General-purpose I/O

The simplest type of I/O via the PIC24 μC external pins are **parallel I/O (PIO) ports**.

A PIC24 μC can have multiple PIO ports named PORTA, PORTB, PORTC, PORTD, etc. Each is 16-bits, and the number of PIO pins depends on the particular PIC24 μC and package. The PIC24HJ32GP202/28 pin package has:

PORTA – bits RA4 through RA0
PORTB – bits RB15 through RB0

These are generically referred to as PORT*x*.

Each pin on these ports can either be an input or output – the data direction is controlled by the corresponding bit in the TRIS*x* registers (‘1’ = input, ‘0’ = output).

The LAT*x* register holds the last value written to PORT*x*.

PORTB Example

Set the upper 8 bits of PORTB to outputs, lower 8 bits to be inputs:

```
TRISB = 0x00FF;
```

Drive RB15, RB13 high;
others low:

```
PORTB = 0xA000;
```

Wait until input RB0 is high:

```
while ((PORTB & 0x0001) == 0);
```

Test returns true while RB0=0
so loop exited when RB0=1

Wait until input RB3 is low:

```
while ((PORTB & 0x0008) == 1);
```

Test returns true while RB3=1
so loop exited when RB3=0

PORTB Example (cont.)

Individual PORT bits are named as _RB0, _RB1, .._RA0, etc. so this can be used in C code.

Wait until input RB2 is high:

```
while (_RB2 == 0);
```

Test returns true while RB2=0 so loop exited when RB2=1. Can also be written as:

```
while (!_RB2);
```

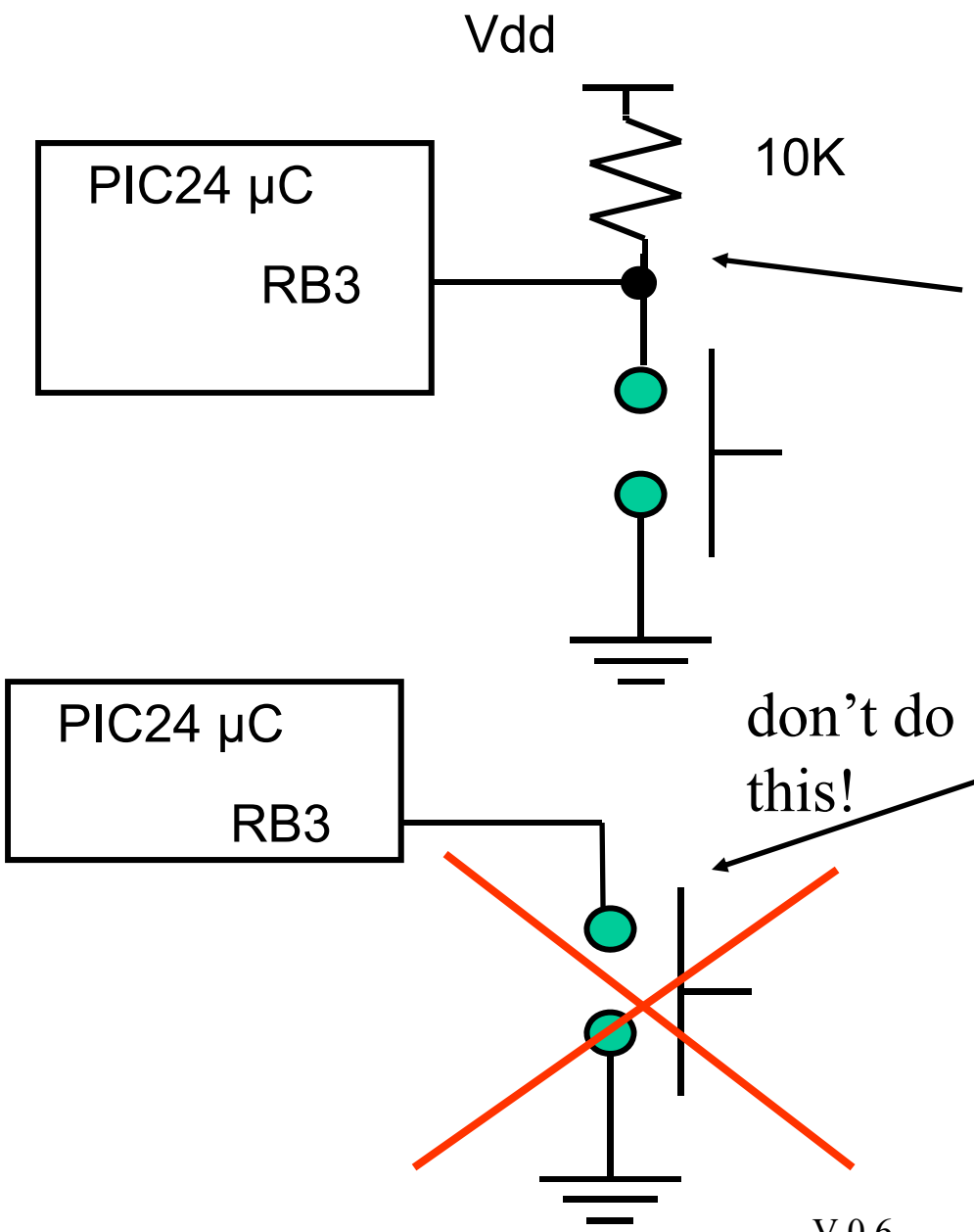
Wait until input RB3 is low:

```
while (_RB3 == 1) ;
```

Test returns true while RB3=1 so loop exited when RB3=0 Can also be written as:

```
while (_RB3);
```

Switch Input



External pullup

When switch is pressed RB3 reads as '0', else reads as '1'.

