locktronics™

Simplifying Electricity

## Automotive ECU Architecture and Logic

Contents

Worksheet 1

Analogue vs digital

We hear more and more about the 'd' and the 'e' words: **d**igital television, **d**ab, **d**vd, **d**igital cameras ... **e**-cards, **e**-commerce, **e**-books, **e**-skills, **e**-learning ... Why is that? Whatever happened to the 'a' word - **a**nalogue?

This worksheet looks at the differences between analogue and digital signals.

The photograph shows a modern car dashboard.
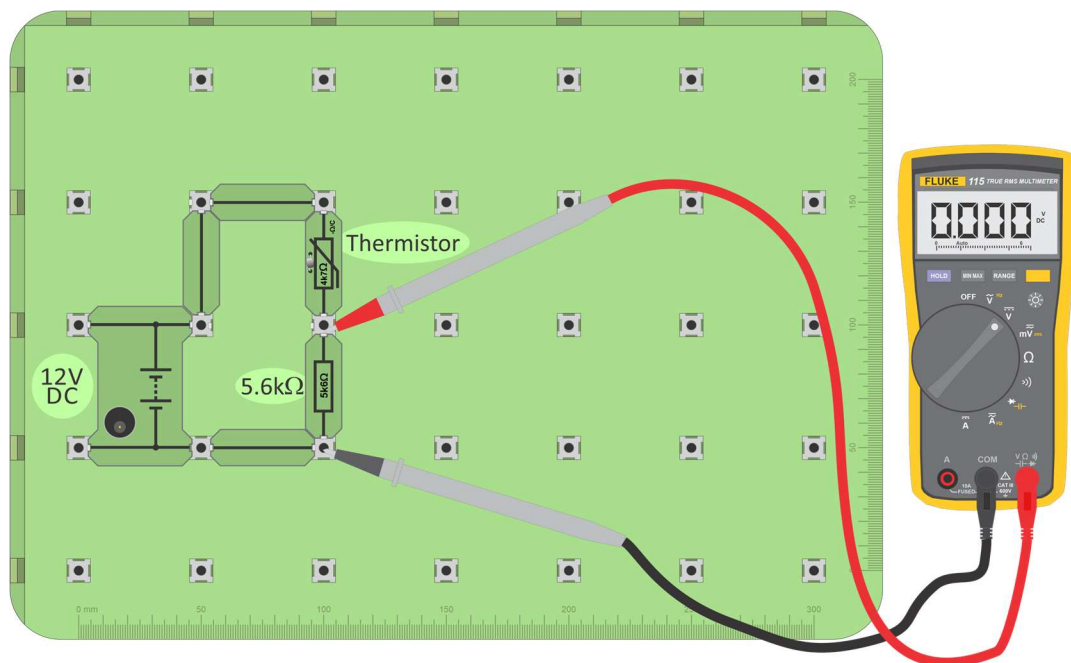
Over to you:

- Set up this circuit with a multimeter on the voltmeter setting to measure DC voltage across the 5k6 resistor.
- Set the power supply voltage to 12V and switch on.
- Warm the thermistor between your thumb and finger.
- What happens to the output voltage? Write your answer in the Student Handout.

So what?

This is a temperature-sensing unit made from a thermistor (temperature-dependent resistor,) in series with a 5.6kΩ resistor. It generates an **analogue** signal, indicated on the voltmeter.

Worksheet 1

Analogue vs digital
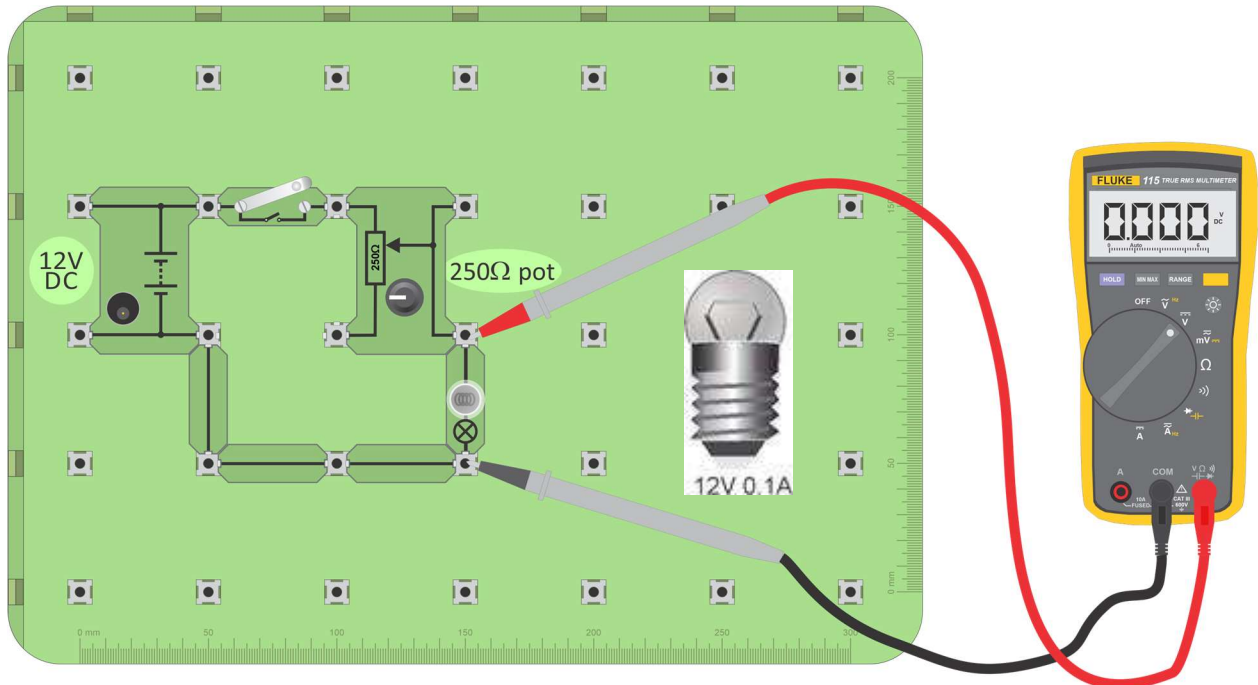
The previous circuit used a **fixed** 1kΩ resistor.

A potentiometer (usually shortened to 'pot') is widely used as a **variable** resistor in sensors, such as light-sensing and temperature-sensing units.

Pots can also be used to create a variable voltage supply.

Over to you:

- Build the circuit shown in the layout above.
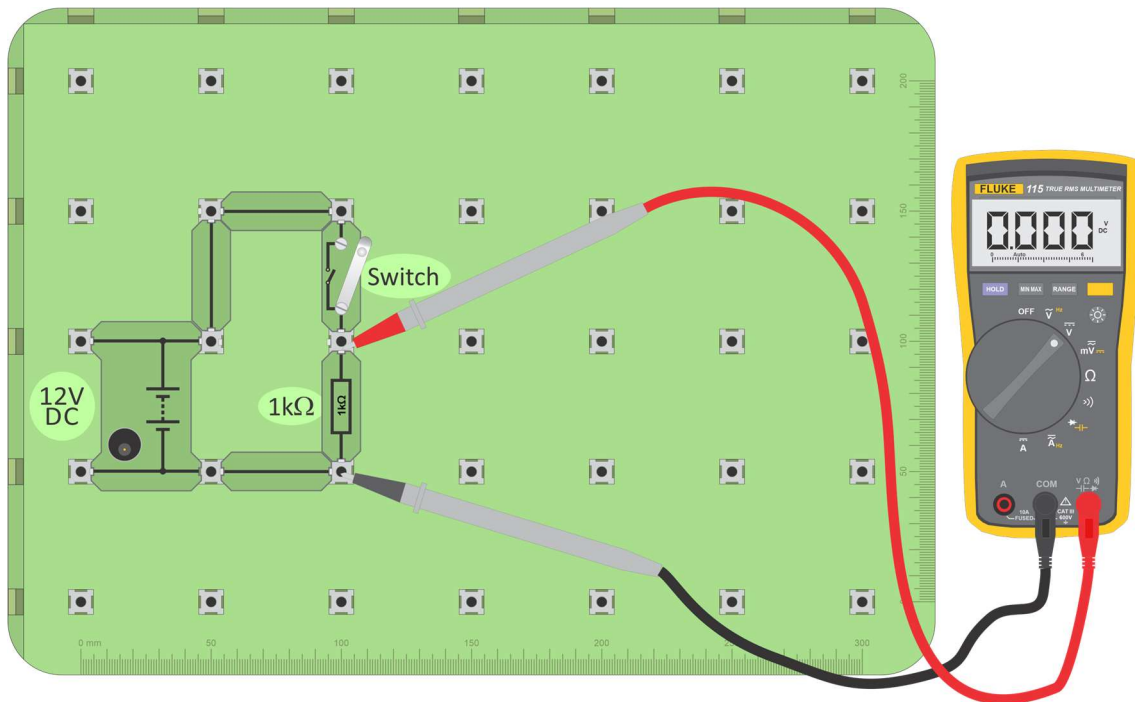- Switch on the power supply, set to 12V.
- Close the switch and slowly turn the knob on the pot.
- Notice the effect on the brightness of the lamp and on the voltmeter reading.
- Record your observations in the Student Handout.

So what?

Used like this, the pot also generates an analogue signal.

Worksheet 1

Analogue vs digital

The next circuit generates a **digital** signal, using a switch, connected as a switch unit.

Over to you:

- Build the circuit shown in the layout above.
- Switch on the power supply, set to 12V.
- Measure the output voltage when the switch is open (off) and again when it is closed (on.)
- Next, invert the switch unit i.e. swap over the switch and the resistor.
- Measure the output voltages again, when the switch is closed and open.
- Record your observations in the Student Handout.

So what?

- An analogue sensing unit gives an analogy - a copy of the behaviour it is sensing. With the temperature-sensing unit, as temperature rises, the output voltage rises.
- The output mimics the temperature. We can change temperature by very small amounts and then the output voltage changes by very small amounts.
- A digital sensor, on the other hand, is a two-state affair. A switch is either on or off - just two possible states. Hence, the output voltage has one of only two possible values.

Worksheet 1

Analogue vs digital

The left-hand graph, below, shows an analogue signal. It changes continuously as the temperature changes.

The right-hand graph shows the digital signal produced by the switch unit. The state of the switch does not change *smoothly* from off to on. It can't be slightly on, then a bit more on, and so forth. It is on or it is off. The 'time' axis shows when the change occurs. The output voltage has only two values.
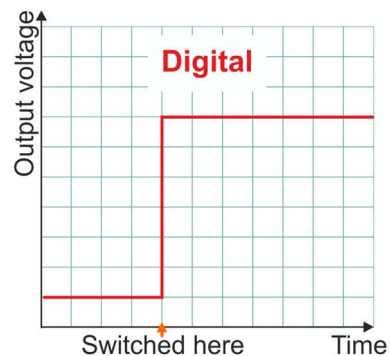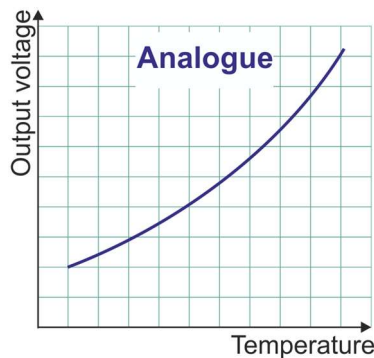
In the vocabulary of digital electronics, these two voltages are called 'logic 0' and 'logic 1'. Somewhere in the design, these are defined, usually as voltage ranges. For example, logic 0 may be specified as any voltage between 0V and 1.0V and logic 1 between 10.0V and 12.0V. Using a range recognises that signals can change a little as they move through the electronic system.

A major advantage of digital signals is that we, and electronic systems themselves, can make a pretty good guess at what the signal should be if, for some reason, it arrives with a voltage between the defined ranges, say 8.7V. We'd guess that it was really logic 1.

This ability to recreate the original signal is called regeneration, and is one of the major benefits of digital signals. Analogue signals do not allow us to do this.

Worksheet 2

Driving output devices

The vehicle's electronic control system should operate its output devices *appropriately*. This includes lights, visual displays, audio systems, engine management components, security and safety systems and climate control devices.

Actuators are devices that move electronically - opening or closing a valve, locking or unlocking a door, wiping a wet windscreen, driving a fan, etc. The photograph shows some automotive actuators.

The control system must deliver and control enough current to allow the output device to operate correctly. Usually this means transforming low current signals, from a switch or a sensor, into high current signals to operate the device.

This worksheet looks at two types of subsystem that can do this, **relays** and **transistors**.

1. The relay:

A relay is an electromechanical switch.

A small current in the control circuit, manages a larger current in the controlled circuit.
The diagram on the right shows a relay used to control a motor.
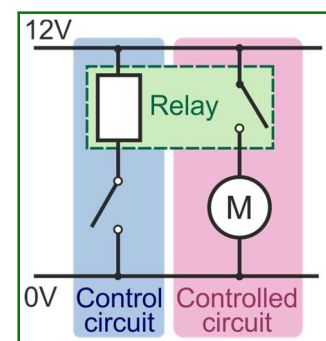
The next diagram illustrates how the relay works.

When the switch is closed, the current flowing in the coil creates a magnetic field which pulls the armature towards the core inside the coil.

As it does so, it pivots and pushes the switch contacts together, closing the switch and turning on the device connected in the controlled circuit.
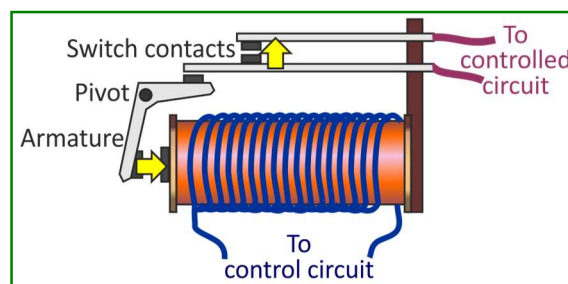
Worksheet 2

Driving output devices

Over to you:

The aim of this investigation is to measure and compare the currents flowing in the control circuit and the controlled circuit.

