expEYES-17

User's Manual

Experiments for Young Engineers and Scientists

http://expeyes.in

from

PHOENIX Project
Inter-University Accelerator Centre
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New Delhi 110 067
www.iuac.res.in

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.

expEYES-17 is an advanced version of expEYES released earlier. It is meant to be a tool for learning by exploration, suitable for high school classes and above. We have tried optimizing the design to be simple, flexible, rugged and low cost. 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.

The software is released under GNU General Public License and the hardware under CERN Open Hardware Licence. The project has progressed due to the active participation and contributions from the user community and many other persons outside IUAC. We are thankful to Dr D Kanjilal for taking necessary steps to obtain this new design from its developer Jithin B P, CSpark Research.

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V V V Satyanarayana

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[1]

[1]For an updated list of experiments visit
http://expeyes.in/experiments-with-expeyes-junior

Chapter 1

Getting Started

1.1 Introduction

Science is the study of the physical world by systematic observations and experiments. Proper science education is essential for cultivating a society where reasoning and logical thinking prevails and not superstition and irrational beliefs. Science education is also essential for training enough technicians, engineers and scientists for the economy of the modern world. It is widely accepted that personal experience in the form of experiments and observations, either carried out by students or performed as demonstrations by teachers, are essential to the pedagogy of science. However, almost everywhere science is mostly taught from the text books without giving importance to experiments, partly due to lack of equipment. As a result, most of the students fail to correlate their classroom experience to problems encountered in daily life. To some extent this can be corrected by learning science based on exploration and experimenting.

The advent of personal computers and their easy availability has opened up a new path for making laboratory equipment. Addition of some hardware to an ordinary computer can convert it in to a science laboratory. Performing quick measurements with good accuracy enables one to study a wide range of phenomena. Science experiments generally involve measuring/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 also opens up the possibility of research oriented science education. Students can compare the experimental data with mathematical models and examine the fundamental laws governing various phenomena. Research scientists do the same with highly sophisticated equipment. The expEYES (expEriments for Young Engineers & Scientists) kit is designed to support a wide range of experiments, from school to post graduate level. It also acts as a test equipment for electronics engineers and hobbyists. The simple and open architecture of expEYES allows the users to *develop new experiments, without getting into the details of electronics or computer programming*. This User's manual describes *expEYES-17* along with

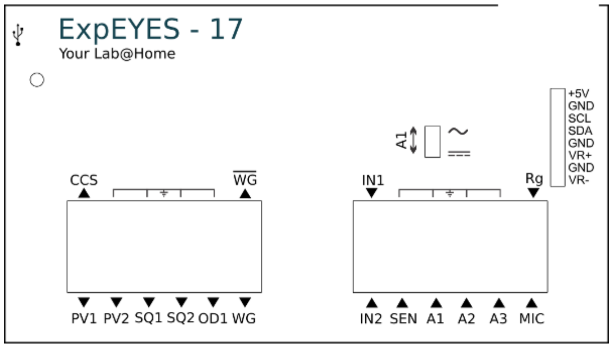


Figure 1.1: The ExpEYES Junior top panel showing the external connections.

several experiments, there is also a Programmer's manual available.

1.2 The equipment

ExpEYES-17 is interfaced and powered by the USB port of the computer, and programmable in Python. It can function as a low frequency oscilloscope, function generator, programmable voltage source, frequency counter and data logger. For connecting external signals, it has two spring loaded terminals blocks, one for output signals and another for input, as shown in figure 1.1. The software can monitor and control the voltages at these terminals. In order to measure other parameters (like temperature, pressure etc.), we need to convert them in to electrical signals by using appropriate sensor elements. The accuracy of the voltage measurements is decided by the stability of the 3.3 V reference used, it is 50ppm per degree celcius. The gain and offset errors are eliminated by initial calibration, using a 16bit ADC. The time interval and frequency measurement accuracy is decided by the 12.000 MHz crystal.

Even though our primary objective is to do experiments, you are advised to read through the brief description of the equipment given below. The device can be also used as a test equipment for electrical and electronics engineering experiments.

IMPORTANT : *The external voltages connected to expEYES must be within the allowed limits. Inputs A1 and A2 must be within* ± 16 *volts range and Inputs IN1 and IN2 must be in 0 to 3.3V range. Exceeding these limits may result is damage to the equipment. To measure higher voltages, scale them down using resistive potential divider networks.*

1.2.1 External connections

The functions of the external connections briefly explained below. All the black coloured terminals are at ground potential, all other voltages are measured with respect to it.

Outputs:

Constant Current Source (CCS) : The constant current source can be switched ON and OFF under software control. The nominal value is 1mA but may vary from unit to unit, due to component tolerances. To measure the exact value, connect an ammeter from CCS to GND. Another method is to connect a known resistance (~1k) and measure the voltage drop across it. The load resistor should be less than 3k for this current source.

Programmable Voltage (PV1) :

Can be set, from software, to any value in the -5V to +5V range. The resolution is 12 bits, implies a minimum voltage step of around 2.5 millivolts.

Programmable Voltage (PV2) : Can be set, from software, to any value in the -3.3V to +3.3V range. The resolution is 12 bits.

Square Wave SQ1: Output swings from 0 to 5 volts and frequency can be varied 4Hz to 100kHz. All intermediate values of frequency are not possible. The duty cycle of the output is programmable. Setting frequency to 0Hz will make the output HIGH and setting it to -1 will make it LOW, in both cases the wave generation is disabled. SQR1 output has a 100Ω ***series resistor*** inside so that it can drive LEDs directly.

Square Wave SQ2: Output swings from 0 to 5 volts and frequency can be varied 4Hz to 100kHz. All intermediate values of frequency are not possible. The duty cycle of the output is programmable. SQR2 is not available when WG is active.

Digital Output (OD1) : The voltage at OD1 can be set to 0 or 5 volts, using software.

Sine/Triangular Wave WG: Frequency can be varied from 1Hz to 5kHz. The peak value of the amplitude can be set to 3 volts, 1.65 volts or 150 mV. Shape of the waveform output is programmable, using the GUI sine or triangular can be selected. WG bar is inverted WG.

Inputs:

Capacitance meter IN1: Capacitance connected between IN1 and Ground can be measured. It works better for lower capacitance values, upto 10 nano Ffarads, but it is possible to measure in micro farad range also.

Frequency Counter IN2: Capable of measuring frequencies upto several Mega Hertz. Also works as an analog input in the 0 to 3.3 volts range.

Resistive Sensor Input (SEN): This is mainly meant for sensors like Light Dependent Resistor, Thermistor, Photo-transistor etc.. SEN is connected to 3.3 volts through a $5.1k\Omega$ resistor.

$\pm 16V$ **Analog Inputs, A1 & A2:** Can measure voltage within the ± 16 volts range. The input voltage range can be selected from .5V to 16V fullscale. Voltage at these terminals can be displayed as a function of time, giving the functionality of a low frequency oscilloscope. The maximum sampling rate is 1 Msps /channel. Both have an input impedance of $1M\Omega$.

$\pm 3.3V$ **Analog Input A3:** Can measure voltage within the ± 3.3 volts range. The input can be amplified by connecting a resistor from Rg to Ground, gain $=1 + \frac{Rg}{10000}$. The input impedance of A3 is $10M\Omega$.

Microphone input MIC: A condenser microphone can be connected to this terminal and the output can be captured.

I2C Sensor Interface:

The four connections (+5V, Ground, SCL and SDA) of the 8 terminal berg strip supports I2C sensors. The software is capable of recognizing a lar

+/-6V / 10mA power supply:

The VR+ and VR- are regulated power outputs. However, they can supply very little current, but good enough to power an Op-Amp.

1.2.2 Accessory Set

Some accessories are provided with expEYES Junior, a photograph is given on back cover of the manual.

- Wires with pin on both ends (5) : For making connections between terminals.
- Condenser microphone with leads.
- Inductor Coil (2) : 44SWG wire on 1cm dia bobbin. Around 3000 Turns (some may have more turns). These coils can be used for studying inductance, electromagnetic induction etc.
- Piezo Electric Discs (2) : Resonant frequency is around 3500 Hz. Can be energized by WG output or SQR1. Discs are enclosed in a plastic shell that forms a cavity, that enhances the amplitude of sound produced.
- DC Motor : Should be powered by a DC voltage less than 3 volts.
- Permanent Magnets : (a) 10mm dia & length (b) 5 mm dia & 10 mm length (c) Button size magnets(2)
- 5mm LEDS : RED, BLUE, GREEN, WHITE
- Capacitors : 100pF, 0.1uF , 1 uF & 22uF
- Inductor : 10 mH / 20Ω,
- Resistors : 560Ω, $1k\Omega$, $2.2k\Omega$, $10k\Omega$, $51k\Omega$ and 100 $k\Omega$

- LDR & Thermistor
- Two silicon diodes (1N4148) and one 3.3 volts zener diode
- Transistor(2N2222)

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 program that presents the USB port as an RS232 port to the application programs. The communication the expEYES is done using a library written in Python programming 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 expEYES 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-17 from the menu **Applications->Education**->ExpEYES-17. You can also start it from a Terminal using the command:

```
$ python /usr/share/expeyes/eyes-17/scope17.py
```

Installing on Debian or Ubuntu GNU/Linux distributions

Download **expeyes-5.0.0.deb** , or higher version, from the software section of **http://expeyes.in** and install it. It depends on python-serial, python-tk, python-scipy and grace (a 2D plotting program).

For other GNU/Linux distributions

Download **expeyes-5.x.x.zip** from **http://expeyes.in** (or https://github.com/expeyes) 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. This can be done by running the *postint* shell script, included in the zip file.

On MSWindows

Even though expEYES is Free Software and is developed using Free and Open software, it runs on non-free platforms also. To install it on MS windows, you need (1) MCP2200 drivers (2) Python-2.x version, python-serial, python-tk, python-numpy and python-scipy (3) expeyes-5.x.x.zip

Unzip the file **expeyes-3.x.x.zip**, and double click on **scope17.py** inside the newly created directory named expeyes-5.x.x\eyes-junior. See the software section on the expeyes website for more details.

