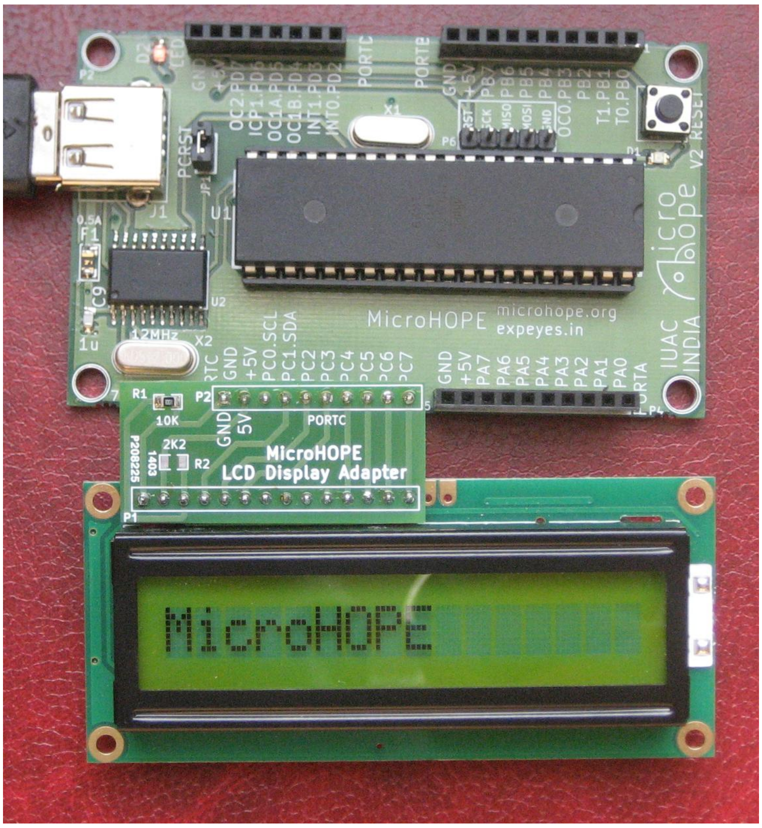
MicroHOPE



User's Manual

Micro-controllers
for
Hobby Projects and Education

Inter-University Accelerator Centre
(A Research Centre of UGC)
New Delhi 110 067

Visit http://expeyes.in/microhope for updates

Chapter 1

Introduction

Most of computer systems in use today are embedded in other machinery, such as automobiles, telephones, appliances, and peripherals for computer systems. Tasks requiring smaller amounts of processing power and memory are generally implemented using micro-controllers (uC). A micro-controller is a small computer on a single integrated circuit consisting of a CPU combined with program and data memory, peripherals like analog to digital converters, timer/counters, serial communication ports and general purpose Input/Output ports. Intel 8051, Atmel AVR, PIC etc. are popular micro controllers available in the market. To design the MicroHOPE hardware, we have chosen ATmega32 micro-controller from Atmel AVR series, after considering the hardware resources available on it and the support of Free Software tools like GNU assembler and C compiler.

Why microHOPE ?

Many people who write programs that run on a PC find it difficult to get started on coding for a microcontroller, mainly due to:

1. Programming a uC requires some knowledge about the target hardware.
2. Transferring the program from the PC to the target device requires some special hardware and software.

There are plenty of micro-controller development kits in the market, but most of them focus on explaining the hardware and software of the development kit rather than the micro-controller. They teach programming the I/O pins of the development board using the library functions provided and the user can get things done without understanding anything about the micro-controller. The objective of this work is to help learning uC architecture and programming, not the MicroHOPE hardware or software. The focus will be on the features of the micro-controller without hiding its details from the user.

A simple Graphical User Interface is provided to Edit, Compile (or Assemble) and upload the program. We start by programming the Input/Output ports of Atmega32, which require some basic knowledge of binary number system and C language, with its bit manipulation operators. After that we will proceed to the programming of the peripherals like ADC, Timer/Counter etc. Since they are more complex, we will start with a software library, in the form of C source files, that can be included in your program[1]. Once you

[1] We are very much aware of the drawback of this method. When you include a file all the functions in that will get added to your executable, increasing its size. Once the code is working, copy the necessary functions to your source file, instead of including the whole file, to get rid of this difficulty.

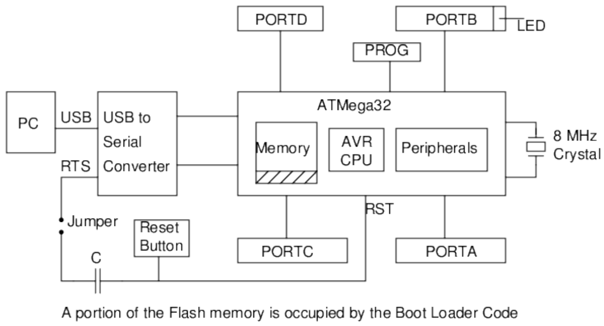


Figure 1.1: (a)MicroHOPE Block diagram.

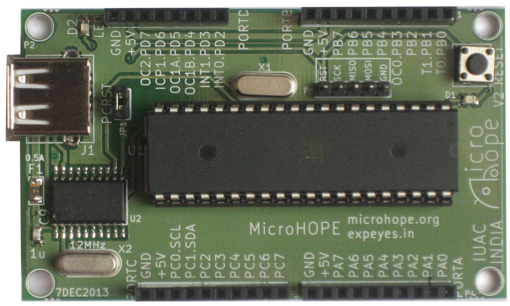


Figure 1.2: MicroHOPE board

learn how to program the peripherals, using the Special Function Registers, there is no need to use these library functions.

MicroHOPE allows you to code in assembly language. This feature is included mainly to get a better idea about the architechture of the uC, by playing with the registers and assembly instructions directly. The content of registers can be displayed using LEDs connected to the I/O ports of the micro-controller.

Since microHOPE comes with a bootloader pre-installed inside the program memory of Atmega32, you can upload code using the USB interface with a single click, from the GUI provided. At the same time, executing the compile and upload programs from a text terminal are also explained. For compiling the C program we use the **avr-gcc** compiler and **avrdude** for uploading it to the target.

1.1 MicroHOPE Hardware

A block diagram of microHOPE hardware is shown in figure 1.1. Programs can be uploaded from the PC through the USB port, with the help of the pre-loaded boot-loader code on the uC. To load a new program, the PC asserts the RTS signal of MCP2200, generating a pulse that resets ATmega32. On reset, the boot loader code will start, waiting for new code from the PC. If new code is available it is loaded and control is transferred to it, otherwise the existing code will start running.

Atmega32 has 32 Input/Output pins, organized as 4 ports, each 8 bit wide. The IC is available in DIP package, that can be socket mounted. The ATmega32 has 32 kB of Flash memory, 512 bytes EEPROM and 2 kB Static RAM. Three Timer/Counters, a serial interface (USART), a byte oriented Two-wire Serial Interface, an 8-channel 10-bit

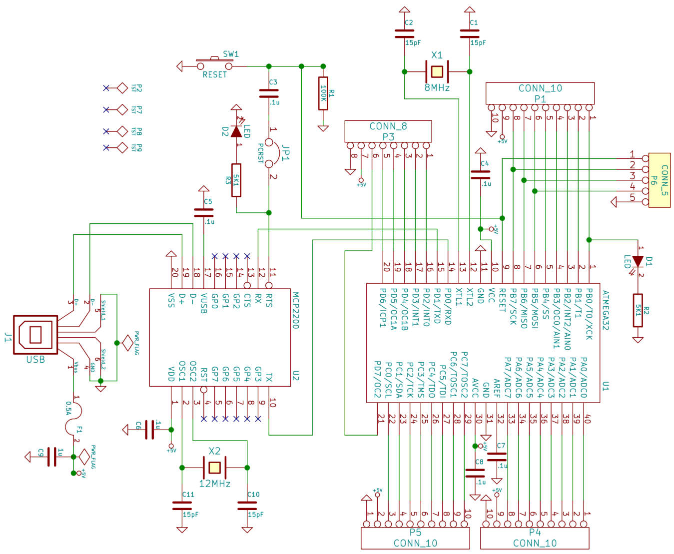


Figure 1.3: Circuit schematic of microHOPE

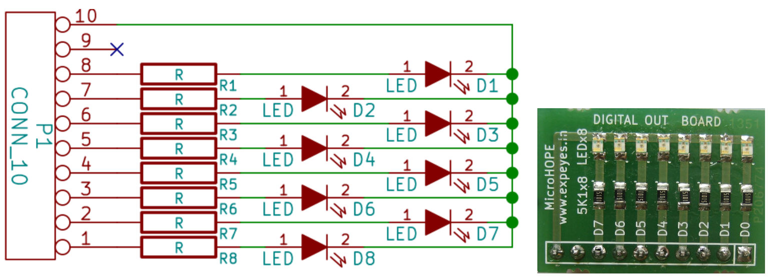


Figure 1.4: The digital output Board

ADC and an SPI serial port are some of the peripheral devices on the chip.

The processor on the microHOPE board runs at 8MHz, using the external crystal. All the I/O pins (except the two bits of port D that are used by the UART Rx/Tx pins) are available to the user on the four I/O connectors. An LED is connected to Bit 0 of Port B, for quick testing of the board. A reset button is also provided. The 5V USB power, via a fuse, is connected to both VCC and AVCC inputs. A jumper is provided to disable the reset option from the PC, required when the board is running programs that need to communicate with a PC, like a data logger or oscilloscope. The circuit schematic is shown in figure 1.3

1.2 Accessories

There are several accessory boards, that can be plugged in to the I/O sockets. Some of them are explained below. Visit the website to know about new additions.

1.2.1 Digital Output Board, 8 LEDs

This can be plugged into any of the four ports to monitor the output, useful for debugging code.

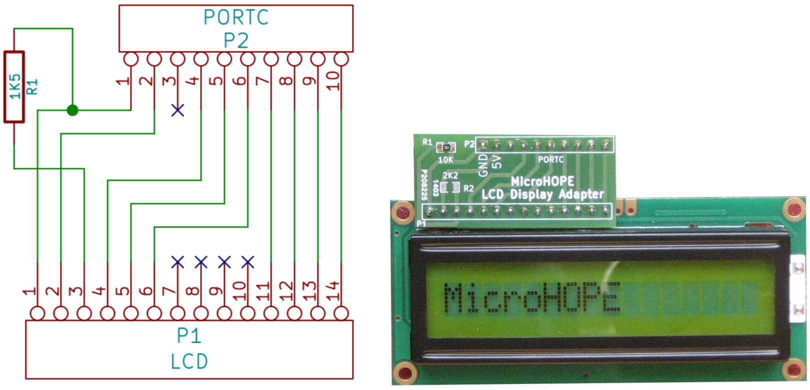


Figure 1.5: LCD display board

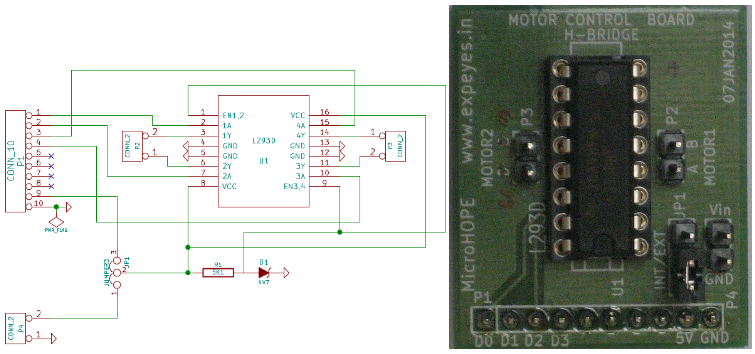


Figure 1.6: H-Bridge board

1.2.2 Alphanumeric LCD

For some applications, it is necessary to have a local display. The HD44780 controller, or compatible IC, based LCD displays are widely available. They come with a 16 pin connector and the transfer protocol is well documented [2]. The connections between microHOPE and the LCD display are shown in figure 1.5(a). Pins 4,5 and 7 of the LCD display are control lines, connected to PC1, PC2 and PC4. The ASCII codes are transferred in the 4bit mode, using pins 11 to 14 connected to PC4, PC5, PC6 and PC7. The LCD should be connected to port C socket, to use the C library functions to access the display.

