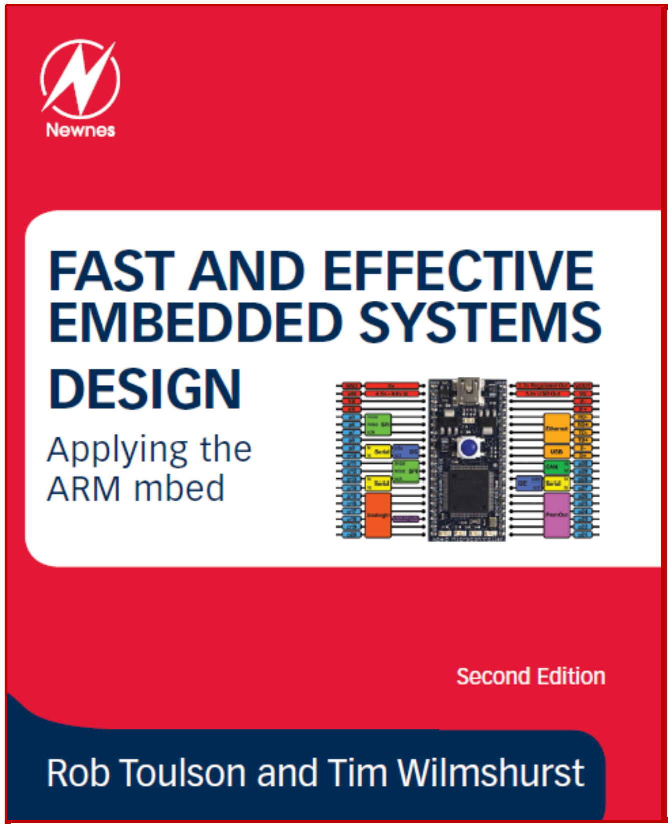

Chapter 3:
Digital Input and Output

tw rev. 20.9.16

(Note to Instructor: Insert "Essentials of C" (Appendix B) presentation here if required

If you use or reference these slides or the associated textbook, please cite the original authors' work as follows:

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www.embedded-knowhow.co.uk

Thinking about the First Program

```
/*Program Example 2.1: A program which flashes mbed LED1 on and off.
Demonstrating use of digital output and wait functions. Taken from the mbed
site.                                                                        */

#include "mbed.h"     //include the mbed header file as part of this program

// program variable myled is created, and linked with mbed LED1
DigitalOut myled(LED1);

int main() {          //the main function starts here
  while(1) {          //a continuous loop is created
    myled = 1;        //switch the led on, by setting the output to logic 1
    wait(0.2);        //wait 0.2 seconds
    myled = 0;        //switch the led off
    wait(0.2);        //wait 0.2 seconds
  }                   //end of while loop
}                     //end of main function
```

C code feature

Check your understanding of how this program is structured, its use of **#include, main()** and **while(1)**, and the **DigitalOut** API feature.

The mbed API, and **DigitalOut**

The mbed comes with an API (Application Programming Interface), which is used to create building blocks for any mbed programme. Learn to tell the difference between regular C/C++, and API elements.

The **DigitalOut** component creates a C++ *class*, called **DigitalOut.** The class then has a set of member functions, listed here in the Table. The first of these is a C++ *constructor,* which must have the same name as the class itself. This can be used to create C++ *objects*. By using the **DigitalOut** constructor, we can create C++ objects.

In our first example we create the object **myled**. We can then write to it and read from it, using the functions **write( )** and **read( )**. These are member functions of the class, so their format would be **myled.write( ),** and so on. Having created the **myled** object we can however invoke the API operator shorthand, mentioned in the Table, which applies the assign operator = . Hence when we write

```
myled = 1;
```

the variable value is then not only changed (normal C usage), but it is also written to the digital output. This replaces **myled.write(1);**. We find similar shorthands offered for all peripheral API groups in the mbed API.

Functions	Usage
DigitalOut	Create a DigitalOut connected to the specified pin
write	Set the output, specified as 0 or 1 (int)
read	Return the output setting, represented as 0 or 1 (int)
operator =	A shorthand for write
operator int()	A shorthand for read

Thinking about the First Program

```
/*Program Example 2.1: A program which flashes mbed LED1 on and off.
Demonstrating use of digital output and wait functions. Taken from the mbed
site.                                                                      */

#include "mbed.h"     //include the mbed header file as part of this program

// program variable myled is created, and linked with mbed LED1
DigitalOut myled(LED1);

int main() {          //the main function starts here
  while(1) {          //a continuous loop is created
    myled = 1;        //switch the led on, by setting the output to logic 1
    wait(0.2);        //wait 0.2 seconds
    myled = 0;        //switch the led off
    wait(0.2);        //wait 0.2 seconds
  }                   //end of while loop
}                     //end of main function
```

C code feature

Check your understanding of how this program is structured, its use of **#include, main()** and **while(1)**, and the **DigitalOut** API feature.

Mbed Library wait Functions

The Wait functions available are shown in the Table. Note the different data types required for each. Misuse use of these can lead to erroneous wait periods!

C/C++ Function	Action
wait	waits for the number of seconds specified (float)
wait_ms	waits for the number of milliseconds specified (int)
wait_us	waits for the number of microseconds specified (int)

Questions from the Quiz

1. Complete the Table, converting between the different number types. The first row of numbers is an example.

Binary	Hexadecimal	Decimal
0101 1110	5E	94
1101		
	77	
		129
	6F2	
1101 1100 1001		
		4096

3. A loop in an mbed program is untidily coded as follows.

```
While (1){
    redled = 0;
    wait_ms(12);
    greenled = 1;
    wait(0.002);
    greenled = 0;
    wait_us(24000);
             }
```

What is the total period of the loop, expressed in seconds, milliseconds, and microseconds?

Exploring the *while* Loop

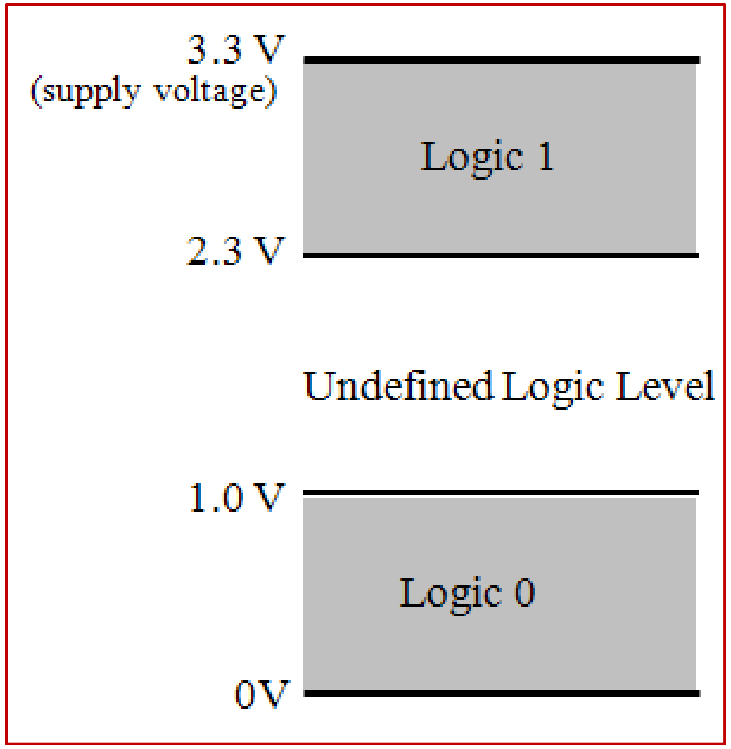
```
/*Program Example 3.1: Demonstrates use of while loops. No external connection required
      */

#include "mbed.h"
DigitalOut myled(LED1);
DigitalOut yourled(LED4);

int main() {
  char i=0;           //declare variable i, and set to 0
  while(1){           //start endless loop
  while(i<10) {       //start first conditional while loop
    myled = 1;
    wait(0.2);
    myled = 0;
    wait(0.2);
    i = i+1;           //increment i
  }                    //end of first conditional while loop
  while(i>0) {         //start second conditional loop
    yourled = 1;
    wait(0.2);
    yourled = 0;
    wait(0.2);
    i = i-1;
    }
  }                    //end infinite loop block
}                      //end of main
```