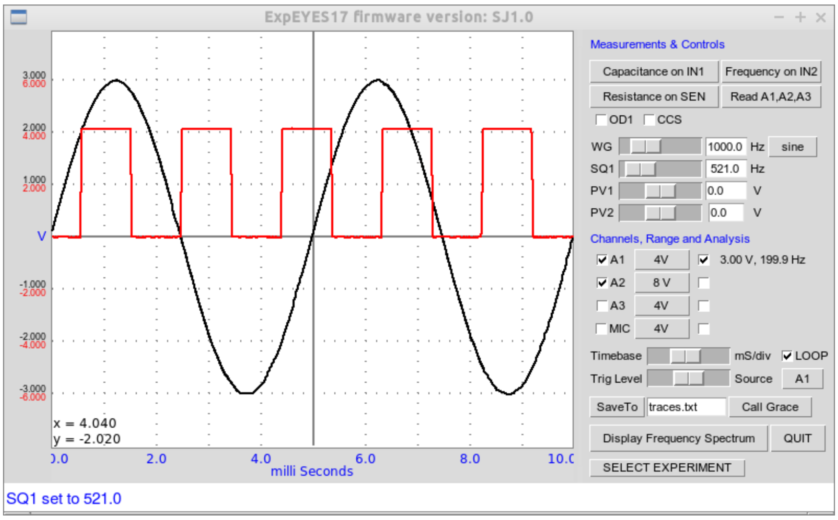


Figure 1.2: The scope17 screen showing four traces

1.4 The main GUI program

Start Applications->Science->EYES-17 from the menu. A four channel oscilloscope screen with several extra features will open as shown in figure 1.2. The **EXPERIMENTS** button pops up a menu of programs for several experiments. The main window will become inactive when an experiment is selected and running.

The Plot Window

The plot window works like a low frequency four channel oscilloscope. The maximum sampling rate is 1 Megasamples/channel/second only. A brief description of this GUI program is given below.

- Any of the four inputs (A1, A2, A3 or MIC) can be enabled using the corresponding checkbox. The input range can be selected by clicking on the menubutton on the right side of the checkbox. Select the desired input range from the popup menu.
- There is another checkbox, to enable mathematical fitting of the data using $V = V_0 \sin(2\pi ft + \theta) + C$ to show the amplitude and frequency.[1]
- The horizontal scale (time base) can be changed by a slider, from .5 mS fullscale to 500 mS full scale.
- The Checkbutton LOOP, allows to pause and resume the oscilloscope operation.
- The Trigger level can be set by a slider, and there is a menubutton to select the trigger source.

[1]Selecting both A1 and A2 and enabling the analysis options will display the phase difference.

- To save the traces to a file, edit the filename and click on the SaveTo button.

- The Call Grace button opens the program xmgrace and transfers the data for the enabled channels to it.

- Clicking on 'Display Frequency spectrum' shows the spectrum of all the eneabled channels, appears on popup windows.

In addition to the Oscilloscope features, you can also control the waveform generators, voltage sources, digital output and the current source from the GUI.

- Frequency of the Waveform generator WG can be set using the slider or the text entry window. You need to press the <Enter> key to get the input accepted. The two input methods follow each other, changing the slider will change the text field and entering data using text field will set the slider to that value. The frequency will be set to the nearest possible value and the text field will be updated with that.

- The shape of the waveform can be selected using the menubutton, default shape is sine. It can be changed to triangular. When the square wave option is selected, the output is shifted to SQ2. You cannot have sine/triangular and SQ2 at the same time.

- SQ1 can be set using the same method as explained above.

- The programmable volages PV1 and PV2 are also set in a similar manner.

- Checkbuttons are provided to control OD1 and CCS.

- Capacitance connected between IN1 and GND can be measured.

- Resitance (in 100 Ohms to 100k range) can be measured by connecting it from SEN to GND. Accuracy is better in 1k to 10k range.

1.5 Getting Familiar with expEYES-17

Before proceeding with the experiments, let us do some simple exercises to become familiar with expEYES-17. Connect the device a USB port and start the ExpEYES-17 program from the menu 'Applications->Education'.

1.5.1 Generate & measure voltages

- Connect PV1 to A1

- Set PV1 to some voltage

- Click on the button 'Read A1,A2,A3' to know the voltage present at A1.

1.5.2 Observe voltage waveforms

- Connect WG to A1 and enable A1.
- Select input range of 4V full scale.
- Set frequency to to 1000 Hz and view the wave form.
- Adjust Time base to view 4 or 5 cycles.
- Change frequency using the slider.
- Enable the checkbox on the right side, to display amplitude and frequency.
- Increase the number of cycles on screen to improve the fitting accuracy.

1.5.3 Frequency Measurement

- Connect SQ1 to IN2
- Set SQ1 to 1000 hz
- Click on the button 'Frequency on IN2'

1.5.4 Capacitance Measurement

- Connect the capacitor (several hundred pF) from IN1 to Ground
- Click on the button 'Capacitance on IN1'

Chapter 2

Activities - Level 1

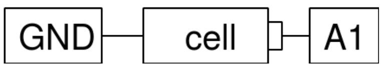
In this chapter we will discuss the experiments and demonstrations without much data analysis. We start with the simple task of measuring the voltage of a dry-cell. Current and resistance are introduced next, followed by resistances changing with temperature and light. The concept of Alternating Current is introduced by plotting the voltage as a function of time. The behavior of circuits elements like capacitors and inductors in AC and DC circuits are explored, by measuring parameters like amplitude, frequency and phase.

For each experiment, make connections as per the diagram given.

2.1 Measuring Voltage

Objective Learn to measure voltage using expEYES and get some idea about the concept of Electrical Ground. A dry-cell and two wires are required.

Procedure



- Click on the button 'Read A1,A2,A3' to display the voltage
- Repeat by reversing the cell connections.

Discussion Voltages measured value is $+1.5$ volts and it becomes -1.5 after reversing the connections.

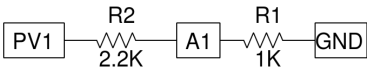
We are measuring the potential difference between two points. One of them can be treated as at zero volts, or Ground potential. The voltage measuring points of expEYES measure the voltage with respect to the terminals marked GND. We have connected the negative terminal of the cell to Ground. The positive terminal is at $+1.5$ volts with respect to the negative terminal. *Will it show correct voltage if GND is not connected ?*

2.2 Voltage, current & resistance

Objective Learn about Current, Resistance and Ohm's law, using a couple of resistors. The voltage across a conductor is directly proportional to current flowing through it. The constant of proportionality is the Resistance. This is known as Ohm's Law, expressed mathematically as

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

Procedure



- Set PV1 to some voltage, say 3 volts
- Click on 'Read A1 A2 A3' to measure the voltage at A1.
- Repeat for different values of PV1.

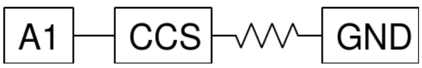
Discussion The current is given by $I = \frac{V_{PV1}}{R1+R2}$. Voltage at A1 should be $I \times R1$.

2.3 Constant Current Source

Objective The 1mA constant current source also can be used for studying Ohm's law, by connecting different values of resistors to CCS and measure the voltage across them. Connecting a 1k resistor from CCS to GND will develop a voltage of $V = 0.001 \times 1000 = 1V$. Try the same using other values (Do not use values more than 2.2k)

Actual output of the constant current source may vary slightly from the specified 1 mA, due to the component tolerances. The currrent can be measured by connecting an ammeter from CCS to GND, or by connecting a known resistance to CCS and measuring the voltage across it. The resistor should be in 100Ω to $2.2k\Omega$ range.

Procedure

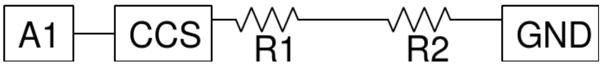


- Enable CCS
- Read A1

Discussion The measured voltage at A1 divided by 1000 gives the current from CCS. For better accuracy, the measured value should be used in experiments using CCS.

2.4 Resistances in series

Objective Finding the effective resistance of a series combination of resistors, $R = R1 + R2 + \cdots$, using a constant current source. A 560Ω and a$1k\Omega$ resistors are used.

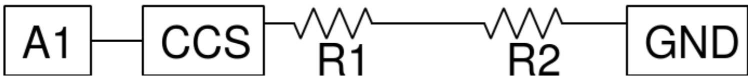
Procedure 

- Connect R1, R2 alone and then both
- Measure A1 for each case

Discussion 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.

2.5 Resistances in parallel

Objective Find the effective resistance of parallel combination of resistors, given by $\frac{1}{R} = \frac{1}{R1} + \frac{1}{R2} + \cdots$

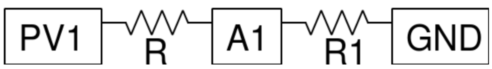
Procedure 

- Connect $1k\Omega$ resistor from CCS to Ground.
- Repeat the same with two resistors connected in parallel.

Discussion Since we know the current, we can calculate the effective resistance from the measured voltage$R = \frac{V_{A1}}{I_{CCS}}$.

2.6 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. 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, $I = \frac{V_{A1}}{R1} = \frac{V_{PV1} - V_{A1}}{R2}$.

Procedure e 

- Connect the unknown resistor R from PVS to A1.
- Connect $1k\Omega$ (R1) from A1 to Ground.
- Set PV1 to 4 volts.
- Measure voltage at A1

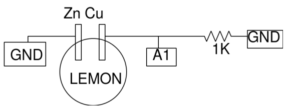
Discussion What is the limitation of this method ? How do we choose the reference resistor ? suppose the unknown value is in Mega Ohms, what will be the voltage drop across a $1k\Omega$ reference resistor ? Our voltage measurement is having a resolution of $\frac{1}{4095}$.

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

2.7 Voltage of a lemon cell

Objective Make a voltage source by inserting Zinc and Copper plates into a lemon. Explore the current driving capability and internal resistance.

Procedure



- Click on A1 to measure voltage
- Measure the voltage with and without the 1k resistor

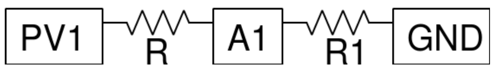
Discussion Voltage across the Copper and Zinc terminals is nearly .9 volts. Connecting the resistor reduces it to 0.33 volts. When connected, current will start flowing through the resistor. But why is the voltage going down ?

What is the internal resistance of the cell ?

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. Does the same happen with a new dry-cell ?

2.8 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. 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, $I = \frac{V_{A1}}{R1} = \frac{V_{PV1} - V_{A1}}{R2}$.

Procedure e 

- Connect the unknown resistor R from PVS to A1.
- Connect $1k\Omega$ (R1) from A1 to Ground.
- Set PV1 to 4 volts.
- Measure voltage at A1

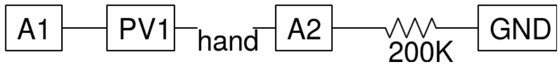
Discussion What is the limitation of this method ? How do we choose the reference resistor ? suppose the unknown value is in Mega Ohms, what will be the voltage drop across a $1k\Omega$ reference resistor ? Our voltage measurement is having a resolution of $\frac{1}{4095}$.

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

2.9 Resistance of human body

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

Procedure



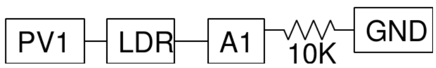
- Set PV1 to 3 volts
- Join PV1 and A2, through your body and measure voltage at A2
- Calculate your body's resistance, as given in section 2.6
- Repeat using SINE instead of PV1. Enable analysis on A1 and A2 to measure voltage.

