Embedded Systems Design: A Unified Hardware/Software Introduction

Chapter 4 Standard Single Purpose Processors: Peripherals

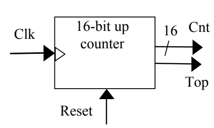
Introduction

- Single-purpose processors
  - Performs specific computation task
  - Custom single-purpose processors
    - Designed by us for a unique task
  - *Standard* single-purpose processors
    - "Off-the-shelf" -- pre-designed for a common task
    - a.k.a., peripherals
    - serial transmission
    - analog/digital conversions
  - Low NRE cost
  - Low unit cost

Timers, counters, watchdog timers

- Timer: measures time intervals - very common
  - To generate timed output events
    - e.g., hold traffic light green for 10 s
  - To measure input events
    - e.g., measure a car's speed
- Based on counting clock pulses
    - E.g., let Clk period be 10 ns
    - And we count 20,000 Clk pulses
    - Then 200 microseconds have passed
    - 16-bit counter would count up to 65,535*10 ns = 655.35 microsec., resolution = 10 ns
    - Top: indicates top count reached, wrap-around
      - Can be used to extend range with use of microprocessor

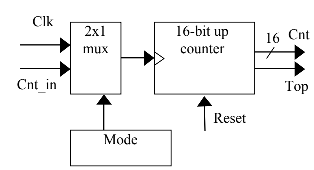
Basic timer



Counters

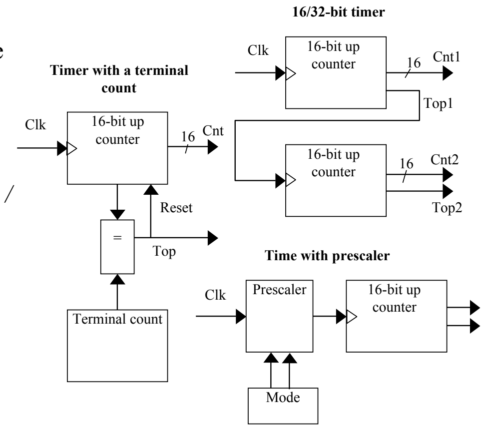
- Counter: like a timer, but counts pulses on a general input signal rather than clock
  - e.g., count cars passing over a sensor
  - Can often configure device as either a timer or counter

Timer/counter

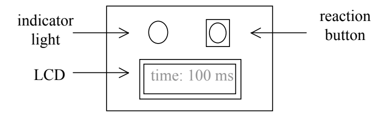


Other timer structures

- Interval timer
  - Indicates when desired time interval has passed
  - We set terminal count to desired interval
    - *Number of clock cycles = Desired time interval / Clock period*
- Cascaded counters
- Prescaler
  - Divides clock
  - Increases range, decreases resolution



Example: Reaction Timer

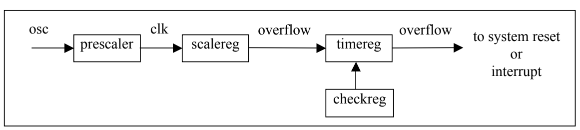


- Measure time between turning light on and user pushing button
  - 16-bit timer, clk period is 83.33 ns (12 MHz), counter increments every 6 cycles (once per instruction cycle - microcontroller specific)
  - Resolution = 6*83.33=0.5 microsec.
  - Range = 65535*0.5 microseconds = 32.77 milliseconds
  - Want program to count millisec., so initialize counter to 65535 – 1000/0.5 = 63535

```
/* main.c */

#define MS_INIT     63535
void main(void){
  int count_milliseconds = 0;

  configure timer mode
  set Cnt to MS_INIT

  wait a random amount of time
  turn on indicator light
  start timer

while (user has not pushed reaction button){
   if(Top) {
     stop timer
     set Cnt to MS_INIT
     start timer
     reset Top
     count_milliseconds++;
   }
 }
 turn light off
 printf("time:  %i ms", count_milliseconds);
}
```


Watchdog timer

- Must reset timer every X time unit, else timer generates a signal
- Common use: detect failure, self-reset
- Another use: timeouts
  - e.g., ATM machine
  - 16-bit timer, 2 microsec. resolution
  - *timereg* value = $2*(2^{16}-1)–X = 131070–X$
  - For 2 min., X = 120,000 microsec.

