.9083e - 3$  and  $B = -5.775e - 7$

### Equipment

PT100 sensor element

330 Ohm resistor

### Procedure

Connect PT100 from CS to Ground

Connect CS to T21 (Non-inverting amplifier input)

Connect T22 (amplifier OUTPUT) to A2

Connect the gain control resistor between T19 & T20

Right click and start **PT100 Sensor**

Enter the resistance value

Select the total time and time interval between measurements

PressSTART

Calibration is required for better accuracy. Keep the sensor on ice and click on **Freezing Point**. Immerse the sensor in boiling water and click on **Boiling Point**. After that click on **Calibrate**. Once the calibration is done the temperature is calculated using the calibration constants.

## Observation

Cooling curve of water is shown in figure6.4 .

## Discussion

PT100 is a platinum element having a resistance of  $100\Omega$  at zero degree celcius. The resistance varies with temperature and tables are available to correlate the resistance and temperature. Our program sets a current of 1mA through PT100 and measures the voltage drop across it. The voltage is amplified for inceasing the resolution.

The program reads the amplifier output voltage. Voltage across PT100 is calculated by dividing this voltage by the gain of the amplifier ( $G = 1 + \frac{10000}{R_g}$ ). Since the current is known the resistance and hence the temperature can be calculated.

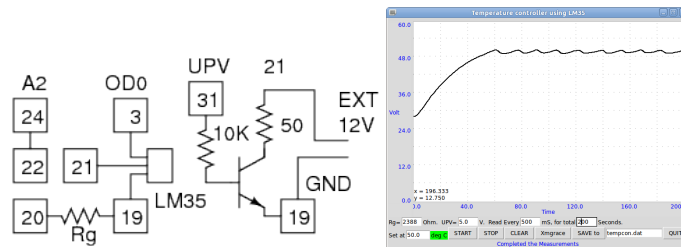


Figure 6.5: Temperature measurement using LM35.

## 6.6 Temperature Controller

### Objective

Implement a temperature controller using the LM35 sensor. A transistor is user as a controllable heater. LM35 is kept pressed to the transistor body with some heat conducting paint in between.

### Equipment

LM35 sensor

2N2222 Transistor

10 k $\Omega$  and 2.4k $\Omega$  resistors

### Procedure

Connect LM35 and the transistor as shown in the figure

Join the plastic bodies of LM35 and 2N2222 using heat conducting compound.

Use an external 12 volts DC power supply

Right click and start **Temp Controller**

Set the temperature setpoint and the base voltage (UPV)

Press START . The vertical scale will be 0 to setpoint + 10 deg.

## **Observation**

Temperature as a function of time is plotted.

## **Discussion**

The temperature is kept within  $\pm 0.5$  degree of the setpoint. LM35 has only that much resolution. The time variation depends on the heat conductivity of the transistor and LM35 body and the collector current.



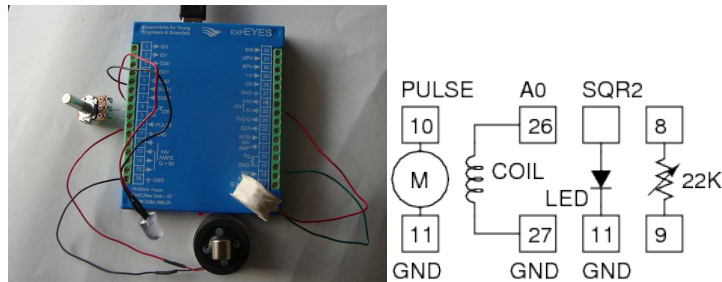


Figure 6.6: Stroboscope using flashing LED. The AC voltage picked up by the coil due to the rotating magnet is used for cross checking the speed of rotation.

## 6.7 Stroboscope

### Objective

An object executing periodic motion will appear stationary when it is illuminated with a light pulse of the same frequency. The simple reason is that the object is illuminated every time when it reaches the same point.

### Equipment

LED

DC motor

3000 turns coil

### Procedure

Connect motor from PULSE to Ground

Connect LED from SQR2 to Ground

Connect the 22k resistor for SQR2

Set Pulse to 20 %

Set SQR2 to 20

Adjust the resistor until the motor axis appears nearly stationary

## Observation

As you adjust SQR2, the movement of the disc on the axis of the motor appears to slow down and then at some point reverses the direction of motion. Note down the frequency at the direction reversal.