- Build the circuit shown in the layout.
- Make sure that the power supply is set to 12V and then switch it on.
- Energise the relay by closing the switch in the control circuit. The motor should start to spin.
- Measure the current in the control circuit, i.e. through the connector coloured yellow, either by removing the connector and replacing it with an ammeter or by using a current clamp meter.
- Then measure the current in the controlled circuit, through the connector coloured blue, again using either an ammeter or a current clamp meter.
- Record the values in the Student Handout and answer the question.
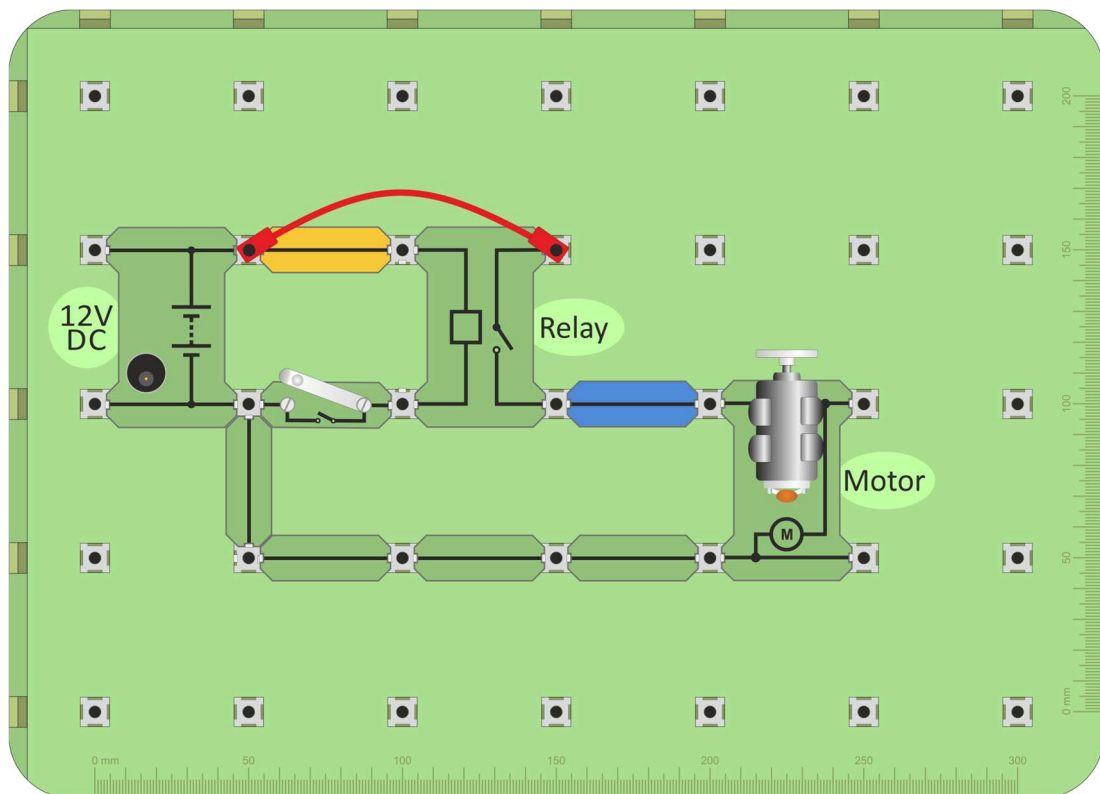
Driving output devices

2. The transistor:
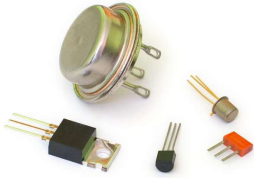
The transistor is the building block of modern electronics.

The picture shows that they come in a variety of forms.

The basic property of a transistor is that it amplifies current - exactly what we want for driving output devices.

The next circuit demonstrates this property.
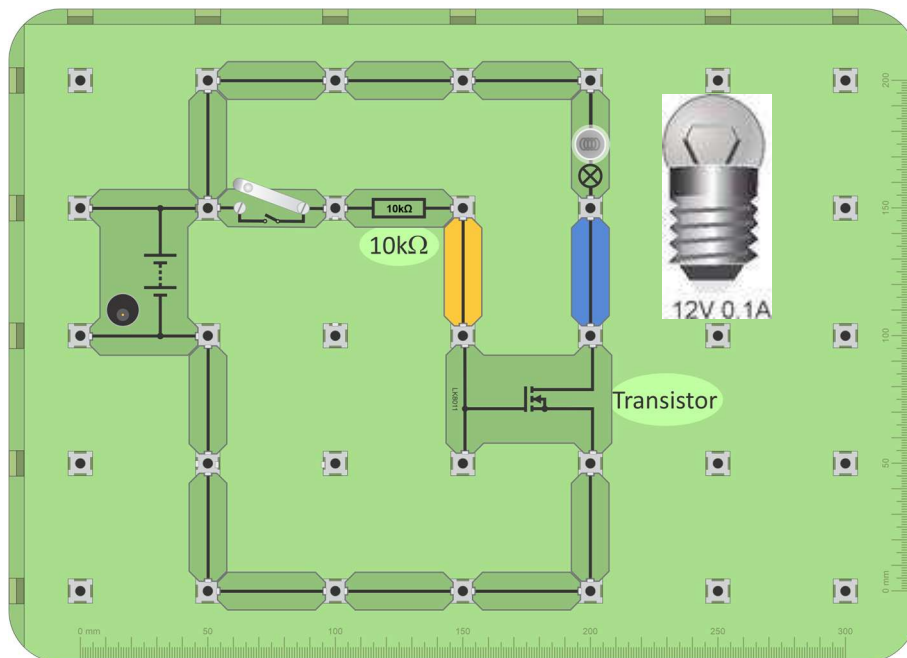
Over to you:

- Build the circuit shown in the layout.
- Make sure that the power supply is set to 12V and then switch on.
- Check that when you close the switch the lamp lights.
- Measure the current in the transistor input circuit, (i.e. through the yellow connector) either by removing it and replacing it with an ammeter or by using a current clamp.
- Then measure the current in the output circuit, (i.e. through the blue connector,) in the same way.
- Record the values in the Student Handout and answer the question.

So what?

First of all, why bother with either a relay or a transistor?

- A computer chip alone may not deliver enough current to operate the device in question.
- High currents require thick copper cables. Using relays or transistors can save on heavy, expensive copper wire.

Relative advantages of the relay over the transistor:

- Relays can deliver higher currents, many tens of amps whereas the transistor is limited to only a few amps.
- Relays can switch either AC or DC currents. The transistor can switch only DC.
- Relays can have more than one set of contacts and so can switch several devices at the same time.
- Relays can isolate the switched device from the switching circuit.

Relative advantages of the transistor over the relay:

- Transistors operate at a much higher speed. A relay takes several milliseconds to switch from off to on. A transistor operates a million times faster.
- Transistors can last longer. They have no moving parts. The relay contacts experience friction and so wear out after a number of switching cycles.
- The control coil in the relay takes a relatively high current and so wastes more energy.
- Transistors are physically smaller and cheaper.

Worksheet 3

ECU structure

Within a modern vehicle, much of the electronics and control logic are hidden away inside an ECU (Electronic Control Unit).

These are usually housed in a cast aluminium case, with rugged connectors, providing water-proof, environment-proof and vibration-proof protection for the electronics.

ECUs may vary in their structure, but they contain much the same types of circuit subsystems.

The photograph shows a Golf ECU.
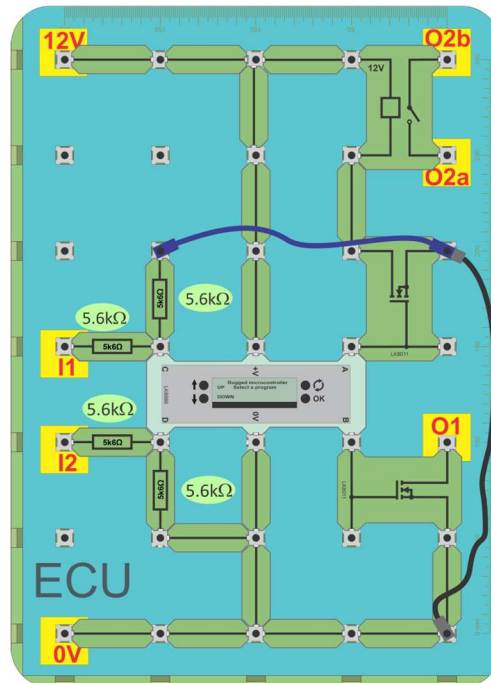
Over to you:

- Build the circuit shown in the diagram above. This is an Electronic Control Unit which you will use in the remaining worksheets. It is coloured blue so that it stands out from the rest of the circuit. First let's investigate it.
- Disconnect the ECU from the power supply.
- Use an ohmmeter to measure the resistance between:
    - point I1 and 0V;
    - point I2 and 0V;
    - the relay terminals O2a and O2b;
    - O1 and 0V.
- Record the values in the Student Handout.

Worksheet 3

ECU structure

So what?

- The heart of the ECU is a small low-power computer chip. Its inputs are at very high input resistance and so the input resistance is dictated by the circuitry around them. In this case it is around 10kΩ, made up of the two 5.6kΩ resistors connected in series.

- The resistance of a relay in the off state is always infinite.

- The resistance across a transistor that is 'off' should be very high.

- To fault-find an ECU when the power is off, you must know the details of the circuit.
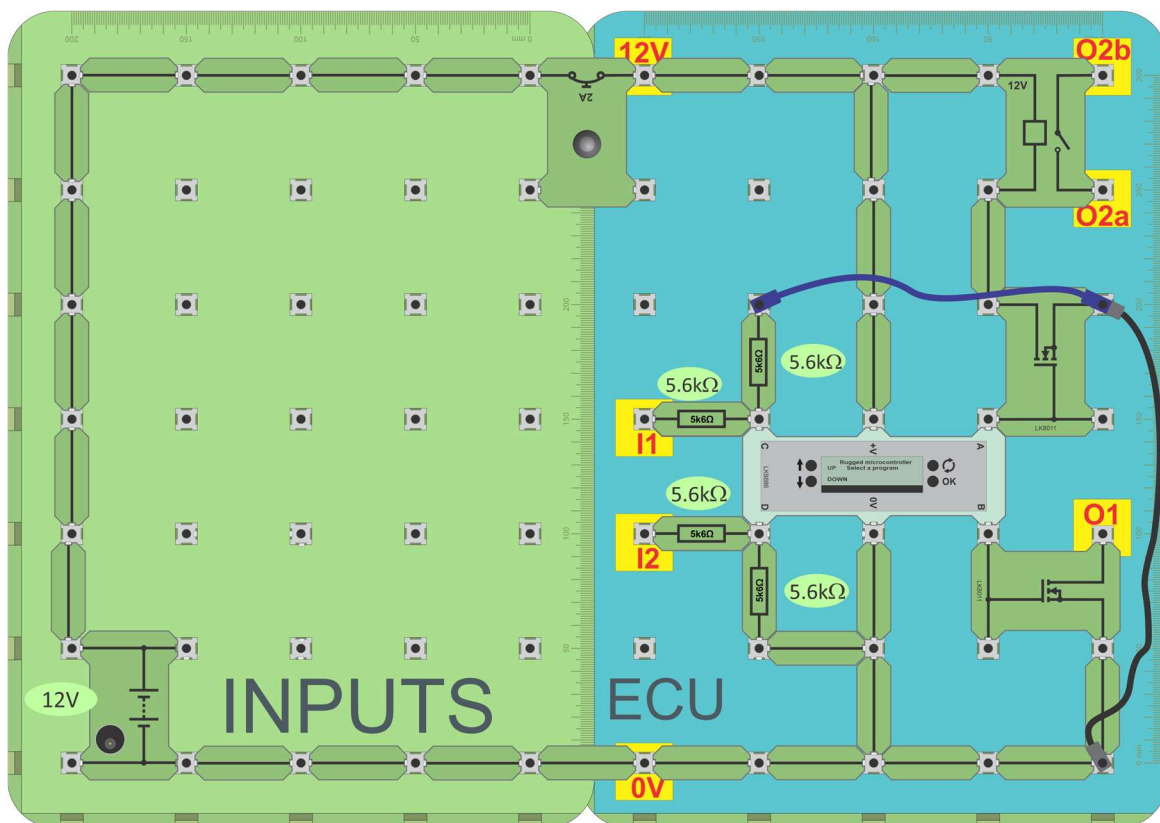
Over to you:

- Add a second base board to provide power through a circuit breaker, as shown above.

- Power up the ECU with a 12V supply.

- In this configuration, the inputs I1 and I2 are 'pulled-down' to 0V through 5.6kΩ resistors.

- Use a voltmeter to measure the voltage between I1 and 0V and I2 and 0V.

- Record the values in the Student Handout.

ECU structure

So what?

The voltage at an ECU input when disconnected depends on its internal circuit. That circuit is determined by the vehicle and ECU designer. It is not the same for all ECUs and not the same, even, for all the inputs of any one ECU.
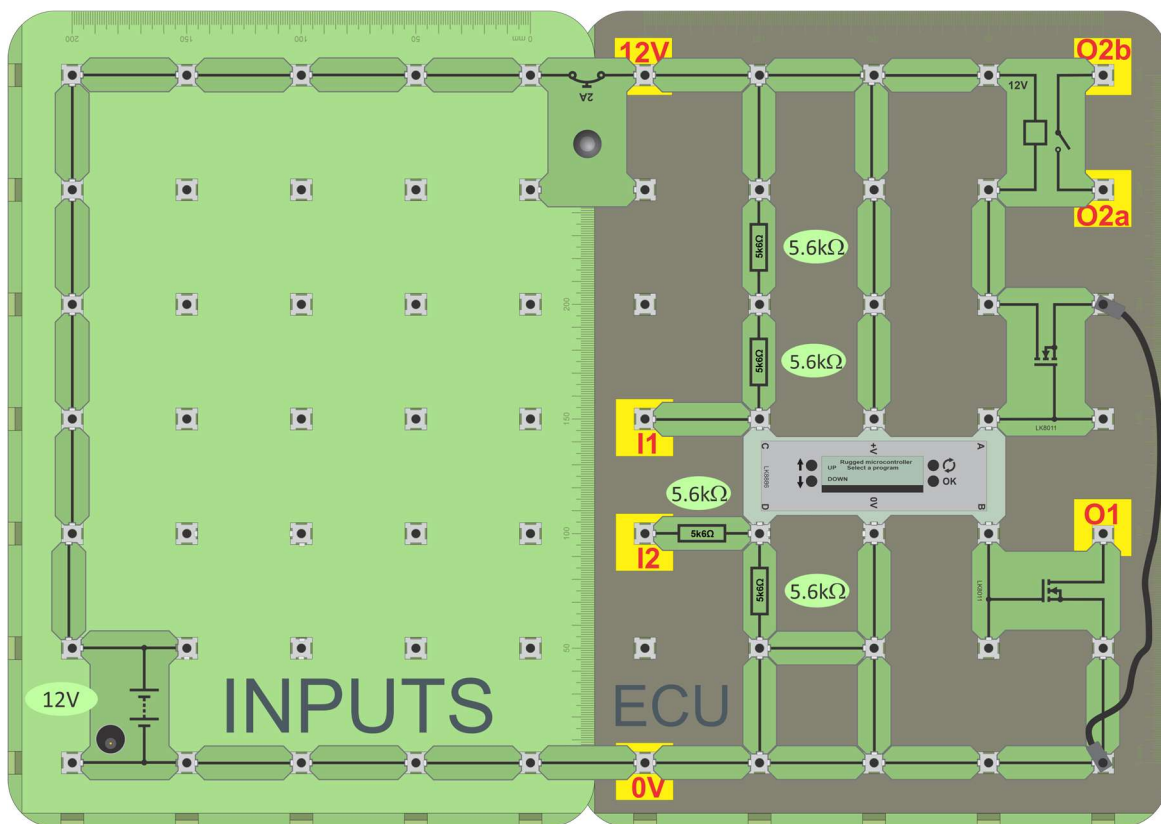
Over to you:

- Alter the layout slightly as shown in the diagram above. This reconfigures the I1 input to 'pull up' the input, using a second 5.6kΩ resistor, rather than to 'pull down' the input.
- Power the ECU up with 12V supply.
- Use a voltmeter to measure the voltage between I1 and 0V and I2 and 0V again.
- Record the values in the Student Handout.