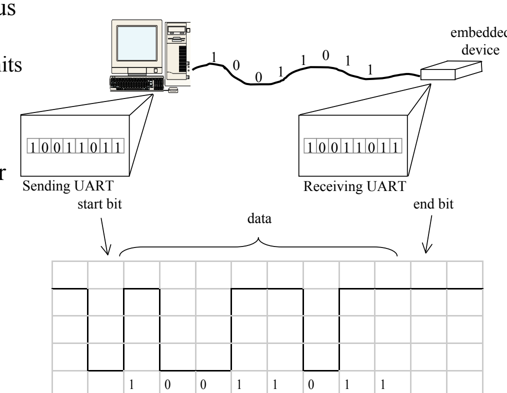



```
/* main.c */

main(){
  wait until card inserted
  call watchdog_reset_routine

  while(transaction in progress){
     if(button pressed){
        perform corresponding action
        call watchdog_reset_routine
     }

/* if watchdog_reset_routine not called every
< 2 minutes, interrupt_service_routine is
called */
}
```

```
watchdog_reset_routine(){
/* checkreg is set so we can load value into
timereg.  Zero is loaded into scalereg and
11070 is loaded into timereg */

   checkreg = 1
   scalereg = 0
   timereg  = 11070
}

void interrupt_service_routine(){
   eject card
   reset screen
}
```

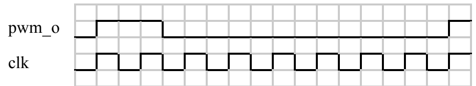

Serial Transmission Using UARTs

- UART: Universal Asynchronous Receiver Transmitter
  - Takes parallel data and transmits serially
  - Receives serial data and converts to parallel
- Parity: extra bit for simple error checking
- Start bit (receiver continually monitors for it), stop bit
- Baud rate
  - signal changes per second
    - Bits shifted out of buffer
  - Speed of communication
  - Configured via configuration register

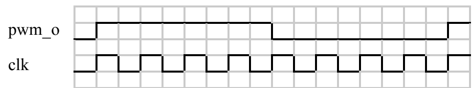


Pulse width modulator

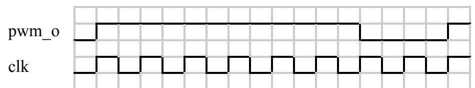
- Generates pulses with specific high/low times
- Duty cycle: % time high
  - Square wave: 50% duty cycle
- Common use: control average voltage to electric device
  - Simpler than DC-DC converter or digital-analog converter
  - DC motor speed, dimmer lights
- Another use: encode commands, receiver uses timer to decode



25% duty cycle – average pwm_o is 1.25V

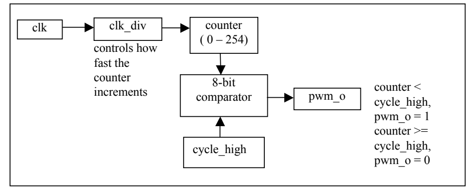


50% duty cycle – average pwm_o is 2.5V.



75% duty cycle – average pwm_o is 3.75V.

Controlling a DC motor with a PWM



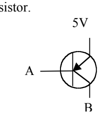
Internal Structure of PWM

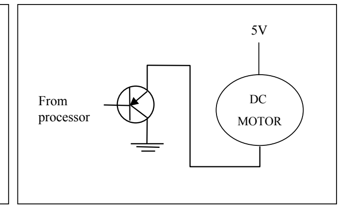
Input Voltage	% of Maximum Voltage Applied	RPM of DC Motor
0	0	0
2.5	50	1840
3.75	75	6900
5.0	100	9200

Relationship between applied voltage and speed of the DC Motor

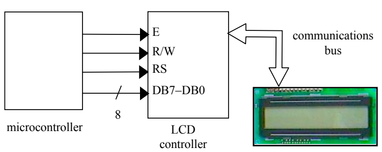
```
void main(void){

   /* controls period */
   PWMP = 0xff;
   /* controls duty cycle */
   PWM1 = 0x7f;

   while(1){};
 }
```

The PWM alone cannot drive the DC motor, a possible way to implement a driver is shown below using an MJE3055T NPN transistor.





