Innovative Experiments

using

PHOENIX

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Chapter 1

Introduction

Phoenix-M is an equipment that can be used for developing computer interfaced science experiments without getting into the details of electronics or computer programming. For developing experiments this is a middle path between the $push - buttonsystems$ and the $developfromscratch$ approach. Emphasis is on leveraging the power of personal computers for experiment control, data acquisition and processing. Phoenix-M can also function as a micro-controller development system helping embedded system designs.

Phoenix-M is developed by Inter-University Accelerator Centre [1]. IUAC is an autonomous research institute of University Grants Commission, India, providing particle accelerator based research facilities to the Universities. This document provides and overview of the equipment, its operation at various levels of sophistication and several experiments that can be done using it.

1.1 Objectives of PHOENIX

One may question the relevance of using a computer for experimental data collection and advocate taking readings manually to improve the experimental skill of the students. The objective of Phoenix is to approach the process

[1]Being a product meant for the education sector, IUAC has granted permission for commercial production of it without any royalty. For more details visit`www.iuac.res.in/~elab/phoenix/vendors`

of laboratory experiments from a different plane. Performing experiments should be the fun part of learning science subjects but students at the college level do the traditional lab experiments by just following a given set of inflexible steps to take some measurements. Limitations of the apparatus does not allow taking sufficient data points involving fast changing parameters like position of a moving body or a fluctuating temperature. This to a major extent affects the accuracy of results, especially where the time measurements are concerned. Generally the students take three readings and calculate the average value. The statistical error analysis techniques are never done and are not possible owing to the lack of sufficient data. One is forced to make assumptions whose validity cannot be checked. The process of experiments is more or less done like performing a ritual and the students have no confidence in the results they obtain.

A more important point is that the ability to perform experiments with some confidence in the results, opens up an entirely new way of learning science. From the experimental data, students can construct a mathematical model and examine the fundamental laws governing various phenomena. Research laboratories around the world performing physics experiments use various types of sensors interfaced to computers for data acquisition. They formulate hypotheses, design and perform experiments, analyze the data to check whether they agree with the theory. Unfortunately the data acquisition hardware used by scientists is too expensive for college laboratories where teaching is the main goal and not research. With the advent of inexpensive personal computers the only missing link is the data acquisition hardware that is fast and sensitive enough to do physics experiments. If such a data acquisition hardware is cheap enough then college level or even school laboratories could afford to do experiments using computers and perform numerical analysis of the data. Physics with Home-made Equipment and Innovative Experiments, PHOENIX is a step in that direction. Phoenix provides microsecond level accuracy for timing measurements but the present version gives only 0.1 % resolution for analog parameters, limited by the 10 bit ADC used.

The basic unit only provides an interface to the PC and the kind of ex-

periments you can do depends on the sensor elements available. The layered software design does not demand much programming skills from the user. At the same time we do not encourage the use of black boxes where you get the results at the click of a mouse button. The approach is to get the data by typing one or two lines of Python code.

Phoenix-M is the micro-controller based version of this interface which also doubles as a training kit for electronics engineering and computer science students. Collecting data from the sensor elements and controlling the different parameters of the experiment from the PC is one of the features of Phoenix-M. This is achieved by loading the required software into the micro-controller. At the same time the tools to change this resident code also is being provided along with the system. This enables the students to use it as a general purpose micro-controller development kit and designing stand-alone projects.

1.2 Features for Developing Experiments

Phoenix-M offers the following features through the front panel sockets for developing computerized science experiments.

1. Four channels of Analog Inputs
2. Programmable voltage source
3. Four Digital Inputs
4. Analog Comparator Input
5. Four Digital outputs (One with 100 mA drive capability)
6. Square Wave Generator (10 Hz to 4 MHz)
7. Frequency Counter (1 Hz to 1 MHz)
8. Constant Current Source (1 mA)
9. Two Variable Gain Inverting Amplifiers

10. One Variable Gain Non-Inverting Amplifier

11. Two Bipolar to Unipolar Converting Amplifiers

12. 5V Regulated DC Output (from the external 9V DC input)

13. Serial Interface to PC

14. Easy to use Python language library

To develop science and electronics experiments suitable sensor elements are wired to the front panel sockets and accessed from the PC using the Python library. The program running on the micro-controller accepts the commands from the PC, performs the tasks and sends the reply. Phoenix-M can run on any computer with a Serial Port and a Python Interpreter with a library to access the serial port. Free Software platforms like GNU/Linux is highly recommended. Required software for both GNU/Linux and MS-Windows are provided on the CD.

The system can also be used by booting from the Live CD without installing anything to the computer hard disk.

1.3 Microcontroller development system

This is another level of application of Phoenix-M and those who are only interested in developing PC interfaced experiments may ignore it. The ATmeag16[1] microcontroller inside Phoenix-M can be programmed in C or assembler. The program is compiled on the PC and the output hex format file is uploaded to the micro-controller through a cable connected to the Parallel port of PC. The C compiler and development tools for this purpose are provided on the CD for both GNU/Linux and MS-Windows operating systems. Most of the ATmega8 micro-controller Input/Output pins are available through the front panel sockets. A 16 Character LCD Display is provided along with C functions to access it. Details of using Phoenix-M as a micro-controller development system will be discussed in chapter 5.

1.4 Stand-alone Systems

The unit can be converted into standalone equipment like frequency counter, function generator, temperature controller etc. by loading appropriate programs and using the sockets and the LCD display for Input/Output. Example applications will be discussed in chapter 6.

Chapter 2

Hardware and Software

Phoenix-M kit comes with some accessories to try some simple experiments quickly. Verify that you get the following components with your Phoenix kit:

1. The Phoenix box (Figure 2.1)
2. 9V DC adapter
3. Serial port cable for communicating with the PC
4. Bootable CD containing Phoenix driver software and assorted tools
5. LED with resistor and three pins (one)
6. RC measurement cable with 4 pins (one)
7. 15 cm long wire with 2mm banana pins (three)
8. 25 cm long wire with 2mm banana pins (two)
9. Condenser microphone with biasing and signal cables (one)
10. 1 KΩ and 100 Ω resistors with pins, for variable gain amplifier. (two+one)
11. 5V DC powered Piezo buzzer (without pin)
12. Metal film Resistors 10 KΩ, 500Ω, 200Ω, 10Ω

The following accessories are available separately:

1. 16x1 LCD display
2. Parallel port cable for micro-controller programming
3. Diode Char Set (Setup to Study several PN junctions)
4. Light barrier (Time measurements by intercepting a beam of light)
5. Pendulum waveform digitizer using DC motor as transducer
6. Rod pendulum
7. PT100 temperature sensor
8. LM35 temperature sensor
9. 40KHz piezo transceiver pair (for sound wave experiments)
10. 10 cm cable with pins (pack of 10)
11. 20 cm cable with pins (pack of 10)

2.1 The front panel

On the front panel you will find several 2mm banana sockets with different colors. Their functions are briefly explained below.

1. 5V OUT - This is a regulated 5V power supply that can be used for powering external circuits. It can deliver only upto 100mA current , which is derived from the 9V unregulated DC supply from the adapter.
2. Digital outputs - four RED sockets at the lower left corner . The socket marked D0* is buffered with a transistor; it can be used to drive 5V relay coils. The logic HIGH output on D0 will be about 4.57V whereas on D1, D2, D3 it will be about 5.0V. D0 should not be used in applications involving precise timing of less than a few milli seconds.

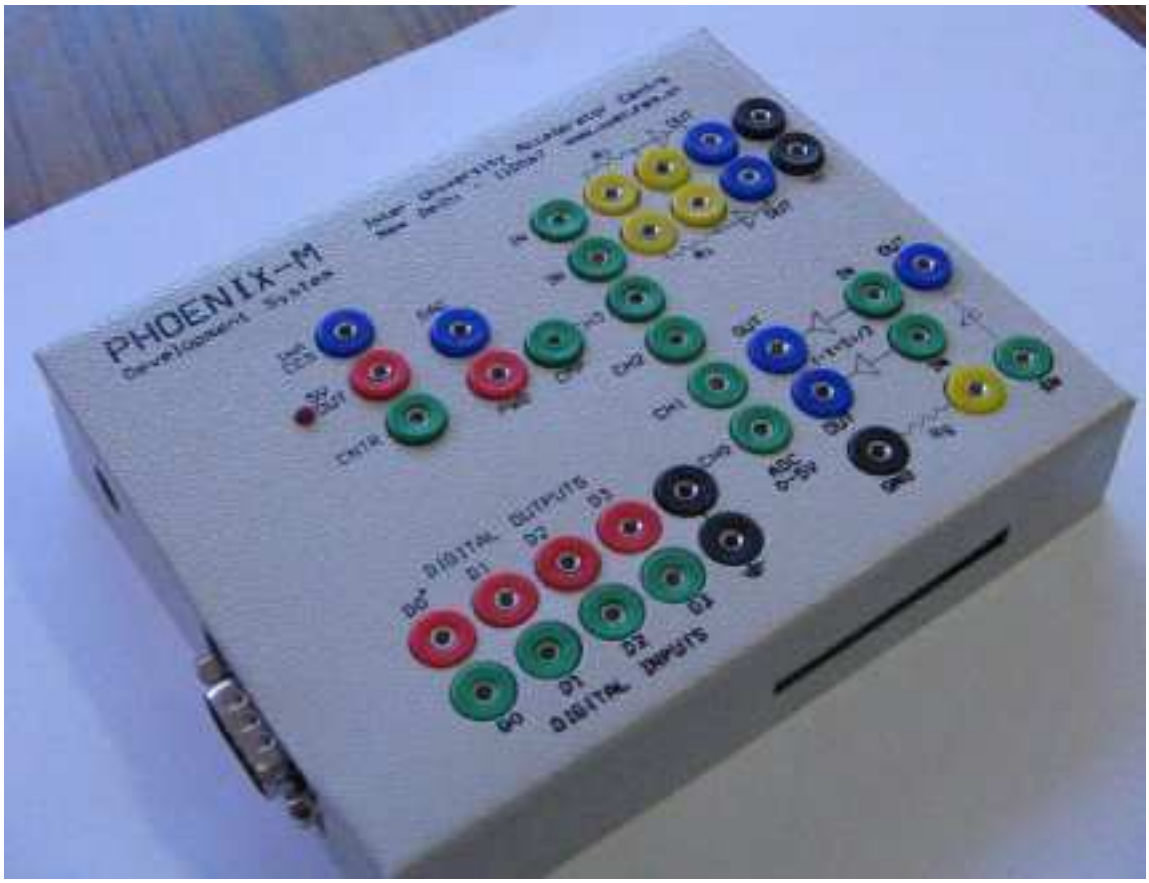


Figure 2.1: The Phoenix-M box

3. Digital inputs - four GREEN sockets at the lower left corner. It might sometimes be necessary to connect analog outputs swinging between -5V to +5V to the digital inputs. In this case, you MUST use a 1K resistor in series between your analog output and the digital input pin.

4. ADC inputs - four GREEN sockets marked CH0 to CH3

5. PWG - Programmable Waveform Generator

6. DAC - 8 bit Digital to Analog Converter output

7. CMP - Analog Comparator negative input, the positive input is tied to the internal 1.23 V reference.

8. CNTR - Digital frequency counter (only for 0 to 5V pulses)

9. 1 mA CCS - Constant Current Source, BLUE Socket, mainly for Resistance Temperature Detectors, RTD.

10. Two variable gain inverting amplifiers, GREEN sockets marked IN and BLUE sockets marked OUT with YELLOW sockets in between to insert resistors. The amplifiers are built using TL084 Op-Amps and have a certain offset which has to be measured by grounding the input and accounted for when making precise measurements.

11. One variable gain non-inverting amplifier. This is located on the bottom right corner of the front panel. The gain can be programmed by connecting appropriate resistors from the Yellow socket to ground.

12. Two offset amplifiers to convert -5V to +5V signals to 0 to 5V signals. This is required since our ADC can only take 0 to 5V input range. For digitizing signals swinging between -5V to +5V we need to convert them first to 0 to 5V range. Input is GREEN and output is BLUE.

To reduce the chances of feeding signals to output sockets by mistake the following Color Convention is used

- GREEN - Inputs, digital or analog

- RED - Digital Outputs and the 5V regulated DC output
- BLUE - Analog Outputs
- YELLOW - Gain selection resistors
- BLACK - Ground connections

2.2 Things to be careful about when using Phoenix

1. The digital output pins can drive only 5mA. Don't connect any load less than 1K Ohm to them.
2. Digital output D0 is transistor buffered and can provide 100 mA. Don't use it for timing controls.
3. Digital and ADC inputs should not be negative or above 5V, ie. should be from 0 to 5V.
4. Variable gain amplifier outputs should be connected to Digital Inputs only through a One KOhm series resistor.
5. Amplifier inputs should be within -5 to +5V range.
6. Output pins should not be tied together.
7. Do not draw more than 100mA current from the 5V regulated supply. Take necessary protections against back emf when connecting inductive loads like motors or relay coils.
8. Forcibly Inserting Multi Meter probes with diameter more than 2 mm to the front panel sockets will damage them.
9. And, don't pour coffee into the sockets !

2.3 Installing Software for PC interfacing

There is no need to install any software if you plan to use Phoenix-M by booting from the Live CD. Otherwise on a GNU/Linux distribution you need to install the pyserial module and the *phm.py* module. To install pyserial , unzip the file $pyserial - 2.2.zip$, located inside the directory $Phoenix - M/Linux$ on the CD, into a directory and run the following commands from that directory.

```
#python setup.py build
#python setup.py install
```

To install the phoenix-M library just copy the file phm.py to directory named $site - packages$ inside the python directory. [1]

On MSWindows install the files inside the directory *MSwin* on the CD, by clicking on them, and copy phm.py to the directory named *lib* inside the python directory (python24 inside the root directory of C: drive) .

2.3.1 Software for programming ATmega16

Again there is no need to install any software if you are working from the live CD. Otherwise you need to install the AVR GCC compiler and other development tools. On GNU/Linux systems that supports installing 'rpm' files , goto the Linux/RPM directory on the CD and run the install script by typing,

```
#sh install.sh
```

This will install all the necessary tools for software development on AVR micro-controllers including ATmega16. On MS-Windows run the self extracting archive $WinAVRGCC.exe$ to install the development suite. Example programs are available inside directory *cprogs* on the CD.

[1] On most systems this will be /usr/lib/python2.x, where x is the version number

2.4 Powering Up

Connect the the provided serial cable between the 9 pin D connector on the Phoenix box and COM1 (first serial port) of the PC[2]. Connect the 9V DC adapter to the socket on the Phoenix box and apply power. The power LED near the 5V socket should light up. The easiest way to use Phoenix-M is to boot the PC with the supplied GNU/Linux live CD; you will get a text prompt along with instructions on how to proceed further.

Enter graphics mode by running the commands 'xconf' followed by 'startx'. You can read various documents concerning Phoenix-M and other other educational tools by simply running the browser. Start a command shell and you are ready to get into the fascinating world of Phoenix-M![3]

[2] If COM1 is not available, you can use COM2, but you will have to make a very small change during library initialization

[3] If you using it under MS-Windows install Python Interpreter , Pywin32, Pyserial and Phoenix library modules provided on the CD. Phoenix Library 'phm.py' should be copied to the directory 'Python24\lib' .Start python from the command prompt by typing 'python24\python' at the 'C:\>' prompt.

Chapter 3

Interacting with Phoenix-M

This chapter is a tutorial introduction on accessing Phoenix-M from the PC using the Python Library. The emphasis is on getting familiar with hardware and software features rather than doing actual experiments. Phoenix-M library functions are explained in Appendix D and a brief introduction to the Python programming language is given in Appendix B. It is assumed that Python Interpreter and Phoenix-M library are installed and the equipment is connected to the serial port of the PC.

Start the Python Interpreter from the command prompt. You should see something like the following

```
Python 2.3.4 (#1, Oct 26 2004, 16:42:40)
[GCC 3.4.2 20041017 (Red Hat 3.4.2-6.fc3)] on linux2
Type "help", "copyright", "credits" or "license" for more information.
>>>
```

The first step is to import the phoenix library and create and object of type class 'phm'. This is done by the the following lines of code

```
>>> import phm
>>> p = phm.phm()
```

The variable 'p' is an object of class 'phm' and represents the Phoenix box in software. These two lines must be present in the beginning of all Python

programs accessing Phoenix-M. Let us start by accessing the features of Phoenix-M one by one.

Again we remind you NOT to connect any signals greater than 5 VOLTS to Phoenix-M.

3.1 The Digital Outputs

You should see four sockets labeled D0 to D3 in a section marked 'Digital Outputs'. It's possible to make these pins go high and low under program control.

Invoke the Python interpreter and enter the following lines:

```
>>> p.write_outputs(0)
```

Connect an LED and a 1K Ohm resistor in series between digital output pin D3 and ground[1] (any one of the Black sockets) - make sure that the longer leg (the anode) of the LED is connected to D3. You will see that the LED is OFF. Now, type the following line:

```
>>> p.write_outputs(8)
```

You will see that the LED has lighted up! Want to put it off? Type:

```
>>> p.write_outputs(0)
```

again! What is happening here?

```
>>>p.write_outputs(8)
```

we are asking the Phoenix box to write the number 8 to the digital output lines. Now, what does that really mean?

The number 15 can be expressed as 1000 in binary - let's call the rightmost bit 'bit0' or the least significant bit and the leftmost bit 'bit3' or the most

[1] A single strand wire with a bit of insulation stripped off its end and bent into a thin hook can be conveniently inserted into the Phoenix connectors. The LED and resistor can be placed on a breadboard.

significant bit. The value of these bits have a relation to the voltages on digital output pins D0 to D3. If bit0 is 1, the voltage on D0 will be +5V and if it is 0, the voltage would be 0V. Thus, when we write 8, bit3 is 1 and the output on pin D3 will be high[2].

If you are new to binary arithmetic, make sure that you understand this clearly[3].

Exercises

1. With a multimeter (or LED's), verify which all pins are high/low when you execute p.write_outputs(10). Is D0 different ?

2. How would you call p.write_outputs() if you want D0 and D3 to be high and all other pins low?

3.1.1 Blinking LED

It's time to make the LED blink! Type the following code at the Python prompt:

```
>>> import time
>>> while 1:
        p.write_outputs(1)
        time.sleep(1)
        p.write_outputs(0)
        time.sleep(1)
...
>>>
```

The logic is easy to understand - writing a '1' results in digital output pin D0 going high; we then delay execution for one second by calling the 'sleep'

[2]The socket marked D0* is buffered using a transistor and can be used for driving 5V relay coils. This output works well only with some load connected to ground. The HIGH level voltage of D0 is slightly less than 5V due to the transistor.

[3]This is *absolutely* important - unless you understand this idea properly, you will not be able to do anything with the Phoenix box

routine - the LED stays high during this period. We then make it go low by writing a '0' and again sleeps for 1 second. The whole process gets repeated infinitely. Press Ctrl-C to come out of the loop.

3.1.1.1 Exercise

Connect an LED each (in series with a 1KOhm resistor) between digital output pins D0, D1, D2, D3 and ground. Write a Python program to make these LED's light up (and go off) sequentially.

3.2 Digital Inputs

The Phoenix box is equipped with four digital input pins labeled D0, D1, D2, D3 (look at the section of the panel marked 'DIGITAL INPUTS'). Execute the following Python code segment and repeat it after connecting a wire from D3 (GREEN socket) to Ground.

```
>>> p.read_inputs()
15
>>>p.read_inputs()
7
```

How do we interpret the results. If we express 15 and 7 in binary forms, we get the bit patterns:

1111 and 0111

According to our convention, we call the rightmost bit 'bit0' and the leftmost bit, 'bit3'. If 'bit3' is 1, it means that the voltage on digital input pin D3 is HIGH[4], ie +5V and if it is 0, it means that the voltage on D3 is LOW, ie, 0V. Similar is the case with all the other bits. All bits are internally pulled up to 5V and we got the 15 , when D3 is grounded we got 7.

