

ExpEYES-Junior

Programmer's Manual

Ajith Kumar B.P

Inter-University Accelerator Centre

New Delhi 110 067

Version 1.1 (26-Oct-2013)

<http://expeyes.in>

Contents

1	Introduction	4
1.1	Software	4
2	Hardware Communication	6
2.1	Analog Output	7
2.1.1	set_voltage()	7
2.2	Digital Inputs (IN1, IN2 and SEN)	8
2.2.1	get_state(channel#)	8
2.3	Digital Output (OD1)	8
2.3.1	set_state(channel#, state)	8
2.4	Analog Inputs (A1,A2,IN1,IN2 & SEN)	8
2.4.1	get_voltage(channel#)	9
2.4.2	get_voltage_time(channel#)	9
2.4.3	get_voltageNS(channel#)	9
2.4.4	capture(ch, NP, tg)	10
2.4.5	capture2, capture3 & capture4	10
2.4.6	capture_hr(ch, NP, tg), capture2_hr(ch1, ch2, NP, tg)	11
2.5	Capture modifiers	11
2.5.1	set_trigger(trigval)	12
2.5.2	set_trigsource(channel#)	12
2.5.3	enable_wait_high(channel#), ..._low(...), ..._falling(...), ..._rising(...)	12
2.5.4	enable_set_high(channel#), ..._low(...), ..._pulse_high(...), ..._low(...)	13
2.5.5	set_pulsewidth(width)	13
2.6	Waveform Generation	13
2.6.1	set_sqr1(freq), set_sqr2(freq)	14
2.6.2	set_sqrs(freq, phase shift in percent)	14
2.6.3	set_sqr1_pwm(dutycycle), set_sqr2_pwm(dutycycle)	14
2.6.4	set_sqr1_dc(voltage), set_sqr2_dc(voltage)	14
2.6.5	get_frequency(pin)	15
2.7	Infrared Transmission	15
2.7.1	irsend1(byte)	15
2.7.2	irsend4(byte, byte, byte, byte)	16

2.8	Passive Time Interval Measurements	16
2.8.1	r2ftime(pin1, pin2) , f2rtime(pin1, pin2)	16
2.8.2	r2rtime(pin1, pin2), f2ftime(pin1, pin2)	16
2.8.3	multi_r2rtime(channel#,skip_edges)	16
2.9	Active Time Interval Measurements	17
2.9.0.1	set2rtime (Digital Output, Digital Input)	17
2.9.0.2	htpulse2rtime(Digital output, Digital Input)	17
2.9.0.3	set_pulse_width(width)	17
2.10	1mA Current Source	18
2.11	Capacitance measurements	18
2.11.1	measure_cap()	18
2.11.2	measure_cv(channel, duration, current)	18
2.11.3	set_current(channel, current)	19
2.12	Resistance Measurements	19
2.12.1	measure_res()	19
2.13	Disk Writing	19
2.13.1	save_data	19
3	Data processing	21
3.0.1	fit_sine	21
3.0.2	fit_dsine	21
3.0.3	fit_exp	22
3.0.3.1	fft	22
4	Experiments	23
4.1	Transient response of LC circuit	23

Chapter 1

Introduction

The design of expEYES is shown schematically in figure1.1, along with the top panel marking the Input/Output connectors explained in table 1.1. Functions for accessing the feature of the expEYES hardware, like measuring a voltage or frequency, setting a voltage or frequency, measuring time intervals etc. are available in Python and C languages. Data analysis and graphics functions are given in two separate Python modules. Application programs are developed using these modules.

1.1 Software

There are mainly three modules under the expeyes package:

- eyesj.py : hardware communication
- eyepplot.py : Graphics using Tkinter module
- eyemath.py : data analysis using modules numpy and scipy
- ejlib.c & ejlib.h : C library and the header file

They can be installed by using the .tgz files or the .deb packages provided on <http://expeyes.in>.