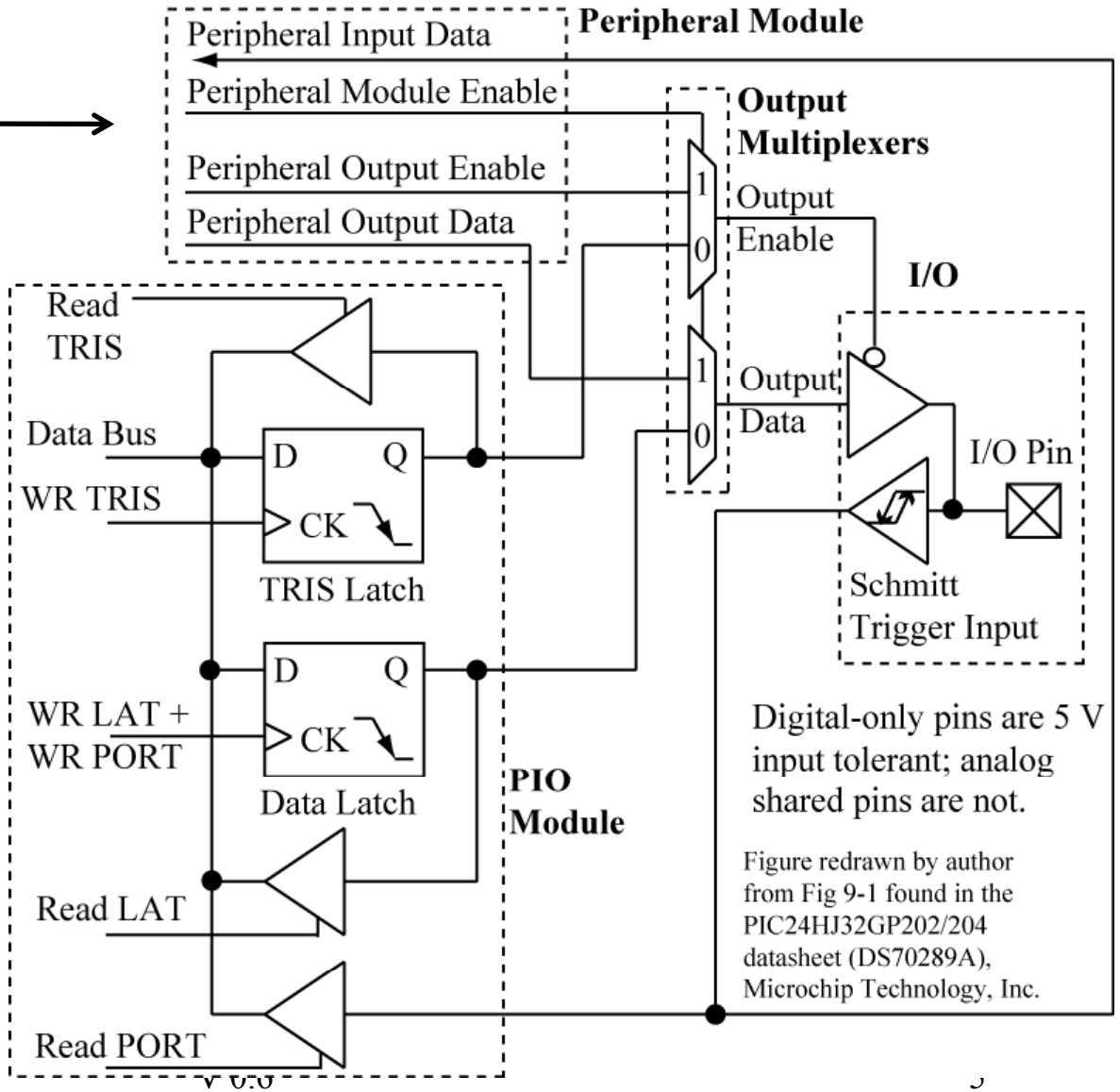
If pullup not present, then input would float when switch is not pressed, and input value may read as '0' or '1' because of system noise.

PORTx Pin Diagram

External pin shared with other on-chip modules →

TRIS bit controls tristate control on output driver →

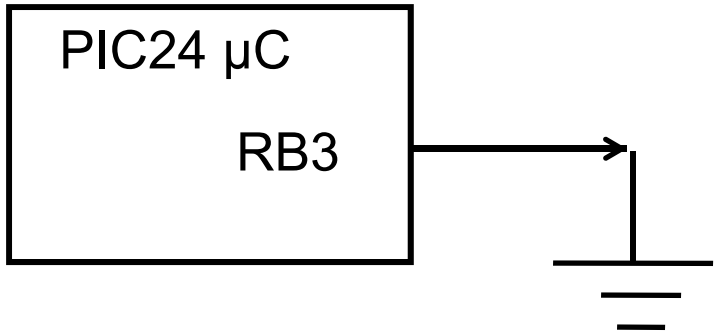
Reading LATx reads last value written; reading PORTx reads the actual pin



LATx versus PORTx

Writing LAT*x* is the same as writing PORT*x*, both writes go to the latch.

Reading LAT*x* reads the latch output (last value written), while reading PORT*x* reads the actual pin value.



Configure RB3 as an open-drain output, then write a ‘1’ to it.

The physical pin is tied to ground, so it can never go high.

Reading _RB3 returns a ‘0’, but reading _LATB3 returns a ‘1’ (the last value written).

LATx versus PORTx (cont)

```
_LATB0 = 1;
_LATB1 = 1;
```

Compiler →

```
bset LATB,#0
bset LATB,#1
```

bitset/bitclr instructions are read/modify/write, in this case, read LATB, modify contents, write LATB. This works as expected.

```
_RB0 = 1;
_RB1 = 1;
```

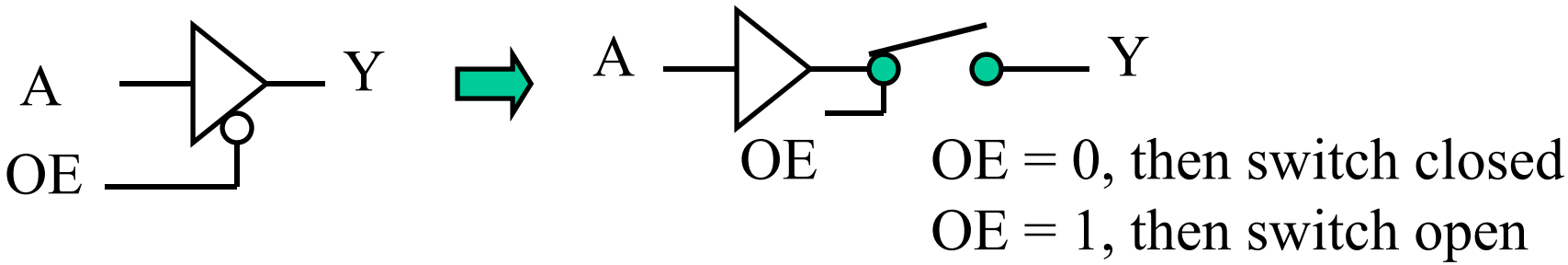
Compiler →

```
bset PORTB,#0
bset PORTB,#1
```