Another experiment. Connect digital output pins D3 to the digital input pins D3. Execute the following code fragment:

[4]We will follow this *HIGH means +5V and LOW means 0V* convention throughout this document.

```
>>> p.write_outputs(0)
>>> p.read_inputs()
7
>>> p.write_outputs(8)
>>> p.read_inputs()
15
```

It's easy to justify the results which we are getting!

The digital inputs are versatile - We will come to the time measurements with microsecond accuracy using them.

3.3 Waveform Generation and Frequency Counting

Identify the socket marked 'PWG' (Programmable Waveform Generator) on the Phoenix box. Now execute the following command at the Python prompt:

```
>>> p.set_frequency(1000)
1000
>>>
```

This results in a 1000Hz (0 to 5V) square waveform being generated on PWG[5]. If you have a CRO, you can observe the waveform on it. An easier way is to simply connect the PWG socket to a socket marked 'CNTR' - the Phoenix box has a built-in frequency counter which can measure frequencies upto 1 MHz. Measuring frequency is simple - once the signal is connected to the CNTR socket, execute the following Python function:

```
>>> p.measure_frequency()
1000
>>>
```

[5]It is possible to set frequencies from 15Hz to 4MHz - but it need not always set the exact frequency which you have specified, only something close to it. The actual frequency set is returned by the function.

In this case, we are getting 1000, which is the frequency of the waveform on the PWG socket. If you have a 0 to 5V range Square wave you can measure its frequency using this call. You can measure the frequency of an external oscillator signal by connecting it to the CNTR input , provided it is a 0 to 5V signal. Measuring frequency using the Digital input sockets and Analog Comparator Socket will be discussed later.

3.4 Digital to Analog converter (DAC)

An analog output voltage ranging from 0 to +5V can be programmed to the socket marked PVS, Programmable Voltage Source. Execute the following lines of code and measure the output with a multimeter after each step.

```
>>>p.set_dac(0)
>>>p.set_dac(128)
>>>p.set_dac(255)
```

The output can be varied from 0 to 5V in 256 steps. When using this function, you need to calculate the number to be used for a given voltage. This can be avoided by using

```
>>>p.set_voltage(2000)
```

The output should now measure near 2000 millivolts. Remember that you can set the voltage in steps of nearly 20 mV only since 5000 mV range is covered in 256 steps.

The DAC on the Phoenix box is made by filtering the Pulse Width Modulated signal from the Programmable Waveform Generator, PWG. Due to this one can't use both PWG and DAC at the same time. If you call 'set_dac()' while a waveform is being generated on the PWG, it's frequency will change. Similarly, if you call 'set_frequency()' after fixing a specific voltage level on the DAC, the voltage will change.

3.5 Analog to Digital converter

3.5.1 Introduction

Analog to Digital converters are a critical part of computerized measurement and control systems. Let's say we wish to measure temperature - a sensor like the LM35 converts temperature in degree Celsius to voltage in milli volts at a rate of 10mV per degree Celsius. Thus, if room temperature is 27 degree Celsius, the sensor output would be 270mV. An ADC helps us convert this voltage into a numerical quantity. Let's see how.

Say the minimum voltage we would like to measure is 0V and maximum is 5000mV (ie, 5V). Let's divide this 0 - 5000 range into 256 discrete steps, each step of 'size' 19.53 (ie, 5000.0/256). The zeroth step is from 0 to 19.53, the first step from 19.53 to 39.06 and so on ... If we have a device which accepts as input a voltage in the range 0 to 5000mV and returns the number of the step to which the input belongs to, our objective of converting the analog input to digital is achieved! An 8 bit (8 bits give you 256 different numbers from 0 to 255) ADC does exactly this. We call the number '8' the 'resolution' of the ADC.

We note that there is a certain amount of inaccuracy in the conversion process - an 8 bit ADC will resolve all voltages in a certain 'step' to one particular step number - thus, you will not be able to differentiate whether your input was exactly 0mV, or 1mV or 2mV or 19.53mV - all these inputs simply map to step zero.

A 10 bit ADC can do a better job - as 10 bits can hold numbers from 0 to 1023 (1024 combinations), a 0 to 5000mV range can be broken down into steps of size 5mV each.

Analog inputs are one of the important features of Phoenix-M. There are four channels of Analog inputs that can digitize a voltage between 0 to 5V. Feeding a voltage outside these limits may damage the micro-controller. The Analog to Digital Converter resolution can set by the user (default is 8 bit). The speed of the ADC (the time it takes to convert an analog input to digital) also can be set within certain limits. To explore the ADCs, connect the DAC

output to channel zero of the ADC and issue the following commands

```
>>>p.set_dac(200)
>>>p.select_adc(0)
>>> print p.read_adc()
(1148439372.3935859, 199)
```

The select_adc() function is used for selecting the channel to which we have connected the input. The read_adc() call returned two values instead of one. The first is the system time stamp from the PC (we are not concerned with it at present) and the second is the output of the ADC received from Phoenix-M. The value is not 200 but 199, this is mainly due to the limitations of the DAC. The above exercise can be done more conveniently by the following functions.

```
>>> p.set_voltage(4000)
>>> m = p.zero_to_5000()
>>> print m
(1148440112.655, 4019.6078431372548)
>>> print m[1]
4019.6078431372548
```

The zero_to_5000() function converts the ADC output into milli volts, the first number in the output is again the time stamp from PC.

The maximum resolution of the ADC output is 10 bits but it can be reduced to 8 bits for faster data transfer. The conversion time of the ADC also can be set by the user by calling 'p.set_adc_delay'. When set to 10 bit resolution the conversion time should be set to larger than 200 microseconds. If we wish to measure static (or slowly changing) parameters like temperature accurately, we better use 10 bit resolution and a conversion delay of over 200 micro seconds. If the objective is to visualize (plot a graph of) a fast varying signal, it is better to use 8 bit resolution and a conversion delay of 10 micro seconds.

We will do one or two experiments to have a better idea of how things work. First, connect digital output D3 to ADC channel 0 and execute:

```
>>> p.write_outputs(15)
>>> p.set_adc_size(2)
>>> p.set_adc_delay(200)
>>> p.select_adc(0)
>>> p.read_adc()
1023
>>>p.zero_to_5000()
(1148537333.2460589, 5000.0)
```

The ADC is now working in 10 bit mode (the function call 'p.set_adc_size(2)' does this) - digital output pin is high (close to +5V), ADC range is 0 to 5000mV - so the ADC will output a value close to 1023 (maximum possible 10 bit number). The zero_to_5000() function converts the output of the ADC into voltage from 0 to 5000 mV irrespective of the adc data size (8 ro 10 bits).

```
>>> p.set_adc_size(1)
>>> m = p.read_adc()
>>> print m[1]
255
```

The ADC is now working in 8 bit mode (maximum output is 255) - the range is 0-5000mV and the input is close to 5V - so the output should be close to 255.

3.5.2 Waveform Digitization

In certain applications, you will be required to capture data from one (or more) ADC channel(s) in bulk (say 200 samples) at precisely timed intervals. There are functions available in the Phoenix library to do exactly this.

There are two important block read functions - 'read_block' and 'multi_read_block'. We will examine 'read_block' first. Connect 5V to ADC channel 0 and execute the following code fragment:

```
>>> p.select_adc(0)
```

```
>>> p.set_adc_size(1)
>>> m = p.read_block(100, 50, 0)
>>>print m
```

We are basically asking the Phoenix box to take 100 readings from the ADC ,from the currently selected channel, with an inter-read delay of 50 microseconds. The last argument to read_block will be 1 only when we are analyzing bipolar signals, connected through the (-X+5)/2 gain block. Here are the first few readings which you might expect:

[(0, 4941.1764705882351), (50, 4980.3921568627447),
(100, 4941.1764705882351), (150, 4980.3921568627447), (200, 4960.7843137254904)]

Each item of the list is a two-element tuple. The first element of the tuple is the time in microseconds at which the reading was taken by the Microcontroller's ADC and the second element is the voltage (in mV) read. The very first reading has a time-stamp of 0 and subsequent readings have a difference of 50 microseconds between them - this value has been specified by us as the second argument to read_block.

Now you can try another experiment. Connect the PWG to channel 0 of the ADC and execute the following code segment:

```
>>> p.set_frequency(1000)
>>> m = p.read_block(100, 50, 0)
>>> p.plot(m)
```

Figure 3.1 is the plot you would get:

Let's now play with the 'multi_read_block' function. The function reads analog data from multiple channels (remember, the Phoenix ADC has 4 channels) and returns them as a list of the form:

[[ts1, adval0, ... advaln], [ts2, adval0, ... advaln], ...]

where adval0 is value read from channel 0, adval1 is data read from channel 1 and so on. Let's try an experiment. Connect channel 0 of the ADC to GND and Channel 1 to +5V. Now, execute the following code segment:

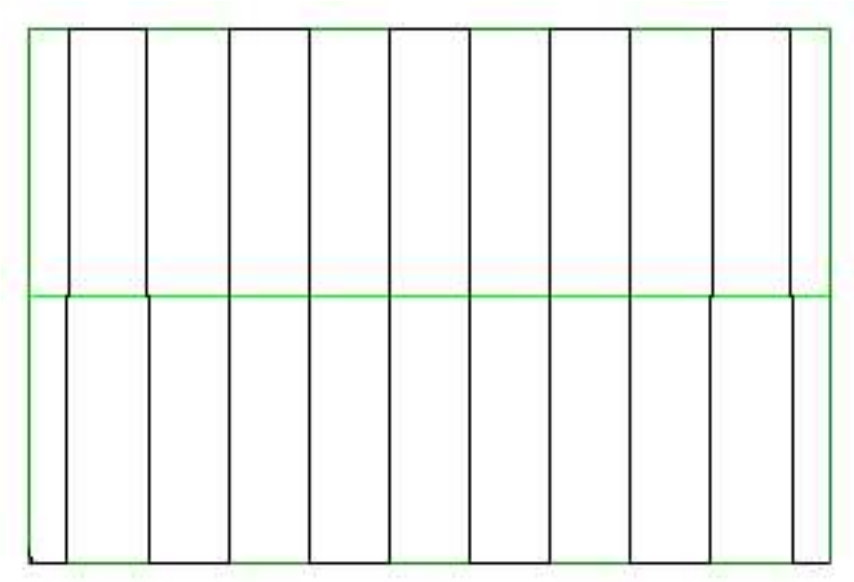


Figure 3.1: Square wave digitized by ADC

```
>>> p.add_channel(1)
>>> m = p.multi_read_block(100, 50, 0)
>>> print m
```

Here are the first few readings:

[[0, 19.607843137254903, 4960.7843137254904], [50, 0.0, 4980.3921568627447], [100, 0.0, 4980.3921568627447], [150, 0.0, 4980.3921568627447], [200, 0.0, 4960.7843137254904]]

Note the time-stamp values increasing in steps of 50 micro seconds while channel 0 and channel 1 values stay close to 0V and 5V.

How does the multi_read_block function know what all channels have to be digitized? Code running on the Phoenix box maintains a channel list which will by default have only channel 0. You can add channels to the list by calling 'add_channel 'and remove channels from the list by calling 'del_channel'. Whenever a multi_read_block is invoked, this channel list is consulted and analog values on all the channels in the list are digitized. As an experiment, try deleting one channel from the list and re-issuing the 'multi_read_block' call.

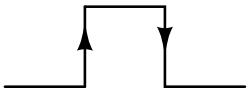


Figure 3.2: Rising-to-falling edge delay

The *multi_ read_ block* function examines only the channel list - it does not care which channel has been set by calling *select_ adc().* The channel list is maintained internal to the memory of the micro-controller which controls the Phoenix box - if an application adds a channel to the list, a call to *multi_ read_ block()* later from another application will result in that channel also getting digitized. Programs like CROs must remove all channels from the list while starting and then add the required ones.

3.6 Time Measurement Functions

The Phoenix library includes several functions which can be invoked to measure time periods. Most of these functions basically measure time delays between rising/falling edges on the various Digital Input pins or Analog Comparator Input. Say you wish to compute the on time of a square wave applied to digital input pin D0 (see figure 3.2); you can simply connect the PWG socket to D0 and execute:

```
>>> p.set_frequency(1000)
>>> p.r2ftime(0, 0)
500
```

The function accepts two digital input pin numbers (which can be the same or different) and returns the time in microseconds between two consecutive rising and falling edges.

Similarly we can measure the falling edge to rising edge time also using the 'p.f2rtime(0,0) call. From which we can calculate the period of the wave and the duty cycle. The arguments can be different. For example you can measure the time between a rising edge on one Input to a rising edge on another Input.

Digital Inputs are specified by argument values from 0 to 3. If the Input is connected to the Analog Comparator use the argument value '4' as shown below.

```
>>> p.r2ftime(4, 4)
500
```

Time measurement capability is important for many experiments. Direct measurement of the velocity of sound, period of a pendulum etc. will be done using this feature. For measuring the time period of a signal applied to an Input we can use the function 'p.multi_r2rtime(pin, skipcycles)'. The skip cycles mentions the number of cycles to be skipped in between. If it is zero, you get the period of the wave. Higher number can be used to get the effect of averaging. The result of measuring a 1 KHz signal connected to 'Input 0', the result is the time taken for 10 cycles.

```
>>> p.multi_r2rtime(0,9)
10000
```

You will find more information regarding these functions in the API reference.

3.7 Non-programmable units

We have had a brief tour of all the programmable features which the Phoenix box provides. There are a few functional units within the Phoenix box which can't be manipulated by code; understanding how these units work is essential for doing practical experiments with Phoenix. In the next part of this document, we shall look at these non-programmable units.

3.7.1 Converting bipolar signals to unipolar

The ADC channels accept only unipolar signals (0-5V); the Phoenix box comes with two amplifiers which take a bipolar -5V to +5V signal and raises it to 0 - 5V. Search around the front panel for a section which looks like what is shown in Figure 3.3

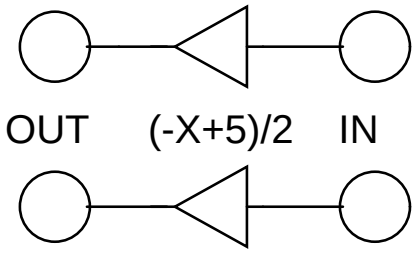


Figure 3.3: Offset amplifier

If the input voltage is X, output is (-X + 5)/2. Test this out by applying 0V and 5V at one of the inputs and measuring the voltage at the corresponding output using a multimeter.

Exercise Test the offset amplifier with an input of -5V. You can use the inverting Op-Amps described in the next section to generate -5V.

3.7.2 Inverting Op-Amps with externally controllable gain[6]

In many practical applications, it would be necessary for us to take a very weak signal (say a few millivolts) and convert it into a 'stronger' one which can be processed by the ADC, Analog comparator or digital inputs. We will have to amplify the signal hundreds of times. The Phoenix box provides two inverting amplifiers (Figure **??**) whose gain (ie, amplification factor) can be set by connecting an external resistor of appropriate value[7]. The value of the resistor is found using the formula:

$$Gain = 10K\Omega/Ri$$

[6] The operational amplifiers used for implemeting them require both positive and negative supply voltages. Phoenix-M generates them by using a charge pump IC that gives output from +/- 6V to +/-7V range. Due to this reason amplifiers in some units may saturate at around 4.5 V. You can test this by giving the +5V supply to the inverting amplifier and check the output using a multimeter (insert a 10K gain resistor for unity gain).

[7] The amplifiers can also be used for implementing summing junctions and other inverting op-amp circuits.

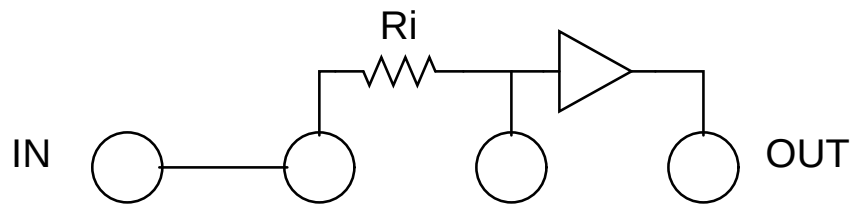


Figure 3.4: Inverting Amplifier

So, if you want a gain of 10, you will choose a resistor of value Ri = 1K (note that resistor values are never exact - a 1K resistor will be never exactly 1K - so don't expect to get a gain of precisely 10). Connect the resistor between the two YELLOW sockets, apply input to the GREEN socket marked 'IN' and take output from the BLUE socket marked OUT. Make sure that you don't choose a gain greater than 40. You can take the output of one amplifier and feed it into the input of another one if you want larger amplification.

The units are implemented by TL084 op-amps and will have some 'offset' - that is, there will be some voltage at the output even when the input is zero. To measure this, ground the input, supply a gain resistor of 10K Ohm and measure the output. You should see a value in the range of 1-2 mV. Try with a gain resistance value of 1KOhm and you will note that it is in the range of 10-20 mV. You should take this effect in consideration when you are doing precise measurements.

3.7.3 Non-Inverting variable gain Amplifier

There is one Non-Inverting amplifier whose gain can be controlled by a plug-gin resistor Rg connected between the Yellow socket and ground. The Internal feed back resistor is 10 KOhm and the gain will be 1 + 10000/Rg. This unit is useful for amplifying the RTD type temperature sensor outputs.

3.7.4 The Constant Current Source Module

Phoenix box has a socket labeled 'CCS' - it's a 1mA constant current source. Connect a 1K resistor between the CCS and ground and measure the voltage across the resistor - it will be 1V. The current through a circuit should vary

as you change the value of the resistance, but a CCS will maintain a constant flow (in this case, 1 milli ampere). Try to verify this behavior!

The CCS module is useful when measuring temperature using thermistors.

3.8 Plug-in Modules

There is a 16 pin connector on the front side of Phoenix-M. It is meant for plugging in the LCD display and other additional circuitry as explained below.

3.8.1 16 character LCD display

3.8.2 High resolution AD/DA card

3.8.3 Radiation detection system

3.9 Other Accessories

For doing experiments using Phoenix we require different kinds of sensors. Sensors for measuring temperature, pressure etc. are commercially available. Most of them provide a low level voltage output proportional to the measured parameter. This can be fed to one of the ADC inputs after amplification. The gain decided in such a way that the maximum output from the sensor is amplified to the upper limit of the ADC input. For example, if we plan to measure temperature up to 100^0celcius and the sensor output is 100 mV at that temperature the gain is selected is 50, to get a maximum 5V at the ADC input. This is required to utilize the ADC to its maximum resolution. There are several other sensors and accessories that we can make using available components.

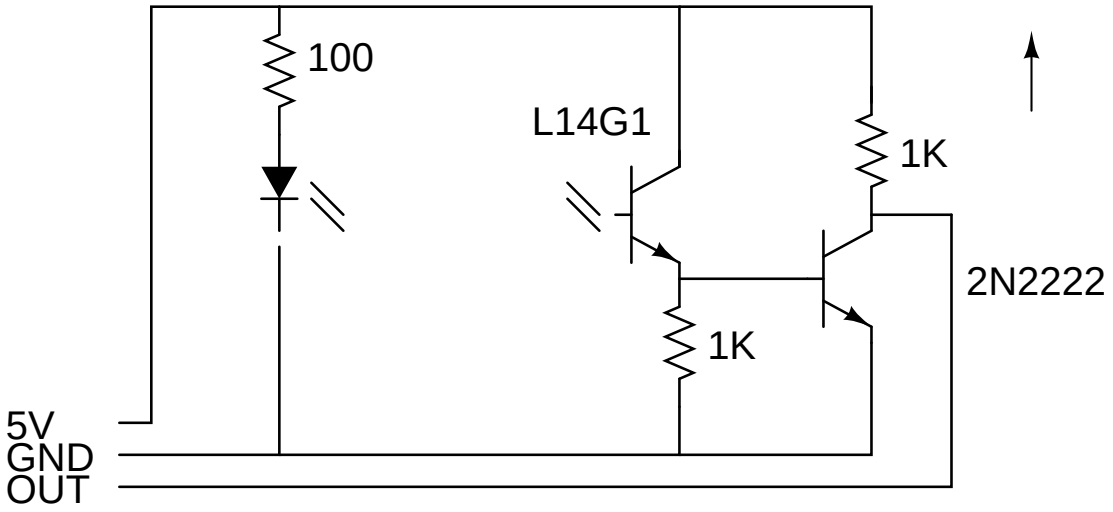


Figure 3.5: Light barrier circuit

3.9.1 Light barrier

The light barrier is a U shaped structure with a photo-transistor and a Light Emitting Diode facing each other with a gap of 2 cm in between, as shown in figure 3.5 . There are three connections to the module, Ground, 5V supply and the signal output. The output of the module is generally LOW and goes high when the light emitted by the LED is prevented from reaching the photo-transistor. By connecting this to Phoenix Digital Input sockets one can measure time intervals.

