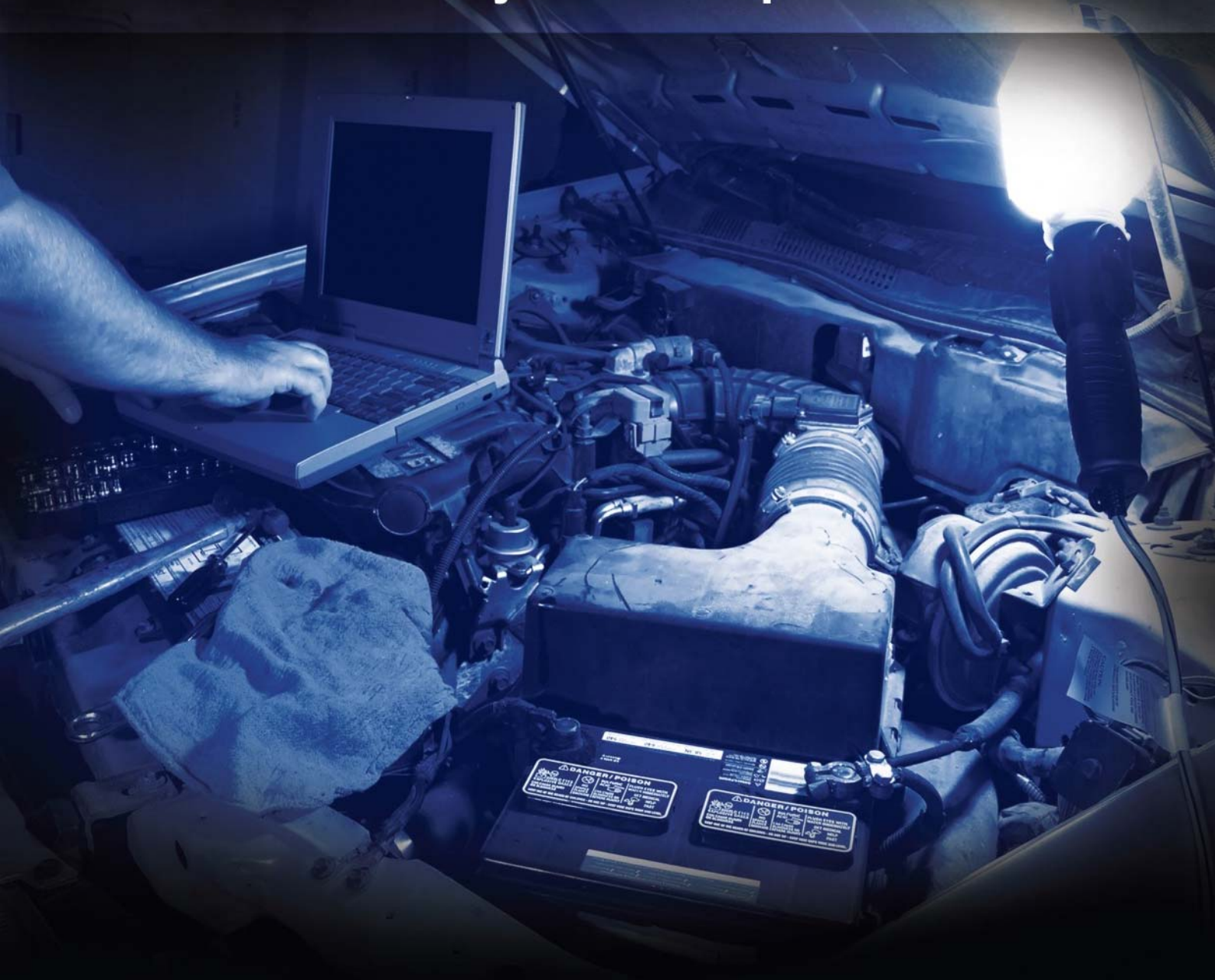


locktronics

Simplifying Electricity

CAN bus systems and operation



LK9893

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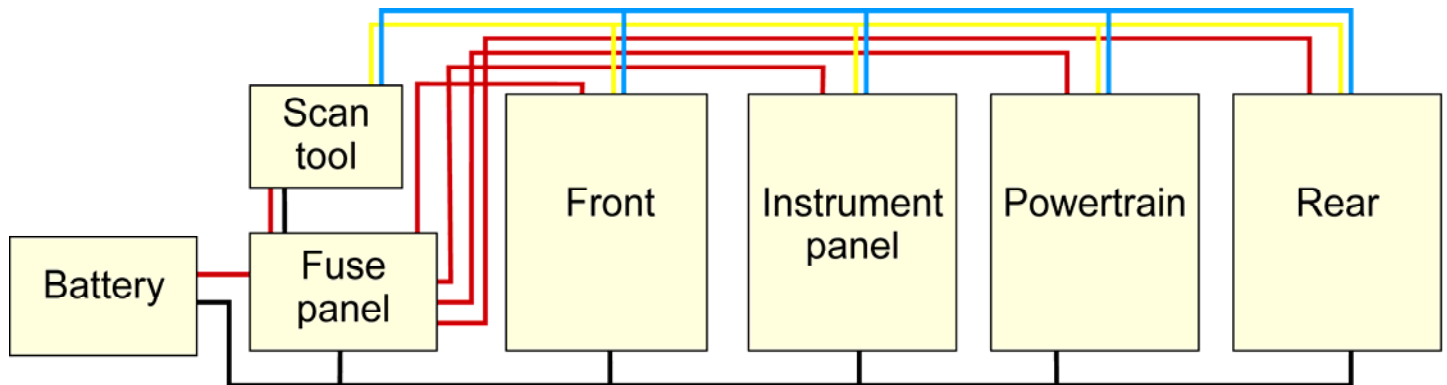
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Introduction

