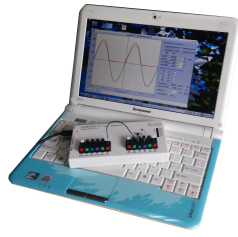


expEYES-17



User's Manual
Experiments for
Young Engineers and Scientists

<http://expeyes.in>

from

PHOENIX Project
Inter-University Accelerator Centre
(A Research Centre of UGC)
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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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 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 it is 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 inputs, 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 3.3V reference used, it is 50ppm per degree celcius. The gain and offset errors are eliminated by initial calibration, using a 16bit ADC. 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 ExpEYES17 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 in 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 coulored 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 1.1 mA but may vary from unit to unit, due to component tolerances. To measure the exact value,



Figure 1.1: The ExpEYES17 top panel showing the external connections.

connect an ammeter from CCS to GND. Another method is to connect a known resistance ($\sim 1k$) 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. SQ1 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. SQ2 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 5Hz to 5kHz. The peak value of the amplitude can be set to 3 volts, 1.0 volt or 80 mV. Shape of the output waveform 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 nanoFarads, results may not be very accurate beyond that.

Frequency Counter IN2: Capable of measuring frequencies upto several MHz.

Resistive Sensor Input (SEN): This is mainly meant for sensors like Light Dependent Resistor, Thermistor, Photo-transistor etc. SEN is internally 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 $= 1 + \frac{Rg}{10000}$. This enables displaying very small amplitude signals. 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 large number of commercially available I2C sensors.

±6V/10mA Power supply:

The VR+ and VR- are regulated power outputs. 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.

- Pieces of wires, with pin and with crocodile clip.
- 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, 1kΩ, 2.2kΩ , 10kΩ , 51kΩ and 100 kΩ
- LDR
- Two silicon diodes (1N4148) and one 3.3 volts zener diode
- NPN Transistor(2N2222)

1.3 Software Installation

ExpEYES can run on any computer having a Python Interpreter and required modules. The USB interface is handled by a device driver program that presents the USB port as a Serial port to the Python programs. The communication the expEYES is done using a library written in Python. Programs with GUI have been written for many experiments. Eyes17 software require the following packages

- python-serial
- python-numpy
- python-scipy
- python-qt4
- python-pyqtgraph

Any GNU/Linux distributions

Download **eyes17-x.x.x.zip** (the latest version) from **<http://expeyes.in>** and unzip it, and change to the newly created folder. Issue the command

```
$ sudo sh postinst          # set user write permission
$ python main.py
```

You will get error messages for any missing packages that are required for expeyes. Install them one by one and try again. Python programs required for several experiments are in the same directory, they are called by 'main.py'.

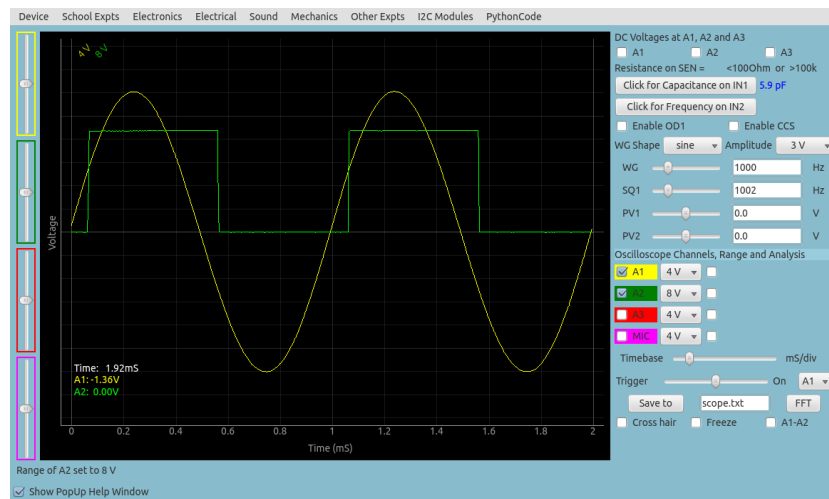


Figure 1.2: The scope17 screen showing two traces

Debian or Ubuntu GNU/Linux distributions

Download **eyes17-x.x.x.deb** (the latest version) from the software section of <http://expeyes.in> and install it using the command;

```
$ sudo gdebi eyes17-x.x.x.deb
while connected to Internet
```

The package 'eyes17' (later than version 3) does not depend on the earlier versions of ExpEYES, like expeyes junior. During installation gdebi will automatically download and install all the required packages.

