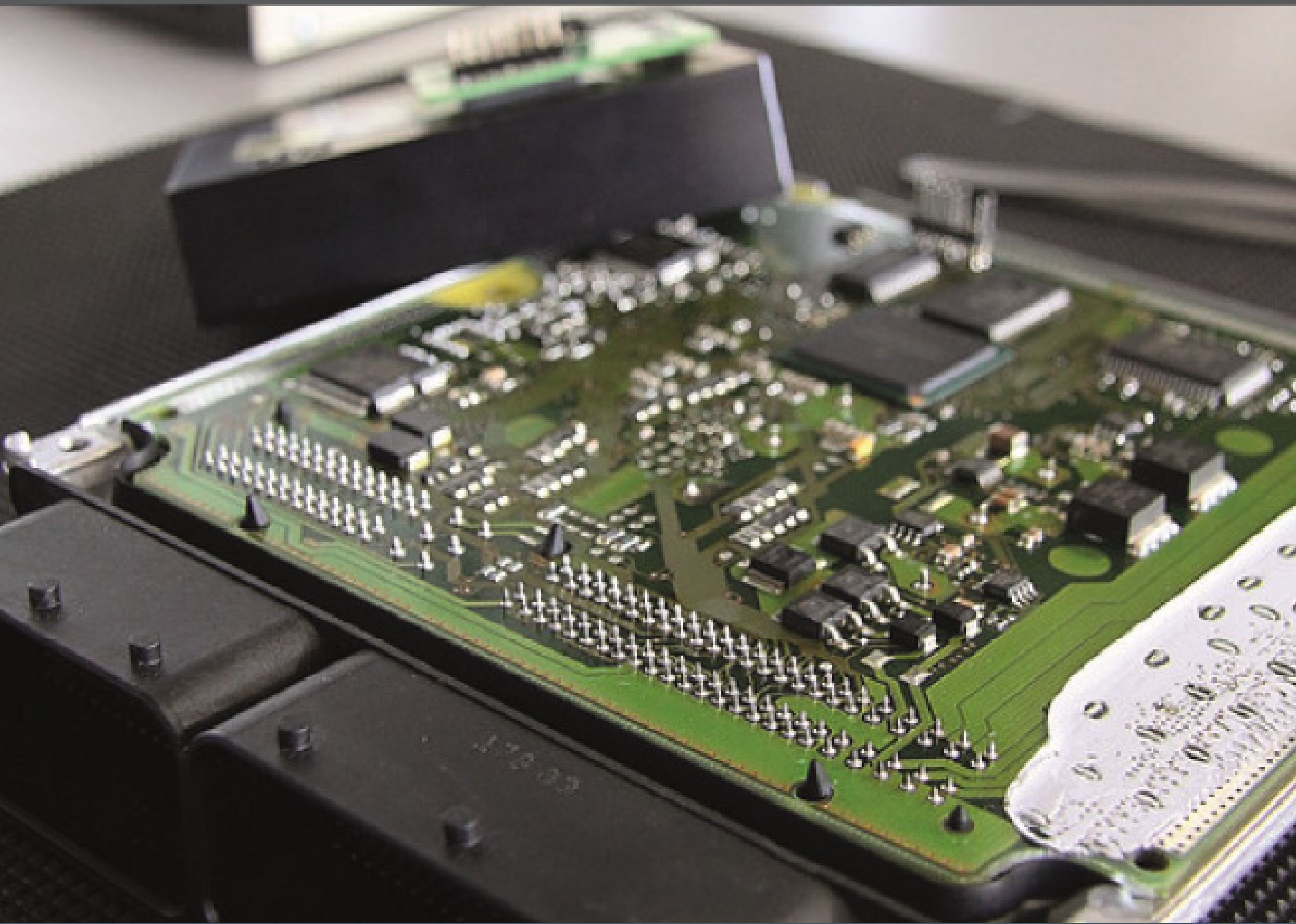

SENSE AND CONTROL

CP7241

Inspiring The Next
Generation Of Engineers

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WORKSHEETS

WORKSHEETS

Worksheet 1 - Simple Digital Sensors

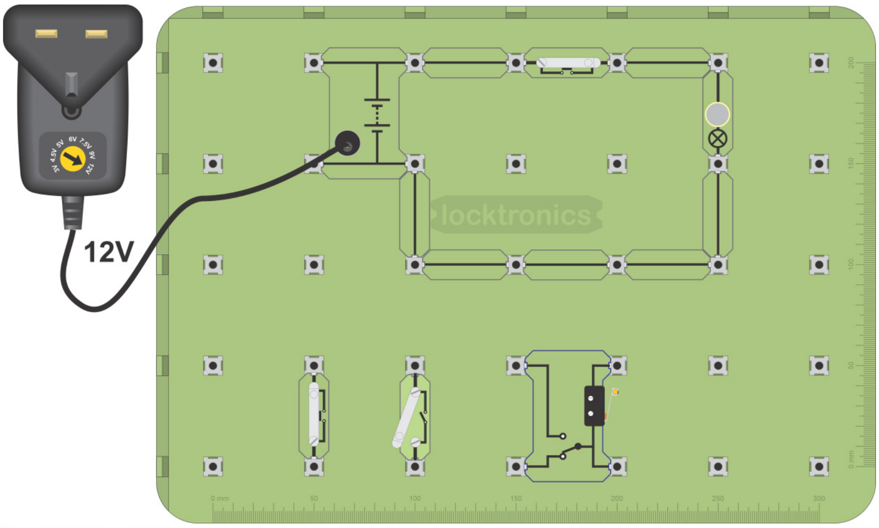
There are many sensors in a modern car. Some are controlled by the driver (like a light switch) and some by factors in the car itself - like the fuel sensor. Each sensor provides an input signal - often directly into an Electronic Control Unit.

The sensors in a car can be divided into two types; **analogue** and **digital. Digital** sensors have a two state output, usually either 'on' or 'off'. The car power supply determines the voltages corresponding to these two states - often 12V (on) and 0V (off).

The photograph shows a brake switch component.

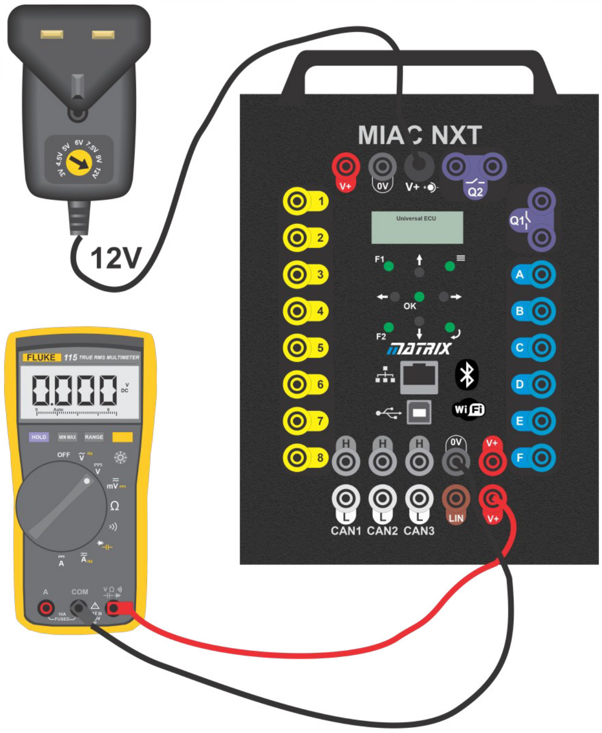
Over to you:

- Build the circuit shown below.
- Set the power supply to 12V, plug into the Locktronics carrier and switch on.
- Press the switch to make the bulb light.
- Connect a multimeter to read the voltage across the bulb.
- Read the voltage across the bulb when the switch is pressed, and when not pressed.
- Complete table 1.1 in the Student Handout with your results.
- Similarly for the three separate switches, use a multimeter to measure the resistance of the switches when open and when closed.
- Record your measurements in table 1.2 in the Student Handout.



So What?

- These simple digital sensors have a two-state output - either open (off) or closed (on).
- They have a very high resistance when open and a very small resistance when closed.



Over to you:

1. Power up the MIAC ECU.
2. Use a multimeter to measure the voltage at input 1.
3. Record it in the Student Handout.

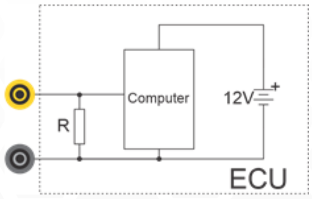
So What?

The MIAC ECU is a computer with inputs and outputs. Computers make decisions based on the state of the inputs.

If the input is not attached to either ground or +5V, it 'floats' between 0V and 5V at an indeterminate level.

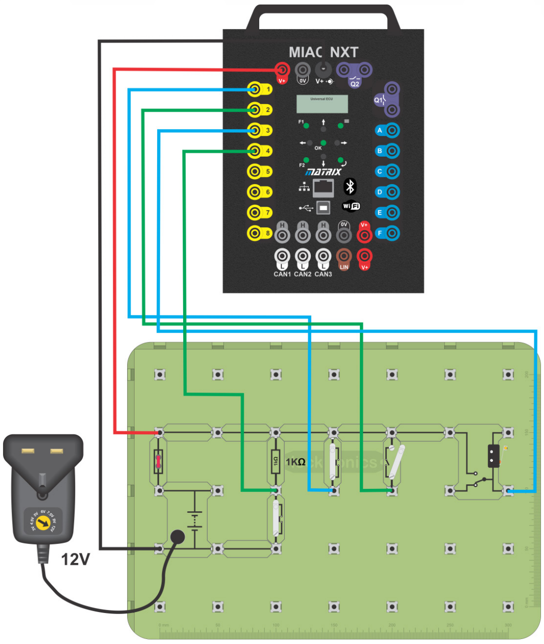
When a computer samples the input, the result is unpredictable.