Discussion The observed waveform is shown in figure 3.3(b). Voltage at A2 is 3V. The ripple in the output is due to the 50Hz AC pickup, can be eliminated by performing the experiment far away from power lines, using a laptop.

2.10 Light dependent resistors

Objective Learn about LDR. Measure intensity of light and its variation with distance from the source. Use the comparison method to find out the resistance.

Procedure



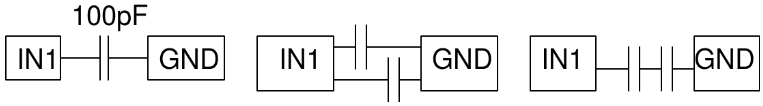
- Set PV1 to 4 volts
- Measure the voltage at A1
- Calculate the LDR's resistance, as explained in2.6
- Repeat by changing intensity of light falling on LDR

Discussion The resistance vary from 1kΩ to around 100 kΩ depending on the intensity of light falling on it. 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 between the LDR and the light source.

2.11 Measuring Capacitance

Objective Measuring capacitance and explore the series and parallel combinations of capacitors.

Procedure



- Click on "Capacitance on IN1"
- Repeat the measurement for different combinations

Discussion We have used 100pF capacitors in this activity. For parallel combination, the effective capacitance is given by $C = C1 + C2 + \cdots$, and for series combination by $\frac{1}{C} = \frac{1}{C1} + \frac{1}{C2} + \cdots$. You can make the capacitors by pasting thin metal foils on both sides of insulators like paper, polythene or glass.

2.12 Measuring Dielectric Constant

Objective Measure the dielectric constant of materials like glass, paper, polyester etc., by making a capacitor. Capacitance $C = \epsilon_0 k \frac{A}{d}$, where ϵ_0 is the permittivity of free space, k the dielectric constant , A the overlapping area of plates and d the separation between them. We have used a 13 cm x 10.6 cm piece of window glass having 4 mm thickness to make a capacitor by pasting metal foil on both sides.

Procedure

- connect the capacitor from IN1 to ground.
- Click on the Button ***Measure C on IN1***
- Repeat without connecting anything to IN1

Discussion The measured capacitance is 255 pF. The stray capacitance is measured after removing the wire from IN1 and it is 30pF, means C = 225pF. $k = \frac{Cd}{\epsilon_0 A} = \frac{225e-12 \times 0.004}{8.854e-12 \times .13 \times .106} = 7.38$. Touching the capacitor during the measurement gives wrong results.

eUsing two parallel plates, the dielectric constant of liquids also can be measured.

Chapter 3

Activities - Level 2

The concept of Alternating Current is introduced by plotting the voltage as a function of time. The behavior of circuits elements like capacitors and inductors in AC and DC circuits are explored, by measuring parameters like amplitude, frequency and phase. Converting electrical signals into sound and back is demonstrated.

For each experiment, make connections as per the diagram given.

3.1 Direct and Alternating Currents

Objective Introduce the concept of time dependent voltages, using a V(t) graph. Compare the graph of DC and AC.

Procedure

- Set PVS to 2 volts
- Set WG to 200 Hz
- Enable analyse on CH1, to measure amplitude and frequency.

Discussion Figure 3.1(a) shows that the graph of DC is horizontal line and for AC it changes direction and magnitude with time. The voltage is changing with time. It goes to both negative and positive around 200 cycles per second. This voltage waveform is generated by using electronic circuits.

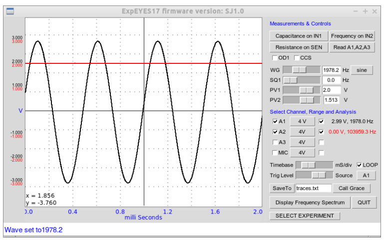


Figure 3.1: Plotting Voltage Vs Time. Graph of DC and AC.

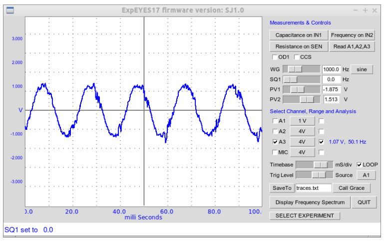
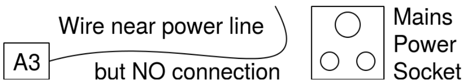


Figure 3.2: AC mains pickup

3.2 AC mains pickup

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



Procedure

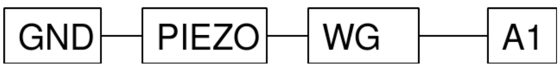
- Connect a long wire to A3
- Enable A3, and it's analysis.

Discussion The power line pickup is shown in figure 3.2. Without making any connection, how are we getting the AC voltage from the mains supply ? Why the voltage increaes when you touch the end of the wire connected to A1 by hand.

3.3 Generating sound

Objective Generate sound from electrical signals, using a Piezo-electric buzzer. Digitize sound and measure its frequency. Use the Piezo buzzer or any other source of sound like a tuning fork.

Procedure



- Enable A1, and its analysis
- Set WG to 1000Hz, change it and listen to the sound.

Discussion When you change the frequency of the voltage that excites the Piezo, both the frequency and the intesity of the sound changes. The intensity is maximum near 3500 Hz, due to resonance. The resonant frequency of the Piezo buzzer is decided by its size and mechanical properties.

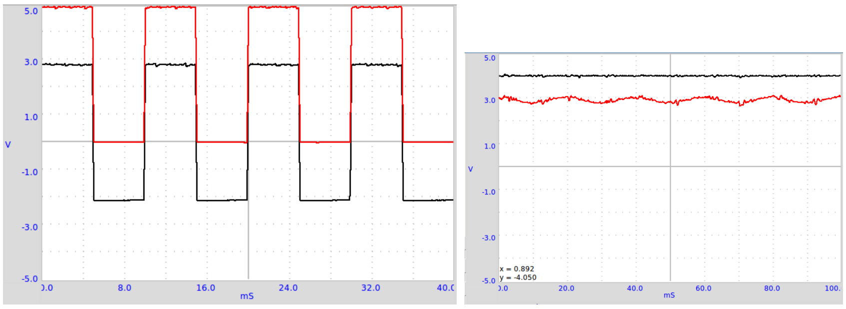
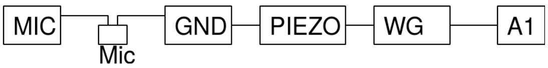


Figure 3.3: (a) A 0 to 5V square wave, with DC component blocked (b) Measuring electrical resistance of human body

3.4 Digtizing sound

Objective Digitize sound signals from a microphone, and measure its frequency. Use the Piezo buzzer or any other source of sound like a tuning fork.

Procedure



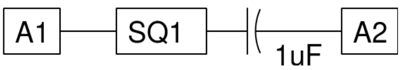
- Enable A1 and MIC , with analysis
- Position the buzzer facing the microphone
- Set WG to 1000Hz, change it and watch the MIC output
- Use a whistle instead of the buzzer and find out the frequency of MIC output.

Discussion The driving signal and the microphone output is shown in figure
Sound waves create pressure variations in the medium through which it travel. The microphone generates a voltage proportional to the pressure. 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.

3.5 DC & AC components of a voltage

Objective Separating AC and DC components of a voltage waveform using a capacitor.

Procedure



- Set SQR1 to 500 Hz
- Assign SQR1 to CH1 and A2 to CH2
- Adjust the horizontal scale to see several cycles.

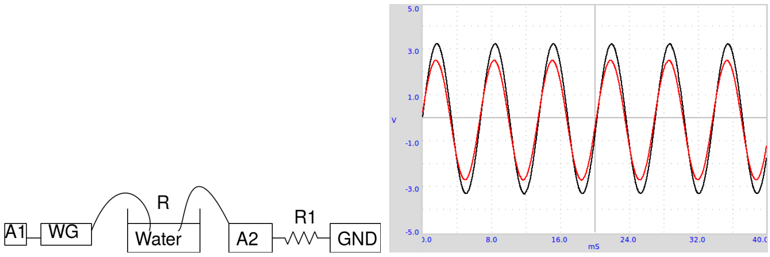


Figure 3.4: Conductivity of water. (b)Total voltage applied and the voltage across the 10k resistor.

Discussion The observed waveforms with and without the series capacitor are shown in figure 3.3. 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.

What will you get if you 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 square wave can be considered as a 2.5V AC superimposed on a 2.5V DC.

You may need to connect a resistor from A2 to GND to see a waveform swinging between -2.5 to +2.5 volts. Remove the resistor and observe the result.

3.6 Conductivity of water, using DC & AC

Objective Measure the resistance of ionic solutions, using both DC and AC voltages. We have used normal tap water.

Procedure

- R1 should be comparable to R, start with 10k.
- Assign A1 to CH1 and A2 to CH2, enable analysis on both
- Calculate the resistance as explained in section 2.6
- Repeat using a DC voltage, PV1 instead of SINE

Discussion Observed values are shown in the table. The DC and AC resistances seems to be very different. With DC, the resistance of the liquid changes with time, due to electrolysis and bubble formation. The resistance does not depend much on the distance between the electrodes, the area of the electrode is having some effect. The resistance depends on the ion concentration and presence of impurities in the water used.

Try changing the distance between electrodes. Try adding some common salt and repeat the measurements. Why is the behavior 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 ?

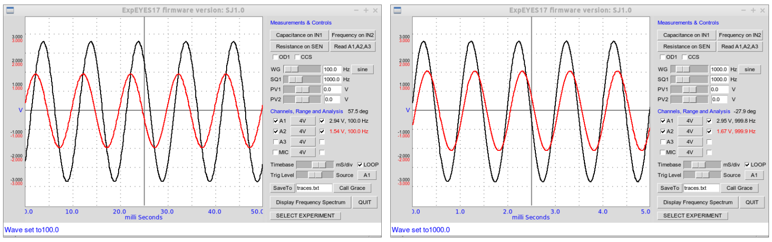
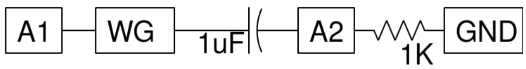


Figure 3.5: Phase shift of AC in an (a) RC circuit (b) RL circuit

3.7 AC Phase shift in RC circuits

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

Procedure



- Set WG to 100 Hz
- Enable A1 and A2, and their analysis option
- Adjust the horizontal scale to view more than 4 cycles.
- Phase difference between A1 and A2 is displayed above the frequency values
- Repeat by changing the frequency.

For a detailed study select **Study of AC Circuits** from **EXPERIMENTS**.

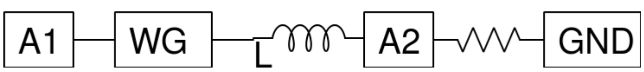
Discussion The voltage waveform before and after the capacitor are shown in figure 3.5(a).

where $X_c = \frac{1}{2\pi fC}$ is the impedance of the capacitor, Frequency is 147.3 Hz. X_R is the resistance.