CAN bus systems and operation



What is this all about?

The 'CAN' in CAN bus stands for 'Controller Area Network' and 'bus' a bundle of wires. CAN bus is a fast computer data bus similar to the network used for linking computers. Its use in cars greatly reduces the number and weight of wires used, simplifies construction, reduces cost and allows the use of advanced features, in troubleshooting and monitoring the automotive system.

The flexibility and power of the CAN standard brings many advantages to modern automotive systems. However it can seem like a 'black art'. This course is designed to introduce you to the technology involved in CAN bus systems, and reveal some of its magic!

The hardware:

The course looks at the role of Electronic Control Units (ECUs), linked by a CAN bus, in controlling automotive systems. Modern motor vehicles can contain over a hundred ECUs, controlling everything from the Anti-lock Braking System (ABS) to the position of the driver's seat.

An ECU contains a microprocessor, running software to control the devices attached to it, and to communicate, using the CAN protocol, with other ECUs.

In this course, MIACs (Matrix Industrial Automotive Controllers) are used as ECUs. Each MIAC is running a program that allows you to make it act as one of five types of node. These types are described in the following sheets.

Using these, you will:

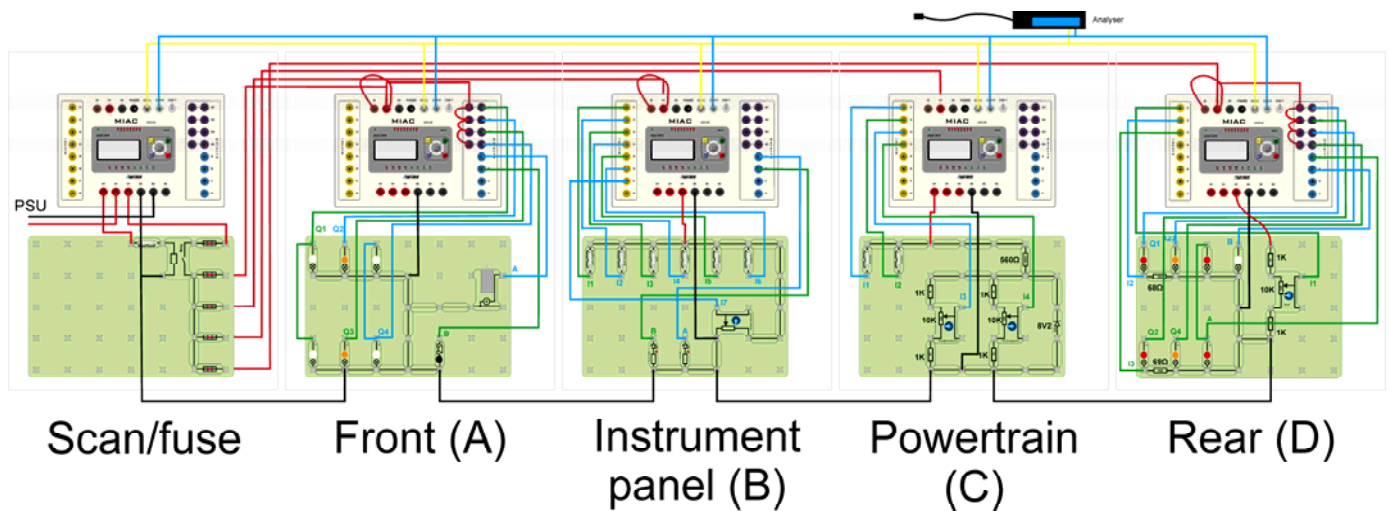
- construct and test a number of ECU nodes, using Locktronics equipment,
- wire these up into a single CAN bus system,
- carry out a range of tests on the whole system.

In doing so, you will learn about:

- the role of the ECU;
- the structure of CAN bus systems;
- the CAN bus message format
- the use of scan tools in fault diagnosis.