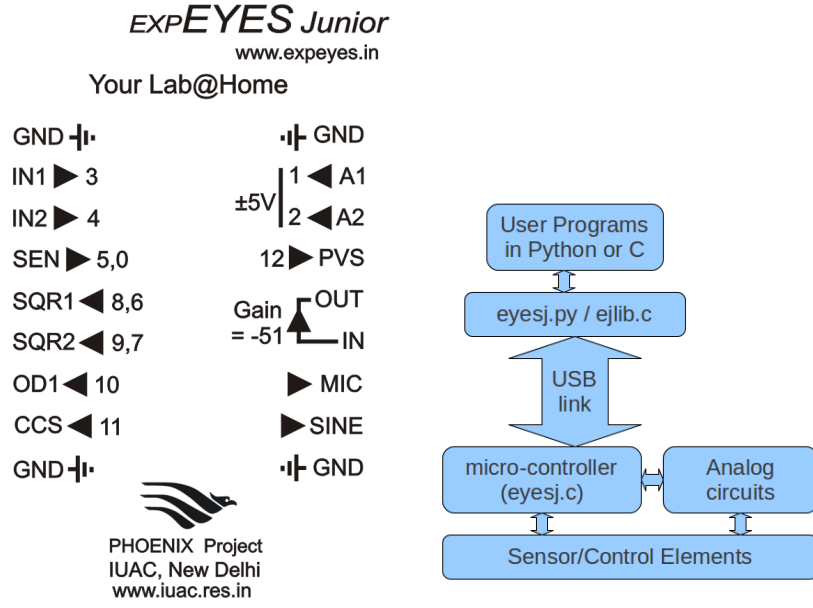


Figure 1.1: expEYES Junior Top panel and Block diagram

Pin #	Name	Description
1	GND	Ground
2	IN1	0 to 5V range Analog /Digital Input, Current Source
3	IN2	0 to 5V range Analog / Digital Input, Current Source
4	SEN	0 to 5V range Analog/Digital Input, with 5K pullup, for resistive sensors
5	SQR1	.7Hz to 200kHz Square Wave Output, 100 Ω series resistor
6	SQR2	.7Hz to 200kHz Square Wave Output, no series resistor
7	OD1	Digital Output, no series resistor
8	CCS	1 mA Constant Current Source with ON/OFF Control
9	GND	Ground
10	GND	Ground
11	SINE	Sinewave output, around 150 Hz, 4 volts
12	MIC	Output of the microphone, amplified 51 times
13	IN	Inverting Amplifier Input, maximum gain = 51
14	OUT	Amplifier output, of Pin13
15	PVS	Programmable Voltage Output, from 0 to 5 volts.
16	A2	$\pm 5V$ range Analog Input
17	A1	$\pm 5V$ range Analog Input
18	GND	Ground

Table 1.1: Description of Input/Output Terminals

Chapter 2

Hardware Communication

The module `expeyes.py` contains all the functions required for communicating to the hardware in addition to some utility functions. The functions are inside a class and the `open()` function returns an object of this class if `expEYES` hardware is detected. After that the function calls to access `expEYES` are done using this object, as shown in the example below.

```
import expeyes.eyesj      # import the eyes library
p = expeyes.eyesj.open()  # returns an object if hardware is found
print p.get_voltage(1)    # print the voltage at input A1
```

A sample program in C language is given below. This should be compiled and executed.

```
#include "ejlib.c"
int fd;
int main()
{
    byte ss[10];
    fd = open_eyesj();
    if(fd < 0)
    {
        fprintf(stderr, "EYES Open Failed\n");
        exit(0);
    }
    if(get_version(ss) != 0) exit(1);
    printf("%s\n", ss);
}
```

On error, the Python functions returns `None` (-1 in the case of time interval measurements). On success the data is returned. The C functions returns zero on success, an errorcode otherwise. The data is always returned using the addresses passed to the function by the calling program. In both Python and C, the functions are given the same names. The main difference is in returning the results. In C, you need to pass an address for that. The function returns only

Channel #	Name
0	Analog Comparator output
1	A1
2	A2
3	IN1
4	IN2
5	SEN
6	SQR1 readback
7	SQR2 readback
8	SQR1 output
9	SQR1 output
10	OD1 output
11	CCS output control
12	PVS Readback

Table 2.1: Signals and Channel Numbers

the status of the operation. Some of the C functions are mentioned below. It is easier to have a look at the header file *ejlib.h*.

For every function, the Python and C versions are described, but no example code given in C. Every function communicates to the program running on the micro-controller on the expEYES Junior board. The hardware communication functions can be broadly grouped into analog inputs, analog outputs, digital inputs, digital outputs, time interval measurements, waveform generation etc. For plotting data from expEYES, the python-matplotlib package is used.

The following sections will introduce features of expEYES with examples. The voltages applied MUST be within the specified limits. *A channel number is assigned to identify every Analog/Digital signal. The function calls uses this number for accessing it.*

2.1 Analog Output

The Programmable Voltage Sources (PVS) can be set anywhere between 0 and 5 volts. The resolution is 12 bits, means the minimum step is 5000/4095, around 1.25 millivolts.