1.2.3 Motor Control Board

The motor control board consists of 2 H-bridges (IC L293D). Board can be powered from outside or from the MicroHOPE socket. An INT/EXT jumper is provided to select the power option. The voltage level at the for outputs of L293 is decided by the four LSBs of the port on which it is connected. The outputs (A,B,C & D) can be used for controlling 2 DC motors or one stepper motor.

[2]For details refer to http://en.wikipedia.org/wiki/Hitachi_HD44780_LCD_controller

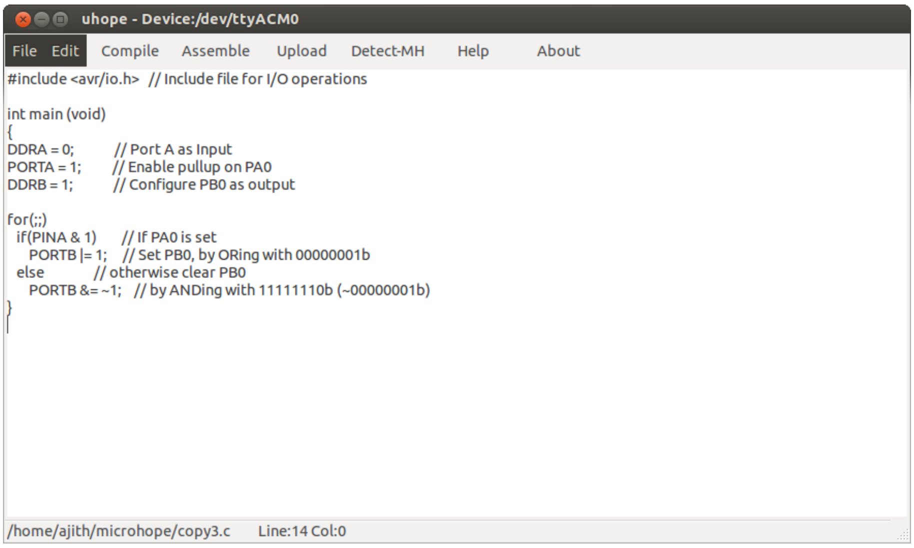
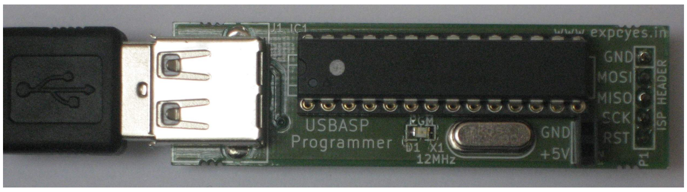


Figure 1.7: MicroHOPE User Interface

1.2.4 USBASP Programmer board

This is an open sourced ISP (In-System Programming) programmer available from http://www.fischl.c . This is provided as an accessory to MicroHOPE due to several reasons. If you want to develop programs that uses the UART of Atmega32, you need to upload code using ISP. It can be used for programming other AVR micro-controllers also. It can be used for burning the boot loader. The LED on the board indicates power. It goes off while uploding code, giving an additional indication. More details are given in chapter 4.



1.3 MicroHOPE Software

MicroHOPE's software requirements are a text editor, a cross compiler and assembler, avr C library, a code uploader and other associated programs. We have written a minimal text editor (that is our IDE) that can invoke the compiler, uploader etc. and also detect the MicroHOPE hardware. It can edit, compile/assemble and upload programs. It is available for both GNU/Linux and MS Windows platforms[3]. On MSwindows, you need to install the Winavr package and the driver for MCP2200 IC from Microchip.

1.3.1 All GNU/Linux Systems

Download and install avr-gcc, avrlib and avrdude from the repositories of your GNU/Linux distribution. Download the source file uhope.c and the Makefile from MicroHOPE website. The command

$ make

[3]Download from http://expeyes.in/microhope

will compile and create the executable uhope, you need to install gtk library. Copy it to /usr/bin.

$ uhope

will start the program

1.3.1.1 Debian and derivatives, like Ubuntu

Debian package is available on the website. After installing the package, run 'create-microhope-env' from a terminal to copy the example programs to a directory named microhope, inside your home directory. The MicroHOPE program can be started from the applications menu. A screen shot of the microhope IDE is shown in figure 1.7. By default it looks for files inside a subdirectory named 'microhope', inside your home directory. The IDE allows you to load/save files, detect the hardware, compile/assemble the code and upload the output.

The examples given in this document will appear inside the directory named 'microhope'. All files starting with **mh-** are the files containing library functions to access the various peripherals of Atmega32. To make the source code visible to the user, they are not compiled as a library file. Do not modify the files starting with **mh-**.

You can select any of the example programs, compile/assemble and upload them using the menu. Correct all the errors before doing Upload. You also need to detect the hardware once before uploading. For assembly language programs, the file name extension should be .s or .S (The pre-processor is invoked if .S is used.)

1.3.2 MS Windows

Download and install the software from

http://www.expeyes.herobo.com/microhope.php .

The requirements are the USB to Serial IC drivers, **winavr** package from sourceforge.net and the microHOPE installer.

Chapter 2

Getting Started

After installing the required software packages, you must have copied the examples to a directory named microhope inside your home directory. Start the microHOPE IDE. Choosing File->Open from the menubar will display all the C files inside the **microhope** directory. You can open any of the examples (do not modify the files starting with mh-), compile/assemble and upload from the IDE. We will start by programming the digital Input/Output ports of Atmega32, and them proceed to the peripheral devices. [1].

2.1 Testing the Hardware

Connect MicroHOPE hardware to a USB port and start the microHOPE IDE from the menu. Click on Detect-MH to get a popup menu of the available USB to Serial devices. It will contain entries like '/dev/ttyACM0', '/dev/ttyACM1' etc[2]. If you are running expEYES, find out the device descriptor used by it from the expEYES GUI titlebar and avoid using the same.

Using File->Open from the menubar, load **blink.c** from the **microhope** directory. Compile and Upload the program by clicking on the menubar. In case of error, check the USB connections first. If problem persists, try pressing and releasing the microHOPE resent button at the same time when you click on Upload. Make sure that the PCRST jumper is closed.

Once the program is uploaded, the LED connected to PB0 should blink at 1 Hz rate. **If not, press the reset button on the board.**

2.2 Input/Output ports of Atmega32

The pinout diagram of Atmega32 is shown in figure 2.1. There are 32 pins organized as four ports named A, B, C and D, each 8 bit wide. Each pin can be configured as an input or output. The data direction and transfer are done by writing to the registers DDRX, PORTX and PINX (where X stands for A, B, C or D). The avr-gcc compiler allows us to program the registers and their individual bits using the same names given in the Atmega32 manual. The C compiler allows you to access them just like normal variables. For example, the statement PORTB = 15 , writes the number 15 to Port B. The individual pins are referred using names like PA0, means BIT 0 of Port A.

[1] For complete details of Atmega32 refer to http://www.atmel.in/Images/doc2503.pdf

[2] For old model of microHOPE using FT232, it will be ttyUSB*

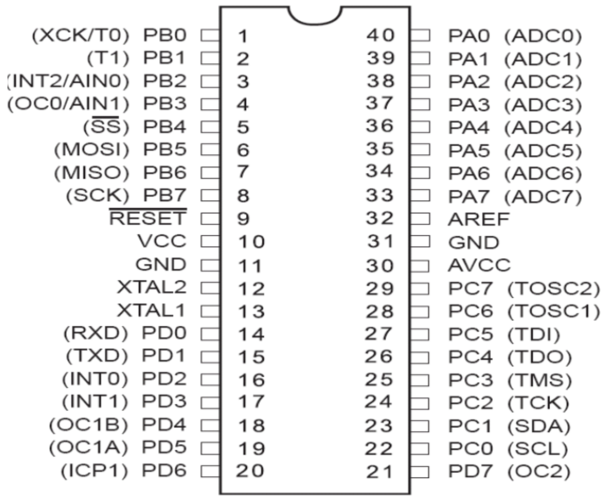


Figure 2.1: Atmega32 Pinout

- DDRX : Direction of every pin of an I/O port is decided by the state of corresponding bit in the Data Direction registers DDRX. To configure a pin as output, make the bit 1, and to make it as input make it zero. For example, DDRA = 1 will configure BIT 0 of Port A (PA0) as output, and all other pins as input.
- PORTX : For pins that are configured as ouput, assigning a value to PORTX will set that data on them. For example PORTA = 1 will make PA0 high, that can be measured on the pin number 40 of the IC.
- PINX : For the pins configured as inputs, PINX will read the status of the external voltage level connected to the pins. For pins that are configured as outputs, PINX will return the data written to PORTX.

If the pins configured as inputs are left unconnected, there could be unwanted level changes due to electrical noise, this can be prevented by enabling the internal pull-up resistor. For pins that are configured as inputs, setting/clearing the bits in PORTX will enable/disable the corresponding internal pullup resistor.

The operations described above can be understood easily with some examples. For a quick test, MicroHOPE hardware has an LED connected to PB0, with a series resistor for current limiting.

2.2.1 Reading and Writing Ports

The program **copy.c** reads the voltage level at PA0 (Pin 0 of Port A) and sets the same on PB0, where we have the LED. We will enable the internal pullup resistor on PA0 so that and it will go LOW only when it is connected to ground using a piece of wire.

```
#include <avr/io.h>   // Include file for I/O operations
int main (void)
{
DDRA = 0;             // Port A as Input
PORTA = 1;            // Enable pullup on PA0
DDRB = 1;             // Configure PB0 as output
```

```
    for(;;)
        PORTB = PINA;   // Read Port A and write it to Port B
    }
```

To test this example, open **copy.c** from the File menu of microHOPE IDE, Click on Compile and then Upload from the menubar The LED on PB0 should start glowing after uploading the program. LED will be off when you connect PA0 to ground. You may rewrite the program so that the LED may be controlled by some other bit configured as input.

The simple program given above has certain drawbacks. It changes PORTB as a whole instead of acting on PB0 alone. Suppose we have something else connected to the other pins of Port B, they also will be affected by the action of $PORTB = PINA$. To avoid such problems, we should manipulate individual bits. The include file **mh-digital.c** contains macros for setting and clearing bits by specifying their position.

2.2.2 Bit manipulation macros[3]

These macros can be used on variables, defined in the program, and also on registers like DDRX, PORTX etc.

BITVAL(bit position)

The value of bit position could be 0 to 7 in the case of 8 bit integers and 0 to 15 for 16 bit integers. This macro returns (1 << bit position). For example BITVAL(3), will give 8, that is binary 1000, obtained by left shifting of 1 thrice.

SETBIT(variable, bit position)

This macro SETS the specified bit in the given variable, without affecting the other bits. For example SETBIT(DDRB, 7), will make the last bit of DDRB high.

CLRBIT(variable, bit position)

This macro clears the specified bit of the given variable. For example CLRBIT(val, 0), clears the least significant bit of 'val', that is an integer type variable.

GETBIT(variable, bit position)

This macro returns the value the specified bit if the specified bit of the variable is 1, else it returns zero. For example: if x = 3, GETBIT(x, 1) will return 2 and GETBIT(x,3) will return zero.

Let us rewrite the previous program as **copy2.c**, using these macros as:

```
#include <avr/io.h>
  int main (void)
```

[3] The macros are implemented using:
#define BITVAL(bit) (1 << (bit))
#define CLRBIT(sfr, bit) (_SFR_BYTE(sfr) &= ~BITVAL(bit))
#define SETBIT(sfr, bit) (_SFR_BYTE(sfr) |= BITVAL(bit))
#define GETBIT(sfr, bit) (_SFR_BYTE(sfr) & BITVAL(bit))

```
{
uint8_t  val;
DDRA = 0;             // Port A as Input
PORTA = 1;            // Enable pullup on PORTA, bit 0
DDRB = 1;             // Pin 0 of Port B as output
for(;;)
   {
   val = GETBIT(PORTA, 0);
   if (val != 0)
      SETBIT(PORTB, 0);
   else
      CLRBIT(PORTB, 0);
   }
}
```

The same can be done, without using the bit manipulation macros, as shown in **copy3.c**

```
#include <avr/io.h>   // Include file for I/O operations
int main (void)
{
uint8_t  val;         // 8 bit unsigned word
DDRA = 0;             // Port A as Input
PORTA = 1;            // Enable pullup on PA0
DDRB = 1;             // Configure PB0 as output
for(;;)
   if(PINA & 1)        // If PA0 is set
       PORTB |= 1;     // Set PB0, by ORing with 00000001b
   else                // otherwise clear PB0
       PORTB &= ~1;    // by ANDing with 11111110b (~00000001b)
}
```

The code fragment shown above uses the Bitwise AND, OR and NOT operators.