Overview

CAN bus systems and operation



Node by node

Your group is going to build five nodes. These are:

Node A - the front ECU and circuit, (side lights, headlights, indicators, wipers and horn,)

Node B - the instrument panel ECU and circuit, (lighting switches, horn switch, wiper speed controller, indicator switches, and warning LEDs,)

Node C - the power train ECU and circuit, (reversing switch, brake light switch, engine temperature sensor and oil pressure sensor,)

Node D - the rear ECU and circuit, (side lights, indicators, brake lights, reversing light, fuel level sensor,)

Scan/fuse - the system controller and scan tool, fuse box and power relay

The number of nodes, and how they are configured, varies greatly from one car to another. Different manufacturers use different software, and different messages within their CAN bus systems. The system used in this course is broadly representa-

tive of systems found in cars.

Each node consists of an ECU and the associated circuitry required to control the devices attached to that node. Each node is supplied with power, ground and the two wires, called CAN High (CANH) and CAN Low (CANL). In motor vehicles, these CAN wires are twisted together.

Note - The Scan/fuse node is not present as such in a car. It is included to allow us to control the overall system and to provide tools to help you understand what is happening.

The whole system can be seen in the diagram above. Do not worry if this looks very complicated - all the wiring will be explained as the course progresses.

Your instructor will provide your group with a larger version of this picture.

Building Node A

CAN bus systems and operation

The following pages describe how to build and test each of the five nodes, consisting of an ECU and the associated circuit to control the components attached to the node. All MIAC units are programmed with the same Flowcode program, called LK8902. Users will choose the function of each ECU unit from a menu offered on power up.

Over to you:

1. Wire up a MIAC unit and Locktronics equipment, as shown in the diagram on the right. This mimics the circuit you might find on the front of a car.
2. Set the voltage on the power supply to 13.5V.
3. Switch on. You will see a message:

```
Locktronics
LK8902
CAN bus systems
and operation
```

followed by:

```
Select a node
A
```

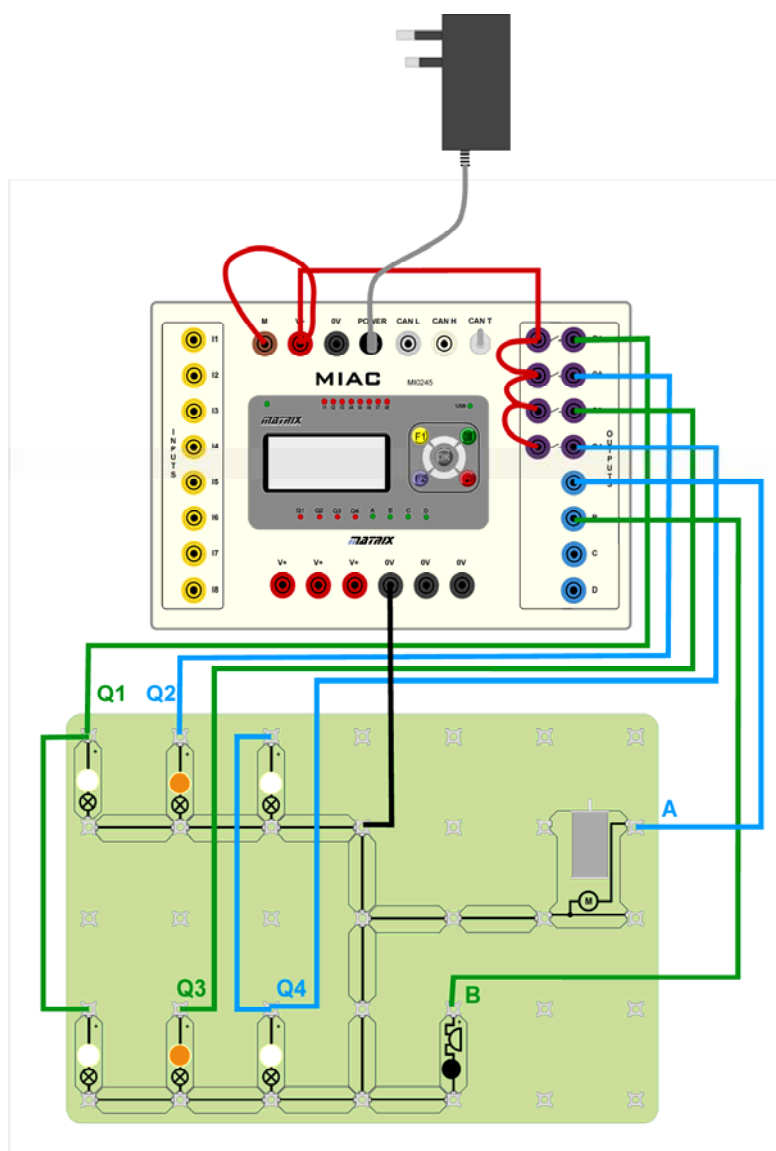
4. Press the OK button to select node A.
5. You should see a message:

```
Node A
F1: Node test
F2: CAN system
OK: Change node
```

Press the F1 button on the MIAC

6. The motor, each indicator and each pair of headlamps should come on in turn with the appropriate message on the MIAC unit. If the motor does not turn, or the lamps fail to light then check your wiring.
7. Press the reset button (top right on the MIAC) to stop the test.