C code feature

Note the declaration of the variable **i**, and the conditional use of **while( ).**

Voltages as Logic Values

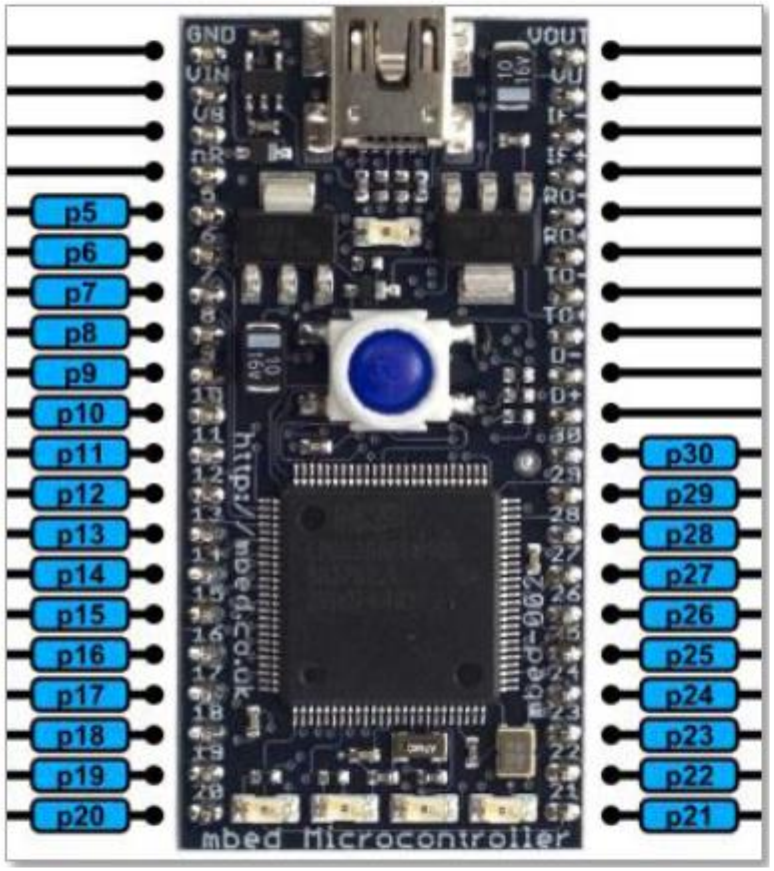
In any digital circuit, logic values are represented as electrical voltages. Here now is the BIG benefit of digital electronics: we don't need a precise voltage to represent a logical value. For most digital inputs, the LPC1678 interprets *any* input voltage below 1.0 V as logic 0, and *any* input voltage above 2.3 V as Logic 1.



General logic levels for the mbed

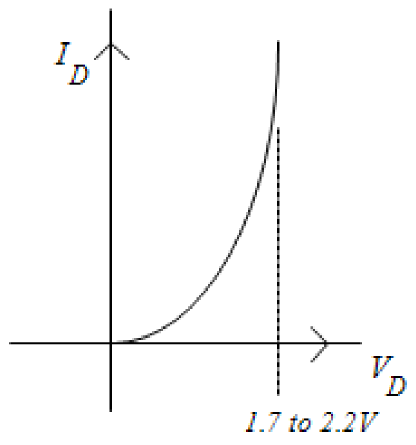
Digital Output Connections on the mbed

The mbed has 26 digital input/output (I/O) pins (pins 5-30 as shown), which can be configured either as digital inputs or outputs.

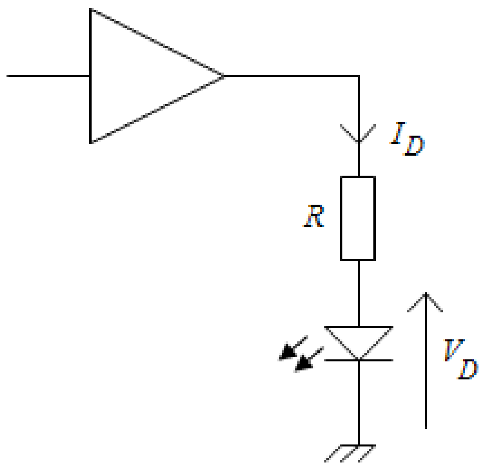


Using LEDs 1

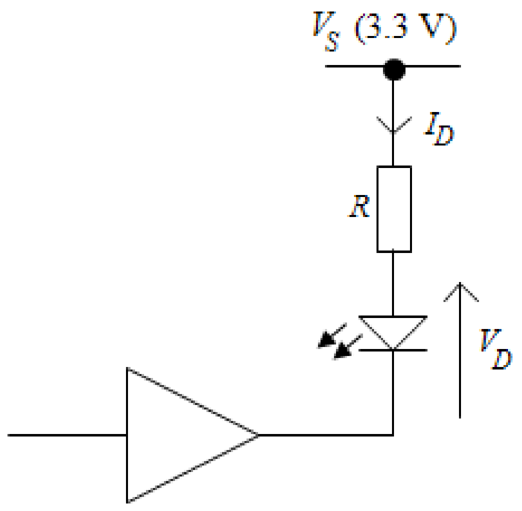
The LED (light emitting diode) has the voltage/current characteristic shown in a). A small forward voltage causes very little current to flow. As the voltage increases there comes a point where the current increases rapidly. Figures b) and c) show circuits used to make direct connections of LEDs to the output of logic gates, for example an mbed pin configured as an output. Some LEDs, such as the ones recommended for the next program, have the series resistance built into them. They therefore don't need any external resistor connected.