The expEYES Live CD / USB pendrive

The ISO image containing support for eyes17 can be downloaded from [HERE](#). Make a DVD or USB memory stick bootable using this ISO image (Download rufus from <https://rufus.akeo.ie> to do this under MSWindows)

Switch off the PC and insert the liveCD/Pendrive and switch it on. Enter the BIOS while booting, make the CDdrive/USB hard disk as the first boot device. 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/eyes17/main.py
```

On MSWindows

The first thing to do is to install the driver software for the USB to serial converter IC MCP2200, available on Microchip website (also given on expeyes website). After installing this the device will appear as a COM port, that can be verified from the device manager of MSWindows. After this there are two options.

A zip file containing all the necessary things for ExpEYES is available on the website, named eyes17win.zip. Unzip this file and run main.py from that. By using this method you will not able to write your own Python code to access expeyes, for that you need to install the following

1. Python-2.x version
2. python-serial
3. python-qt4
4. python-pyqtgraph,
5. python-numpy
6. python-scipy

Download the eyes17-x.x.x.zip (take latest version) from the website. Unzipping the files will create a directory **named eyes17**, run **main.py** from that.

1.4 The main GUI program

Start Applications->Education->ExpEYES-17 from the menu. A four channel oscilloscope screen with several extra features will open as shown in figure 1.2. Various experiments can be selected from the menu.

The main window looks like a low frequency four channel oscilloscope, with some extra features, on the right side panel. Applications for various experiments can be selected from the pulldown menu. A brief description of the oscilloscope 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.
- The horizontal scale (time base) can be changed by a slider, from .5 mS fullscale to 500 mS full scale.
- The Checkbutton **Freeze**, 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.
- To save the traces to a file, edit the filename and click on the **SaveTo** button.
- Clicking on **FFT** shows the frequency spectrum of all the enabled channels, appears on popup windows.

In addition to the Oscilloscope, there are several measurement/control options available on the GUI, they are explained below.

- If selected, the voltages at the inputs A1, A2 and A3 are sampled every second and displayed.
- The resistance connected between SEN and Ground is measured and displayed every second.
- Clicking **Capacitance on IN1**, measures the value of the capacitor connected between IN1 and GND.
- Clicking **Frequency on IN2**, measures the frequency of an external digital (TTL standard) pulse connected to IN2
- 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.