3.8 AC phase shift in RL circuits

Objective Measure the AC voltage phase shift in an RL circuit. 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 $\triangle\Phi = \arctan\left(\frac{X_L}{X_R}\right)$, where R is the resistance in Ohms.

Procedure



- Set WG to 1000 Hz

- Enable A1 and A2, and their analysis optionAssign A1 to CH1 and A2 to CH2
- Adjust the horizontal scale to view more than 4 cycles.
- Repeat for different frequencies.
- Insert an iron or ferrite core to the coil, to observe the effect of ferromagnetic materials.

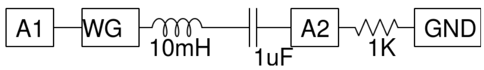
Discussion Waveforms for the 125 mH inductor is shown in figure 3.5(b). The phase shift is given by $\triangle\Phi = \arctan\left(\frac{X_L}{X_R}\right)$ where $X_L = 2\pi f L$. The resistance of the inductor also should be included while calculating the phase shift.

Insert an iron or ferrite core to the coil and observe the effect of ferromagnetic materials.

3.9 Study of AC circuits

Objective Study the effect of series LCR elements in an AC circuit. The total applied AC voltage is measured on A1 and the voltage across the resistor on A2. Subtracting the instantaneous values of A2 from A1 gives the voltage across the inductor and capacitor. We need to use an inductor with negligible resistance for good results. The phase difference between current and voltage is given by $\triangle\Phi = \arctan\left(\frac{X_c - X_L}{X_R}\right)$.

Procedure



- Connect 1uF, 10mH and 1K as shown in the figure
- select **Study of AC Circuits** from **EXPERIMENTS**
- Measure the phase shift for different frequencies
- Around 1600 Hz, series resonance is observed

Discussion The total voltage, voltage across R and the voltage across LC are shown in figure 3.6. The phasor diagram shows the phase angle between the current and the voltage. The inductance used in this experiment is around 10mH, having a resistance of 20Ω.

At 1600 Hz, $X_c \approx X_L$ and the voltage across LC is decided by the resistance of the inductor. At the resonant frequency, the current and voltage will be in phase.

3.10 Transient Response of RC circuits

Objective Plot the voltage across a capacitor, when it is charged by applying a voltage step through a resistor. Calculate the value of the capacitance from the graph.

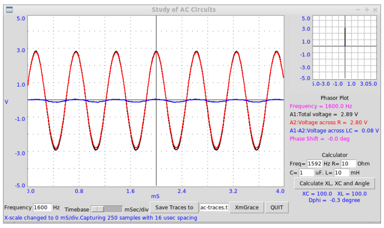


Figure 3.6: AC response of series RLC circuit

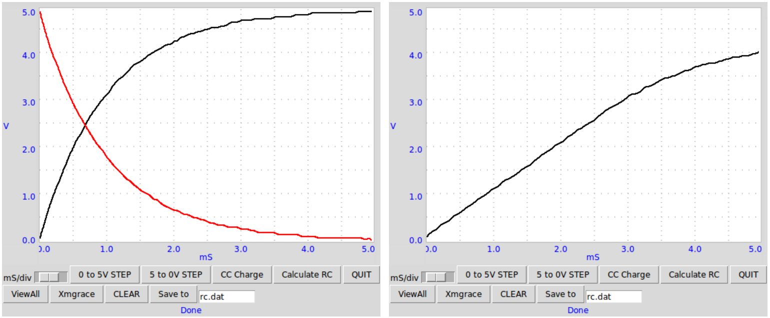
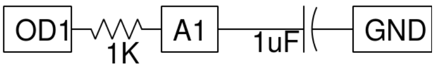


Figure 3.7: (a)Transient response of RC circuit. (b) Charging of capacitor with constant current.

Procedure e



- From **EXPERIMENTS** , select **RC Circuit**
- Click on *0->5V STEP* and *5->0V step* Buttons to plot the graphs
- Adjust the horizontal scale, if required, and repeat.
- Calculate RC time constant.
- Use CCS instead of OD1 to charge capacitor with constant current.

Discussion Applying a 0 to 5V step makes the voltage across the capacitor to rise exponentially as shown in the figure3.7(a). By fitting the discharge curve with $V(t) = V_0 e^{-\frac{t}{RC}}$,we can extract the RC time constant and find the values of capacitance from it.

The voltage across a capacitor is exponential only when it is charged trough a linear element, a resistor for example. When charged from a constant current source, the voltage shows linear increase, as shown in figure 3.7(b), because $Q = It = CV$, and voltage increases linearly with time as $V = \left(\frac{I}{C}\right) t$.

3.11 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 inductance.

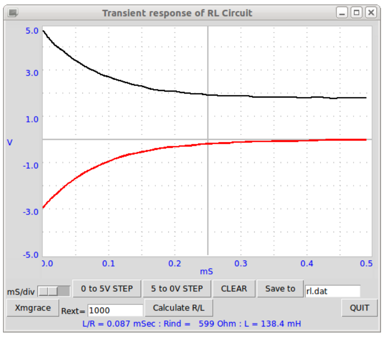
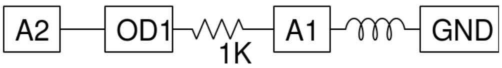


Figure 3.8: Transient response of RL circuit

In an RL circuit $V = IR + L\frac{dI}{dt}$ and 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, $R = R_{ext} + R_L$. [1]

Procedure



- Inductor is the 3000 Turn coil
- From **EXPERIMENTS** select **RL Circuit**
- 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
- Insert an iron core into the inductor and repeat

Discussion The transient response of the inductor is shown in figure 3.7. 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. A2 is connected to OD1 for a more accurate measurement of the coil resistance.

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 ?

Repeat with two coils in series, by (a) placing them far away (b) placing one over the other and (c) after changing the orientation. The effect of mutual inductance can be seen.

3.12 Transient response of LCR circuits

Objective Explore the oscillatory nature of L and C in series. Resonant frequency of series LC circuit is given by $\omega_0 = \frac{1}{2\pi\sqrt{LC}}$. The damping factor is

[1] http://nptel.iitm.ac.in/courses/Webcourse-contents/IIT-KANPUR/esc102/node14.html

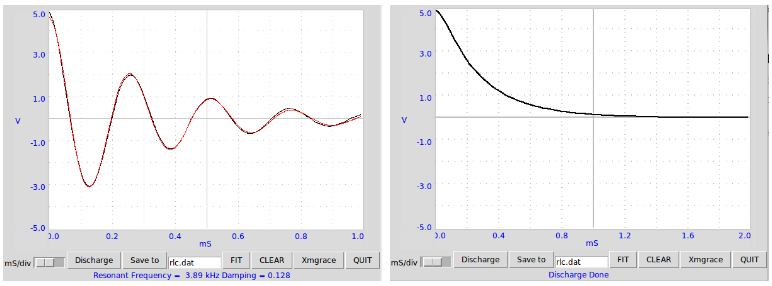
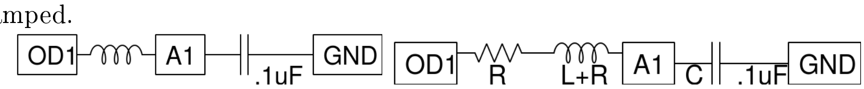


Figure 3.9: Transient response of LCR circuit,(a)Under-damped (b)Over-damped.

$\frac{R}{2}\sqrt{\frac{C}{L}}$, and it is equal to 1 for critical damping.[2] Depending upon the value of C/L and R, the response could be under-damped, critically-damped or over-damped.



Procedure

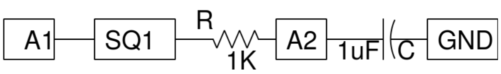
- From **EXPERIMENTS** select **RLC Discharge**
- Click on 5->0V STEP. Adjust x-axis and repeat if required.
- FIT the graph to find the resonant frequency & Damping.
- Repeat the experiment with different values of L, C and R
- Repeat with a resistor in series.

Discussion We have used the 3000 turn coil and a 0.1uF capacitor, added a 2.2k series resistor in the second case. The voltage across the capacitor after a 5 to 0V step is shown in figure 3.9 .The measured resonant frequency tallies with $f = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$, within the component tolerance values.

3.13 RC Integration & Differentiation

Objective RC circuits can integrate or differentiate a voltage waveform with respect to time. A square wave is integrated to get a triangular wave and differentiated to get spikes at the transitions.

Procedure



- Set SQR2 to 1000Hz
- Assign SQR2 to CH1 and A1 to CH2

[2]http://en.wikiversity.org/wiki/RLC_circuit

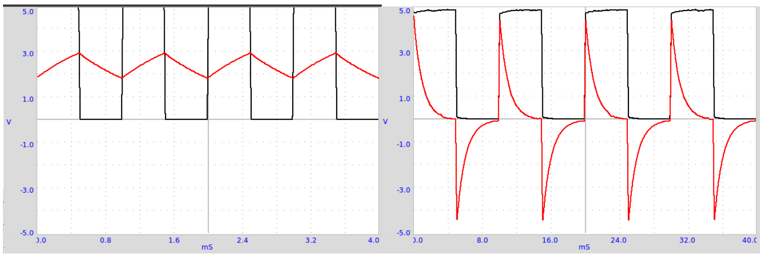
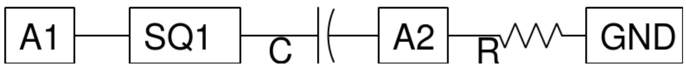


Figure 3.10: (a)1kHz Squarewave after RC Integrator (b) 100Hz after RC Differentiator

- Adjust the horizontal scale to view more than 4 cycles.
- Set SQR2 to 1kHz (T = 1mS) and other values and view the waveforms.
- Repeat the same for RC differentiator, at 100Hz.

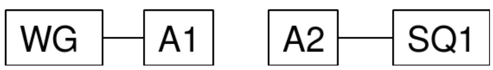


Discussion Integration observed at 1kHz and differentiation at 100Hz are shown in figure 3.10, using an RC value of 1 milliseconds. When the time period becomes comparable with the RC value, the output waveform is triangular. The differentiation can only be shown at lower frequency since capturing the narrow spike requires a fast oscilloscope.

3.14 Fourier Analysis

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

Procedure



- Set SQR1 to 150Hz
- Assign A1 to CH1 and SQR1 to CH2
- Assign CH1 & CH2 to FTR to view the Fourier transform

Discussion In the Fourier transform plot, frequency is on the x-axis and the y-axis shows the relative strength of each frequency components of the signal. This is called the frequency domain representation[3]. For the sine wave there is only one dominant peak, the smaller ones are a measure of distortion of the sine wave.