a) Led V-I Characteristic



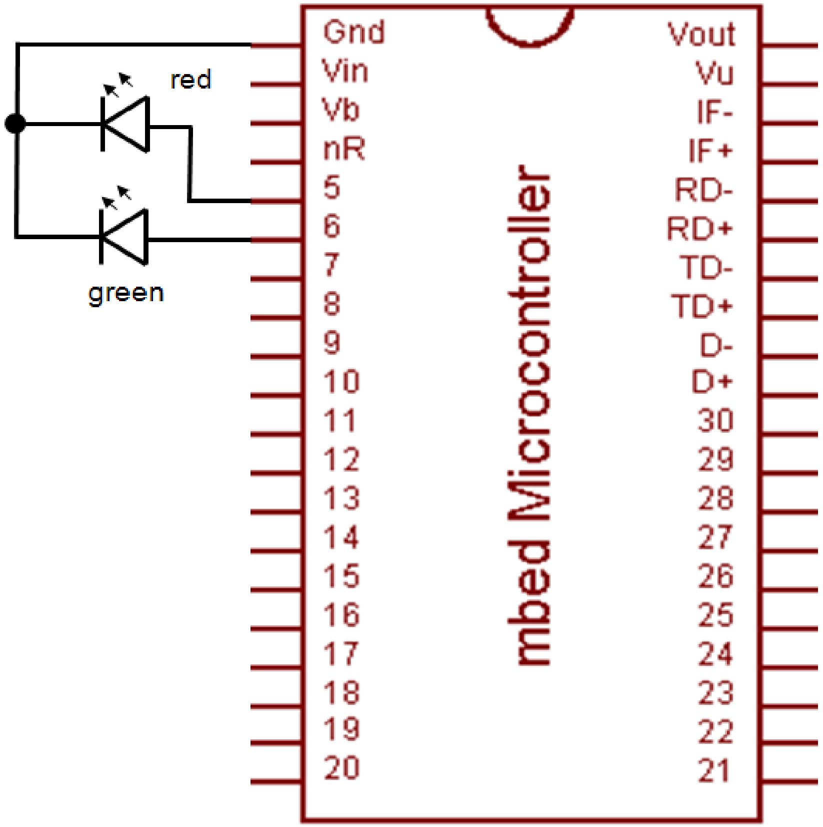
b) Gate Output Sourcing Current to LED Load

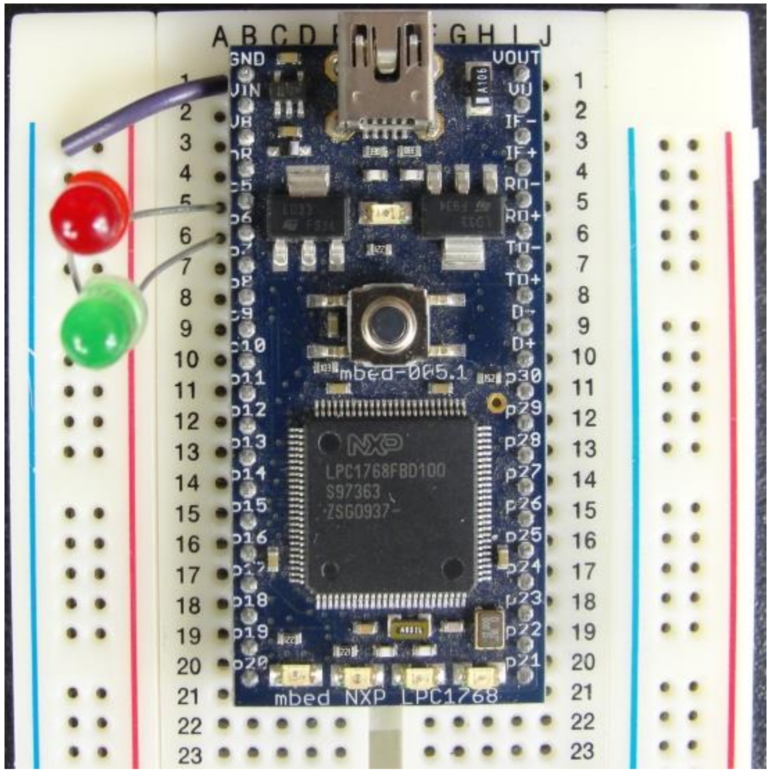


c) Gate Output Sinking Current from LED

Using mbed External Pins

Connect the circuit shown. The mbed has a ground connection on pin 1. Remember to attach the anode of the LEDs (the side with the longer leg) to the mbed pins. The negative side (cathode) should be connected to ground. For this and many circuits we take power from the USB bus.





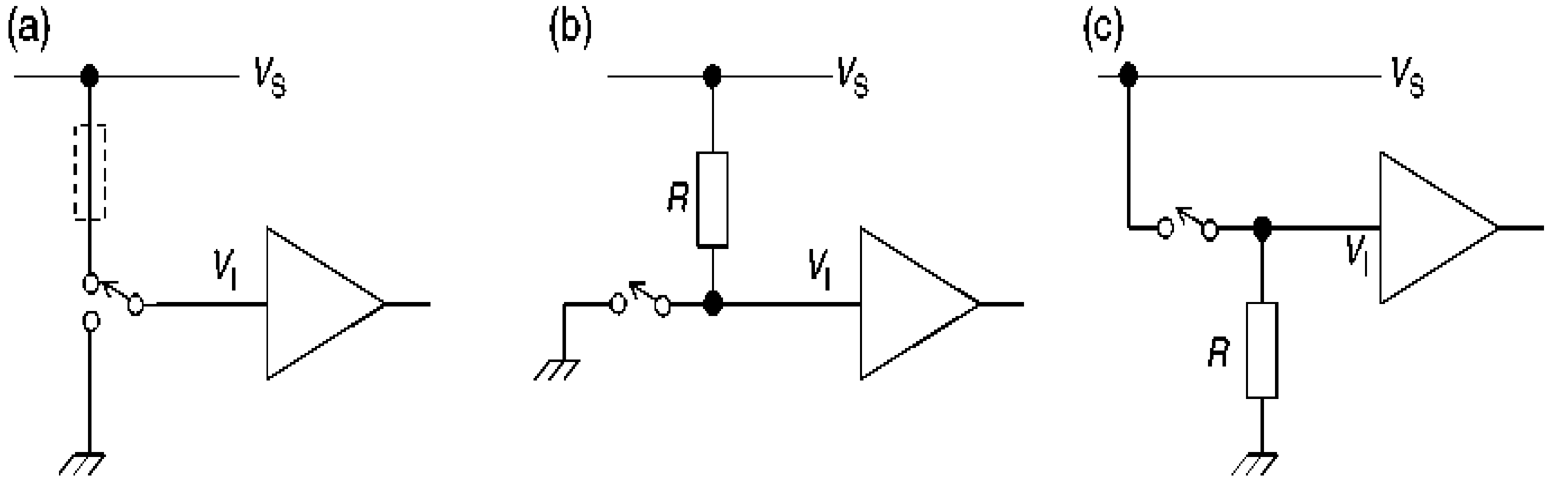
Example Program using DigitalOut

The code extends ideas already applied, so it should be easy to understand that the green and red LEDs are programmed to flash alternately.

```
/*Program Example 3.2: Flashes red and green LEDs in simple time-based pattern
                                            */
#include "mbed.h"
DigitalOut redled(p5);      //define and name a digital output on pin 5
DigitalOut greenled(p6);    //define and name a digital output on pin 6

int main() {
  while(1) {
    redled = 1;
    greenled = 0;
    wait(0.2);
    redled = 0;
    greenled = 1;
    wait(0.2);
  }
}
```

Connecting Switches to a Digital System

We can use ordinary electromechanical switches to create logic levels, which will satisfy the logic level requirements seen earlier. Three commonly used ways are shown here.



a) Single-pole double-throw (SPDT) connection.
b) Single-pole single-throw (SPST) with pull-up resistor.
c) SPST with pull-down resistor
Note: the diagrams show a logic buffer, which can in each case be a microcontroller/mbed input.