To prevent this, the input is 'tied' to a known voltage level with a resistor. In the case of the MIAC, the inputs are tied to +0V through an internal 10k resistor, R, as you can see in the circuit diagram below.



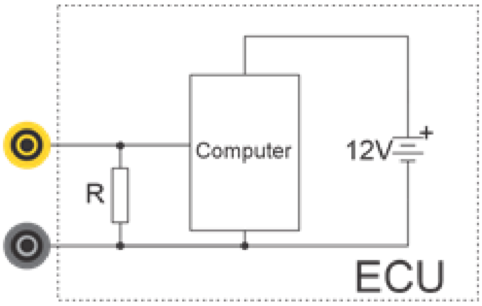
Over to you:

1. Build the circuit shown opposite, which connects a number of switches to a MIAC ECU.
2. Plug the power supply (12V) into the Locktronics carrier. It provides power for the full system.
3. Select program 1 on the MIAC.
4. Close the switches in turn. Complete the first four rows of table 1.3 in the Student Handout.
5. Choose a switch and measure the input current when the switch is activated.
6. Note this measurement in the table in the Student Handout.



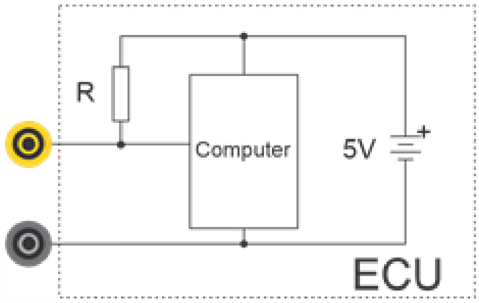
So What?

- The internal pull-down resistor on the MIAC ECU input keeps the input at 0V when the switches are open.
- Hence, for switches connected to 12V:
- When the switch is open, the output is 0V;
- When the switch is closed, the output is 12V.
- If a switch is connected to 12V, it has no effect on the circuit when it is closed.



ECU with pull down resistor

This is not the case on all ECU inputs. The system designer could include a pull-up resistor on an input as shown in this circuit. In this case the switch would be wired to 0V, the input would be at +5V when the switch is open and 0V when the switch was closed.



ECU with pull up resistor

Most inputs in ECUs have pull-down resistors.
Thermistor inputs generally use pull-up resistors.

Over to you:

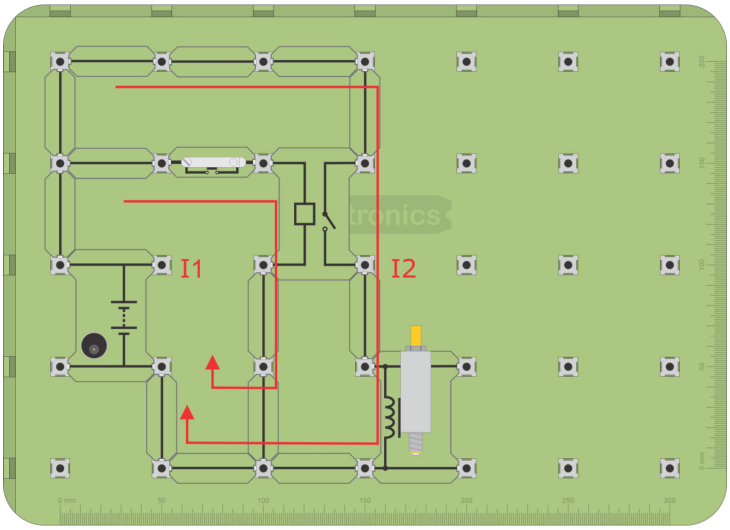
If you have the 'Sensors and Actuators' pack, then you can do Worksheets E1, 2

A key function of the electronics in a car is to turn low current signals, from a switch or sensor, into high current signals to operate the output device.

The output current of transistors is limited to a few amps at the most. When higher currents are needed, we use relays.

The photograph shows a typical starter motor relay, often called a 'solenoid'

Over to you:



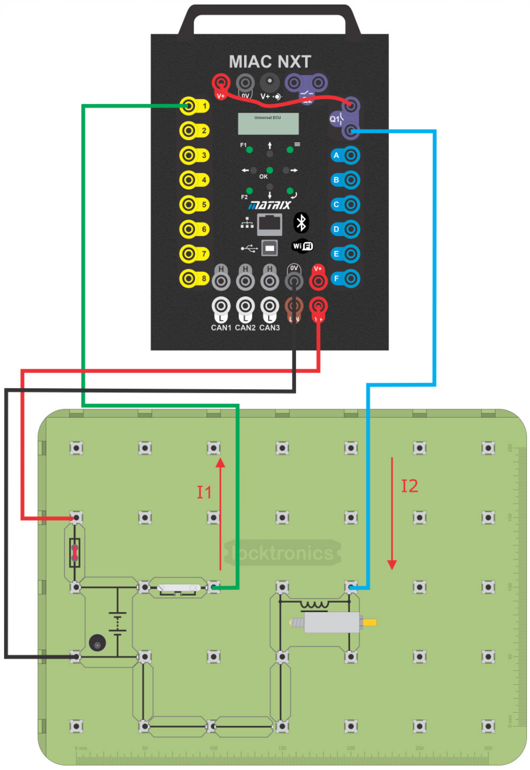
1. Build the circuit shown above, to investigate the relay.
2. Set the power supply to 12V, plug into the Locktronics carrier and switch on.
3. Connect a multimeter to read current **I1**, when the switch is pressed. This is the current through the coil that activates the relay, equivalent to the transistor input current.
4. Move the multimeter to measure the current **I2**, through the solenoid. This is the current delivered by the relay contacts to the output device, the solenoid in this case. It is equivalent to the transistor output current.
5. Record your readings in table 2.1 in the Student Handout.

So What?

- A relay uses a small solenoid (coil) to control a switch, located nearby but electrically isolated from it.
- When the solenoid is energised (i.e. passing a sufficient current ,) it closes the switch.
- In this way, it uses a low current to control a high one, up to 40A in a car.

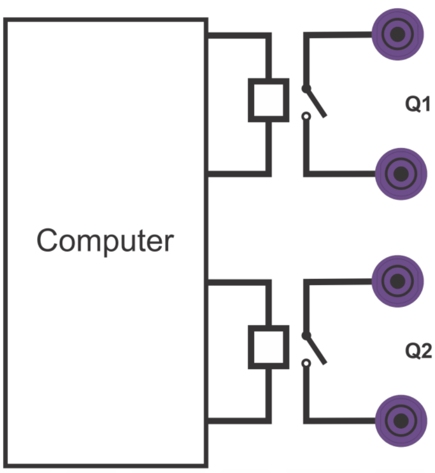
Over to you:

1. Build the system shown opposite.
2. Plug the power supply (set to 12V) into the Locktronics carrier, to power the full system.
3. Select program 4 on the MIAC.
4. Press the switch to check that the system is working.
5. Use a multimeter to measure the new current **I1** through the switch. This is the MIAC input current. You should find that it is much less than the relay input current in the previous worksheet.
6. Now measure current **I2**, through the solenoid. This current should be similar - it depends on the solenoid used.
7. Record your readings in table 2.2 in the Student Handout.



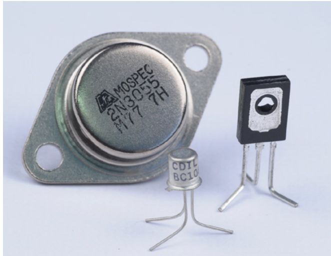
So What?

- Inside the MIAC, there are two relays connected to an internal computer, each capable of switching up to 10 amps.
- Each relay has two terminals, with an internal high current switch.
- Both terminals must be connected into the circuit. In the system above, the top relay terminal is connected to the power supply V+.
- Relay outputs on ECUs have the advantage that they can switch high current, but have the disadvantage that they are quite slow to act, compared to transistors.
- The diagram shows how the relays are wired inside the MIAC



Over to you:

If you have the ‘Sensors and Actuators’ pack then you can do Worksheet E3.



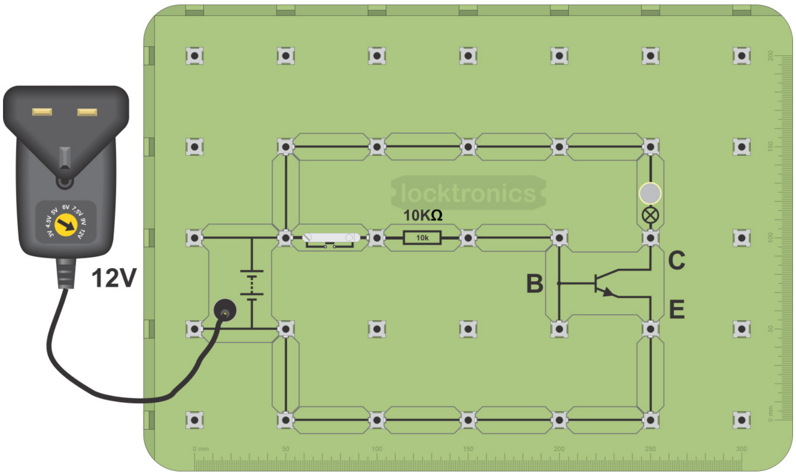
The transistor is the building block of modern electronics. You will rarely see a 'stand alone' transistor in an automotive application, but they are there, embedded in radios, ECUs and other subsystems.

The most basic use of a transistor is to amplify current. It is useful to understand how they work, and what their limitations are.

The photograph shows several types of transistor.