A square wave function can be represented as $f(\theta) = sin(\theta) + \frac{sin(3\theta)}{3} + \frac{sin(5\theta)}{5} + \cdots$. In the Fourier transform of a square wave of frequency f , there

[3] http://en.wikipedia.org/wiki/Fourier_transform

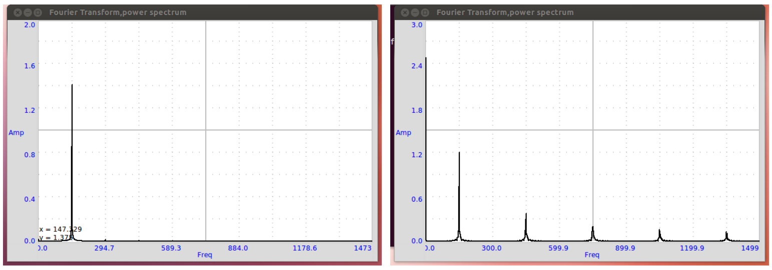


Figure 3.11: Frequency spectrum of (a)Sine wave. (b) Squarewave

will be a $3f$ component (having an amplitude of one third of f), $5f$ component (amplitude one fifth) etc. as shown in the figure 3.11(b). Note the peak at 0 Hz, due to the DC component.

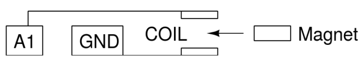
Chapter 4

Electricity & Magnetism

Electromagnetic induction is demonstrated by dropping a magnet in to a coil. Working of transformer is demonstrated using two coils. A simple AC generator, capable of generating multi-phase output, is made using a rotating magnet.

4.1 Electromagnetic induction

Objective Explore the voltage induced across a coil by a changing magnetic field, by dropping a small cylindrical magnet into a coil. Use a tube to guide the magnet through the coil.

Procedure 

- From ***EXPERIMENTS*** open ***EM Induction***
- Click on Start Scanning. A horizontal trace should appear
- Drop the magnet through the coil, until a trace is caught.
- Repeat the process by changing the parameters like magnet strength, speed etc.

Discussion The result is shown in figure 4.1(a). 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.

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.

4.2 Mutual induction, transformer

Objective Demonstrate mutual induction using two coils. One coil is powered by the SINE output. The axes of the coils are aligned and a ferrite core is inserted.

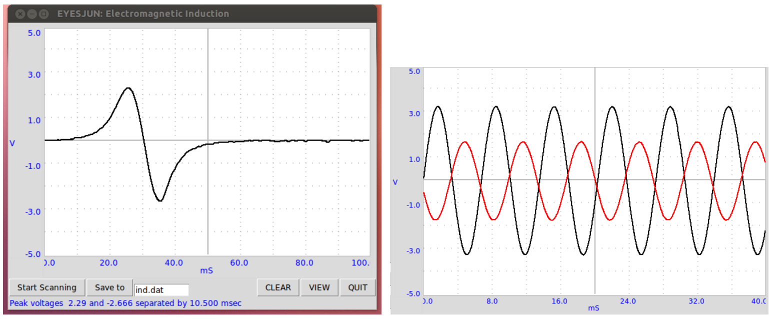
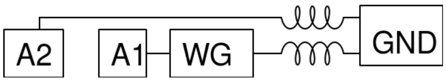


Figure 4.1: (a)Voltage induced on a coil by a moving magnet.(b)Mutual Induction between two coils, the applied and induced voltages are shown

Procedure



- Assign A1 to CH1 and A2 to CH2

Discussion The applied waveform and the induced waveform are shown in figure 4.1(2). A changing magnetic filed is causing the induced voltage. In the previous two experiments, the changing magnetic field was created by the movement of permanent magnets. In the present case the changing magnetic field is created by a time varying current.

The output should have been in phase with the input as per the theory.[1] 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 1kΩ resistor across secondary coil to reduce ringing.

4.3 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. Use the 10 mm x 10 mm magnet and the 3000T coils that comes with the kit.

Procedure

- Mount the magnet horizontally and power the DC motor from a 1.5 volts cell
- Hold the coil perpendicular to the axis of rotation of the motor, close to the magnet. Be careful not to touch it.
- Assign A1 to CH1 & A2 to CH2
- Assign CH1 and CH2 to FIT

[1] http://sound.westhost.com/xfmr.htm

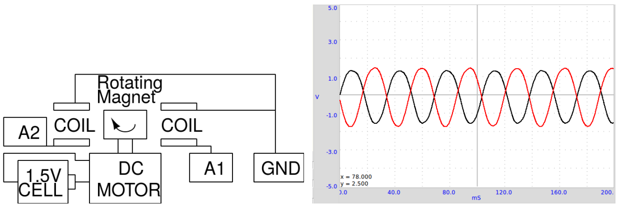


Figure 4.2: Wiring schematic and voltage output of the AC generator, with coils placed on opposite sides of the rotating magnet..

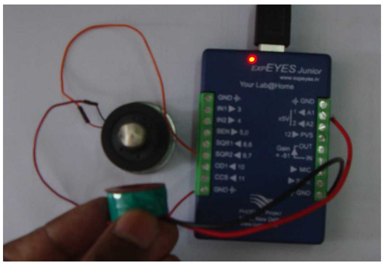


Figure 4.3: Photograph of the simple AC generator.

Discussion The voltage output is shown in figure 4.2. The phase difference between the two voltages depends on the angle between the axes of the two coils.

Bring a 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.

It is possible to power the DC motor from SQR2 set to PWM mode, as shown in figure 4.3. The function *set_sqr2_pwm(40)* is equivalent to applying 2 volts DC. Do NOT give duty cycle more than 50 percent to avoid damage to the unit.

4.4 Making an Electromagnet

Objective To demonstrate the equivalence of a bar magnet and a current carrying solenoid coil.

Procedure

- Connect the 3000T coil from OD1 to GND
- Suspend the cylindrical magnet in front of the coil
- Enable Check button OD1 to make it 5 volts
- Repeat by reversing the coil connections

Discussion When OD1 is set to 5 volts, the magnet will be either repelled or attracted depending on the direction of the current and the pole of the magnet near the coil. The direction of force can be reversed by changing any one of them.

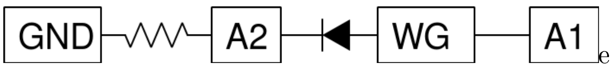
Chapter 5

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 mechanical movements. Amplitude and Frequency modulation are explored. A bread board is required to carry out some of the experiments described in this section.

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.

Procedure 

- Assign A1 to CH1 and A2 to CH2
- Add different values of filter capacitors from A2 to ground

Discussion The negative half is removed by the diode as shown in figure 5.1(a). Also notice that the voltage in the positive half is reduced by around 0.7 volts, the voltage drop across a silicon diode. A load resistor is required for

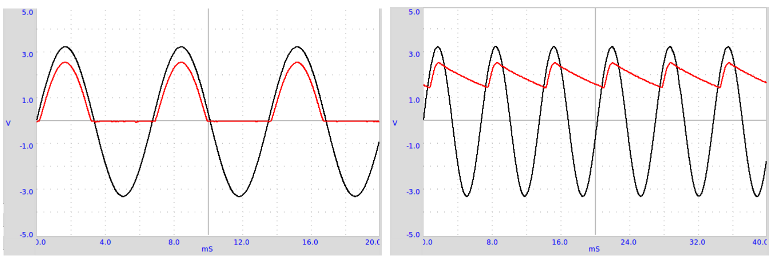


Figure 5.1: (a) Half wave rectifier input and output.(b) With capacitor filter.

the proper operation of the circuit, it could be more than 1kΩ but do NOT use very low values since our AC source can drive only up to 5 mA current.

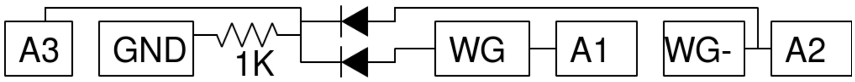
The effect of a capacitor is shown in figure 5.1(b). We can see that the capacitor charges up and then during the missing cycle it maintains the voltage. The remaining AC component is called the ripple in the DC.

Can we use very large capacitance to reduce the ripple ?

During what part of the cycle does current flow through the diode ?

Amount of peak current is decided by what ?

Objective Make a full wave rectifier, using two diodes. Two AC waveforms, differing by 180 degree in phase as required, are made as described in the previous section. The rectified output is connected to the third channel.



Procedure

- Assign A1 to CH1, A2 to CH2 and IN1 to CH3
- Add Capacitor from IN1 to ground , for filtering.

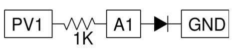
Discussion The result is shown in the figure **??**. Adding capacitors to reduce the ripple is left as an exercise to the user. This experiment is only to demonstrate the working of a full wave rectifier, it cannot provide more than few milli amperes of current.

Why full-wave rectifier is superior to half-wave rectifier ?

5.2 Diode I-V characteristic

Objective Draw the I-V Characteristic of diode and compare the result with the theory. The IV characteristic of an ideal PN junction diode is given by equation $I = I_0 \left(e^{\frac{qV}{kT}} - 1 \right)$, where I_0 is the reverse saturation current, q the charge of electron, k the Boltzmann constant, T the temperature in Kelvin. For a practical, non-ideal, diode, the equation is $I = I_0 \left(e^{\frac{qV}{nkT}} - 1 \right)$, where n is the ideality factor, that is 1 for an ideal diode. For practical diodes it varies from 1 to 2. We have used a IN4148 silicon diode.

Procedure



e

- From ***EXPERIMENTS*** select ***Diode IV*** .
- Click on START to draw the characteristic curve.
- Click on FIT to calculate the Diode Ideality factor.
- Plot the IV of LEDs

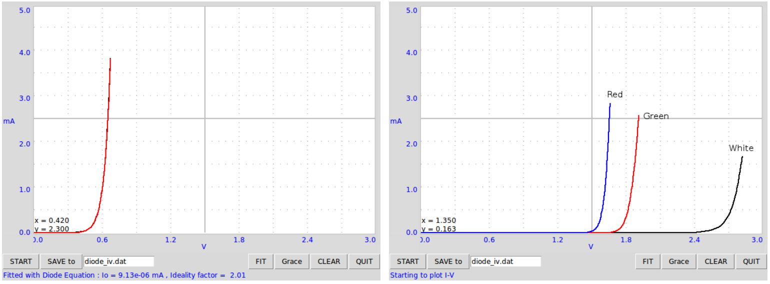


Figure 5.2: I-V characteristic of (a) Silicon diode (b) several LEDs

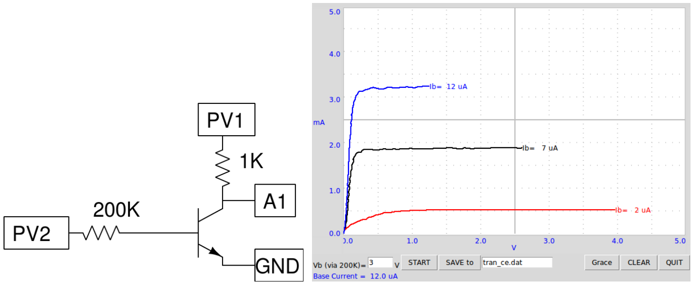


Figure 5.3: Transistor common emitter characteristics

Discussion The curves obtained are shown in figure 5.2(a). The value of n for 1N4148 is around 2. We have calculated the value of n by fitting the experimental data with the equation[1]. Figure 5.2(b) shows the IV curves of few LEDs, of different wavelengths.