- Frequency of the Waveform generator WG can be set using the slider or the text entry window. 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 it will be displayed in the message window at the bottom. The amplitude of WG output can be set to 3 volts, 1 volt or 80 mV.
- SQ1 can be set using the same method as explained above. The duty cycle can be set between 1% to 99%, default is 50%.
- The programmable volages PV1 and PV2 are also set in a similar manner.
- Checkbuttons are provided to control OD1 and CCS.

1.5 Getting Familiar with ExpEYES17

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'. Enable the 'Popup Help' option and select the first few items from the school menu.

The following chapters are organized according to the pulldown menus of the eyes17 program, each chapter containing the experiments under the corresponding menu; like School level, Eelectronics, Eelectrical etc. To perform the experiment, select it from the menu. Online help is available for every experiment, making this manual almost redundant.

The screen shots given in this document are not from the GUI program, because the black background images are difficult to print. The plots are generated by separate code.

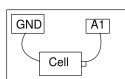
Chapter 2

School Level Experiments

This chapter will discuss the experiments and demonstrations without much data analysis, experiments given in the menu SchoolExpts. Simple tasks like measuring voltage, resistance, capacitance etc. will be done followed by resistances changing with temperature or light. The concept of Alternating Current is introduced by plotting the voltage as a function of time. Generating and digitizing sound will be covered. When an experiment is selected, the corresponding help window will popup, if enabled.

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

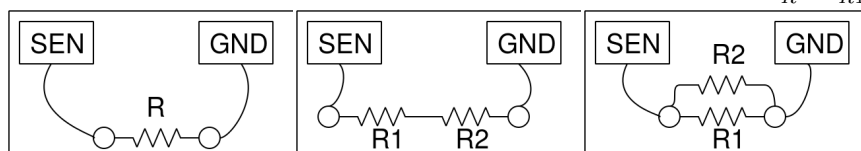
- Observe the voltage at A1 displayed.
- Repeat by reversing the cell connections.

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 Measuring Resistance

Objective ExpEYES has a terminal marked **SEN**, that can be used for measuring resistances in the range of 100Ω to $100\text{ k}\Omega$. You can also study the series and parallel combination of resistors. Effective resistance of a series combination of resistors, $R = R_1 + R_2 + \dots$. For parallel combination it is given by $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$

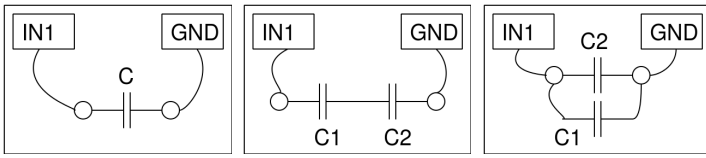


Procedure

- Connect the resistor between SEN and any Ground terminal
- Observe the value shown on the right side panel
- Try series and parallel combinations

2.3 Measuring Capacitance

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



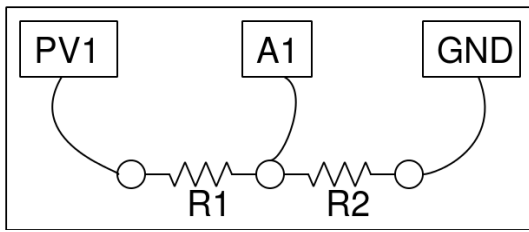
Procedure

- Connect the capacitor between IN1 and Ground.