2.2.3 Blinking LED

Making pin PB0 HIGH and LOW in a closed loop result in the blinking of the LED conencted to it. We need to slow down the rate of blinking so that it can be perceived by our eyes. This can be done by making the processor wait for a while between writing to PORTB. There are some delay functions provided for this. The file **mh-utils.c** contains the following functions:

delay_100us(int n)

This function will make the CPU idle for n x100 microseconds. For example to insert a 200 microsecond delay, call delay_100us(2)

delay_ms(int n)

This function will make the CPU idle for n milliseconds. For example to insert a 500 millisecond delay, call delay_ms(500)

The program blink.c lis listed below:

```
#include ‘‘mh-utils.c’’
int main (void)
{
   DDRB = 1;     // configure PB0 as output
   for(;;)
   {
   PORTB = 1;
   delay_ms(500);
   PORTB = 0;
   delay_ms(500);
   }
}
```

If everything goes fine, you should see the LED blinking. You can remove the delay statements and watch the high frequency pulses on PB0 using an oscilloscope.

2.3 The LCD Display

The file **mh-lcd.c** contains functions to access the display, connected to port C. The example program **hello.c** listed below demonstrates the usage of the LCD display.

```
#include "mh-lcd.c"
int main()
{
lcd_init();
lcd_put_string("Hello World");
}
```

The file mh-lcd.c provides the following functions :

- lcd_init() : Initializes the LCD display, must be called once in the beginning
- lcd_clear() : Clears the display
- lcd_put_char(char ch) : Outputs a single character to the LCD display
- lcd_put_string(char* s) : Displays a string to the LCD
- lcd_put_byte(uint8_t i) : Diplays an 8 bit unsigned integer
- lcd_put_int(uint16_t i) : Displays a 16 bit unsigned integer
- lcd_put_long(uint32_t i) : Displays a 32 bit unsigned integer

The file mh-lcd-float.c provides lcd_put_float(float val, uint8_t ndec), where ndec is the number of decimal places, restricted to 3. Defining float type data increases the program size a lot.

2.4 Analog to Digital Converter

Most of the I/O PORT pins of Atmega32 have alternate functions. PA0 to PA7 can be used as ADC inputs by enabling the built-in ADC. All the pins configured as inputs in the DDRA will become ADC inputs, but the ones configured as outputs will remain as digital output pins. The ADC converts the analog input voltage in to a 10-bit number. The minimum value represents GND and the maximum value represents the ADC reference voltage. The reference inputs could be AVCC, an internal 2.56V or a voltage connected to the AREF pin. The selection is done in software. The ADC operation is controlled via the registers ADMUX and ADCSRA. The data is read from ADCH and ADCL.

The include file 'mh-adc.c' provides the following functions:

1. adc_enable() : Enables the ADC
2. adc_disable() : Disables the ADC
3. adc_set_ref(ref) : Select the reference, where ref is REF_EXT is an external voltage is applied to the AVREF pin, REF_INT to use the internal 2.56 V reference and REF_AVCC to connect the AVCC supply internally to AVREF.
4. read_adc(ch) : Converts the voltage on channel ch and returns it in a 16 bit number.

2.4.1 Reading an Analog Voltage

The example program *adc.c* , reads an ADC input and display the result on the LCD.

```
#include "mh-lcd.c"
#include "mh-adc.c"
main()
{
uint16_t data;
lcd_init();
adc_enable();
data = read_adc(0);
lcd_put_int(data);
}
```

2.4.2 Programmig ADC registers

The operation of the ADC is controlled mainly by the registers ADCSRA and ADMUX. Setting ADEN will enable the ADC and setting ADSC will start a conversion. The bit ADIF is set after a conversion and this bit can be cleared by writing a '1' to it. The ADSP bits decide the speed of operation of the ADC, by pre-scaling the clock input. The channel number is selected by the MUX0 to MUX4 bits in the ADMUX rregister. The reference input is selected by the REFS0 and REFS1 bits.

7	6	5	4	3	2	1	0
ADEN	ADSC	ADATE	ADIF	ADIE	ADPS2	ADPS1	ADPS0
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
0	0	0	0	0	0	0	0

7	6	5	4	3	2	1	0
REFS1	REFS0	ADLAR	MUX4	MUX3	MUX2	MUX1	MUX0
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
0	0	0	0	0	0	0	0

The program adc-v2.c, demonstrates the usage of these registers.

```
#include <avr/io.h>
#include "mh-lcd.c"
// convert channel 0, set pre-scaler to 7
main()
{
uint16_t data;
lcd_init();
ADCSRA = (1 << ADEN) | 7;       // Enable ADC, set clock pre-scaler
ADMUX =  (1 << REFS0);   // AVCC reference, channel 0
ADCSRA |=  (1 <<ADSC);           // Start ADC
while ( !(ADCSRA & (1<<ADIF)) ) ;  // wait for ADC conversion
data = (ADCH << 8) | ADCL;    // make 10 bit data from ADCL and ADCH
lcd_put_int(data);
}
```

2.4.3 Reading in a Loop

The example program **adc-loop.c** , reads an ADC input in a loop and display the result on the LCD. If the input is left unconnected, the displayed value could be anywhere between 0 an 1023. Connecting PA0 to 5V will display 1023, the maximum output.

```
#include "mh-lcd.c"
#include "mh-adc.c"
#include "mh-utils.c"
main()
{
uint16_t data;
lcd_init();
adc_enable();
for (;;)
   {
    data = read_adc(0);
    lcd_clear();
    lcd_put_int(data);
    delay_ms(100);
   }
}
```

Modify the code for reading other ADC channels.

2.4.4 Temperature Control

The program adc-loop.c can be easily modified to make a temperature monitor/controller using the LM35 temperature sensor. Connect LM35 output to PA0. At 100^0C , the

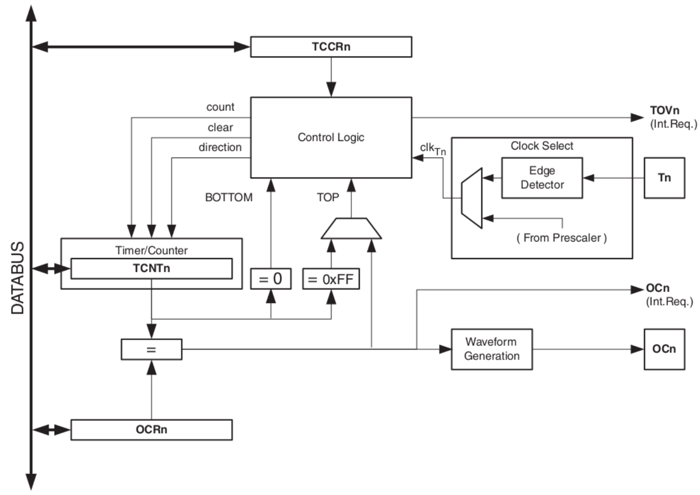


Figure 2.2: 8 bit Timer/Counter0 Schematic

output of LM35 will be 1 volt. With the internal 2.56 volts as reference, the ADC output will be around 400 (1.0 / 2.56 * 1023).

Drive the relay contact controlling the heater from PB0, via a transistor. Insert the following line in the beginning

```
DDRB = 1
```

and within the loop:

```
if (data > 400)        // switch off heater
    PORTB = 0;
else if (data < 395)   // switch on heater
    PORTB = 1;
```

The heater will be switched OFF when the ADC output is greater than 400. It will be switched ON only when the output goes below 395. The window of 6 is given to avoid the relay chattering.

2.5 Timer/Counters

ATmega16 has three counter/timer units. Two of them are of 8 bit size and one is 16 bit. The counter input could be derived from the internal clock or from an external source. The output of the counter is compared with setpoint registers and different types of actions are taken on compare match. The mode of operation of Counter/Timer is programmed by setting the bits in the control registers. These circuits are useful for time interval measurements and generating different kinds of waveforms.

2.5.1 8 bit Timer/Counter0

A block diagram of Timer/Counter0 is shown in figure2.2. The counter TCNT0 gets its input and control signals from the control logic circuit. The counter output is compared with a Output Compare Register OCR0 and a compare match can trigger different types of actions, like generating a waveform on OC0 (pin 4 of Atmega32, same as PB3). The mode of operation is decided by the register TCCR0, shown below:

7	6	5	4	3	2	1	0
FOC0	WGM00	COM01	COM00	WGM01	CS02	CS01	CS00
W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Let us start using Timer/Counter0 with the help of the following functions.

sqwave_tc0(csb, ocrval)

This function generates a square wave on OC0, whose frequency is decided by the clock select bits (csb) and ocrval. Example **sqwave-tc0.c** listed below demonstrates the usage of this function.

```
// example : sqwave-tc0.c
#include "mh-timer.c"
csb = 2;        // Clock select bits
ocrval = 99;    // Output Compare register vaule
int main()
{
sqwave_tc0(csb, ocrval);
}
```

The 8MHz system clock is divided by 8 (csb =2, refer to table below) to get a 1MHz input to the counter. The OCR0 register is set to 99. The mode bits are set such that the when the counter value reaches the OCR0, the output is toggled and counter is cleared. This will result in the waveform generator output toggles after every 100 clock cycles, giving a 5kHz sqaurewave on pin OC0 (PB3). You may view this on an oscilloscope. If you do not have one, connect a loudspeaker with a 100Ω series resistor from PB3 to ground. We have used expEYES for viewing and characterizing the waveforms generated by microHOPE.

Changing ocrval to 199 will give output 2.5kHz on the output. The output frequency is given by the relation

$$f = \frac{f_{clock}}{2.N.(1 + OCR0)}$$

where f_{clock} is the system clock and N is the clock division factor, as shown below.

CS02	CS01	CS00	Description
0	0	0	No clock source (Timer/Counter stopped).
0	0	1	$clk_{I/O}$/(No prescaling)
0	1	0	$clk_{I/O}$/8 (From prescaler)
0	1	1	$clk_{I/O}$/64 (From prescaler)
1	0	0	$clk_{I/O}$/256 (From prescaler)
1	0	1	$clk_{I/O}$/1024 (From prescaler)
1	1	0	External clock source on T0 pin. Clock on falling edge.
1	1	1	External clock source on T0 pin. Clock on rising edge.

pwm_tc0(csb, ocrval)

This function generates a Pulse Width Modulated waveform on OC0, whose frequency is decided by the clock select bits (csb) and the duty cycle by the ocrval. The output OC0 is cleared when the counter reaches the OCR0 value, the counter proceeds upto 255 and then sets OC0. The program **pwm-tc0.c** generates a 3.9 kHz PWM with 25% dutycycle.

```
// example : pwm-tc0.c
#include "mh-timer.c"
uint8_t  csb = 2;   // Clock select bits uint8_t
ocrval = 63;       // Output Compare register vaule
int main()
{
  pwm_tc0(csb, ocrval);
}
```

PWM waveforms are often used for generating analog DC voltages, in 0 to 5 volts range, by filtering it using an RC circuit. It is better to set a higher frequency so that the filter RC value could be small. The frequency can be made 31.25kHz by setting csb=1. The DC level is decided by the value of OCR0, ranging from 0 to 255. Once you learn howto manipulate the control registers, the same thing can be done without calling the library function, as shown below.

```
// example : pwm-tc0-v2.c
#include <avr/io.h>
uint8_t csb = 1;     // Clock select bits uint8_t
ocrval = 254/4;      // Output Compare register vaule
int main()
{
// Set TCCR0 in the Fast PWM mode
TCCR0 =(1 << WGM01) | (1 << WGM00) | (1 << COM01) | csb;
OCR0 = ocrval;
TCNT0 = 0;
DDRB |= (1 << PB3); // Set PB3(OC0) as output
}
```

Connect a 1k resistor and 100uF capacitor in series from PB3 to ground,as shown below, and measure the voltage across the capacitor using a voltmeter.

2.5.2 16 bit Timer/Counter1

The Timer/Counter1 has more features like two Output Compare Registers, Input Capture unit etc., as shown in figure2.3. The frequency and duty cycle of the waveforms can be controlled better due to the 16 bit size of the counters. Some C functions to use the T/C1 are given below.