The voltage at which LED starts emitting light depends on its wavelength and Planck's constant. Energy of a photon 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 Planck's constant $h = eV_0\lambda/c$, where λ is the wavelength of light from the LED, e the charge of electron and c the velocity of light.

Repeat the experiment by heating the diode to different temperatures.

5.3 Transistor CE characteristic

Objective Plot the CE characteristic curve of a transistor. Collector is connected to PVS through a 1K resistor. The base voltage is obtained by filtering a variable duty cycle pulse from SQR1. Base current is decided by this voltage and the $200k\Omega$ series resistor. For better results use an external DC supply (1.5V cell will do) for base voltage.

Procedure

- From ***EXPERIMENTS*** open **Transistor CE**

[1]If the FIT is not successful, transfer data to *xmGrace* and use the option Data->Transformations->Nonlinear curve fitting with equation y=a0*exp(a1*x).

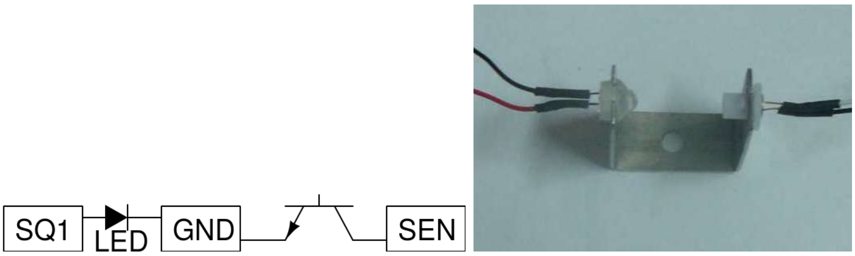


Figure 5.4: LED and photo-transistor. Electrical connections and mechanical mounting.

- Enter the Bias supply voltage to the base and START. Repeat for different Vb.

Discussion The characteristic curves for different base currents are shown in figure 5.3. The collector current is obtained from the voltage difference across the 1k resistor.

The base current is set by setting the voltage at one end of the 200 kΩ resistor, the other end is connected to the transistor base. The value of base current is calculated by, $I_b = \frac{V_{bias}-0.6}{200\times10^3} \times 10^6 \mu A$

5.4 Transmission of Light, Photo-transistor

Objective Measure the transmission of light through semi-transparent material using a photo-transistor. The material is kept between an LED and the photo-transistor. The collector current depends on the amount of light falling on the transistor.

Procedure

- Set SQR1 to 0 Hz, to turn on the LED
- Assign SEN to CH1
- Measure voltage at SEN, by clicking on it.
- Repeat by changing the material between LED and photo-transistor.

Discussion The voltage at the collector of the photo-transistor reduces with the intensity of light falling on the transistor. The voltage measured after placing a piece of paper between LED and photo-transistor is shown in figure5.5(a).

5.5 Opto-electric signal transmission

Objective Demonstrate the transmission of signals using light. An LED is powered by a 1kHz signal and the light is made to fall on a photo-transistor. The SEN input is internally connected to 5 volts through a 5.1k resistor.

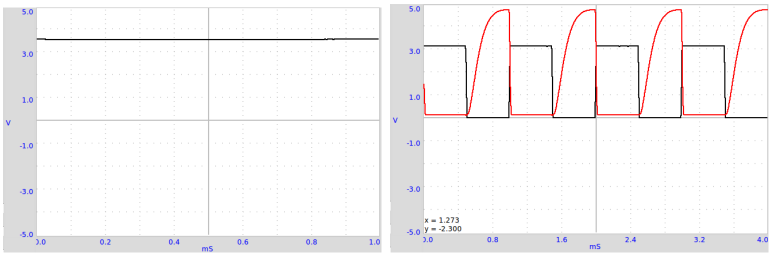


Figure 5.5: (a) Voltage at the photo-transistor with light passing through a piece of paper. (b) Pulse transmission, voltage driving the LED and the voltage across the photo-transistor.

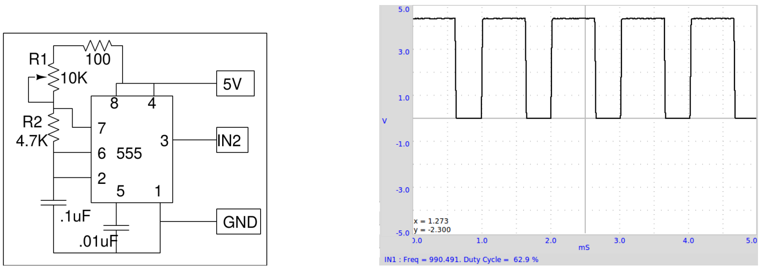


Figure 5.6: IC555 astable multi-vibrator. (a) schematic (b) Output waveform

Procedure 

- Keep the LED facing the photo-transistor and set SQR1 to 1000Hz
- Assign SQR1 to CH1 and SEN to CH2
- Repeat the experiment by changing the frequency.

Discussion The output of the photo-transistor at 1kHz is shown in figure5.5. The square trace is the voltage across the LED. When the LED is ON, photo-transistor conducts and the voltage across the collector drops to .2 volts. When the LED is OFF the photo-transistor goes into cut off mode and the collector shows almost the supply voltage. The rise and fall times of the photo-transistor seem to be different.

Repeat this experiment with a Fiber Optic cable to guide the light from LED to the photo-transistor.

5.6 IC555 Oscillator

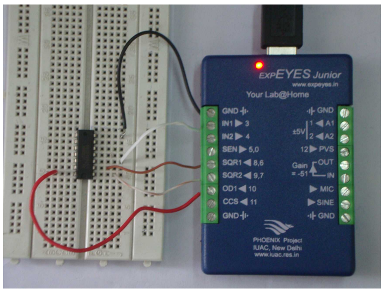


Figure 5.7: Testing of Logic gates

Objective Make an astable multivibrator using IC555 and measure its frequency and duty cycle. Circuit is shown in figure 5.6(a). The 5 volt supply for IC555 is taken from OD1, by setting it HIGH. The frequency is given by $f = 1/(\ln 2 \times C \times (R_1 + 2R_2))$. The HIGH time is given by $\ln 2 \times C \times (R_1 + R_2)$ and LOW time by $\ln 2 \times C \times R_2$.

Procedure

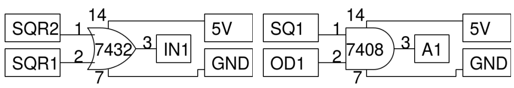
- Assign IN1 to CH1 and enable FIT on CH1
- Right-click on IN1 to measure frequency and duty cycle.
- Repeat by changing the value of R1

Discussion The output waveform is shown in figure 5.6(b). The HIGH and LOW times can be measured by using r2ftime(3,3) and f2rtime(3,3) functions.

5.7 Logic gates

Objective Study of logic gates using two square waves with a phase difference, using TTL logic ICs 7408 and 7432.

Procedure



- Assign SQR1 to CH1, SQR2 CH2 and IN1 to CH3
- Set 100Hz, 25% and enable BOTH. (SQR1 & SQR2)
- Check OD1, to power the TTL AND gate 7408
- Repeat using the OR gate, 7432

Discussion The input and output waveforms are shown in figure5.8. The results will not be accurate for high frequencies because the sampling rate is limited to around 80,000 per second for 3 channel capture.

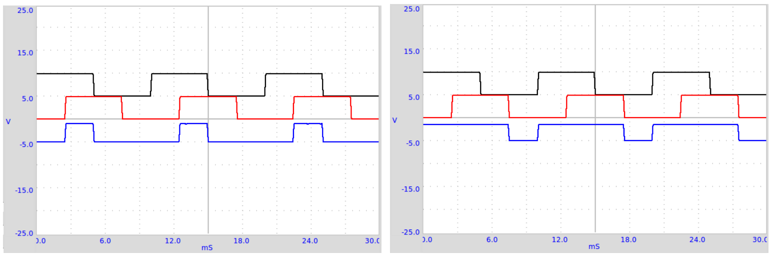


Figure 5.8: Operation of logic gates with square wave inputs.(a)AND gate (b) OR gate

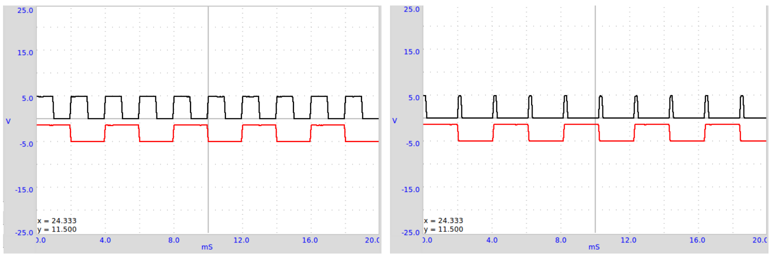
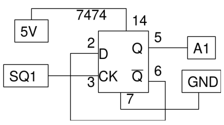


Figure 5.9: A clock divider circuit, using a D-flipflop. Outputs for two different types of input are shown

5.8 Clock Divider

Objective Study of a clock divider, using a D flip-flop (TTL family, 7474).



Procedure

- Set SQR1 to 500 Hz. Assign SQR1 to CH1 and IN1 to CH2
- Check OD1, to power the flipflop

Discussion The output toggles at every rising edge of the input, resulting in a division of frequency by two. The output is a symmetric squarewave, irrespective of the duty cycle of the input pulse. The HIGH output of the TTL IC is around 4 volts only.

Chapter 6

Sound

Pressure variations, about an equilibrium pressure, transmitted through a medium is called sound. They are longitudinal waves. Moving a sheet of paper back and forth in air can generate these kind of pressure waves, like the paper cone of a loudspeaker. When the frequency is within 20 to 20000Hz range, we can hear the sound. In this chapter, we will generate sound from electrical signals, detect them using the built-in microphone (a pressure sensor) and study the properties like amplitude and frequency. Velocity of sound is measured by observing the phase shift of digitized sound with distance.

6.1 Frequency of sound

Objective Digitize sound and measure its frequency. Use the Piezo buzzer or any other source of sound like a tuning fork.