Over to you:

1. Build the circuit shown below.



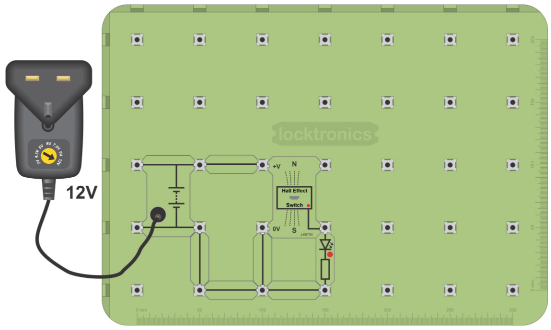
2. Press the switch to check that the bulb lights.
3. Connect a multimeter to read the current through the 10kΩ resistor when the bulb is lit. This is the transistor **input** current
4. Move the meter to measure the current through the bulb - the transistor **output** current.
5. Press the switch and measure the bulb current.
6. Record your results in table 3.1 in the Student Handout.

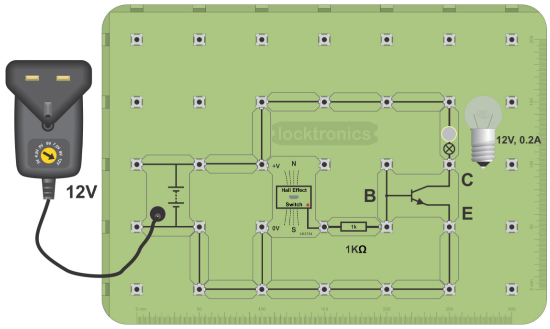
So What?

- There are many types of transistor. This one is a 'NPN' transistor. The three terminals, shown on the symbol by the letters 'B', 'C' and 'E' are the base, collector and emitter.
- Transistors are useful because they amplify current - a small current flowing into the base controls a much larger current flowing from the collector to the emitter.

Over to you:

1. Build the circuit shown - a Hall effect sensor connected to an incandescent bulb (12V, 0.1 A).
2. Unscrew the bulb and hold a magnet near the Hall effect sensor. (The LED on the sensor should turn off when the sensor is activated).
3. Now screw in the bulb. Does it light when the magnet is brought close to the sensor?
4. Next, connect a transistor on the output of the Hall effect sensor as shown in the second circuit.
5. Again, use a magnet to turn the sensor on.
6. Does the bulb light now?
7. Answer the questions raised in the Student Handout about what you observed.

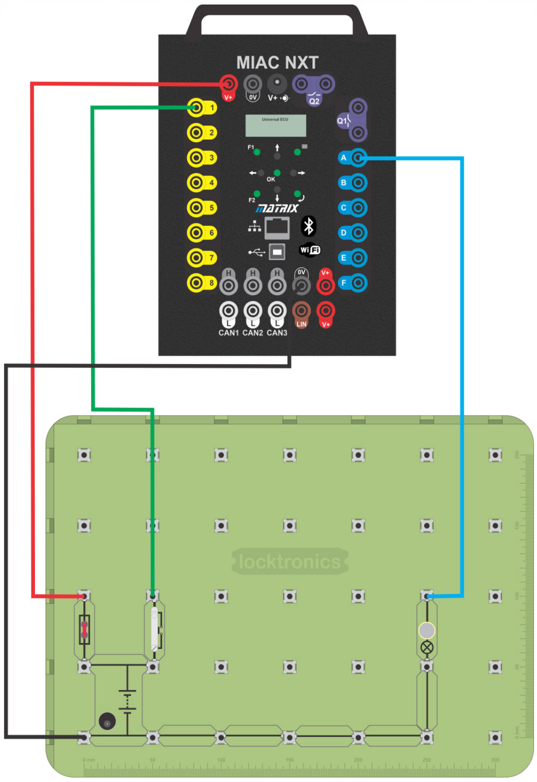




So What?

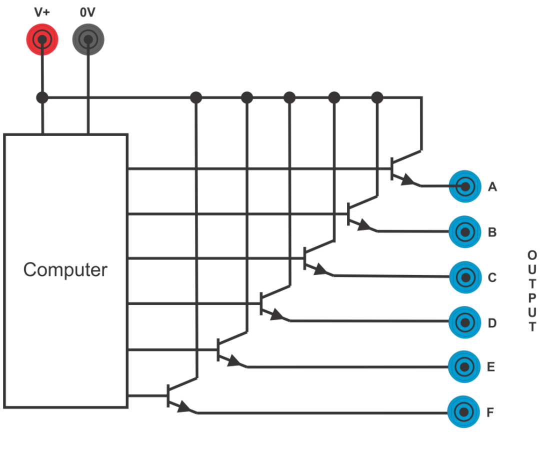
- The Hall Effect sensor is 'active low'. It outputs 12V normally and 0V when it detects a magnet.
- In the first circuit, the sensor cannot provide enough current to power the bulb, connected across the output.
- When a transistor is added, it amplifies the current from the Hall Sensor and allows 0.2A to flow through the bulb.
- Most ECU outputs are transistor outputs. They can switch more than 10 amps.
- Some ECU outputs 'sink' current - the ECU output is connected to the collector with the emitter connected to 0V inside the ECU.
- Some ECU outputs are connected to the emitter, with the collector connected to +12V. These outputs 'source' current. The MIAC ECU outputs source current.

Over to you:



1. Build the system shown opposite, which is effectively the same circuit as on the previous page, but using a transistor located inside the MIAC.
2. Plug the power supply (set to 12V) into the Locktronics carrier to power the full system.
3. Use the 'Up' and 'Down' keys on the MIAC to select program 6.
4. Measure the current through the switch, (MIAC **input** current,) and then through the lamp (MIAC **output** current.)
5. Record your results in table 3.2 in the Student Handout.
6. Compare these results with those obtained for the stand-alone transistor previously.

So What?



- Inside the MIAC, outputs **A** to **F** are controlled by an internal computer, connected to power transistors.
- Power for the whole system comes from the V+ and 0V terminals.
- In practice, the circuitry inside the MIAC, (and ECU's in general) is more complicated. Outputs are protected against short circuits, and against high voltages caused by inductive loads, such as motors and coils.

Over to you:

If you have the 'Sensors and Actuators' pack, then you can do Worksheet E4.

Worksheet 4 - Analogue Inputs

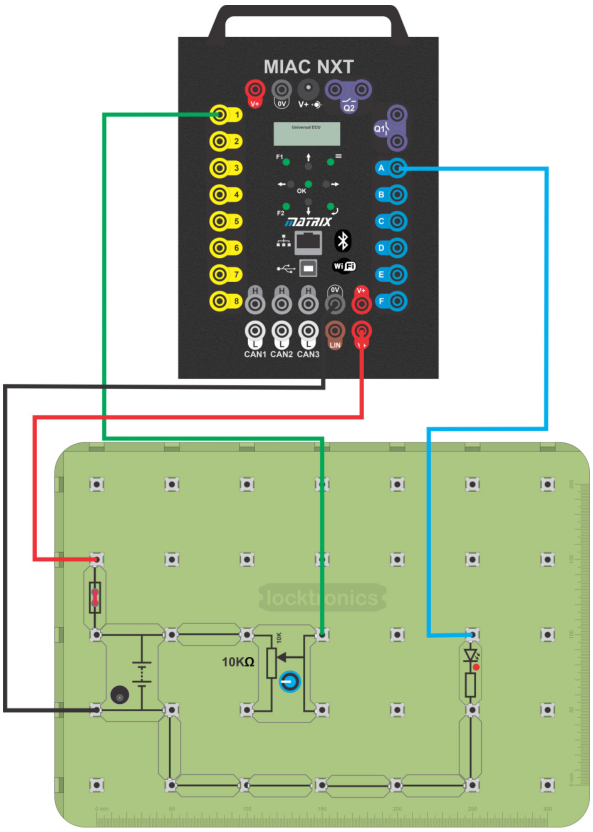
Two types of sensor, **analogue** and **digital**, are found in a car.

Analogue sensors provide more information than just the sensor being 'on' or 'off' and can be used to interpret the state of a system more accurately. They provide information about how full?, how far?, how many?, how hot? etc.

The photograph shows a fuel sensor with float.

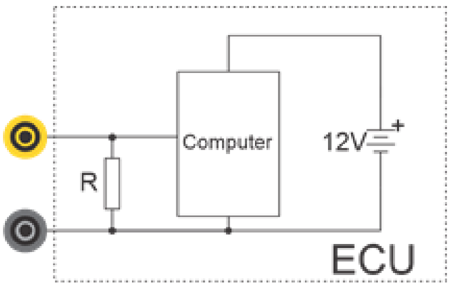
Over to you:

1. Build the system shown opposite. The potentiometer is an analogue sensor. It is equivalent to the fuel sensor in a car.
2. Plug the power supply (set to 12V) into the Locktronics carrier to power the full system.
3. Select program 8 on the MIAC ECU.
4. Use a multimeter to measure the output voltage of the potentiometer.
5. Turn the potentiometer to reduce the output in steps of two volts from 12V down to 6V. Record the corresponding fuel levels, shown on the MIAC display, in table 4.1 in the Student Handout.
6. At what value does the 'low fuel' LED come on?
7. Twist the potentiometer quickly from one side to another, to simulate fuel slopping around in the tank. Notice how quickly the readout on the MIAC changes. Why is this a problem?
8. Next, short-circuit the potentiometer output first to 0V and then to the supply voltage.
9. Make a note of the corresponding fuel level readings in the Student Handout. You will need this information later.



So What?

- If you know how the resistance of a sensor varies with the quantity it is sensing, then you can design a system that measures that quantity. Using a simple voltage divider chain of two resistors, where one is the sensor, you can design a circuit where the computer input voltage varies with the quantity we are trying to measure - in this case fuel level.
- You should have seen that changing the variable resistor (potentiometer) changes the fuel reading in the tank. But there is only one resistor in this circuit so how does this work?
- Inside the MIAC ECU, there is a pull-down resistor, R, connected to the input, rather like the one shown in the diagram. Having it inside the ECU saves on wiring and external components. Pull-down resistors are present on most ECU inputs. The value of the resistor is not always the same.



