

Interfacing Students' Projects with the PIC Microprocessor

Abstract

Recent developments in simplifying programming of PIC Microprocessors have made the devices more accessible to students and to school design and technology departments. Our research¹ has shown that although many Key Stage 4 students are now beginning to use PICs in their design and make projects, for many students driving LEDs to simulate output devices is as far as many get. Our research also suggests that many students are having difficulty using the IC for driving output devices such as motors and solenoids because of the inductive loads created by the device. This induction effect causes electronic noise, which in turn effects the reliability of the PIC and often causes the program to malfunction.

This paper looks at some general solutions to the problem and provides students with some ready-made solutions that could be incorporated into their design and make projects.

Background

The recent development of Programmable Integrated Circuits (PICs²) and associated simplified programming software³ is now bringing this technology within the grasp of many secondary schools. This paper provides teachers and their students with some design tools to help develop knowledge and understanding of using a PIC to control output devices.

It is important to understand ways of using outputs to drive components that require higher current ratings such as, DC motors, buzzers, bulbs, solenoids and relays. For many students driving DC motors is the most important use of a PIC and by way of illustration, the control of DC motors (both forward and reverse) is described later in the paper.

The PIC is capable of receiving inputs, these inputs may be either analogue or digital depending on the member of the PIC family that is being used, and is also able to provide low current outputs. The level of output varies slightly among the PIC family, but it is important to note that no PIC will drive high current output devices without the use of additional components.

The low current outputs can source (give out) a maximum of around 50mA. This means that without 'interfacing' LEDs are the only feasible output devices that can be used. LEDs are fine to simulate an output function, but most students will want to drive real devices such as motors, solenoids and buzzers. To increase the current output in

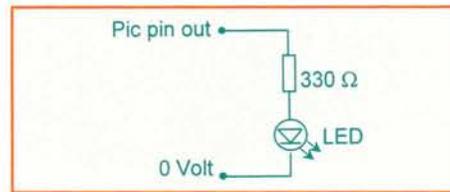


Figure 1: PIC output driving a LED using a current limiting resistor.

order to drive other components, a method of current amplification is needed.

For example if a student wished to use a PIC's output channel to drive an LED they would set it up as in figure 1 using a 300Ω series resistor as a current limiting resistor.

The simplest way of obtaining current gain is by using either a single Darlington transistor such as the BCX38B. Connect the base of the transistor to the pin of the PIC that is designated as an output via a 10KΩ resistor, the emitter to 0V and the collector to the output that is being driven, as we show in figure 2.

Students could use a Darlington Driver IC such as the ULN2003A. This IC is a very useful component which also provides a NOT function, back EMF suppression diodes as well as 7 Darlington drivers. (We shall discuss possible uses of this IC later in the paper.)

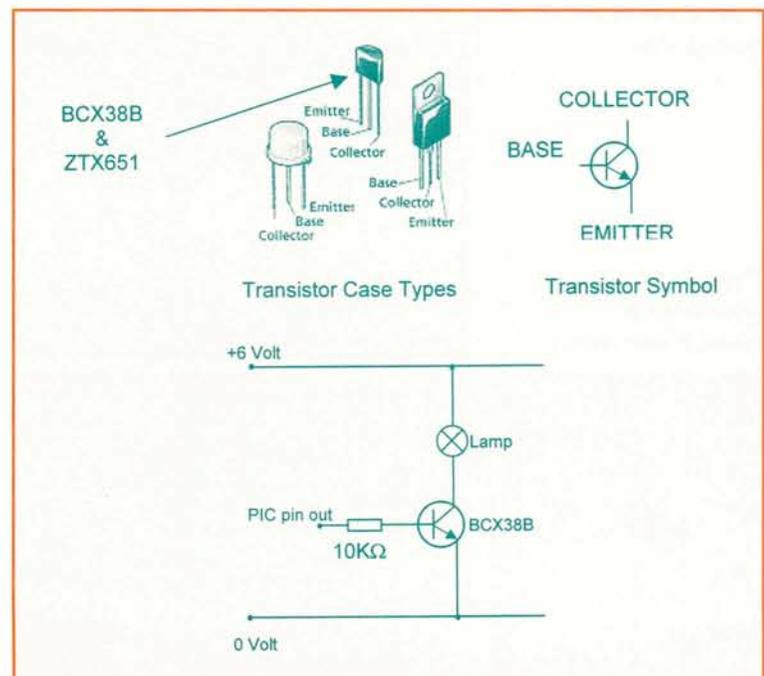
The Darlington Pair

In order to make PIC outputs drive efficiently, we need both high gain and quite a high current and to do this we could use two

Les Porter and
Daniel Stanton

Design Department,
Brunel University

Figure 2: Using the BCX38B Darlington transistor used to power an output.