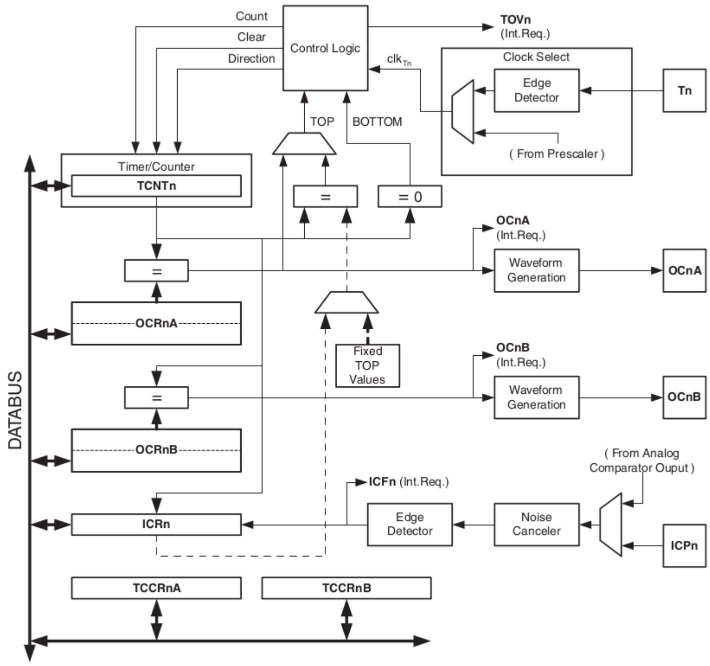


Figure 2.3: 16 bit Timer/Counter1 schematic

sqwave_tc1(csb, OCRA)

```
// example : sqwave-tc1.c
#include "mh-timer.c"
uint8_t  csb = 2;       // 2 is divide by 8 option, 1MHz clock in
uint16_t  ocra = 50000;  // Output Compare register A
int main()
    {
    sqwave_tc1(csb, ocra);
    }
```

pwm10_tc1(csb, OCRA)

This function generates a PWM waveform with 10bit resolution. The value of ocra should be from 0 to 1023 to set the duty cycle.

```
// example : pwm-tc1.c
#include "mh-timer.c"
uint8_t  csb = 1;        // 1 => 8MHz clock in
uint16_t  ocra = 1024/3;  // Duty cycle arounf 33%
int main()
  {
  pwm10_tc1(csb, ocra);
  }
```

2.5.3 8 bit Timer/Counter2

This one is similar to Timer/Counter0.

sqwave_tc2(uint32_t freq)

This function generates a square wave on OC2. The clock selction bits and the OCR2 value are calculated. It is not possible to set all frequency values using this method. The actual frequency set is returned and displayed on the LCD.

```
//Example sqwave-tc2.c
#include "mh-timer.c"
#include "mh-lcd.c"
int main()
{
uint32_t f;
lcd_init();
f = set_sqr_tc2(1500);
lcd_put_long(f);
}
```

PWM by programming the registers

The example given below demonstrates the usage of T/C2 as a PWM waveform generator, by setting the control register bits. The duty cycle is set to 25% by setting the OCR2 to one fourth of the maximum.

```
// example : pwm-tc2.c
#include <avr/io.h>
uint8_t csb = 2;     // Clock select bits uint8_t
ocrval = 255/4;      // Output Compare register vaule
int main()
{
// Set TCCR2 in the Fast PWM mode
TCCR2 =(1 << WGM21) | (1 << WGM20) | (1 << COM21) | csb;
OCR2 = ocrval;
TCNT0 = 0;
DDRD |= (1 << PD7); // Set PD7(OC2) as output
}
```

2.5.4 More applications of Timer/Counter

Timer/Counter can be used for timing applications, like measuring the time elapsed between two events or counting the number of pulse inputs during a specified time interval.

measure_frequency()

This function counts the number of pulses received on the external input of Timer/Counter1 (PB1) during 500 milliseconds to calculates the frequency of the input pulse.

```
// Example freq-counter.c
#include "mh-utils.c"
#include "mh-timer.c"
#include "mh-lcd.c"
```

```
int main()
{
uint32_t f;
set_sqr_tc2(1500);    // Set a square wave on TC2 output (PD7)
lcd_init();
while(1)
   {
   f = measure_freq();
   lcd_clear();
   lcd_put_long(f);
   delay_ms(200);
   }
return 0;
}
```

Connect PD7 to PB1 and upload the program **freq-counter.c** to read the frequency on the LCD display. You can also connect PB1 to an external pulse source to measure its frequency. The maximum frequency that can be measured is limited by the size of the counter, that is 63535, means we it can handle upto around 126 kHz.

Time Interval Measurement

The T/C units can be programmed to keep track of time interval between two events. The program **r2ftime.c** measures the rising edge to falling edge time on PB1.

```
// Example r2ftime.c
#include "mh-utils.c"
#include "mh-timer.c"
#include "mh-lcd.c"
int main()
{
lcd_init();
set_sqr_tc2(500);    // Test signal on PD7
while(1)
   {
   lcd_clear();
   lcd_put_long(r2ftime(PB1));
   delay_ms(100);
   }
}
```

The function r2ftime() uses two other functions, called start_timer() and read_timer(), that are explained below.

- void start_timer() : Start the counter with a 1 MHz clock input. An interrupt service routine is activated when the count reached 50000, that increments another interger.
- uint32_t read_timer() : Stops the counter and returns the microseconds elapsed after calling start_timer(). There will be an error of 2 to 3 microseconds, that is due to the overhead of the function calls.

2.5.4.1 Distance Measurement

This technique is used for measuring distance using an ultrasound echo module HY-SRF05[4], using **ultra-sound-echo.c**. The trigger is connected to PB0 and the echo is connected to PB1. The distance is measured by

```
// Example ultra-sound-echo.c
#include "mh-utils.c"
#include "mh-timer.c"
#include "mh-lcd.c"
int vsby2 = 17;  // velocity of sound in air = 34 mS/cm
int main()
{
uint32_t x;
DDRB |=  (1 << PB0);  // set PB0 as output
DDRB &= ~(1 << PB1);  // and PB1 as inpt
lcd_init();
while(1)
   {
   PORTB |=  (1 << PB0);   // set PB0 HIGH
   delay_100us(1);
   PORTB &=  ~(1 << PB0);  // set PB0 LOW
   delay_100us(5);         // Wait for a while to avoid false triggering
   start_timer();
   while( (PINB & 2) != 0 ) ;   // Wait for LOW on PB1
   x = read_timer() + 400;
   lcd_clear();
   lcd_put_long(x*vsby2/1000);  // distance in cm
   delay_ms(500);
   }
}
```

2.6 Talking to the PC, via USB

On the microHOPE board, the Rx/Tx pins of ATmega32 are connected to the USB to Serial Converter IC. User programs also can use this path to communicate to the PC via the USB port.

The following functions are available for handling the UART

1. uart_init(baud) : 38400 is the maximum baudrate supported. You can use any submultiple of that. We use 1 Stop Bit and the parity is Even.

2. uart_recv_byte() : Waits on the UART receiver for a character and returns it

3. uart_send_byte(c) : Sends one character over the UART transmitter.

On the PC side, we use a simple Python program to communicate to the micro-controller. The USB to Serial interface will appear as a virtual COM port on the PC, on GNU/Linux

[4] http://www.robot-electronics.co.uk/htm/srf05tech.htm

systems it can be accessed as /dev/ttyACM0. You need to install Python interpreter and the python-serial module on the PC for this to work. These Python programs should be terminated before using MicroHOPE again to upload programs.

2.6.1 Send/receive Characters

The program **echo.c** waits for data from the PC, vis the USB to serial converter, increment it by one and sends it back. The received data is also displayed on the local LCD display.

```
#include "mh-lcd.c"
#include "mh-uart.c"
int main(void)
{
uint8_t data;
lcd_init();
uart_init(38400);
for(;;)
     {
      data = uart_recv_byte();
      lcd_put_char(data);
      uart_send_byte(data);
     }
}
```

After uploading this program, open a terminal window, change to the directory named microhope and run the python program **echo.py** listed below, using the commands:[5]
$ cd microhope
$ python echo.py

```
import serial
fd = serial.Serial('/dev/ttyACM0', 38400, stopbits=1, \
    timeout = 1.0)
while 1:
    c = raw_input('Enter the character to send: ')
    fd.write(c)
    print 'Receiced ', fd.read()
```

We can rewrite echo.c without using the library functions. The program **echo-v2.c** listed below id functionally identical to echo.c

```
#include "mh-lcd.c"
int main(void)
{
  uint8_t data;
  lcd_init();
  //38400 baudrate, 8 databit, 1 stopbit, No parity
  UCSRB = (1 << RXEN) | (1 << TXEN);
```

[5]If you are using old microHOPE with FT232 IC, edit echo.py to replace ttyACM0 with ttyUSB0. The same thing applies to programs like cro.py, pymicro.py etc.

```
    UBRRH = 0;
    UBRRL = 12;            // At 8MHz (12 =>38400)
    UCSRC = (1<<URSEL) | (1<<UCSZ1) | (1<< UCSZ0);
    for(;;)
       {
       while ( !(UCSRA & (1<<RXC)) );  //wait on Rx
       data = UDR;                    // read a byte
       lcd_put_char(data);
       while ( !(UCSRA & (1<<UDRE)) ); // Rx Empty ?
       UDR = data;
    }
}
```

2.6.2 Sending ADC data

The program **remote-adc.c**, listed below, on receiving a channel number, in 0 to 7 range, reads the corresponding channel and send the data to the PC using the UART, via the USB to Serial converter. Use the Python program **remote-adc.py** on the PC side.

```
#include "mh-lcd.c"
#include "mh-uart.c"
#include "mh-adc.c"
int main(void)
{
uint8_t chan, low, hi;
uint16_t adcval;
lcd_init();
uart_init(38400);
adc_enable();
for(;;)
    {
    data = uart_recv_byte();
    if (chan <= 7)
      {
      adcval = read_adc(chan);
  lcd_clear();
      lcd_put_int(low);
      low = adcval & 255;
      hi = adcval >> 8;
      uart_send_byte(low);      // send LOW byte
      uart_send_byte(hi);       // send HI byte
      }
  }
}
```

2.6.3 A simple Oscilloscope

The program **cro.c** can waits for a command byte from the PC. On receiving a '1', it digitizes the input at PA0 500 times, with 100 microseconds in between samples, and sends the data to the PC. The program **cro.py** sends the necessary command, receives the data and displays it as shown in the figure2.4. While running cro.py , the PCRST jumper should be open. The C program running on the micro-controller is listed below.

```
#include <avr/io.h>
#define READBLOCK  1    // code for readblock is 1
#define NS 500  // upto1800 for ATmega32
#define TG 100  // 100 usec between samples
uint8_t tmp8, dbuffer[NS];
uint16_t tmp16;
int main (void)
{
// UART at 38400 baud, 8, 1stop, No parity
UCSRB = (1 << RXEN) | (1 << TXEN);   UBRRH = 0;
UBRRL = 12;
UCSRC = (1 <<URSEL) | (1 << UCSZ1) | (1 << UCSZ0);
ADCSRA = (1 << ADEN); // Enable ADC
for(;;)
    {
    while ( !(UCSRA & (1<<RXC)) ); // wait for the PC
    if(UDR == 1)  // '1' is our command
      {
      TCCR1B = (1 << CS11);
      ADMUX = (1 << REFS0) |(1 << ADLAR) | 0;
      ADCSRA |= ADIF;
      for(tmp16 = 0; tmp16 < NS; ++tmp16)
        {
        TCNT1 = 1; // counter for TG
        ADCSRA |= (1 << ADSC) | 1; // Start ADC
        while ( !(ADCSRA & (1<<ADIF)) ) ; // Done ?
        dbuffer[tmp16] = ADCH; // Collect Data
        ADCSRA |= ADIF; // reset ADC DONE flag
    while(TCNT1L < TG) ; // Wait TG usecs
        }
    while( !(UCSRA & (1 <<UDRE) ) );  // Wait Tx empty
    UDR = 'D'; // Send a 'D' first
    for(tmp16=0; tmp16 < NS; ++tmp16) // Send to the PC
    {
    while( !(UCSRA & (1 <<UDRE) ) );
    UDR = dbuffer[tmp16];
    }
     }
    }
}
```

The Python program cro.py

```
import serial, struct, time
import numpy as np
```