2.1.1 set_voltage()

Set the output voltage of the PVS. The value of V should be in 0 to 5 volts range. The function returns the actual value set, by reading it back using an ADC input (channel number 12).

```
print p.set_voltage(2.5)      # Sets 2.5 volts on PVS
```

C function: `byte set_voltage(float v, float* vset);` // vset returns the readback of PVS

2.2 Digital Inputs (IN1, IN2 and SEN)

You can connect them externally to GND or 5 volts , to make the voltage level HIGH or LOW. Any voltage less than 1 volt is taken as a LOW or 0. Anything greater than 2.5 volts is treated as a HIGH or 1. These terminals can also be configured as Analog Inputs.

2.2.1 `get_state(channel#)`

Returns 0 or 1, depending on the voltage level at the input pin

```
print p.get_state(3)    # prints logic level of IN1.  IN2 = 4, SEN = 5
print p.get_state(0)    # Returns "1" if SEN > 1.25 volts
```

Channel 0 represents the analog comparator output. The positive input of analog comparator should be connected to SEN. Negative input is internally connected to 1.25 volts.

One of the powerful feature of digital inputs is the ability to measure the time between level transitions with microsecond resolution. This will be discussed later.

C function: `byte get_state(byte pin, byte *st);` // variable st returns 0 or 1.

2.3 Digital Output (OD1)

You can set the voltage level on them to LOW or HIGH volts using software. If you connect LEDs to them, use a 1K Ω series resistor for current limiting.

2.3.1 `set_state(channel#, state)`

This function sets the specified channel to state "0" or "1".

```
p.set_state(10,1)      # Sets OD1 HIGH. Channel number of OD1 is 10
```

The outputs SQR1 (8) and SQR2 (9) also can behave as digital outputs, provided they are not configured to generate Square or PWM outputs.

C function: `byte set_state(byte pin, byte state);` // pin is set to 0 or 1, according to the value of state.

2.4 Analog Inputs (A1,A2,IN1,IN2 & SEN)

The analog inputs A1 and A2 accept voltages between -5 volts and +5 volts. The Inputs IN1, IN2 and SEN can accept voltages in the 0 to 5 volts range. We can read the voltage level at any of this inputs, either as single reads or multiple reads in a single function call, normally to capture a waveform. The time interval between consecutive reads within a capture can be set with microsecond resolution.

2.4.1 `get_voltage(channel#)`

```
print p.get_voltage(1) # voltage at A1
print p.get_voltage(2) # voltage at A2
print p.get_voltage(3) # voltage at IN1
print p.get_voltage(4) # voltage at IN2
print p.get_voltage(5) # voltage at SEN
print p.get_voltage(6) # voltage at SQR1 output
print p.get_voltage(7) # voltage at SQR2 output
print p.get_voltage(12) # voltage at PVS output
```

Connect PVS to A1 using a piece of wire and run the following program several times.

```
import expeyes.eyesj      p = expeyes.eyesj.open()
v = input('Enter V (0 to 5)')
print p.set_voltage(v)    # prints the voltage set on PVS
print p.get_voltage(1)    # voltage at A1
```

If the voltages are in the 0 to 5 volts range, use IN1 or IN2 for better results. The $\pm 5V$ range inputs A1 & A2 are converted in to 0 to 5V range using summing junctions. The amplifiers used for this will have some gain and offset errors. The resolution also is halved because of the doubles total range. The input SEN has a 5k pullup resistor to 5 volts, for connecting photo-transistors and other resistive sensors .

C function: `byte get_voltage(byte ch, float* v)`

2.4.2 `get_voltage_time(channel#)`

This function returns the time stamp, from the PC clock, and the voltage in a tuple. This is useful for data logging applications.

C function: `byte get_voltage(byte ch, int* t, float* v)`

2.4.3 `get_voltageNS(channel#)`

The `get_voltage()` function mentioned in the previous section measures the voltage after putting the micro-controller in SLEEP mode, for better accuracy. This will stop waveforms set on SQR1 & SQR2. If that is not acceptable for a particular experiment, one can use this function.

```
print p.get_voltageNS(1) # voltage at A1
```

C function: `byte get_voltageNS(byte ch, float* v)`

2.4.4 capture(ch, NP, tg)

The argument *ch* is the input channel number, *NP* is the number of measurements and *tg* is the time between two measurements in microseconds. Two lists containing the time (milliseconds) and voltage (volts) coordinates are returned by this function. Capture calls return analog data with 8 bit resolution. Maximum value of NP is 1800, limited by the micro-controller RAM available.

The minimum value of 'tg' is 4 microseconds. The value of 'tg' is decided by the frequency of the signal to be captured. For example, one cycle of a 1kHz sine wave is 1000 microseconds. A tg of 20 will give 50 data points per cycle.