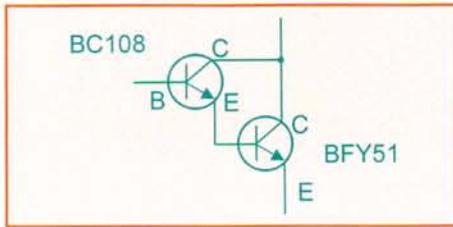


Figure 3: Darlington Pair arrangement.

transistors linked together, one with high gain and one with a high power rating (figure 3).

The total gain of the pair is found by multiplying the gain of the first transistor by the gain of the second. In figure 3 a BC108 transistor gives us a gain of 200 (at its lowest) and a BFY51 (a low gain transistor with high power output) of about 40 so multiplying the two together gives us a gain of 8000 and the possibility of controlling 1 Amp of output.

You may find you would like your students to do a little experimental work here. If you get them to set a multimeter to DC volts and measure the **trigger voltage** in the position as shown figure 4 above they will no longer find that this is 0.6Volt as they might expect. Ask them to suggest why!

As we mentioned earlier, instead of using two separate transistors, we would suggest using a transistor called BCX38B which looks like a single transistor, but is in fact two transistors set up as a Darlington Pair in a single package which gives a high gain and a high current capability. This discrete device has a

Figure 4: Measuring the trigger voltage for a Darlington Pair arrangement.

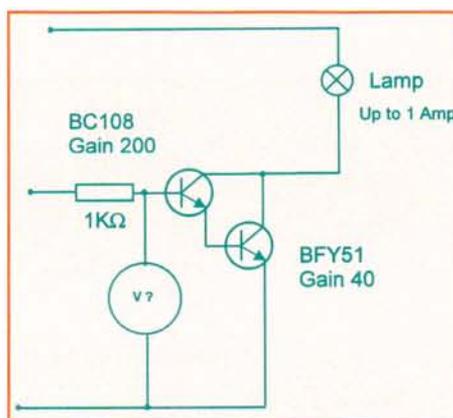
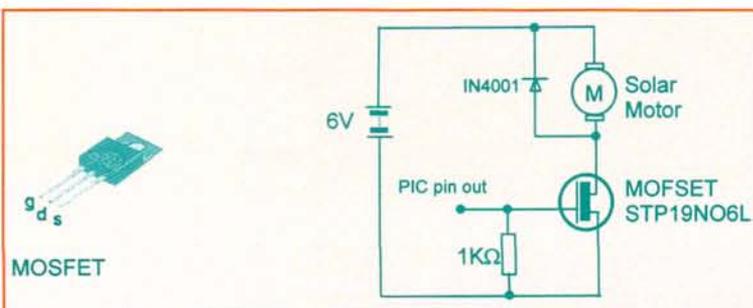


Figure 5: MOSFET circuit used for driving a solar motor.



collector-current rating of 800mA and will easily drive output devices such as small DC motors.

Power MOSFET⁺

Instead of using a Darlington Transistor Pair to switch power devices students could use a MOSFET transistor such as STP19NO6L. This device requires only 5V for its gate drive voltage and can be driven directly from logic level IC outputs. A typical circuit for this device is shown in figure 5. It is usual to connect a back EMF suppression diode across the output device. This is because, when devices such as motors, solenoids and relays are switched, this creates a back EMF that disturbs the operation of the PIC. A diode of the type 1N4001 would again be suitable for this task.

The ZTX651

As an alternative to using the BCX38B a transistor called ZTX651 could be used. Figure 6 shows a simple circuit that allows a DC motor to be driven in a single direction. This is an inexpensive transistor and uses a clamping diode to protect the transistor. A suitable diode would be 1N4001 connected as shown in the diagram. This circuit will drive a DC motor up to a maximum current rating of about 600 – 700 mA under load.

Motor reversing

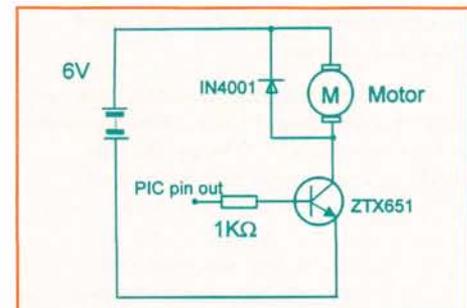
There are three ways of reversing a motor:

1. relays
2. H-bridge
3. a motor driver IC.