3.9.2 Rod Pendulum

3.9.3 Pendulum motion digitizer using DC motor

3.9.4 Temperature Sensors

Chapter 4

Experiments

Phoenix-M is a computer interface with some added features. Several experiments on electricity and electronics can be done without much extra accessories. Science experiments require sensor elements that converts physical parameters into electrical signals. The number of science experiments one can do with Phoenix-M is limited mainly by the availability of sensor elements. Here we describe several experiments that can be done using some sensor elements that are easily available. During the tutorial introduction we interacted with Phoenix-M by typing commands at Python prompt. Typing them in a file using a text editor and executing under python makes correcting errors much easier. Here we will follow that approach and all the programs listed below are available on the Phoenix CD.

4.1 A sine wave for free - Power line pickup

There are two types of electric power available ,generally known as AC and DC power. The Direct Current or DC flows in the same direction and is generally made available from battery cells. The electricity coming to our houses is Alternating Current or AC, which changes the direction of flow continuously. What is the nature of this direction change. The frequency of AC power available in India is 50 Hz. Let us explore this using Phoenix-M and a piece of wire. A frequency of 50 Hz means the period of the wave

is 20 milliseconds. If we capture the signal for 100 milliseconds there will be 5 cycles during that time interval. Let us digitize 200 samples at 500 microsecond intervals and analyze it.

Connect one and of a 25 cm wire to the Ch0 input of the ADC and let the other end float. The 50 Hz signals picked up by the ADC can be displayed as a function of time by the *read_ block()* and *plot_ data()* functions. With few lines of code you are making a simple CRO !

Type in the following program in a text editor [1] and save it as a file named say 'pickup.py'.

```
import phm
p = phm.phm()
p.select_adc(0)
while p.read_inputs() == 15:
    v = p.read_block(200, 500,1)
    p.plot_data(v)
p.save_data(v, 'pickup.dat')
```

Run the program (by typing 'python pickup.py' at the Operating System command prompt) after plugging one end of 25 cm wire to Ch0 of the ADC. Make sure that none of the digital input pins are grounded. You should see a waveform similar to that of figure 4.1. Adjust the position of the wire or touch the floating end with your hand to see the changes in the waveform.

How do you terminate the program? The 'while' loop is continuously reading from the digital inputs and checking whether the value is 15 - if none of the sockets D0 to D3 are grounded, the value returned by read_inputs() will definitely be 15 and the loop body will execute. If you ground one of the digital inputs, the value returned by read_inputs will be something other than 15; this will result in the loop terminating. Terminate the program when a good trace is on the screen, last sample collected is saved to the disk file 'pickup.dat' just before exiting.

[1] if you are not familiar with standard GNU/Linux editors like vi or emacs, you can use 'Nedit', which is available from the start menu of the Live-CD. Notepad under MSWindows

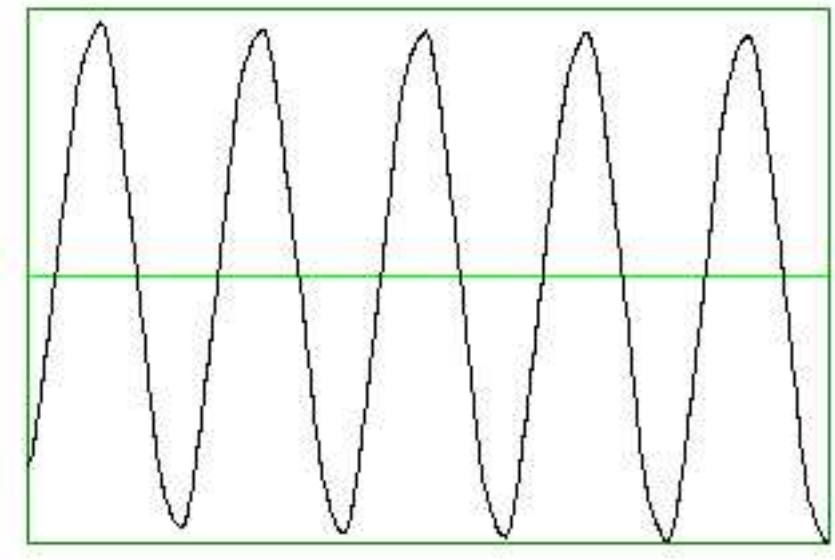


Figure 4.1: Power line Pickup

4.1.1 Mathematical analysis of the data

By counting the number of waves within a given time interval one can roughly figure out the frequency of the line pickup but it won't be accurate and don't tell us much about the nature of the wave. Let us approach the problem in a more systematic manner. We have measured the value of the voltage at 200 different instances of time and want to find out the function that governs the time dependency of the voltage. Problems of this class are solved by fitting the experimental data with some mathematical formula provided by the theory governing the physical phenomena under investigation. Curve fitting is a method of comparing experimental results with a theoretical model.

Here the theoretical value of voltage as a function of time is given by a sinusoidal wave represented by the equation $V = V_0 \sin 2\pi f$, where V_0 is the amplitude and f is the frequency. The experimental data can be 'fitted' using this equation to extract these parameters. We use the two dimensional plotting package *xmgrace* [2] for plotting a fitting the data. Xmgrace is free software and included on the CD along with user manual and a tutorial. Xmgrace is started from the command prompt with file 'pickup.dat' , saved

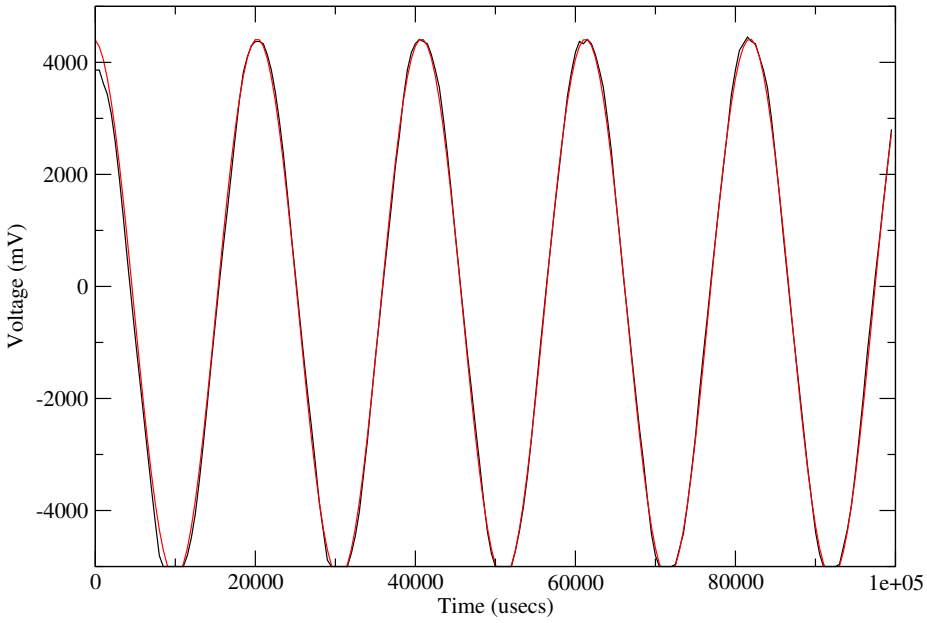


Figure 4.2: Power line pickup and its sine wave fit

by the python program, as the argument.

```
# xmgrace pickup.dat
```

Select $Data- > Transformation- > NonLinearCurveFitting$ from the main menu and enter the equation $V(t)$= V_0 $\sin(2\pi ft/1000000.0 + \theta) + C$. Xmgrace accepts the adjustable parameters as A0, A1 etc.

- $V(t)$ is the value of voltage at time = t
- $V_0$is the amplitude. The value will be close to 5000 milli volts (represented by parameter A0)
- f is the frequency of the wave (parameter A1)
- t is the value of time, divided by 1000000 to convert micro seconds to seconds
- $\theta$is the phase offset since we are not starting the digitization at zero crossing (parameter A2)

- C is the amplitude offset that may be present (parameter A4)

Reasonable starting values should be given by the user for V_0 and f to guide the fitting algorithm. Try different values until you get a good fit. The figure 4.2 shows the data plotted along with the fitted curve. The Curve fitting window 4.3 shows the parameter values.

The extracted value of frequency is 48.73 Hz ! Did not believe it and cross checked it by feeding a 50 Hz sine wave from a precision function generator to the ADC input. The result of a similar analysis gave 49.98 Hz. Checked with the power distribution people and confirmed that the line frequency was really below 49 Hz.

Exercise: Repeat the experiment by changing the length of the wire, touching one end by your hand and rising the other hand, moving it near any electrical equipment etc. (do not touch any power line). You can also analyze other wave forms if you have a signal generator.

4.2 Capacitor charging and discharging

Every student learning about electricity knows that a capacitor charges and discharges exponentially but not very many has seen it doing so. Such experiments require fast data acquisition since the entire process is over within milli seconds. Let us explore this phenomena using Phoenix-M. All you need is a capacitor and a resistor.

Refer Figure 4.4 on page 40 for the experimental setup. The RC circuit under study is connected between the Digital output socket D3 and Ground. The voltage across the capacitor is monitored by the ADC channel 0. The voltage on D3 can be set to 0V or 5V under software control. Taking D3 to 5V will make the capacitor charge to 5V through the resistor R and then taking D3 to 0V will cause it to discharge. All we need to do is digitize the voltage across C just after changing the output of D3. Let us study the discharge process first. The python program *cap.py* listed below does the job.

```
import phm, time
```

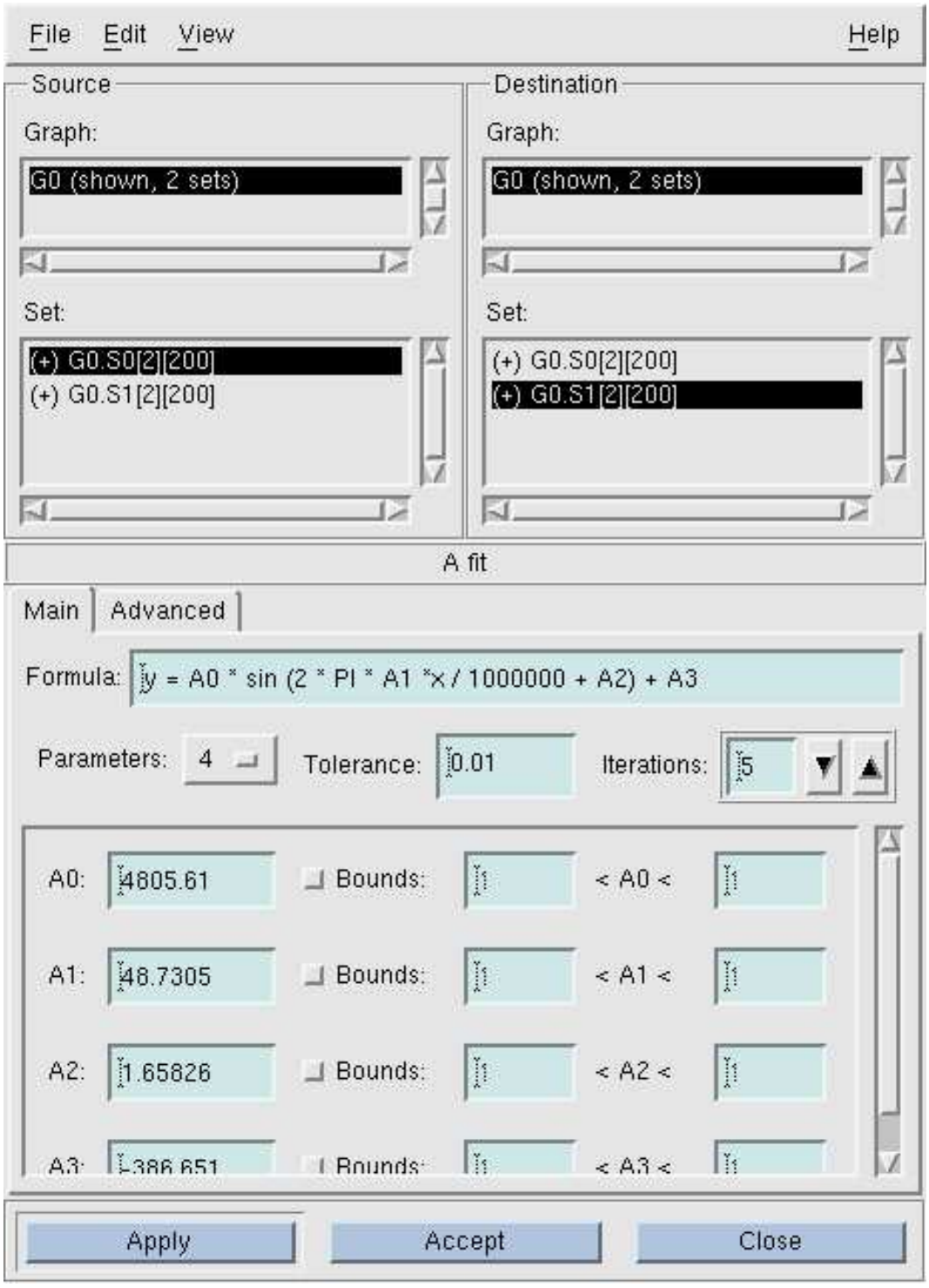


Figure 4.3: Curve fitting window of *xmgrace*

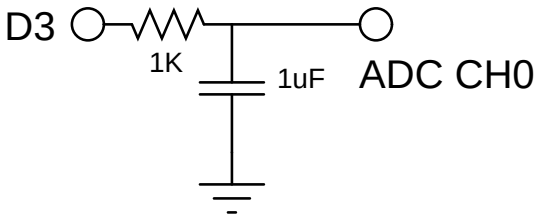


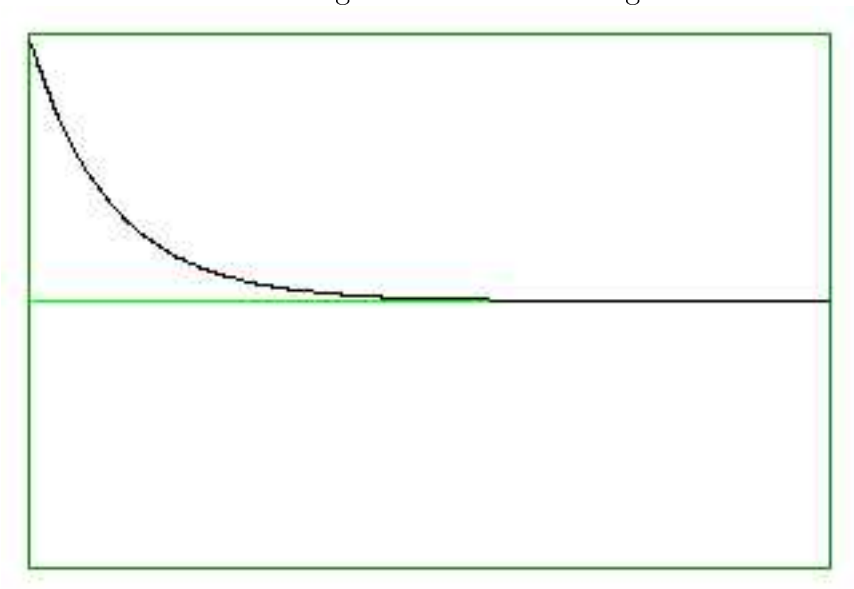
Figure 4.4: Circuit to study Capacitor

```
p = phm.phm()
p.select_adc(0)
p.write_outputs(8)
time.sleep(1)
p.enable_set_low(3)
data = p.read_block(200,50, 0)
p.plot_data(data)
time.sleep(5)
```

We make the digital output pins go high and sleep for 1 second (allowing the capacitor to charge to full 5V). The call to function *p.enable_set_low(3)* is similar to *select_adc()* or *add_channel()* ,whose effect is seen only later, when a read_block or multi_read_block is called. The idea is this - in certain situations, an ADC read should begin immediately after a few digital outputs are set to 1 or 0 - so we can combine the two together and ask the ADC read functions themselves to do the 'set to LOW or HIGH' and then start reading. In this case, it brings to logic LOW pin D3, thereby starting the capacitor discharge process. The function then starts reading the voltage across the capacitor applied on ADC channel 0 at 250 microsecond intervals[2]. The voltage across the capacitor as a function of time is shown

[2]You may wonder as to why such a seemingly complicated function like enable_set_low is required. We can as well make the digital output pin go high by calling write_outputs and then call read_block. The problem is that all these functions communicate with the Phoenix box using a slow-speed serial cable. For example, the read_block function simply sends a request (which is encoded as a number) over the serial line asking the micro-controller in the Phoenix box to digitize some input and send it back. By the time this request reaches the micro-controller over the serial line, the capacitor would have discharged to a certain extend! So we have to instruct the Phoenix micro-controller in just ONE command to set a pin LOW and then start the digitization process.

Figure 4.5: RC Discharge Plot



in Figure 4.5, which looks like an exponential function. When the rate of change of something is proportional to its instantaneous value the change is exponential.

Let us examine why it is exponential and what is an exponential function with the help of some elementary relationships.

The discharge of the capacitor results in a current I through the resistor and according to Ohm's law $V = IR$.

Voltage across the capacitor at any instant is proportional to the stored charge at that instant, $V = Q/C$.

These two relations imply $I = \frac{Q}{RC}$ and we current is nothing but the rate of flow of charge, $I = \frac{dQ}{dt}$.

Solving the differential equation $\frac{dQ}{dt} = \frac{Q}{RC}$ results in $Q(t) = Q_0 e^{-\frac{t}{RC}}$ which also implies $V(t) = V_0 e^{-\frac{t}{RC}}$

Exercise: Modify the python program to watch the charging process. Change the code to make D3 LOW by calling p.write_outputs(0) and set it to HIGH just before digitization with p.enable_set_high(3). Extract the RC value by fitting the data using the equation using xmgrace package.