- In general, ECU inputs use pull-down resistors. The exception is where the input uses a thermistor. These use pull-up resistors. Understanding this is important when fault-finding - an open circuit on a digital input would result in a 0V reading on a multimeter, whereas, on a thermistor input, it would result in a 12V reading.

Over to you:

One of the problems with the previous circuit is that the fuel level indicator can give a false reading when the car goes up a hill or over a bump.

1. Select program 9 on the MIAC ECU.
2. Twist the pot. quickly from one side to another. Notice the response now. The reading is 'damped' by the software program running on the MIAC so that the low fuel indicator only changes status slowly.

So What?

- ECUs offer many advantages in a modern car. One is that the behaviour of a system can be changed by altering the software. In older cars, changing the system would have required a hardware design change.

Over to you:

If you have the 'Sensors and Actuators' pack, you can do Worksheets E5, 6, 7, 8, 10, 11.

WORKSHEETS

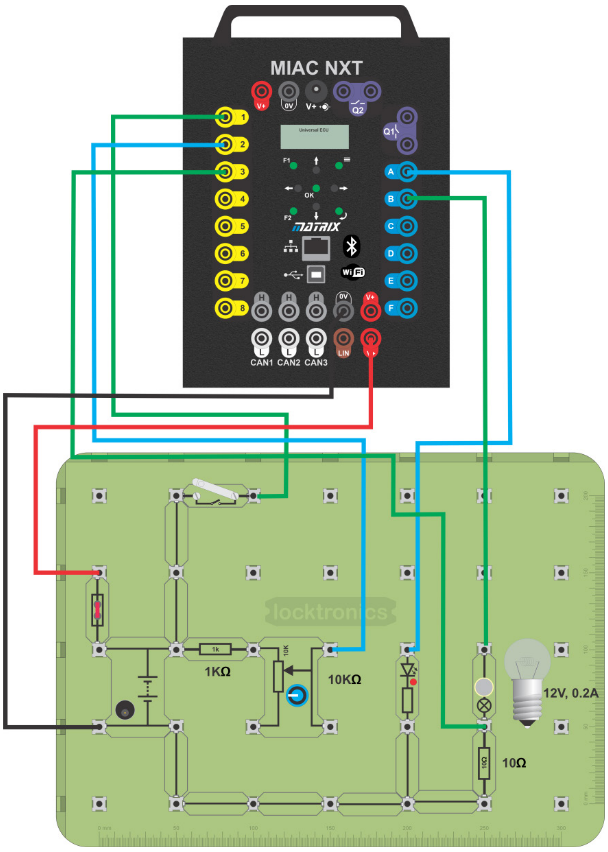
Worksheet 5 - Fault Detection With ECUs

In modern automotive systems, ECUs are used for much more than control. They can also report on the status of the vehicle and many of its components.

The photograph shows a Volvo V70 dashboard. The ECU has detected that the front headlight bulb is faulty and has reported it to the dashboard so that the driver can replace it.

Over to you:

1. Build the system shown below. It contains features to monitor both the fuel level sensor and the incandescent headlamp bulb connected to output B.



2. Plug the power supply (set to 12V) into the Locktronics carrier to power the full system.
3. Select program 15 on the MIAC ECU.
4. Use a multimeter, on the 20V DC range, to measure the potentiometer output voltage.
5. Turn the potentiometer to change the output in regular one volt intervals. (It may not be possible to obtain all the values shown in the table.)
6. Record the corresponding fuel levels in table 5.1 in the Student Handout.
7. Note the value at which the 'low fuel' LED come on.
8. Comment on the difference between this and the previous program?

At this point, you are going to create a number of faults in the system.
The circuit and software are set up to detect these faults.

Fault 1: Short-circuit to 0V

9. Short-circuit the potentiometer output to 0V
10. What is shown on the MIAC display?

Fault 2: Short-circuit to positive supply

11. Remove the short-circuit.
12. Next, short-circuit the potentiometer output to the positive supply terminal. To do this, con-nect a wire from the output of the potentiometer to one of the V+ terminals. This simulates a fault where the sensor output is connected, by accident, to the positive supply voltage in the car.
13. Verify that the fault is recognised by the MIAC.
14. Measure the voltage on MIAC input I2 and record it.

Fault 3: Sensor output is open-circuit

15. Remove the short-circuit.
16. Disconnect the lead from the potentiometer to the MIAC.
17. Verify that the fault is recognised by the MIAC.

Fault 4: A faulty headlamp bulb

18. Connect a multimeter to measure the voltage across the 10Ω resistor.
19. Measure this voltage when the switch is pressed and the headlamp is lit.
20. Remove the bulb, to simulate a blown filament fault .
21. Close the switch and record the new voltage across the resistor:
22. Hence, describe how the MIAC ECU is able to detect this fault.

So What?

- With careful design of the system and software, it is possible to provide detailed information to the driver, and service centre, of the state of a system and its fitness for purpose.
- However, it is not always possible for an ECU to diagnose the exact fault - an open-circuit for a sensor at the ECU can give the same electrical symptoms as a short-circuit.

There are two main types of control systems in a car - **open-loop** and **closed-loop.**

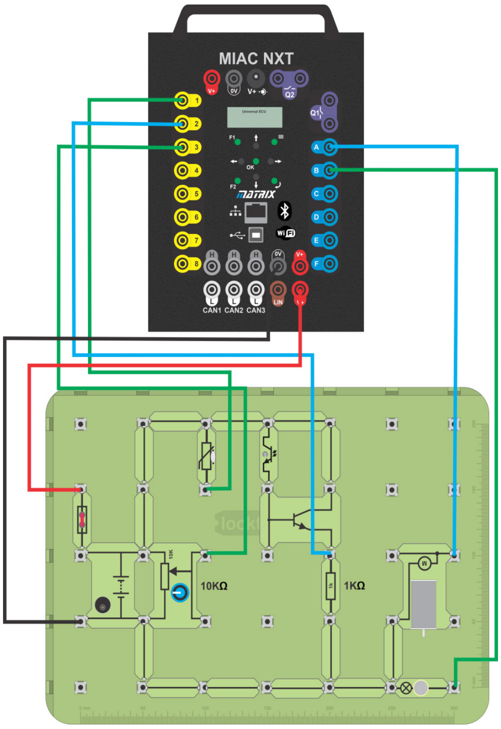
In a closed-loop system, the system output state is fed back to the input, so that the system can check when the desired outcome has been attained.

The photograph shows a rear view mirror.

The open-loop system on the mirror uses a light sensor to dim the mirror's reflection.

Over to you:

1. Build the system shown below.



It contains two output devices - a motor and a lamp and three analogue sensors:
A potentiometer, (rotation-dependent resistor);
A thermistor, (temperature-dependent resistor);
A phototransistor, (light-dependent resistor).

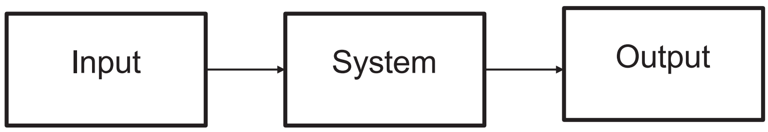
The motor represents the car fan heater motor. The temperature inside the car is set using the potentiometer, and is sensed by the thermistor. The bulb represents the headlamps. It switches on automatically when it gets dark, sensed by the phototransistor.

2. Plug the power supply (set to 12V) into the Locktronics carrier to power the full system.
3. Select program 16 on the MIAC ECU.
4. Cover the phototransistor with your finger. Make a note of what happens in the Student Handout.
5. Adjust the potentiometer so that the motor is only just running.
6. Use a multimeter to measure the voltage on the MIAC input connected to the thermistor. Warm the thermistor between your fingers to simulate the car interior getting hotter. What happens to the voltage at the MIAC input? What happens to the motor? Record your measurements and findings in the Student Handout.
7. What happens as the thermistor cools down? (simulating the car interior cooling.) Again, make a note in the Student Handout.

So What?

- The light sensor circuit is open-loop.

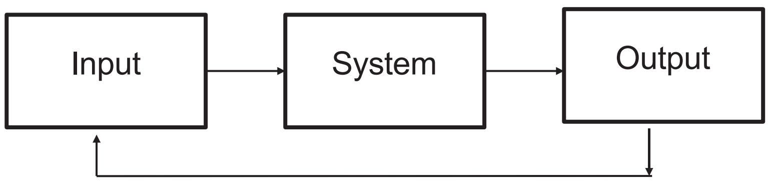
Open-loop control system



- The sensor detects that it is dark enough that the headlamps should be turned on. However, the system cannot verify that this happens, i.e. that the light has reached a given brightness.

- The thermistor circuit is closed-loop.

Closed-loop control system



- The fan heater warms the car up. A signal from the thermistor, indicating the current temperature, is fed back to the system and compared with the desired temperature, set by the potentiometer signal. Hence the system can know when the desired temperature has been reached.