The relay

Relays, such as the ones shown in figure 7, are electronic switches that allows one circuit to switch another on or off. One circuit is electrically isolated from the other so, for example students could use a circuit with a small current of say 40mA to switch a circuit with a larger current of say 3A.

Figure 6: Transistor ZTX651 controlling a motor.



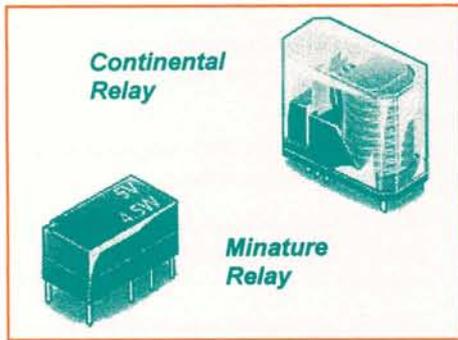


Figure 7: Typical relays as could be used in student projects.

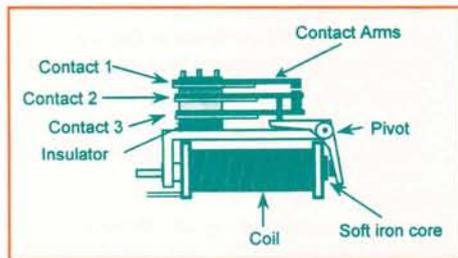


Figure 8: Operating principle of a relay.

The relay is simply an application of an electromagnet. It consists of a wire coil with a soft iron core. When a small current is passed through the coil the soft iron core is magnetised. At the end of the coil, there is a pivoted arm, which is attracted toward the magnetised core.

In figure 8 the principle of the relay is shown. As the arm moves it closes the contacts between 1 and 2 and opens the contacts between 2 and 3. Contacts 1 and 2 are said to be *normally open (NO)* and contacts 2 and 3 are said to be *normally closed (NC)* contact 2 is called the *common*. This sort of relay is called an NC change over relay. The main disadvantage of relays is that they can only be used at low switching speeds and they are relatively expensive.

If students intend to use a relay to switch a higher power motor or a solenoid as in the circuit below it is better to power the device from a 12 volt supply isolated from the PIC (see figure 9). When using power supplies like this it is not necessary to join the 0 volt lines as it is better to keep the supplies totally isolated then 'noise' will not effect the Microcontroller. Note again the use of a back EMF suppression diode across the relay contacts. This is again because of the problem caused by inductive loads. As before IN4001 would be a suitable diode for this. Watch which way the diode is put into the circuit!

There are two types of H-bridge design, either utilising two pairs of transistors PNP and NPN as shown in figure 10 or 4 NPN

transistors in the same arrangement as shown in figure 11.

Both circuits work, but it is important to note that when using the 4 NPN transistor array the motor rating is limited by the power supply driving the PIC (5 – 6v). To drive, for example, a 9v motor in both directions, which requires a higher voltage than the PIC, the PNP-NPN array must be used.

With each of these methods, each motor uses four outputs from the PIC. Therefore, to drive a small buggy with two motors, eight outputs are used.

The H-bridge system, shown in figure 10 is created using four transistors, two NPN and two PNP. By sending connections A, B, C and D into the PIC, one motor may be controlled in both directions.

Below: Figure 9: Output from a PIC using a relay to drive a 12 volt motor.

Below centre: Figure 10: A pnp-npn 'H Bridge' arrangement used for reversing a motor.

Bottom: Figure 11: A 4 x npn 'H Bridge' arrangement used for reversing a motor.