The **DigitalIn** API

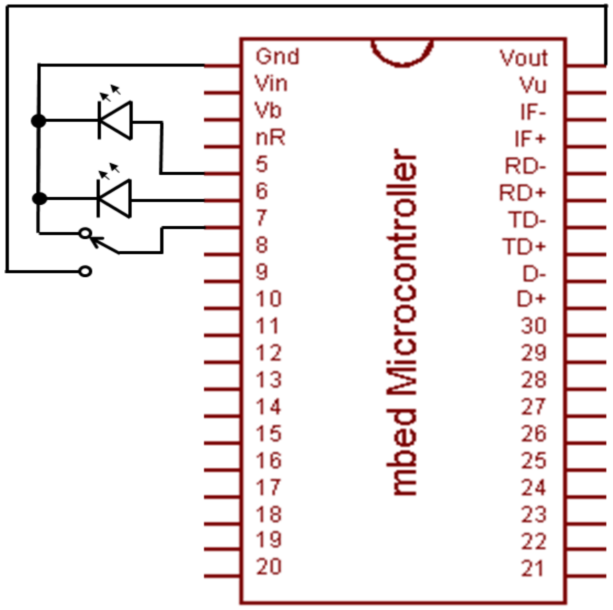
The mbed API has the digital input functions listed here, with format identical to that of **DigitalOut,** already seen.

Note that use of **DigitalIn** enables by default the internal pull-down resistor, i.e. the input circuit is configured as Figure (c) in previous slide. This can be disabled, or an internal pull-up enabled, using the **mode( )** function.

Functions	Usage
DigitalIn	Create a DigitalIn connected to the specified pin
read	Read the input, represented as 0 or 1 (int)
mode	Set the input pin mode, with parameter chosen from: PullUp, PullDown, PullNone, OpenDrain
operator int()	A shorthand for read()

Using *if* to Respond to a Switch Input

```
/*Program Example 3.3: Flashes one of two LEDs, depending on the state of a 2-way switch
*/

#include "mbed.h"
DigitalOut redled(p5);
DigitalOut greenled(p6);
DigitalIn  switchinput(p7);

int main() {
  while(1) {
    if (switchinput==1) {     //test value of switchinput
    //execute following block if switchinput is 1
      greenled = 0;           //green led is off
      redled = 1;             // flash red led
      wait(0.2);
      redled = 0;
      wait(0.2);
    }                        //end of if
    else {                   //here if switchinput is 0
      redled = 0;            //red led is off
      greenled = 1;          // flash green led
      wait(0.2);
      greenled = 0;
      wait(0.2);
    }                         //end of else
  }                           //end of while(1)
}                             //end of main
```



C code feature

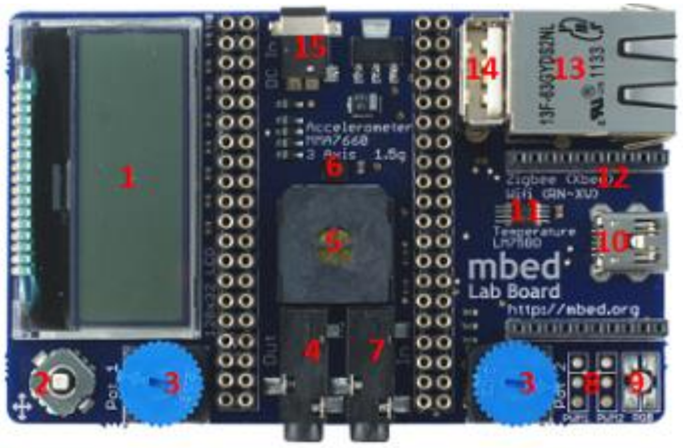
Check carefully the use of **if** and **else**, to allow selection of actions.

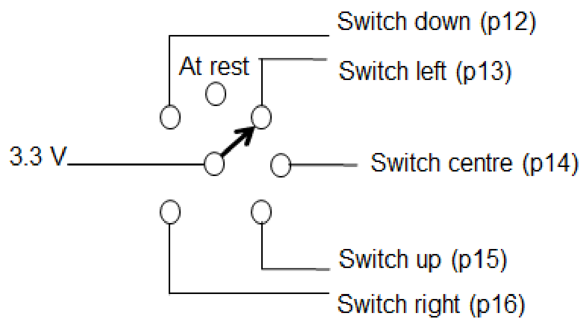
Digital Input and Output with the Application Board

The application board has a Joystick, which is a set of switches, and a tricolour LED. These are both symbolised below, with mbed pin connections.

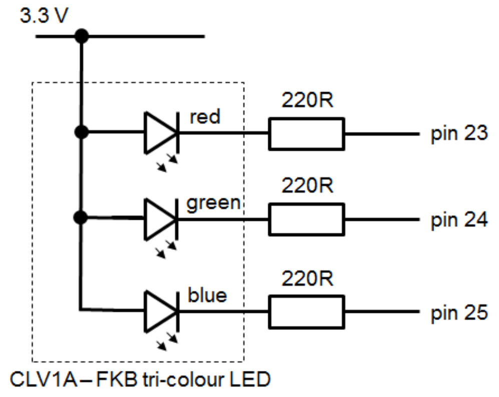
The joystick (item 2 in figure) acts as a 5-position multi-way switch, with the wiper connected to the supply voltage.

The tri-colour LED (item 9 in figure) connects through current-limiting resistors to mbed pins. The LED is a "common anode" type, which means the three internal LED anodes are connected ("commoned") together, and available externally as a single connection. It requires a logic 0 on the mbed pin to light the LED.





(a) Joystick



(b) Three-colour LED

Controlling application board LED with the Joystick

```
/*Program Example 3.4.
Uses Joystick values to switch tri-colour led */

#include "mbed.h"
DigitalOut redled(p23);    //leds in tri-colour led
DigitalOut greenled(p24);
DigitalOut blueled(p25);
DigitalIn  joyleft(p13);  //Joystick left
DigitalIn  joyright(p16); //Joystick right

int main() {
    greenled=redled=blueled=1; //switch all leds off (logic 1 for off)
    redled = 0;           //switch red led on, diagnostic (logic 0 for on)
    wait(1);
    redled = 1;           //switch red led off
    while(1) {
      if (joyleft==1) {     //test if the joystick is pushed left
        greenled = 0;       //switch green led on
        wait(1);            //wait one second
        greenled = 1;       //switch green led off
        }
      if (joyright==1) {    //test if the joystick is pushed right
        redled = 0;         //switch red led on
        wait(1);
        redled = 1;         //switch red led off
        }
      }
}
```