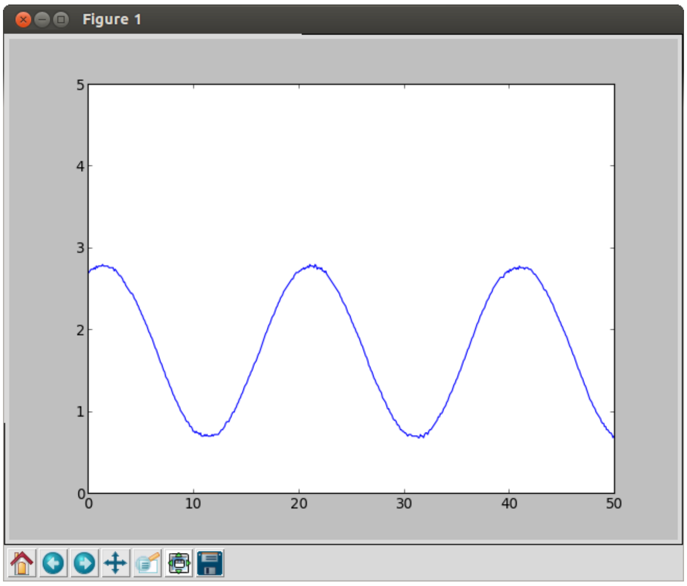


Figure 2.4: Oscilloscope screen shot

```
import matplotlib.pyplot as plt
NP = 500
TG = 100
fd=serial.Serial('/dev/ttyACM0',38400,stopbits=1,timeout = 1.0)
fd.flush()
fig=plt.figure()
plt.axis([0, NP*TG/1000, 0, 5])
plt.ion()
plt.show()
va =ta = range(NP)
line, = plt.plot(ta,va)
while 1:
  fd.write(chr(1)) # command for the uC
  print fd.read()  # This must be a 'D'
  data = fd.read(NP)
  raw = struct.unpack('B'* NP, data) # convert to byte array
  ta = []
  va = []
  for i in range(NP):
    ta.append(0.001 * i * TG) # micro to milliseconds
    va.append(raw[i] * 5.0 / 255)
  line.set_xdata(ta)
  line.set_ydata(va)
  plt.draw()
  time.sleep(0.05)
```

Modifed versions (cro2.c and cro2.py), that allows changing NS and TG from the Python program are also provided.

2.6.4 Controlling the uC from Python

This section demonstrates a simple method to read/write the Input/Output ports and other registers of the micro-controller, from the PC using Python. A program called **pymicro.c** runs on the micro-controller. It listens over the serial port for two commands, READB or WRITEB. The first one should be followed by the address of the register to be read. The WRITE command is followed by the register address and the data to be written.

On the PC side, **pymicro.py** handles the communication to the micro-controller. It defines a class named atm32, that contains the communication routines. The example program listed below demonstrates a blinking LED code in Python

```
import time
from pymicro import *
u=atm32()
while 1:
    u.outb(PORTB, 1)
    time.sleep(0.5)
    u.outb(PORTB, 0)
    time.sleep(0.5)
```

To run this program, compile and upload pymicro.c, remove the PCRST jumper and then run blink.py. It is very easy to implement some programs, for example a stepper motor controller in Python, using this method.

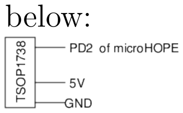
2.7 Motor Control, H-bridge

The H-bridge accessory is useful for controlling DC and stepper motors. The circuit schematic is shown in figure2.5. One can use the pymicro.c program to test the H-bridge. After uploading pymicro, you can control the motor control outputs from Python interpreter. For example, connect the board to port A and a DC motor (with series resistor for current limiting) between the H-bridge output pins A and B. The following Python code will rotate the motor.

```
from pymicro import *
p=atm32()
p.outb(DDRA,15)
p.outb(PORTA,1)
```

2.8 Infrared Receiver

The program ir-recv.c can receive data using the TSOP1738 IR receiver. The output of the chip is connected to bit 2 of PORTD. The received byte is displayed on the LCD display. The receiver tested using TV remote controls. To test ir-recv.c, make the connections as shown below:



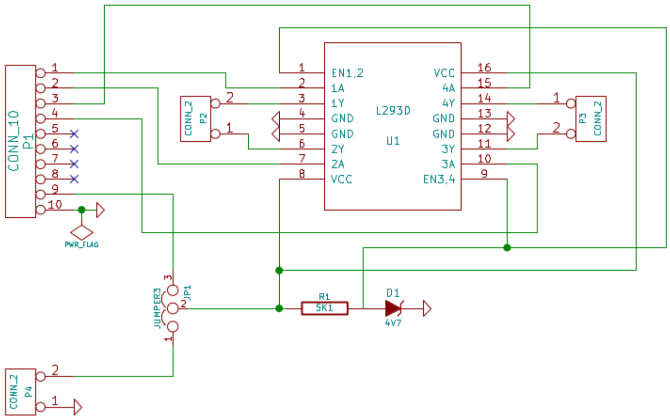


Figure 2.5: H-bridge schematic

Press some buttons on the remote control panel. The received number will be displayed on the LCD display of microHOPE. The code ir-recv.c is available on the website. It can be modified to work with the single byte IR transmitted from expEYES.

2.9 Alternate Serial Port

The Atmega32 controller has only one Serial Port (UART), that is already connected to the USB to Serial converter. In order to communicate to other devices that supports serial communication, we have a simple library that will convert PD2 to a Transmit pin and PD3 a Receive pin. The functions available are:

- enable_uart(9600) // baudrates 2400,4800, 9600 & 19200 only
- uart_read() , returns one byte from the receiver buffer, call only when variable ubcount is nonzero
- uart_write(uint8_t) , writes a byte to the transmitter
- disable_uart() , disable the interrupts

The Soft Serial code is tested by connecting PD2 (soft Rx) and PD3 (soft Tx) to a computer through the USB to Serial converter MCP2200 (by using another microHOPE board with the uC removed). The Transmit output from MCP2200 that appears on pin 14 of the uC socket is connected to PD2. Receive input (on pin15) is connected to PD3. The program **soft-echo.c,** listed below, waits for data from the PC and the received data is send to the LCD display and also to the PC via PD3.

```
#include "mh-soft-uart.c"
#include "mh-lcd.c"
int main()
  {
  uint8_t x=0;
  lcd_init();
  enable_uart(9600); // 2400,4800, 9600 & 19200 allowed
  for(;;)
```

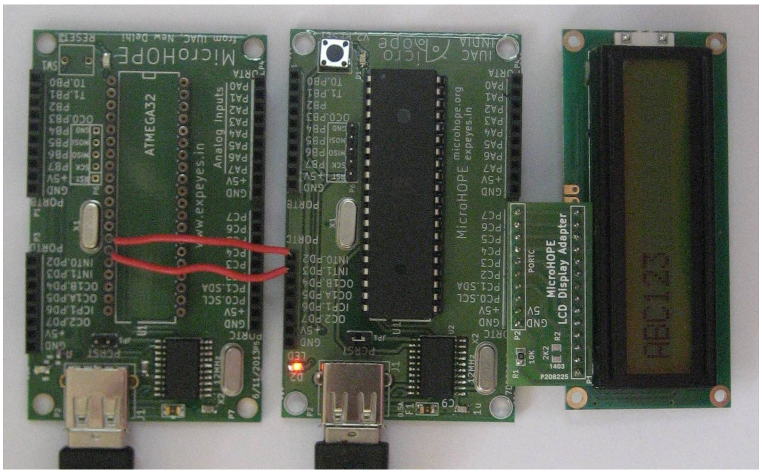


Figure 2.6: Connection to PC via soft serial port

```
{
    while(!ubcount) ;  // wait for Rx data
    x = uart_read();
    lcd_put_char(x);
    uart_write(x);
    }
  }
```

The Python echo.py is used on the PC side. The device name is shown as /dev/ttyACM1, assuming that /dev/ttyACM0 is already taken by the microhope board used for program development.

```
import serial
fd = serial.Serial('/dev/ttyACM1', 9600, stopbits=1, \
    timeout = 1.0)
while 1:
    c = raw_input('Enter the character to send: ')
    fd.write(c)
    print 'Receiced ', fd.read()
```

Even though this code has been tested, it seems to be having severe limitations. Receiver cannot handle data coming a high rates, require at least 2 to 3 milliseconds gap between bytes.

Chapter 3

Coding in Assembly Language

Main objective of this chapter is to learn the architecture of the micro-controller rather than developing large programs. Some examples justifying coding in assembly for better performance will be demonstrated. One concern with assembly or machine language coding is that the work is specific to the architecture of the selected device. The approach will be to examine the architecture in a generic manner and provide some example programs that are more or less common to any kind of processors.[1]

Major components of a micro-controller are shown in figure3.1. After powering up (or Reset) the Program Counter in initialized to zero, so that it points to the beginning of the Program Memory. The instruction stored at that location is brought to the Instruction Decoder and executed. This could be operations like; moving data between the Working Registers and RAM, performing some arithmetic and logical operations, changing the content of the program counter, etc. Writing to the Special Function Registers control the Input/Output pins and also the operation of peripheral devices like ADC, Timer/Counter etc. The popular family of micro-controllers like 8051, AVR and PIC follows the same architechture, even though the details may differ. Understanding them from a generic point of view makes switching from one type of device to another easier.

To program in assembly language, we need to have some understanding about the Instruction Set, the Registers and the memory configuration of the micro-controller. We also need to know the syntax supported by the assembler we use, there is usually small differences between various assemblers. Since we are using Atmega32, belonging to the AVR family, and the GNU assember for AVR, further discussions will be restricted to them.

3.1 Format of an Assembler Program

A single line of code may have a

- Label: , always terminated by a colon
- The instruction
- The operands (could be 0, 1 or 2 of them)
- A comment starting with a semicolon

[1] http://sourceware.org/binutils/docs/as/

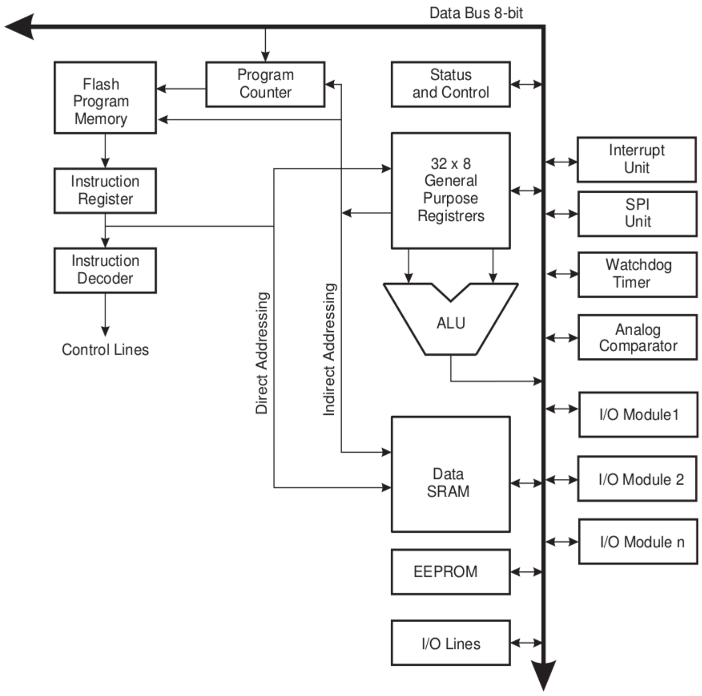


Figure 3.1: A block diagram of Micro-controller

```
lab1: INC  R1  ;increment the content of Register r1
```

The instruction and operand is not case sensitive but the labels are case sensitive, Lab1 is not the same as lab1. A complete program is shown below.

```
;first.s , example assembler program, for avr-gcc.
work = 1
  .equ DDRB, 0x37  ; memory mapped addresses
  .equ PORTB, 0x38 ; of DDRB and PORTB
  .section .data ; the data section
var1:
  .byte 15  ; global variable var1
  .section .text  ; The code section
  .global __do_copy_data  ; initialize variables
  .global __do_clear_bss  ; and setup stack
  .global main ; declare label main as global
main:
  lds work, var1  ; load var1 to R1
  sts DDRB, work  ; PB0 as output
  sts PORTB, work ; set  PB0  HIGH
  .end
```

1. The Working registers (R1 to R31) and the SFRs can be assigned different names, as shown in the beginning.

2. .data, starts a data section, initialized RAM variables.