Connect SINE to A1 and run the following program.

```
from pylab import * import expeyes.eyesj p = expeyes.eyesj.open()
t,v = p.capture(1,300,100)
plot(t,v)      # from pylab
show()         # from pylab
```

Terminal	Channel #	Range(V)
A1	1	-5 to +5
A2	2	-5 to +5
IN1	3	0 to 5
IN2	4	0 to 5
SEN	5	0 to 5
SQR1(read)	6	0 to 5
SQR2(read)	7	0 to 5

If the voltage to be measured is in the 0 to 5V range, use IN1 or IN2, for a better resolution. The SEN input has a 5k Ω pullup resistor to 5V supply. We can calculate the value of a resistance connected from SEN to GND, from the measured voltage, using Ohm's law.

C function: byte capture(int ch, int ns, int tg, float* data);

The variable data returns an array of 2*ns float type elements, first ns time coordinates and after that ns voltage coordinates. It is the responsibility of the calling program to pass the address of an array having sufficient size. capture_hr() also returns data in the same format.

2.4.5 capture2, capture3 & capture4

These functions captures multiple channels together, with timing correlation. The maximum value of NP for capture4 = 1800/4 = 450. The minimum value of 'tg' is 4 microseconds per channel, capture4 should have a minimum tg of 16.

```
t1,v1,t2,v2 = capture2(ch1, ch2, NP, tg)
t1,v1,t2,v2 = capture2_hr(ch1, ch2, NP, tg)
t1,v1,t2,v2,t3,v3 = capture3(ch1, ch2, ch3, NP, tg)
t1,v1,t2,v2,t3,v3,t4,v4 = capture4(ch1, ch2, ch3, ch4, NP, tg)
```

C function: `byte capture2(int ch1, int ch2, int ns, int tg, float* data);`

The variable data returns an arrays of $2(2*ns)$ float type elements. First $(2*ns)$ are the time and voltage values for channel 1 and the next $(2*ns)$ for channel 2. Function capture3 and capture4 also returns data in a similar manner.

2.4.6 `capture_hr(ch, NP, tg)`, `capture2_hr(ch1, ch2, NP, tg)`

These two functions captures data with higher resolution (12 bits). In this case each value takes 2 bytes and the maximum value of NP is 900 for `capture_hr`, and 450 for `capture2_hr`. High resolution version is NOT available for capture3 and capture4.

```
t1,v1 = capture_hr(ch1, 900, 10)
t1,v1,t2,v2 = capture2_hr(ch1, ch2, 450, 20)
plot(t1,v1, t2,v2)
show()
```

We can find out the amplitude and frequency of the input waveform by mathematically fitting the captured data to the equation of a sine wave $V = V_0 \sin(2\pi ft + \theta) + C$. By capturing 4 to 5 cycles, the frequency can be obtained within 0.1% error.

2.5 Capture modifiers

When a periodic wave form is captured, the starting point could be at any voltage, within the minimum and maximum voltage. To implement an oscilloscope, we need to make sure that the starting point is always same, else the trace will be jumping around. This is a simple example of a capture modifier. expEYES implements several other types of capture modifiers to enhance the functionality of the capture functions. The basic idea is to perform some action just before starting the waveform capture. The important types of modifiers (or actions) are

- Analog Trigger on any input channel, trigger level can be set by the user.
- Wait for HIGH, LOW, Falling Edge or Rising Edge on Inputs IN1, IN2, SEN, SQR1 or SQR2
- Set, Clear or send Pulse one of the Digital Outputs, mainly OD1. SQR1 & SQR2 also will act as digital outputs if frequency is set to zero.

`enable_action(action, Selected I/O)` is the function call for registering actions. They will be valid on subsequent capture calls. Calling `disable_actions()` removes all registered actions and capture goes back to its default state of analog triggering on the captured channel. For convenience, we have defined more functions that internally call the function `enable_action()`

Action	Code	Description
AANATRIG	0	Trigger on analog input level
ASET	1	Makes the specified Output HIGH
ACLR	2	Makes the specified Output LOW
APULSEHT	3	Send High True Pulse on Output
APULSELT	4	Send Low True Pulse on Output
AWAITHI	5	Wait for HIGH level on specified Input
AWAITLO	6	Wait for LOW level on specified Input
AWAITRISE	7	Wait for Rising Edge on specified Input
AWAITFALL	8	Wait for Falling Edge on specified Input