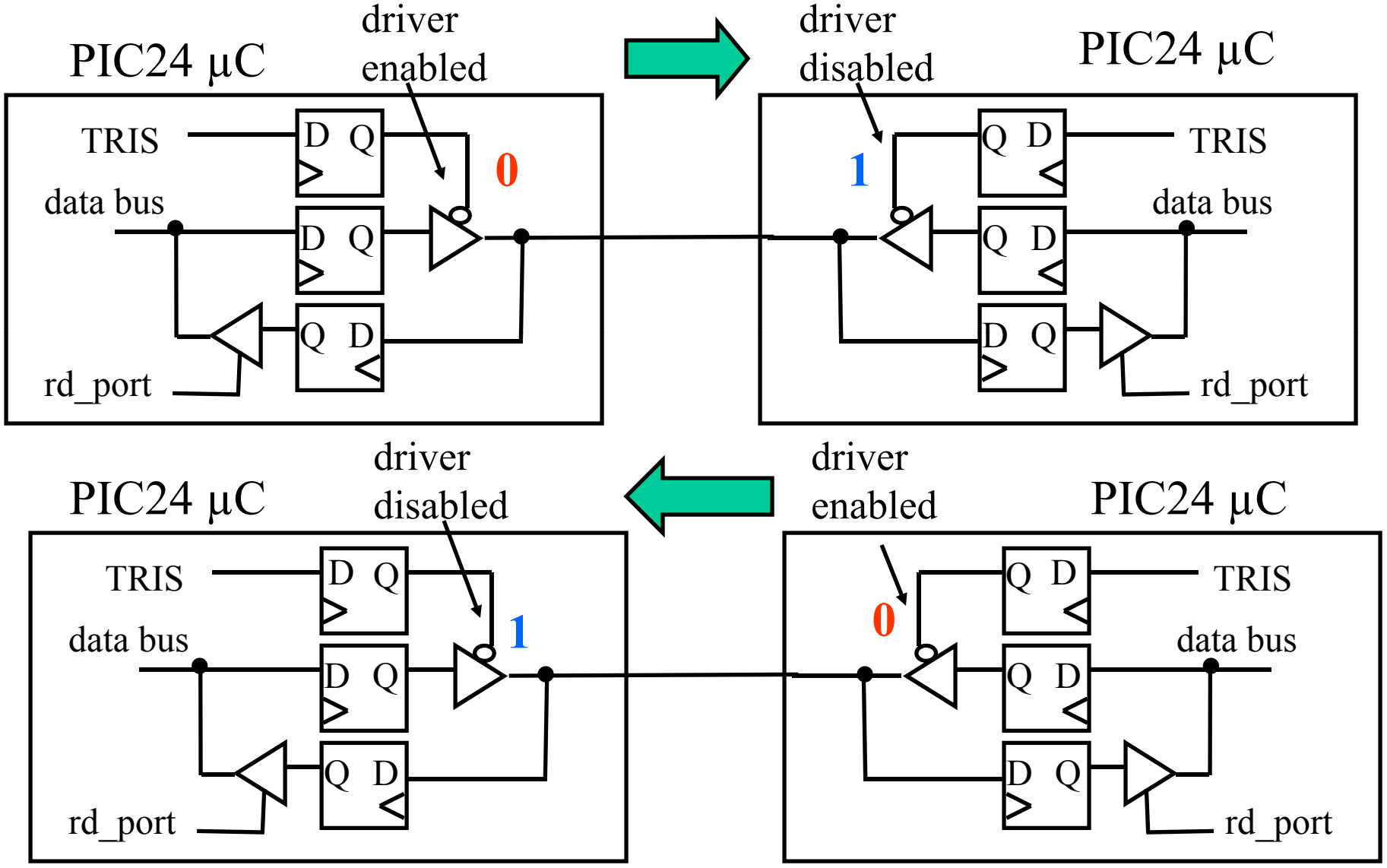
bset/bclr instructions are read/modify/write – in this case, read PORTB, modify its contents, then write PORTB. Because of pin loading and fast internal clock speeds, the second bset may not work correctly! (see datasheet explanation). For this reason, our examples use LATx when writing to a pin.

Aside: Tri-State Buffer (TSB) Review

A tri-state buffer (TSB) has input, output, and output-enable (OE) pins. Output can either be '1', '0' or 'Z' (high impedance).

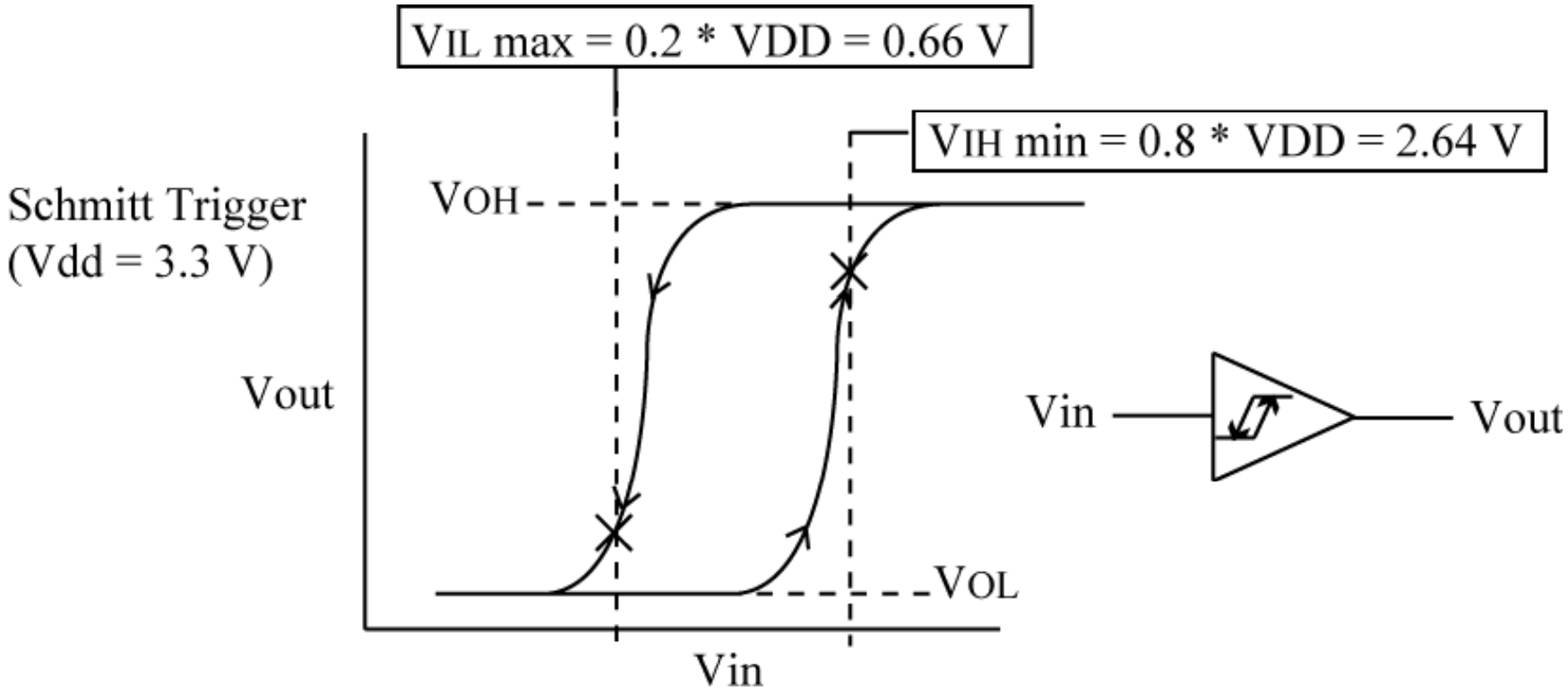


Bi-directional, Half-duplex Communication



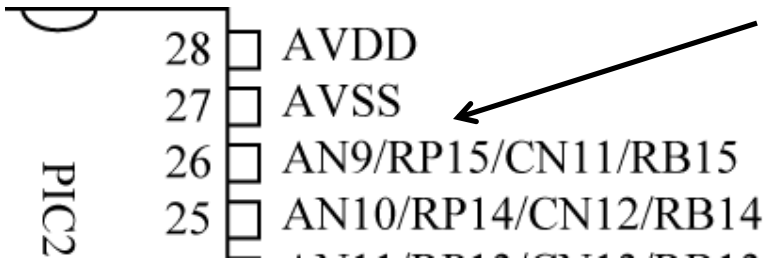
Schmitt Trigger Input Buffer

Each PIO input has a *Schmitt* trigger input buffer; this transforms slowly rising/falling input transitions into sharp rising/falling transitions internally.