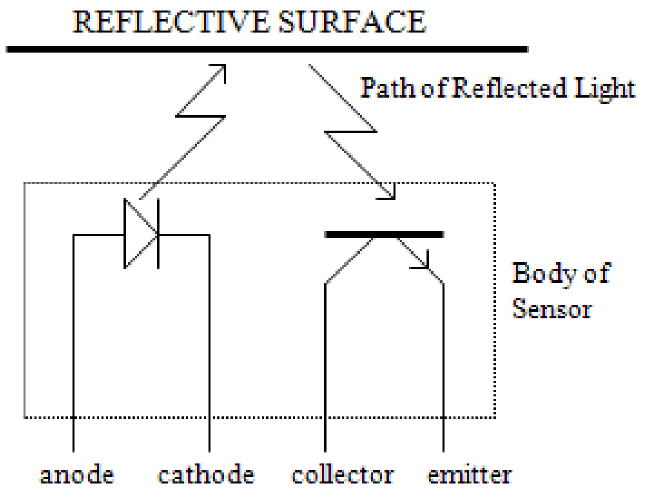
Controlling mbed LEDs from the app board Joystick

C code feature

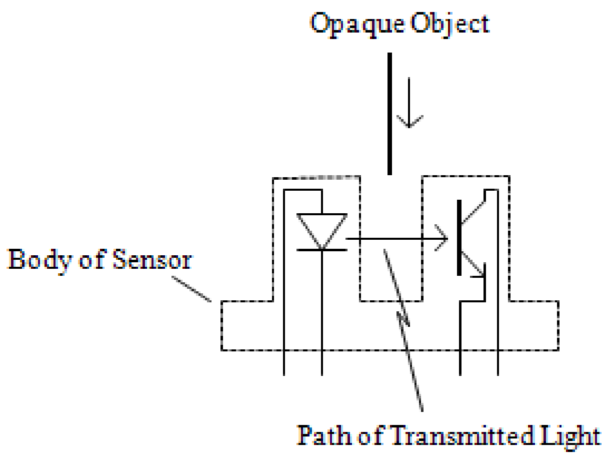
It’s useful to be able to group digital inputs or outputs, so that we can read or switch whole groups at the same time. **BusIn** allows you to group a set of digital inputs into one bus, so that you can read a digital word direct from it. The equivalent output is **BusOut**. Applying either simply requires you to specify a name, and then list in brackets the pins which will be members of that bus, msb first.

```
/*Program Example 3.5: Transfers the value of the joystick to mbed LEDs
                                                                          */
#include "mbed.h"

BusIn joystick(p15,p12,p13,p16);
DigitalIn fire(p14);
BusOut leds(LED1,LED2,LED3,LED4);

int main(){
    while(1){
        if (fire) {
            leds=0xf;
        }
         else {
            leds=joystick;
        }
        wait(0.1);
    }
}
```

Interfacing Simple Opto Devices

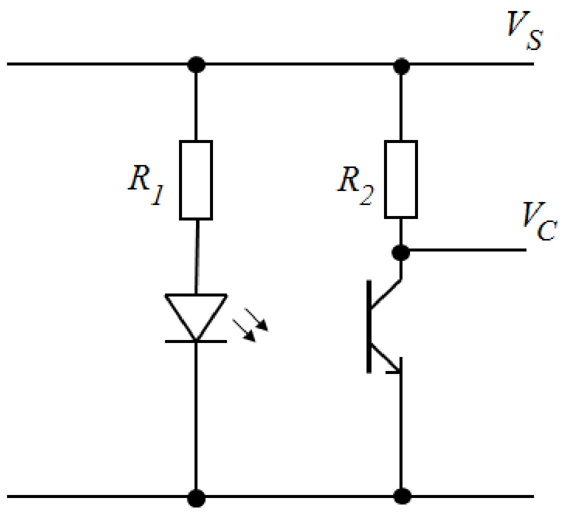


a) The reflective opto-sensor



b) The transmissive opto-sensor

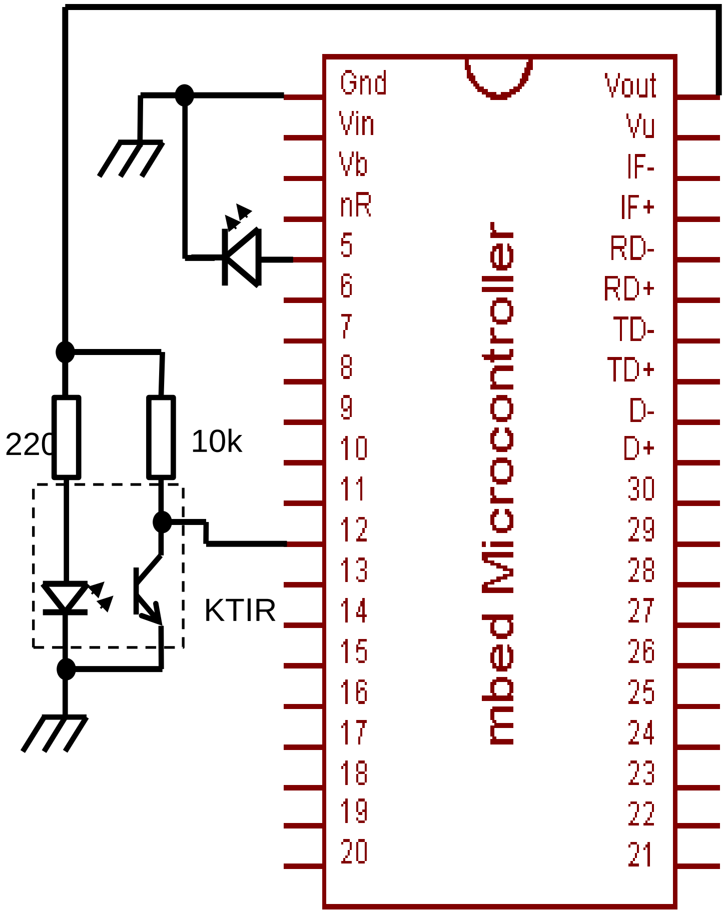
Opto-sensors are simple examples of sensors with “almost” digital outputs. When a light falls on the base of an opto-transistor, it conducts; when there is no light it doesn’t. Either of the sensors shown can be connected in the circuit of (c).

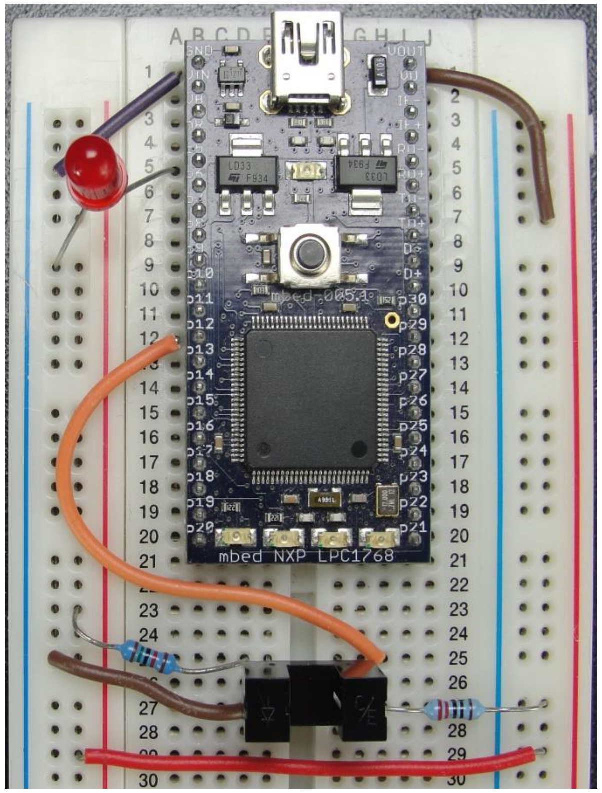


c) Simple drive circuit for opto-sensor

Connecting an Opto-Sensor to the mbed

The figure shows how a transmissive opto-sensor can be connected to an mbed. The device used is a KTIR0621DS, made by Kingbright; similar devices can be used.