Table 2.2: Capture Modifiers

2.5.1 `set_trigger(trigval)`

Sets the analog voltage trigger level, for the capture function. If the specified voltage value is not found at the input, within the timeout period, the capture is done ignoring the trigger condition.

```
p.set_trigger(2048)    # 0 to 4095 is the analog range
```

2.5.2 `set_trigsource(channel#)`

The Input source to be used for analog level triggering. It need not be the one that is captured. The example code below demonstrates the effect of this function. Connect SINE to A1 before running.

```
from pylab import * import expeyes.eyesj p = expeyes.eyesj.open()
ts = 1          # run the program by changing this to 2
p.set_trig_source(ts)
t,v = p.capture(1,300,50)
plot(t,v)
t,v = p.capture(1,300,50)
plot(t,v)
show()
```

The traces will not overlap if the trigger source is set to some other channel, provided there is no time correlation between the two inputs.

C function: `byte set_trig_source(byte ch);`

2.5.3 `enable_wait_high(channel#), ..._low(...), ..._falling(...), ..._rising(...)`

Calling this function makes all the subsequent **capture** calls to wait for a HIGH / LOW / rising edge/ falling edge, on the specified input before starting the digitization.

```

p.enable_action(1, 11)    # Start CCS before capturing
p.enable_wait_rising(3)   # wait for a rising edge on IN1
p.disable_actions()       # removes all modifiers

```

C function: `byte enable_wait_high(byte ch);`

2.5.4 `enable_set_high(channel#), ..._low(...), ..._pulse_high(...), ..._low(...)`

In some applications, it would be necessary to make a digital output high/low or send a pulse, width set by another function, with before digitization starts. Capturing the voltage across a capacitor while charging / discharging is a typical application of this feature. Connect a 1uF capacitor between A1 and GND. Connect a 1K Ω resistor from OD1 to A1 and run the following code.

```

from pylab import * import expeyes.eyesj p = expeyes.eyesj.open()
p.set_state(10,1)          # Take OD1 HIGH
p.enable_set_low(10)       # OD1 go LOW before capture
t,v = p.capture(1,200,20)
plot(t,v)
show()

```

C function: `byte enable_set_high(byte ch);`

2.5.5 `set_pulsewidth(width)`

Sets the width of the pulse that is send on the digital outputs before capturing, in microseconds, up to 250.

```

p.set_pulsewidth(100)    # sets the pulsewidth

```

C function: `byte set_pulsewidth(u16 width);`

2.6 Waveform Generation

ExpEYES can generate square waves on SQR1 and SQR2. The frequency can vary from 0.7 Hz to 100 kHz. All intermediate values are NOT possible since the output is generated by timers and comparators. The function returns the actual values set, closest possible to the requested. Output SQR1 has a 100 Ω series resistor for current limiting, but SQR2 is directly connected.

2.6.1 `set_sqr1(freq)`, `set_sqr2(freq)`

Generates a square waveform, having 50% duty cycle, on SQR1/SQR2. SQR1 has a 100Ω series resistor on it. Setting `freq = 0` will make the output HIGH and setting `freq = -1` will make it LOW. Both these cases disables the Timer/Counter and configures it as a normal digital output.

```
import expeyes.eyesj      p = expeyes.eyesj.open()
print p.set_sqr1(1000)
```

C function: `byte set_sqr1(float freq, float *fset);`

The desired value is specified in 'freq', after the call 'fset' will contain the actual frequency set.

2.6.2 `set_sqrs(freq, phase shift in percent)`

Generates a square waveform of same frequency on both SQR1 and SQR2. The phase shift between the two can be set in percentage of the Time Period.

```
p.set_sqrs(1000,50)      # Two out of phase waveforms
```

C function: `byte set_sqrs(float freq, float diff, float *fset);`

2.6.3 `set_sqr1_pwm(dutycycle)`, `set_sqr2_pwm(dutycycle)`

SQR1 and SQR2 can be configured for making Pulse Width Modulated waveform. The duty cycle is specified in percentage. The frequency is 488Hz by default, because the second argument is set to 14 by default. This is the index of counter's bit which triggers the PWM. Specifying the second argument can be used for changing the frequency. Reducing it by 1 will double the frequency and increasing by 1 will halve it.

```
print p.set_sqr1_pwm(20)      # 488Hz, 20% duty cycle  print p.set_sqr1_pwm(50, 15)
print p.set_sqr1_pwm(50, 13)  # 976Hz, 50% duty cycle
```

C function: `byte set_sqr1_pwm(byte dc);`

2.6.4 `set_sqr1_dc(voltage)`, `set_sqr2_dc(voltage)`

SQR1 and SQR2 can be configured to generate a DC voltage, by external filtering, from a PWM waveform. The voltage, 0 to 5V range, is specified as the argument.

```
print p.set_sqr1_dc(2)      # 7.8 kHz, 40% duty cycle
```

Filtering the waveform generates a DC voltage. Connect 10k from SQR1 to IN1 and 100uF from IN1 to GND.

```
print p.get_voltage(3)    # voltage at IN1
```

The output voltage depends on the supply voltage provided by USB. Setting 3 volts means only setting 60% of the supply voltage. The readout from IN1 will give the correct value.