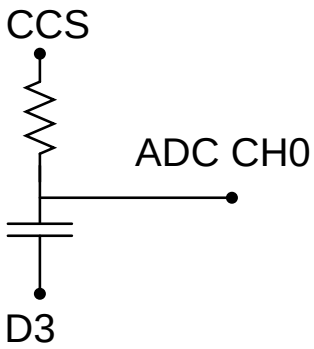


Figure 4.6: Linear Charging of Capacitor

4.2.1 Linear Charging of a Capacitor

Exponential charging and discharging of capacitors are explained in the previous section. If we can keep the current flowing through the resistor constant, the capacitor will charge linearly. Let's wire up the circuit shown in Figure 4.6 When D3 is HIGH no charging occurs. When D0 goes LOW the capacitor starts charging through the 1mA constant current source.

and run the following Python script:

```
import phm, time
p = phm.phm()
p.enable_set_low(3)
p.write_outputs(8)
time.sleep(1)
v = p.multi_read_block(400, 20, 0)
p.plot_data(v)
time.sleep(5)
```

You will obtain a graph like the one shown in Figure

4.3 IV Characteristics of Diodes

Diode IV characteristic can be obtained easily using the DAC and ADC features. The circuit for this is shown in figure 4.8. Connect one end of a 1

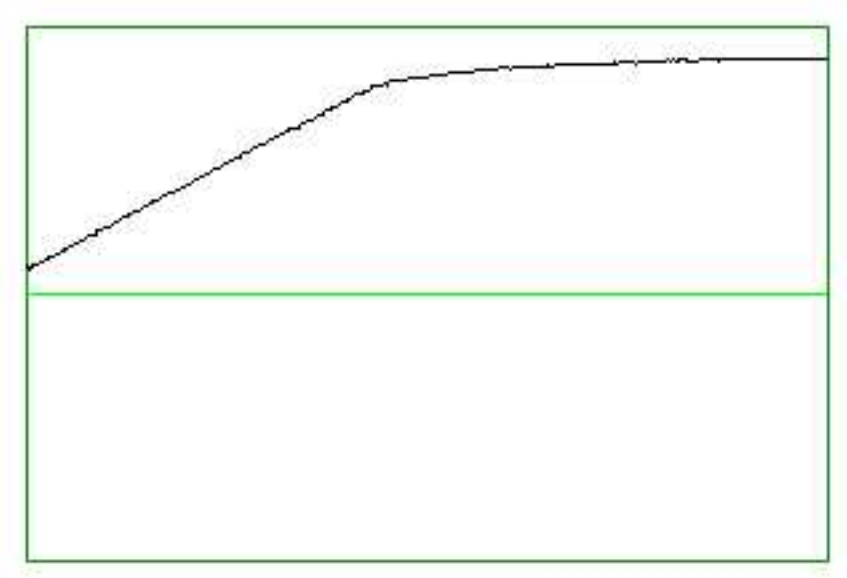


Figure 4.7: Linear charging. R = 1 KOhm , C = 1 uF

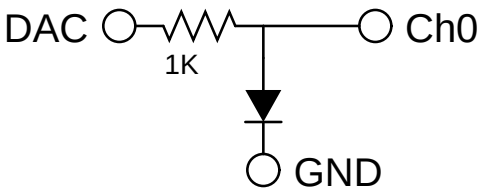


Figure 4.8: Circuit for Diode IV Characteristic

KOhm resistor to the DAC output. The other end is connected to the ADC Ch0 Input. Positive terminal of the diode also is connected to the ADC Ch0 and negative to ground. The Voltage across the diode is directly measured by the ADC and the current is calculated using Ohm's law since the voltage at both ends of the 1 KOhm resistor is known.

We have tried to study different diodes including Light Emitting Diodes with different wavelengths. The code 'iv.py' is ran for each diode and the output redirected to different files. For example; 'python iv.py > red.dat' after connecting the RED LED. The code 'iv.py' is listed below.

```
import phm, time
p=phm.phm()
```

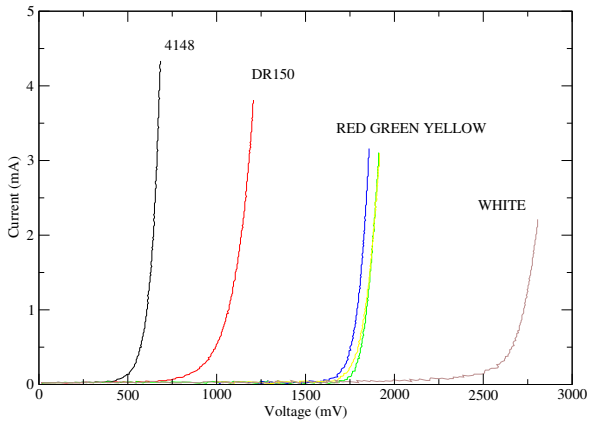


Figure 4.9: Diode Characteristics

```
p.set_adc_size(2)
p.set_adc_delay(200)
va = 0.0
while va <= 5000.0:
   p.set_voltage(va)
   time.sleep(0.001)
   vb = p.zero_to_5000()[1]
   va = va + 19.6
   print vb, ' ' , (va-vb)/1000.0
```

The program output is redirected to a file and plotted using the program 'xmgrace', by specifying all the data files as command line arguments. The output is shown in the figure 4.9. Note the difference between different diodes. If the frequency of the LEDs are known it is possible to estimate the value of Plank's constant from these results.

4.4 Mathematical operations using RC circuits

RC circuits can be used for integration and differentiation of waveforms with respect to time. For example a square-wave of a particular frequency can be integrated to a triangular wave using proper RC values. In this experiment,

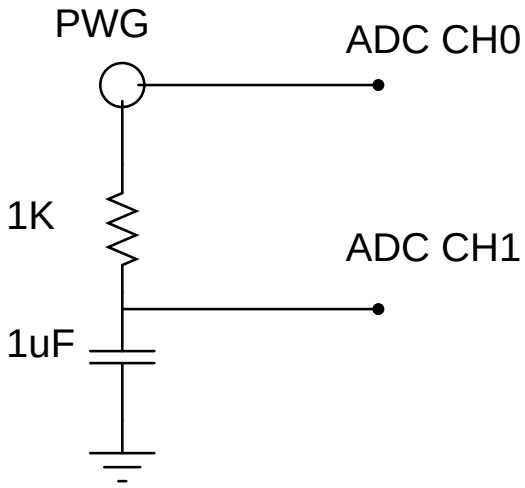


Figure 4.10: Integration circuit

we will apply a square wave (produced by the PWG) to CH0 of the Phoenix ADC. We will apply the same signal to an RC circuit (R=1K, C=1uF) and observe the waveform across the capacitor. The circuit is shown in figure 4.10.We will repeat the experiment for 3 different cases by varying the Period of the square wave to show the different results.

1. RC $\approx$T , Results in a Triangular wave form4.11
2. RC $>>$ T, The result is a DC level with some ripple4.12
3. RC $<<$ T, The sharp edges becomes exponential. 4.13

The code 'sqintegrate.py' which generated these three plots is as follows:

```
"""data was taken with 1K resistor, 1uF capacitor
Three sets are taken:
a) freq=1000 Hz and sampling delay = 10micro seconds, samples=400
b) freq=5000 Hz and sampling delay = 10micro seconds, samples=300
c) freq=100 Hz sampling delay = 20micro seconds, samples=300
"""
import phm
p = phm.phm()
```

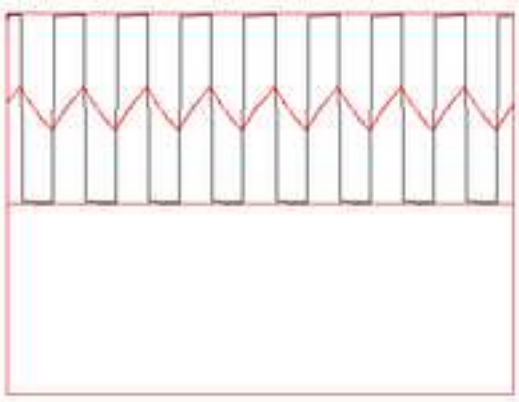


Figure 4.11: RC $>$ T

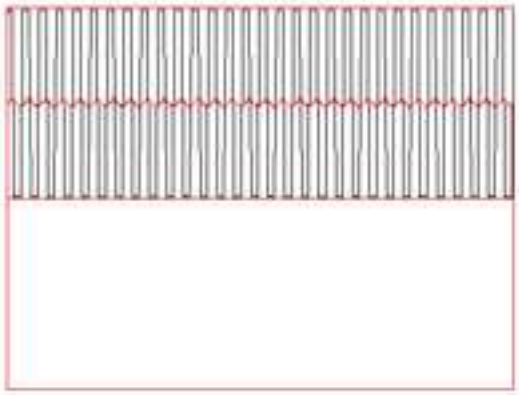


Figure 4.12: RC $>>$ T

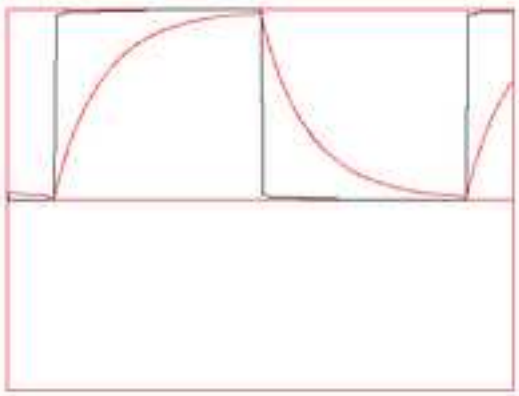


Figure 4.13: RC $<<$ T

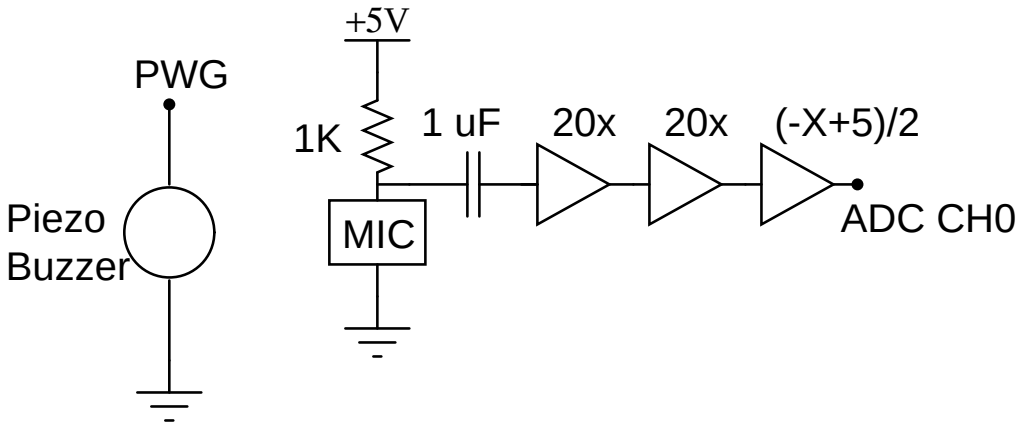


Figure 4.14: Microphone digitizing buzzer sound

```
freq = 1000
samples = 300
delay = 10
p.add_channel(0)
p.add_channel(1)
print p.set_frequency(freq)
while p.read_inputs() == 15:
   p.plot_data(p.multi_read_block(samples, delay, 0 ))
```

Run the code by changing the frequency to study the relation between RC and T

4.5 Digitizing audio signals using a condenser microphone

A condenser microphone is wired as shown in figure 4.14to capture the audio signals. One end of the microphone goes to Vcc through a resistor, the other end is grounded. The output is taken via a capacitor to block the DC used for biasing the microphone. The signal is amplified by two variable gain inverting amplifiers in series with a total gain of 400. The amplified output is level shifted and connected to ADC channel 0. The program 'cro.py' is

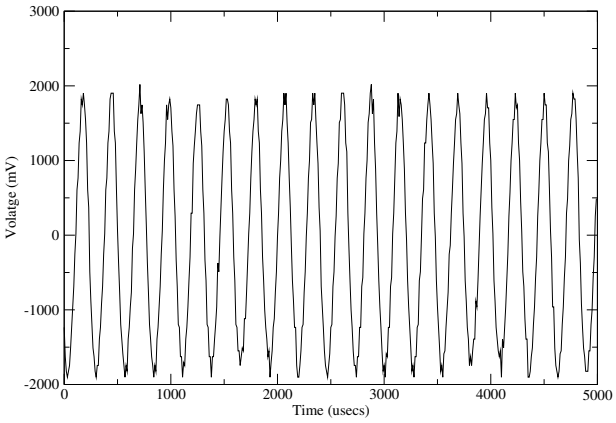


Figure 4.15: Buzzer output digitized

used to capture the waveform and a screen-shot is shown in figure 4.15.

4.5.1 Exercise

The data collected by the program 'cro.py' is in the file 'buzzer.dat' on the CD. Open it in *xmgrace* and do a curve fitting to extract the frequency as described in section 4.1. The frequency can be roughly estimated by looking through the data file for time interval between two zero crossings. Hint:The value is close to 3.7KHz

The technique of taking Fourier Transforms using Python is discussed in an Appendix. Go through it and see whether you can calculate the frequency using that.

4.6 Synchronizing Digitization with External 'Events'

In the previous examples we have seen how to digitize a continuous waveform. We can start the digitization process at any time and get the results. This is not the case for transient signals. We have to synchronize the digitization process with the process that generates the signal. For example, the signal induced in a coil if you drop a magnet into it. Phoenix-M does this by making the 'read_block()' and 'multi_read_block()' calls to wait on a transition on the Digital Inputs or Analog Comparator Input.

Connect the condenser microphone as shown in figure. Configure the two inverting amplifiers to give a gain of 20 and 10. (first plug-in resistor is 500 Ohm and second one is 1 KOhm). The output of the second inverting amplifier is given to Digital Input D3 through a 1K resistor. The same is given to ADC through the level shifting amplifier.

Make some sound to the microphone. The 'p.enable_rising_wait(3)' will make the read_block() function to wait until D3 goes HIGH. With no input signal the input to D0 will be near 0V, that is taken as LOW. The program 'wcro.py' used is listed below.

```
import phm
p = phm.phm()
p.select_adc(0)
p.enable_rising_wait(3)
while 1:
   v = p.read_block(200,20,1)
   if v != None:
      p.plot_data(v)
```

Exercise: Use a similar setup to study the voltage induced on a coil when a magnet is suddenly dropped into it.

4.7 Temperature Measurements

In certain experiments it is necessary to measure temperature at regular time intervals. This can be done by connecting the output of a temperature sensor to one of the ADC inputs of Phoenix and record the value at regular intervals. There are several sensors available for measuring temperature, like thermocouples, platinum resistance elements and solid state devices like AD590 and LM35. They work on different principles and require different kind of signal processing circuits to convert their output into the 0 to 5V range required by the ADC. We will examine some of the sensors in the following sections.

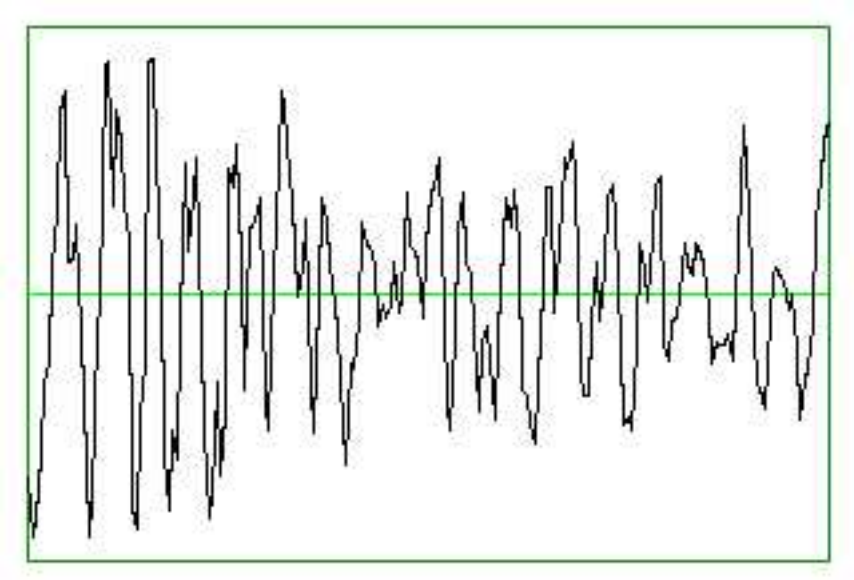


Figure 4.16: Collision sound.microphone

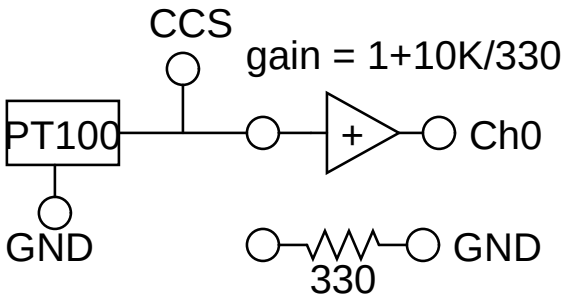


Figure 4.17: PT100 Circuit

4.7.1 Temperature of cooling water using PT100

PT100 is an easily available Resistance Temperature Detector , RTD, that can be used from -200^{0}C to 800^{0}C. It has a resistance of 100 Ohms at zero degree Celsius; the temperature vs resistance charts are available. The circuit for connecting PT100 with Phoenix-M is shown in figure 4.17

The PT100 sensor is connected between the 1mA Constant Current Source and ground. The voltage across PT100 is given by Ohm's law, for example if the resistance is 100Ω the voltage will be 100 * 1 mA = 100 mV. This must be amplified before giving to the ADC. The gain is chosen in such a

way that that amplifier output is close to 5V at the maximum temperature we are planning to measure. In the present experiment we just observe the cooling curve of hot water in a beaker. The maximum temperature is 100^0C and the resistance of PT100 is 138Ωat that point that gives 138 mV across it. We have chosen a gain of roughly 30 to amplify this voltage. The gain is provided by the non-inverting amplifier with a 330Ωresistor from the Yellow socket to ground.

How do we calculate the temperature from the measured voltage ? The resistance is easily obtained by dividing the measured voltage by the gain of the amplifier. To get the temperature from the resistance one need the calibration chart of P100 or use the equation to calculate it.

R_{T}= $\mathrm{R}_0[1 + AT + BT^2 - 100CT^3 + CT^4]$

- R_T = Resistance at temperature T
- $R_0$is the resistance at 0^0Celsius.
- $A = 3.9083 \times 10^{-3}$
- $B = -5.775 \times 10^{-7}$

The first three terms are enough for temperatures above zero degree Celsius and the resulting quadratic equation can be solved for T. The program 'pt100.py' listed below prints the temperature at regular intervals. The output of the program is redirected to a file named 'cooling_pt100.dat' and plotted used xmgrace as shown in figure4.18

```
import phm, math, time
p = phm.phm()
gain = 30.7       # amplifier gain
offset = 0.0      # Amplifier offset, measured with input grounded
ccs_current = 1.0 # CCS output 1 mA
def r2t(r):       # Convert resistance to temperature for PT100
   r0 = 100.0
   A = 3.9083e-3
```

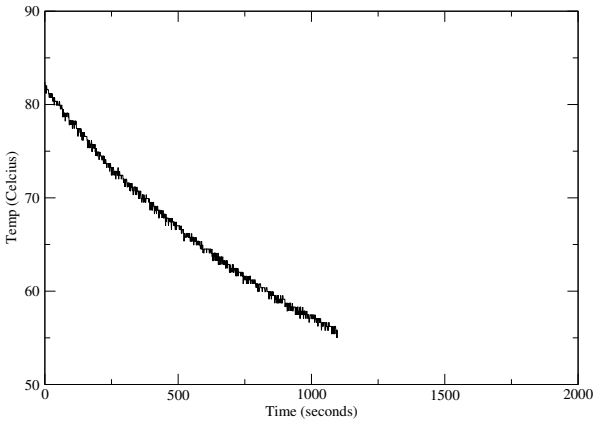


Figure 4.18: PT100. Cooling water temperature

```
    B = -5.7750e-7
    c = 1 - r/r0
    b4ac = math.sqrt( A*A - 4 * B * c)
    t = (-A + b4ac) / (2.0 * B)
    return t
def v2r(v):
  v = (v + offset)/gain
  return v / ccs_current
p.select_adc(0)
p.set_adc_size(2)
p.set_adc_delay(200)
strt = p.zero_to_5000()[0]
for x in range(1000):
    res = p.zero_to_5000()
    r = v2r(res[1])
    temp = r2t(r)
    print '%5.2f %5.2f' %(res[0]-strt, temp)
    time.sleep(1.0)
```

Even though the experiment looks simple there are several errors that need to be eliminated. The CCS is marked as 1 mA but the resistors in the circuit implemented that can have upto 1% error. To find out the actual

current do the following. Take a 100 Ohm resistor and measure its resistance 'R' with a good multimeter. Connect it from CCS to ground and measure the voltage 'V' across it. Now V/R gives you the actual current output from CCS.

For measurements around room temperature the voltage output is under a couple of hundred millivolts. For better precision this need to be amplified to 5V, to utilize the full range of the ADC. A gain of 20 to 30, depends on the upper limit of measurement, can be implemented using the variable gain amplifiers. The offset voltage of the amplifier should be measured by grounding the input and subtracted from the actual readings. The actual gain should also should be calculated by measuring the input and output at a a couple of voltages.