So what?

- The two circuits below illustrate the difference between the use of pull-up and pull-down resistors on the inputs.
- To debug ECU-based circuits, you need to know something about their default voltage or about the circuit on the inside of the ECU.
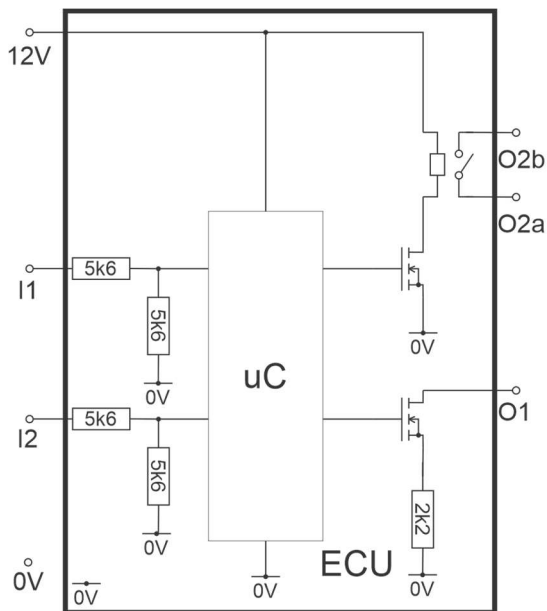
I1 pull down
I2 pull down
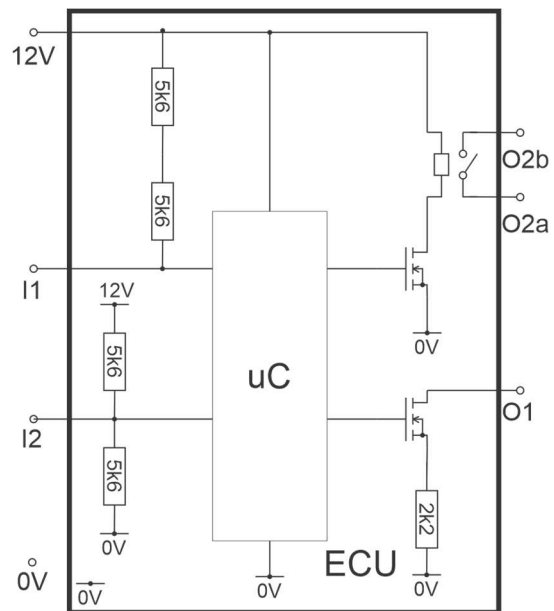
I1 pull up
I2 pull down

Worksheet 4

The NOT function

The ECU is a small computer. It looks at inputs, makes decisions based on them and the logic programmed inside it and adjusts the outputs accordingly.

If you understand logic then you understand a little of how computers 'think'.

There are several logic functions. This worksheet looks at the simplest, the **NOT** function.

The photograph shows an ECU microcontroller chip.
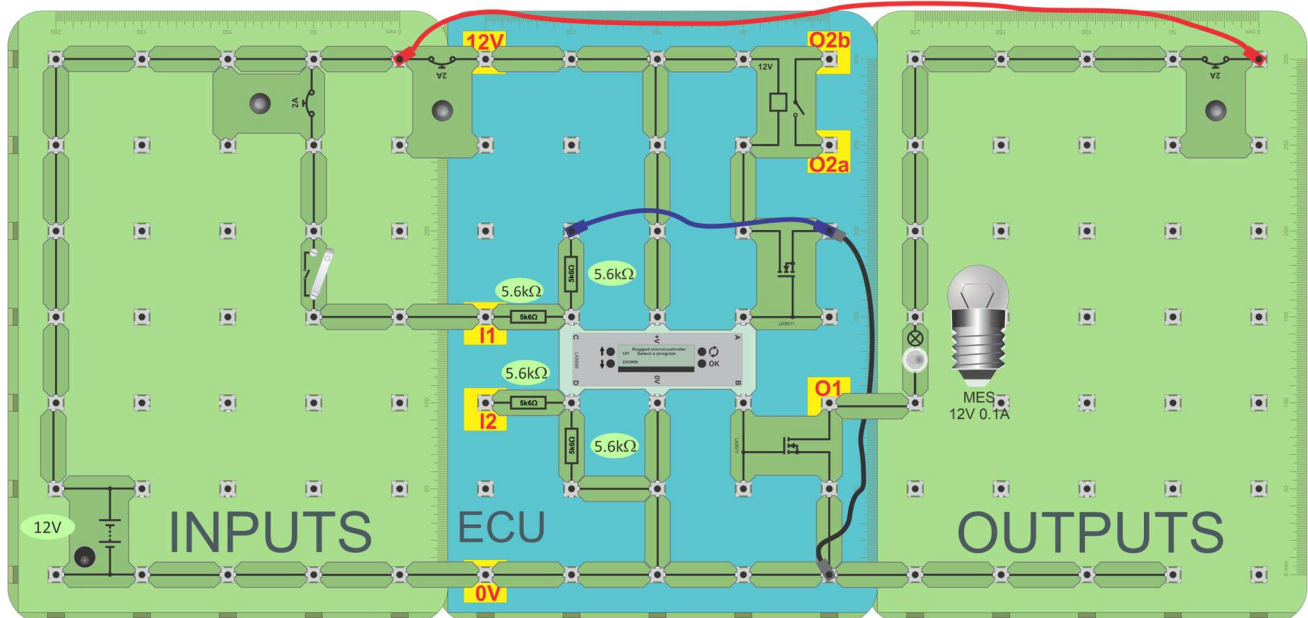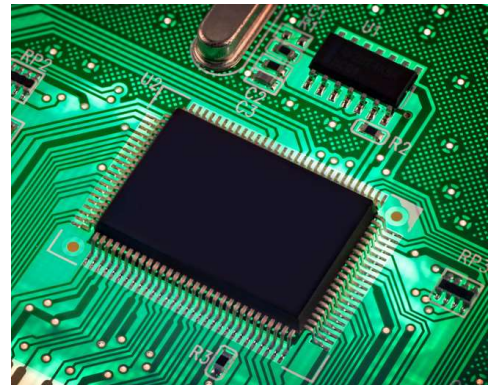
Program	Name	Input terminal(s)	Output terminal(s)
1	Logic NOT	C	B

Over to you:

- Set up the circuit shown in the layout.
- Locate program 1, 'Logic NOT'. Press the 'OK' button to run this program.
- With the switch open, measure the voltages at input I1 and output O1.
- Close the switch and measure the voltages again.
- Complete the table in the Student Handout with your observations.

So what?

- The program looks at the signal at ECU terminal '**C**' and outputs 'NOT C' to terminal '**B**'.
- In this system 'logic 1' is represented by a 12V signal and 'logic 0' by a 0V signal.
- We often refer to 'logic 1' as 'HIGH', and 'Logic 0' as 'LOW'. Here, 'switch open' results in a HIGH output. 'Switch closed' results in a LOW output.
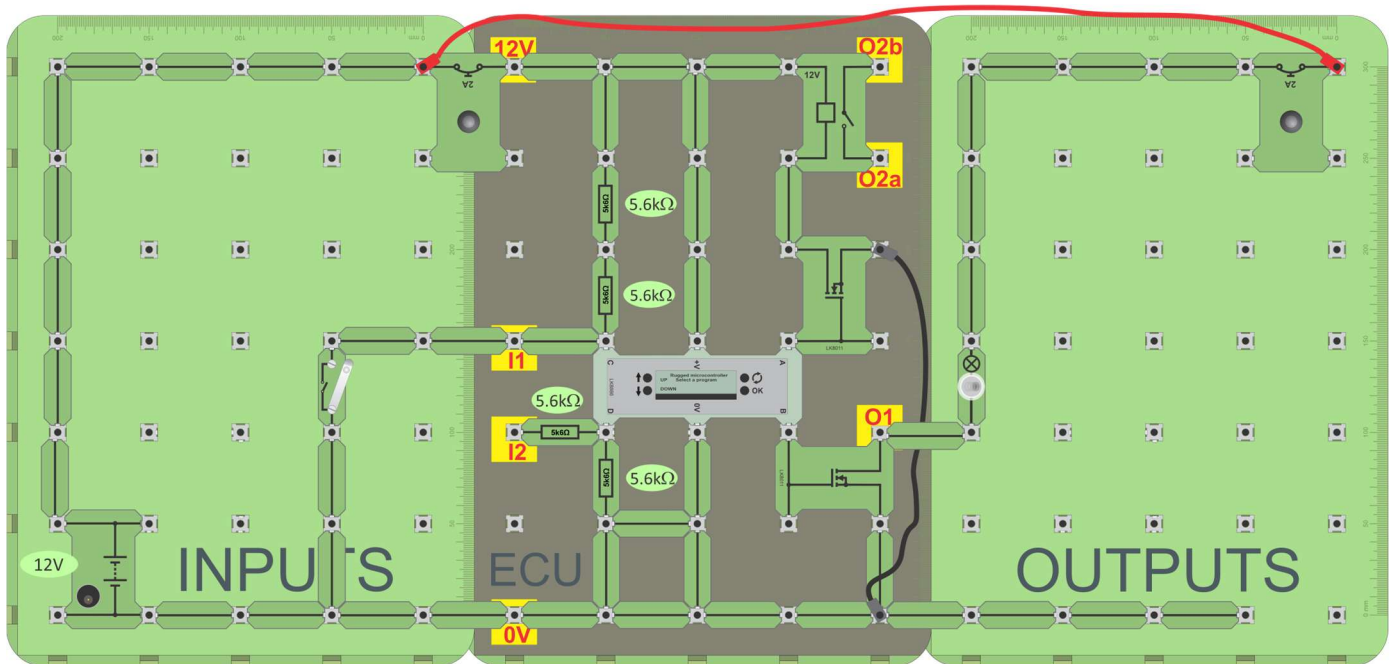
Over to you:

- Build the layout shown above. It uses the same input and output circuits as before but the ECU is modified to pull up the input at terminal **C**.

- Repeat the previous exercise:

    - locate program 1, 'Logic NOT'.

    - press the OK button to run the program.

    - with the switch open, measure the voltages at input I1 and output O1.

    - close the switch and measure the voltages again.

- Complete the table in the Student Handout with your observations.

So what?

- The program is the same as before.

- This time, however, 'switch open' results in a LOW output. 'Switch closed' results in a HIGH output. The logic is reversed.

- For a computer, whether a HIGH or LOW is produced on a given action is not important as the program can be adjusted accordingly.

- To debug ECU circuits you need to understand something about the design of the ECU itself and whether inputs are pulled up or pulled down.

Worksheet 5

The AND function

Often, devices in a vehicle, e.g. the headlights, operate only when the headlight switch AND the ignition switch are both turned on. Hence, the need for the AND function.

In this worksheet, the ECU generates the AND function on output A and the NAND function on output B.
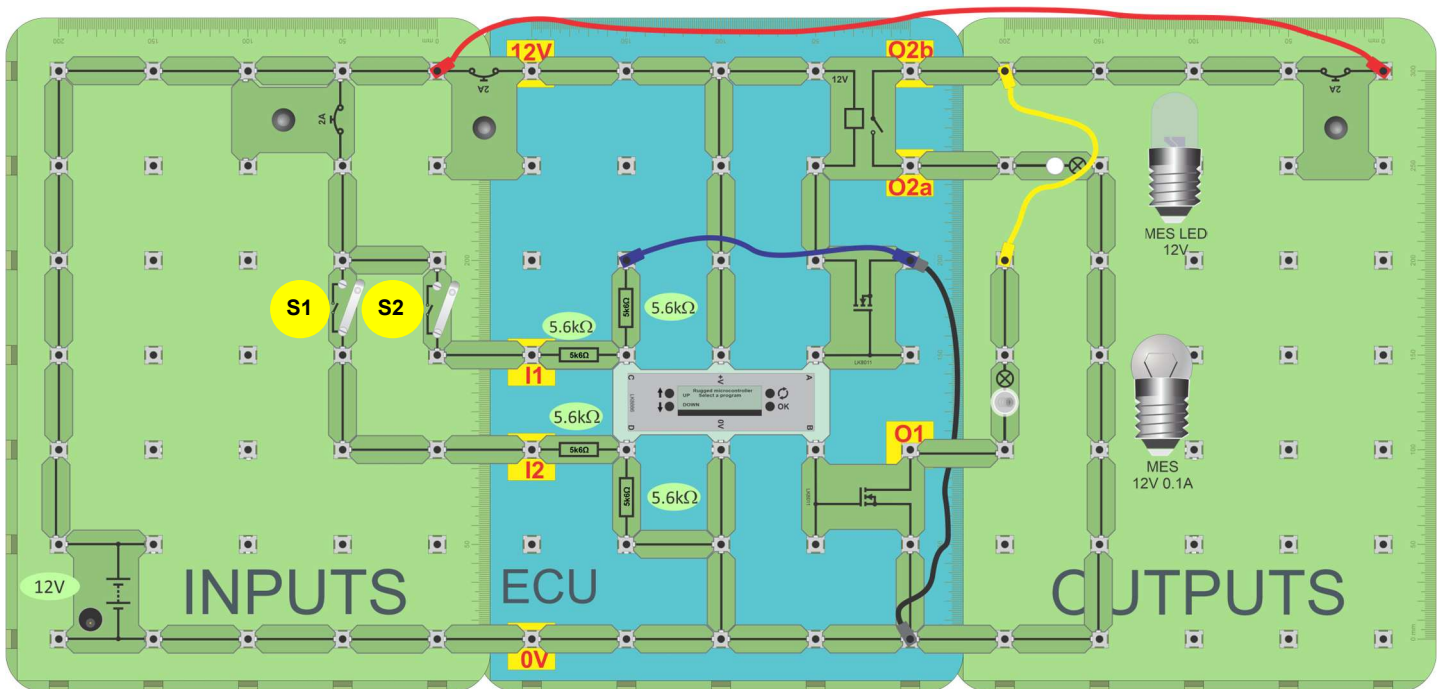
Program	Name	Input terminal(s)	Output terminal(s)
2	Logic AND	C D	A(NAND) B (AND)

Over to you:

- Set up the circuit shown in the layout.
- Make sure that the power supply is set to 12V and then switch it on.
- Find program 2, 'Logic AND' and press the 'OK' button.
- Two switch units, **S1** and **S2**, provide input signals to **C** and **D**.
  There are only four combinations possible - both switches open, **S1** open and **S2** closed, the reverse - **S1** closed and **S2** open and both closed.
- For each of these, measure the voltages at terminals **A**, **B**, **C** and **D** on the MicroECU.
- Record your observations in the Student Handout.

