

# ME 333: Introduction to Mechatronics

## Assignment 2: Getting to know the PIC32

Electronic submission due **before** 12:30 p.m. on January 25th

### 1 Converting between different numbering systems

The following questions will walk you through converting between binary (or base-2), decimal (base-10), and hexadecimal (base-16) numbers. In order to keep track of the three numbering systems, a number with a subscript 2, e.g.,  $101101_2$ , refers to a number in binary, a subscript 10, like  $55_{10}$ , is a number written in base-10, and a subscript 16, as in  $7F_{16}$ , refers to a number in hexadecimal (or hex for short).

The following recipe will convert from base-10 to binary:

1. Divide the number,  $n$ , by 2, keeping track of the quotient and the remainder
2. Repeat step 1, using the quotient in step 1) as your new number,  $n$ , until the quotient is zero
3. To get the binary number, simply write the remainders in reverse order

**Example:** Convert  $55_{10}$  to binary.

Divide $n$ by 2	Quotient	Remainder
$55/2$	27	1 (this is the last bit written)
$27/2$	13	1
$13/2$	6	1
$6/2$	3	0
$3/2$	1	1
$1/2$	0	1 (this is the first bit written)
$0/2$	0	0

Hence,  $55_{10}$  in base-10 is  $110111_2$  in base-2 (we can ignore leading zeros).

#### Questions

- (a) What is  $79_{10}$  in binary?
- (b) What is  $18_{10}$  in binary?

The conversion from binary to decimal is a little simpler, but first we introduce a commonly used convention. A generic  $n$ -bit binary number is often written as:  $b_{n-1}b_{n-2}\dots b_i\dots b_2b_1b_0$ , where  $i$  is the position (or index) of the bit and  $b_i$  is its value (this is the same convention used with

arrays in C). We refer to  $b_{n-1}$  as the most significant bit (MSB)<sup>1</sup> and  $b_0$  as the least significant bit (LSB). To convert from binary to decimal, you compute the following sum:

$$d = \sum_{i=0}^{n-1} 2^i \times b_i = (b_{n-1} \times 2^{n-1}) + \dots + (b_1 \times 2^1) + (b_0 \times 2^0)$$

where  $d$  is the final number in base-10 and  $b_i$  is the value of the  $(i + 1)$ -st bit in the binary number.

**Example:** Convert  $101101_2$  to base-10.

$$101101_2 = (1 \times 2^5) + (0 \times 2^4) + (1 \times 2^3) + (1 \times 2^2) + (0 \times 2^1) + (1 \times 2^0) = 45_{10}$$

### Questions

- What is  $10110101_2$  in decimal?
- What is the maximum number in decimal that a 10-bit number can hold?

As the previous two examples have shown, converting between binary and decimal numbers isn't always the quickest operation and dealing with long binary numbers can get cumbersome. This is where hexadecimal or base-16 numbers come in. The following table shows the relationship between the three bases.

decimal	binary	hexadecimal
0	0000	0
1	0001	1
2	0010	2
3	0011	3
4	0100	4
5	0101	5
6	0110	6
7	0111	7
8	1000	8
9	1001	9
10	1010	A
11	1011	B
12	1100	C
13	1101	D
14	1110	E
15	1111	F

Similar rules can be developed to convert from binary to hexadecimal, but here is a simple and quick shortcut.

- Starting with the LSB partition the binary number into groups of 4 (remember leading zeros do not affect the number, so every bit should be in a group of 4)
- Replace each group of 4 with its corresponding hexadecimal number

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<sup>1</sup>In certain contexts, MSB can also refer to the most significant byte. It should be clear from context whether bit or byte is assumed.

**Example:** Convert  $101101_2$  to hexadecimal.

$$101101_2 = (0010)(1101)_2 = 2D_{16}$$

### Questions

- (a) What is  $1011011_2$  in hexadecimal?
- (b) What is  $80_{10}$  in hexadecimal?

By default all numbers are in base-10 in C. If you want to write a number in base-16, prepend “0x” to a valid hex number. For example,  $0xFF$  (or  $0xff$ , case doesn’t matter) is how we would type  $255_{10}$  in C using hex. To write a number in binary, prepend the binary number with “0b”, as in  $0b101$ . The syntax for writing numbers in binary is particular to the MPLAB C compiler, so you should only use the syntax when compiling a PIC program.

## 2 The C bitwise operators

### Questions

After reading Essential C, Bitwise Operators (pp. 9-10),

- (a) What are the four bitwise operators?
- (b) Write the truth table for each bitwise operator

The C programming language does not have a bit data type, but, with its bitwise operators, we can modify the bits within any integral data type (int, short, long, signed, unsigned, and char). The bitwise operators are applied to each individual bit and the result is stored in a data type of the same size.

**Example:** In the lines below, what is the final value of z?

```
char x = 0xC4;
char y = 0xAA;
char z = x | y;
```

variable	$b_7$	$b_6$	$b_5$	$b_4$	$b_3$	$b_2$	$b_1$	$b_0$
x	1	1	0	0	0	1	0	0
y	1	0	1	0	1	0	1	0
z	1	1	1	0	1	1	1	0

Hence,  $z = 0xEE$ .

### Questions

- (a) What is  $0x55 \& 0x17$ ?
- (b) What is  $0x55 \wedge 0x17$ ?
- (c) What is  $(\sim 0x55) | 0x17$ ?
- (d) Given  $a = 0x3F$ ,  $c = 0x5E$ , what is b in  $c = a \& b$ ?

### 3 The PIC32 Hardware

The following questions are based on the wiki page, NU32v2: Introduction to the PIC32. You may also have to consult the PIC32 data sheet (DS) and reference manual(RM).