3. .text, starts a text section, code and ROM constants.

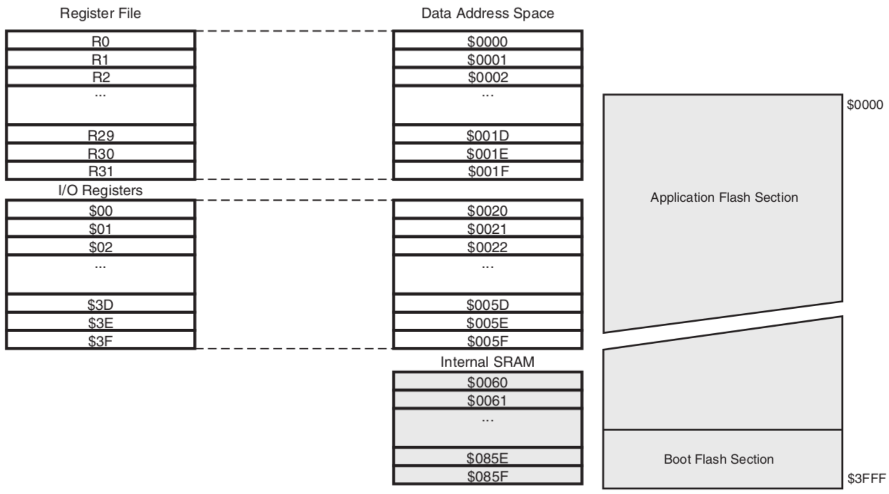


Figure 3.2: AVR memory maps.(a)Data memory.(b) Program memory

4. .byte, allocates single byte constants.
5. .ascii, allocates a non-terminated string.
6. .asciz, allocates a \0-terminated string.
7. .set declares a symbol as a constant expression (identical to .equ)
8. .global, declares a public symbol that is visible to the linker
9. .end, singifies the end of the program

The lines .global __do_copy_data and .global __do_clear_bss will tell the compiler to insert code for initializing variables, which is a must for programs having initialized data. Assembling and uploading first.s will set the 4 LSBs of port B.

3.2 AVR Architecture

A schematic of the AVR architecture is shown in figure 3.1. The 32 General Purpose Registers (R1 to R31, 8 bit wide) are also called the Register File. Data is moved between the Registers and the memory. Addressing memory locations above 255 is done by combining two 8bit registers to form a 16 bit register. R26 and R27 combined is the X register, R28 with R29 is the Y register, and R30 with R31 is the Z register. Different types of addressing modes are defined for transferring data between the Registers and the memory locations, mostly the SRAM.

In the AVR data memory space (figure 3.2), locations 0 to 31 (0x1F)are occupied by the Register File. Generally the assembler refers to them by names R1 to R31, not by the adresses. Location 0x20 to 0x5F (32 to 95) are occupied by the Special Function Registers (SFR), like the Status Register, the Stack Pointer and the control/status registers of the peripherals. The Special Function Registers can also be accessed using the I/O address space ranging from 0 to 0x3F, using IN and OUT insructions. Some of the special function registers are shown in figure 3.3(b), refer to the Atmega32 data sheet for a complete list. Use the address given inside the parantheses to access them as memory locations.

The first Register is SREG, the status register that holds the flags resulting from the last executed arithmetic or logical instruction. There are several instructions whose results depend on the status of the bits inside SREG. Availability of SREG as a special function register allows us to examine the status of various flags, after arithmetic and logical operations. Stack Pointer is used as a pointer to the data address space. PUSH and POP instructions are used for moving data between the register file and location specified by the stack pointer.

All the peripherals and the general purpose I/O ports are operated by accessing the corresponding SFRs. We will be using ports A and B to view data written to them using 8 LEDs. The SFRs used often in the example programs are listed below.

Name	I/O Addr.	Mem Addr	Function
DDRA	0x1A	0x3A	Data Direction of Port A
PORTA	0x1B	0x3B	Output to Port A
PINA	0x19	0x39	Input from Port A
DDRB	0x17	0x37	Data Direction of Port B
PORTB	0x18	0x38	Output to Port B
PINB	0x16	0x36	Input from Port B
SREG	0x3F	0x5F	Status Register

3.2.1 The Program Memory Space

3.3 Atmega32 Instruction Set

For a complete list of instructions supported by Atmega32, refer to the data sheet. We will only examine some of them to demonstrate different types of memory addressing and the arithmetic and logical operations.

3.4 Addressing Modes

The micro-controller spends most of the time transferring data between the Register File, SFRs and the RAM. Let us examine the different modes of addressing the Registers and Memory.

3.4.1 Register Direct (Single Register)

The contents of the register is read, specified operation is performed on it and the result is written back to the same register. For example

```
Lab1:  INC  R2   ; increments Register 2
```

The line above shows the format a line of code in assembly language. The label field is required only if the program needs to jump to that line. Everything after the semicolon is comment only.

3.4.2 Register Direct (Two Registers)

The contents of the source and destination registers are read, specified operation is performed and the result is written back to the destination register. The format is to specify the destination first. For example

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
$3F ($5F)	SREG	I	T	H	S	V	N	Z	C
$3E ($5E)	SPH	–	–	–	–	SP11	SP10	SP9	SP8
$3D ($5D)	SPL	SP7	SP6	SP5	SP4	SP3	SP2	SP1	SP0
$3C ($5C)	OCR0	Timer/Counter0 Output Compare Register							
$3B ($5B)	GICR	INT1	INT0	INT2	–	–	–	IVSEL	IVCE
$3A ($5A)	GIFR	INTF1	INTF0	INTF2	–	–	–	–	–
$39 ($59)	TIMSK	OCIE2	TOIE2	TICIE1	OCIE1A	OCIE1B	TOIE1	OCIE0	TOIE0
$38 ($58)	TIFR	OCF2	TOV2	ICF1	OCF1A	OCF1B	TOV1	OCF0	TOV0
$37 ($57)	SPMCR	SPMIE	RWWSB	–	RWWSRE	BLBSET	PGWRT	PGERS	SPMEN
$36 ($56)	TWCR	TWINT	TWEA	TWSTA	TWSTO	TWWC	TWEN	–	TWIE
$35 ($55)	MCUCR	SE	SM2	SM1	SM0	ISC11	ISC10	ISC01	ISC00
$34 ($54)	MCUCSR	JTD	ISC2	–	JTRF	WDRF	BORF	EXTRF	PORF
$33 ($53)	TCCR0	FOC0	WGM00	COM01	COM00	WGM01	CS02	CS01	CS00
$32 ($52)	TCNT0	Timer/Counter0 (8 Bits)							
$31[1] ($51)[1]	OSCCAL	Oscillator Calibration Register							
	OCDR	On-Chip Debug Register							
$30 ($50)	SFIOR	ADTS2	ADTS1	ADTS0	–	ACME	PUD	PSR2	PSR10
$2F ($4F)	TCCR1A	COM1A1	COM1A0	COM1B1	COM1B0	FOC1A	FOC1B	WGM11	WGM10
$2E ($4E)	TCCR1B	ICNC1	ICES1	–	WGM13	WGM12	CS12	CS11	CS10
$2D ($4D)	TCNT1H	Timer/Counter1 – Counter Register High Byte							
$2C ($4C)	TCNT1L	Timer/Counter1 – Counter Register Low Byte							
$2B ($4B)	OCR1AH	Timer/Counter1 – Output Compare Register A High Byte							
$2A ($4A)	OCR1AL	Timer/Counter1 – Output Compare Register A Low Byte							
$29 ($49)	OCR1BH	Timer/Counter1 – Output Compare Register B High Byte							
$28 ($48)	OCR1BL	Timer/Counter1 – Output Compare Register B Low Byte							
$27 ($47)	ICR1H	Timer/Counter1 – Input Capture Register High Byte							
$26 ($46)	ICR1L	Timer/Counter1 – Input Capture Register Low Byte							
$25 ($45)	TCCR2	FOC2	WGM20	COM21	COM20	WGM21	CS22	CS21	CS20
$24 ($44)	TCNT2	Timer/Counter2 (8 Bits)							
$23 ($43)	OCR2	Timer/Counter2 Output Compare Register							
$22 ($42)	ASSR	–	–	–	–	AS2	TCN2UB	OCR2UB	TCR2UB
$21 ($41)	WDTCR	–	–	–	WDTOE	WDE	WDP2	WDP1	WDP0
$20[2] ($40)[2]	UBRRH	URSEL	–	–	–	UBRR[11:8]			
	UCSRC	URSEL	UMSEL	UPM1	UPM0	USBS	UCSZ1	UCSZ0	UCPOL
$1F ($3F)	EEARH	–	–	–	–	–	–	EEAR9	EEAR8
$1E ($3E)	EEARL	EEPROM Address Register Low Byte							
$1D ($3D)	EEDR	EEPROM Data Register							
$1C ($3C)	EECR	–	–	–	–	EERIE	EEMWE	EEWE	EERE
$1B ($3B)	PORTA	PORTA7	PORTA6	PORTA5	PORTA4	PORTA3	PORTA2	PORTA1	PORTA0
$1A ($3A)	DDRA	DDA7	DDA6	DDA5	DDA4	DDA3	DDA2	DDA1	DDA0
$19 ($39)	PINA	PINA7	PINA6	PINA5	PINA4	PINA3	PINA2	PINA1	PINA0
$18 ($38)	PORTB	PORTB7	PORTB6	PORTB5	PORTB4	PORTB3	PORTB2	PORTB1	PORTB0
$17 ($37)	DDRB	DDB7	DDB6	DDB5	DDB4	DDB3	DDB2	DDB1	DDB0
$16 ($36)	PINB	PINB7	PINB6	PINB5	PINB4	PINB3	PINB2	PINB1	PINB0
$15 ($35)	PORTC	PORTC7	PORTC6	PORTC5	PORTC4	PORTC3	PORTC2	PORTC1	PORTC0
$14 ($34)	DDRC	DDC7	DDC6	DDC5	DDC4	DDC3	DDC2	DDC1	DDC0
$13 ($33)	PINC	PINC7	PINC6	PINC5	PINC4	PINC3	PINC2	PINC1	PINC0
$12 ($32)	PORTD	PORTD7	PORTD6	PORTD5	PORTD4	PORTD3	PORTD2	PORTD1	PORTD0
$11 ($31)	DDRD	DDD7	DDD6	DDD5	DDD4	DDD3	DDD2	DDD1	DDD0
$10 ($30)	PIND	PIND7	PIND6	PIND5	PIND4	PIND3	PIND2	PIND1	PIND0

Figure 3.3: AVR Special Function Registers.

```
MOV  R2, R5   ; content of R5 is copied to R2
ADD  R1, R2   ; r1 + r2 stored to r1
```

3.4.3 I/O Direct

These type of instructions are to transfer data between the Registers (r1 to r31) and the Special Function Registers, that can also be accessed as I/O ports. The following example demonstrates this. At this point we are writing a complete example program, **io-direct.s** .

```
     .section .text    ; denotes code section

     .global main

main:

     clr  r1
     inc  r1          ; R1 now contains 1
     out  0x17, r1    ; using I/O address, DDRB and
     out  0x18, r1    ; PORTB. LED should glow
     .end
```

Executing this program should switch ON the LED connected to the LSB of Port B. Modify the program to remove the INC instruction, assemble and upload it again, the LED should go off.

3.4.4 Immediate

In this mode, data to be transferred from/to any of the Registers, is part of the instruction itself. Registers below r16 cannot be used under this mode.

```
; immed.s  , demonstrate Load Immediate mode
  .section .text    ; denotes code section
  .global main
main:
  ldi r16, 255      ; load r16 with 255
  out 0x17, r16  ; Display content of R16
  out 0x18, r16  ; using LEDs on port B
  .end
```

Assembling and running **immed.s** listed above makes all port B bits HIGH, can be viewed using the LED board.