Another method of calibrating the setup is to measure the ADC output at $0^0 and 100^0$ and assume a linear relation, which may not be very accurate, between the ADC output and the temperature.

4.8 Measuring Velocity of sound

The simplest way to measure the velocity of anything is to divide the distance s by time taken. Since phoenix can measure time intervals with microsecond accuracy we can apply the same method to measure the velocity of sound. We will first try to do this with a pair of piezo electric crystals and later by using a microphone.

4.8.1 Piezo transceiver

A piezo electric crystal has mechanical and electrical axes. It deforms along the mechanical axis if a voltage is applied along the electrical axis. If a force is applied along the mechanical axis a voltage is generated along the electrical axis. We are using a commercially available piezo transmitter and receiver pair that has a resonant frequency of 40 KHz. The experimental setup is shown in figure 4.19.

The transmitter piezo is excited by sending a 13 micro seconds wide pulse

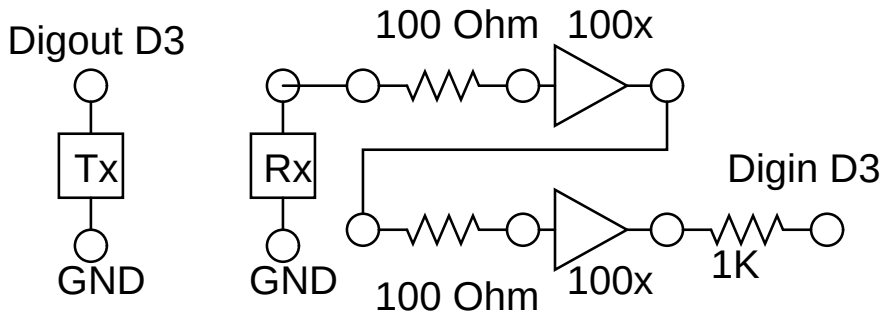


Figure 4.19: Piezo Transceiver setup measuring velocity of sound

Distance (cm)	Timeusec)	Dist. difference	Time diff.	Vel. (m/s
4	224			
5	253	1	29	344.8
6	282	2	58	344.8
7	310	3	86	348.8

Table 4.1: Velocity of sound

on Digital Output Socket D3 to generate a sound wave. The sound wave reaches the receiver piezo kept several centimeters away and induces a small voltage across it. This signal is amplified by two variable gain amplifiers in series, each with a gain of 100. The output is fed to Digital Input D3 through a 1K resistor[3]. The interval between the output pulse and the rising edge of D3 is measured by the following program 'piezo.py'. The output is redirected to a file

```
import phm
p=phm.phm()
p.write_outputs(0)
for x in range(10):
   print p.pulse2rtime(3,3,13,0)
```

To avoid gross errors in this experiment one should be aware of the following. Applying one pulse to the transmitter piezo is like banging a metal plate

[3]It is very important to use this resistor. The amplifier output is bipolar and goes negative values. Feeding negative voltage to D3 may damage the micro-controller. The 1KOhm resistor acts as a current limiter for the diode that protects the micro-controller from negative inputs.

to make sound, it generates a train of waves whose frequency is around 40 KHz. The receiver output is a wave envelope whose amplitude rises quickly and then goes down rather slowly. When we amplify this signal one of the crests during the building up of the envelope makes the Digital Input HIGH. When we increase the distance between the crystals the amplitude of the signal also goes down. At some point this will result in sudden jump of 25 microseconds in the time measurement which is caused by D3 going HIGH by the next pulse. This can be avoided by taking groups of reading at different distances varying it by 3 to 4 centi meters.

4.8.2 Condenser microphone

Velocity of sound can be measured by banging two metal plates together and recording the time of arrival of sound at a microphone kept at a distance. One metallic plate is connected to ground, another one is connected to a digital input say D0. The generated sound travels through air and reaches the microphone and induces an electrical signal. The electrical signal is amplified 200 times by two amplifiers in series and connected to D3. The experimental setup is shown figure 4.20. We have used 1 mm thick aluminium plates to generate the sound. When we strike one by the other, the digital input D0 gets grounded resulting in a falling edge at D0. The amplified sound signal causes a rising edge on D1 [4]. The software measures the time interval between two falling edges using the following lines of code. To get better results repeat the measurement several times and take average.

```
import pm
p = phm.phm()
print p.f2ftime(0,1)
```

Here is a table of measurements obtained experimentally:

[4]Rising or falling edge depends on the amplifier offset etc. If the amplifier output will start oscillating when the sound signal arrives. If is already HIGH it will go LOW when the sound signal arrives and we should look for a falling edge.

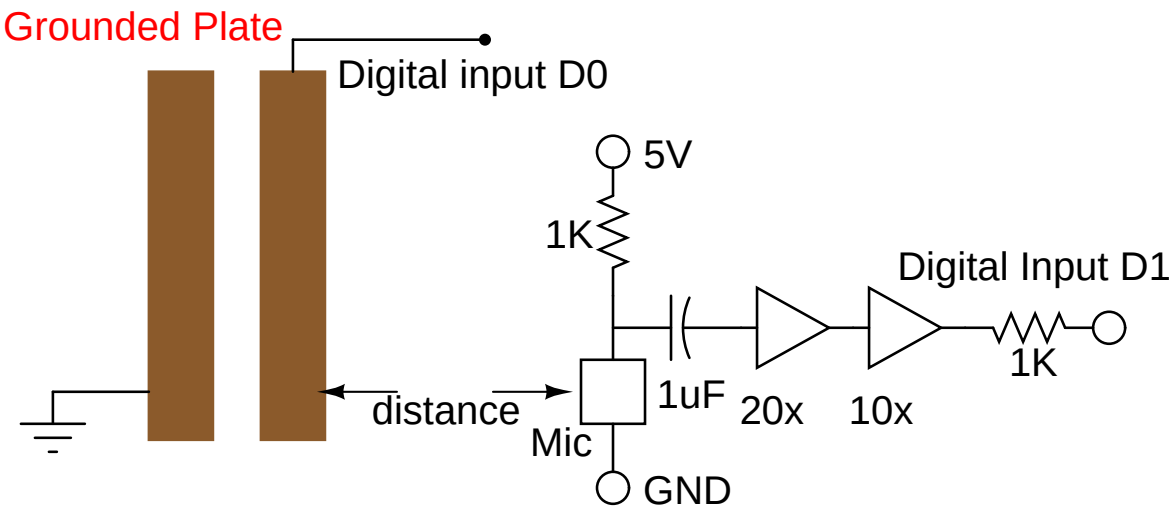


Figure 4.20: Velocity of sound by microphone

Distance (cm)	Time (milli seconds)	Speed = distance/time
0	0.060	To be treated as offset
10	0.350	344.8
20	0.645	341.8
30	0.925	346.8
40	1.218	345.4
50	1517	343.1
60	1810	342.8

4.9 Study of Pendulum

Studying the oscillations of a pendulum is part of any elementary physics course. Since the time period of a pendulum is a function of acceleration due to gravity, one can calculate g by doing a pendulum experiment. The accuracy of the result depends mainly on how accurate we can measure the period T of the pendulum. Let us explore the pendulum using phoenix.

4.9.1 A Rod Pendulum - measuring acceleration due to gravity

A rod pendulum is very easy to fabricate. We took a cylindrical rod and fixed a knife edge at one end of it to make a T shaped structure. The pendulum is suspended on the knife edges and its lower end intercepts a light barrier while oscillating. The light barrier is made of an LED and photo transistor. The output of the light barrier is connected to Digital Input D3. The program 'rodpend.py' is used for measuring T and calculating the value of g. The code is listed below.

```
import phm, math
p=phm.phm()
length = 14.65                # length of the rod pendulum
pisqr = math.pi * math.pi
for i in range(50):
   T = p.pendulum_period(3)/1000000.0
   g = 4.0 * pisqr * 2.0 * length / (3.0 * T * T)
   print i, ' ',T, ' ', g
```

The output of the program is redirected to a file and a histogram is made using 'xmgrace' program as shown in figure 4.21. The mean value and percentage error in the measurement can be obtained from the width of the histogram peak.

4.9.2 Nature of oscillations of the pendulum

A simple pendulum can be studied in several different ways depending on the sensor you have got. If you have an angle encoder the angular displacement of the pendulum can be measured as a function of time. What we used is a DC motor with the pendulum attached to its shaft. When the pendulum oscillates it rotates the axis of the motor and a small time varying voltage is induced across the terminal of the motor. This voltage is amplified and

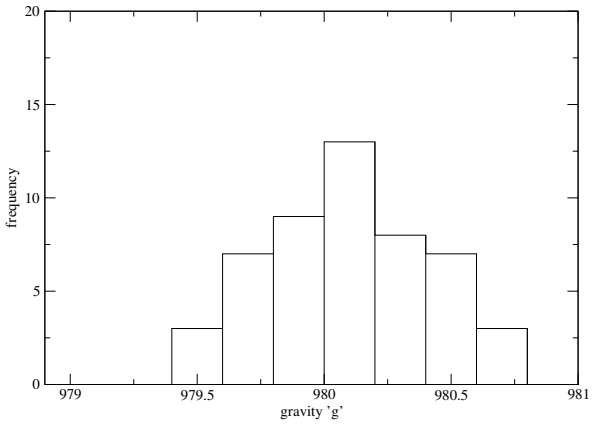


Figure 4.21: Measured 'g'. Histogram

plotted as a function of time. The experimental setup and output are shown in figure 4.22 on the facing page. The program pend_digitize.py is listed below.

The output of the program is send to a file and plotted using *xmgrace*. The period of oscillation can be extracted by fitting the data with the equation of an exponentially decaying sinusoidal wave. The equation used for fitting the data is the following.

$A(t) = A_0 \sin(\omega t + \theta) e^{-\mathrm{dt}} + C$

- $A(t)$ - Displacement at time t
- A_0 - Maximum displacement
- ω - Angular velocity
- θ - displacement at t=0
- d - Damping factor
- C - Constant to take care of DC offset from amplifiers

The angular velocity $\omega$is found to be 7.87 and the length of the pendulum is 15.7 cm. The calculated value of 'g' using the simple pendulum equation $\omega^2 L$ = 972 cm/sec^2. The errors are due to the simple pendulum approaximation and the error in measurement of length.

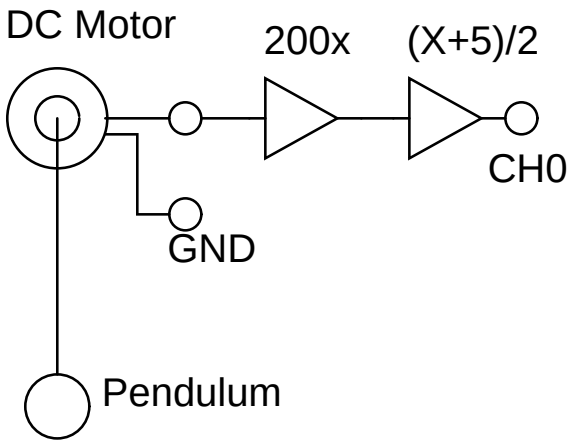


Figure 4.22: Pendulum block diagram

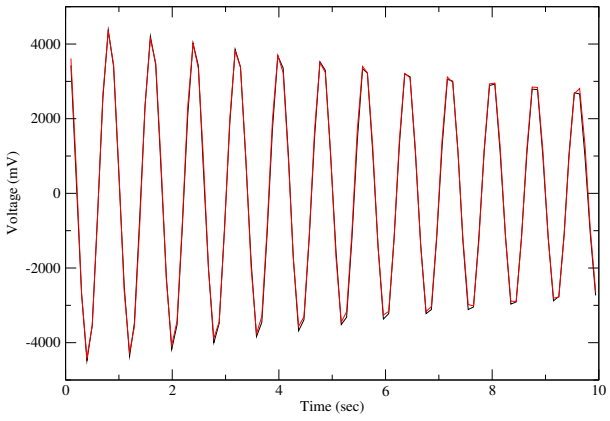


Figure 4.23: Decaying oscillations

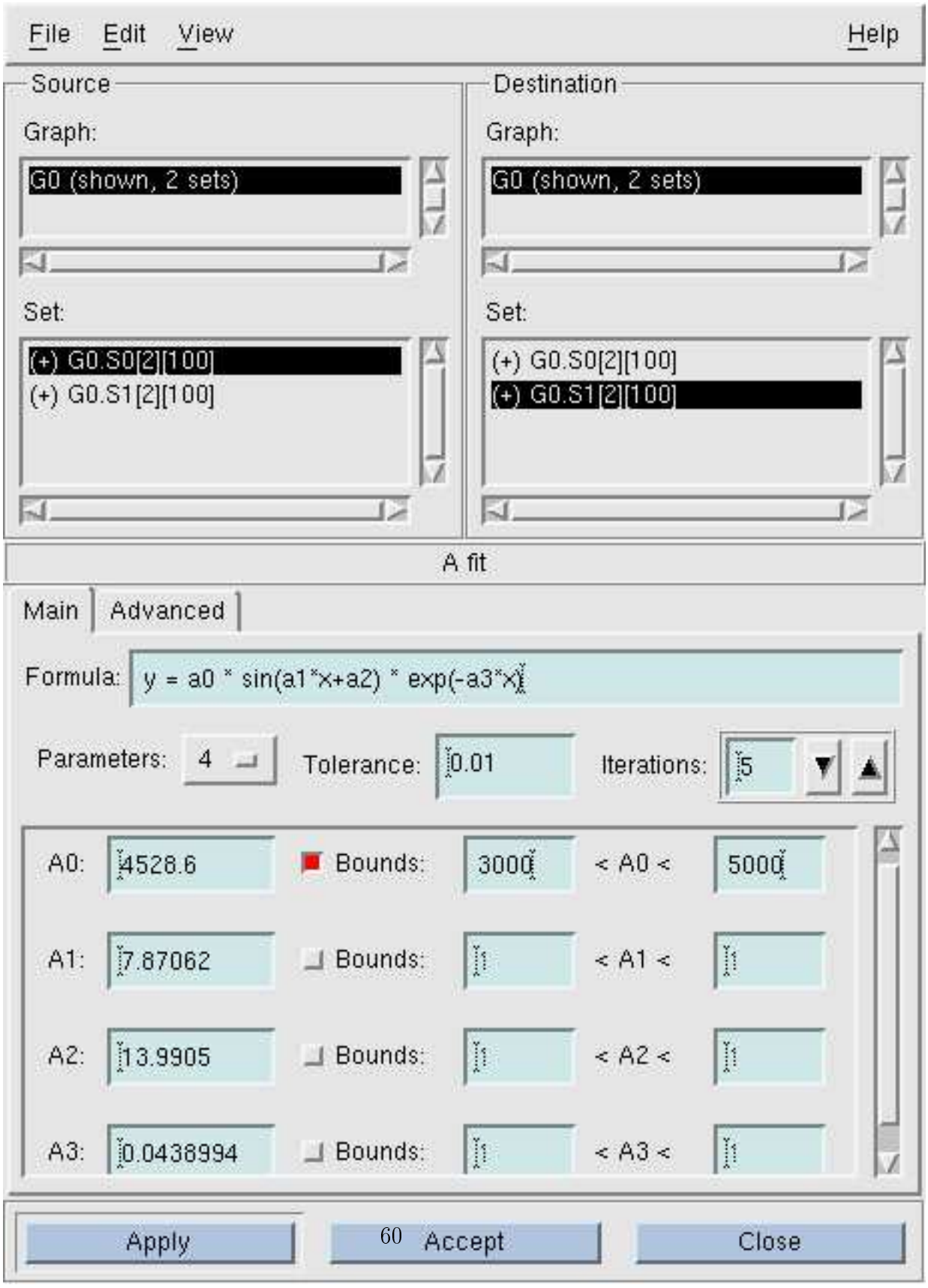


Figure 4.24: Pendulum Data fitted with equation

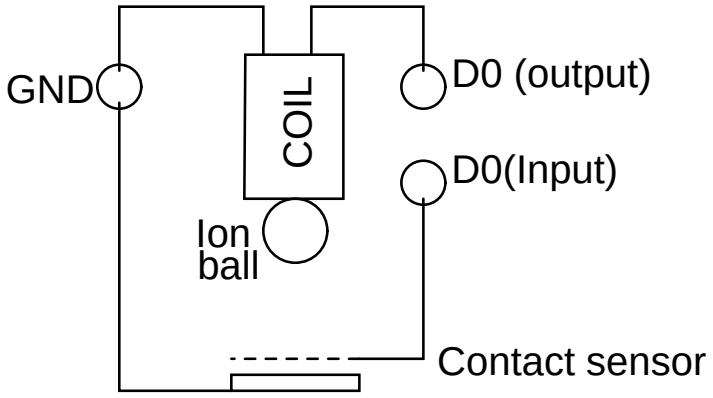


Figure 4.25: Gravity by free fall

4.9.3 Acceleration due to gravity by time of flight method

There are many ways to time the free fall of an object under gravity - here is one interesting idea. Take a small relay and remove its cover so that you can access the coil directly. Connect one end of the coil to the Digital Output D0 (the only output with transistor buffering). We have used the coil from 12V relay with a coil resistance of 150 Ohms. The coil resistance should not be less than 100 Ohms and it should be able to magnetically hold a metal ball of radius around 1 cm. The experimental setup is shown in figure 4.25. Digital Output D0 is made high to energize the coil. Now attach the metal ball to the relay and and release it under software control. The ball falls on the contact sensor and takes the Input D0 to LOW. The code 'gdirect.py' is listed below.

```
import phm, time
p=phm.phm()
p.write_outputs(1)    # energize the coil
time.sleep(2)         # time to attach the ball to the coil
print p.clr2ftime(0,0)# time of flight
```

The value of gravity g can be calculated using the expression $S = \frac{1}{2}gt^2$where S is the distance and t is the time of flight. There are certain sources of error in this experiment. We assume that the ball is released at the moment the

current is withdrawn but due the inductance of the coil the balls falls after a delay. This delay error can be estimated by taking the readings at different heights. Using two light barriers at different hieghts is another solution.

4.10 Study of Timer and Delay circuits using 555 IC

Constructing astable and monostable multi-vibrators using $IC555$ is done in elementary electronics practicals. Using phoenix one can measure the frequency and duty-cycle of the output with micro second accuracy. In the case of mono-stable Phoenix can apply the trigger pulse and measure the width of the output.

4.10.1 Timer using 555

An astable multi-vibrator is wired using IC 555 as shown in figure 4.26. The output of the circuit is fed to CNTR input for frequency measurement and then to Digital Input D0 for duty cycle measurement. The code used is shown below along with the results obtained at each step.

```
print p.measure_frequency()     # signal connected to CNTR
904
print p.r2ftime(0,0)            # signal to D0 input
733
print p.f2rtime(0,0)
371
```

Exercise: Cross check the above results with that predicted by the equation for frequency and duty cycle. The resistor values used are of 1% tolerance and capacitor of 5% tolerance.