- Click on “Capacitance on IN1” . Should not touch the capacitor while measuring
- Repeat the measurement for Series and parallel combinations

Discussion We have used 100pF capacitors in this activity. For parallel combination, the effective capacitance is given by $C = C_1 + C_2 + \dots$, and for series combination by $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$. You can make the capacitors by pasting thin metal foils on both sides of insulators like paper, polythene or glass.

2.4 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, $I = \frac{V_{A1}}{R_2} = \frac{V_{PV1} - V_{A1}}{R_1}$.



Procedure

- Connect the unknown resistor R from PV1 to A1.
- Connect $1k\Omega$ (R_2) from A1 to Ground.
- Set PV1 to 4 volts.
- Measure voltage at A1. Calculate the current $I = \frac{V_{A1}}{R_2}$. Value of $R_1 = \frac{V_{PV1} - V_{A1}}{I}$.
- Select Electrical->Plot I-V curve from the menu to get an I-V plot

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.

2.5 Direct and Alternating Currents

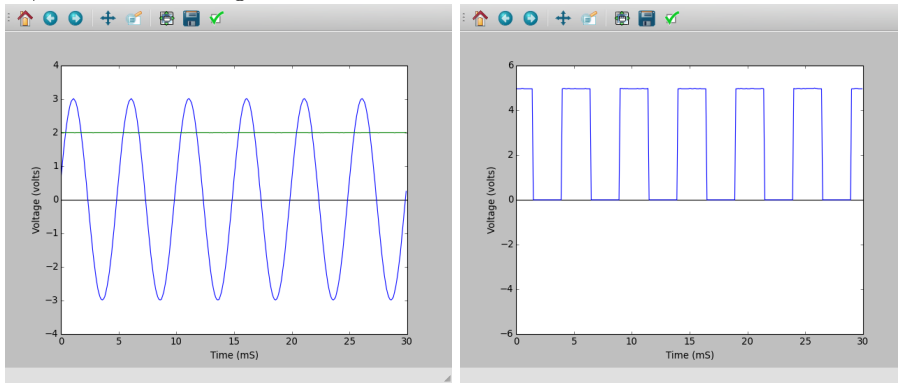
Objective Introduce the concept of time dependent voltages, using a V(t) graph. Compare the graph of DC and AC.



Procedure

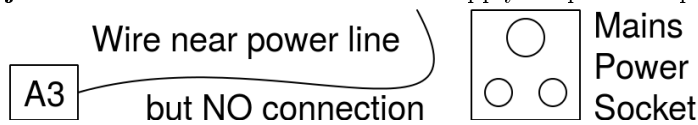
- Set PV1 to 2 volts and Set WG to 200 Hz
- Enable analyse on A1, to measure amplitude and frequency.
- Enable A2

Discussion In the plot if voltage is not changing, it is pure DC. If the voltage is changing with time, it has an AC component. if the average voltage is zero, it is pure AC. In the second plot, the voltage is changing from zero to five volts, is it AC, DC or something else ???



2.6 AC mains pickup

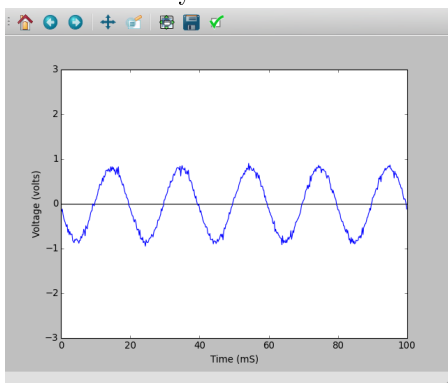
Objective Learn about the AC mains supply. Explore the phenomenon of propagation of AC through free space.



Procedure

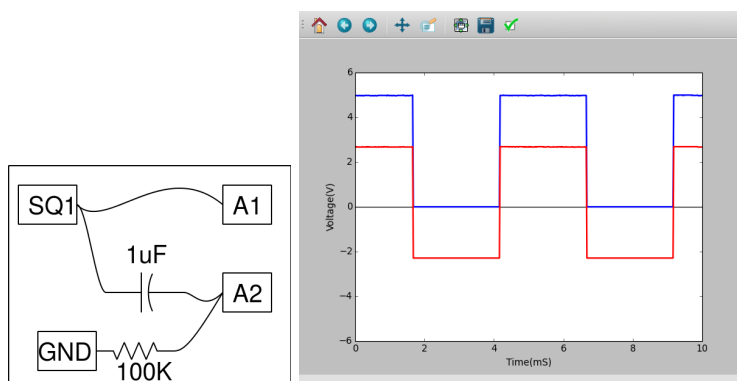
- Connect a long wire to A3
- Take one end of the wire near the AC mains line, without touching any mains supply.
- Enable A3, and it's analysis.

Discussion The power line pickup is shown below, there are five cycles in 100 milliseconds. Without making any connection, how are we getting the AC voltage from the mains supply ? Why the voltage increases when you touch the end of the wire connected to A1 by hand.



2.7 Separating DC & AC components

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



Procedure

- Set SQR1 to 500 Hz
- Enable A1 and A2
- Adjust the horizontal scale to see several cycles.

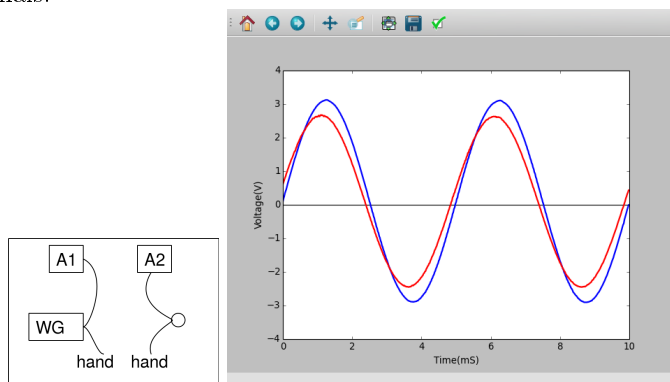
Discussion The observed waveforms with and without the series capacitor are shown in figure. The voltage is swinging between 0 and 5 volts. After passing through the capacitor the voltage swings from -2.5 volts to +2.5 volts.

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.

2.8 Human body as a conductor