PORTx Shared Pin Functions

External pins are shared with other on-chip modules. Just setting _TRISx = 1 may be not be enough to configure a PORT*x* pin as an input, depending on what other modules share the pin:



RB15 shared with AN9, which is an analog input to the on-chip Analog-to-Digital Converter (ADC). Must disable analog functionality!

```
_PCFG9 = 1;
```
← Disables analog function

```
_TRISB15 = 1;
```
← Configure as input

```
_PCFG9 = 1;
```
← Disables analog function

```
_TRISB15 = 0;
```
← Configure as output

Analog/Digital Pin versus Digital-only Pin

Pins with shared analog/digital functions have a maximum input voltage of Vdd + 0.3 V, so 3.6 V

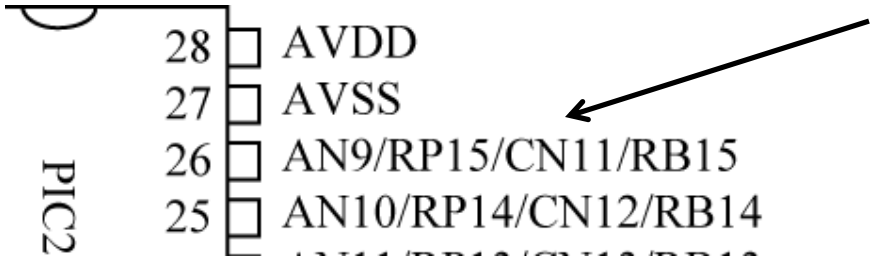
Pins with no analog functions (“digital-only” pins) are 5 V tolerant, their maximum input voltage is 5.6 V.

This is handy for receiving digital inputs from 5V parts.

Most PIO pins can only source or sink a maximum 4 mA. You may damage the output pin if you tie a load that tries to sink/source more than this current.

Internal Weak Pullups

External pins with a CN*y* pin function have a weak internal pullup that can be enabled or disabled.

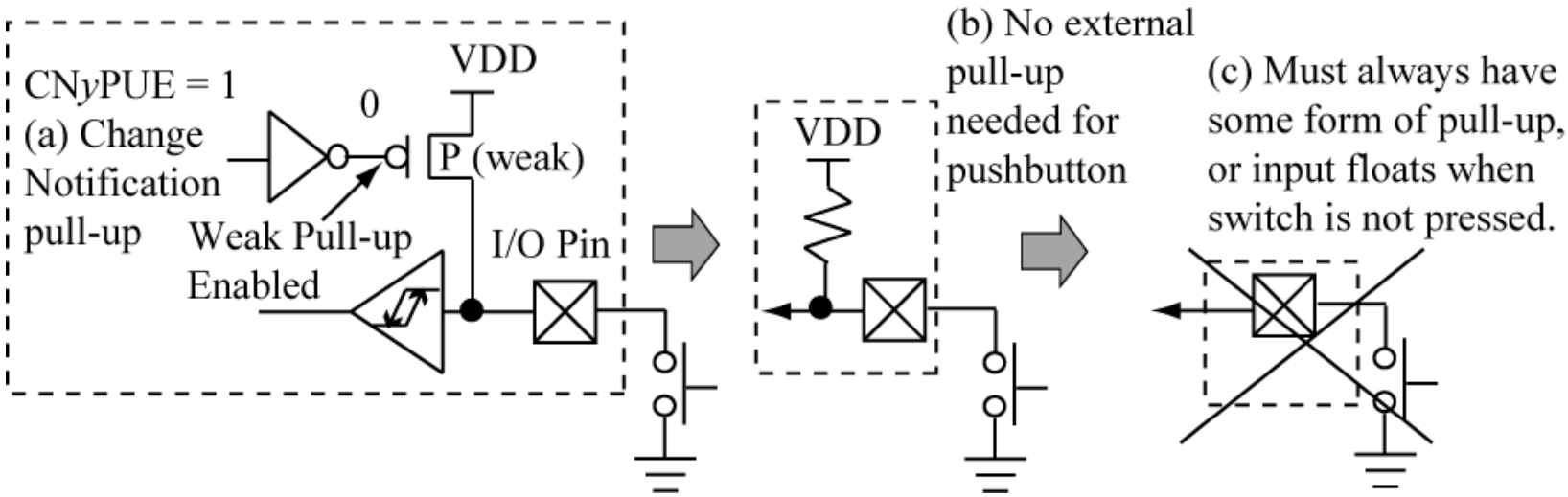


Change notification input; to enable pullup:

CN11PUE = 1;

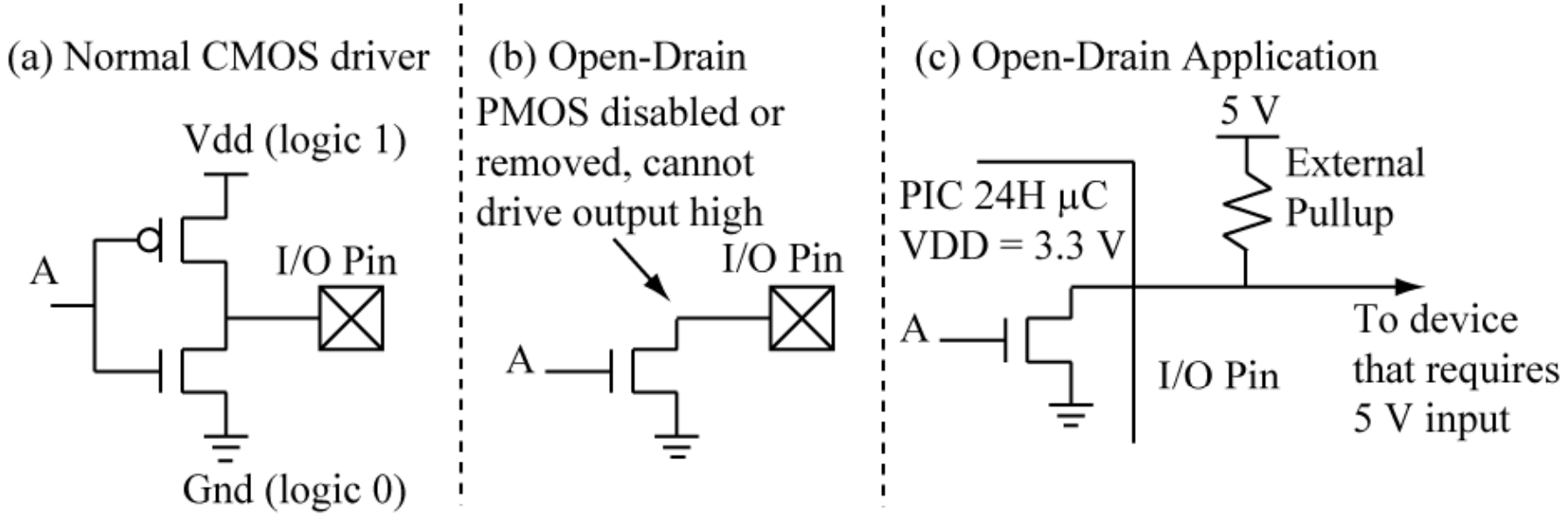
To disable pullup:

CN11PUE = 0;



Open Drain Outputs

Each PIO pin can be configured as an *open drain* output, which means the pullup transistor is disabled.



_ODC*xy* = 1 enables open drain, _ODC*xy* = 0 disables open drain

```
_ODCB15 = 1;
```
← Enables open drain on RB15

Port Configuration Macros

For convenience, we supply macros/inline functions that hide pin configuration details:

```
CONFIG_RB15_AS_DIG_OUTPUT();
```

```
CONFIG_RB15_AS_DIG_INPUT();
```

These macros are supplied for each port pin. Because these functions change depending on the particular PIC24 μC, the *include/devices* directory has a include file for each PIC24 μC, and the correct file is included by the *include/pic24_ports.h* file.