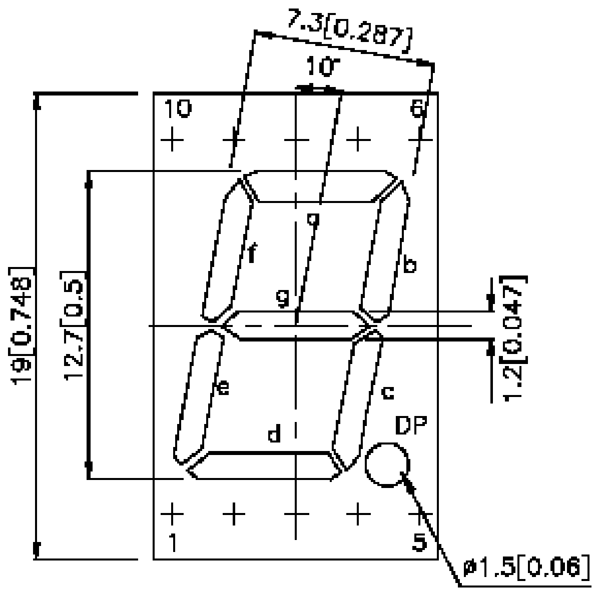
Applying the Photo-Interrupter

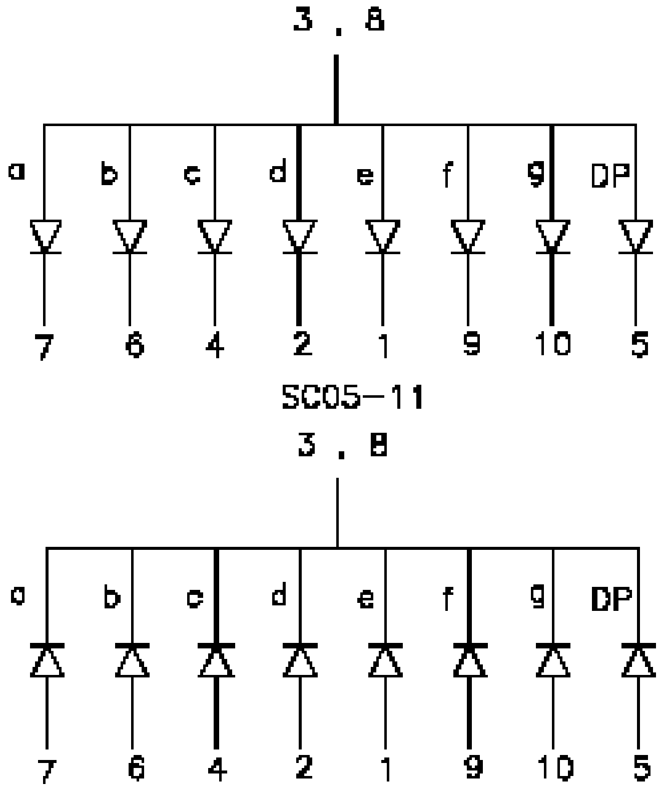
The output of the sensor is connected to pin 12, which is configured in the program as a digital input. The program switches the LED on when the beam is interrupted, i.e. an object has been sensed. To make the selection, we use the **if** and **else** keywords, as in the previous example. Now however there is just one line of code to be executed for either state. It is not necessary to use braces to contain these single lines.

```
/*Program Example 3.6: Simple program to test KTIR slotted optosensor.
Switches an LED according to state of sensor
*/

#include "mbed.h"
DigitalOut redled(p5);
DigitalIn  opto_switch(p12);

int main() {
  while(1) {
    if (opto_switch==1)             //input = 1 if beam interrupted
      redled = 1;                   //switch led on if beam interrupted

    else
      redled = 0;                   //led off if no interruption
  }                                 //end of while
}
```

Seven-Segment Displays

The seven-segment display is a versatile configuration. By lighting different combinations of the seven segments, all numerical digits can be displayed, as well as a surprising number of alphabetic characters. A decimal point is usually included, as shown. This means that there are eight LEDs in the display, needing 16 connections. To simplify matters, either all LED anodes ("common anode") are connected together, or all LED cathodes ("common cathode").



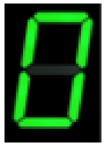
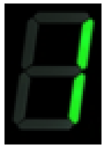
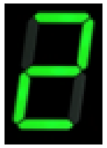
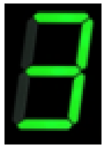
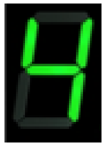
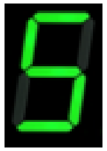
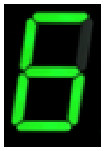
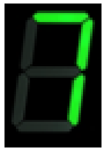
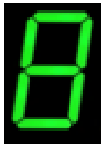
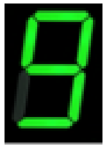


Driving the Display

A small seven-segment display can be driven directly from a microcontroller. In the case of common cathode, the cathode is connected to ground, and each segment is connected to a port pin. If the segments are connected in this sequence to form a byte,

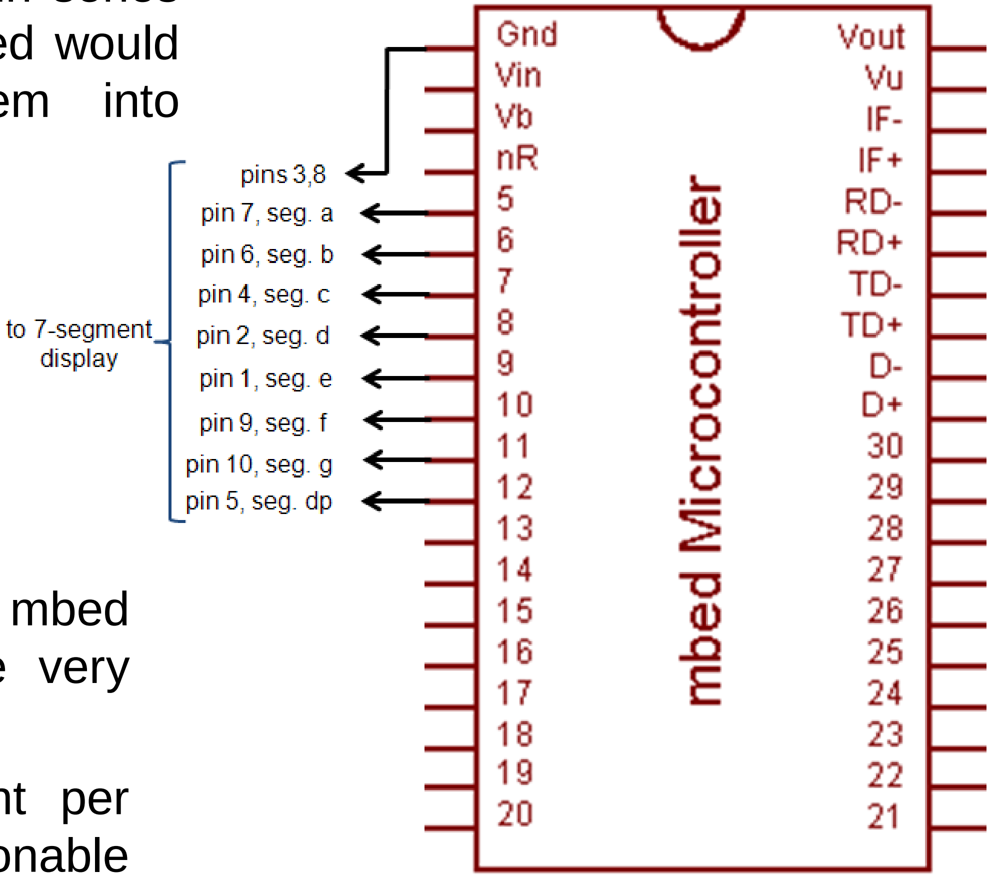
(MSB) DP g f e d c b a (LSB)