C function: byte set_sqr1_dc(float volt)

2.6.5 get_frequency(pin)

Measure the frequency of a 0 to 5V square wave connected to IN1, IN2 or SEN. You can also measure the frequency of SQR1 & SQR2 outputs from channels 6 and 7 respectively. Connect SQR1 to IN1 and run the following code

```
import expeyes.eyesj      p = expeyes.eyesj.open() p.set_sqr1(1000)
print p.get_frequency(3)   # frequency of squarewave at IN1
print p.get_frequency(6)   # frequency of SQR1, same as above
```

C function: byte get_frequency(byte pin, float *fr)

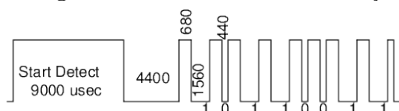
2.7 Infrared Transmission

The SQR1 output supports two types of 38kHz infrared transmission protocol. One is a non-standard 1 byte transmission, that can be received by another program running on an AT-mega32 micro-controller. This can be used for controlling some device from expEYES junior.

2.7.1 irsend1(byte)

Sends the byte over SQR1. Just connect an IR LED from SQR1 to GND and issue the command.

To signify a start 38kHz is kept on for 9000 microseconds followed by a silence of 4400 microseconds. After that 38kHz is kept ON for 680 usec followed by (a) silence of 1560 usecs to transmit a 1 and 440 usecs to transmit a 0. This process is repeated 8 times, starting with the MSB of the byte to be transmitted. The sequence ends by transmitting a 340 usecs long burst again. This is received by a program¹ given on the website.



¹<http://expeyes.in/sites/default/files/debs/recv.c>

2.7.2 irsend4(byte, byte, byte, byte)

The Start and End are identical to irsend1() but instead of 1 byte, 4 bytes are sent in a single transmission. If the numbers are chosen properly, you can control TVs or other instruments using this.

2.8 Passive Time Interval Measurements

Digital Inputs can be used for measuring time intervals between level transitions on the digital inputs with microsecond resolution. The transitions defining the start and finish could be on the same terminal or on different ones.

2.8.1 r2ftime(pin1, pin2) , f2rtime(pin1, pin2)

r2ftime returns delay in microseconds from a rising edge on pin1 to a falling edge on pin2, the channel numbers corresponding to the inputs should be given as the arguments. The pins could be same or distinct. Similarly f2rtime() measures time from a falling edge to a rising edge.

Connect SQR1 to IN1 and run the following code, should print around 500 usecs.

```
import expeyes.eyesj      p = expeyes.eyesj.open()
p.set_sqr1(1000)          # 1kHz, T=1msec. half period = 500 usecs
print p.r2ftime(3,3)
```

C function: byte r2ftime(byte pin1, byte pin2, float *ti)

2.8.2 r2rtime(pin1, pin2), f2ftime(pin1, pin2)

r2rtime returns delay in microseconds from a rising edge to rising edge. The pins should NOT be the same. The following code shows how to use this for measuring delay between two transitions.

```
import expeyes.eyesj      p = expeyes.eyesj.open()
p.set_sqrs(1000, 25)      # 1000Hz on both SQR1 & 2. Delay by 25%, 250us
print p.r2rtime(6,7)      # Channels 6 & 7 are readback of SQR1 and SQR2
```

2.8.3 multi_r2rtime(channel#,skip_edges)

Measures time interval between two rising edges of a waveform applied to a digital input. The second argument is the number of rising edges to be skipped between the two measured rising edges. This way we can decide the number of cycles to be measured.

Connect SQ1to IN1 and run the following code.

```

import expeyes.eyesj      p = expeyes.eyesj.open() p.set_sqr1(1000)
a = p.multi_r2rtime(3)    # time for 1 cycle in usecs
b = p.multi_r2rtime(3,9) # time for 10 cycles in usecs
print 10.0e6/a # frequency in Hz

```

For a periodic waveform input, the fourth line of the program returns the time for one cycle and the fifth one returns the time for 10 cycles (9 rising edges in between skipped). This call can be used for frequency measurement. The accuracy can be improved by measuring larges number of cycles.