Worksheet 5

The AND function

So what?

- The program uses terminals **C** and **D** as inputs and terminals **A** and **B** as outputs.

- Two switch units provide four possible combinations of input signals to **C** and **D**.

- When a switch is open, the switch unit produces a LOW signal (logic 0). When the switch is closed, the switch unit produces a HIGH signal (logic 1).

- The incandescent lamp shows the state of the signal at output **B** . The lamp is on only when both **C** AND **D** are HIGH.

- The LED lamp shows the state of the signal at output **A** . This is on when the signals at either **C** or **D** or both are LOW. This is referred to as a 'NAND' function i.e. *Not AND*.

- An ECU is constantly making logical decisions. For example, an automatic car will start only when the start button is pressed AND the driver's foot is on the brake pedal.   Note that the signals produced in the ECU by 'start button pressed' and 'brake pedal pressed' could be high or low depending on the system design.

Worksheet 6

The OR function

In the same way as circuits need to make a decision when voltage A AND voltage B are present, sometimes logic circuits need to make a decision when voltage A OR voltage B are present.

This worksheet shows how the **OR** function is realised with the Matrix ECU.
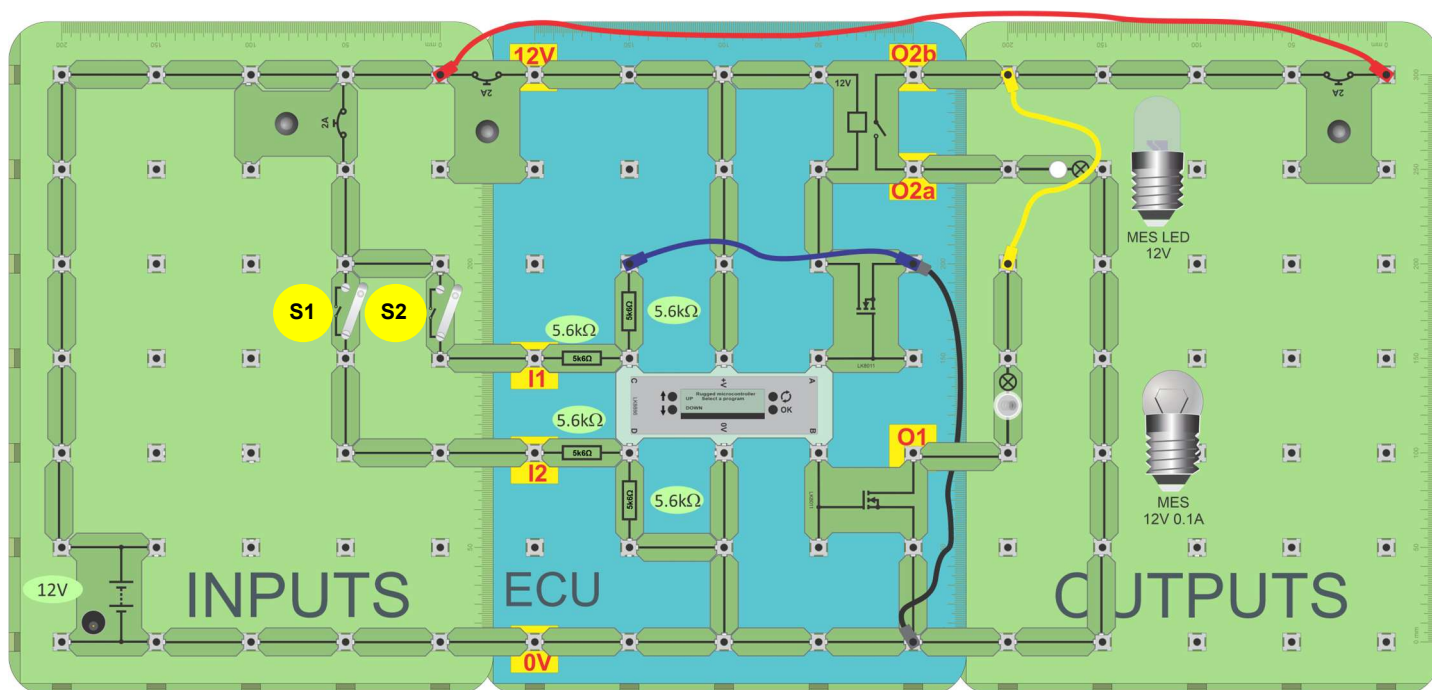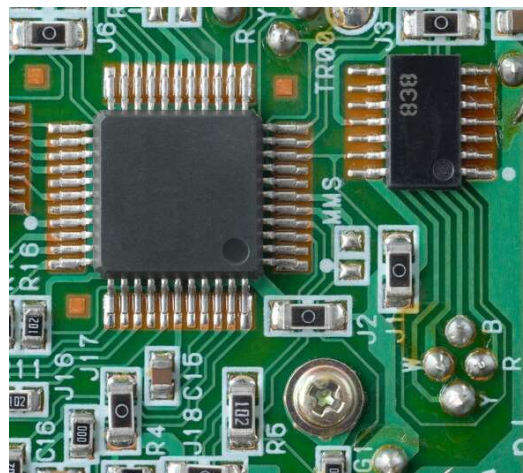
Program	Name	Input terminal(s)	Output terminal(s)
4	Logic OR	C D	A(NOR) B (OR)

Over to you:

- Set up the circuit shown in the layout.
- Find program 4, 'Logic OR on the MicroECU and then press the OK button. The two switches offer only four combinations: both switches open; **S1** open and **S2** closed; the reverse - **S1** closed, **S2** open; both closed.
- For each of these, measure the voltages at **A**. **B**. **C** and **D**.
- Record your observations in the Student Handout.

Worksheet 6

The OR function

So what?

- The program defines terminals, **C** and **D** as inputs and terminals **A** and **B**, as outputs.
- You can see the state of inputs and outputs on the LCD.
- The incandescent lamp shows the state of the signal at output **B** . This is on when either **C** OR **D** (or both) are HIGH.
- The LED lamp shows the state of the signal at output **A** . This is on when either **C** OR **D** are LOW (or both). This is referred to as a 'NOR' function, i.e. *Not OR*.
- An ECU is constantly making logical decisions. For example: the interior light in a car will come on when front left door OR front right door OR back left door OR back right door is open.

Worksheet 7

PWM

Pulse-width modulation (PWM) is used to control the speed of electric motors and the brightness of lights. It is a digital technique - the signal is rapidly pulsed on and off to control the power delivered.

Its advantages include:

- superior energy efficiency, compared to analogue control techniques;
- compatibility with digital devices, e.g. microcontrollers.

The photograph shows an automotive electric motor.
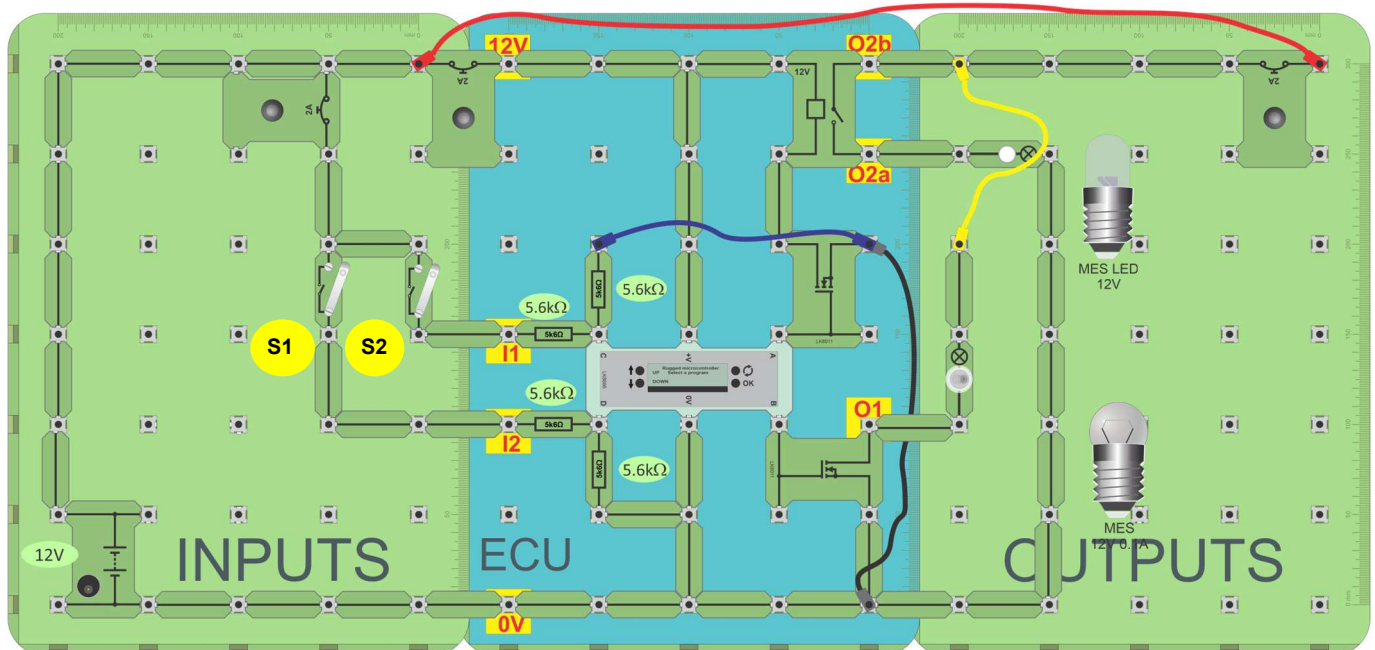
Program	Name	Input terminal(s)	Output terminal(s)
5	Slow PWM	C D	B

Over to you:

- Build the circuit shown in the layout.
- Make sure that the power supply is set to 12V and then switch on.
- Locate program 5, 'Slow PWM'. Press the 'OK' button to run it.
- Notice what happens to the incandescent bulb when you:
    - close switch **S1**, but leave switch **S2** open;
    - close switch **S2**, but leave switch **S1** open;
    - close both switches?

Worksheet 7

PWM

So what?

- This form of control is called pulse-width modulation (PWM). The ratio of on time to off time is controlled by **M**odulating (modifying) the **W**idth of the **P**ulse, i.e. changing the 'mark:space ratio' (m:s) of the pulse, - the on:off ratio.

- Referring to the diagram, the 'mark' (*on* time) lasts for three units of time, whereas the 'space' (*off* time) lasts for only one.

- This is known as a 'mark-to-space ratio (m:s) of 3:1. It can also be described using the term 'duty cycle' - the fraction of the signal for which the bulb is 'on'. A m:s of 3:1 is the same as duty cycle of 75%.
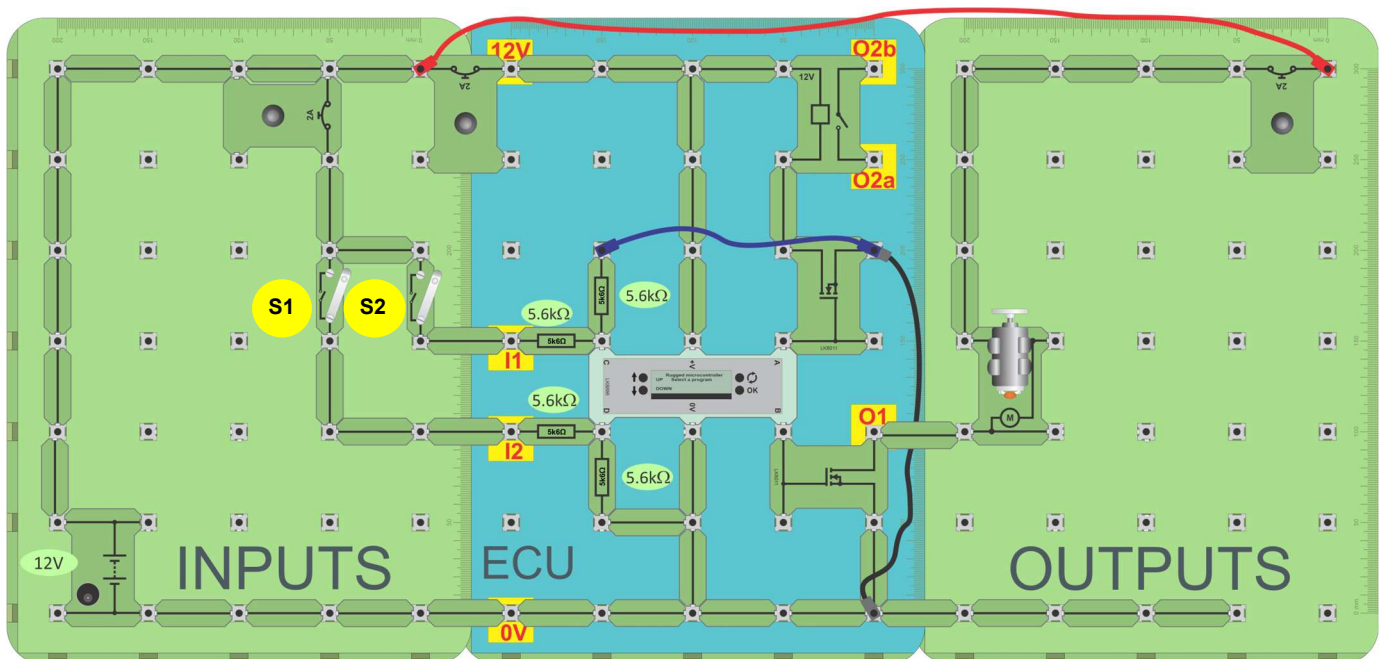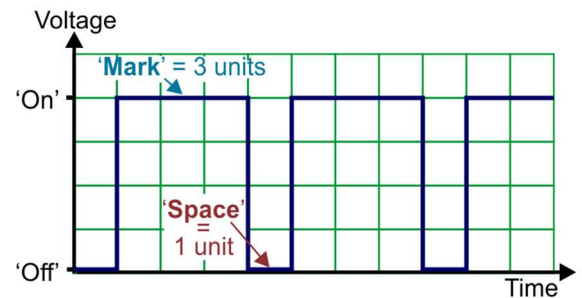
Program	Name	Input terminal(s)	Output terminal(s)
6	Fast PWM	C D	B

Over to you:

- Build the layout shown in the diagram above.
- Locate and load program 6, 'Fast PWM'.
- Measure the voltage at terminal **O1** with a multimeter.
- Using an oscilloscope, measure and sketch the waveform at the output of the transistor with both switches on.
- Report on your findings in the Student Handout

Oscilloscope settings:

Timebase - 100us/div

Voltage range - ±12V DC

Trigger Mode - Repeat

Trigger Channel - ch A

Trigger Direction - Rising

Trigger Threshold - 1V

So what?