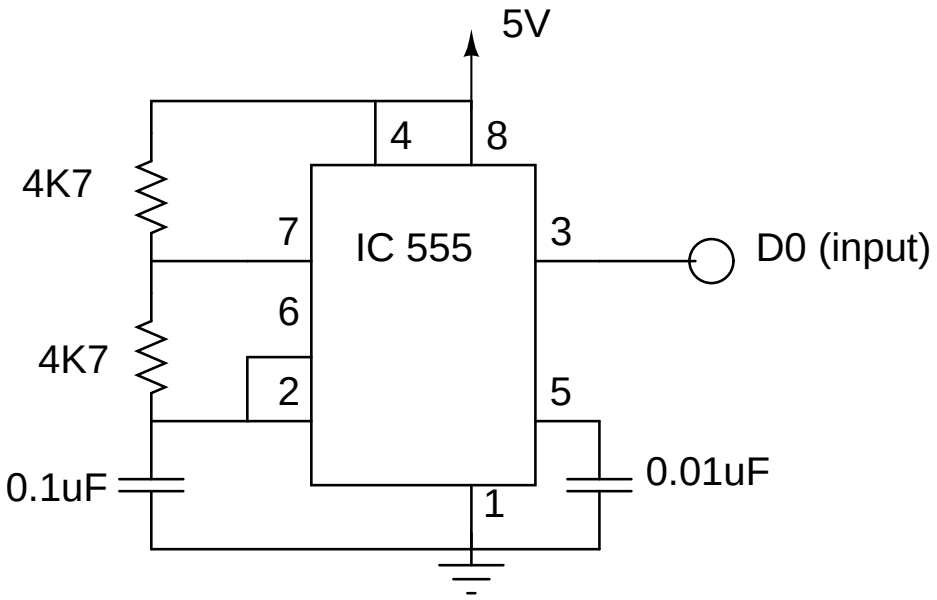


Figure 4.26: 555 oscillator circuit

4.10.2 Mono-stable multi-vibrator

The monostable circuit is wired up as shown in figure4.27 . The 555 IC require a LOW TRUE signal at pin 2 to trigger it. The output goes HIGH for a duration decided by the R and C values and comes back to LOW. The following lines of code is used for triggering 555 and measuring the time interval from trigger to the falling edge of the signal from pin 3.

```
p.write_outputs(8)          # keep D3 high
p.pulse2ftime(3,0,1,1)      # 1 usec wide LOW TRUE pulse on D3 to a falling edge
123
```

Again it is left as an exercise to the reader to verify whether 123 microseconds is acceptable based on the RC values used.

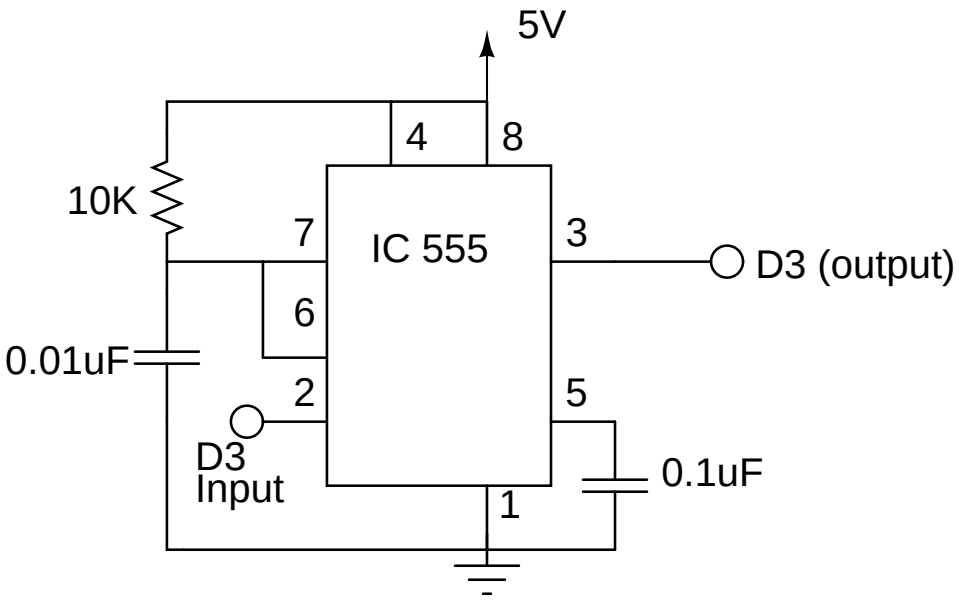


Figure 4.27: Monostable multi-vibrator using 555

Chapter 5

Micro-controller development system

The heart of Phoenix-M hardware is an ATmega16 micro-controller. The system comes with a pre-loaded program that listens for commands from the PC through the Serial Port. This program is developed using the same hardware setup and the AVR GCC compiler. The program is compiled on the PC and the executable output is uploaded to the micro-controller through a cable connected to the Parallel port of PC. The AVR GCC compiler for both GNU/Linux and MS-Windows is provided on the Phoenix CD . Most of the ATmega16 micro-controller Input/Output pins are available through the front panel sockets. A 16 Character LCD Display is provided along with C routines to access it. An introduction to ATmega16 micro-controller is given below. For more details refer to the PDF document on the CD.

Features

High-performance, Low-power AVR 8-bit Micro-controller

Advanced RISC Architecture

- 131 Powerful Instructions - Most Single Clock Cycle Execution
- 32 x 8 General Purpose Working Registers
- Up to 6 MIPS Throughput at 16MHz
- Fully Static Operation
- On-chip 2-cycle Multiplier

Nonvolatile Program and Data Memories

- 16k Bytes of In-System Self-Programmable Flash
- Optional Boot Code Section with Independent Lock Bits
- 512K Bytes EEPROM
- Programming Lock for Software Security

JTAG (IEEE std. 1149.1 Compliant) Interface

- Boundary-scan Capabilities According to the JTAG Standard
- Extensive On-chip Debug Support
- Programming of Flash, EEPROM, Fuses, and Lock Bits through the JAGS

Interface

Peripheral Features

- On-chip Analog Comparator
- Programmable Watchdog Timer with Separate On-chip Oscillator
- Master/Slave SPI Serial Interface
- Two 8-bit Timer/Counters with Separate Prescalar, Compare
- One 16-bit TImer/Counter with Separate Prescaler, Compare and Capture mode
- Real TIme Counter with Separate Oscillator
- Four PWM Channels
- 8-channel, 10-bit ADC
- Byte-oriented Two-wire Serial Interface
- Programmable Serial USART

Special Micro-controller Features

- Power-on Reset and Programmable Brown-out Detection
- Internal Calibrated RC Oscillator
- External and Internal Interrupt Sources
- Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and Extended Standby

I/O and Packages

- 32 Programmable I/O Lines
- 40-pin PDIP, 44-lead TQFP, and 44-pad MLF

Operating Voltages

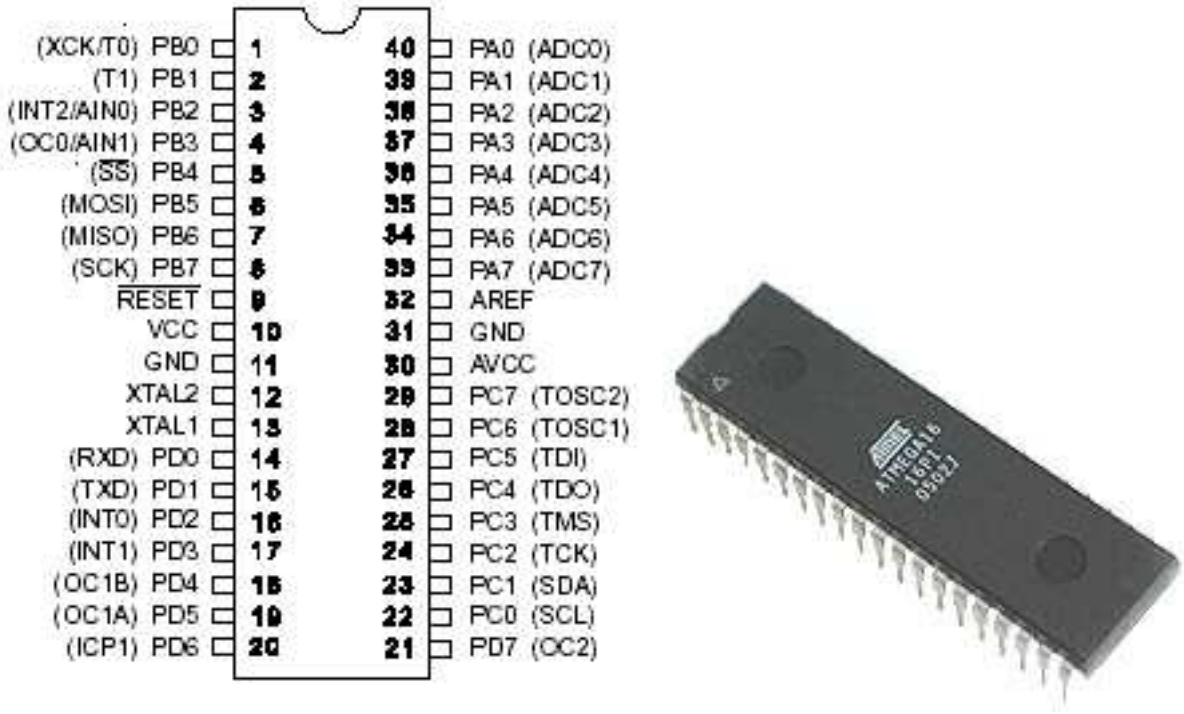


Figure 5.1: ATmega16 . Pin diagram and DIP package

- 4.5-5.5V for ATmega16

Speed Grades

- 0-16 MHz for ATmega16

Power Consumption at 4 Mhz, 3V, 35 °C

- Active: 1.1mA
- Idle Mode: 0.35mA
- Power-down Mode: $< 1\ \mu$A

5.1 Hardware Basics

ATmega16 interacts with the external world through four I/O ports, named as A,B,C and D. The ports are 8 bit wide and each bit can be configured as input or output. The behavior of the ports are controlled by programming the corresponding internal registers. In addition to the normal digital Input/Output operation, most of the pins have alternate functions as shown in

figure 5.1. Once the alternate functions are enabled internally, corresponding PIN will get connected to those units. For example enabling the on-chip ADC will make Port A pins as ADC inputs. We will try to introduce the different features of ATmega16 by small example programs. For more details refer to the ATmega16 manual provided on the CD. Refer to the schematic diagram5.2 to find out the wiring between the front panel sockets and ATmega8.

5.1.1 Programming tools

The AVR GCC compiler and associated tools are on the CD. It is desirable to start with the Live CD first, where all the programs are installed and ready to use. On GNU/Linux systems install the 'rpm' files using the script 'install.sh' in the RPM directory. The directory */opt/cdk4avr/bin* should be added to the path for the tools to work properly. Under MS-Windows run the file $WinAVR - install.exe$ to install the compiler and tools. To save typing the necessary commands are put in a file named 'compile.bat' [1]. This script can be used for compiling the code and generate the executable format file.

```
echo "compiling $1.c"
avr-gcc -Wall -O2 -mmcu=atmega16 -Wl,-Map,$1.map -o $1 $1.c
avr-objcopy -j .text -j .data -O ihex $1 $1.hex
avr-objdump -S $1 > $1.lst
```

More information on the AVR GCC compiler and the library functions are on the CD in 'html' format.

5.1.2 Setting Clock Speed by Programming Fuses

Several parameters like processor clock source, clock speed etc. can be programmed through the same cable that is used for uploading the executable

[1] The .bat extension may look odd but there is a reason. With that extension it can be used under MSWindows also.

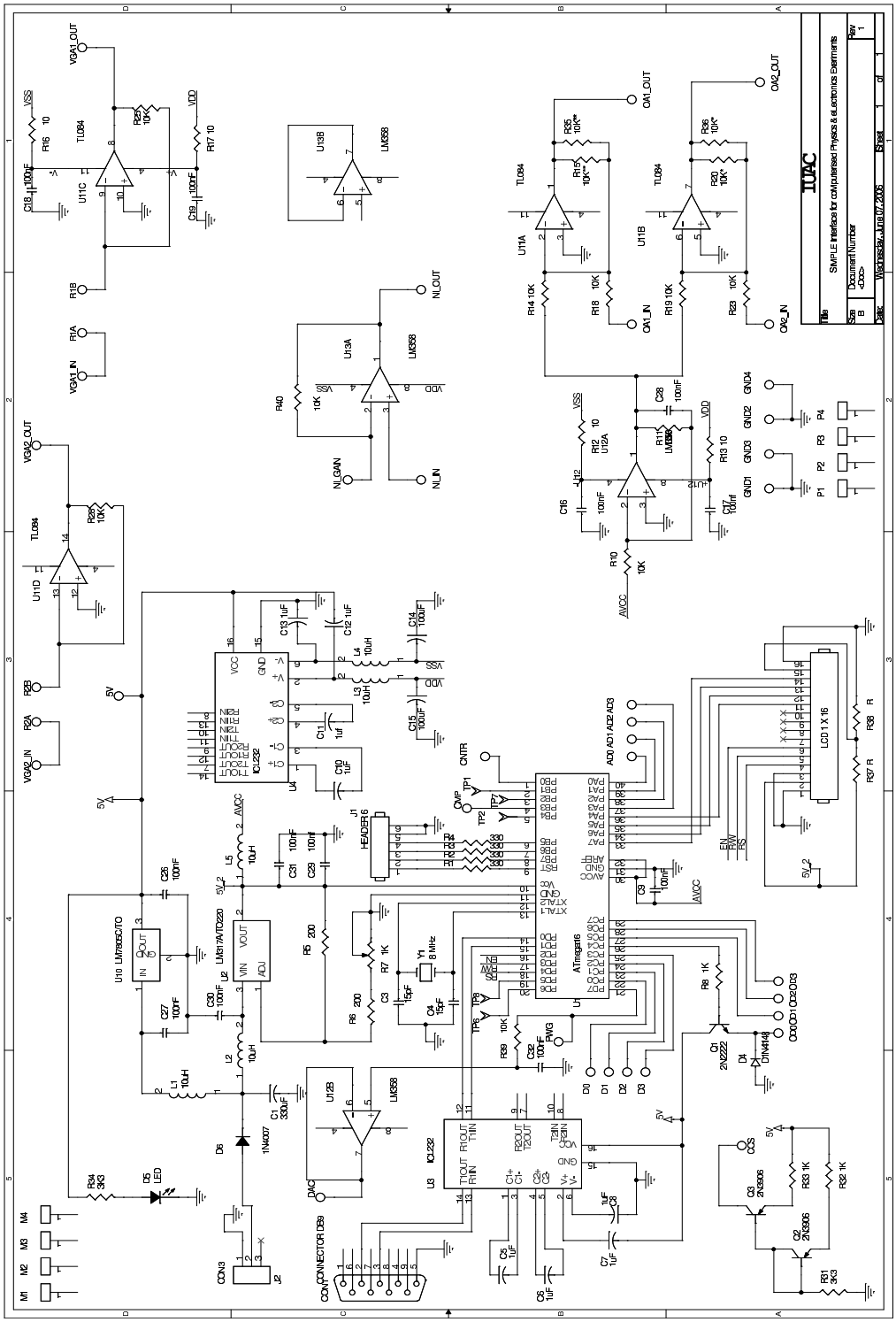


Figure 5.2: Phoenix-M Hardware schematics

6pin con. pin #	Signal	AT pin #	P.Port pin #
1	RESET	9	16
2	SCK	8	1
3	MISO	7	11
4	MOSI	6	2
5,6	GROUND	11	19

Table 5.1: Parallel port programming cable

code. To set 8MHz clock speed with external crystal and disable the JTAG interface, set the fuse LOW to EF and HIGH to D9.

```
uisp -dprog=dapa -dpart=atmega16 -dlpt=0x378 --wr_fuse_l=0xEF
uisp -dprog=dapa -dpart=atmega16 -dlpt=0x378 --wr_fuse_h=0xD9
```

The Phoenix-M programs are written for 8MHz clock speed. The RS232 baud rates are derived from the processor clock and it is 38400 baud for 8MHz clock. The Python library uses this speed and the processor MUST be set to 8MHz for things to work . Refer to the ATmega16 documentation for more details.

5.1.3 Uploading the HEX file

The executable file is generated in the HEX format. It is uploaded to ATmega16 through the PC parallel port using the cable provided. The pin connections of the cable are shown in table5.1. One end of the cable is a 6 pin connector and other end is 25 pin D connector for the PC parallel port.

A program named *uisp* is used for uploading the HEX file. The same program is used for setting the fuses of ATmega16. The script 'load.bat' , listed below, contains the commands to upload a file. The usage of this is explained in the examples section.

```
echo "Uploading $1.c"
uisp -dprog=dapa -dpart=atmega16 -dlpt=0x378 --erase
uisp --verify -dprog=dapa -dpart=atmega16 -dlpt=0x378 --upload if=$1.hex
```

For example, executing the following command from the directory where 'load.bat' and '.hex' are located will upload 'avrk.hex' to the micro-controller.

```
# ./load.bat avrk
```

Uploading this program is necessary for the python library to communicate to Atmega8. After trying any of the following examples load *avrk* if you want to restore the functioning of Phoenix-M as a PC interface.

5.2 Example Programs

The example programs will use Phoenix-M hardware for demonstrating various features of ATmega16. Extra hardware will be plugged into the front panel sockets as required. It is desirable to have a multimeter to test the results.

5.2.1 Blinking Lights

If you have booted from the live CD, open a command prompt and set the default directory as 'root/phm'. Create a file named 'blink.c' with the following lines in it. Connect an LED from the socket marked ADC Ch0 to ground through a 1KOhm resistor.

```
#include <stdio.h>
#include <stdlib.h>
#include <inttypes.h>
#include <avr/io.h>
void delay (uint16_t k) // roughly 2 usec per loop at 8 MHz system clock
{
volatile uint16_t x = k;
while (x) --x;
}
int main (void)
{
```

```
DDRA = 0xff;    // Configure all bits of PORT A as output
for(;;)
  {
  PORTA = 255;
  delay(20000);
  PORTA = 0;
  delay(20000);
  }
}
```

Compile the code and upload it to ATmega8 using the scripts as shown below;

```
# ./compile.bat blink
# ./load.bat blink
```

Now the LED should start blinking. What is happening? How our ADC input became an output ? . The program *blink.c* has configured the PORT A as an output port and we have not enabled the ADC. All the four ports can be configured as input or output in a similar fashion.

5.2.2 Writing to the LCD Display

Phoenix-M has a provision to attach a 16 character LCD display to the board. We have used the Hitachi 44780 based LCD display that is available easily. The connections between the LCD module and ATmega16 are shown in the table5.2 . There are total seven connections between LCD and ATmega16, four of them are data lines and three are control lines.

Programming details of the LCD module and the example programs are available on given on the CD. We will use the file *lcd*16.*c* from the *cprog* directory. A program named *lcdtest.c* also is given in the same directory. Here is a small program *hello.c* that writes to the LCD display. LCD Display was the main debugging tool during Phoenix-M program development.

```
#include <stdio.h>
#include <stdlib.h>
```

Pin	Function	Description	ATmega8 Pin
1	Vss	Ground pin	
2	Vdd	+5V supply	
3	V_0	Intensity, 0V for maximum	
4	RS	HIGH for Data, LOW for Commands	PD4
5	R/W	H for read, L for write	PD3
6	EN	Enable signal	PD2
7	DB0		
8	DB1		
9	DB2		
10	DB3		
11	DB4		PA4
12	DB5		PA5
13	DB6		PA6
14	DB7		PA7
15	x	Back light LED control, not used	
16	x		

Table 5.2: LCD connections

```
#include <inttypes.h>
#include <avr/io.h>
#include "lcd16.c"
int main (void)
{
DDRA = 255;      // PORT A as output
DDRD = 255;      // PORT D as output
initDisplay ();
writeLCD('H');
writeLCD('e');
writeLCD('l');
writeLCD('l');
writeLCD('o');
}
```

5.2.3 Analog to Digital Converters

The on-chip 10 bit ADC has 8 multiplexed inputs. ATmega16 has analog supply volatge pin AVCC and an external ADC reference voltage pin. Internal reference voltage source also has been provided. T. Phoenix-M circuit gives same 5V DC to both AVCC and AREF. Operation of the ADC is controlled through the special registers provided for that purpose. ADCSRA, ADMUX, ADCL, ADCH etc are the important registers to control the ADC. Let us explore the ADC functioning using the program *adc.c* listed below, which reads the input of channel 0 and writes the digital output to the LCD display.

```
#include <stdio.h>
#include <inttypes.h>
#include <avr/sfr_defs.h>
#include <avr/io.h>
#include "lcd16.c"
uint8_t lo, hi;
uint16_t dat;      // 16 bit unsigned datatype
int main()
{
DDRA = 0xf0;      // 4 bits ADC Input + 4 bits LCD data output
DDRD = 255;       // PORTD as output
for(;;)
  {
  initDisplay();
  ADMUX = 0; // External reference, 10 bit data, channel 0
  ADCSRA = BV(ADEN) | BV(ADSC) | 7;    // Enable, Start, Low clock speed
  while ( !(ADCSRA & (1<<ADIF)) )  ;   // wait for ADC conversion
  lo = ADCL;
  hi = ADCH;
  sbi(ADCSRA, ADIF);                   // get ready for next conversion
  dat = (hi << 8) | lo;
  write16(dat);
```

```
  delay(10000);
  }
}
```

5.2.4 Pulse width modulation using Timer/Counters

ATmega16 has three Timer/Counter units, two of them are 8 bit and one is 16 bit. For a quick demo let us generate a 31.25 KHz pulse on OC2 (pin # 21). For this we program the control register and set point registers of TC2 as shown in the code *pwm.c* below.

```
#include <avr/sfr_defs.h>
#include <avr/io.h>
int main()
{
  DDRD = 255;
  OCR2 = 127; // Change this from 0 to 255 for changing duty cycle
  TCCR2 = BV(WGM21) | BV(WGM20) | BV(COM21) | 1; // Fast PWM mode
  TCNT2 = 0;
}
```

Timer/Counters are very versatile and programming them could become really complex depending on the application. Read the documentation for more details.