Procedure GND — PIEZO — WG   MIC — A1

- Set SQR1 around 3500Hz, keep buzzer in front of the microphone
- Enable FIT to measure the frequency
- Repeat with other sources of sound

Discussion The amplified output of the microphone is shown in figure 6.1(a). The amplitude is maximum near 3500 Hz, due to resonance. Driving with 1200Hz gives more amplitude than 2000Hz, due to the third harmonic of the square wave matching the resonant frequency.

Sound waves create pressure variations in the medium through which it travel. The microphone generates a voltage proportional to the pressure. Since this signal is very small, we amplify it 51 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.

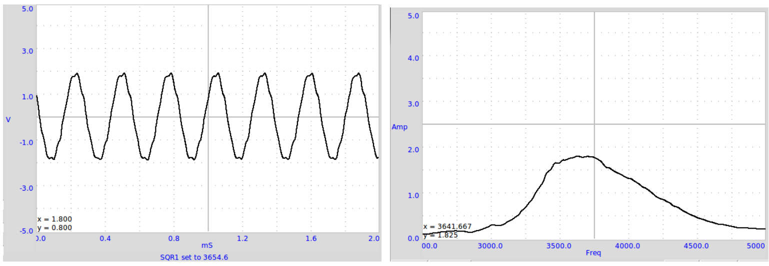


Figure 6.1: (a) Digitized sound wave (b)Frequency response curve of the Piezo disc

6.2 Frequency response of Piezo

Objective Plot the frequency response curve of the Piezo disk by scanning through the frequency and measuring the amplitude of the microphone output.

Procedure GND — PIEZO — WG   MIC — A1

- From ***EXPERIMENTS*** select **Frequency Response**
- Press START button

Discussion The Frequency Vs Amplitude plot is shown in figure 6.1(b). The amplitude is maximum around 3700 Hz.

6.3 Velocity of sound

Objective Calculate the velocity of sound by measuring the pressure variation with distance. Sound travels as a series of compressions and rarefactions. Figure 6.2(a) shows the High and Low pressure regions along the direction of travel, along with output of a pressure sensor at corresponding positions.

We can display the pressure variation at any point with respect to the variation at the starting point. The phase of the microphone output changes as you change its distance from the Piezo. Moving by one wavelength changes the phase by 360 degrees. If the phase changes by X degrees for $\triangle D$ cm change in distance, the wavelength is given by $\lambda = \frac{360 \times \triangle D}{X}$. The velocity of sound can be calculated by multiplying the frequency with this.

Procedure GND — PIEZO — WG   MIC — A1

- From ***EXPERIMENTS*** start **Velocity of Sound**
- Set frequency to resonant maximum by measuring the frequency response 6.2
- Keep the Piezo facing the microphone, on the same axis

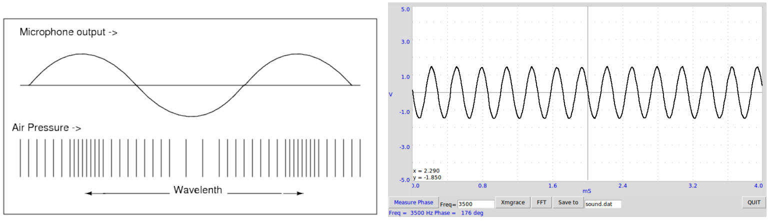


Figure 6.2: (a)Propagation of sound waves, variation of microphone output with pressure. (b) Output of microphone

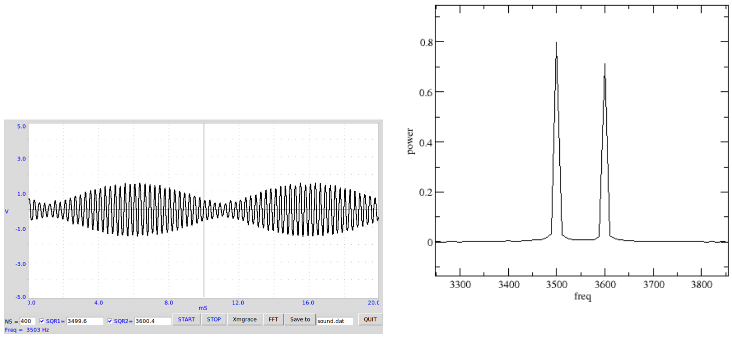


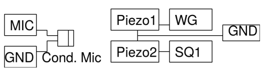
Figure 6.3: (a) Sum of sound having two nearby frequencies (b) Fourier transform showing the frequency components.

- Enable measurement
- Adjust the distance to make both the traces in Phase
- Change the distance to make them 180 degree out of phase, that distance is half wave length.

Discussion At 3500 Hz, for a 2 cm change in distance the phase changed from 176 to 102. Using the equation, $v = f \times \frac{360\times\triangle D}{X} = 3500 \times \frac{360\times2}{(176-102)} = 34054$ cm/sec. It is important to keep the mic and the Piezo disc on the same axis, for accurate results.

6.4 Interference of sound

Objective Study the interference of sound from two individual sources. Two Piezo buzzers are powered by two different sources, and the sound is directed towards the microphone.

Procedure 

- From ***EXPERIMENTS*** start ***Interference of Sound***

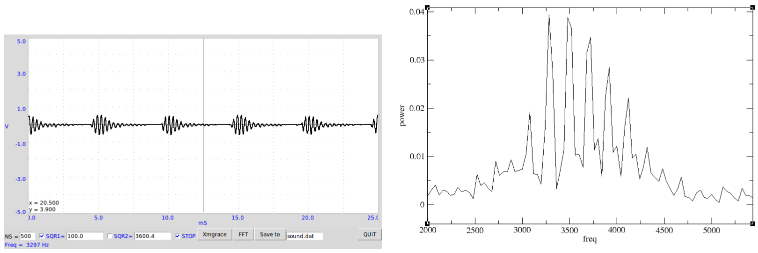


Figure 6.4: Sound output from Piezo, driven by 100Hz square wave and the Fourier transform of the output.

- Set SQR1 to 3500 Hz and SQR2 to 3600 Hz
- Adjust positions of Piezo buzzers, from the mic, to get clear beat pattern.
- Repeat with other values of frequencies.
- Capture with NC=1800 and take Fourier Transform

Discussion From figure 6.3(a) it can be seen how the low frequency envelope is created. Distance between two minimum pressure points., of the envelope, corresponds to the beat wavelength. The Fourier transform of the output is shown in figure 6.3.

6.5 Forced Oscillations of Piezo-electric crystal

Objective Study the behavior of a Piezo-electric disc at low excitation frequencies, using a square wave.

Procedure GND — PIEZO — WG   MIC — A1

- From ***EXPERIMENTS*** open **Interference of Sound**
- Tick only SQR1, set it to 100
- Press START to capture mic output
- Try different frequencies
- Capture with larger NS (<=1800) for doing Fourier transform.

Discussion The resonant frequency of the Piezo crystal is around 3600 Hz. Driven by a square wave, the piezo gets a kick on every rising and falling edge, and it undergoes several cycles of oscillations at its natural resonant frequency. The Fourier transform shows a peak at the resonant frequency and side band 200 Hz separated from the peak. It may be interesting to repeat this study using a variable frequency sine wave instead of the square wave.

Chapter 7

Mechanics, Optics & Heat

Resonance phenomena is studied using a driven pendulum. Value of acceleration due to gravity is measured using a pendulum. Cooling of a liquid is studied using a PT100 sensor.

7.1 Resonance of a driven pendulum

Objective Demonstrate the resonance of a driven pendulum. .

Procedure Make a pendulum using two button magnets and a piece of paper. Suspend it and place the 3000T coil near that, as shown in figure 7.1(a).

- Connect the coil between SQR1 and ground
- From ***EXPERIMENTS*** select ***Driven Pendulum***
- Scan the frequency upwards starting from 1Hz, very slowly.

Discussion When SQR1 reaches the resonant frequency of the pendulum, the amplitude goes up due to resonance. A 4 cm (from the center of the magnet to the axis of oscillation) long pendulum resonated at around 2.5 Hz, almost tallying with its calculated natural frequency. The resonant frequency of the pendulum is given by $f = \frac{1}{2\pi}\sqrt{\frac{g}{\ell}}$, where ℓ 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. [1]

7.2 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. Period of oscillation of a uniform rod about one end is given by $T = 2\pi\sqrt{\frac{2\ell}{3g}}$, where ℓ is the length and g is the acceleration due to gravity. The pendulum (T-shaped, a knife edge attached to a 6mm dia rod) is made to swing between an LED and

[1] SQR1 cannot go below 0.7 Hz

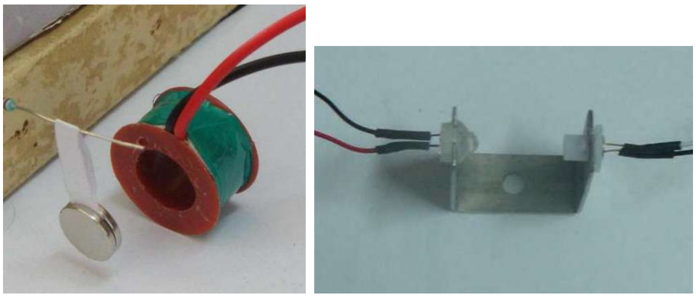
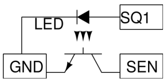


Figure 7.1: (a) Driven pendulum setup. (b) LED & photo-transistor mounted on a bracket.

photo-transistor, connected to expEYES. The LED and photo-transistor are mounted on a U-shaped bracket as shown in figure 7.1(b).

Procedure



- From ***EXPERIMENTS*** Start ***Rod Pendulum***
- Oscillate the pendulum and click on START
- Repeat with different pendulum lengths.

Discussion The time period is measured 50 times, using a 14.6cm rod pendulum, and the average value is 0.627 seconds. The calculated value of 'g' is 977.4 cm/sec^2, slightly different from the actual value 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.

7.3 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. But using a DC motor as a sensor, we can measure the angular velocity as a function of time.

Procedure

- Attach some sort of rigid pendulum to the axis of the motor.
- Connect the motor between IN and GND
- Connect OUT to A1
- From ***EXPERIMENTS*** start ***Pendulum Waveform***.

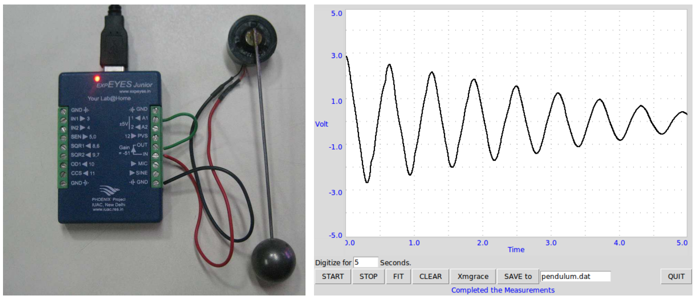


Figure 7.2: Pendulum oscillations digitized

- Oscillate the pendulum and START digitizing

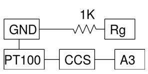
Discussion The observed waveform is shown in figure 7.2(b). Fitting it with equation $A = A_0 sin\left(\omega t + \theta\right) * \exp\left(-dt\right) + C$, using Grace gave an angular frequency of 10 Hz.