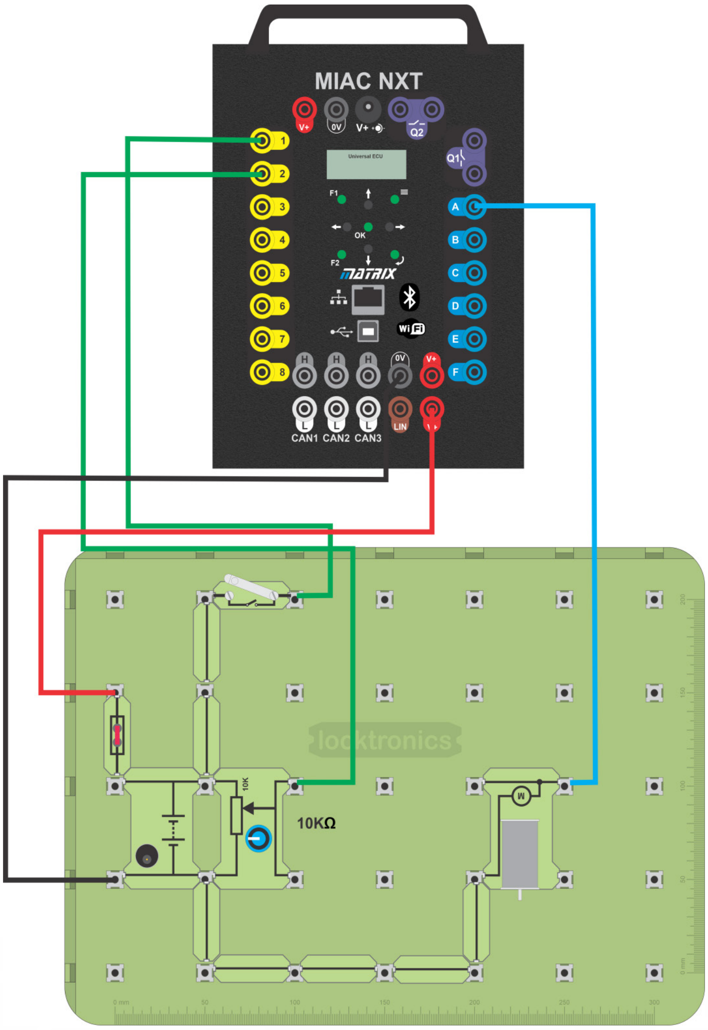
So far we have considered circuits that provide only one level of power to a motor- turning it fully on or fully off. However, in many situations, we want to vary the **power** supplied to it, in order to control the speed of a motor, for example, and this requires a new technique.

The two easiest ways of doing so are to vary the voltage, or vary the **duty cycle** of the motor supply.

The photograph shows a car seat motor with linkage.

Over to you:

1. Build the system shown below.



It contains a switch, a potentiometer and a motor.

The motor represents the windscreen wiper motor and the potentiometer controls the wiper speed.

2. Plug the power supply (set to 12V) into the Locktronics carrier, to power the full system.
3. Select program 17 on the MIAC ECU.
4. Close the switch to turn the wipers on. Check that the motor speed is controlled by the potentiometer.
5. For two settings of the potentiometer, one where the motor runs slowly and the other where it runs fast, monitor the MIAC output waveform on an oscilloscope. Sketch the waveforms on the templates provided in the Student Handout . Label each with significant voltages and times.

So What?

- Using the **first** form of speed control:
- When the MIAC output is a constant 0V, no power supplied to the motor;
- When the MIAC output is a constant 12V, maximum power is supplied to the motor.
- Using the second form of control, the motor speed is varied by pulsing the output to the motor.
- In the first oscilloscope trace, notice that the output is seldom on, so that the power transferred is small, and the resulting speed is low.
- In the second trace, notice that the output is on for most of the time and so the power supplied to the motor, and the resulting speed, is high.
- This technique of pulsing the output is known as Pulse Width Modulation (PWM.)
- The ratio of the time for which the pulse voltage is high to the time for which it is low is called the **’duty cycle’**.

Over to you:

If you have the ‘Sensors and Actuators’ pack then you can do Worksheets E9.

Worksheet 8 - Controlling Steppers Motors

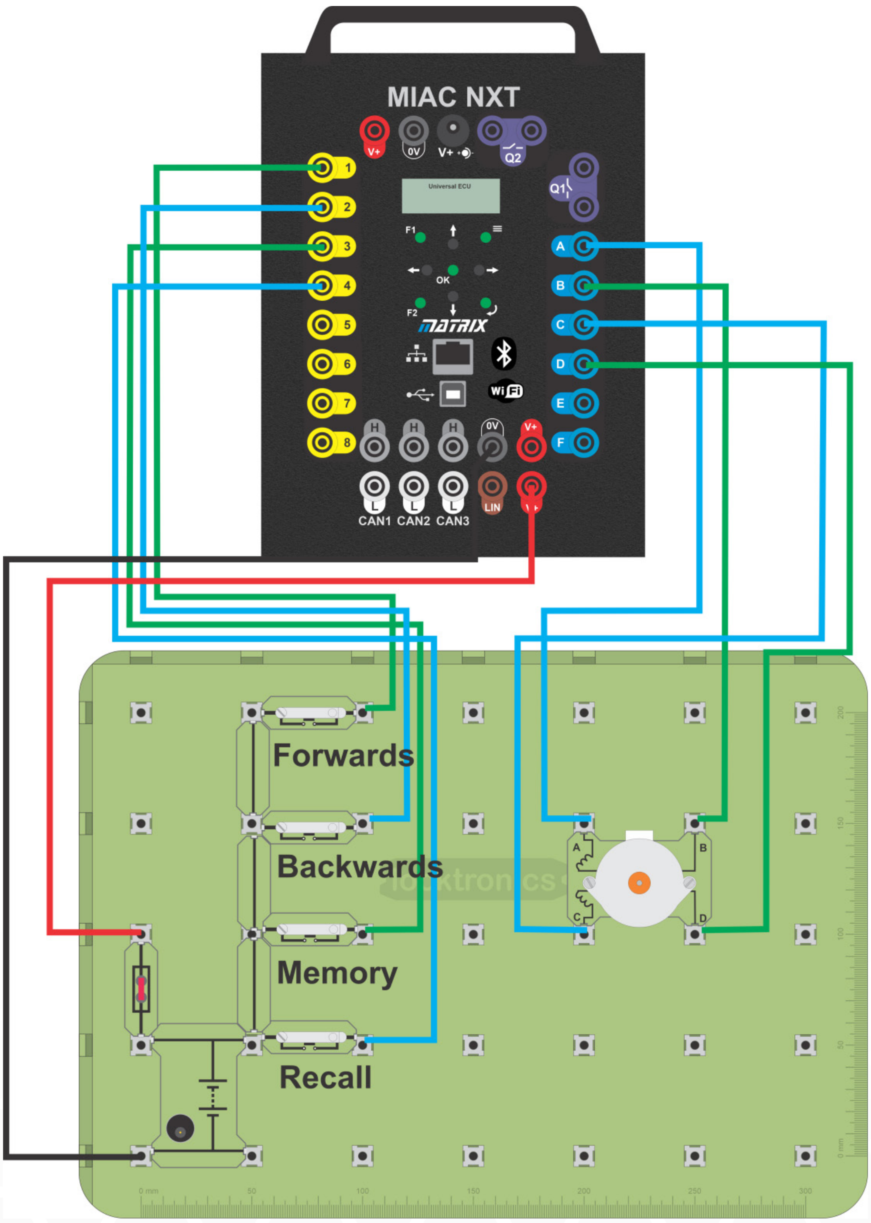
DC motors are cheap and reliable but are difficult to control when a measured, precise movement or rotation is required.

Stepper motors use four internal coils which allow the rotor to be moved in small steps - forwards or backwards. In our case the step size is 3.75 degrees per step.

The photograph shows an idle valve stepper motor.

Over to you:

1. Build the system shown below.



2. Plug the power supply (set to 12V) into the Locktronics carrier, to power the full system.

3. Press the reset switch on the MIAC and select program 18.

4. The four switches represent **forwards, backwards, memory and recall.** Check that they work correctly.

5. For eight steps of the motor going forward (clockwise), measure the voltages at the MIAC outputs, **A, B, C, D.**

6. Fill in the table in the Student Handout, using a '1' to represent the supply voltage and a '0' to represent 0V.

7. The direction in which a stepper motor moves is dictated by the sequence of voltages on its four coils. In completing the table, you observed the forward pattern. Confirm that when you reverse the motor, this pattern is simply reversed.

8. Change the connections to the stepper motor. Connect **A** on the MIAC to **B** on the stepper, and **B** on the MIAC to **A** on the stepper. What happens when you try to make the motor go forward or backwards? Make a note in the Student Handout.

So What?

- Stepper motors allow precise, predictable movement
- They need four wires rather than two.
- The outputs have to be driven in a particular sequence or the motor will not rotate.
- The connections to the motor have to be correct or the motor will not rotate.

EXTENSION WORK - USING REAL AUTOMOTIVE SENSORS

Worksheet E1 - Coolant Level Switch

In a coolant level switch, a magnet encased in a floating arm interacts with a reed relay in the main body of the sensor.

When there is sufficient coolant in the system, the arm touches the main body and the relay is closed.

When the level drops too far, the magnet falls and the relay becomes open circuit.

The photograph shows a typical coolant level switch.

Over to you:

1. Connect the coolant level switch to the MIAC as shown in the diagram.
2. Plug the 12V power supply into the MIAC.
3. Use the Up / Down arrows on the MIAC to select program 2.
4. What warning message does the MIAC display when the coolant level is low (switch is open)?
5. What is the voltage at the switch when there is low coolant? Record your answers in the Student Handout.

So What?

The MIAC ECU can be programmed to carry out a number of tasks.

In this case the program is told that input 1 is a coolant level switch and that it should display a message when the voltage at input 1 is 12V.