Chapter 6

Building Standalone Systems

The Phoenix-M hardware can be converted into standalone systems that can be used independent of the PC. The LCD panel provides a minimalistic display device. The front panel sockets can be configured for Input/Output of various kinds. The concept is demonstrated with the following examples.

6.1 Frequency Counter for 5V square wave signal

The CNTR socket is connected to PB0 (T0). We will configure Timer/Counter 0 to count the external pulses applied to this pin and count the number of pulses for one second. The 16 bit Timer/Counter TC1 will be programmed to run on a 1 MHz clock generated internally to generate a signal when we reach one second. The result is displayed on the LCD panel. The program 'frcount.c' is listed below.

```
#include <stdio.h>
#include <stdlib.h>
#include <inttypes.h>
#include <avr/sfr_defs.h>
#include <avr/io.h>
#include "lcd16.c"
```

```
uint32_t x;
uint16_t tmp16;
uint8_t  tmp8;
char ss[20];
int main()
{
  DDRA = 0xf0;                  // 4 bits ADC Input + 4 bits LCD data output
  DDRB = 0x00;                  // Configure as input
  PORTB = 255;
  DDRC = 0xf0;                  // Low nibble Input & High nibble output
  PORTC = 15;                   // Enable pullup resistors (low 4)
  DDRD = 255;                   // PORTD as output
// Three lines of code below generates a 31.25 KHz pulse on PWG.
// Connect PWG to CNTR for testing the standalone frequency meter
  OCR2 = 127;   // Change this from 0 to 255 for changing duty cycle
  TCCR2 = BV(WGM21) | BV(WGM20) | BV(COM21) | 1;        // Fast PWM mode
  TCNT2 = 0;
// Frequency counter code starts here
while (1)
  {
  TCCR1B = BV(WGM12) | BV(CS11);// Wavegen mode, Clock/8 to TCC1
  TCCR0 = 7;                    // normal, External  clock
  TIFR = 255;                   // clear all flags
  OCR1A = 49999;
  tmp16 = 0;
  tmp8 = 0;
  TCNT0 = 0;                    // counts external input
  TCNT1 = 0;                    // to keep time with clk/8
  while(1)
        {
        if(TIFR & BV(OCF1A))            // 50000 usecs elapsed
          {
          if (++tmp8 == 20)
```

```
            {
            TCCR0 = 0;                  // 1 second. Stop counting
            break;
            }
          TIFR |= BV(OCF1A);
          }

        if(TIFR & BV(TOV0))             // overflow after 255 counts
          {
          ++tmp16;
          TIFR |= BV(TOV0);             // Clear OVF flag
          }
        }
  x = tmp16;
  x = (x << 8) | TCNT0;
  sprintf(ss,"%ld",x);
  initDisplay();
  tmp8 = 0;
  while(ss[tmp8]) writeLCD(ss[tmp8++]);
  delay(20000);
  }
}
```

The above program also generates a 31.25 KHz square wave on PWG (pin 21 of ATmega8) that can be used for quick testing of the system. The following table gives the values measured by this program for different frequency inputs from a HP33120A function generator.

Frequency from HP33120A	displayed by ATmega8 program
50	50
100	100
1000	1000
5000	4999
10000	9999
50000	49992
100000	99983
500000	4999913
1000000	999828

For counting small amplitude signals amplify them using the gain blocks provided on Phoenix and feed to the CNTR input through a 1KOhm resistor in series.

6.2 Room Temperature Monitor

We use the LM35 temperature sensor along with phoenix-M to display the room temperature on the LCD display. LM35 is a three pin IC with 5V supply, Ground and the output leads. The output voltage is zero at 0 degree Celsius and increases 10mV per degree. The output of LM35 is amplified by the non-inverting amplifier. A 1K resistor is used to get a gain of 11. The amplifier output is fed to ADC Ch0. The program 'lm35.c' listed below is uploaded to the system.

```
#include <stdio.h>
#include <stdlib.h>
#include <inttypes.h>
#include <avr/sfr_defs.h>
#include <avr/io.h>
#include "lcd16.c"
int gain = 11;          // amplifier gain is 11 for 1K resistor
uint16_t tmp16;
uint8_t  tmp8;
```

```
uint32_t x,y;
char     ss[20];
int main()
{
  DDRA = 0xf0;                  // 4 bits ADC Input + 4 bits LCD data
  DDRB = 0x00;                  // Configure as input
  PORTB = 255;
  DDRC = 0xf0;                  // Low nibble Input & High nibble output
  PORTC = 15;                   // Enable pullup resistors (low 4)
  DDRD = 255;                   // PORTD as output
  ADMUX =  0;                   // 10 bit data, channel 0
  while (1)
    {
    ADMUX =  0;                 // 10 bit data, channel 0
    ADCSRA = BV(ADEN) | BV(ADSC) | 7;          // Low clock speed
    while ( !(ADCSRA & (1<<ADIF)) ) ;          // wait for ADC conversio
    tmp8 = ADCL;
    tmp16 = (ADCH << 8) | tmp8;
    sbi(ADCSRA, ADIF);
    x = tmp16;
    x = x * 5000;
    x = x/1023/gain;
    y = x;

    x = x / 10;
    sprintf(ss,"%ld.%ld",x,y-(x*10));
    initDisplay();
    tmp8 = 0;
    while(ss[tmp8]) writeLCD(ss[tmp8++]);
    delay(32000);
    }
}
```

Floating point calculations are avoided. Loading the floating point library will make the size of the executable beyond 16 kilo bytes.

6.2.1 Exercise

Modify the above system to make a temperature controller. Pin #26 (PC4) of ATmega8 is transistor buffered on the phoenix board. This can be used for driving a 5V relay that in turn will switch the heater power On or OFF. The state of PC4 can be controlled by software depending on the difference between the measured temperature and the reference point.

Chapter 7

Appendix A - Number systems

A basic understanding of binary and hexadecimal number systems is required to work with Phoenix-M.

The Binary Number System

Only two digits, 1 and 0 are available for counting in binary; here is how you do it: 00, 01, 10, 11, 100, 101, 110, 111, 1000, ... and so on.

Converting a binary number to decimal is simple. Let's convert 1011 to decimal:

$$1 * 2^0 + 1 * 2^1 + 0 * 2^2 + 1 * 2^3$$

Take each digit of the binary number (from the rightmost one) and keep multiplying it with increasing powers of 2. Converting small decimal numbers to binary becomes quite easy with practice - simply visualize this sequence:

.... 128 64 32 16 8 4 2 1

Say you want to convert 37 to binary; 37 is 32 + 4 + 1, so you visualize a bit pattern

0 0 1 0 0 1 0 1

with 1's at positions occupied by 32, 4 and 1 and zero's at all other places.

The rightmost bit (the so called 'least significant bit') of an eight bit pattern will be labeled D0 and the leftmost bit (the most significant bit) will be labeled D7.

The Hexadecimal Number System

Counting

You count in decimal like this: 0, 1, 2, ... 8, 9, 10, 11, 12 ..... There are only ten distinct symbols from 0 to 9 available. In hexadecimal, you have 16 distinct symbols - you count in hex like this: 0, 1, 2, ...8, 9, A, B, C, D, E, F, 10, 11, ... 18, 19, 1A, 1B, 1C, 1D, 1E, 1F, 20, ... The symbol A represents 10 in decimal, symbol B represents 11 and so on.

Conversion to decimal

It's very easy to convert a hexadecimal number to decimal; let's take the hex number 12 as an example. The procedure is:

$$2 * 16^0 + 1 * 16^1$$

The result is 18, which is the equivalent decimal number. One more example would make things clear. Let's convert the number 2ab3 to decimal. The procedure is:

$$3 * 16^0 + 11 * 16^1 + 10 * 16^2 + 2 * 16^3$$

We are simply taking each digit of the number from the least significant (rightmost) to the most significant, converting it to decimal and multiplying it by increasing powers of 16.

Conversion to binary

Lets convert the hex number 2A to binary - the idea is to take each hex digit and convert it into a 4 bit binary number and append all the 4 bit sequences obtained.

The number A in hex is 10 in decimal - the equivalent binary is 1010. The number 2 in binary is 0010. So 2A is:

00101010

The reverse conversion (binary to hex) too is simple - group the binary number into 4 bit sequences, convert each 4 bit sequence to hex and append all the hex digits together.

Chapter 8

Appendix B - Introduction to Python Language

After booting your machine with the Live-CD and logging in as 'root' (as per the instructions provided on the boot up screen), you should familiarize yourself with the Python programming language as it will be your primary vehicle for interacting with the Phoenix box.

Arithmetic

Python (http://www.python.org) is a very high level language with clear syntax and predictable behavior (unlike 'C', which never works the way you imagine it to work!). You can start interacting with it by invoking the command:

```
python
```

at the interpreter prompt. You would see something similar to this:

```
[root@don user-manual]# python
Python 2.3.4 (#1, Sep 11 2004, 22:35:14)
[GCC 3.3.2 20031022 (Red Hat Linux 3.3.2-1)] on linux2
Type "help", "copyright", "credits" or "license" for more information.
>>>
```

The >>> sequence represents the Python 'prompt' where you can interactively enter short Python programs. Let's try out our first program:

```
>>> print 1+2
3
>>> 1+2
3
>>> print "hello,world"
hello,world
>>>
```

That's about as simple as you can get[1]! You can do all standard math operations:

```
>>> 2 * 3
6
>>> 2 ** 3
8
>>> 2 ** 50L
1125899906842624L
>>> 1 / 2
0
>>> 1/2.0
0.5
>>>
```

Note that adding a suffix 'L' converts the number to a 'long' integer which can have as many digits as can be computed within the constraints of time and space.

It's possible to represent integer constants in three separate bases - decimal (default), octal and hexadecimal.

[1]Be careful not to insert any additional space before the first character of each line you type at the prompt! Python has some unusual interpretations for whitespace which may bewilder a newbie.

```
>>> 0x10
16
>>> 010
8
>>> hex(255)
'0xff'
>>> oct(8)
'010'
>>>
```

The '0x' prefix stands for hexadecimal and a simple '0' prefix makes the constant an octal constant.

The dynamic nature of Python

Let's look at a few lines of Python code:

```
>>> a=1
>>> type(a)
<type 'int'>
>>> a='hello'
>>> type(a)
<type 'str'>
```

Python does not have any kind of variable declaration, unlike C/C++. A Python variable is created when an assignment statement is executed. So, the variable 'a' is created only when the statement 'a=1' executes - the interpreter assigns the type 'int' to 'a' at that point of time. Later, 'a' can be assigned to an object of an entirely different type (as in the example above).

Strings

A Python string is a sequence of characters written within single or double quotations.

```
>>> a= 'hello'
>>> b = 'world'
>>> print a[0]
'h'
>>> print a[-1]
'o'
>>> print a+b
'helloworld'
>>> print a * 3
'hellohellohello'
```

The manipulations done above are very simple. You can extract individual characters of a string by 'indexing' it - the first index starts at '0'. It is possible to do 'negative indexing' which helps you extract elements from right to left. The addition and multiplication operations behave logically.

Let's try another experiment:

```
>>> str(123)
'123'
>>> str(1.23)
'1.23'
>>>
```

The 'str' functions converts an integer to string. We will find this useful when we wish to concatenate an integer or floating point number and a string.

Let's find out the ASCII value of a character:

```
>>> ord('A')
65
>>> ord('a')
97
>>>
```

And let's convert an ASCII value into its equivalent character form:

```
>>> chr(65)
'A'
>>> chr(97)
'a'
>>>
```

Complex Numbers

Python has built-in complex numbers. Here are a few statements which demonstrates this capability:

```
>>> a = (1 + 2j)
>>> b = (3 + 4j)
>>> a + b
4 + 6j
>>> a * b
-5 + 10j
>>>
```

Arrays (Lists)

Here is how you go about manipulating a set of numbers (or any other objects) in Python:

```
>>> a = [1,2,3.9,"hello"]
>>> a[0]
1
>>> print a[3]
hello
>>> a[4]
Traceback (most recent call last)
  File "<stdin>", line 1, in ?
IndexError: list index out of range
```

The expression 'a[0]' is said to 'index' the array with 0, the first index. Note that it is not possible to index the array with 4 as the last element is at index 3; the Python interpreter generates what is called an 'exception' if you try doing it. This is standard behaviour.

You can concatenate arrays, and do more interesting stuff:

```
>>> a = [1, 2, 3]
>>> b = [4, 5, 6]
>>> a + b
[1, 2, 3, 4, 5, 6]
>>> a * 3
[1, 2, 3, 1, 2, 3, 1, 2, 3]
>>> a.append(10)
>>> print a
[1, 2, 3, 10]
>>> print a[0:3] # from index 0 to index 2
[1, 2, 3]
>>> print a[-1] # negative indexing
10
>>> a = range(10)
>>> print a
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
>>>
```

The '#' sign is the comment symbol in Python; comment lines are ignored by the language interpreter and are written for readability's sake.

Tuples

Tuples are like lists, but with a major difference. You can't modify the contents of a tuple in any way.

```
>>> a=(1,2,3) # a sequence of objects within ordinary parenthesis forms a tuple
>>>a[0] = 9 #error
```

Functions

Here is how you define a function in Python:

```
>>> def sqr(x): # note the 'colon'
...         return x*x
...
>>>
```

The '...' character sequence (which appears automatically only if you are in the interactive mode) denotes the fact that you are now within a function definition. Python syntax says that body of a function should be 'indented' - I have used a 'tab' for this purpose[2]. We have defined a simple function 'sqr' which accepts a number[3] and returns it's square. Here is how we call it:

```
>>> sqr(3)
9
>>>
```

Here is another example:

```
def add(a, b):
        return (a+b, a-b)
```

A Python function can return anything - in this case, we are building a tuple containing a+b and a-b and returning it.

8.0.1.1 Exercises

1. Write a function which accepts time in seconds and returns the distance travelled by an object falling under gravity. Test it out!

2. Write a function which accepts four 'co-ordinates' x1, y1, x2, y2 and returns the distance between (x1, y1) and (x2, y2).

[2]Be careful with the way you do the indentation - if your function has multiple lines, each line should be indented at the same level - use a single 'tab' before each statement and do not mix space and tab. The Python interpreter uses indentation to judge which all statements are within a function (or a loop) - if you don't get it right, you might end up with subtle syntax errors!

[3]Called a 'parameter' or 'argument' to the function

While and For loops

Here is an example of the Python 'while' loop:

```
a = 0
while (a < 10):
    print a
    a = a + 1
print 'over'
```

The indented statements are within the body of the loop. Note the use of 'colon' after 'while'. This is the way the loop works: the Python interpreter first evaluates the expression 'a<10' - as it is true, the body is executed. The interpreter again evaluates the expression 'a<10' which is found to be true, so the body is executed once again. The sequence repeats until the expression evaluates to false (which happens when 'a' is 10); at this point, control comes out of the loop and the 'print over' statement executes. The loop prints numbers from 0 to 9 and then terminates.

The 'for' loop in Python is used mostly for the purpose of examining elements of an array one by one. Here is an example:

```
a = [10, 'hello', 20]
for i in a:
   print i
```

The loop will repeat as many times as there are elements in the array 'a'. The first time, value of 'i' will be a[0], next time a[1] and so on. Here is a nested for loop, written under the assumption that all the elements of the list being processed are themselves lists:

```
a = [[1,2,3], [4,5], ['hello', 10]]
for m in a:
   for i in m:
      print i
```

The value of 'm' in the first iteration of the outer loop will be [1,2,3]. The inner loop simply extracts all the elements of this list and prints them out. The process is repeated for the two other sub-lists.

If statement

Here is a Python code segment which makes use of an 'if' statement:

```
a = input()
if a > 5:
    print 'hello'
elif a < 2:
    print 'world'
else:
    print 'nothing'
```

Importing libraries

You might sometimes have to make use of functions which are not part of the core Python interpreter but defined in some external 'library' - good examples are the math functions sin, cos etc. Here is how you go about doing it:

```
>>> import math
>>> math.sin(0)
0.0
>>> math.cos(0)
1.0
>>>
```

The 'import' statement lets you use the functions defined in the math library; note that the function names have to be prefixed with the library name. An alternate notation is:

```
>>> from math import *
>>> sin(0)
0.0
>>> cos(0)
1.0
>>>
```

Note that now we don't have to prefix the function name with the library name.

With this much of a background in Python, we are ready to conduct experiments with our Phoenix box! Later, as the need arises, we shall explore a bit more of Python syntax (looping, plotting, higher order functions etc) to make our experiments more sophisticated.

Data manipulation in Python*

The Phoenix-M library makes very heavy use of the elegant list manipulation abilities of Python. As you start writing more advanced programs on your own, you will feel the need for doing non-trivial list manipulations. Let us look at two examples:

Let's say we have a list of the form [(1,20), (2, 15), (3,36)]. Now we want to generate a new list of the form [(1,2,3), (20,15,36)]. Here is a program which does just this:

```
a = [(1,20), (2,15), (3,36)]
b = [[], []]
for v in a:
    b[0].append(v[0])
    b[1].append(v[1])
print b
```

Now, lets do the reverse process, ie, take a list of the form [(1,2,3), (20,15,36)] and convert it into a list of the form [(1,20),(2,15),(3,36)].

```
a = [(1,2,3), (20,15,36)]
b = []
n = len(a[0])
for i in range(n):
    b.append((a[i], b[i]))
```

There are 3 functions in Python, 'map', 'filter' and 'reduce' using which you can perform complex list manipulations in a compact way. The interested reader should look up these functions once he gets a firm foundation in Python basics[4].

Plotting with Python

The Phoenix LiveCD comes with the **Grace** plotting package which can be accessed from Python. Here is how you do a simple plot:

```
>>> import pygrace
>>> pg = pygrace.grace()
>>> x = [1,2,3]
>>> y = [4,5,6]
>>> pg.plot(x, y)
```

Using the idea presented in section 8.0.1.1 it should now be possible for you to visualize the RC discharge curve using **Pygrace.**

Running programs in batch mode

If your program is more than a few lines long, its better to save it in a file to make future modifications easier. The convention is that Python program files have an extension of .py - a typical name would be 'hello.py'. Once the file has been created, you can run it by typing:

```
python hello.py
```

at the Operating System command prompt.

[4]An earlier version of this document had explained these functions - but participants of a workshop on Phoenix found it difficult to understand - so we thought og eliminating them from this introductory document.

Chapter 9

Appendix C - Signal Processing with Python Numeric

One of the disadvantages of Python is that it is slow - a Python program runs considerably slower than an equivalent C program. This becomes an issue when we start doing compute intensive applications like say finding out the Fourier Transform or doing matrix math. But there is a way out - it's possible to call high-speed C code directly from Python. The designers of the 'Numeric' extension to Python have taken this approach and the result is a powerful library using which we can do complex numerical computation efficiently.