Node A represents the front ECU. The lamps on this node mimic the side lights, headlights and indicators. The motor represents the windscreen wiper motor. The buzzer represents the horn.



Building Node B

CAN bus systems and operation

This node represents the ECU that controls the instrument panel.

To help you keep track of the functions of the various switches you may wish to label each Locktronics switch carrier with its function.

The switches on this node mimic (left to right) side lights, headlights, left indicator, right indicator, horn and wipers.

The potentiometer controls wiper speed.

The left hand LED is the fault light which illuminates whenever a fault is detected. It will not go off until the fault is reset on the Scan/fuse node.

The LED on the right represents the low fuel warning light.

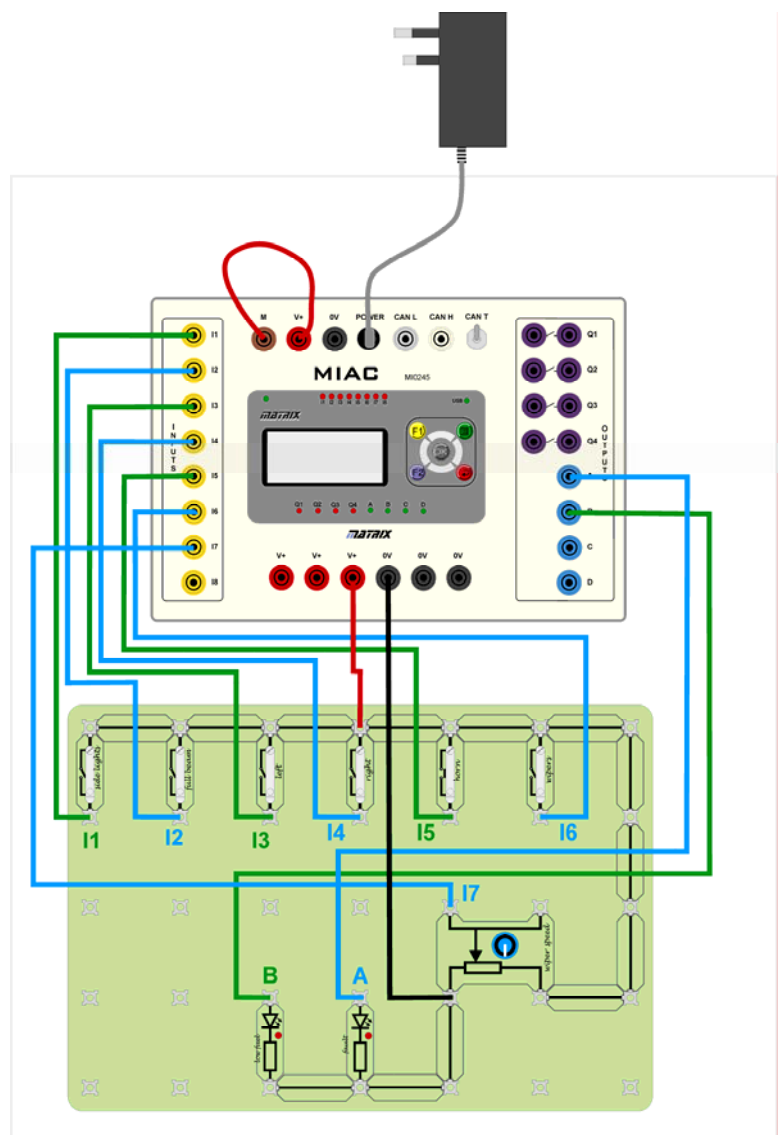
Over to you:

1. Wire up a MIAC and the circuit shown opposite for Node B. This circuit mimics the switches and controls on the instrument panel.
2. Set the voltage on the power supply to 13.5V.
3. Switch on.
4. Select 'Node B' from the menu system using the up / down keys on the MIAC.
5. You will see the message:


```
Node B
F1: Node test
F2: CAN system
OK: Change node
```

Press the F1 button on the MIAC

6. Look at the MIAC panel and check that each switch and the potentiometer are performing their appropriate functions. The potentiometer should give a readout of 0 (minimum) to 255 (maximum). If the circuit does not function as expected then check your wiring.
7. Press the reset button (top right on the MIAC) to stop the test.



Building Node C

CAN bus systems and operation

This node represents the ECU that controls the power train.
In motor vehicles, this ECU controls functions such as fuel injection and ignition timing.