The pendulum should be made with a heavy bob and a light weight rod connecting it to the axis of the motor. In this case, the DC motor acts like a generator and the voltage is proportional to the instantaneous angular velocity.

7.4 Temperature measurement, PT100

Objective Record the temperature of a liquid by using a Platinum Resistance Thermometer. Resistance of a PT100 element is related to the temperature by the equation $R_T = R_0 \left[1 + AT + BT^2\right]$, where $A = 3.9083e - 3$ and $B = -5.775e - 7$.

Procedure To measure the resistance of the PT100 element, we connect it from the CCS to ground and measure the voltage across it. The actual current of CCS should be measured as explained in section 2.3. The voltage across CCS is amplified using an external DC amplifier (gain = 11).



- From ***EXPERIMENTS*** start ***PT100 Sensor***.
- Enter the measured current value.
- Select the required parameters and press START [2]

[2]The resistance of PT100 is100Ω at 0^0C . It changes nearly $0.4\Omega/C$, changing the voltage by 0.4 milli volts. The 12 bit ADC output changes by 1 LSB for 1.22 mV change in input voltage, hence any temperature change less than 3 degrees will not be detected. Use an external non-inverting amplifier to increase the resolution. The gain of the amplifier should be such that the maximum temperature measured should give an output less than 5 volts. Change the gain field entry accordingly.

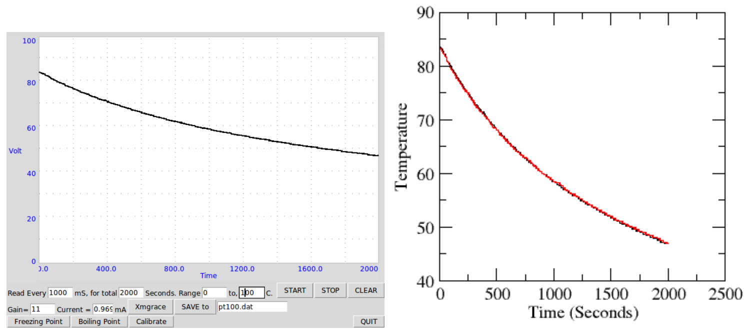


Figure 7.3: Cooling of water. (a) Screen shot of the program. (b) Graphs for clear water and coloured water

Discussion Cooling curve of water is shown in figure 7.3. The temperature is changing in big steps, this can be improved by using an amplifier between CCS and IN1, as explained in section **??**.

Instead of measuring the current and calculating the actual amplifier gain, one can follow a calibration procedure to obtain good results. This procedure assumes a linear variation of resistance with temperature. To do calibration, place the sensor in 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.

7.5 Stroboscope

Objective An object executing periodic motion will appear stationary when it is illuminated with a light pulse of the same frequency, since the object is illuminated every time only when it reaches the same point. If the frequencies are slightly different, it will appear to move with the difference in frequency.

Procedure

- From ***EXPERIMENTS*** select ***Stroboscope***
- Connect the White LED from SQR1 to GND
- Power the motor by a battery and illuminate it with the LED
- Adjust SQR1 to make the motor appear stationary.

Discussion 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.

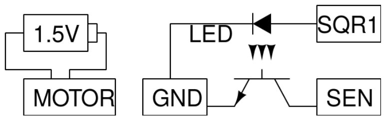
When viewed in a pulsed light source of frequency 11 Hz, a motor rotating clockwise at 10 rotations per second will look like rotating anti-clockwise once a second. During stopping and starting, the ceiling fans sometimes looks like rotating backwards, in the light of fluorescent tubes.

How is the RPM of a car engine adjusted ?

7.6 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.

Procedure A single leaf is attached to the motor and it is placed between the photo-transistor and the LED, intercepting the light once during every rotation.



- Set SQR2 to 100Hz, to rotate the motor
- Assign SEN to CH1
- Right Click on SEN to measure the frequency (FIT option may not work for these pulses)

Discussion The photo-transistor output goes HIGH when the light is obstructed. The observed values can be cross checked by using a magnet and coil as explained in section 4.3.

Chapter 8

Coding expEYES in Python

The GUI programs described in the previous sections are meant for a fixed set of experiments. To develop new experiments, one should know how to access the features of expEYES from software. Important function calls used for communicating with the device is given below. For more details, refer to the *Programmer's manual.*

8.1 Installing the Python Libraries

The expEYES-17 package consists of three files (eyes17.py, eyeplot17.py and eyemath17.py) inside a subdirectory named expeyes. This subdirectory should be inside your PYTHON LIBRARY PATH (or inside your working directory). On Debian based GNU/Linux systems, this will be done by installing the expeyes-5.x.x.deb file. On other systems unzip the file expeyes-5.x.x.zip and follow the instructions in the README file.

8.2 Hardware Communication

Start the Python interpreter in the interactive mode. Type the following two lines to load the library and establish connection to the device.

```
>>>import expeyes.eyes17
>>>p=expeyes.eyes17.open()
```

If you get an error message, check the connections, close other programs already using expEYES. Only one program can use expEYES at a time. We will start by setting and measuring some voltages.

```
>>>p.set_pv1(3.0)    # set PV1 to 3 volts
```

Connect PV1 to A1 using a piece of wire, and measure the voltage at A1

```
>>>print p.get_voltage('A1')
```

It should print a 3 volts, within the limits of error. You can try the same using PV2, A2 etc.

Now, let us explore AC signals. Connect WG to A1 and try:

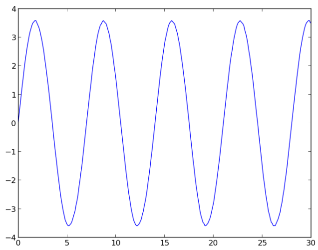


Figure 8.1: Input waveform captured and plotted using pylab

```
>>>print p.get_sine(100)   # set WG to 100 Hz (or closest possible) sine wave
>>>print p.get_voltage('A1')
```

You will get different results every time you issue the command (use cursor and backspace keys to edit previous commands). Since the voltage is changing with time, it makes better sense to measure this voltage for some duration and plot it. We will import the

matplotlib library for plotting, capture the sine wave and plot it.

```
>>>from pylab import *
>>>ion()   # set pylab interactive mode
>>>t,v = p.capture('A1',300,100)     # 300 points, 100 usec between two points
>>>plot(t,v)
```

We have sampled the voltage on A1 300 times with a delay of 100 micro seconds between two consecutive readings, i.e. the voltage is captured for total 30 milliseconds.

The graph will popup in a new window, as shown in figure **??**(a). For measuring with higher resolution (12 bits), you may use capture_hr().

```
>>>t,v = p.capture1_hr('A1',300,100)
>>>plot(t,v)
```

Now let us connect a rectifier diode from A1 to A2 and capture both the inputs simultaneously.

```
>>>t,v,tt,vv = p.capture2(300,100)    # capture2 gets data from A1 and A2
>>>plot(t,v)
>>>plot(tt,vv)
```

The out put is shown in figure 8.2(a). The last line plots a Lissajous figure as shown in figure8.2(b). There are more than one ellipse, one over the other, since we captured more than one cycle.

In some experiments, the captured voltage may be generated by some other actions like changing a voltage level. This is done by implementing capture modifiers. This can be easily demonstrated by capturing the voltage across a capacitor, just after applying a voltage step to it through a resistor. Connect 1k resistor from OD1 to A1, a 1uF capacitor from A1 to GND, and run;

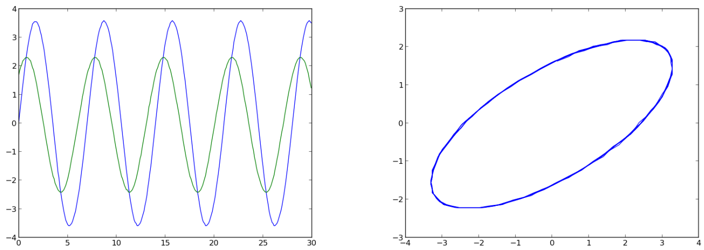


Figure 8.2: (a)Phase shift of sine wave across a capacitor. (b) Lissajous plot of the voltages

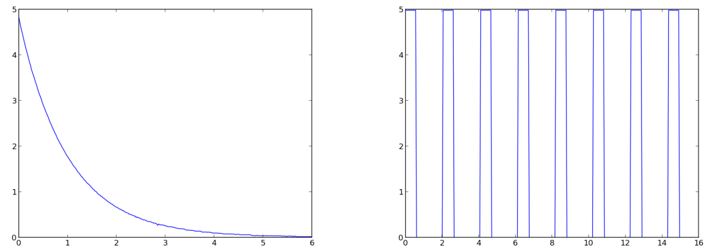


Figure 8.3: (a) Capacitor discharge (b) PWM waveform

```
>>>p.set_state(1)        # OD1 5 volts
>>>t,v=p.capture1_hr('A1',300,20)  # OD1->0 before capture
>>>plot(t,v)
```

The result is shown in figure 8.3(a).

The outputs SQR1 and SQR2 can generate square waves ranging from .7Hz to 200kHz, function returns the actual frequency set. They can also be programmed to generate Pulse Width Modulated (PWM) waveforms, at some fixed frequencies.

```
>>>print p.set_sqr1_pwm(30)    # 30% duty cycle, 488 Hz
>>>t,v=p.capture_hr(6, 300,50)   # get the wave form
>>>plot(t,v)
```

The result is shown in figure 8.3(b).

expEYES can measure time interval between voltage transitions at the digital inputs. The results returned are in microseconds. Connect SQR1 to IN1 and try:

```
>>>print p.set_sqr1(1000)     # 1kHz square wave
>>>print p.r2ftime(3,3)       # rising to falling
500
>>>print p.multi_r2rtime(3)   # two rising edge
1000
>>>print p.measure_frequency(3)
1000
```

Try to set square waves of different frequencies and measure them.

From a captured waveform, we can measure the amplitude and frequency by curve fitting. The results are accurate with a sine wave input but frequency measurement works with other shapes also. Connect SINE to A1 and try:

```
>>>import expeyes.eyemath as em
>>>t,v= p.capture_hr(1, 400,50)
>>>vfit, par = em.fit_sine(t,v)
>>>print par[0], par[1]*1000   # Amplitude & Frequency
```

The peak voltage and the frequency will be printed.

For more information read the Programmer's manual. You can get a brief description of all the functions by giving the command

```
>>>help(expeyes.eyesj)
```

Once you learn Python language, it will be easier to read through the source code *eyesj.py* to understand the working of the program.

```
If you find mistakes, send a mail to ajith@iuac.res.in
```