Let's start with a simple program:

```
>>> from Numeric import *
>>> x = array([1,2,3,4])
>>> y = sin(x)
>>> print y, y[0
```

The function 'array' takes an ordinary Python list as argument and returns a 'special' Numeric array. The Numeric array is very different from a Python list - even though it can be indexed like a list, it can be used to store only integers, real numbers or complex numbers. There are specialized functions to manipulate the elements of a Numeric array at a very high speed. The

'sin' function used in the program above is one example; it is not the usual Python 'sin' function - you note that this function accepts a Numeric array and finds out the sin of each and every element of the array - a new array holding the computed values is returned. This is the behaviour of almost all Numeric function - they act on arrays as a whole.

9.1 Constructing a 'sampled' sine wave

Let's imitate what the Phoenix ADC does in software - we will 'sample' a 50Hz sine wave at a frequency of 1KHz; we will take 200 samples. The samples will be taken at points of time 0.001, 0.002, .003 .... Let's create a Numeric array to represent these points in time:

```
>>> t = arange(0, 200) * 0.001
>>> print m
```

The 'arange' function creates a Numeric array of 200 numbers from 0 to 199 - the multiplication operator acts on each and every element of this array and the result is stored in m. Now, let us create our 'sampled sine wave':

```
>>> signal1 = sin(50*2*pi*t)
```

To verify that we are indeed getting a sine wave, we can think of writing a simple Python script to store the elements of the array 'signal 1'to a file and then do a plot using 'xmgrace'. We will be getting 10 full cycles of a sine wave (signal frequency is 50Hz and sampling frequency is 1KHz; so if we take 1000 samples, there will be 50 cycles in it; if we take 200 samples, we will get 10 cycles).

Let's now create another signal with a frequency of 25Hz:

```
>>> signal2 = sin(25*2*pi*t)
```

We will combine these signals:

```
>>> signal = signal1 + signal2
```

Note that the addition operator is adding up the corresponding elements of both the arrays (the addition operator works in a very different way when applied to ordinary Python lists; it simply returns a concatenated list!).

A fundamental problem in signal processing is: given a digitized waveform, identify what all frequencies are present in it. In the above example, the question is whether it is possible to find out, given the array 'signal' and the sampling frequency (1KHz), that 'signal' is composed to two sine waves of frequency 25Hz and 50Hz. The magic of Fourier transforms lets us do it!

9.2 Taking the FFT

Let's execute the following program:

```
from Numeric import *
from FFT import *
t = arange(0,200) * 0.001
signal1 = sin(50*2*pi*t)
signal2 = sin(25*2*pi*t)
signal = signal1 + signal2
f = abs(real_fft(signal))
for i in f:
    print i
```

The *real_fft* function returns a 100 element array of complex numbers (the input array was 200 elements long; the reason for this reduction in half is that the remaining elements are simply complex conjugates). We are interested in the absolute value of these complex numbers - so we take the 'abs'. Now we have a hundred element array of numbers which if analyzed properly will give us a clear picture as to what all frequencies are present in our 'signal'!

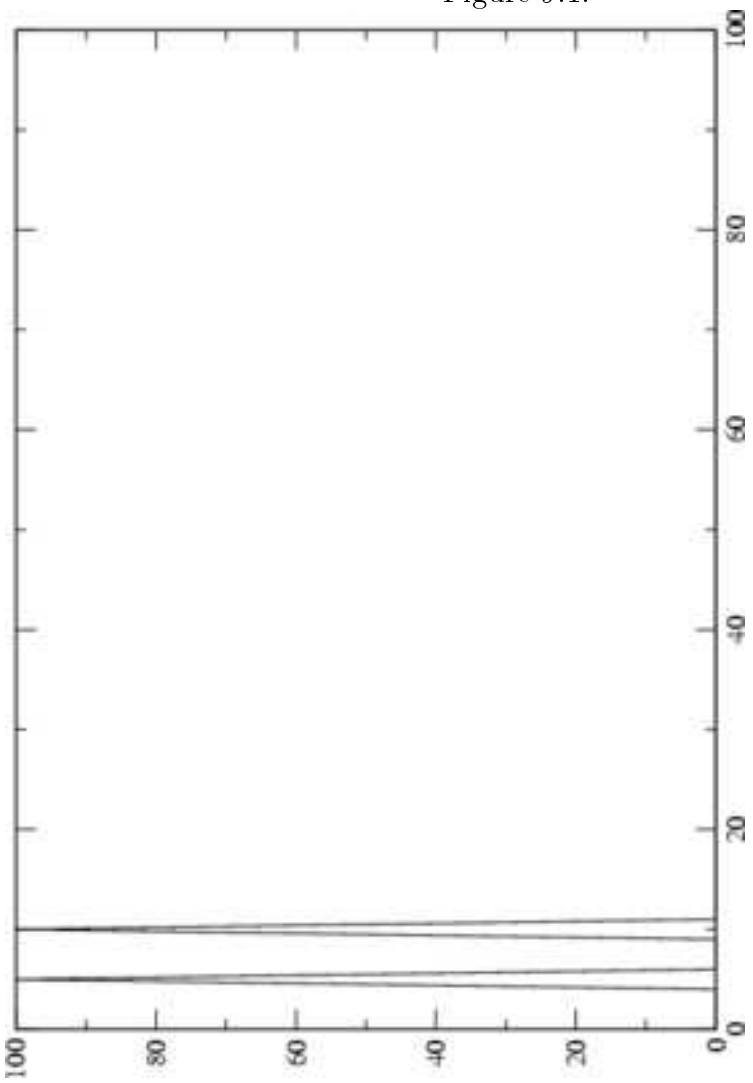
Running the above program results in a lot of numbers getting printed on the screen. Assuming you are working on GNU/Linux, you can use 'redirection' at the shell prompt to store these numbers in a file; you simply type:

```
python analyze.py > data
```

Now, the data can be plotted using xmgrace. Figure 9.1 is the resulting graph. You see two peaks, one at 5 and the other at 10. How do you interpret this?

We have a 100 element array of numbers. Our sampling frequency was 1000Hz and we had 200 samples. The 100 numbers in the array represent a frequency spectrum from 0 to 500. Each slot of the array should be thought of as a bin which holds the 'strength' of signals of frequency 0-4Hz, 5-9Hz, 10-14Hz etc in the original signal. We have two peaks at slots 5 and 10 because the two frequency components of our signal are 25Hz and 50Hz. We have been able to recover frequency information from a sequence of sampled data points. This is a very powerful idea, so powerful that much of modern multimedia, audio and video processing would not exist without it.

Figure 9.1:



Chapter 10

Appendix D - Python API Library for Phoenix-M

The Python Application Programming Interface (API) used for manipulating the Phoenix box has a collection of around 30 functions. A list of these functions together with their parameters and typical invocation is presented in this Appendix.

Conventions

A statement of the form:

void write_outputs(integer n)

Describes a function whose name is write_outputs, which does not return anything and which has just one argument whose type is integer. Note that this is just an elaborate description of the function (called a PROTOTYPE in C terminology) and does not represent the way in which the function is to be invoked in a Python program; that is described in detailed in the tutorial presented in the Chapter *Interacting with Phoenix-M.*

Simple Digital I/O

write_outputs

PROTOTYPE

void write_outputs(integer n)

DESCRIPTION

The function writes the number 'n' to the digital outputs D0 to D3

EXAMPLE

p.write_outputs(1)

read_inputs

PROTOTYPE

integer read_inputs(void)

DESCRIPTION

The function reads data from the digital inputs and returns it as an integer

EXAMPLE

m = p.read_inputs()
print m

read_acomp

PROTOTYPE

integer read_acomp(void)

DESCRIPTION

Returns 1 or 0 depending on whether the voltage on the Analog Comparator input is respectively less than or greater than 1.23V.

EXAMPLE

p.read_acomp()

Waveform generation, frequency counting and time measurement

set_frequency

PROTOTYPE

integer set_frequency(integer n)

DESCRIPTION

The function generates a square waveform on the PWG socket of the Phoenix box whose frequency is 'n' Hz. The frequency can vary from 15Hz to 4MHz. We may not get the exact frequency which we have specified, only something close to it. The function returns the actual frequency in Hz. Note that waveform generation is done purely in hardware - the Phoenix box can perform some other action while the waveform is being generated.

The DAC unit should not be used while PWG is running - doing so will result in a waveform of a different frequency.

EXAMPLE

m = p.set_frequency(1000)

measure_frequency

PROTOTYPE

integer measure_frequency(void)

DESCRIPTION

Measure the frequency of the square waveform at the CNTR input. Returns the frequency in Hz. The function is very accurate for values up to 100KHz.

EXAMPLE

f = p.measure_frequency()

adc_freq

PROTOTYPE

integer adc_freq(integer chan)

DESCRIPTION

Measure the time period of a signal applied on one of the ADC channels. Returns period in microseconds.

pulse_out

PROTOTYPE

integer pulse_out(integer delay_us)

DESCRIPTION

Send one pulse out on digital output pin D3 with high time equal to delay_us

EXAMPLE

p.pulse_out(1000) # generate 1ms pulse

pendulum_period

PROTOTYPE

integer pendulum_period(integer pin)

DESCRIPTION

range 0 to 4 (0, 1, 2, or 3 if the light barrier output is connected to digital input pins D0 to D3; 4 if connected to analog comparator input)

multi_r2rtime

PROTOTYPE

integer multi_r2rtime(integer pin, integer skipcycles)

DESCRIPTION

Measure time in microseconds between two rising edges of a waveform applied to a digital input pin (D0 to D3) or analog comparator input. If 'skipcycles' is zero, period of the waveform is returned. In general, 'skipcycles' number of consecutive rising and falling edges are skipped between the two rising edges.

EXAMPLE

p.multi_r2rtime(0, 3)

pulse2rtime, pulse2ftime

PROTOTYPE

integer pulse2rtime(integer tx, integer rx, integer width, integer pol)

integer pulse2ftime(integer tx, integer rx, integer width, integer pol)

DESCRIPTION

This function sends out a single pulse of width 'width' on the digital output pin specified by tx and waits for a rising/falling edge on the digital input or analog comparator input pin specified by rx (rx = 0-3 means digital inputs D0 to D3; rx = 4 means analog comparator input). If 'pol' is 0, the pulse is logic HIGH and if it is 1, the pulse is logic LOW.

This call is useful for doing experiments like measuring velocity of sound using ultrasound transducers - the idea is to send out a pulse on the transmitter and wait for reception at the receiver.

EXAMPLE

p.pulse2rtime(0, 1, 20, 0)

r2ftime, r2rtime, f2rtime, f2ftime

PROTOTYPE

integer r2ftime(integer pin1, integer pin2)
(remaining functions have similar prototypes)

DESCRIPTION

r2ftime returns delay in microseconds between a rising edge on pin1 and falling edge on pin2 - the pins can be the same. Pin numbers 0 to 3 indicate digital input pins D0 to D3 and pin number 4 stands for the analog comparator input. The remaining functions behave similarly, computing the time difference between two consecutive rising edges, falling and rising edges and two consecutive falling edges. However, there is one restriction. In the case of r2rtime and f2ftime, the pins CAN NOT be the same.

EXAMPLE

p.r2ftime(0, 1)

set2rtime, set2ftime, clr2rtime, clr2ftime

PROTOTYPE

integer set2rtime(pin1, pin2)
(remaining functions have similar prototypes)

DESCRIPTION

These functions set/clear a digital output pin specified by 'pin1' and wait for the digital input (or analog comparator) pin specified by 'pin2' to go high or low.

EXAMPLE

p.set2rtime(0, 1)

DAC Functions

set_dac

PROTOTYPE

void set_dac(integer n)

DESCRIPTION

Write a one byte value to the 8 bit DAC. The DAC output varies from 0 to 5000 mV. Writing a 0 to the DAC results in an output voltage of 0 and writing a 255 results in an output voltage of 5V. Intermediate values give appropriately scaled outputs. Almost always, you will not have to use this function in your code - the *set_voltage* function is much more convenient.

Note that using the PWG (by calling *set_frequency*) will result in the DAC output changing - these units should not be used at the same time.

EXAMPLE

p.set_dac(127)

set_voltage

PROTOTYPE

void set_voltage(integer n)

DESCRIPTION

Set the output voltage of the DAC. The value of n should be an integer between 0 and 5000. It represents voltage in mV.

EXAMPLE

p.set_voltage(1250)

ADC functions

read_adc

PROTOTYPE

tuple read_adc(void)

DESCRIPTION

Digitizes the analog voltage on the current ADC channel (set by the 'select_adc' call) and returns a number in the range 0-255 or 0-1023 (depending on the ADC sample size set by the 'set_adc_size' function) and the system time stamp as a tuple.

EXAMPLE

p.read_adc()

select_adc

PROTOTYPE

void select_adc(integer channel)

DESCRIPTION

Selects the current ADC channel. The functions read_adc, minus5000_to_5000, zero_to_5000 and read_block read from the channel selected by invoking select_adc.

EXAMPLE

select_adc(2) # select channel 2

minus5000_to_5000

PROTOTYPE

tuple minus5000_to_5000(void)

DESCRIPTION

Reads the analog voltage on the current ADC channel and returns a voltage reading in mV between -5000 and +5000. This call is used only when we wish to read bipolar signals level shifted to 0-5V range by the (-X+5)/2 amplifier. System time stamp is also returned.

EXAMPLE

p.minus5000_to_5000()

zero_to_5000

PROTOTYPE

tuple zero_to_5000(void)

DESCRIPTION

Reads the analog voltage on the current ADC channel and returns a voltage reading in mV between 0 and +5000. This call is used when we wish to read unipolar signals connected directly to the ADC channels. System time stamp is also returned.

EXAMPLE

p.zero_to_5000()

cro_read

PROTOTYPE

list cro_read(integer np)

DESCRIPTION

Special function to support the CRO program. Assumes that ADC data size is 1 byte. The parameter is the number of samples to take. Returns a list of tuples with raw 8 bit ADC data

EXAMPLE

p.cro_read(100)

multi_read_block

PROTOTYPE

list multi_read_block(integer np, integer delay, integer bipolar)

DESCRIPTION

Returns a block of data from the ADC. The first argument specifies the number of samples to read. The second argument is the delay between two samples (in microseconds). The third argument should be 1 if the ADC reading is to be interpreted as bipolar (ie, between -5V and +5V); it should be 0 otherwise. The function reads from multiple ADC channels specified by a channel list; on powerup, the list will contain only channel 0. The functions get_chanmask,add_channel and del_channel can be used to manipulate the channel list.

The list returned by the function will look like this, assuming channel 0 and channel 1 are there in the channel list:

[[ts0, chan0_val0, chan1_val0],[ts1, chan0_val1, chan1_val1], ... [tsn, chan0_valn, chan1_valn]]

The first element of each list is the time stamp and the subsequent elements are the readings (in mV) taken from the respective channels.

Care should be taken to see to it that np * num_channels * sample_size is less than 800, which is the maximum buffer size allowed for storing ADC data.

EXAMPLE

p.add_channel(1) # add channel 1 also to the list, channel 0 is present by default

v = p.multi_read_block(100, 10, 0)

read_block

PROTOTYPE

list read_block(integer np, integer delay, integer bipolar)

DESCRIPTION

Similar to multi_read_block - only difference is that data is read from a single channel selected by the select_adc call.

ExAMPLE

p.read_block(100, 10, 0)

set_adc_delay

PROTOTYPE

void set_adc_delay(int delay_us)

DESCRIPTION

Sets the delay between ADC conversions. A delay of 6 to 100 microseconds is good for 8 bit conversions while 10 bit conversions will require more than 100 microseconds delay. Default is set to 10 microseconds.

EXAMPLE

p.set_adc_delay(20)

set_adc_size

PROTOTYPE

void set_adc_size(int size)

DESCRIPTION

The Phoenix-M ADC can take 8 bit or 10 bit samples. Calling this function with argument 1 will choose 8 bits, an argument of 2 chooses 10 bits. Default size is 8 bits.

EXAMPLE

p.set_adc_size(1)

get_chanmask, add_channel, del_channel

PROTOTYPE

integer get_chanmask(void)
void add_channel(integer channel)
void del_channel(integer channel)

DESCRIPTION

get_chanmask returns the current ADC channel mask. The channel mask decides which all channels will be read by a multi_read_block call. Let's say the channel mask's value is 5. Expressed in binary, 5 is 0101. Bits D0 (rightmost bit) as well as D2 are set - this means that channels 0 and 2 will be read by a multi_read_block call.

add_channel adds a channel to the mask. Say the current mask is 5 (channels 0 and 2 present); calling add_channel(1) will result in the mask becoming 7 (binar 0111 - bits D0, D1 and D2 set and D3 clear). Calling del_channel results in the specified channel being removed from the mask.

set_adc_trig

PROTOTYPE

void set_adc_trig(integer tr1, integer tr2)

DESCRIPTION

This function is useful when writing a CRO application. The effect of the function is evident only when a MULTIREADBLOCK function is called to read data in bulk. A CRO application typically reads a number of samples from the ADC in bulk and plots it on to the screen; this process is repeated. If every time we start digitizing from a different part of the signal (say a periodic sine wave), the display will not remain static and will tend to 'run around'. The solution is to sample the waveform at a fixed point every time. If we call the function set_adc_trig with arguments say 10 and 20, each MULTIREADBLOCK will digitize the signal when it is on a 'rising' path between 10 and 20.

EXAMPLE

p.set_adc_trig(10,20)

enable_set_high, enable_set_low

PROTOTYPE

void enable_set_high(integer pin)
void enable_set_low(integer pin)

DESCRIPTION

In some applications, it would be necessary to make a digital output pin go high/low before digitization starts. It is ofcourse possible to do this by first calling write_outputs and then starting digitization - but the in-between delay may not be acceptable

in some applications. This function, when called with a digital output pin number as argument, makes a subsequent ADC block digitization function set/clear the pin before it begins the digitization process.

EXAMPLE

p.enable_set_high(integer pin)
p.enable_set_low(integer pin)

disable_set

PROTOTYPE

void disable_set(void)

DESCRIPTION

If this function is called, the ADC block read functions will no longer set a digital output pin high or low before starting digitization. In short, this function cancels the effect of calling enable_set_high or enable_set_low

EXAMPLE

p.disable_set()

enable_rising_wait, enable_falling_wait

PROTOTYPE

void enable_rising_wait(integer pin)
vooid enable_falling_wait(integer pin)

DESCRIPTION

If an ADC block read function is called after invoking one of these functions, the block read will wait for one of the digital (0 to 3) or analog comparator (4) inputs to go high/low before starting the digitization process.

EXAMPLE

```
p.enable_rising_wait(2)
p.enable_falling_wait(1)
```

disable_wait

PROTOTYPE

```
void disable_wait(void)
```

DESCRIPTION

Similar to disable_set. This function will cancel the effect of calling enable_rising_wait or enable_falling_wait.

save_data

PROTOTYPE

```
void save_data(data, fn='plot.dat')
```

DESCRIPTION

Save the data returned by the ADC block read functions into a file in multi column format. Default filename is 'plot.dat'; this can be overriden.

EXAMPLE

```
v = p.read_block(200, 10, 1)
p.save_data(v, 'sine.dat')
```

Plotting Functions

PROTOTYPE

void plot(data, width=400, height=300, parent=None)

DESCRIPTION

Plots the data returned by read_block and multi_read_block. Provides grid, window resizing and coordinate measurement facilities. Any previous plot existing on the window will be deleted.

EXAMPLE

```
v = p.read_block(200, 10, 1)
p.plot(v)
```

PROTOTYPE

void plot_data(data, width=400, height=300)

DESCRIPTION

Plots the data returned by read_block and multi_read_block. Use this inside infinite loops where plot() function may not work properly.

EXAMPLE

```
v = p.read_block(200, 10, 1)
p.plot_data(v)
```

Bibliography

[1] ATMega16 Documentation, Atmel corporation www.atmel.com/dyn/resources/prod_documents/doc2466.pdf

[2] Plotting package xmgrace http://plasma-gate.weizmann.ac.il/Grace/