Objective Touching the AC mains is fatal to us because our body is a conductor. We can explore this using low voltage signals.



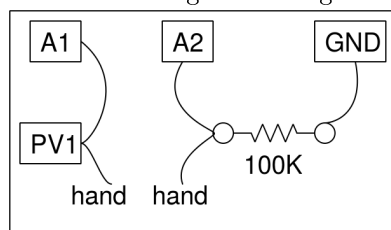
Procedure

- Set WG to 200 Hz.
- Enable A1, A2 with analysis enabled.
- Connect WG and A1, with a wire
- Connect WG and A2 through your body and note voltages
- Repeat it using a 3 volt DC signal from PV1.

Discussion The observed peak voltage will be less than 3volts, due to the resistance of the body. There could be some ripple due to the 50Hz AC pickup. This can be eliminated by performing the experiment far away from power lines, using a laptop.

2.9 Resistance of human body

Objective Measure the resistance of human body by comparing it with a known resistor. We start with a DC input from PV1 and then using the AC signal from WG.



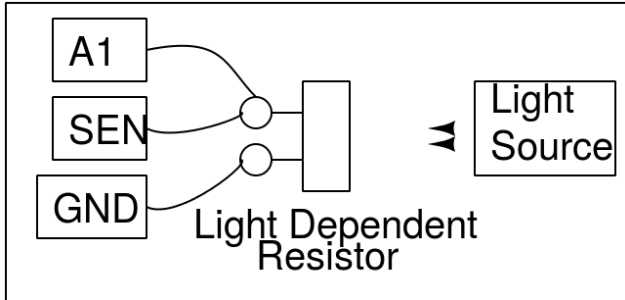
Procedure

- 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 2.4
- Repeat using SINE instead of PV1. Enable analysis on A1 and A2 to measure voltage.

Discussion The DC measurements are affected more by the electrical noise. The AC resistance should be less than the DC resistance. The resistance is due to our skin and AC can pass through this, like it passes through a capacitor.

2.10 Light dependent resistors

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



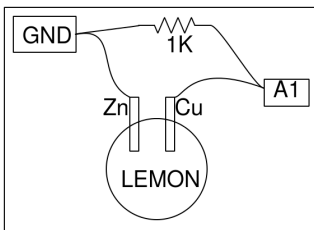
Procedure

- Measure the LDR's resistance, for different light intensities.
- Illuminate LDR using a fluorescent lamp, A1 should show ripples
- Put A1 in AC mode and measure ripple frequency

Discussion The resistance vary from $1\text{k}\Omega$ to around $100\text{ k}\Omega$ 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 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

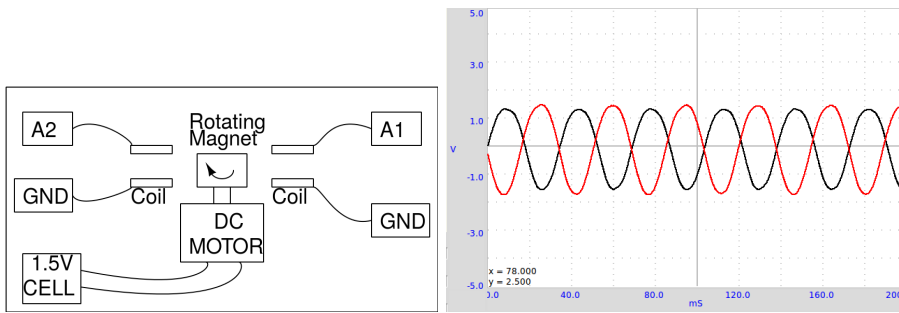
Discussion Voltage across the Copper and Zinc terminals is nearly .9 volts. Connecting the resistor reduces it to 0.33 volts. When connected, current will start flowing through the resistor. But why is the voltage going down ?

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 ?

2.12 A simple AC generator

Objective Measure the frequency and amplitude of the voltage induced across a solenoid coil by a rotating magnet. Use the 10 mm x 10 mm magnet and the 3000T coils that comes with the kit.



Procedure

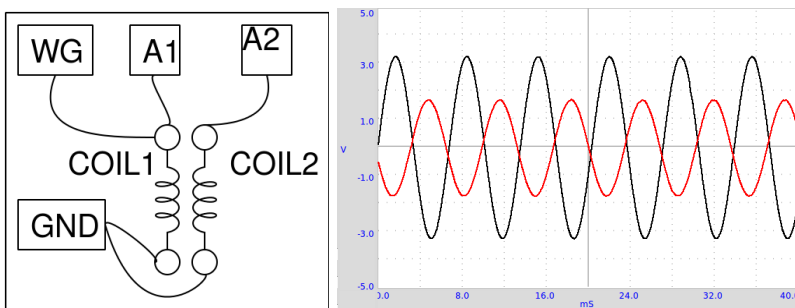
- Mount the magnet horizontally and power the DC motor from a 1.5 volts cell
- Enable A1 and A2, with analysis option
- Set timebase to 100 mS full scale
- Bring the coil near the magnet (not to touch it), watch the induced voltage
- Repeat the experiment using 2 coils.

Discussion The voltage output is shown in figure. 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.

2.13 AC Transformer