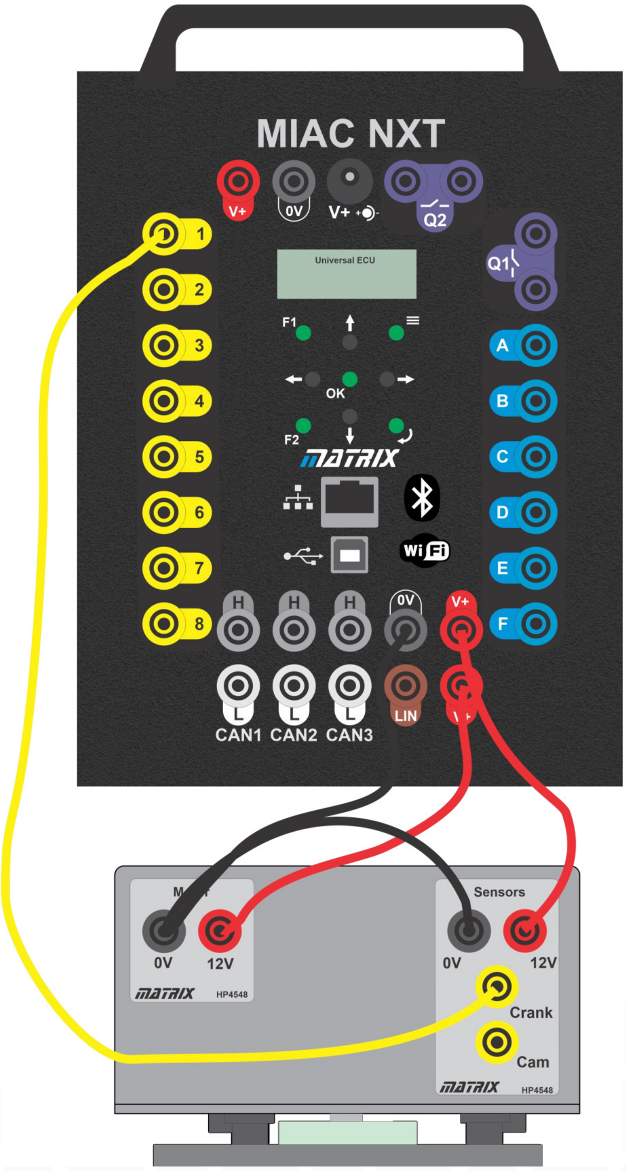
Cam and crank sensors are essentially the same device but probably contained in a different physical package.

They detect the presence of a metal object close to the sensor, such as the teeth of a cog.

A circuit inside these sensors uses the Hall effect or a property called magnetic reluctance to detect the proximity of metal. The photograph shows a Nissan camshaft sensor.

Over to you:

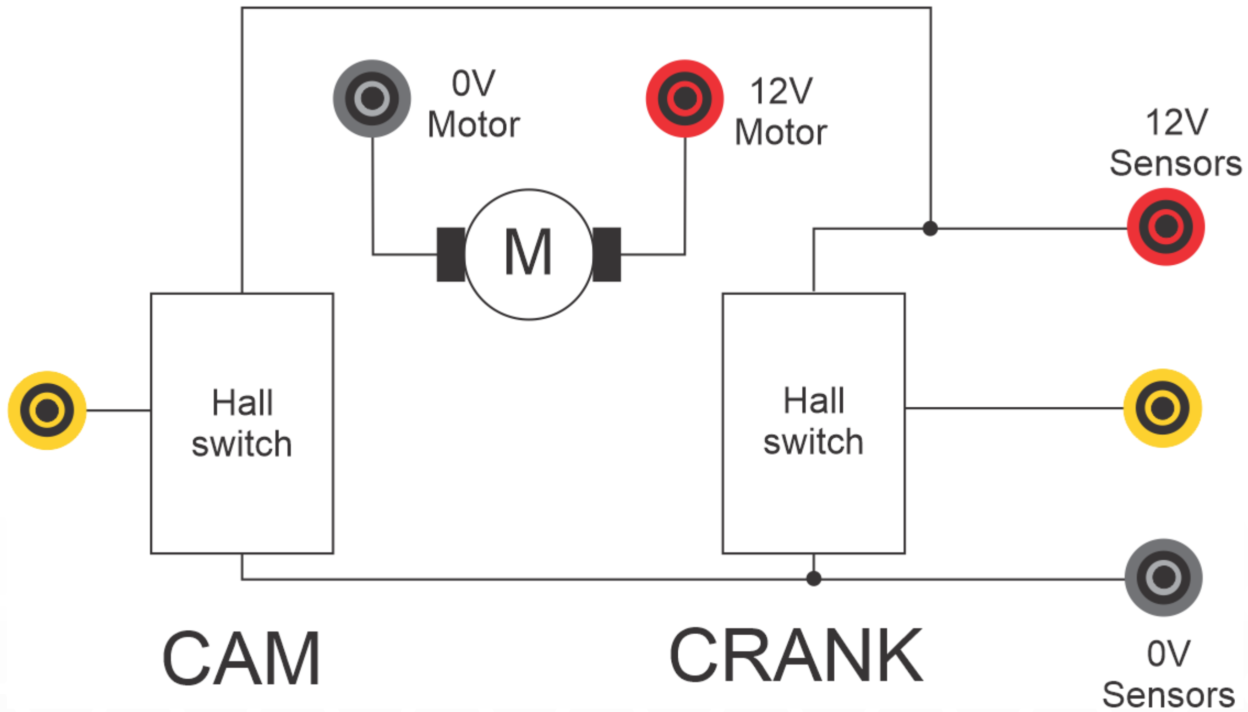
1. Connect the CAM crank motor and sensor to the MIAC as shown in the diagram. The cog on the unit should rotate at a fixed speed.



2. Plug the 12V power supply into the MIAC.
3. Use the Up / Down arrows on the MIAC to select program 3.
4. After a few seconds, the display shows you the frequency of rotation of the device.
5. Connect an oscilloscope to obtain traces of the cam sensor and crank sensor signals. Sketch them, using the templates provided in the Student Handout.
6. Look at the metal rotating disk. When does each sensor give out a high voltage and when a low voltage? Comment on this in the Student Handout.

So What?

1. The diagram shows the circuit of the CAM CRANK system. An electric motor makes the metal disk rotate.
2. The two sensors are identical but operate in different ways. The CAM shaft sensor switches on whenever a tooth of the cog passes by the sensor. There is a one tooth missing so that one of the positive pulses is longer than the others. This is how the vehicle detects the position of the cam shaft and sets the timing for other parts of the engine.
3. The CRANK sensor detects the presence and absence of the metal on the inside of the disk. The resulting waveform is very different.
4. The MIAC ECU measures the timings of the waveform and hence derives the speed of the engine.



Worksheet E3 - Lights Using Relays

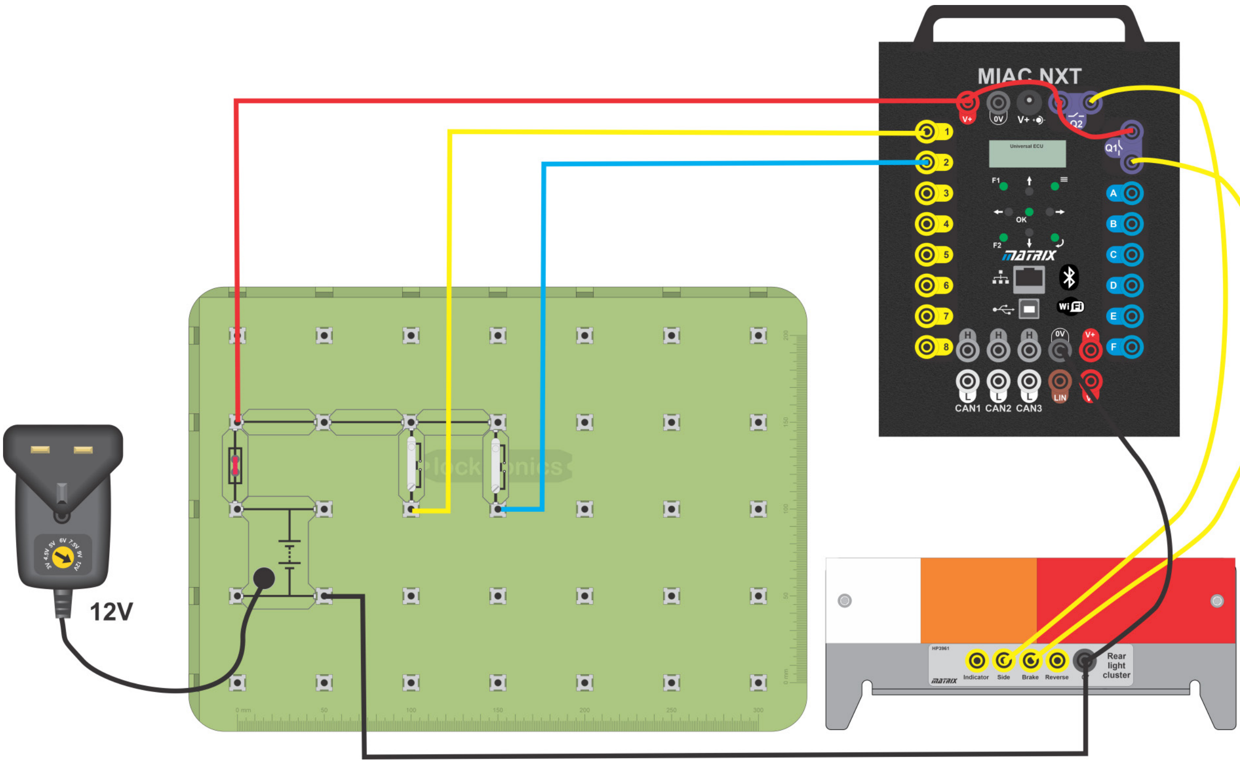
As modern transistor performance has improved, the use of relays for switching lights in ECUs is less common than in the past.

The big advantage of relays is that they can control larger currents.

The photograph shows a truck with headlights on.

Over to you:

1. Construct the circuit shown below and connect it to a 12V supply.
2. Select program 5 on the MIAC: 'High Current Outputs'.
3. Each switch should activate one part of the lighting cluster.



So What?