then the values shown in the Table apply. For example, if 0 is to be displayed, then all outer segments, i.e. abcdef must be lit, with the corresponding bits from the microcontroller set to 1.

Display Value	0	1	2	3	4	5	6	7	8	9
Segment Drive (B) (MSB) (LSB)	0011 1111	0000 0110	0101 1011	0100 1111	0110 0110	0110 1101	0111 1101	0000 0111	0111 1111	0110 1111
B (hex)	0x3F	0x06	0x5B	0x4F	0x66	0x6D	0x7D	0x07	0x7F	0x6F
Actual Display										

Mbed Connected to a Common Cathode Display

The mbed runs from a 3.3 V supply. Each display LED requires around 1.8 V across it in order to light. This is within the mbed capability. If there were two LEDs in series in each segment however, the mbed would barely be able to switch them into conduction.



The internal resistance of the mbed output pins can be shown to be very approximately 100 Ω.

Calculating as shown, the current per diode is around 15 mA, a reasonable value for an LED.

$$I_D \cong (3.3 - 1.8)/100 = 15 \text{ mA}$$

Questions from the Quiz

6. What is the current taken by the display in the previous slide, when the digit 3 is showing?

7. If in the previous slide a segment current of approximately 4 mA was required, what value of resistor would need to be introduced in series with each segment?

Driving the Display, and some new Programming Features

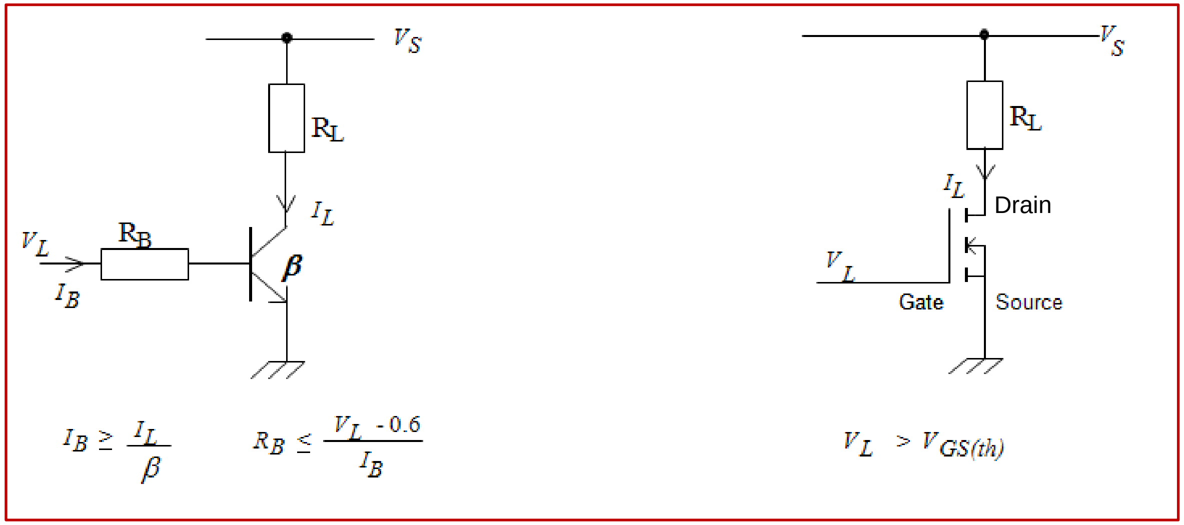
```
/*Program Example 3.7: Simple demonstration of 7-segment display. Display
digits 0, 1, 2, 3 in turn.
*/

#include "mbed.h"
BusOut display(p5,p6,p7,p8,p9,p10,p11,p12);   // segments a,b,c,d,e,f,g,dp

int main() {
  while(1) {
    for(int i=0; i<4; i++) {
      switch (i){
        case 0: display = 0x3F; break;        //display 0
        case 1: display = 0x06; break;        //display 1
        case 2: display = 0x5B; break;
        case 3: display = 0x4F; break;
      }                                       //end of switch
    wait(0.2);
    }                                         //end of for
  }                                           //end of while
}                                             //end of main
```

C code feature

Note the use of the **for( )** loop, an alternative to **while(**) for creating conditional loops. Using **switch( )** allows selection of one of a range of options within a list, identified with the **case** keyword. Each option is terminated with **break.**

Switching Larger DC loads

The mbed can drive simple DC loads directly with its digital I/O pins. If it's necessary to drive a load - say a motor - which needs more current than an mbed port pin can supply, or which needs to run from a higher voltage, then an interface circuit will be needed.