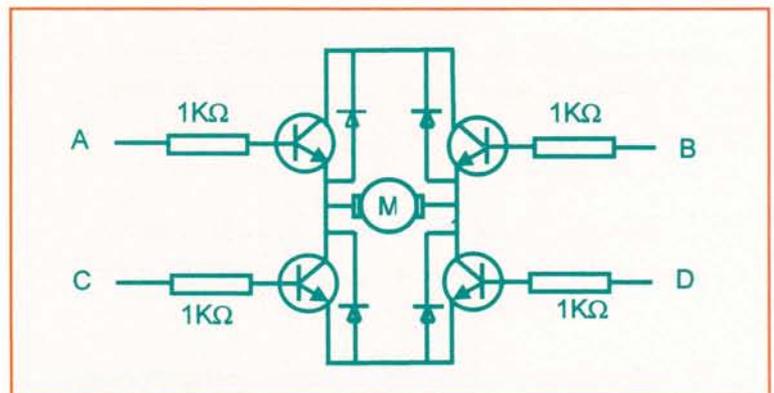
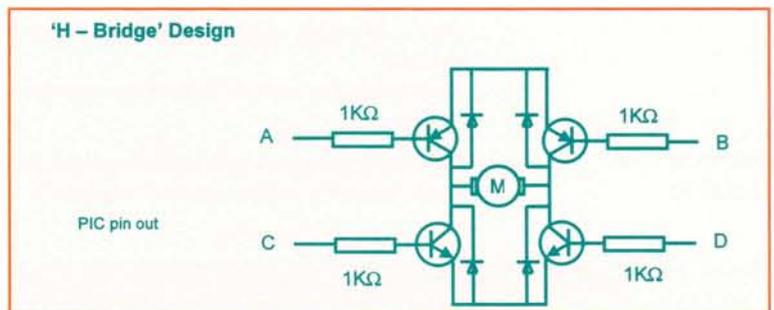
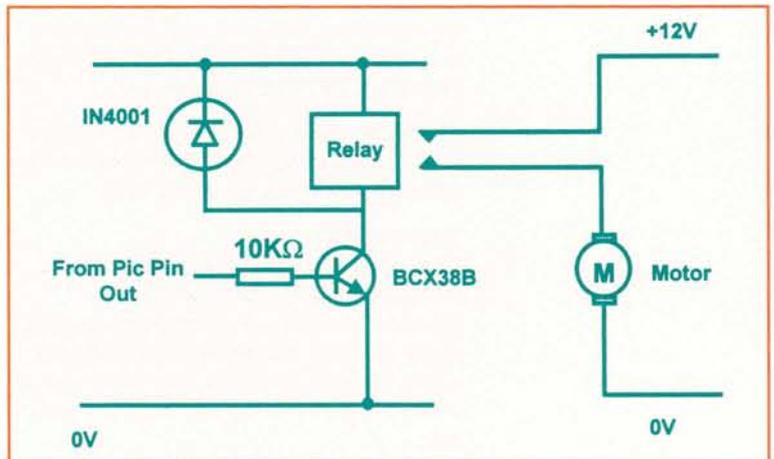


Figure 12: PIC codes supplied to transistor bases for controlling motors.

Clockwise	Anticlockwise
A=0 (low)	A=1 (high)
B=1 (high)	B=0 (low)
C=0 (low)	C=1 (high)
D=1 (high)	D=0 (low)

The NPN transistors are type ZTX651 and the partnering PNP transistors are ZTX751. (Unlike NPN transistors PNP transistors conduct until a base current is generated at which point they stop conducting). By sending an output from the PIC to the appropriate transistor motors can be controlled. However, the disadvantage of using this method is that it is possible to short circuit the transistors. Although the transistors are fairly resilient, they do get very hot. To enable directional control of the motor, the following code (see figure 12) needs to be applied to the transistor bases:

An alternative method of dual motor control is by utilising the IC L293D. This component uses only 2 PIC outputs per motor.

This allows two motors to be driven with the same amount of legs from the PIC as a single H-bridge controlling one motor only.

The IC L293D

In some cases students may wish to run a motor in both directions (forward and reverse). In this case it is convenient to use a motor driver IC such as the L293D which is shown in figure 13. This IC will allow control of two DC motors using four outputs from a PIC.

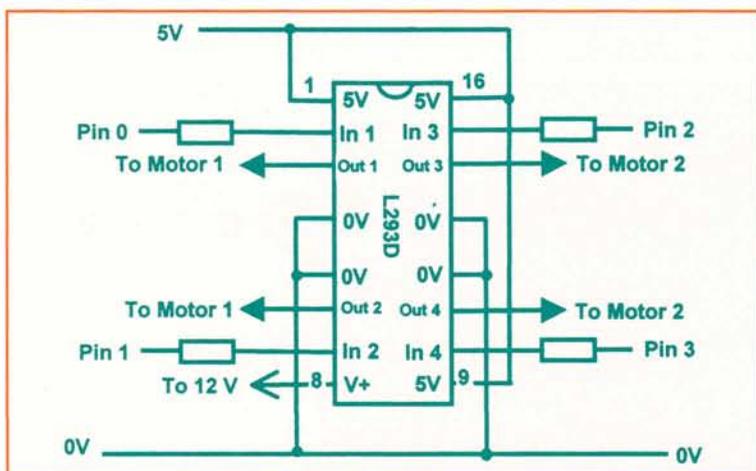
Example

First output high, second output low – motor forward,

First output low, second output high – motor reverse.

Obviously if students only wish to control one motor they only need to use two output lines.

Figure 13: The L293D IC.