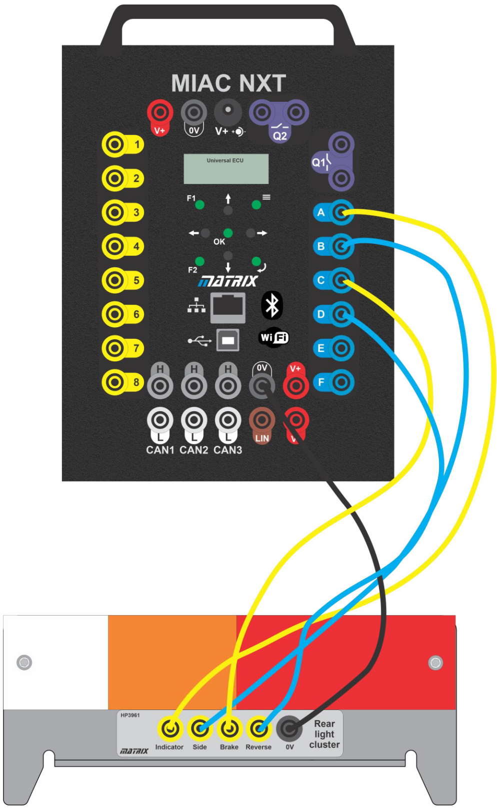
- Relay outputs are ideal for switching high currents, (though the currents needed by this modern LED light cluster are not that high.)
- Relays do not switch as fast as transistor outputs.

Older cars used relays to switch high current to the headlights. Modern cars now use transistor outputs in Electronic Control Units for this purpose. Whilst modern transistor outputs in ECUs can switch 20 amps and more, many cars now use low current LED lamps and indicators meaning that the current requirements are smaller.

Photograph shows modern headlight unit.

Over to you:

1. Construct the circuit shown opposite and connect it to a 12V supply.
2. Using the Up / Down keys on the MIAC, select program 7: 'Low current outputs'.
3. The four lights in the lighting cluster should come on alternately.



So What?

- Transistor outputs are ideal for switching relatively low currents.
- They are cheaper than relays and are electrically more reliable.
- For low current LED lights like these, transistors are fine. For high current headlights a relay might still be needed.

A modern air temperature sensor uses a semiconductor device whose resistance varies with temperature, connected in a voltage divider chain.

They are often integrated into a MAF (Mass Air Flow) sensor.

The photograph shows a typical air temperature sensor.

Over to you:

1. At room temperature, measure the resistance between the terminals of the air temperature sensor.
2. Connect the air temperature sensor to the MIAC as shown in the diagram opposite.
3. Plug the 12V power supply into the MIAC.
4. Select program 10 on the MIAC ECU.
5. Use a hair dryer to raise the air temperature and notice the effect on the display.
6. Remove the sensor from the circuit and quickly measure its resistance again.
7. Make a note of all your measurements in the Student Handout.

So What?

- If you know how the resistance of a sensor varies with the quantity it is sensing, you can design a system that measures that quantity.
- Using two resistors connected in a voltage divider chain, you can design a circuit in which the voltage at the input of a computer varies with the quantity you want to measure - in this case fuel level air temperature.
- On most automotive ECUs, thermistor-based sensors like this one would be wired between the ECU input and 0V. On the MIAC ECU, all inputs have internal pull-down resistors and so we wire the thermistor between the ECU input and 12V.

WORKSHEETS

Worksheet E6 - Throttle Position Sensor

All modern cars are 'drive by wire'.

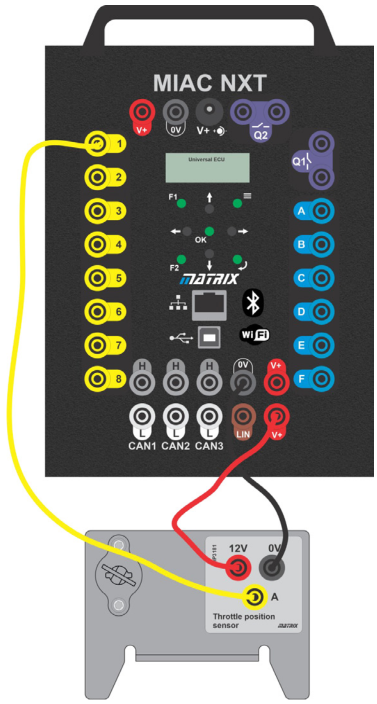
At one time, the fuel / air mixture entering the carburettor was controlled by a cable from the throttle pedal to the carburettor.

Modern cars have replaced this with a system using a potentiometer connected to the throttle pedal.

The photograph shows a typical throttle position sensor.

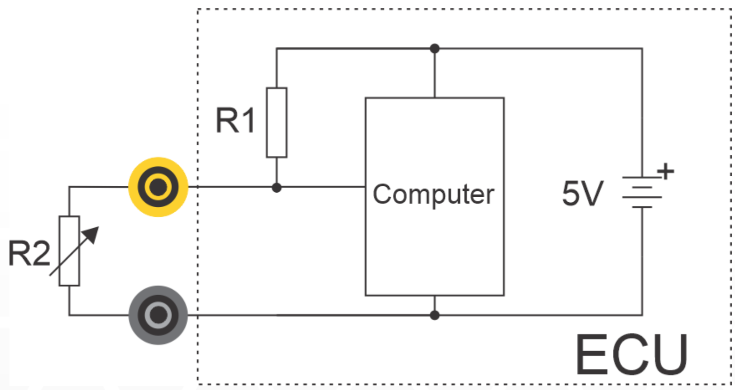
Over to you:

1. Connect the throttle position sensor wire to the MIAC as shown opposite.
2. Plug the 12V power supply into the MIAC.
3. Select program 11 on the MIAC ECU.
4. Use a key to alter the position of the sensor.
5. In the Student Handout, comment on the effect of this on the MIAC display.



So What?

- The throttle position sensor resistance varies between 1kΩ and 10kΩ.
- The internal 10kΩ resistor forms the upper half of the voltage divider chain for the throttle position detector circuit, shown as R1 in the diagram below.



Over to you:

For each of the following sensors wire up the sensor to the MIAC, change the quantities that the sensors are measuring and check that the sensor works.

For each sensor, devise a strategy to test that the sensor is working, and describe it in the Student Handout.

1. **Exhaust pressure sensor**

Simple analogue sensor:
- MIAC programme 12
- Connect to MIAC input 1

To test the sensor, use the pump and tube provided to increase the pressure on In 2.

2. **Coolant level sensor**

Simple analogue sensor
- MIAC programme 13
- Connect output A to MIAC input 1.
- Decide where to connect socket B, remembering that MIAC inputs incorporate pull-down resistors!

To test the coolant level sensor, dip the sensor prongs into a cup of water or use a wet towel between the electrodes.

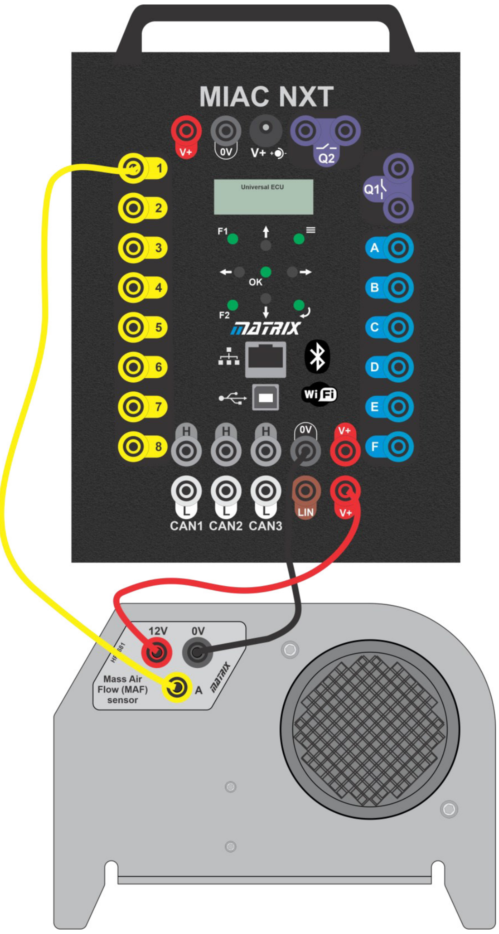
In modern cars, sensors are no longer simply analogue or digital. There are now a number of sensors which are more complex. The MAF (Mass Air Flow) sensor is a case in point.

The MAF sensor gives out a stream of pulses which indicate to the ECU the flow of air through the sensor and into the carburettor.

The photograph shows a typical MAF sensor.

Over to you:

1. Connect the MIAC ECU and MAF sensor as shown in the diagram
2. Plug the power supply into the MIAC.
3. Select program 14 on the MIAC ECU.
4. Use an oscilloscope to view the waveform coming from the MAF sensor.
5. Using the template in the Student Handout, sketch this waveform.
6. Record the initial airflow reading shown on the MIAC in the Student Handout.
7. Use a hairdryer to send a modest amount of air through the MAF sensor.
8. Record the new airflow reading.
9. Turn the hairdryer on to full power.
10. Record the new airflow reading.



Note that you will need quite a powerful hair dryer to make a change.

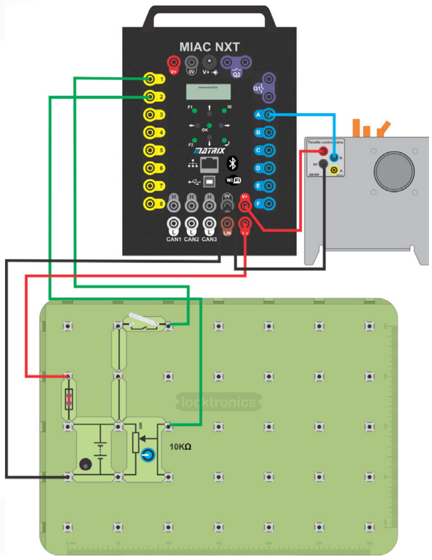
Worksheet E9 - Throttle Valve

In previous worksheets you saw how Pulse Width Modulation can control the speed of a DC motor, and you saw how using a stepper motor allows control of the position of a motor.