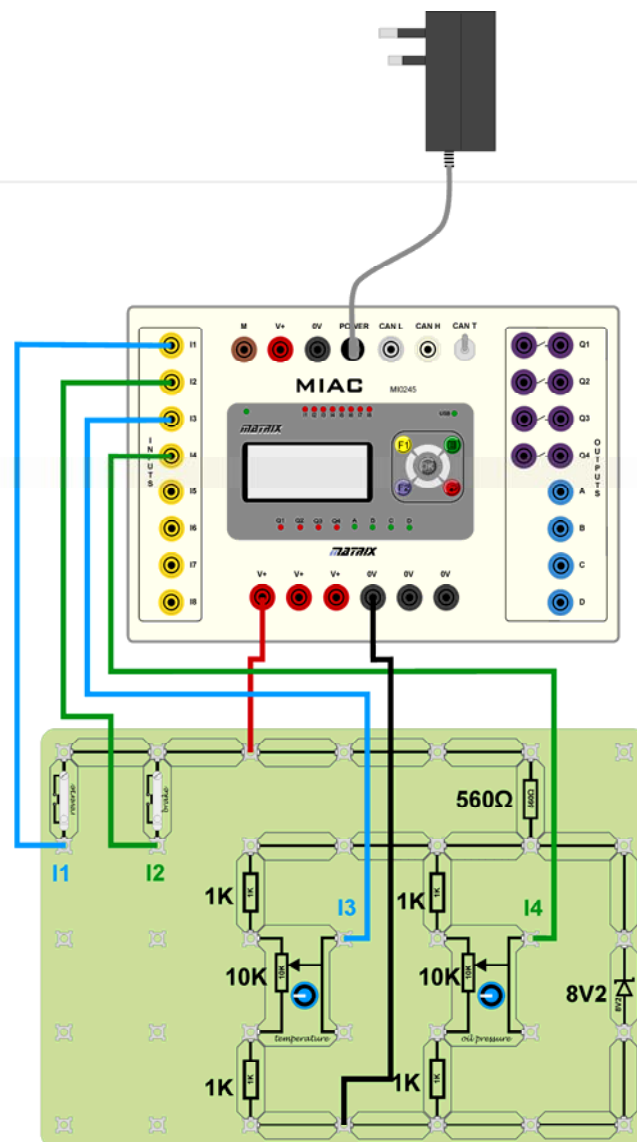
The switches on this node (left to right) mimic the reverse switch in the gearbox, and the brake switch on the brake pedal.

The two potentiometers represent the engine temperature sensor and oil pressure sensor.

Over to you:

1. Wire up a MIAC and the circuit shown opposite for Node C. This circuit mimics some of the switches and sensors that are connected to the power train ECU.
2. Set the voltage on the power supply to 13.5V.
3. Switch on.
4. Select 'Node C' from the menu system using the up / down keys on the MIAC.
5. You will see the message:


```
Node C
F1: Node test
F2: CAN system
OK: Change node
```
6. Press the F1 button on the MIAC and look at the MIAC panel and check that each switch and the potentiometer are mimicking their appropriate functions. The potentiometer should give a readout of around 21 (minimum) to 234 (maximum).
7. Press the reset button (top right on the MIAC) to stop the test.



Building Node D

CAN bus systems and operation

This node represents the ECU that controls the functions at the back of the motor vehicle. These are usually mainly lighting components.

The lamps on this node mimic the various lamps controlled by the rear ECU: side lights, indicators, brake lights and a reversing light.

The potentiometer represents a fuel sensor.

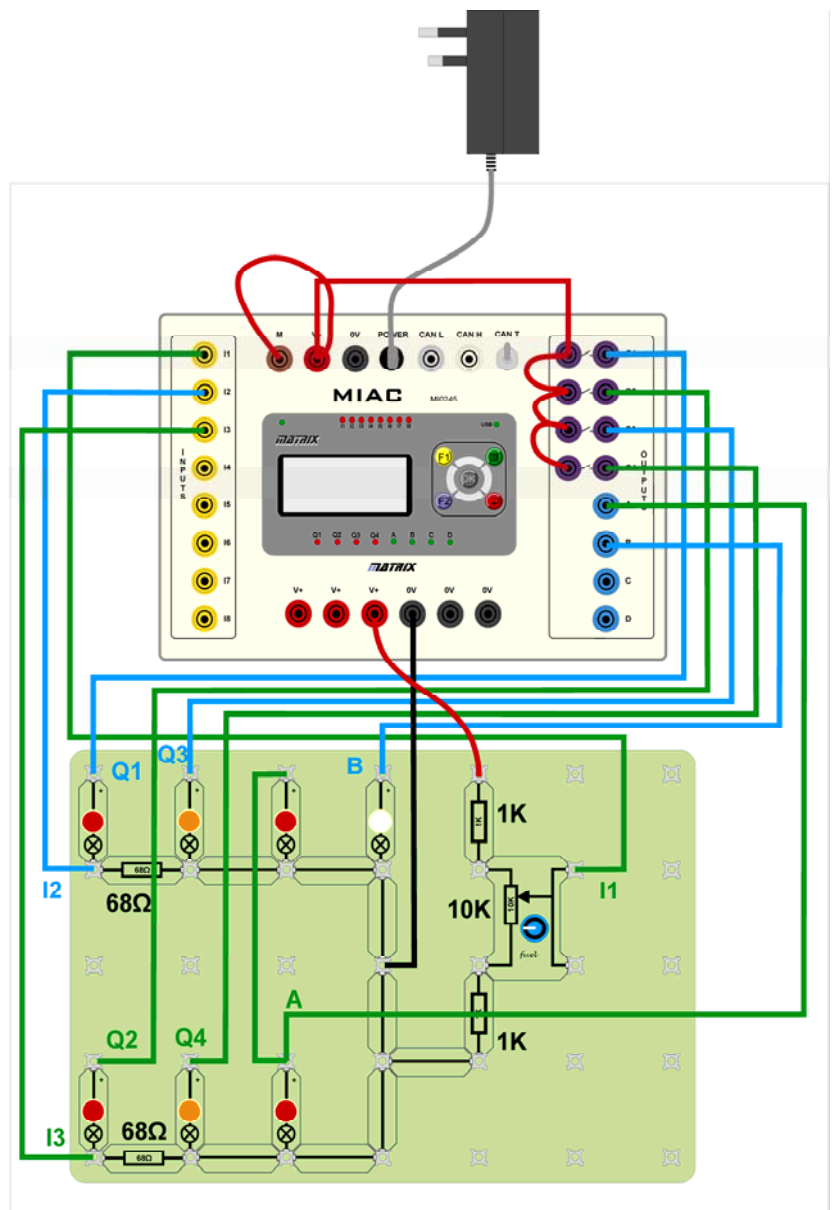
Over to you:

1. Wire up a MIAC and the circuit shown opposite for Node D, which mimics the indicators and sensors connected to the Rear ECU.
2. Set the voltage on the power supply to 13.5V.
3. Switch on.
4. Select 'Node D' from the menu system using the up / down keys on the MIAC.
5. You should see a message:

```
Node D
F1: Node test
F2: CAN system
OK: Change node
```

Press the F1 button on the MIAC

6. Look at the MIAC panel and check that the potentiometer is mimicking the fuel sensor. Check that all the lamps are working - if not then check your wiring.
7. Press the reset button (top right on the MIAC) to stop the test.



Building the Scan/fuse Node

CAN bus systems and operation

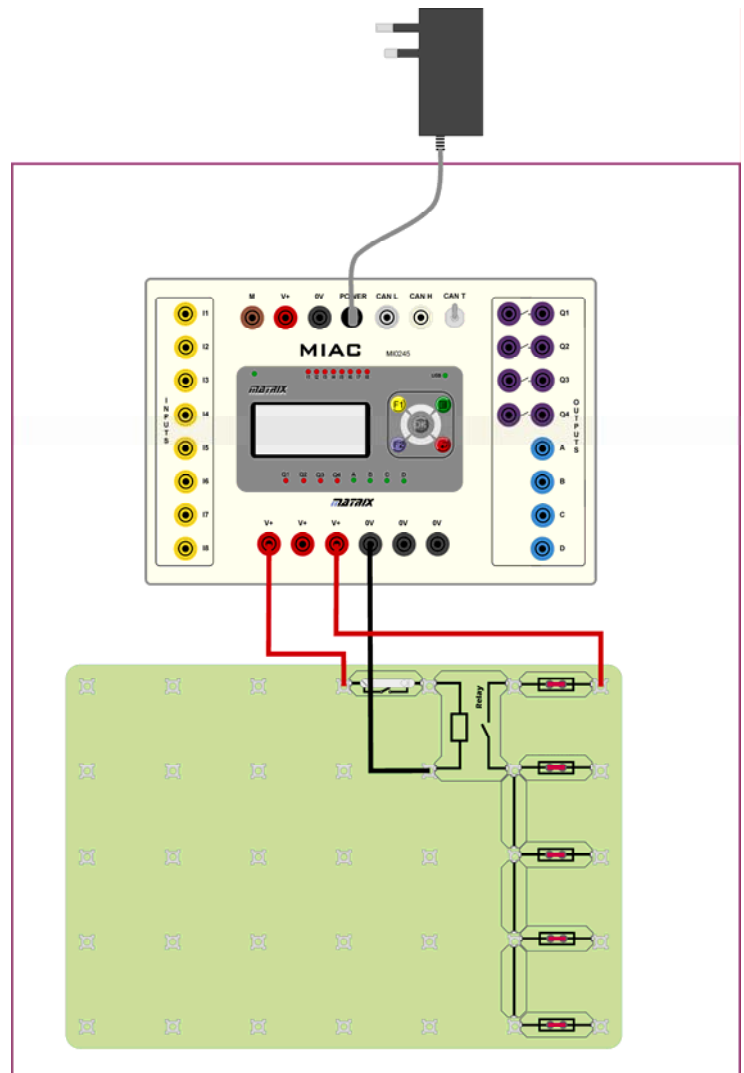
This node is not found in the motor vehicle itself, but may be part of the troubleshooting equipment used by mechanics to locate faults.

The equipment attached to this ECU represents a basic fuse box.

You would not find a single power relay like this in a car - but it helps to control this system. The first fuse limits the current into the overall system, and each additional fuse limits the current to a particular node.