#### Questions

- (a) What does “peripheral” mean for the PIC?
- (b) Go to the Microchip homepage, check out the Parametric Table of PIC32s, and find a PIC with the following specs: 80 MHz max clock speed, 512 K flash (program memory), 32 K RAM (data memory), 4 channels of DMA, 16 A/D converters with 10-bit resolution, USB capabilities, 2 comparators, 5 16-bit timers and 1 32-bit timer, 5 PWM channels and 5 input compare channels, 2 UARTs, 2 SPI, and 2 I2C pins, no CAN modules, no Ethernet, and 100 pins. What is the part number? What types of packages does it come in (e.g., DIP, or different kinds of surface mount packages, etc.)? How much does it cost in quantity 1? What is the difference in price and features from our PIC, the PIC32MX795F512L?
- (c) Refer to the “Block diagram of the PIC32MX7XX” under “PIC32 Hardware Overview” or p. 31 “Device Overview” in the DS. In one sentence each, without going into detail, explain the basic function of the following items shown in the block diagram: Timing Generation, MCLR, SYSCLK, PBCLK, USBCLK, PORTA...G (and indicate which of these can be used for analog input on our PIC), Timer 1-5, 10-bit ADC, Comparators, Ethernet, UART 1-6, I2C 1-5, SPI 1-4, IC 1-5, PWM OC 1-5, CN1-22, Data RAM, Program Flash Memory, and Pre-Fetch Module.
- (d) Describe the four functions that pin 23 of our PIC32 can have. Is it 5V tolerant?
- (e) How many pins from the PIC32 are available on the NU32v2 board?
- (f) What is the absolute maximum amount of current that the NU32v2 board can provide from the 9V wall plug? What are some limiting factors in drawing the full amount of current from the plug?
- (g) How wide is PORTG on our PIC32 (i.e., how many pins does it have)? You should use Table 1-1 in the DS, don’t search and count for the pins in a diagram.

### 4 Putting it all together

You’ve been introduced to different number systems, new C syntax, and the PIC32 hardware. In the following programming exercise, you will use what you’ve just learned to interact with the LATG register in C to modify the blinking pattern of the LEDs on the NU32v2 board. The LATG register is a 32-bit special function register (SFR) that sets or reads the state of the physical PORTG I/O pins. When a pin is configured as output, writing a “1” will set the pin to digital high and when a “0” is written, the pin outputs a digital low signal. You should refer to Table 4-31 in the DS to see the register layout of LATG. Note that not all of the bits in the register are used.

Deeply buried in the Microchip header files (which you indirectly include through `<plib.h>`), LATG is defined as an unsigned int. Unfortunately, the problem with using a C data type is that we can’t directly manipulate the bits. We could access the bits one by one using the predefined structs in `<plib.h>`, but, more often than not, you want the outputs to change at the same time.

This is where the bitwise operators come in, especially bitwise-and (&) and bitwise-or (|). The following are useful rules to remember:

- To set the  $i$ -th bit(s) to 1 (or “on”) use bitwise-or (|), to leave the bit(s) unchanged use 0
- To clear the  $i$ -th bit(s) to 0 (or “off”) use bitwise-and (&), to leave the bit(s) unchanged use 1

For example, say that the current state of  $LATG = 0x9F35$ , if we wanted to only change the output of pin G12 to low while preserving the state of the other pins, then we would turn the LATG bit position 12 to “off” using bitwise-and. To pose the problem differently, given  $a = 0x9F35$ ,  $c = 0x8F35$ , what is  $b$  in  $c = a \& b$ ?

Bit	G15	G14	G13	G12	G11	G10	G9	G8
$a = LATG < 15 : 8 >$ (initially)	1	0	0	1	1	1	1	1
$b = MASK < 15 : 8 >$	?	?	?	?	?	?	?	?
$c = LATG < 15 : 8 >$ (desired)	1	0	0	0	1	1	1	1

Bit	G7	G6	G5	G4	G3	G2	G1	G0
$a = LATG < 7 : 0 >$ (initially)	0	0	1	1	0	1	0	1
$b = MASK < 7 : 0 >$	?	?	?	?	?	?	?	?
$c = LATG < 7 : 0 >$ (desired)	0	0	1	1	0	1	0	1

The value for  $b$  (aka MASK) has to be  $0xEFFF$ , you can verify this for yourself. This will clear bit G12 and preserve the previous state of the other pins. The corresponding C code is:

```
LATG = LATG & 0xEFFF;
```

We would actually define  $0xEFFF$  as a constant. This type of constant is known as a bit mask or mask for short. If later on we change our minds and we want to set G12 back to high, then we would do:

```
LATG = LATG | 0x1000;
```

You can work this out to verify that G12 is now set to high and that we’ve left all other pins unmodified.

### Programming Assignment

Starting with the HelloWorld Code, modify only the while loop in main, so that the LEDs blink in the following sequence:

1. Both LED\_1 and LED\_2 are off for WAIT\_LOOPS amount of time
2. Only LED\_1 is on for WAIT\_LOOPS amount of time
3. Only LED\_2 is on for WAIT\_LOOPS amount of time
4. Both LED\_1 and LED\_2 are on for WAIT\_LOOPS amount of time
5. Repeat

For any credit, you must use the LATG register and the bitwise operators in your solution. There should be no reference to the constants LED\_1 or LED\_2 in your code.

## 5 What to turn in

You must submit typed responses to the questions in this assignment and your .c file used in the programming assignment in a zip file through Blackboard before class on the date the assignment is due. The name of the zip file you submit will be lastname.a2.zip. For example, the TA would submit his homework as Rosa.a2.zip

In addition to submitting your assignment via Blackboard, you will also demonstrate your program to the teaching staff at the beginning of class on the date the assignment is due. For this assignment you will demo the blinking sequence of lights.

For full credit you must follow these instructions exactly.