When controlling the speed of a motor or the brightness of a lamp, the frequency of pulses used in PWM is much higher than that used in the 'Slow PWM' illustration.

The pulses happen so quickly that the inertia of the motor keeps it rotating in between pulses, or the slow response of the human eye does not notice the light flashing.

A note on ECU construction

- When an ECU needs to deliver more power it needs a relay or a transistor to deliver that power. In this case we used a power Field Effect Transistor to amplify the signal from the MicroECU.
- The FET is used to 'ground the circuit rather than supplying current to the circuit to operate the motor.

Worksheet 8

Fibre optics

Fibre optics are used increasingly in cars because:
- they allow large amounts of data to be transmitted;
- they are immune to electrical interference and offer greater signal security than copper wires.

Fibre optics are used to transmit digital data between a transmitter and a receiver.

The photograph shows a couple of fibre optic cables.
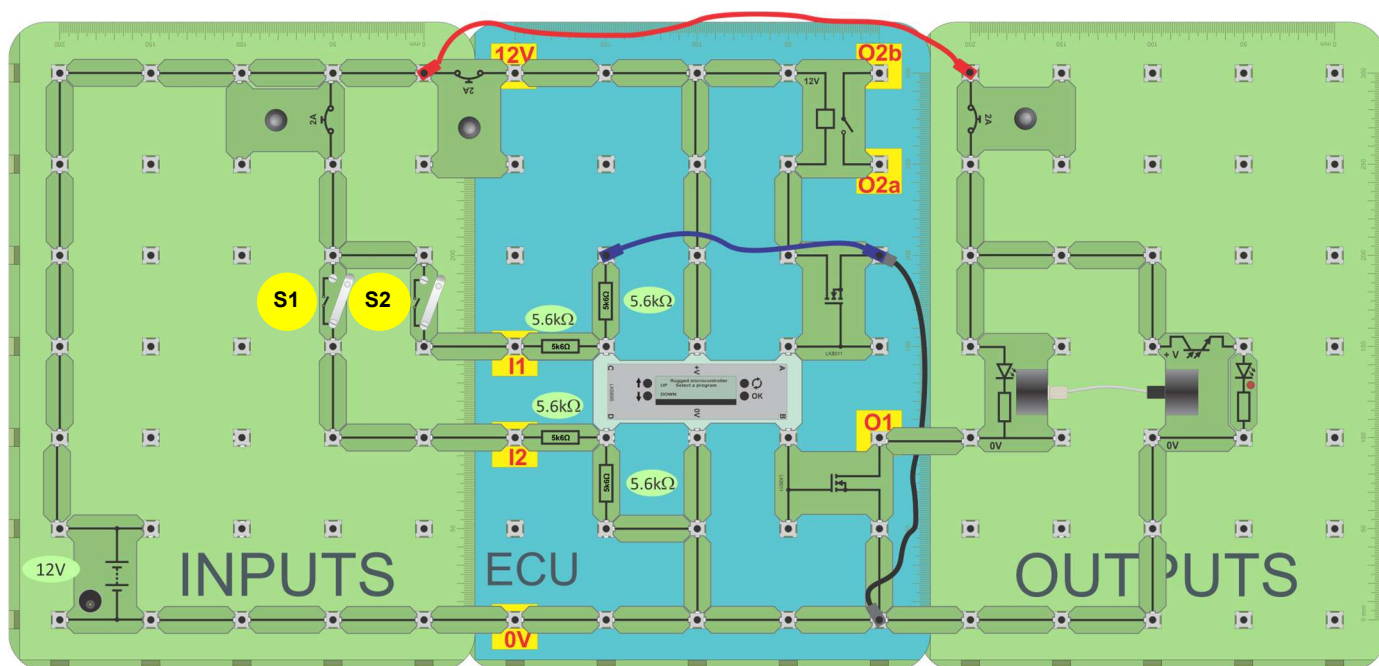
Program	Name	Input terminal(s)	Output terminal(s)
5	Slow PWM	C D	B

Over to you

- Set up the circuit shown in the layout above. Just push the fibre into the transmitter and receiver - you do not need to tighten the screw housings.
- Select program 5 on the MicroECU. The PWM output signal is transmitted over a short length of optical fibre to the receiver, where it drives the red LED.
- Look closely at the optical fibre. You should be able to see some red light escaping from the fibre.
- Report on your findings in the Student Handout

Worksheet 9

Reversing alarm

Road vehicles are becoming quieter and quieter. Electric vehicles, in particular, often creep up with little warning.

Increasingly safety-conscious, vehicle manufacturers are adding an audible alarm to the traditional reversing lights to warn that a vehicle is reversing.

The photograph shows a 'reversing vehicle' warning sign.
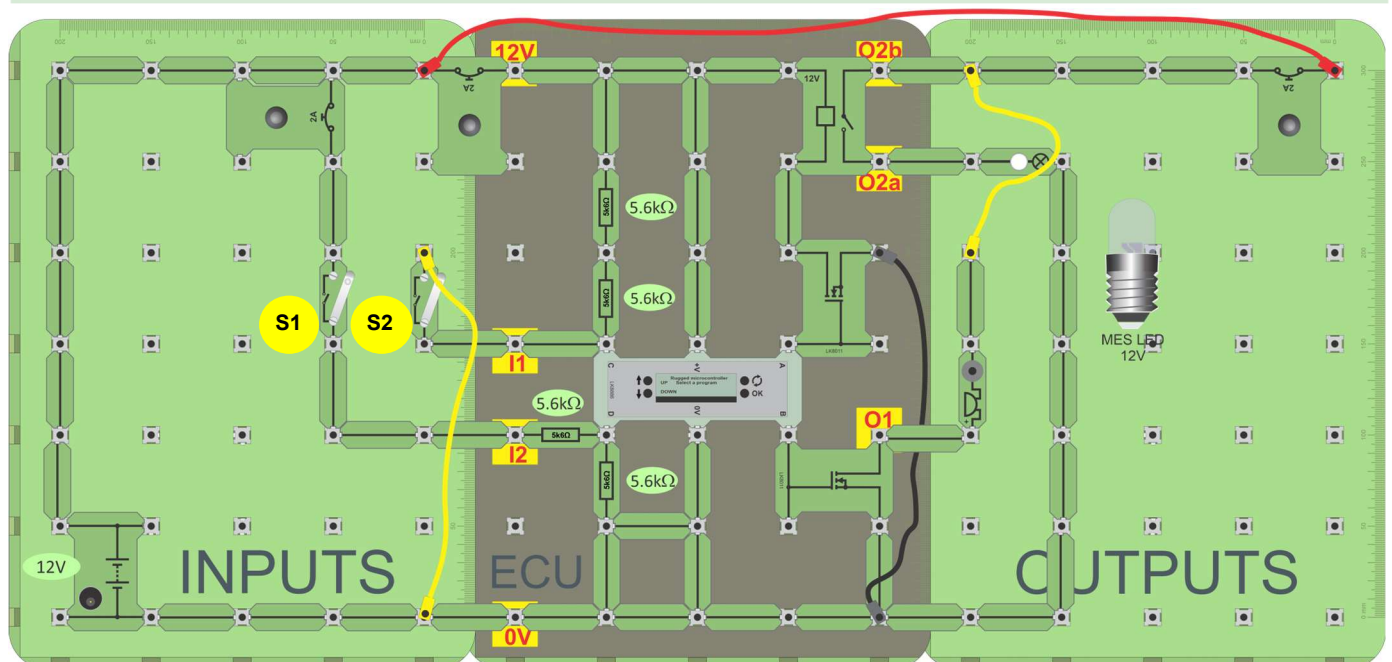
Program	Name	Input terminal(s)	Output terminal(s)
8	Reverse alarm	C D	A B

Over to you:

- Set up the circuit shown in the layout.
- Select and run program 8 on the MicroECU. This uses two inputs, '**C**' and '**D**', provided by switch units, representing the ignition switch, S1, and gear lever reverse switch, S2.
- Devise a set of tests to check on the performance of program 8, 'Reverse alarm'.
- Describe your tests and the results in the Student Handout.

So what?

- In this example 'Ignition switch on' is represented by 12V at the ECU and 'reverse switch on' is represented by 0V at the ECU input.
- To debug circuits you need to understand how they are wired.

Worksheet 10

Temperature alarm

Internal combustion engines run hot and need coolant systems to control their temperature. The traditional car thermostat uses the expansion of a substance, like wax, to both sense temperature and operate a flow valve adjusting the flow of coolant.

Modern methods use an electronic sensor and an ECU to control valves and fans and communicate temperature data.

Should there be a problem, an alarm warns the driver.
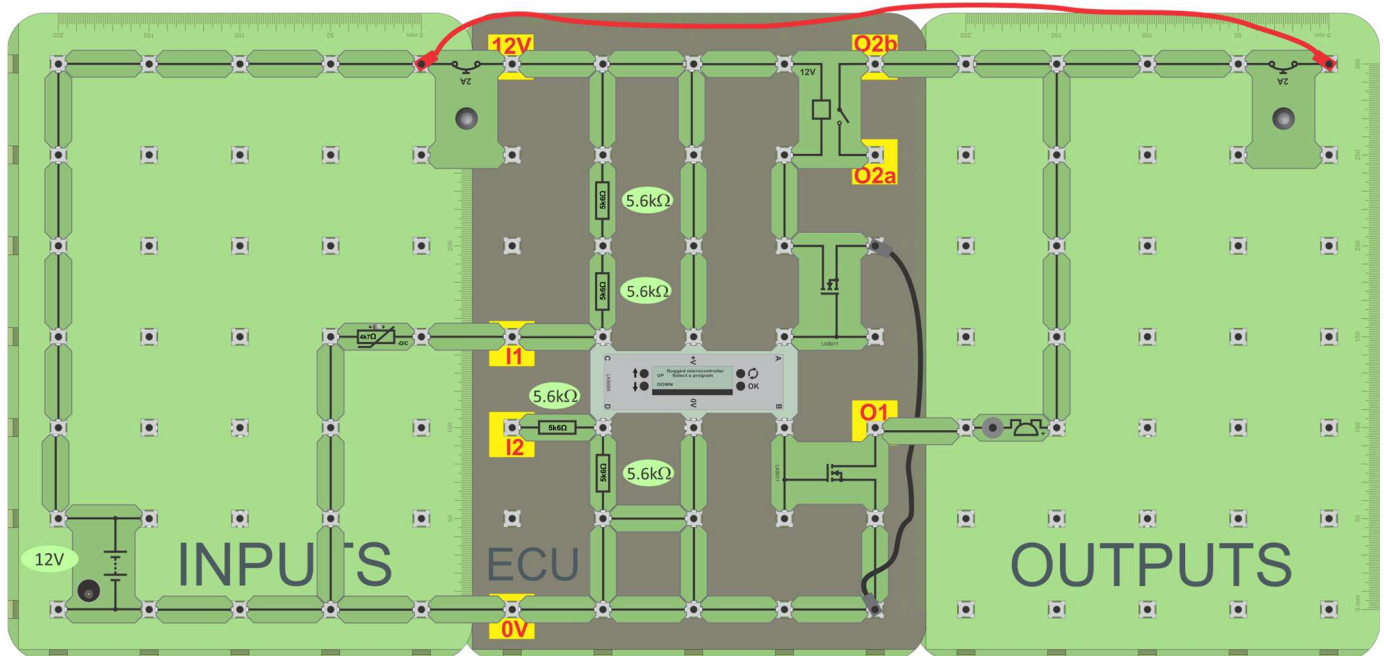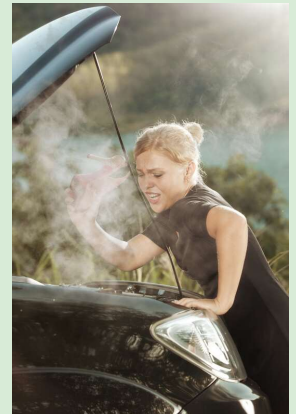
Program	Name	Input terminal(s)	Output terminal(s)
7	Temperature alarm B	C	B

Over to you:

- Set up the circuit shown in the layout.
- Select and run program 7 on the Micro ECU.
- Measure the voltage at terminal **C** when the thermistor is at room temperature.
- Use a hair dryer, or just hold the thermistor between your fingers, to raise its temperature. The MicroECU LCD shows you the temperature reached.
- Measure the voltage at input **C** at each of the temperatures given in the Student Handout.
- Determine the temperature that triggers the alarm.
- Record your results in the Student Handout.

So what?

- The thermistor resistance varies with temperature.

- For a 'negative temperature coefficient' (NTC) thermistor, resistance falls as the temperature increases.

- In this circuit, that means that the voltage at C falls as the temperature rises.

Worksheet 11

Heater fan control

Modern cars often have sophisticated cabin heating systems in which the driver selects the temperature and leaves the rest to the car's electronics! When the selected temperature is much higher, the control system speeds up the heater fan.

This system illustrates this idea, using two controls - the MicroECU program, to set a target temperature, and a temperature-sensing unit to monitor current temperature. The ECU uses PWM to adjust fan speed, depending on the difference between them.
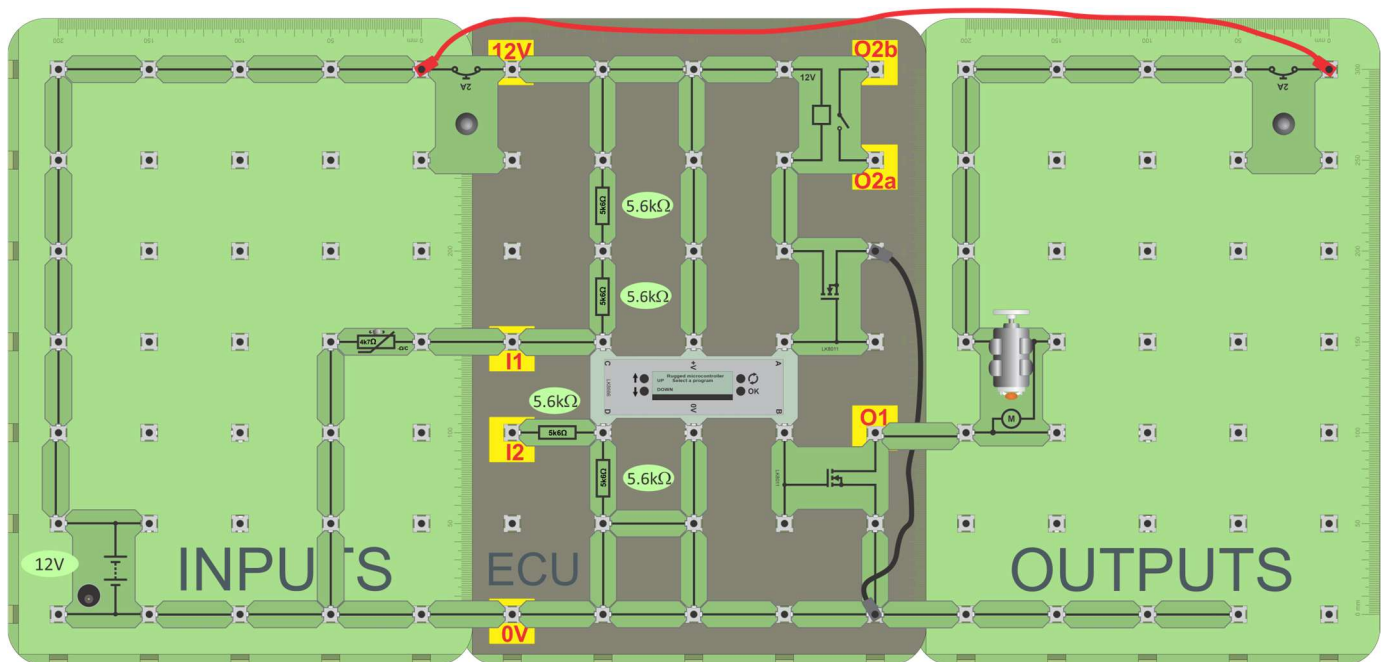
rogram	Name	Input terminal(s)	Output terminal(s)
10	Heater fan control	C	B

Over to you:

- Set up the circuit shown in the layout.
- Locate program 10 and run it.
- Using the 'up' and 'down' switches on the MicroECU, adjust the 'set temperature' to room temperature. The motor (mimicking the heater blower) will be on.
- Touch the thermistor to warm it up a couple of degrees. The motor will turn off.