Objective Demonstrate mutual induction using two coils, supplied with ExpEYES. One coil, the primary, is connected between WG and Ground. The axes of the coils are aligned and a ferrite core is inserted.



Procedure

- Make connections as shown in the figure
- Enable A1 and A2
- Set WG to 500 Hz
- Bring the coils close and watch the voltage on A2.
- Try inserting an iron core

Discussion The applied waveform and the induced waveform are shown in figure. A changing magnetic field 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.

Try doing this experiment using a squarewave. Connect a $1k\Omega$ resistor across secondary coil to reduce ringing.

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.

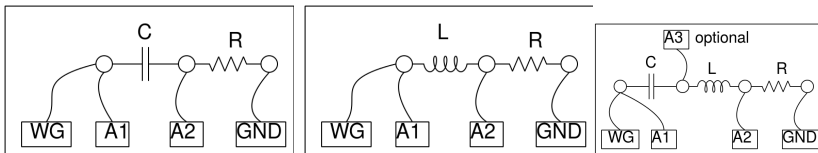
Chapter 4

Electricity and Magnetism

This section mainly contains experiments on the steady state and transient response of LCR circuit elements. the experimental results with the theory. It also gives an experiment of electromagnetic induction.

4.1 RLC circuits, steady state response

Objective Study the effect of series LCR elements in an AC circuit. Three different combinations can be studied.



Procedure

- Make connections one by one, as per the drawing
- Note down the amplitude and phase measurements, in each case
- Repeat the measurements by changing the frequency.
- For RLC series circuit, the junction of L and C is monitored by A3
- For resonance select $C = 1\mu\text{F}$, $L = 10\text{mH}$ and $F = 1600\text{ Hz}$, adjust F to make phase shift zero
- The total voltage across L and C together goes almost to zero, the voltage across them are out of phase at resonance

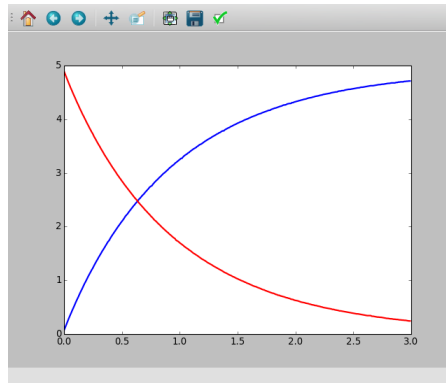
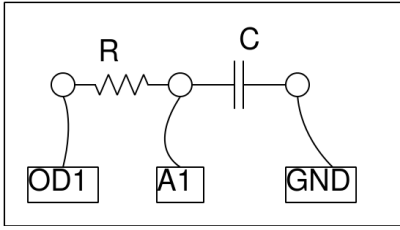
Discussion The applied AC voltage is measured on A1 and the voltage across the resistor on A2. Subtracting the instantaneous values of A2 from A1 gives the combined voltage across the inductor and capacitor. We need to use an inductor with negligible resistance for good results. The phase difference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

The total voltage, voltage across R and the voltage across LC are shown in figure. 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 voltage drop across LC will be minimum, decided by the resistance of the inductor. The input A3 is connected between L and C, so that the individual voltage drop across L and C can be displayed.

4.2 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.



Procedure

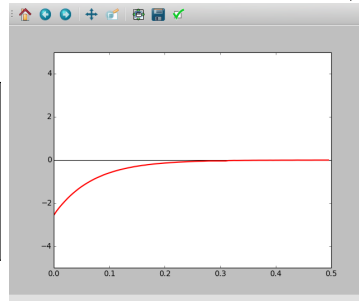
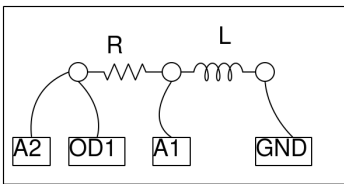
- From **Electrical** , select **RC Transient response**
- Click on **0->5V STEP** and **5->0V step** Buttons to plot the graphs
- Adjust the horizontal scale, if required, and repeat.
- Calculate RC time constant.