Other Port Configuration Macros

Other macros are provided for pull-up and open drain configuration:

```
ENABLE_RB15_PULLUP();
DISABLE_RB15_PULLUP();
ENABLE_RB13_OPENDRAIN();
DISABLE_RB13_OPENDRAIN();
CONFIG_RB8_AS_DIG_OD_OUTPUT();
```

Output + Open drain config in one macro

General forms are ENABLE_R*xy*_PULLUP(), DISABLE_R*xy*_PULLUP(), ENABLE_R*xy*_OPENDRAIN(), DISABLE_R*xy*_OPENDRAIN(), CONFIG_Rxy_AS_DIG_OD_OUTPUT()

A port may not have a pull-up if it does not share the pin with a change notification input, in this case, the macro does not exist and you will get an error message when you try to compile the code.

ledflash.c Revisited

```
#include "pic24_all.h"

/**
A simple program that
flashes an LED.
*/

#define CONFIG_LED1()

#define LED1   _LATB15

int main(void) {

  configClock();     //clock configuration
  /********** PIO config **********/
  CONFIG_LED1();   //config PIO for LED1
  LED1 = 0;

  while (1) {
    DELAY_MS(250);  //delay
    LED1 = !LED1;    // Toggle LED
  } // end while (1)
}
```

Defined in device-specific header file in *include\devices* directory in the book source distribution.
Macro `CONFIG_RB15_AS_DIG_OD_OUTPUT()` contains the statements `_TRISB15=0,_ODCB15 = 1`

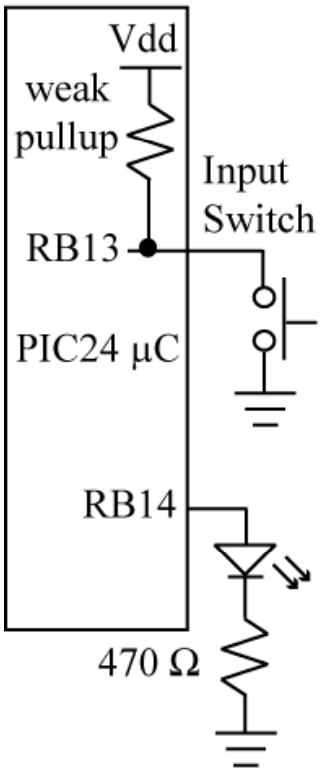
```
CONFIG_RB15_AS_DIG_OD_OUTPUT()
```

LED1 macro makes changing of LED1 pin assignment easier, also improves code clarity.

`DELAY_MS(ms)` macro is defined in *common\pic24_delay.c* in the book source distribution, `ms` is a `uint32` value.

LED/Switch IO: Count number of press/releases

```
/// LED1, SW1 Configuration
#define CONFIG_LED1()  CONFIG_RB14_AS_DIG_OUTPUT()
#define LED1   _LATB14      //led1 state
inline void CONFIG_SW1()  {
  CONFIG_RB13_AS_DIG_INPUT();   //use RB13 for switch input
  ENABLE_RB13_PULLUP();         //enable the pull-up
}
#define SW1                  _RB13  //switch state
#define SW1_PRESSED()    SW1==0  //switch test
#define SW1_RELEASED()   SW1==1  //switch test
```



Count number of switch presses.

```
main(){
 ...other config...
 CONFIG_SW1();
 DELAY_US(1);
 CONFIG_LED1();
 LED1 = 0;
 while (1) {
   if (SW1_PRESSED()) {
   //switch pressed
   //toggle LED1
   LED1 = !LED1
   }
 }
}
```

a. Incorrect, LED1 is toggled as long as the switch is pushed, which could be a long time!

```
main(){
 ...other config...
 CONFIG_SW1();
 DELAY_US(1); //pull-up delay
 CONFIG_LED1();
 LED1 = 0;
 while (1) {
  // wait for press, loop(1)
  while (SW1_RELEASED());
  DELAY_MS(15); //debounce
  // wait for release, loop(2)
  while (SW1_PRESSED());
  DELAY_MS(15); // debounce
  LED1 = !LED1; //toggle LED
 }
```

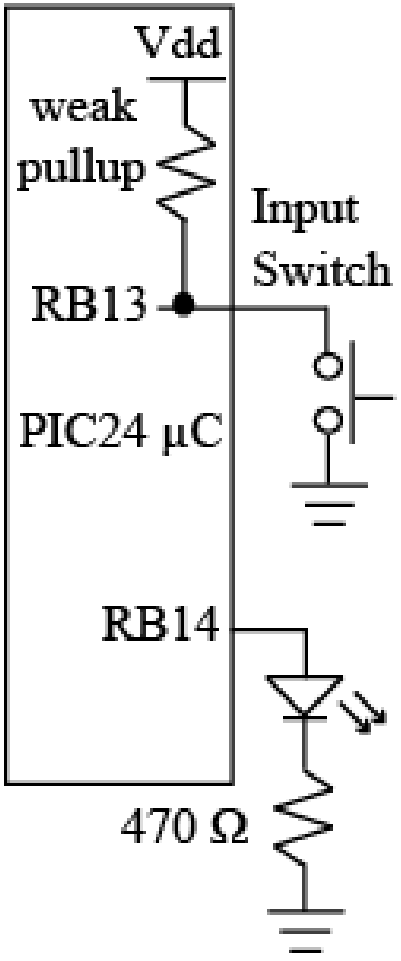
b. Correct, loop(1) executed while switch is not pressed. Once pressed, code becomes trapped in loop(2) until the switch is released, at which point LED1 is toggled.

I/O Configuration

```
/// LED1, SW1 Configuration
#define CONFIG_LED1()  CONFIG_RB14_AS_DIG_OUTPUT()
#define LED1   _LATB14      //led1 state
inline void CONFIG_SW1()  {
  CONFIG_RB13_AS_DIG_INPUT();    //use RB13 for switch input
  ENABLE_RB13_PULLUP();          //enable the pullup
}
#define SW1                 _RB13  //switch state
#define SW1_PRESSED()    SW1==0  //switch test
#define SW1_RELEASED()   SW1==1  //switch test
```

Use macros to isolate pin assignments for physical devices so that it is easy to change code if (WHEN!) the pin assignments change!