Example

Both inputs low – motor halt,
Both inputs high – motor halt.

Suitable PICs

Currently there are two PICs very suitable for use in schools. These are the:

1. 16C84/F84 because it is electronically erasable⁶ and can be re-written over and over (cost £3.45).
2. 12C [series]. One advantage of this PIC series is that they have an internal clock and so they do not require external components to operate. This will reduce the cost of a project and also allow simple products to be manufactured quickly. (Although the re-writeable version can be erased under UV⁶ radiation, the single use, one time programmable (OTP) versions, can be bought for under £1.)

Darlington driver IC

Earlier we talked about the ULN2003A and said we would discuss its use in detail later! If students are controlling a number of output devices they may need to use a number of output transistors. It may be more convenient to use a ULN2003A Darlington Driver IC. This is simply a single chip that contains 7 Darlington transistors similar to BCX38B, the chip also contains back EMF suppression diodes so therefore no external diodes are required. Each Darlington Pair in the IC has a collector-current rating of 550mA which makes it a very useful device for driving small inductive components. This really is a versatile IC and has lots of uses, but in figure 14 below, we give you an example of how it could be used.

Noise

Cheaper motors create a large amount of 'electronic noise' and also draw current well in excess of 600mA when under any minor load. To save costs it is possible to salvage high quality motors from tape players e.g. Walkman's and VHS etc. These motors are low current consumers and have reasonable torque. However, caution is needed when stripping mains operated tape players. Mains power supplies may still be charged with a residual voltage. Needless to say, students should not dismantle mains operated products.

Noise suppression

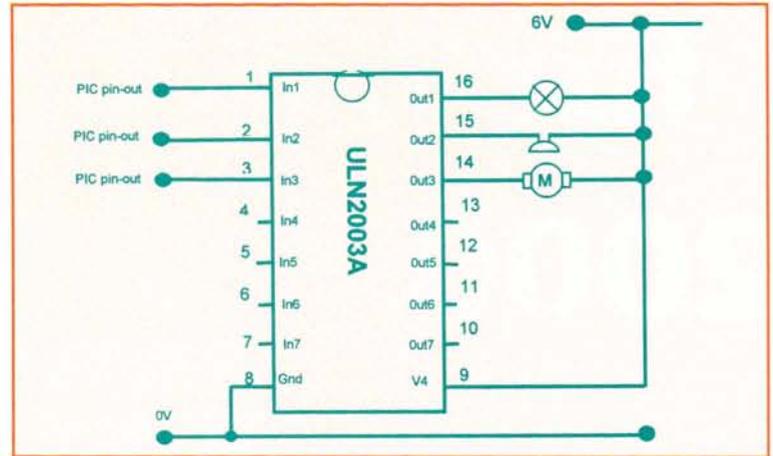
If you find that students are having problems when driving motors, solder a small ceramic capacitor (about 0.1 micro farads) across the back of the motor. If this still fails use two capacitors as shown in the small sketch. Use a 0.22 µF ceramic capacitor and a 10 µF electrolytic capacitor. It is important to make sure that the electrolytic capacitor is correctly

connected to the power supply. The side of the capacitor with the black stripe should be connected to the -ve supply.

Conclusion

There is much, much more to know about interfacing to the PIC, such as using analogue devices as inputs, for example using LDRs where the falling/rising light level changes gives an input or about potentiometers as position sensors, or about using stepper motors as output devices. If you want to go further visit <http://www.brunel.ac.uk/depts/des/bureau/home.htm> (look at the control technology project) but the most important thing is "Have Fun".

1. A national research project investigating teaching and learning within the systems and control strand of the design and technology National Curriculum.
2. PIC: Programmable Integrated Circuit, the trade name of a Programmable Logic Circuit developed by Microchip Technology Inc.
3. TEP's (Technology Enhancement Programme) Chip Shop (Starter Kit £99 + optional software £32) Economatics – PIC Logicator (£125 including software) Icon Soft Electronics – Nottingham Trent University (£98 single user license).
4. MOSFET = Metal Oxides Field Effect Transistor – A Field Effect Transistor is usually a voltage amplifier, rather than a current amplifier. They can be switched on by a very small input voltage applied to the gate. This makes them useful as amplifiers for low-powered process circuits. Types which handle high currents usually have metal heat sinks attached to them.
5. EMF = electro motive force.
6. UV = Ultra-Violet light source supplied from a suitable IC eraser such as Rapid Electronics 85-2790.



Notes

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Figure 14: ULN 2003A used to control outputs.

Figure 15: Capacitor soldered across the back of the motor acting as a noise suppresser.