Discussion Applying a 0 to 5V step makes the voltage across the capacitor to rise exponentially as shown in the figure. 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, because $Q = It = CV$, and voltage increases linearly with time as $V = (\frac{I}{C}) t$.

4.3 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.



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, $R = R_{ext} + R_L$.

Procedure

- Inductor is the 3000 Turn coil
- 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 RL circuit is shown in figure. 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.

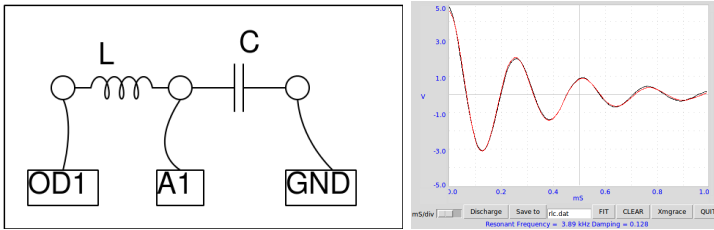
The applied voltages are above zero, but the graph went to negative voltages. Why ?

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.

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



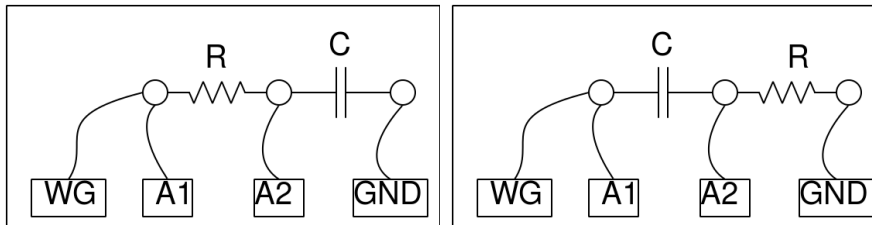
Procedure

- Start with the coil and 0.1 uF capacitor
- Click on 5->0V STEP. Adjust x-axis and repeat if required.
- FIT the graph to find the resonant frequency & Damping.
- Repeat with a resistor between OD1 and the inductor.
- Repeat the experiment with different values of L, C and R

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

4.5 RC Integration & Differentiation

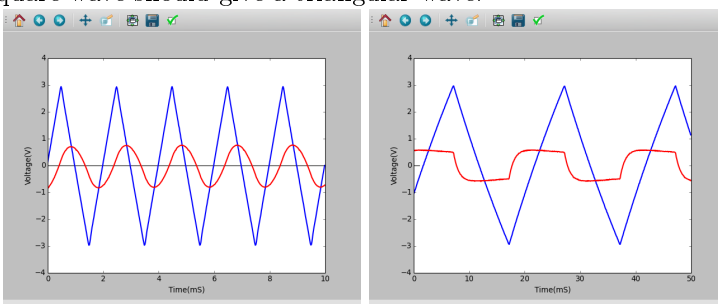
Objective RC circuits can integrate or differentiate a voltage waveform with respect to time. A square wave is integrated to get a triangular wave and differentiated to get spikes at the transitions.



Procedure

- Select WG triangular wave option
- Set WG to 500Hz (T = 1mS), R=1k and C = 1uF
- Adjust the horizontal scale to view more than 4 cycles.
- Repeat the same for RC differentiator, at 50Hz.

Discussion Integration of a triangular waveform gives parabolic shape and differentiation gives a square shape. The differentiation can only be shown at lower frequency. Try these for other wave shapes, for example a squarewave. Integrating a square wave should give a triangular wave.



¹http://en.wikiversity.org/wiki/RLC_circuit

4.6 Fourier Analysis

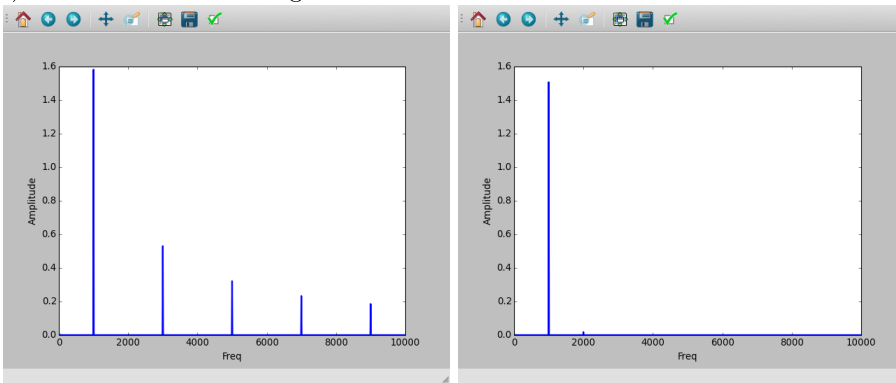
Objective Learn about Fourier Transform of a signal. Time and Frequency domain representations.

Procedure

- Connect SQ1 to A1 and WG to A2. Put A1 in AC coupled mode (slide switch on the box)
- Enable A1 and A2, select 4 volt scale
- Set both WG and SQ1 to 500Hz
- Press the FFT button

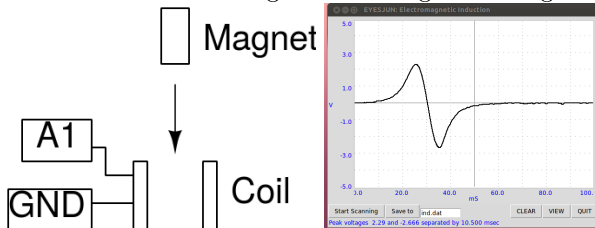
Discussion In the Fourier transform plot, frequency is on the x-axis and the y-axis shows the relative strength of the frequency components of the signal. This is called the frequency domain representation². For the sine wave there is only one dominant peak, the smaller ones are a measure of distortion of the sine wave.

A square wave function can be represented as $f(\theta) = \sin(\theta) + \frac{\sin(3\theta)}{3} + \frac{\sin(5\theta)}{5} + \dots$. 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.