Counting # of Press/Releases



Count number of switch presses.

```
main(){
  ..other config..
  CONFIG_SW1();
  CONFIG_LED1();
  LED1 = 0;
  while (1) {
     if (SW1_PRESSED()) {
     //switch pressed
     //toggle LED1
     LED1 = !LED1
     }
  }
}
```

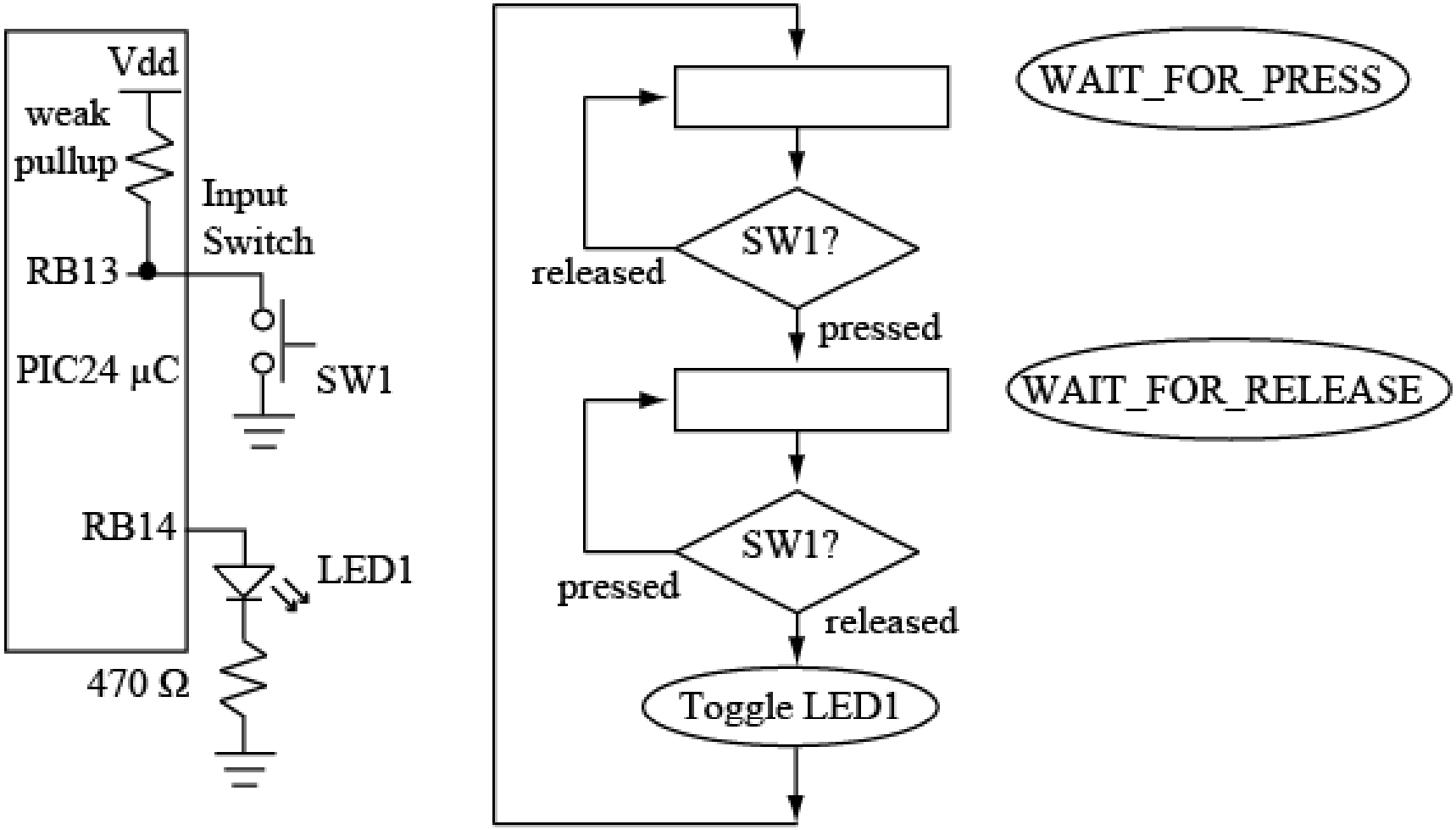
a. Incorrect, LED1 is toggled as long as the switch is pushed, which could be a long time!

```
main(){
  ..other config..
  CONFIG_SW1();
  CONFIG_LED1();
  LED1 = 0;
  while (1) {
   // wait for press, loop(1)
   while (SW1_RELEASED());
   DELAY_MS(15); //debounce
   // wait for release, loop(2)
   while (SW1_PRESSED());
   DELAY_MS(15); // debounce
   LED1 = !LED1; //toggle LED
  }
```

b. Correct, loop(1) executed while switch is not pressed. Once pressed, code becomes trapped in loop(2) until the switch is released, at which point LED1 is toggled.

From: Reese/Bruce/Jones, “Microcontrollers: From Assembly to C with the PIC24 Family”.

State Machine I/O



From: Reese/Bruce/Jones, “Microcontrollers: From Assembly to C with the PIC24 Family”.

C Code Solution

```
main(){
  STATE e_mystate;
  configBasic(HELLO_MSG);
  CONFIG_SW1();      //configure switch
  CONFIG_LED1();     //config the LED
  DELAY_US(1);       //pull-up delay
  e_mystate = STATE_WAIT_FOR_PRESS;
  while (1) {
    printNewState(e_mystate);  //debug message when state changes
    switch (e_mystate) {
      case STATE_WAIT_FOR_PRESS:
        if (SW1_PRESSED()) e_mystate = STATE_WAIT_FOR_RELEASE;
        break;
      case STATE_WAIT_FOR_RELEASE:
        if (SW1_RELEASED()) {
          LED1 = !LED1;   //toggle LED
          e_mystate = STATE_WAIT_FOR_PRESS;
        }
        break;
     default:
        e_mystate = STATE_WAIT_FOR_PRESS;
    }//end switch(e_mystate)
    DELAY_MS(DEBOUNCE_DLY);      //Debounce
    doHeartbeat();     //ensure that we are alive
  } // end while (1)
}
```

(c) The state variable used for tracking the current state.

(d) `configBasic()` combines previously used separate configuration functions into one function call, defined in *common\pic24_util.c*

(e) Give pull-ups time to work

(f) Initialize `e_mystate` to the first state.

(g) Change state only if switch is pressed.

(h) Toggle LED and change state when switch is released.

(i) Put debounce delay at bottom of loop, means that we only look at the switch about every `DEBOUNCE_DLY` milliseconds.

(j) Call `doHeartbeat()` to keep heartbeat LED pulsing.

From: Reese/Bruce/Jones, “Microcontrollers: From Assembly to C with the PIC24 Family”.

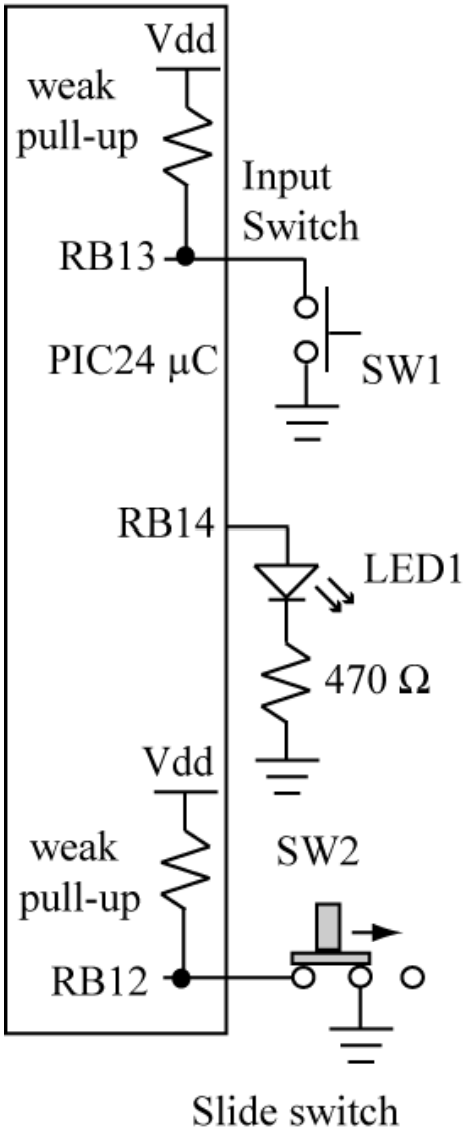
C Code Solution (cont).