## Discussion

How the RPM of a car engine adjusted ?

When viewed in a pulsed light source of frequency 11 Hz, a motor rotating clockwise at 10 rotations per second will look like rotating anti-clockwise once a second. During stopping and starting, the ceiling fans some times looks like rotating backwards, in the light of fluorescent tubes.

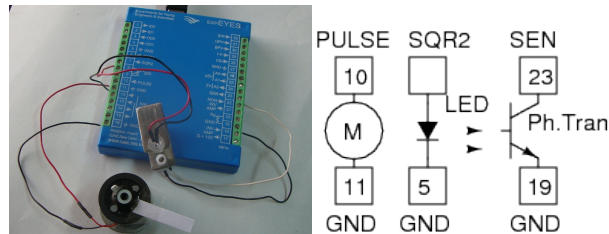


Figure 6.7: Measuring the speed of rotation of a motor using light barrier.

## 6.8 Speed of rotation of a motor

### Objective

Learn about making sensors to detect mechanical movements. Use a photo-transistor to find the rotational speed of a motor.

### Equipment

Photo-transistor

LED

Small DC motor

### Procedure

Attach a paper leaf to the Motor

Connect motor to PULSE

Connect LED from SQR2 to Ground

Set SQR2 to zero

Connect phototransistor collector to SEN

Emitter to ground

Position the LED and phototransistor such that the leaf moves between them

set PULSE to different duty cycle values to rotate the motor at different speeds.

## Observation

The rotations per second observed for different duty cycle values are given below. Except for the first reading speed is proportional to the duty cycle, ie. the power given to the motor.

| PULSE % | SEN Freq. |
|---------|-----------|
| 9.8     | 5.6       |
| 20      | 14.4      |
| 29.8    | 21.4      |
| 40      | 28.2      |

## Discussion

The observed values can be cross checked by using a magnet and coil as explained in section3.2 or by using the stroboscope explained in the previous section.

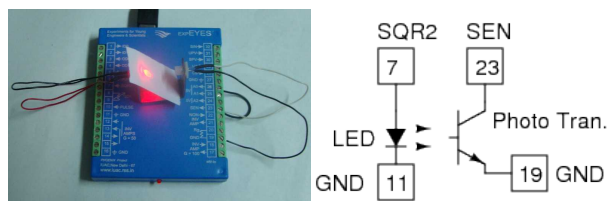


Figure 6.8: Light transmission measurement using photo transistor

## 6.9 Transparency Measurement

### Objective

Compare the transmission of light through different semi transparent materials.

### Equipment

Photo-transistor, LED and 10 k $\Omega$  resistor

### Procedure

Connect the Photo-transistor collector to SEN and Emitter to Ground.

Connect the LED from SQR2 and Set SQR2 to 0

Right click and start the **CRO** from the menu. Select the SEN.

Place the LED facing the transistor and note down the voltage.

Place some semitransparent material in between and see the difference.

### Observation

The voltage decreases with the intensity of light falling on the photo-transistor. Try LEDs of different color and compare the results. Try the transmission of red light through RED and GREEN foils with the same thickness.

## 6.10 Standing waves on a String

### Objective

Study standing waves on a stretched thread excited by a relay coil. The tension on the thread is varied by changing the suspended mass.

### Theory

Velocity of wave propagation in a string is given by  $v = \sqrt{\frac{T}{\mu}}$ , where T is the tension and  $\mu$  is the linear mass density. The velocity  $v = f\lambda$ . On a vibrating string, the fundamental harmonic has only two nodes, at both ends, and the length of the string  $L = \lambda/2$ . Fundamental frequency  $f_0 = \frac{v}{2L} = \frac{1}{2L} \sqrt{\frac{T}{\mu}}$

### Equipment

A relay coil with amplifier, powered by 12 AC adapter

22k potentiometer

### Procedure

Connect the Grounds of expEYES and the vibrating string accessory.

Connect SQR2 to the relay amplifier input of the amplifier.

Connect 22k pot and set SQR2 to 30 Hz

Set the suspended mass to 30 gm

Adjust 22k to get the standing wave fundamental (single loop)

### Observation

The frequency is proportional to the square of tension applied, within experimental errors.

### Discussion

Make the string such that one half of it has double the linear mass density than the other half. Watch the higher order modes.