C function: byte multi_r2rtime(byte pin, byte skip, float *ti)

2.9 Active Time Interval Measurements

During some experiments, we need to initiate some action and measure the time interval to the result of of that action. These functions are used in experiments like gravity by time of flight and velocity of sound using ultrasound piezo discs.

2.9.0.1 set2rtime (Digital Output, Digital Input)

This makes the specified Digital Output HIGH and waits for a HIGH on the Digital Input. Connect a 1k resistor from OD1 to IN1 and a 1uF capacitor from IN1 to GND.

```
p.set2rtime(10, 3)
```

2.9.0.2 httpulse2rtime(Digital output, Digital Input)

```
int httpulse2rtime(out, in)
```

Sends out a single High True pulse on **out** (SQR1, SQR2 or OD1) and waits for a rising/falling edge on **in** (IN1, IN2 or SEN). The duration of the pulse is set by set_pulsewidth(). On powerup the width is 13 microseconds. The initial level of **out** should be set according to the kind of pulse.

Similarly we have httpulse2ftime(), ltpulse2rtime() and ltpulse2ftime().

```

p.set_pulse_width(1)
print p.httpulse2rtime(10, 3)

```

measures the time from a 1usec wide High True pulse on OD1 to a rising edge on IN1.

2.9.0.3 set_pulse_width(width)

Sets the pulse width, in microseconds, to be used by the httpulse2rtime(), httpulse2ftime(), ltpulse2rtime(), ltpulse2ftime() functions.

```
p.set_pulse_width(10)
```

2.10 1mA Current Source

The 1mA constant current can be switched ON or OFF by channel number 11, as shown below

```
p.set_state(11, 1)    # switch on CCS
```

We can plot the linear charging of a 1uF capacitor by connecting it between CCS and GND, and running the following code. Connect CCS to IN1 for voltage measurement.

```
from pylab import *
import expeyes.eyesj, time
p = expeyes.eyesj.open()
p.set_state(11,0)      # switch of CCS
time.sleep(1)          # wait for discharge
p.enable_set_high(11)  # enable CCS just before capture
t1,v1= p.capture_hr(3,500,10)
plot(t1,v1)
show()
```

2.11 Capacitance measurements

The IN1 pin can be used for measuring capacitance, ranging from hundred to several thousand pico Farads. This is done using an internal programmable constant current source.

2.11.1 measure_cap()

Connect the capacitor between IN1 and ground and run the function `measure_cap()`.

```
import expeyes.eyesj
p = expeyes.eyesj.open()
print p.measure_cap()
```

The capacitance is measured by charging the capacitor with a 5.5 uA constant current source for a fixed duration. The total charge is given by $Q = It = CV$. If V,I and t are known, C can be calculated. The value of the current source may vary from 5.5 uA and the empty socket, along with tracks, also has some capacitance. These error are taken can by calibrating it using a known capacitor. The error factors are stored in EEPROM of the micro-controller.

2.11.2 measure_cv(channel, duration, current)

This is a more flexible version of `measure_cap`, allowing to set the current source on IN1 or IN2. The current source is activated for 'duration' microseconds. The last argument could be .55, 5.5, 55 or 550 microamps. The function returns the voltage at the selected input after applying the current for the specified duration.

Depending on the value of the capacitor connected, we need to select duration and current such that the voltage developed is between 2 to 4 volts for good results. Connect a 330 pF capacitor from IN1 to GND and run the following code.

```
import expeyes.eyesj
p = expeyes.eyesj.open()
print p.measure_cv(3, 200, 5.5) # result was 3.017 volts
```

The capacitance can be calculated using the expressions $Q = CV$ and $Q = I \cdot t$. $C = I \cdot t / v = 5.5 \cdot 200 / 3.017 = 364 \text{ pF}$. Subtracting the Stray capacitance 32pF gives a result of 332pF.

2.11.3 set_current(channel, current)

This function enables the internal current source on IN1 or IN2. This Constant Current Source may be used for measuring the current with some other device. The voltage readback is not working as expected. Using an ammeter connected from IN1 to ground, it is found that the current is 5.5 uA , 47 uA and 450 uA, somewhat less than the specification, in higher ranges.

2.12 Resistance Measurements

The SEN input is internally connected to 5 volts through a 5100Ω resistor. It is possible to calculate the value of a resistor connected from SEN to GND using Ohm's law. However, the internal resistor may not be exactly 5100 due to component tolerance.