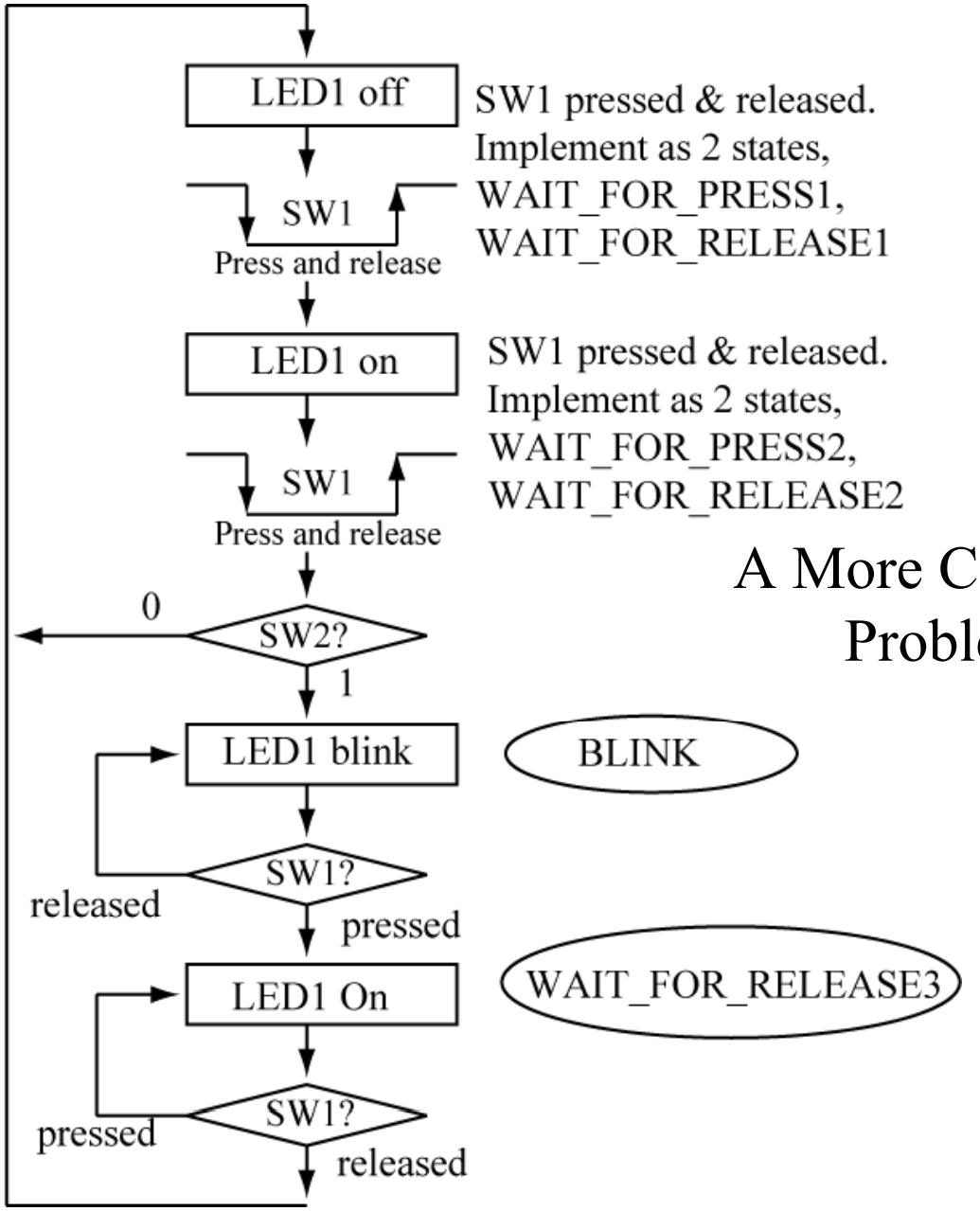
```
typedef enum   {
  STATE_RESET = 0,
  STATE_WAIT_FOR_PRESS,
  STATE_WAIT_FOR_RELEASE
} STATE;

STATE e_lastState = STATE_RESET;
//print debug message for state when it changes
void printNewState (STATE e_currentState){
  if (e_lastState != e_currentState) {
  switch (e_currentState) {
   case STATE_WAIT_FOR_PRESS:
     outString("STATE_WAIT_FOR_PRESS\n");
     break;
   case STATE_WAIT_FOR_RELEASE:
     outString("STATE_WAIT_FOR_RELEASE\n");
     break;
   default:
     outString("Unexpected state\n");
   }
  }
  e_lastState = e_currentState;  //remember last state
}
```

(a) `enum` type is used to make readable state names. The `STATE_RESET` is used to determine when `main()` initializes its state variable to its first state.

(b) `printNewState()` is used to print a message to the console whenever the state changes (when `e_lastState` is not equal to `e_currentState`).

From: Reese/Bruce/Jones, “Microcontrollers: From Assembly to C with the PIC24 Family”.





SW1 pressed & released.
Implement as 2 states,
WAIT_FOR_PRESS1,
WAIT_FOR_RELEASE1

SW1 pressed & released.
Implement as 2 states,
WAIT_FOR_PRESS2,
WAIT_FOR_RELEASE2

BLINK

WAIT_FOR_RELEASE3

A More Complex Problem

From: Reese/Bruce/Jones, “Microcontrollers: From Assembly to C with the PIC24 Family”.

Solution, Part 1

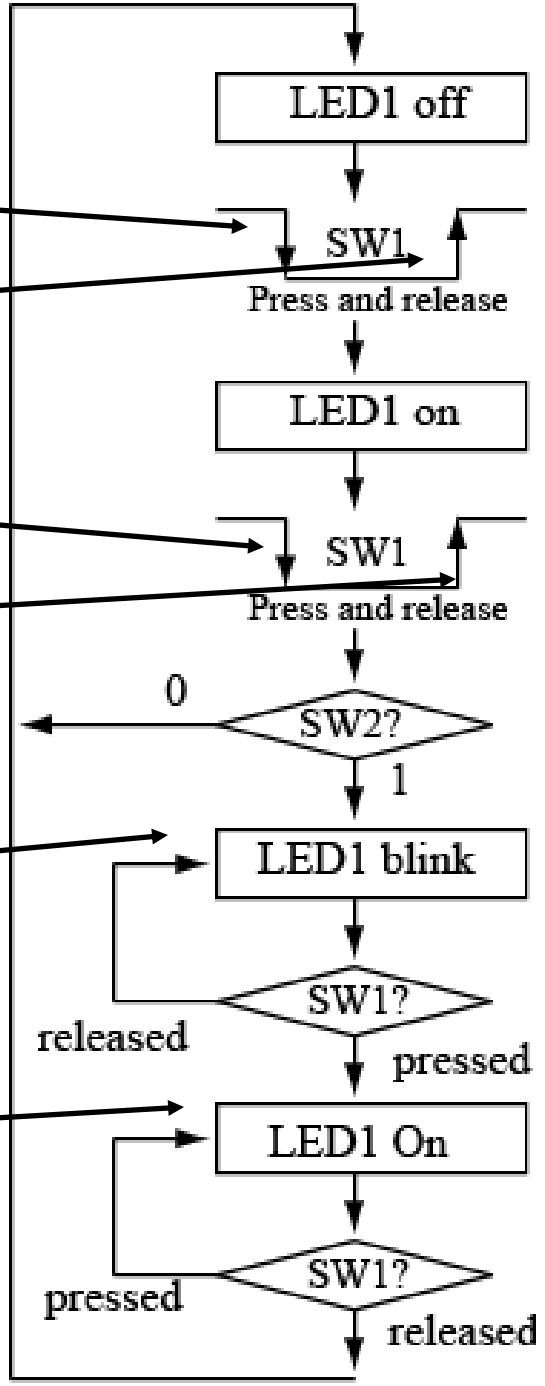
```
typedef enum  {
  STATE_RESET = 0, STATE_WAIT_FOR_PRESS1, STATE_WAIT_FOR_RELEASE1,
  STATE_WAIT_FOR_PRESS2, STATE_WAIT_FOR_RELEASE2, STATE_BLINK,
  STATE_WAIT_FOR_RELEASE3
} STATE;
int main (void) {
  STATE e_mystate;
  configBasic(HELLO_MSG);
  CONFIG_SW1();          //configure switch
  CONFIG_SW2();          //configure switch
  CONFIG_LED1();         //config the LED
  DELAY_US(1);           //give pull-ups time to work
  e_mystate = STATE_WAIT_FOR_PRESS1;
```