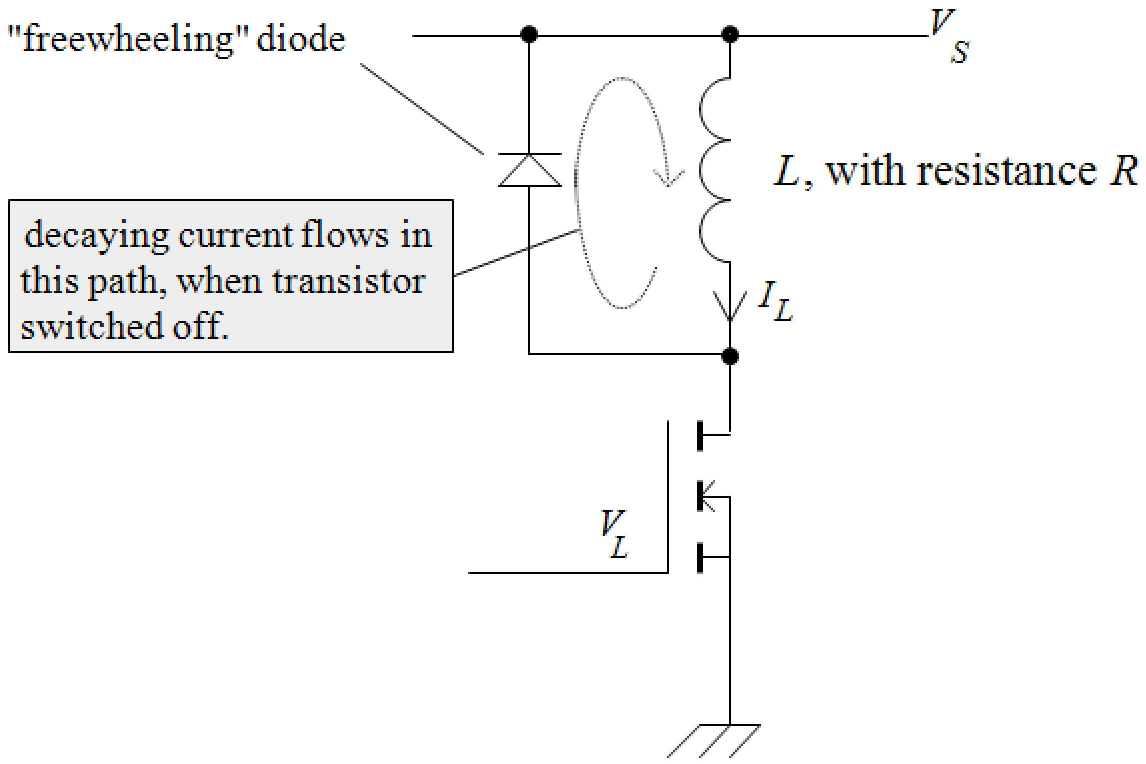
A good switching transistor for small DC loads is the ZVN4206A, with main characteristics shown. An important value is the maximum V_{GS} threshold value, shown as 3 V. This means that the MOSFET will respond, just, to the 3.3V Logic 1 output level of the mbed.

Characteristic	ZVN4206A
Maximum Drain-Source Voltage V_{DS}	60V
Maximum Gate-Source Threshold $V_{GS(th)}$	3V
Maximum Drain-Source Resistance when 'On'. $R_{DS(on)}$	1.5Ω
Maximum Continuous Drain current I_D	600mA
Maximum Power Dissipation	0.7W
Input Capacitance	100pF

Table 3.5: Characteristics of the ZVN4206A n-channel MOSFET

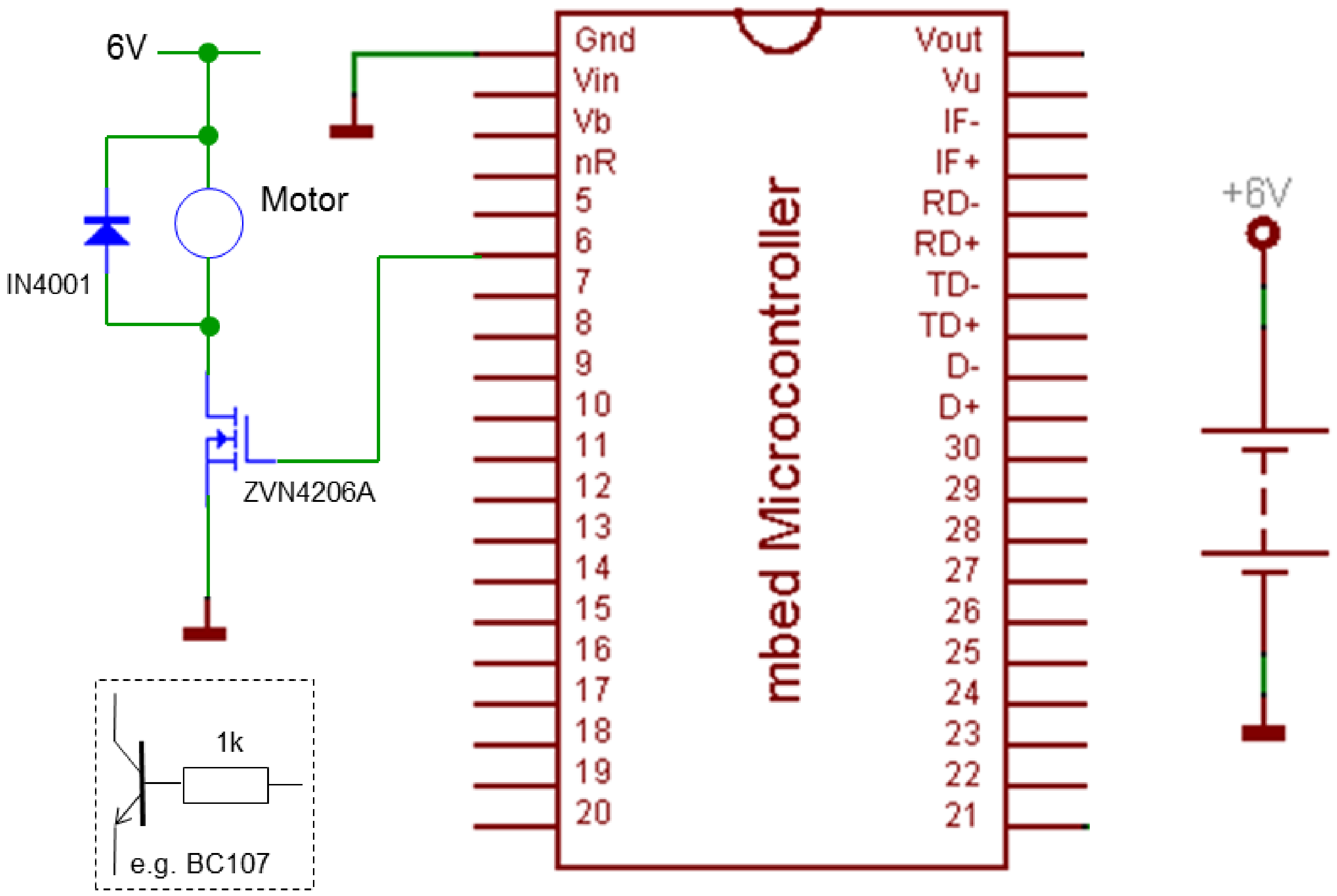
Switching Inductive Loads

A *freewheeling diode* is now needed because any inductance with current flowing in it stores energy in the magnetic field which surrounds it. When that current is interrupted, in this case by the transistor being switched off, the energy has to be returned to the circuit. This happens through the diode, which allows decaying current to continue to circulate.


"freewheeling" diode
V_S
L, with resistance R
decaying current flows in this path, when transistor switched off.
I_L
V_L

Switching a DC motor with the mbed

The circuit shown can be applied. Any mbed digital output pin can of course be used.



Alternative bipolar transistor switch

Chapter Review

- Logic signals, expressed mathematically as 0 or 1, are represented in digital electronic circuits as voltages. One range of voltages represents 0, another represents 1.
- The mbed has 26 digital I/O pins, which can be configured either as input or output.
- LEDs can be driven directly from the mbed digital outputs. They are a useful means of displaying a logic value, and of contributing to a simple human interface.
- Electromechanical switches can be connected to provide logic values to digital inputs.
- Multi-coloured LEDs can be made by enclosing several individual LEDs of different colors in the same housing. The mbed application board contains one of these.
- A range of simple opto-sensors have almost digital outputs, and can with care be connected directly to mbed pins.
- Where the mbed pin cannot provide enough power to drive an electrical load directly, interface circuits must be used. For simple on/off switching a transistor is often all that is needed.