LCD controller

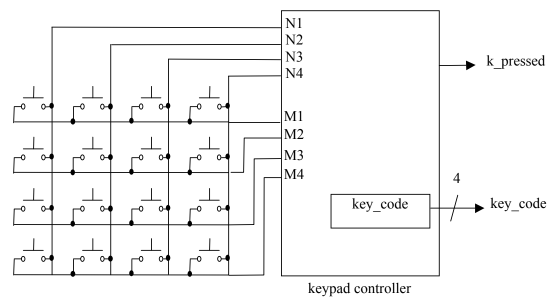



```
void WriteChar(char c){

  RS = 1;                /* indicate data being sent */
  DATA_BUS = c;          /* send data to LCD */
  EnableLCD(45);         /* toggle the LCD with appropriate delay */
}
```

CODES	
I/D = 1 cursor moves left	DL = 1 8-bit
I/D = 0 cursor moves right	DL = 0 4-bit
S = 1 with display shift	N = 1 2 rows
S/C =1 display shift	N = 0 1 row
S/C = 0 cursor movement	F = 1 5x10 dots
R/L = 1 shift to right	F = 0 5x7 dots
R/L = 0 shift to left	

RS	R/W	DB_7	DB_6	DB_5	DB_4	DB_3	DB_2	DB_1	DB_0	Description
0	0	0	0	0	0	0	0	0	1	Clears all display, return cursor home
0	0	0	0	0	0	0	0	1	*	Returns cursor home
0	0	0	0	0	0	0	1	I/D	S	Sets cursor move direction and/or specifies not to shift display
0	0	0	0	0	0	1	D	C	B	ON/OFF of all display(D), cursor ON/OFF (C), and blink position (B)
0	0	0	0	0	1	S/C	R/L	*	*	Move cursor and shifts display
0	0	0	0	1	DL	N	F	*	*	Sets interface data length, number of display lines, and character font
1	0	WRITE DATA								Writes Data

Keypad controller

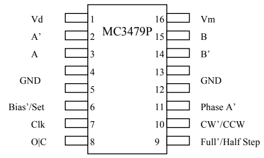


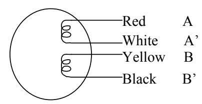
N=4, M=4

Stepper motor controller

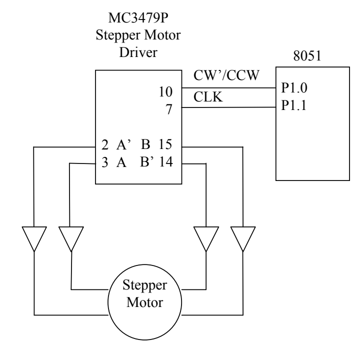
- Stepper motor: rotates fixed number of degrees when given a “step” signal
  - In contrast, DC motor just rotates when power applied, coasts to stop
- Rotation achieved by applying specific voltage sequence to coils
- Controller greatly simplifies this
- If step is 7.5 degrees, but do entire sequence to rotate 7.5 degrees
  - Opposite order for opposite direction
- Can use a driver chip or do in software

Sequence	A	B	A’	B’
1	+	+	-	-
2	-	+	+	-
3	-	-	+	+
4	+	-	-	+
5	+	+	-	-





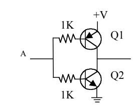
Stepper motor with controller (driver)



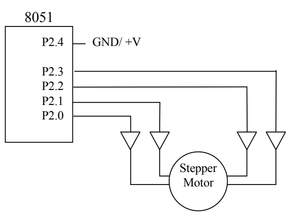

```
/* main.c */

sbit clk=P1^1;
sbit cw=P1^0;

void delay(void){
  int i, j;
  for (i=0; i<1000; i++)
    for ( j=0; j<50; j++)
      i = i + 0;
}
```

```
void main(void){

  */turn the motor forward */
  cw=0;          /* set direction */
  clk=0;         /* pulse clock */
  delay();
  clk=1;

  /*turn the motor backwards */
  cw=1;          /* set direction */
  clk=0;         /* pulse clock */
  delay();
  clk=1;

}
```

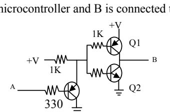
The output pins on the stepper motor driver do not provide enough current to drive the stepper motor. To amplify the current, a buffer is needed. One possible implementation of the buffers is pictured to the left. Q1 is an MJE3055T NPN transistor and Q2 is an MJE2955T PNP transistor. A is connected to the 8051 microcontroller and B is connected to the stepper motor.