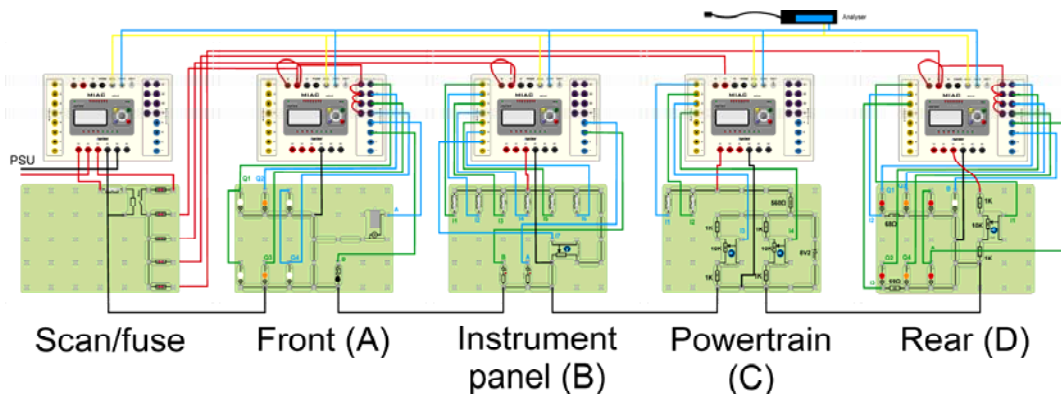
Over to you:

1. Wire up a MIAC and the circuit shown opposite for the Scan/fuse node. The circuit connected to the MIAC mimics the fuse box. The switch represents the ignition key which controls the power supplied, via the relay and fuses, to each of the ECUs in the system. This MIAC monitors the other nodes. It does not play a part in controlling any functions in the automotive system. It will be used later on in the course to insert faults and to monitor CAN signals.
2. Set the voltage on the power supply to 13.5V.
3. Switch on.
4. Select 'Admin' from the menu system using the MIAC's up / down keys.
5. You will see the message:
Admin node
6. Check that you can scroll through the six options on the menu using the up / down keys.
7. Check that your circuit is working by checking the output voltages on the



Wiring It All Up

CAN bus systems and operation



Your group now has wired up and tested the individual nodes of the CAN bus system. Next, you need to connect them all together.

Over to you:

The power supply:

All nodes will receive power from the 'fuse box' attached to the Scan/fuse node.

1. With the power supply turned off, connect a 13.5V power supply to the MIAC and relay on the Scan/fuse node.
2. Connect wires from each fuse to power one of the nodes A to D. In this way, each ECU has its own fuse.
3. Connect the 0V terminals on all nodes together.
4. Switch on the power supply. If you have wired everything up correctly the power LED on each MIAC will light up. If not, then check your wiring.
5. Switch off.

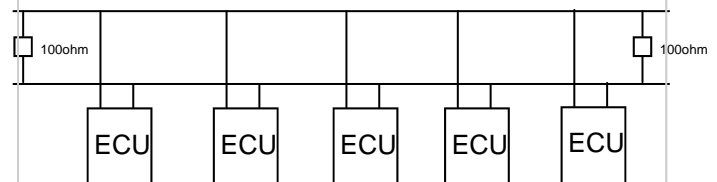
Connecting the CAN bus

The CAN bus consists of just two wires. CAN H (for CAN High) and CAN L (for CAN Low). In a motor vehicle, these are normally very fine wires that are twisted together - known as a 'twisted pair'. The nodes are wired in parallel, i.e. CAN H of node D is connected to CAN H of nodes A, B and C. CAN L is wired up in the same way.

Notice that there is no physical hierarchy in the CAN bus system - no central server. All nodes have equal status.

For clarity, use blue wires for CANH and yellow wires for CANL connections.

The CAN bus requires a 100Ω resistor, connected between CAN H and CAN L, at each end of the CAN bus, as shown in the diagram:



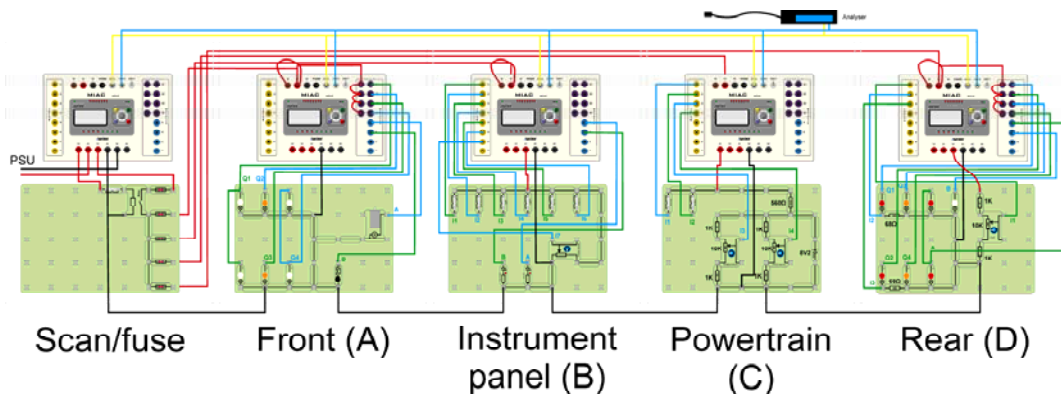
These resistors absorb the energy of the data signals, and prevent reflections back down the bus. The MIACs contain suitable resistors, connected internally between the CAN H and CAN L wires.