3.4.5 Data Direct

In this mode, the address of the memory location containing the data is specified, instead of the data itself. Data could be transferred from the specified location to a register (LDS) or from a register to the memory location (STS). The instruction mnemonics are LDS, for moving data from RAM to Register, and STS for storing Register content to RAM. The example **data-direct.s** demonstrates the usage of LDS and STS instructions. First we use the immediate mode to initialize R17 with some value.

```
; data-direct.s,demonstrate data direct mode
DDRB = 0x37
PORTB = 0x38
   .section .data
var1:
   .section .text    ; denotes code section
   .global main
main:
  ldi  R17, 0xf0      ; set r17 to 11110000b
  sts  var1, r17      ; store r17 to location var1
  lds  r16, var1      ; content of RAM at var1 to r16
  sts  DDRB, r16      ; store R16 to DDRB & PORTB
  sts  PORTB, r16     ; using their memory addresses
  .end
```

The actual address of the memory location is not known to us, it is decided by the linker. The label 'var1', defined inside the data section is used inside the code. The actual value can be seen from the .lst file generated by the avr-objdumb program. Generated machine language code for the section 'main' is shown below. It can be seen that the label 'var1' is given the RAM address of 0x0060. Also note that the main is at address 0x0000006c in the program address space. Examine the .lst file to have a look at the complete code, including the sections added by the assembler. Moving data from R16 to DDRB and PORTB is done using both the I/O space address and the memory space address. The generated code is smaller in the case of I/O space addressing using the OUT instruction.

```
0000006c <main>:
  6c:  10 ef        ldi r17, 0xF0
  6e:    10 93 60 00  sts 0x0060, r17
  72:  00 91 60 00  lds r16, 0x0060
  76:  07 bb        out 0x17, r16
  78:  08 bb        out 0x18, r16
  7a:  00 93 37 00  sts 0x0037, r16
  7e:  00 93 38 00  sts 0x0038, r16
```

3.4.6 Data Indirect

In the previous mode, the address of the memory location is part of the instruction word. In Data Indirect mode the address of the memory location is taken from the contents of the X, Y or Z registers. This mode has several variations like pre and post incrementing of the register or adding an offset to it.

```
 ; data-indirect.s, addressing using pointer
  .section .data    ; data section starts here
var1:
   .section .text    ; denotes code section
   .global main
main:
   ldi  r17, 0b10101010 ; set r17 to 10101010b
   sts  var1, r17       ; store it to RAM at var1
```

```
        ldi  r26, lo8(var1)  ; lower byte and
        ldi  r27, hi8(var1)  ; higher byte of the address
        ld   r16, X          ; data from where X is pointing to
        out  0x17, r16
        out  0x18, r16
        .end
```

The operators lo8() and hi8() are provided by the assembler to extract the high and low bytes of the 16bit memory address.

3.5 Variable Initialization

In the previous examples, we have not initialized the global variable 'var1' inside the program. The example **global-init.s** listed below demonstrates this feature.

```
; global-init.s, variable initialization
DDRB = 0x37
PORTB = 0x38
   .section .data
var1:
   .byte 0xee
   .section .text    ; denotes code section
   .global main
   .global __do_copy_data ; initialize global variables
   .global __do_clear_bss ; and setup stack pointer
main:
  lds  r16, var1      ; content of RAM at var1 to r16
  sts  DDRB, r16      ; store R16 to DDRB & PORTB
  sts  PORTB, r16     ; using their memory addresses
  .end
```

The lines

```
.global __do_copy_data ; initialize global variables
.global __do_clear_bss ; and setup stack pointer
```

are for initializing variables and setting up the stack, essential for programs with initialized data.

3.6 Program Flow Control

The programs written so far has an execution flow from beginning to end, without any branching or subroutine calls, generally required in all practical programs. The execution flow can be controlled by CALL and JMP

3.6.1 Calling a Subroutine

The subroutine call can be relative or direct. For a direct call, the content of the Program Counter is replaced by the operand of the CALL instruction. For an indirect call, the operand is added to the current value of the Program Counter. In both cases the current value of the PC is pushed into the memory location pointed by the Stack Pointer register. The RET instruction, inside the called subroutine, pops the stored PC to resume execution from the called point. Program sub-routine.s listed below demonstrates this feature.

```
  ; sub-routine.s  , CALL instruction
IO_DDRB = 0x17
IO_PORTB = 0x18

   .section .text    ; code section starts
disp:                ; subroutine
   inc r1
   out  0x18, r1   ; PORTB
   ret
   .global main
main:
   ldi  r16, 255
   out  0x17, r16   ; DDRB
   clr  r1
   rcall disp   ; relative call
   ;call disp    ; direct call
   .end
```

The LED connected to PB0 will light up. Uncomment the CALL DISP and find out the difference in the generated code, from the .lst file. Functionally both are same but relative jump is possible only if the offset is less than 256.

3.6.2 Jump instructions

The program counter can be modified to change the flow of execution of the code.

```
  .section .data    ; data section starts here
  .section .text    ; denotes code section
  .global main
main:
  ldi  r16, 255
  out  0x17, r16   ; DDRB
  jmp lab1
  ldi r16, 15 ; load 15 ro r16
lab1:
  out  0x18, r16    ; r16 to PortB
  .end
```

Running this code, **jump.s**, will put on all the LEDs. Comment the JMP instruction and execute the code again to figure out the difference it is making. Jumps can be conditional also, like:

Vector No.	Program Address[2]	Source	Interrupt Definition
1	$000[1]	RESET	External Pin, Power-on Reset, Brown-out Reset, Watchdog Reset, and JTAG AVR Reset
2	$002	INT0	External Interrupt Request 0
3	$004	INT1	External Interrupt Request 1
4	$006	INT2	External Interrupt Request 2
5	$008	TIMER2 COMP	Timer/Counter2 Compare Match
6	$00A	TIMER2 OVF	Timer/Counter2 Overflow
7	$00C	TIMER1 CAPT	Timer/Counter1 Capture Event
8	$00E	TIMER1 COMPA	Timer/Counter1 Compare Match A
9	$010	TIMER1 COMPB	Timer/Counter1 Compare Match B
10	$012	TIMER1 OVF	Timer/Counter1 Overflow
11	$014	TIMER0 COMP	Timer/Counter0 Compare Match
12	$016	TIMER0 OVF	Timer/Counter0 Overflow
13	$018	SPI, STC	Serial Transfer Complete
14	$01A	USART, RXC	USART, Rx Complete
15	$01C	USART, UDRE	USART Data Register Empty
16	$01E	USART, TXC	USART, Tx Complete
17	$020	ADC	ADC Conversion Complete
18	$022	EE_RDY	EEPROM Ready
19	$024	ANA_COMP	Analog Comparator
20	$026	TWI	Two-wire Serial Interface
21	$028	SPM_RDY	Store Program Memory Ready

Figure 3.4: Interrupt vectors of Atmega32. Addresses according to a 2byte word arrangement.

```
CPI   R16, 100
BREQ  loop1
```

The branching will happen only if R16 is equal to 100.

3.6.3 Interrupt, Call from anywhere

So far we have seen that the execution flow is decided by the program instructions. There are situations where the uC should respond to external events, stopping the current program temporarily. This is done using Interrupts, that are external signals, either from the I/O pins or from from some of the peripheral devices. On receiving an interrupt signal, the processor stores the current Program Counter to the memory location pointed to by the Stack Pointer and jumps to the corresponding interrupt vector location, as shown in figure . For example, the processor will jump to location 0x0002 (0x0004 if you count them as bytes), if external interrupt pin INT0 is activated, provided the interrupt is enabled by the processor beforehand.

The interrupt vector location is filled with the address of the subroutine handling the interrupt. For the interrupts that are not used by the program, the assembler fills some default values. After executing the Interrupt Service Routine, the program execution resumes at the point where it was interrupted. The program **interrpt.s** listed below shows the usage of interrupts. Connect 8 LEDs to Port B and run the code. Connect PD2 to ground momentarily and watch the LEDs.

```
  .section .data    ; data section starts here
  .section .text    ; denotes code section
  .global __vector_1 ; INT0_vect
__vector_1:
  inc r1
```

```
  out 0x18, r1
  reti
  .global main
main:
ldi  r16, 255
out  0x17, r16   ; DDRB
out  0x12, r16   ; Port D pullup
ldi  r16, 0x40   ; enable INT0
out  0x3b, r16
clr r1
    sei
loop:
rjmp loop
.end
```

3.7 Output of the Assembler

We have learned howto write, assemble and execute simple assembler programs. Let us assemble a program with a single instruction, as shown below.

```
 ; test.s , an single line program
  .section .data ; data section starts here
  .section .text ; denotes code section
  .global main
main:
  clr r1
  .end
```

The generated machine language output can be examined by looking at the .lst output, shown below, generated by the objdump program. It can be seen that the assembler generates some code that is required for the proper operation of the uC. In the Atmega32 Program memory, the first 80 (50hex) bytes are supposed to be filled with the addresses of the 20 interrupt vectors. It can be seen that, the program jumps to location __ctors_end (54hex). The porcessor status register (0x3F) is cleared and the Stack Pointer is initialized to 0x085F (the last RAM location), before calling our main section. After returning from the main, it jumps to _exit (0x6e), clears the interrupt flag and then enters an infinite loop. That means we need to end the main section with an infinite loop, if our program uses interrupts.

```
/home/ajith/microhope/ASM/test:     file format elf32-avr
Disassembly of section .text:
00000000 <__vectors>:
   0:  0c 94 2a 00  jmp 0x54 ; 0x54 <__ctors_end>
   4:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
   8:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
   c:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
  10:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
  14:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
```

```
  18:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
  1c:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
  20:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
  24:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
  28:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
  2c:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
  30:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
  34:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
  38:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
  3c:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
  40:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
  44:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
  48:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
  4c:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
  50:  0c 94 34 00  jmp 0x68 ; 0x68 <__bad_interrupt>
00000054 <__ctors_end>:
  54:  11 24        eor r1, r1
  56:  1f be        out 0x3f, r1 ; 63
  58:  cf e5        ldi r28, 0x5F ; 95
  5a:  d8 e0        ldi r29, 0x08 ; 8
  5c:  de bf        out 0x3e, r29 ; 62
  5e:  cd bf        out 0x3d, r28 ; 61
  60:  0e 94 36 00  call 0x6c ; 0x6c <main>
  64:  0c 94 3e 00  jmp 0x7c ; 0x7c <_exit>
00000068 <__bad_interrupt>:
  68:  0c 94 00 00  jmp 0 ; 0x0 <__vectors>
0000006c <main>:
  6c:  88 27        eor r16, r16
0000006e <_exit>:
  6e:  f8 94        cli
00000070 <__stop_program>:
  70:  ff cf        rjmp .-2; 0x70 <__stop_program>
```

3.8 Using Pre-processor, .s and .S

The examples described so far used the **.s** extension for the filenames. The program **square-wave-tc0.s** listed below generates a 15.93 kHz square wave on PB3.

```
TCCR0 = 0x53
WGM01 =  3
COM00 = 4
OCR0 = 0x5C
DDRB = 0x37
PB3 =  3
  .section .text  ;code section
  .global main
main:
  ldi r16,  (1 << WGM01) | (1 << COM00) |  1  ;CTC mode
```

```
    sts TCCR0 , r16
    ldi r16, 100
    sts OCR0, r16
    ldi r16, (1 <<  PB3)
    sts DDRB, r16
    .end
```

The addresses of the Special Function Registers and the various bits inside them are defined inside the program (first 6 lines). Instead of entering them like this, we can use the corresponding include file. We need to use the **.S** file extension to tell avr-gcc to call the assembler with the suitable pre-processor options. The same program re-written with .S extension**, square-wave-tc0.S**, is listed below.

```
#include <avr/io.h>
  .section .text
  .global main
main:
  ldi r16,(1 << WGM01) | (1 << COM00) | 1 ; CTC mode
  sts TCCR0 , r16
  ldi r16, 250
  sts OCR0, r16
  ldi r16, (1 << PB3)
  sts DDRB, r16
  .end
```

The second method is advisable if you plan to develop larger assembler programs for practical applications.

3.9 Example Programs

The programs described below performs better than their C counterparts.