4.7 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

- 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. 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.

²http://en.wikipedia.org/wiki/Fourier_transform

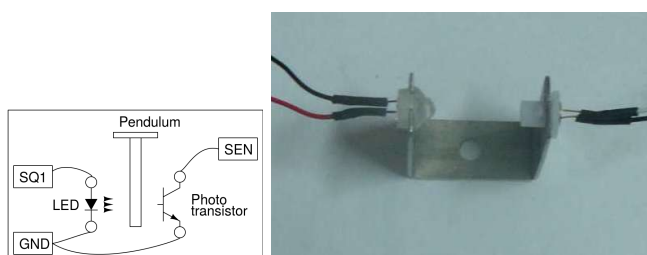
Chapter 6

Mechanics & 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.

6.1 Acceleration due to gravity using 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 photo-transistor, connected to expEYES. The LED and photo-transistor are mounted on a U-shaped bracket as shown in figure.



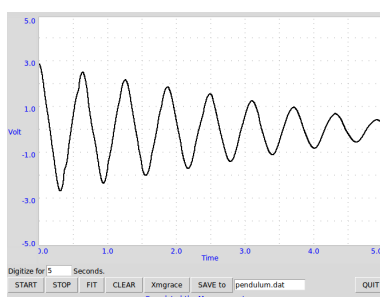
Procedure

- 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.

6.2 Angular Velocity of 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

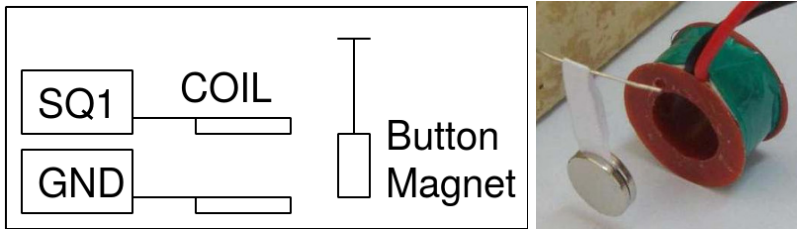
- Attach some sort of rigid pendulum to the axis of the motor.
- Connect the motor between A3 and GND
- Connect 100Ohm resistor from Rg to Ground
- Oscillate the pendulum and START digitizing

Discussion The observed waveform is shown in figure. Fitting it with equation $A = A_0 \sin(\omega t + \theta) * \exp(-dt) + C$, 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.

6.3 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.

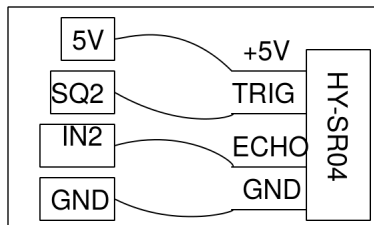
- Connect the coil between SQ1 and ground
- Calculate the resonant frequency from the length of the pendulum
- Scan the frequency around the expected resonance frequency

Discussion When SQ1 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.

6.4 Distance Measurement, by ultrasound echo

Objective Measure distance by measuring the time taken by 40kHz pulse train to echo from a hard surface.



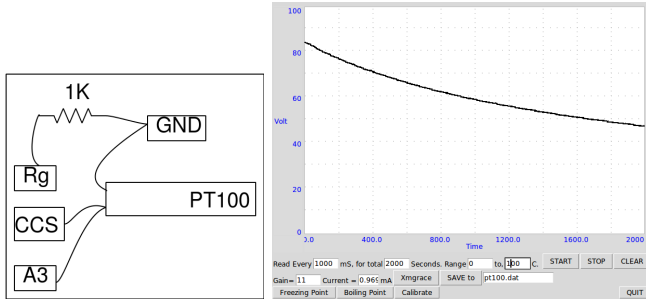
Procedure

- Keep a flat surface, like a cardboard sheet, around 10 cm from the echo module
- Press START
- Change the distance with time

Discussion The distance is calculated from the time taken by a burst of sound to echo from the surface kept in front of the module. The distance can be measured as function of time, enabling to calculate velocity, acceleration etc.

6.5 Temperature measurement using 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 $R_T = R_0 [1 + AT + BT^2]$, where $A = 3.9083e - 3$ and $B = -5.775e - 7$.



Procedure

- Enter the Gain, Offset error and the Current from CCS
- Select the temperature range and time intervals
- Select the required parameters and press START

Discussion Cooling curve of water is shown in figure

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 using an ammeter or by measuring the voltage drop across a known resistor. The input to A3 is amplified 11 times by connecting a 1kOhm resistor from Rg to Ground.

The resistance of PT100 is 100Ω at $0^\circ C$. 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 3.3 volts. Change the gain field entry accordingly.