Record all your findings, including voltage measurements, in the Student Handout

Worksheet 11

Heater fan control

So what?

Two types of control systems are found in a car - **open-loop** and **closed-loop**.

In an **open-loop** system, the output has no effect on the input signal.

There is no feedback between output and input in other words.

The system does not 'know' when the output has reached its final target state.

Instead, it carries on regardless following the input signal.

In a **closed-loop** system, the output state of the system is fed back into the input, so that the system can check when the desired outcome has been attained. Closed-loop control uses feedback to reduce the effect of any external disturbances.
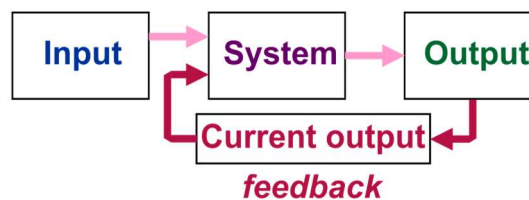
The car heater fan control system investigated in this worksheet is a closed-loop system. The fan speed depends on the difference between the set value and actual value of cabin temperature, When the cabin is much colder than the set temperature, the system runs the fan at high speed to warm up the cabin quickly. When it reaches the target temperature, the fan slows to maintain it at that level.

A sudden drop in temperature, caused by the opening of a door or window, boosts the speed of the fan as the control system tries to restore the cabin temperature.

Worksheet 12

Fault-finding project 1
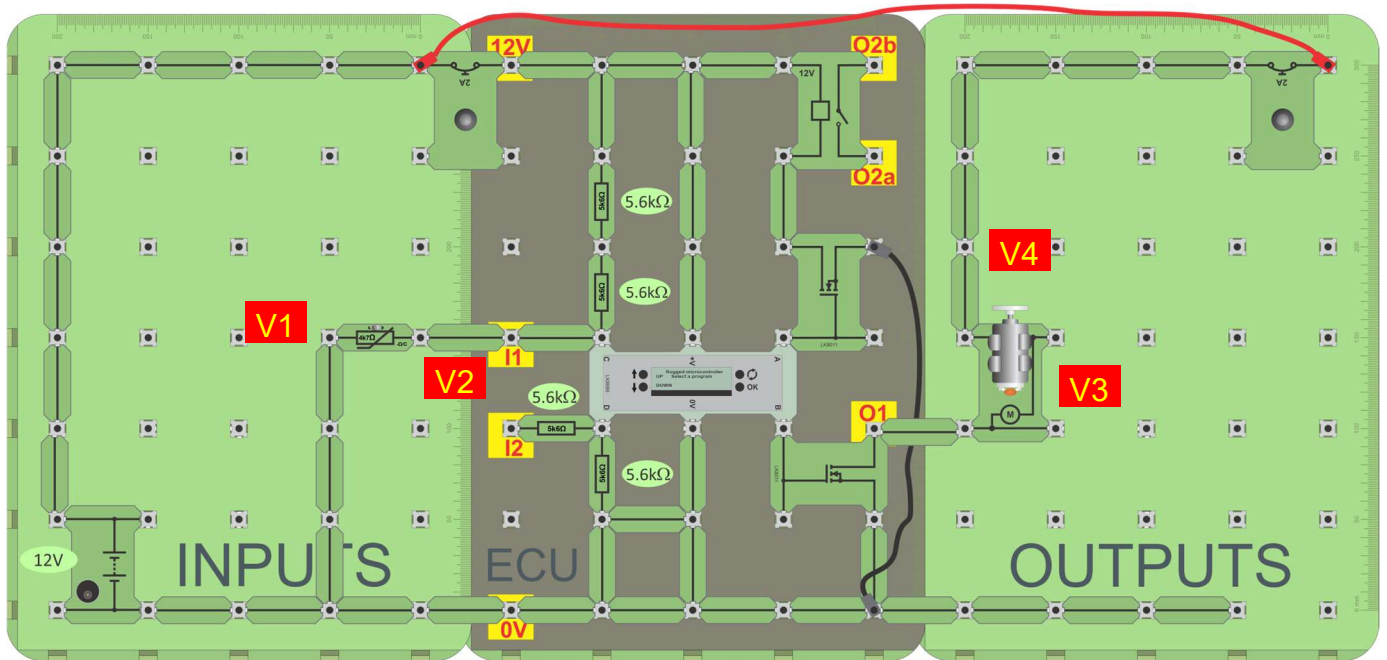
Program	Name	Input terminal(s)	Output terminal(s)
10	Heater fan control	C	B

Over to you:

- Build the layout shown above.
- Load program 10 into the MicroECU and press OK.
- The 'up' and 'down' switches set the set point where the motor comes on - this mimics a heater blower in a vehicle. Adjust them so that the fan is only just on.
- Measure voltages **V1** to **V4**, shown in the circuit on the next page and record them in the 'Circuit working, fan on' row of the table in the Student Handout.
- The thermistor resistance varies with temperature. Touch the thermistor to warm it up. The fan should turn off.
- Now measure **V1** to **V4** again and record them in the second row of the table.

Worksheet 12

Fault-finding project 1

Issues:

A customer reports that the fan circuit is not working.

How you would use a multimeter to diagnose the following faults:

1. a broken thermistor:

2. a broken fuse on the input side to the circuit:

3. a broken fan motor:

4. a broken fuse on the output side to the circuit?

Describe your approach to each problem in the space provided in the Student Handout.

Worksheet 13

Automatic headlights

You are driving along a quiet lane at night.
Your headlights are on full beam.

Suddenly, a car comes towards you.

Fortunately, the lighting control system kicks in and dims your headlights.

Once the car passes, the headlights return to main beam automatically.
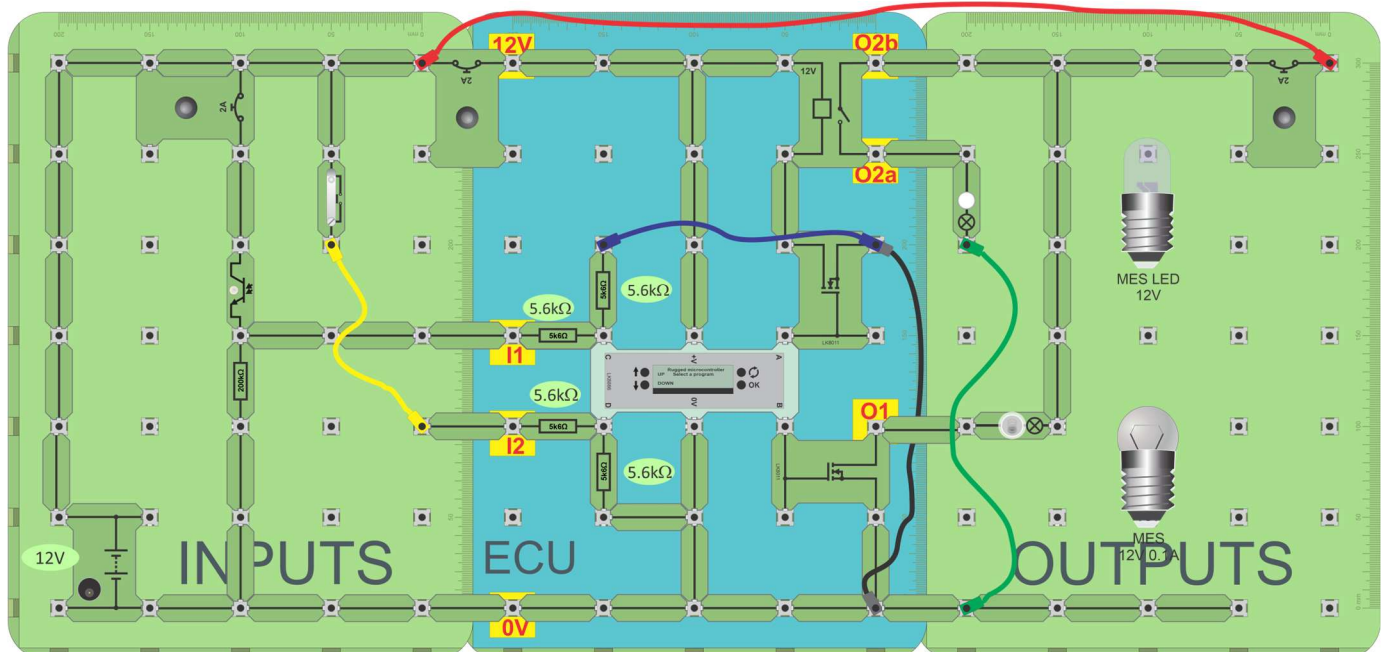
Program	Name	Input terminal(s)	Output terminal(s)
12	Auto headlights	C D	A B

Over to you:

- Build the circuit shown.
- Test the behaviour of program 12 both in darkness (phototransistor covered) and in bright light (phototransistor uncovered.)

  You may need to use the palm of your hand to make the light sensor dark enough, and then your mobile phone torch to make it bright enough.

- Report on the performance of this system in the Student Handout.

So what?

- In this circuit, the switch represents a headlight switch.
  - Pressing it once turns the headlights on dipped beam.
  - Pressing it again, turns them to full beam.
  - A third press returns to dipped, and so on.
- However, when the light-sensing unit, detects a bright light, it:
  - switches the headlights from main beam to dipped;
  - prevents the push-to-make switch from switching to full beam.

Challenge:

In the Student Handout, outline two ways, one involving modification of the hardware and one a change the software, to adjust the light level that triggers the system.

Worksheet 14

Brake light alarm

Imagine! Wet night, heavy traffic!

You need to rely on your brake lights to warn the driver behind you that you're braking **NOW!**

A faulty brake lamp bulb would be dangerous, but how do you know?

The ECU controlling the rear light cluster can detect such a malfunction, an example of how an ECU can directly identify a fault.
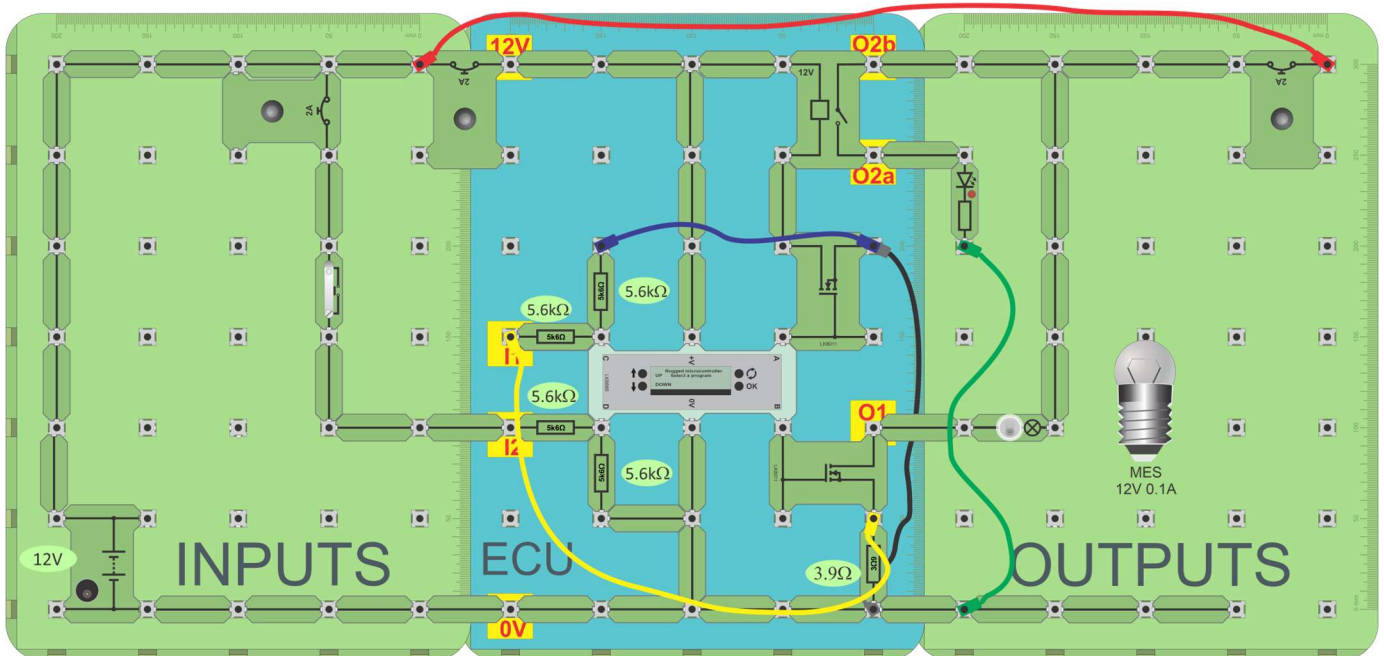
Program	Name	Input terminal(s)	Output terminal(s)
13	Brake light alarm	C D	A B

Over to you:

- Build the circuit shown in the layout above.

    Note - the ECU is modified - the transistor on **B** has a 3.9 ohm resistor in its ground path.
- Load and run program 13, 'Brake light alarm'.
- Test it as follows:
    - Close the switch - the incandescent lamp should light.
    - Now simulate a faulty bulb by unscrewing the bulb.
    - The warning LED should light and a warning should appear on the display.
- Report on your findings in the Student Handout and answer the questions.

So what?

- Program 13 configures terminals **C** and **D** as inputs and **A** and **B** as outputs.

- When **D** receives an 'on' signal from the switch unit, it turns on the 'brake light' bulb, connected to terminal **B**.

- The 3.9Ω resistor is in series with the brake light bulb (via the transistor).

  Any current flowing through the bulb also flows through this resistor and causes a small voltage drop across it.