3.9.1 R2R DAC on Port B

A R2R network, as shown in figure 3.5(a), is connected to port B. The program writes the content of R1 to port B in an infinite loop. R1 ia incremented every time and after reaching 255, it will become 0, resulting in a ramp at the output of the R-2R network, figure 3.5(b). The frequency of the ramp generated is around 8 kHz.

```
; program ramp-on-R2RDAC.S , generates ramp on Port B
#include <avr/io.h>
   .section .text
   .global main
main:
   ldi r16, 255
   sts DDRB, r16 ; all bits of DDRB set
loop:
   inc r1
   sts PORTB, r1   ; R1 to PORTB. LEDs
```

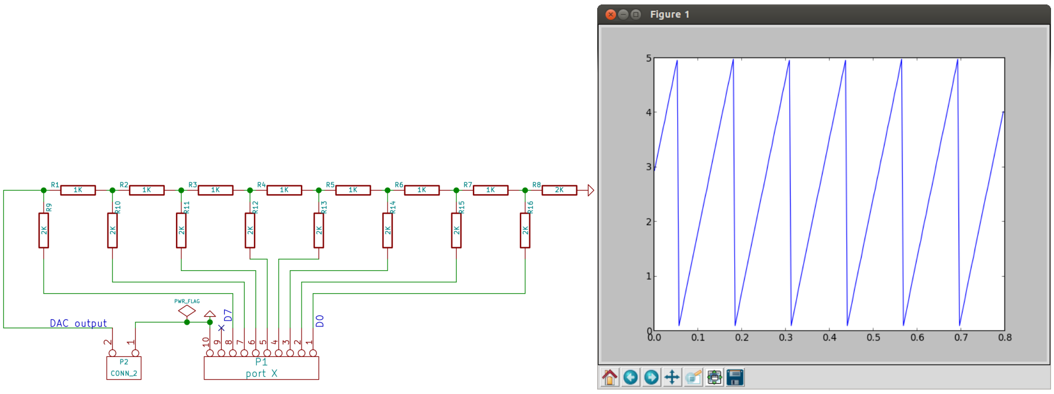


Figure 3.5: R2R DAC on port B (a) schematic (b) output waveform

```
    rjmp loop
    .end
```

3.9.2 Sine wave Generator

The program **sine-wave.S** listed below uses Timer/Counter 0 to trigger an interrupt when the counter reaches the set point register OCR0. Register X is pointed to a sine table stored in SRAM. On an interrupt the value from sine table, pointed to by X, is written to Port B where the R-2R DAC is connected. Register R22 is used for reseting the pointer after 32 increments. The R-2R DAC on port B generates the DC values, that makes the sine wave.

```
#include <avr/io.h>
   .section .data
   .global stab
stab:  ; sine table
   .byte 128,150,171,191,209,223,234,240,242,240,234,\
223,209,191,171,150,128,105,84,64,46,32,21,\
    15,13,15,21,32,46,64,84,105,127
   .section .text   ; code section
   .global __do_copy_data
   .global __do_clear_bss
   .global  TIMER0_COMP_vect
TIMER0_COMP_vect:      ; ISR
   ld   r24, X+ ; load from table, increment
   sts  PORTB, r24 ; write it to PORTB
   inc  r22 ; increment r22
   CPSE r20,r22 ; reached the end ?
   reti         ; Skip if equal
   clr  r22 ; ready for next round
   subi r26,32  ; set X to table start
   reti

   .global main
main:
```

```
    ldi  r16, 255
    sts  DDRB, r16
    ldi  r16, (1 << WGM01) |  1  ; TCCR0 to CTC mode
    sts  TCCR0 , r16
    ldi  r16, 50   ; Set point reg to 50
    sts  OCR0, r16
    ldi  r16, (1 << OCIE0)  ; set TC0 compare interrupt enable
    sts  TIMSK, r16
    ldi  r16, (1 << OCF0)   ; interrupt enable bit
    sts  TIFR, r16
    ldi  XL, lo8(stab)  ; point X to the sine table
    ldi  XH, hi8(stab)
    clr  r22  ; R22 will keep track of the  location in table
    ldi  r20,32  ; Store size of the table in R20
    sei
loop:
    rjmp loop   ; infinite loop
    .end
```

Chapter 4

Programming details

MicroHOPE does program loading through the Rx/Tx pins of the UART, with the help of the pre-loaded boot loader program. The boot loader code is first loaded using the In-System Programming (ISP) feature of the uC, implemented using the Serial Peripheral Interface (SPI) interface of the micro-controller. Both the methods are explained below.

4.1 Compile and Upload, using bootloader

Even though the IDE does the job, it is a good idea to learn about the programs used behind the seen, to compile and upload the code. The software packages used are:

- avr-gcc : To compile the C program, also require the C library avr-libc
- avr-objcopy : To generate the HEX file
- avrdude : To upload the Hex file

These packages are available under GNU/Linux. For Debian/Ubuntu distributions they can be installed from the repository using the commands:

```
# apt-get install avr-libc
# apt-get install avrdude
# chmod u+s avrdude
```

Insatlling avr-libc, automatically installs gcc-avr and other required packages. The last command will enable non-root users to use avrdude. The installed programs can be invoked from the command line. Use a text editor to create your source program, for example **blink.c**, and compile it using:

```
$ avr-gcc  -Wall -O2 -mmcu=atmega32 -o blink blink.c
```

We have asked the compiler to print all the warnings, optimize to level 2, generate code for atmega32. The executable output stored in blink and input taken from blink.c. The executable file is converted into Intel Hex format using the following command:

```
$ avr-objcopy -j .text -j .data -O ihex blink blink.hex
```

The Hex file is now ready for upload. This can be done using the command:

```
$ avrdude -b 19200 -P /dev/ttyACM0 -pm32 -c stk500v1 -U flash:w:blink.hex
```

We have specified a baudrate of 19200, the output device is /dev/ttyACM0, m32 processor and the transfer protocol stk500v1.

CDC ACM Device

The PC is connected to the uC through the USB to Serial Converter IC, MCP2200. This chip implements the Communication Device Class (CDC) protocol of USB and is classified as an Abstract Control Model (ACM) device. It apprears as a virtual COM port to the application program. They get the device names /dev/ttyACM0, /dev/ttyACM1 etc. in the order in which they are plugged in. Remember to close the application programs before disconnecting the device, otherwise it will get higher numbers when connected again.

4.1.1 Batch files

Since a lot of command line arguments are required to specify the compiler, linker and loader options, it is convenient to put them in small batch files or shell scripts. These files can be found inside the **microhope** directory, once the package is installed. The compilation of C code and generation of Intel Hex format file for uploading is done by **compile-mega32.sh**, listed below.

$ avr-gcc -Wall -O2 -mmcu=atmega32 -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

For example, to compile a program named 'hello.c', it should be invoked from the command line as;

```
$./compile-mega32.sh hello
```

The .c extension should not be specified. The script also generates the linker MAP file and a listing file, that may be used for examining the generated output.

Under GNU/Linux, microhope on the USB port will appear as file '/dev/ttyACM0'[1] and program uploading is done by **mh-upload.sh**, listed below

```
$ avrdude -b 19200 -P /dev/ttyACM0 -pm32 -c stk500v1 -U flash:w:$1.hex
```

To upload hello.hex, use the command

```
$./mh-upload hello
```

Running from DOS prompt

Use a text editor like notepad to edit the source program and save it with a .c extension. The commands for compilation and uploading are:

```
C:\> avr-gcc  -Wall -O2 -mmcu=atmega32 -o blink blink.c
C:\> avr-objcopy -j .text -j .data -O ihex blink blink.hex
C:\> avrdude -b 19200 -P COMxx -pm32 -c stk500v1 -U flash:w:blink.hex
```

Where COMxx is the virtual com port number assigned by Windows. We have found it very difficult due to the arbitrary numbering of the COM ports.

[1]For the old model of microhope using FT232 IC, this will be /dev/ttyUSB0

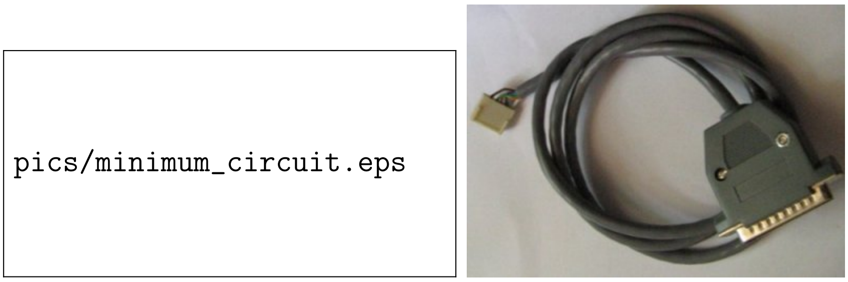


Figure 4.1: PC Parallel port cable for Serial loading of program memory.

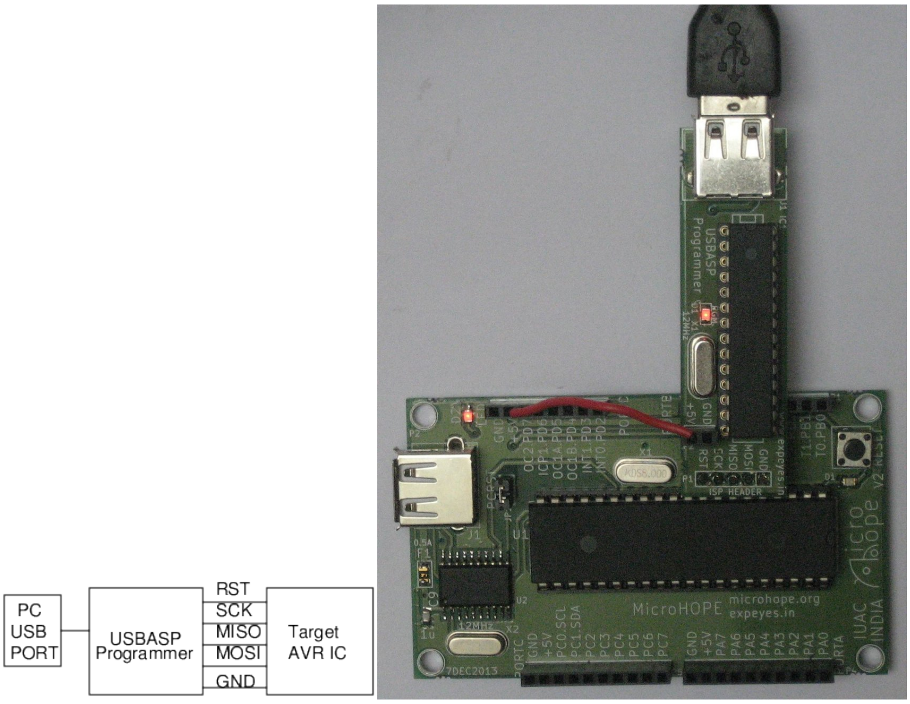


Figure 4.2: USBASP programmer.(a) block diagram (b) with MicroHOPE

4.2 Serial Loading of Program memory

Most of the uCs have the In-System Programming (ISP) feature, implemented using three pins, Serial ClocK (SCK), Master-In–Slave-Out (MISO) and Master-Out–Slave-In (MOSI). All types of memory on the micro-controller can be accessed using the SCK, MISO and MOSI pins, while holding the RESET pin LOW. These pins, along with ground, are available on the 5 pin header J7 on the microHOPE board. For details, refer to the circuit schematic shown in figure 1.3.

The SPI pins can be accessed by connecting to the Parallel port of the PC, using a cable as shown is figure 4.1. We can also use In-System Programmers that can be connected to the USB port of the PC. We are using an ISP called the USBASP, that is open hardware.

The microHOPE IDE can upload programs using the USBASP programmer

4.2.1 Software

The program **avrdude** can be used for programming the micro-controller by using Parallal port or the USBASP programmer. The commands to use, as root user, are:

```
# avrdude -c dapa -patmega32 -U flash:w:blink.hex
# avrdude -c usbasp -patmega32 -U flash:w:blink.hex
```

The -c option is used for specifying the programmer to be used. The commands should be given from a terminal, after changing to the directory 'microhope', where all the data files are kept.

Setting up the Boot Loader

We can use one of these methods for uploading the bootloader program of microHOPE. The commands for uploading the hex file and setting the fuses, using the parallel port cable, are:

avrdude -c dapa -patmega32 -U flash:w:ATmegaBOOT_168_atmega32.hex

avrdude -c dapa -patmega32 -U lfuse:w:0xef:m -U hfuse:w:0xda:m

If you are using USBASP, use:

avrdude -B10 -c usbasp -patmega32 -U flash:w:ATmegaBOOT_168_atmega32.hex

avrdude -B10 -c usbasp -patmega32 -U lfuse:w:0xef:m -U hfuse:w:0xda:m

For more details refer to the microhope section of the website expeyes.in

Latest version of this document can be downloaded from expeyes.in/microhope. This product is from the PHOENIX project of IUAC, New Delhi, with contributions from the academic community.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