# Appendix A : Accessories

Every experiment require something to be connected to expEYES interface. It could be just a peice of wire or a set of sensors. The standard accessory set is sufficient to perform most of the experiments described in this manual. There are some other accessories available presently and their number is likely to grow. The standard accessory set available along with expEYES contains the following components. The values of the parameters, like inductance, specified are nominal, measured from random samples.

**Crocodile Clips with wires** If the connection to any terminal is changed many times during an experiment, it is easier to make the connection using the crocodile clip provided.

**Microphone assembly** A condenser microphone with a biasing resistor and a DC blocking capacitor. It should be fixed to T16 & T15, with the wire conneted to UPV. The capacitor lead goes to T15.

**3000 Turns Coil (2)** Inductance $\approx$  125 mH, Resistance $\approx$  560 $\Omega$  , made from insulated copper wire 44 SWG. These coils are be used for studying inductance, electromagnetic induction etc.

**1000 Turns coil** Inductance $\approx$  4 mH, Resistance $\approx$  45 $\Omega$  , made from insulated copper wire 40 SWG. With the ferrite rod inserted, the Inductance increases to around 25 mH.

**Electromagnet (with iron core)** Inductance $\approx$  20 mH, Resistance $\approx$  45 $\Omega$  , made from insulated copper wire 40 SWG. This coil has iron core fixed inside and used as an electromagnet in some experiments. 50 cm long leads are provided.

**Piezo Electric Discs (2)** Resonant frequency is around 4000 Hz. Can be energized by SQR1, SQR2 or PULSE outputs. Discs are enclosed in a plastic shell that forms a cavity, that enhances the amplitude of sound produced.

**Loud Speaker (big)** The resistance of the speaker is  $150\Omega$ , different from the commonly available  $8\Omega$  speakers. Can be powered by SQR1, SQR2 or PULSE.

**Loudspeake (small)**

This is a low impedance speaker, but more rugged. We will use it as a microphone also in some experiments.

**DC Motor** Fixed on a metallic base. Should be powered by a DC voltage less than 3 volts. In some experiments, we power the motor with the PULSE output, with a duty cycle less than 40%. It is safer to connect a diode in series when the motor is powered from the terminal PULSE.

**Transistor Holder** A three pin socket to insert transistors to plot the characteristic curve,  $200k\Omega$  at base.

**Permanent Magnets**

10mm diameter & 10 mm length

12 mm diameter & 1.5 mm length

5 mm diameter & 10 mm length

**Other Items**

22 k potentiometer, used for SQR2.

Holder for two dry cells.

Aluminium Disc with center hole.

Mild Steel ball,  $D = 10$  mm

Ferrite rod,  $D = 6$  mm,  $L = 20$  mm

Ferrite Rod,  $D = 12$  mm,  $L = 50$  mm





Figure 6.9: (a) Light Barrier and Rod Pendulum (b) 40 kHz Piezo Transmitter and Receiver. (c) Vibrating string apparatus.

5mm LEDS : RED, BLUE, GREEN

10 mm white LED, with leads

Capacitors : 100uF, 47uF, 10 uF, 1uF and 0.1 uF

Resistors : 100Ω, 200Ω, 330Ω, 560Ω, 1kΩ, 10kΩ and 100kΩ

Diode : 1N4148

Zener Diode, 3.3 volts

Transistor : 2N2222

15 cm wire - 5 pcs

8 cm wire - 5 pcs

Screwdriver

LDR

Thermistor

## Light Barrier and Rod Pendulum

The light barrier can be used for timing mechanical movements. A light beam falling on a photo-transistor is intercepted and the time intervals are measured. Can be used for finding the speed of rotation of a motor, period of oscillations of a pendulum etc.

### **Ultrasound Piezo Tranceiver**

The 40 kHz ultra-sound Piezo-electric transmitter and receiver can be used for studying sound. The velocity of sound can be found by measuring the time of flight of a sound packet from the transmitter to receiver. The 40 kHz signal cannot be viewed properly using the expEYES oscilloscope feature, you need a higher frequency CRO to view the signals properly.

### **Vibrating String Apparatus**

This is powered by 12 volts DC and driven by a signal from SQR2. The amplified SQR2 drives a relay coil and a string attached to the relay contact vibrates. Standing waves can be formed by adjusting the tension and frequency of vibration.