- Terminal **C**, an input, monitors this voltage. Should the bulb 'blow', the current through **B** and the voltage across it would fall and trigger the alarm. This would light the LED connected to output terminal A and cause the error message on the LCD display.

- Vehicles designers use this technique to give 'intelligence' to the car so that the driver can monitor the state of bulbs and sensors.

Worksheet 15

Fault-finding project 2
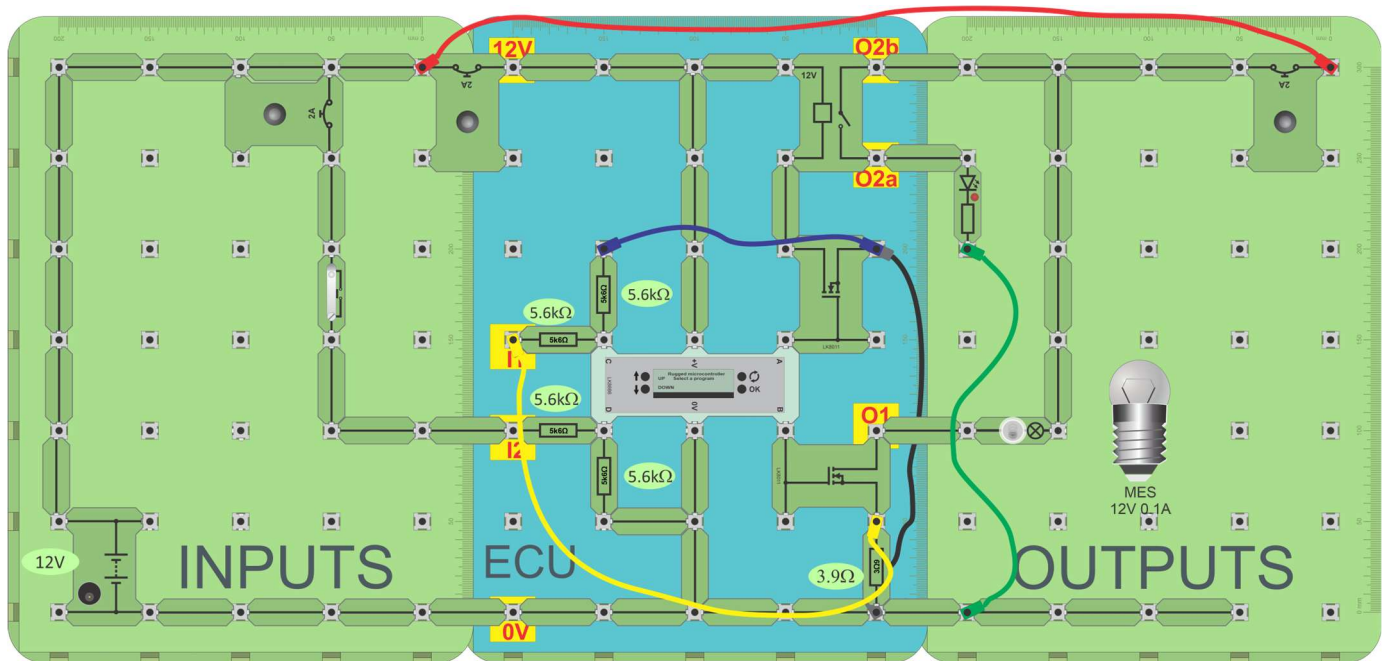
Program	Name	Input terminal(s)	Output terminal(s)
13	Brake light alarm	C D	A B

Over to you:

The ECU has flagged up a brake light problem, but hasn't identified exactly what the problem is.

There are a number of possibilities, including:

1) a 'blown' bulb;

2) a fault inside the ECU, such as a bad connection between the series resistor and ground;

3) a bad connection between the ECU and the brake light;

4) a 'blown' fuse;

5) a bad connection between the fuse and the bulb.

Using a multimeter and the circuit diagram shown on the next page, write down the voltages you would expect to find at significant points for each of these possible faults, when the switch is open and when closed.

Then, remove components from the circuit, to simulate the faults and use the multimeter to test your predictions.
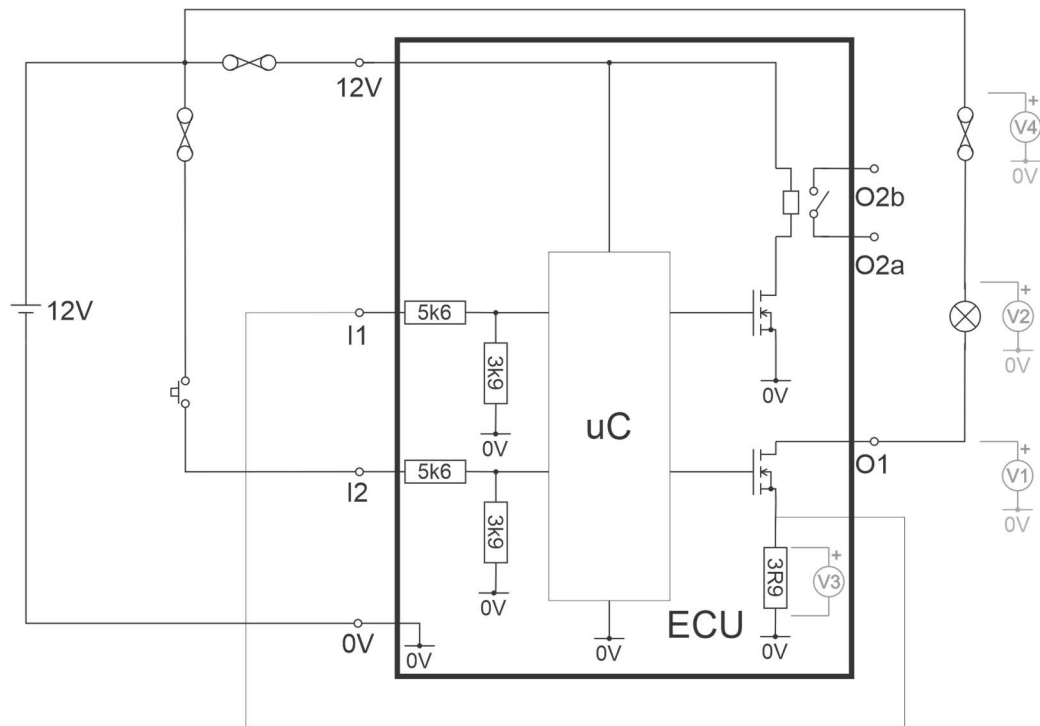
Student Handout

You can print out a copy of the worksheets and Student Handout for each student. This can be expensive for many copies.

Alternatively, you can print and bind the worksheets in colour and then print this Student Handout in black and white, for students to use to record their results.

Student Handout

Worksheet 1 - Analogue vs digital

Analogue sensor:

What happens to the output voltage when the thermistor is warmed?

……

Variable resistor:

What happens to the brightness of the bulb and the output voltage when the variable resistor is adjusted by rotating the spindle clockwise?

……

Digital sensor:

Measurements:

Initial orientation   Inverted

Switch	Output voltage
off	
on	

Switch	Output voltage
off	
on	

Describe the difference between analogue signals and digital signals.

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Student Handout

Worksheet 2 - Driving output devices:

1. The relay:

When the motor is running:

- current flowing in the control circuit = ...mA

- current flowing in the controlled circuit, (motor) = ...mA

2. The transistor:

When the lamp is lit:

- input current (yellow connector) = ...mA

- output current (blue connector) = ...mA

Comparing relays and transistors:

Describe four ways in which the relay outperforms the transistor and four ways in which the transistor outperforms the relay.

Advantages of the relay:

1. ……
……
2. ……
……
3. ……
……
4. ……
……

Advantages of the transistor:

1. ……
……
2. ……
……
3. ……
……
4. ……
……

Student Handout

Worksheet 3 - ECU structure

Resistance between			
I1 and 0V	I2 and 0V	O2a and O2b	O1 and 0V

ECU with pull-down resistors:

Voltage across	
I1 and 0V	I2 and 0V

ECU with pull-up resistors:

Voltage across	
I1 and 0V	I2 and 0V

Worksheet 4 - The NOT function:

ECU with pull-down resistors:

Switch	I1 input voltage	O1 output voltage
off		
on		

ECU with pull-up resistors:

Switch	I1 input voltage	O1 output voltage
off		
on		

Worksheet 5 - The AND function

Observations:

	Voltage at				
	C	D	A	B	Output O1
S1open, S2 open					
S1 closed, S2 open					
S1 open, S2 closed					
S1 closed, S2 closed					

Student Handout

Worksheet 6 - The OR function

Observations**:**

	Voltage at				
	C	D	A	B	Output O1
S1open, S2 open					
S1 closed, S2 open					
S1 open, S2 closed					
S1 closed, S2 closed					

Car theft alarm:

Describe how this system could be used as a car theft alarm?

……

……

……

Worksheet 7 - PWM

For the four combinations of switch settings, record the PWM% and the voltage at output **O1**.

	PWM%	Voltage at B
C open, D open		
C closed, D open		
C open, D closed		
C closed, D closed		

Sketch the oscilloscope trace for the '**C** closed , **D** closed' option:

Student Handout
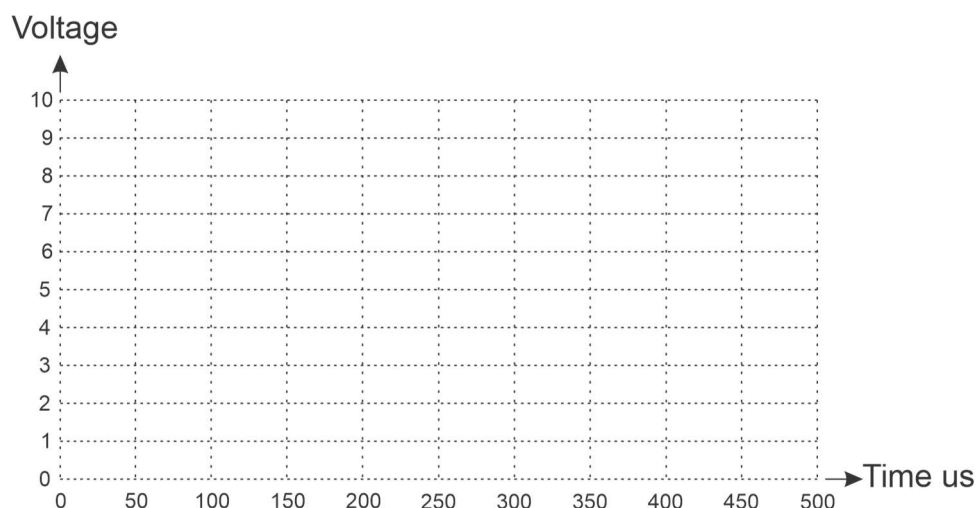
Worksheet 8 - Fibre optics

Additional connections needed to complete the circuit to include the fibre optic subsystem:

………

………

Describe the effect of adding the fibre optic subsystem to the performance of the circuit.

………

………

Describe three advantages of optical fibre communications over copper cable communications.

………

………

Worksheet 9 - Reversing alarm

Describe how you tested the system and comment on the results.

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Student Handout

Worksheet 10 - Temperature alarm

Effect of temperature on voltage at I1

ECU with pull-down resistors:

Temperature	Voltage at I1
19C	
20C	
21C	
22C	
23C	
24C	
25C	
26C	
27C	
28C	
29C	

Worksheet 11 - Heater fan control

Describe the effect of temperature changes on:

- on the voltage at **C**;
- the output of the MicroECU at **B**;
- the voltage at the transistor/motor junction.

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………

Student Handout

Worksheet 12 - Fault-finding project 1

	V1	V2	V3	V4
Circuit working, fan on				
Circuit working, fan just				

A customer reports that the fan circuit is not working.

Describe how you would use a multimeter to diagnose the following faults and how you would use V1 to V4 to diagnose the issue:

1. Thermistor broken:

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……………………………………………………

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……………………………………………………

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……………………………………………………

2. Broken fuse on the input side to the circuit:

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……………………………………………………

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……………………………………………………

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……………………………………………………

3. Fan motor broken:

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……………………………………………………

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……………………………………………………

……
……………………………………………………

4. Broken fuse on the output side to the circuit:

……
……………………………………………………

……

Student Handout

Worksheet 13 - Automatic headlights

Describe how you tested the system and comment on the results.

……

……

……

……

……

Challenge:

Describe two ways, one involving modifying the hardware and one the software, to adjust the light level that triggers the system.

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Worksheet 14 - Brake light alarm

Describe how you tested the brake light alarm system and give the results of the tests.

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Student Handout

Worksheet 14 - Brake light alarm continued...

Including the expected outcome of any *voltage* measurements, describe how you could use a multimeter to check:

1.   whether the ECU is receiving signals from the brake light switch;

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2.   whether the ECU is generating an appropriate signal to the brake light;

   ....

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   ....

3.   whether there is a bad connection between the series resistor and ground.

   ....

   ....

   ....

   ....

   ....

   ....

Student Handout

Worksheet 15 - Fault-finding project 2

Issue	Switch on				Switch off			
	V1	V2	V3	V4	V1	V2	V3	V4
a 'blown' bulb								
a fault inside the ECU, such as a bad connection								
a bad connection between ECU and brake light.								
a 'blown' fuse								
a bad connection between fuse and bulb.								

Notes

for the

Instructor

Notes for the instructor

About this course

Introduction

Using the MicroECU module, students investigate the use of ECUs in modern vehicles.

The course is essentially a practical one. Locktronics equipment makes it simple and quick to construct and test electrical circuits that demonstrate how a programmable system, the MicroECU, in this case, processes data received from sensors to control output devices.

This leads to a study of how ECUs communicate with each other using protocols like CANbus.

Aim

The course introduces students to the power and flexibility of microcontrollers in ECUs through practical implementation of a number of vehicle control applications.

Prior Knowledge

It is recommended that students have followed the 'Automotive Electrics' course, or have equivalent knowledge and experience of building and testing simple circuits.

Using this course:

There are two main parts to the workbook: the worksheets and the Student Handout.

We envisage that you print (and bind) one copy of the workbook it, for each set of equipment. This stays with the equipment. You print a Student Handout for each student.

The worksheets are written in a student-centred way. Our plan is that you give each pair of students a set of equipment, the bound workbook and a Student Handout each. You then allow them to work through the topics in the workbook, offering help and assistance where needed. Students should not write on the worksheets but instead record their measurements in the Student Handout.

The format encourages self-study, with students working at a rate that suits their ability. It is for the instructor to monitor that their understanding is keeping pace with their progress through the worksheets. The Student Handout is one element of this. The instructor can assess progress by looking at the quality of their entries. It can be the basis for the feedback given to the students.

Knowing that multidisciplinary teaching teams are increasingly popular, the 'Notes for the instructor' aims to help instructors for whom this topic is not their principal area of experience.

Time:

It will take students about seven and ten hours to complete the worksheets. It is expected that a similar length of time will be needed to support the learning that takes place as a result.