From: Reese/Bruce/Jones, “Microcontrollers: From Assembly to C with the PIC24 Family”.

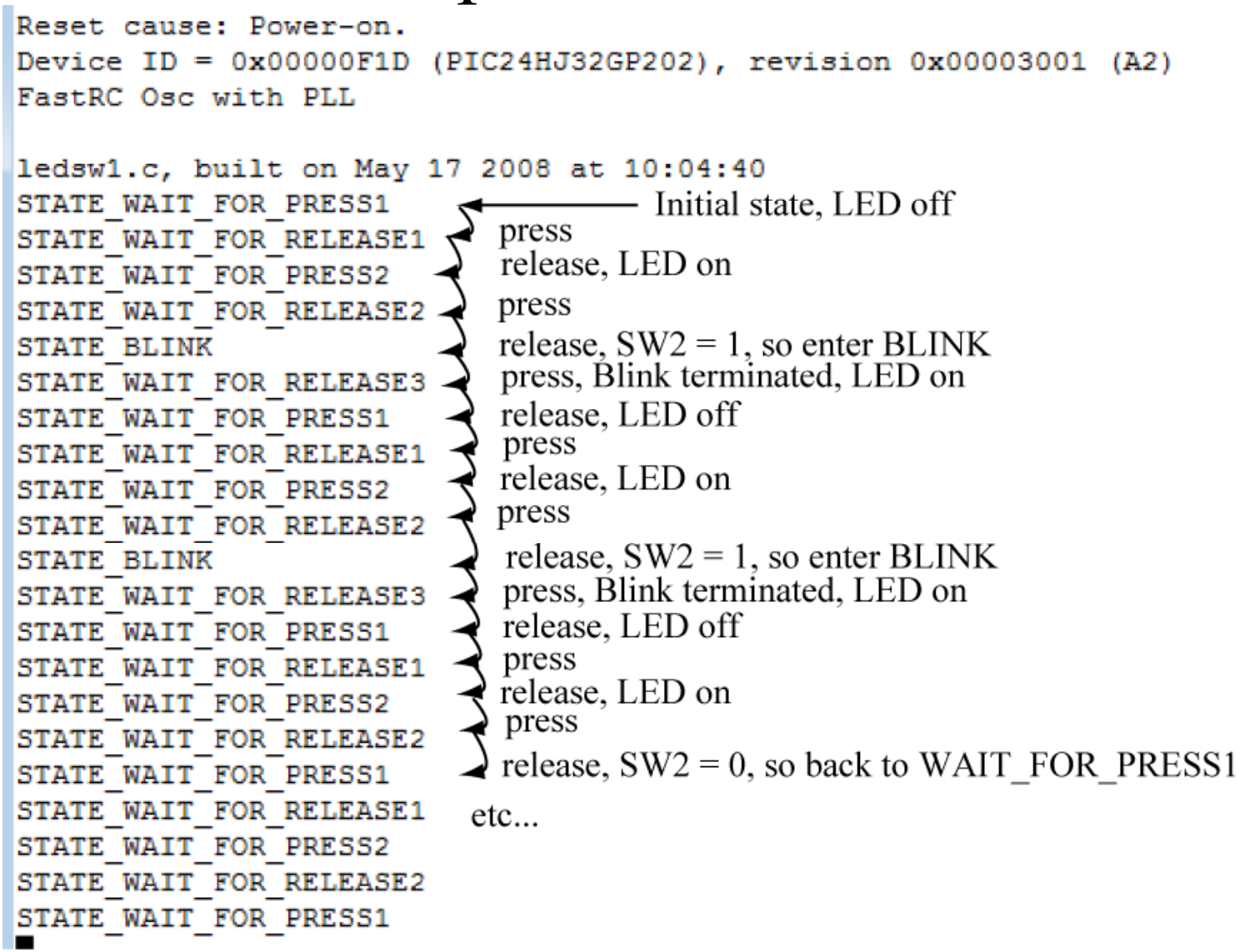
```
while (1) {
  printNewState(e_mystate);  //debug message when state changes
  switch (e_mystate) {
    case STATE_WAIT_FOR_PRESS1:
      LED1 = 0; //turn off the LED
      if (SW1_PRESSED()) e_mystate = STATE_WAIT_FOR_RELEASE1;
      break;
    case STATE_WAIT_FOR_RELEASE1:
      if (SW1_RELEASED()) e_mystate = STATE_WAIT_FOR_PRESS2;
      break;
    case STATE_WAIT_FOR_PRESS2:
      LED1 = 1; //turn on the LED
      if (SW1_PRESSED())e_mystate = STATE_WAIT_FOR_RELEASE2;
      break;
    case STATE_WAIT_FOR_RELEASE2:
       if (SW1_RELEASED()) {
        //decide where to go
        if (SW2) e_mystate = STATE_BLINK;
        else e_mystate = STATE_WAIT_FOR_PRESS1;
      }
      break;
    case STATE_BLINK:
       LED1 = !LED1;    //blink while not pressed
       DELAY_MS(100);    //blink delay
       if (SW1_PRESSED()) e_mystate = STATE_WAIT_FOR_RELEASE3;
       break;
    case STATE_WAIT_FOR_RELEASE3:
       LED1 = 1;   //Freeze LED1 at 1
       if (SW1_RELEASED()) e_mystate = STATE_WAIT_FOR_PRESS1;
       break;
   default:
      e_mystate = STATE_WAIT_FOR_PRESS1;
```

(a) Test SW2 to determine next state.

(b) Need delay so that LED blink is visible.



Console Output for LED/SW Problem



From: Reese/Bruce/Jones, “Microcontrollers: From Assembly to C with the PIC24 Family”.

What do you have to know?

- GPIO port usage of PORTA, PORTB
- How to use the weak pullups of PORTB
- Definition of Schmitt Trigger
- How a Tri-state buffer works
- How an open-drain output works and what it is useful for.
- How to write C code for finite state machine description of LED/Switch IO.