2.12.1 measure_res()

The input SEN is connected to 5 volts internally through a 5100 Ohm resistor. Connecting an external resistor from SEN to GND makes a potential divider. It is possible to calculate the value of the resistor connected using Ohm's law.

This function returns the value of a resistance connected from SEN to GND, calculated using the equation

$$R_{ext} = R_{int} * V_{SEN} / (5.0 - V_{SEN})$$

2.13 Disk Writing

2.13.1 save_data

Input data is of the form, [[x1,y1], [x2,y2],....] where x and y are vectors, are save to a text file.

Save the data returned by the capture functions into a text file. Default filename is 'plot.dat', that can be overridden by the second argument. Connect SINE to A1 and run the following code.

```
import expeyes.eyesj      p = expeyes.eyesj.open()
t,v = p.capture(1, 200, 100)
p.save([[t,v]], 'sine.dat')
```

open the file using the command

```
$xmgrace sine.dat
```

Chapter 3

Data processing

The data acquired from expEYES hardware is analyzed using various mathematical techniques like least-square fitting, Fourier transform etc. The module named eyemath.py does this with the help of functions from the 'scipy' package. Most of the functions accepts the data format returned by capture functions.

3.0.1 fit_sine

Accepts two vectors [x] and [y] and tries to do a least-square fitting of the data with the equation $A \sin(2\pi ft + \theta) + C$. Returns the fitted data and the parameter list $[A, f, \theta, C]$. Connect SINE to A1 and run the following code.

```
from pylab import *
import expeyes.eyesj, expeyes.eyemath as em
p = expeyes.eyesj.open()
t,v= p.capture(1,400,100)
vfit, par = em.fit_sine(t,v)
print par          # A, f,  $\theta$ , C
plot(t,v)          # The raw data
plot(t,vfit)       # data calculated from par
show()
```

par[1] is frequency in kHz, since the time is given in milliseconds.

3.0.2 fit_dsine

Accepts two vectors [x] and [y] and tries to do a least-square fitting of the data with the equation $A = A_0 \sin(2\pi ft + \theta) \times \exp(-dt) + C$. Returns the fitted data and the parameter list $[A, f, \theta, C, d]$. par[1] is frequency in kHz, since the time is given in milliseconds and 'd' is the damping factor.

3.0.3 fit_exp

Accepts two vectors [x] and [y] and tries to do a least-square fitting of the data with the equation $A = A_0 \exp(kt) + C$. Returns the fitted data and the parameter list $[A, k, C]$. Connect a 1uF capacitor from A1 to GND, 1k Ω resistor from OD1 to A1 and run the following code.

```
from pylab import * import expeyes.eyesj, expeyes.eyemath as em
p = expeyes.eyesj.open() p.set_state(10,1)      # Take OD1 HIGH
p.enable_set_low(10)      # OD1 go LOW before capture
t,v = p.capture(1,200,20)
plot(t,v)
vfit, par = em.fit_exp(t,v)
print par
plot(t,v)      # The raw data
plot(t,vfit)    # data calculated from par
show()
```

-(1/par[1]) is the time constant RC in seconds.

3.0.3.1 fft

Does a Fourier transform of a given data set. The sampling interval in milliseconds is the second argument. Returns the frequency spectrum, ie. the relative strength of each frequency component. Connect SINE to A1 and run the following code.

```
from pylab import *
import expeyes.eyesj, expeyes.eyemath as em
ns = 1000    # number of points to be captured
tg = 100     # time between reads in usecs p = expeyes.eyesj.open()
t,v= p.capture(1, ns, tg)
x,y = em.fft(v, tg * 0.001) # tg in millisecs
plot(t,v)    # The raw data
plot(x,y)    # data calculated from par
show()
```

The frequency spectrum should feature a peak at frequency $f=150\text{Hz}$. A small peak at frequency $2f$ may be visible.

Modify this program to show the frequency spectrum of a square wave.

Chapter 4

Experiments

Most of the experiments described in the user manual can be done by writing few lines of Python code.

4.1 Transient response of LC circuit

Connect inductor from OD1 to A1, capacitor from A1 to GND.

```
NP = 200    # number of readings
tg = 10     # time gap between them, keep NP*tg around 3*RC
from pylab import *
import expeyes.eyesj, expeyes.eyemath as em
p = expeyes.eyesj.open()
p.set_state(10,1)
p.enable_set_low(10)           # OD1 go LOW before capture
t,v = p.capture_hr(1,NP,tg)    # choose NP*tg according to time constant
plot(t,v)
vf, par = em.fit_exp(t,v)      # exponential fit
plot(t, vf, 'r')
print abs(1./par[1])           # print RC value
show()
```