Notes for the instructor

Learning Objectives

On successful completion of this course the student will be able to:

- use Locktronics kit to construct circuits, following a given layout diagram;

- select and run a program on the MicroECU carrier;

- distinguish between analogue and digital signals;

- explain the terms 'logic 0' and 'logic 1' and describe how they can be coded as electrical signals;

- state one advantage of digital signals over analogue signals;

- predict the logic levels at the output of a given switch unit when the switch is pressed or not pressed;

- state the function of a driver subsystem in a control system;

- compare the relative merits of the transistor and relay as a driver subsystem'

- outline the structure of a relay;

- distinguish between a 'pulled-up', a 'pulled-down' and a 'floating' input;

- describe the effect of a NOT logic function

- use logical language to describe the relationship between the logic AND and NAND functions;

- describe one application for the AND function in a vehicle;

- use logical language to describe the relationship between the logic OR and NOR functions;

- describe one application for the OR function in a vehicle;

- explain how a PWM output controls the speed of a motor;

- draw a diagram to illustrate the meaning of mark:space ratio of a PWM signal;

- distinguish between open-loop and closed-loop control systems;

- describe how the trigger level from a light-sensing unit can be adjusted;

- describe how an ECU can identify a faulty lamp in the system;

- appreciate that the several faults may lead to the same symptoms;

- appreciate that the diagnosis offered by the control system may not be accurate;

- create and use a fault table to diagnose faults and failures that may arise;

- use a fault table to devise a plan to identify a faulty component;

- use a multimeter to identify the cause of a fault in the vehicle's electrical system.

Notes for the instructor

What the student will need:

To complete the Automotive Electricity course, the student will need the following equipment:

1	HP2666	Adjustable DC power supply
2	HP4039	Tray Lid
2	HP5540	Deep tray
2	HP7750	Daughter tray foam cutout
2	HP9564	62mm daughter tray
1	HP8600	Crash foam
2	LK2346	12V incendescent MES bulb
1	LK2347	MES bulb, 6V 0.06A
1	LK3246	Buzzer, 12V
1	LK3548	Fibre optic tx
1	LK5202	Resistor, 1k, 1/4W, 5% (DIN)
1	LK5203	Resistor, 10k, 1/4W, 5% (DIN)
1	LK5208	Potentiometer, 250ohm (DIN)
4	LK5209	Resistor, 5k6, 1/4W, 5% (DIN)
50	LK5250	Connecting Link
1	LK5280	Relay, 12V coil
1	LK5291	Lampholder, MES
1	LK5402	Thermistor, 4k7 ohm, NTC (DIN)
1	LK5601	Lead, green, 4mm to 4mm
1	LK5603	Lead, red, 4mm to 4mm
1	LK5604	Lead, black, 4mm to 4mm
1	LK5607	Lead, yellow, 4mm to 4mm
1	LK5609	Lead, blue, 4mm to 4mm
1	LK6207	Switch, push to make, metal strip
2	LK6209	Switch, on/off, metal strip
1	LK6238	Resistor 200k, 1/4W, 5% (DIN)
1	LK6635	LED, red
1	LK6706	Motor, 3 to 12V
1	LK6774	Fibre optic cable, 1m
2	LK6841	MES bulb, 12V, LED, white
1	LK7290	Phototransistor
2	LK8011	Power MOSFET
1	LK8275	Power supply carrier
1	LK8279	Fibre optic rx
3	LK8623	Circuit breaker
1	LK8886	Locktronics PIC II
3	LK8900	7 x 5 metric baseboard + pillars

General checks

- Is the plug-top power supply on the correct voltage setting?

  If not, the results in the Student Handout will be wrong.

- Is the multimeter connected to the power-supply carrier correctly?

  If not, the '-' sign will appear in the wrong place.

- Is the multimeter set on the correct range?

  If not, the results in the Student Handout will be wrong.

- The multimeter does not measure current.

  The internal fuse may have blown.

- Are the leads connected to the correct sockets on the multimeter?

  If not, the student will not be able to take a reading.

- Some voltage readings are negative.

  The multimeter leads are the wrong way round.

- Bulbs do not light.

  One of the bulbs is faulty or not screwed fully into the bulb holder.

- The system does not behave as intended.

  The layout has not been constructed correctly or uses components with incorrect values.

- The system does not behave as intended.

  One of the circuit breakers has 'tripped'.

- The system does not behave as intended.

  The connecting links between baseboards are not seated properly.

- The system does not behave as intended.

  The wrong program has been selected on the MicroECU.

Notes for the instructor

| Worksheet	Notes
1 Analogue vs digital:	Points for discussion: • What is meant by 'voltage' 'current' and 'resistance'? • Why do we need a complete circuit? • Series and parallel connections. • How to encode data as an electrical signal. • Regenerating digital signals.

2
 	
Driving output devices:
	Specific problems:
	• Student unable to take a current reading.
	  Is the instrument on the correct range?
	  (For a multimeter,) are the leads in the correct sockets?
	• Motor does not function.
	  Does the relay 'click' when the switch is closed?
	  If so. substitute a bulb for the motor.
	  If that lights, then there is a fault with the motor.
	
	Points for discussion:
	• Trace out the 'control' and 'controlled' circuit.
	• Why may a driver subsystem be needed?
	• Relative merits of relays and transistors for use in driver subsystems.

3 ECU structure:	Specific problem: • Resistance readings are erratic. Is the power supply disconnected? Points for discussion: • Uses of ECUs in modern vehicles (a possible student presentation.) • Significance of 'bi-directional' ports. • Meaning of 'pull up' and 'pull down', applied to inputs. • Potential problem with 'floating' inputs.
4 The NOT function:	Points for discussion: • Trace the pull-up and pull-down structure of the inputs. • Discuss the significance of this.

Notes for the instructor

Worksheet	Notes
5 The AND function:	Points for discussion: • Trace the pull-up and pull-down structure of the inputs. • Relationship between AND and NAND functions. • Examples of AND and NAND in automotive systems, (student project?)
6 The OR function:	Points for discussion: • Trace the pull-up and pull-down structure of the inputs. • Relationship between OR and NOR functions. • Examples of OR and NOR in automotive systems, (student project?)
7 PWM:	Specific problem: • Students unable to use oscilloscope. Demonstrate the use of an oscilloscope to show PWM signals. Points for discussion: • Are the inputs 'pulled up' or 'pulled down'? • PWM - digital or analogue? • Why is PWM energy efficient? • Significance of mark:space ratio and duty cycle. • Meaning of frequency.
8 Fibre optics:	Points for discussion: • Fibre optics - how does it work? • Advantages of fibre optic communications. • Uses of fibre optic systems in a vehicle.
9 Reversing alarm	Points for discussion: • Are the inputs 'pulled up' or 'pulled down'? • This application involves the AND function. Explain why. • Why use separate output terminals for the reversing lamp and the buzzer?
10 Temperature alarm	Points for discussion: • Review the conversion to pull-up resistors. • How could an ohmmeter show the thermistor's change in resistance directly?

Worksheet	Notes

11
Heater fan control:
	Points for discussion:
	• Discuss the control principle that the difference between set temperature and actual temperature determines the size of the response.
	• Recall:
	  • why PWM is the technique used here to control motor speed;
	  • why the driver is a transistor and not a relay.
	• Examples of open and closed loop control systems, (student project?)
	• Relative merits of open and closed loop control systems.

12 Fault-finding project 1:	Specific problem: • Students unable to identify test points for voltage reading. 'Translate' the features of the circuit diagram, (class discussion?) Points for discussion: • Development and use of a fault grid in fault-finding. • Testing components 'in-circuit' and 'out-of-circuit'. • Predicting voltages - examples and exercises. • Using Kirchhoff's voltage law to check voltage readings.
13 Automatic headlights:	Points for discussion: • Measuring light intensity. • Ways to vary light-level reliably. • Issues when implementing this system in a vehicle.
14 Brake light alarm:	Points for discussion: • Other problems that could trigger the brake light alarm, how to test for them and identify expected outcomes. • How to modify the rear-screen heater circuit so that the associated ECU could spot a malfunction.
15 Fault-finding project 2:	Specific problem: • Students unable to identify test points for voltage reading. 'Translate' the features of the circuit diagram, (class discussion?) Points for discussion: • Development and use of a fault grid in fault-finding. • Testing components 'in-circuit' and 'out-of-circuit'. • Predicting voltages - examples and exercises. • Using Kirchhoff's voltage law to check voltage readings.

Reference

MicroECU
User instructions
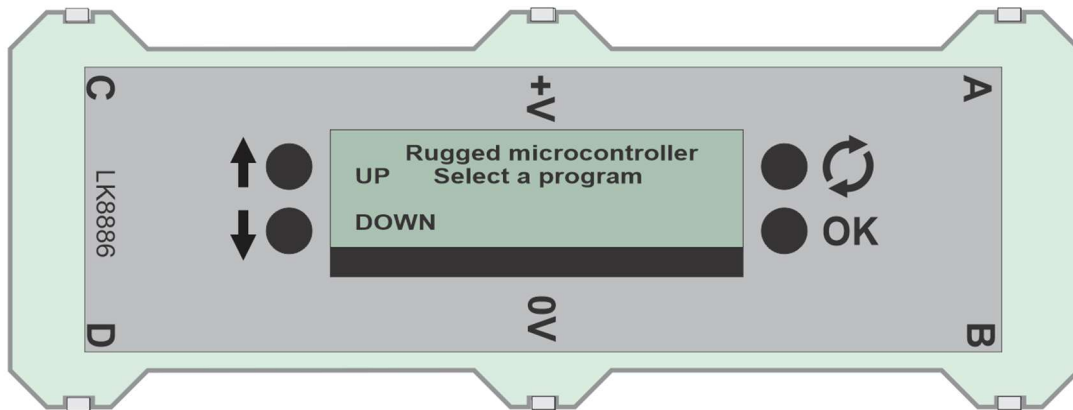
locktronics®

For users

The LK8886 MicroECU is housed in a layered clear Acrylic package with six standard Locktronics legs that allow it to be inserted into a Locktronics base board.

The controls on the MicroECU are as follows:

UP allows program selection and control from within a program.

DOWN allows program selection and control from within a program.

RESET resets the MicroECU into program selection mode.

OK confirms program selection and may also be used within a program.

A, **B**, **C**, **D** are input / output connections.

The function of these is dictated by the program.

To select a program:

- press the **RESET** switch;
- use the **UP** and **DOWN** buttons to navigate to the program you want;
- press the **OK** button to start the program.

Maximum supply voltage is 12VDC.

The list of programs at the date of publishing is as follows:

1. Logic NOT
2. Logic AND
3.
4. Logic OR
5. Slow PWM
6. Fast PWM
7. Temperature alarm B
8. Reverse alarm
9. Temperature alarm A
10. Heater fan control
11.
12. Auto headlights
13. Brake light alarm
14. DC motor drive
15.
16. Alternator feedback loop
17. Spark creator

MicroECU
Programming instructions
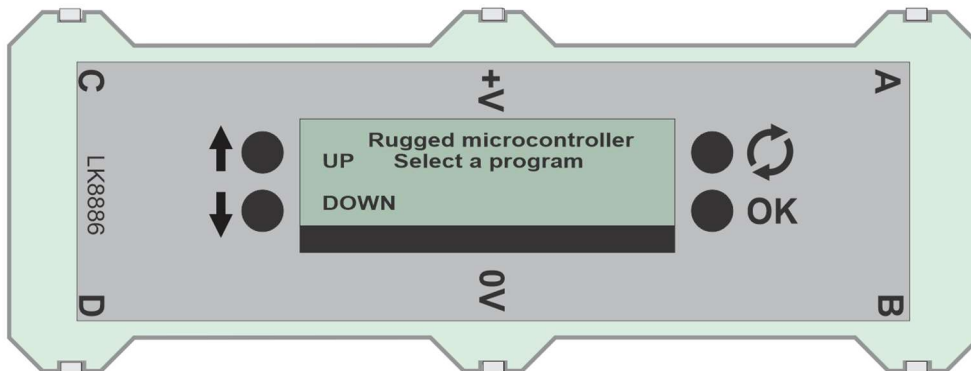
For programmers:

The MicroECU contains a PIC18F24K50, fitted with microUSB socket and an internal bootloader for reprogramming.

Programming software is available from the Matrix web site.

The connections are:

A	A1
B	C2
C	A0
D	C1
UP	C0
DOWN	C6
RESET	MCLR
OK	C7
LED	A5
LCD SDA	B3
LCD SCL	B1
LCD A0	B2
LCD Reset	B4
LCD CSB	B5

The LCD is a HZYO12832E.

The supply voltage is 5 - 12V. The MicroECU can be powered from the +V and 0 pins or from the MicroUSB socket.

Each of terminals **A**, **B**, **C** and **D** is fitted with series 220Ω resistors between the microcontroller and the output pin and will sink or source 20mA.

Terminals **B** and **D** can be programmed to output a PWM signal.

Flowcode components for the PWM outputs and LCD display are available.

To change the program in the Micro ECU:

- Go to this page: https://www.matrixtsl.com/resources/
- Enter 'mloader' in the 'search for resources' box. The 'Mloader programming software' link appears. Click on this link
- The Mloader software will download – you need to UNZIP it in a new directory.
- Run the 'mloader.exe' application and a new screen will appear.
- Click on the three dots to the right of the 'file name' field and load the 'Automotive PIC ECU Firmware.hex' file. This file is available on the
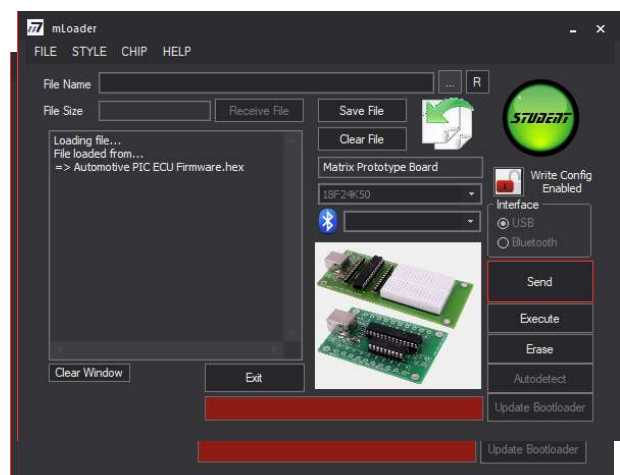
Matrix web site.
- Using a USB cable, plug the Micro ECU into you computer USB port. A red box will appear around 'SEND' indicating that the Micro ECU is in bootloader mode.
- Click SEND and the program will download.
- The micro ECU is now ready to use.

Version control

03 12 20 first release

10 05 21 small amendments and 3R9 added to BOM

05 04 22 Changed WS10,11,12 so that the default is pull up resistor rather than pull down.

23 11 22 small text changes

16 08 23 Reformatted to new style

25 01 23 updated BOM on page 52 to include 50 x LK5250 links