Stepper motor without controller (driver)



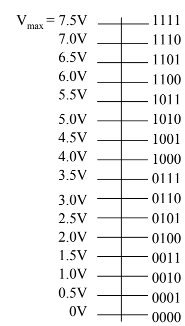
A possible way to implement the buffers is located below. The 8051 alone cannot drive the stepper motor, so several transistors were added to increase the current going to the stepper motor. Q1 are MJE3055T NPN transistors and Q3 is an MJE2955T PNP transistor. A is connected to the 8051 microcontroller and B is connected to the stepper motor.



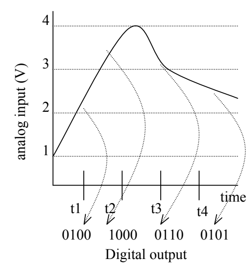

```
/*main.c*/
sbit notA=P2^0;
sbit isA=P2^1;
sbit notB=P2^2;
sbit isB=P2^3;
sbit dir=P2^4;

void delay(){
  int a, b;
  for(a=0; a<5000; a++)
    for(b=0; b<10000; b++)
      a=a+0;
}

void move(int dir, int steps) {
int y, z;
  /* clockwise movement */
  if(dir == 1){
    for(y=0; y<=steps; y++){
      for(z=0; z<=19; z+4){
        isA=lookup[z];
        isB=lookup[z+1];
        notA=lookup[z+2];
        notB=lookup[z+3];
        delay();
      }
    }
  }
```

```
/* counter clockwise movement */
  if(dir==0){
    for(y=0;  y<=step; y++){
      for(z=19; z>=0; z - 4){
        isA=lookup[z];
        isB=lookup[z-1];
        notA=lookup[z -2];
        notB=lookup[z-3];
        delay( );
      }
    }
  }
}
void main( ){
  int z;
  int lookup[20] = {
    1,  1,  0,  0,
    0,  1,  1,  0,
    0,  0,  1,  1,
    1,  0,  0,  1,
    1,  1,  0,  0  };
  while(1){
    /*move forward, 15 degrees (2 steps) */
    move(1, 2);
    /* move backwards,  7.5 degrees (1step)*/
    move(0, 1);
  }
}
```

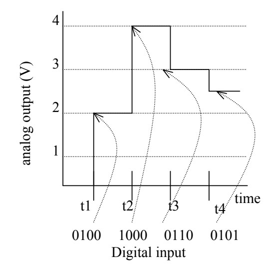

Analog-to-digital converters



proportionality



analog to digital



digital to analog

DAC/ADC conversion

- Using ratio: $e/V_{max} = d / (2^n-1)$

  e = present analog voltage
  d = digital encoding
  n = number of bits

  Assume V_{min} - 0

- Resolution is the number of volts between successive digital encodings
- DACs are easy: input *d* for digital encoding and max voltage and output analog *e* using resistors and op-amp
- ADCs are hard: Given V_{max} and *e* how does converter know the binary value to assign to satisfy the ratio?
  - No simple analog circuit

ADC

- ADCs may contain DACs
- ADC guesses at encoding and then evaluates its guess using the DAC
- So how do we guess the correct encoding?
  - Sequential search? Too slow with 2^n encodings
  - Binary search?
- ADCs take a bit of time to get correct encoding

Digital-to-analog conversion using successive approximation

Given an analog input signal whose voltage should range from 0 to 15 volts, and an 8-bit digital encoding, calculate the correct encoding for 5 volts. Then trace the successive-approximation approach to find the correct encoding.

5/15 = d/(28-1)
d= 85

Encoding: 01010101

Successive-approximation method

½(V_{max} – V_{min}) = 7.5 volts V_{max} = 7.5 volts.	0	0	0	0	0	0	0	0
½(7.5 + 0) = 3.75 volts V_{min} = 3.75 volts.	0	1	0	0	0	0	0	0
½(7.5 + 3.75) = 5.63 volts V_{max} = 5.63 volts	0	1	0	0	0	0	0	0
½(5.63 + 3.75) = 4.69 volts V_{min} = 4.69 volts.	0	1	0	1	0	0	0	0
½(5.63 + 4.69) = 5.16 volts V_{max} = 5.16 volts.	0	1	0	1	0	0	0	0
½(5.16 + 4.69) = 4.93 volts V_{min} = 4.93 volts.	0	1	0	1	0	1	0	0
½(5.16 + 4.93) = 5.05 volts V_{max} = 5.05 volts.	0	1	0	1	0	1	0	0
½(5.05 + 4.93) = 4.99 volts	0	1	0	1	0	1	0	1