Electronic throttle valves allow control of a different type of mechanism - a kind of servo motor that uses a DC motor and PWM to drive a butterfly valve. The valve is connected to a spring. When the DC motor PWM falls to zero, the spring closes the valve.

The photograph shows an electronic throttle valve.

Over to you:



1. Modify the system built in worksheet 7 by replacing the motor with the electronic throttle valve.
2. Plug the power supply into the MIAC.
3. Select program 17 on the MIAC ECU.
4. Close the switch to turn the system on.
5. Check that the motor speed is controlled by the potentiometer.

So What?

- The electronic throttle valve is a kind of servo motor where increasing the PWM mark:space ratio determines the extent of the valve opening. It has a return spring so that when the PWM M:S ratio drops, the valve closes.

Over to you:

Replace the potentiometer with the throttle position sensor.

So What?

You now have a fully working throttle control system.

So What?

1. Some sensors are more complex than analogue or digital. Some include additional circuitry - or a small computer - that allow information to be conveyed in the form of pulses.
2. Debugging sensor operation with just a multimeter is not always possible.

WORKSHEETS

Worksheet E10 - Knock Sensor

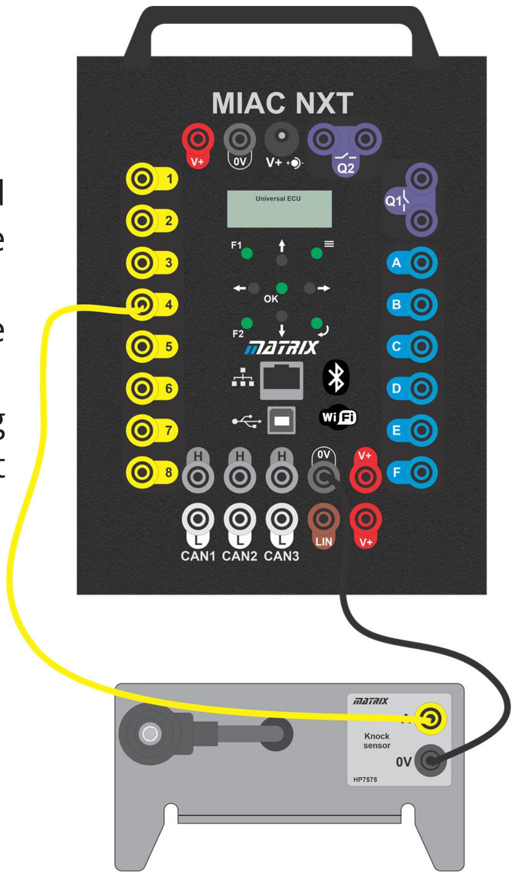
The knock sensor contains a small piezoelectric sensor (essentially a microphone) that detects high frequency vibrations.

It gives out a short pulse when the engine 'knocks'. This knocking is caused by an irregularity in combustion - often a result of bad timing of the ignition signals.

The photograph shows a typical knock sensor.

Over to you:

1. Build the system shown opposite.
2. Connect a 12V power supply to the MIAC.
3. Select program 19 on the MIAC ECU.
4. Tap the knock sensor with a hammer or hard object. The display should register a knock for five seconds.
5. In the Student Handout, note the message displayed on the MIAC.
6. Using an oscilloscope, monitor the incoming signal on input 4 of the MIAC. What factors affect the shape of the knock signal?



So What?

- The knock sensor is a simple sensor that detects short, large vibrations in the engine. Low frequency vibrations are filtered out.
- When the knock sensor is triggered, the engine management system adjusts the timing and power of the ignition signal.

WORKSHEETS

Worksheet E11 - Ultrasonic Parking Sensor

Ultrasonic parking sensors send out bursts of ultrasonic energy at regular intervals.

A nearby object will reflect some of this back to the sensor. The time interval between transmission and reception gives an indication of how close the object is to the sensor.

The ECU calculates this distance using the speed of sound.

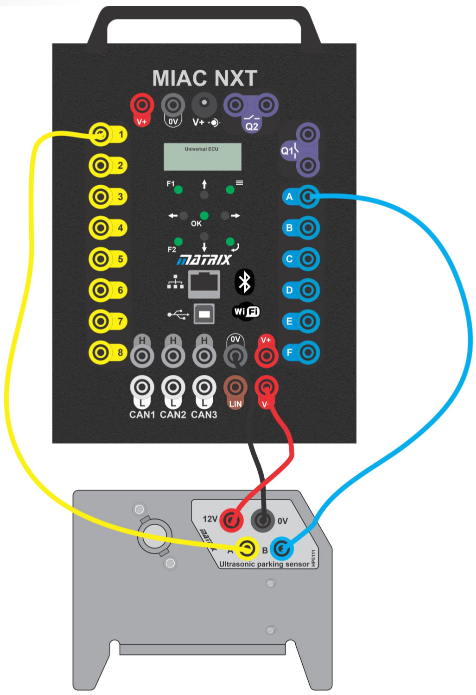
The photograph shows a ultrasonic parking sensor.

Over to you:

1. Build the system shown opposite.
2. Connect a 12V power supply to the MIAC.
3. Select program 20 on the MIAC ECU.
4. Point the sensor at various objects.
5. For an object at a known distance, use an oscilloscope to examine the pulses leaving terminal A and the reflection on B.
6. Check that the sensor is measuring distance correctly by using the formula:

   distance = speed * time

   where speed is 343m.s-1. (Note that the time is for the pulse to travel to and from the object in front of the sensor)



The parking sensor has a very wide field of view. You will need to make sure that the area around the sensor is clear.

So What?

- The ultrasonic parking sensor is a good example of an active sensor.
- The MIAC sends out an ultrasonic pulse and then times the interval for the reflected pulse and shows the time difference in microseconds.
- The time difference is proportional to the distance the sound has travelled.

STUDENT HANDOUT

Worksheet 1 - Simple digital sensors

Table 1.1

Switch	Voltage across bulb
Pressed	
Not Pressed	

Table 1.2

Component	State	Resistance
Push-to-make switch	Open (Off)	
	Closed (On)	
Slide switch	Open	
	Closed	
Microswitch	Open	
	Closed	

Voltage at input 1 = ________________________

Table 1.3

Input number	Signal voltage - switch closed	MIAC NXT message	Signal voltage - switch open	MIAC NXT message
1				
2				
3				
4				
....	Input current = ...			

Worksheet 2 - Using relays

Table 2.1 - external relay

Relay	Current in mA
Input, I1	
Output, I2	

Table 2.2 - MIAC relay

Relay	Current in mA
Input, I1	
Output, I2	

Worksheet 3 - Using transistors

Transistor behaviour

Table 3.1

Transistor	Current in mA
Input	
Output	

Hall sensor circuits:

In the first circuit, describe what happens when the magnet is placed near the sensor.

With the transistor added, what is the difference in the behaviour?

MIAC transistor control:

Table 3.2

MIAC	Current in mA
Input	
Output	

Compared with the stand-alone transistor (table 3.1), the advantage of the MIAC is:

Worksheet 4 - Analogue inputs

Table 4.1 - Fuel level potentiometer results:

Input voltage (V)	12	10	8	6
Fuel level (l)				

At what value does the 'low fuel' LED come on? ________________

Why is fuel slopping around in the fuel tank a problem?

____

When potentiometer short-circuited to 0V, fuel level reading = ________________

When potentiometer short-circuited to 12V, fuel level reading = ________________

Worksheet 5 - Fault detection with ECUs

Table 5.1

Input voltage (V)	12	11	10	9	8	7	6
Fuel level (l)							

At what value does the 'low fuel' LED come on? ________________

What is the difference between the performance of this and the previous program?

____

Fault 1: What is shown on the MIAC display? ________________

Fault 2: Voltage on MIAC input I2: ________________

Fault 3: How do you know that MIAC has recognised the fault?

____

Fault 4: Switch pressed and headlamp lit - voltage across the 10Ω resistor: ________

Switch pressed and headlamp not lit - voltage across the 10Ω resistor: ________

How do you know that MIAC has recognised the fault?

____

Worksheet 6 - Open-loop vs closed-loop

What happens when you cover the phototransistor with your finger?

____

Thermistor voltage when cold: ____________________

Thermistor voltage when warmed: ____________________

What is the effect of this warming on the motor?

____

What happens as the thermistor cools down?

____

Worksheet 7 - Controlling DC motors

Slow

Fast

Worksheet 8 - Controlling stepper motors

	A	B	C	D
Step 1				
Step 2				
Step 3				
Step 4				
Step 5				
Step 6				
Step 7				
Step 8				

When the connections between the stepper motor and MIAC are changed:

____

____

Worksheet E1 - Coolant level switch

When the coolant level is low:

- MIAC displays the message ____________________________
- The voltage at the switch is ____________________________

Worksheet E2 - Cam and crank sensors

Slow **Fast**

A sensor gives out 12V when: ____________________

A sensor gives out 0V when: ____________________

Worksheet E5 - Air temperature sensor

Resistance of air temperature sensor:

- At room temperature ____________________
- When warm ____________________

Worksheet E6 - Throttle position sensor

What is the effect of turning the position of the sensor?

____

Worksheet E7 - Exhaust pressure and coolant level sensor

Test strategy for exhaust pressure sensor:

Test strategy for coolant level sensor:

Worksheet E8 - MAF sensor

At rest

10ms / div

Low Power

10ms / div

High Power

10ms / div

How does the waveform change as more air flows through it?

____

____

Worksheet E10 Knock sensor

What message is displayed on the MIAC when it detects a ’knock’?

____

How does the waveform change as more air flows through it?

____

____

Worksheet E11 Ultrasonic parking sensor

For the chosen object:

Time between pulses = ______________________ s

Using velocity of sound = $343 m.s^{-1}$

distance between sensor and object ______________ m

SENSE CONTROL

CP7241

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