6. On the Scan/fuse node and on node D, turn the 'CAN termination' switch to the 'ON' position.
7. Check that the 'CAN termination' on the other MIACs is switched off.
8. The system is now ready for testing.

Worksheet 1

The Startup Routine

CAN bus systems and operation



All MIAC units are running the same program. The hardware inside each MIAC is the same. They carry out different functions, as separate nodes, because of choices you made when the nodes were set up. These choices are stored in memory, so that the MIAC remembers what functions to carry out when power is restored.

Over to you:

1. Set the voltage on the power supply to 13.5V.
2. Switch on and check that the power LED on each MIAC is lit.
3. Each MIAC ECU should display:


```
Node X
F1: Node test
F2: CAN system
OK: Change node
```

Select F2 to make the MIAC mimic the preset CAN bus function.

Note: Carry out this step last on Node C, as node C runs the Startup routine.

In the Startup routine one ECU in the system is programmed to check that all of the other ECUs are present.

Node C - the power train ECU - is often given this task. It sends a message on the CAN bus to each node in turn and waits for a reply. It will display 'Checking Node X' and then verify the presence of each node in turn.
4. Check that each node is registered.
5. Switch off.

6. Remove the fuse carrier for Node D
7. Switch on and select F2 to initialise each node, but do Node C last.
8. Look at the messages displayed on Node C.
9. Switch off, and replace the fuse carrier.
10. Repeat step 7.
11. What is the status of the fault light on Node B?
12. Discuss what should happen when a fault like this is detected.
 - Should the car start?
 - Should it be disabled?
 - What level of fault should be tolerated?
 - What faults are critical?
13. On the Scan/fuse Node menu, use the up/down keys to select 'Release flts'.
14. You will then see a sub menu:


```
Get fault info
Clear all faults
```
15. Select 'Clear all faults' and then press F2. The fault light on Node B will go off.

Worksheet 2

Seeing the Messages

CAN bus systems and operation



The Scan/fuse Node takes no part in controlling components in our CAN bus system. It is just another computer connected to the CAN bus, which helps us to see what is going on in the system.

It has some features that are found in the scan tools used in automotive diagnostics. These vary greatly in their features and complexity. Some just report faults. Others both report faults and allow you to reset them. Some connect to a PC, while others have a hand-held display.

Over to you:

1. Set the voltage on the power supply to 13.5V.
2. Switch on and check that the power LED on each MIAC is lit.
3. On the Scan/fuse Node, use the up / down keys to select the `Msg monitor` option.
The Scan/fuse MIAC unit will now display messages sent on the CAN bus.
4. On Nodes B and C, turn off all switches.
5. Next, press each switch in the system and hold it down.
6. As you do so, make a note of the **first** message - there will be more than one - on the Scan/fuse Node.
7. Complete the table shown opposite.

Sensor	ID	D0
Side lights (A1) switch on	8	1
Full beam (A2) on		
Left (A3) on		
Right (A4) on		
Horn (A5) on		
Wiper (A6) on		
Reverse (B1) on		

Worksheet 2

Seeing the Messages... continued...

CAN bus systems and operation

Messages are at the heart of the CAN system. Without them, it's just a load of wires and circuit boards.

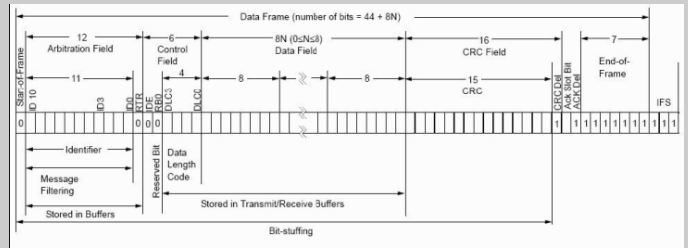
Each message contains an identifier (ID) and data. Actually, there's more – acknowledgment bits, checksums, transmission details etc. which need not worry us now.

A node will accept or reject a message, depending on its ID. Messages can contain data or be completely empty. Simple signals, such as 'turn on the horn' need little data. For others, e.g. engine temperature readings, more data is transmitted. Each message frame can contain up to eight bytes of data, (D0 to D7). (A byte is an eight bit binary number. It can identify up to 256 different conditions.)

Unfortunately, different manufacturers use different codes within this structure. Our CAN bus system is relatively simple and designed to illustrate principles. It uses only the **ID** and **D0** bytes, and does not populate the D1 to D7 bytes.

Each ECU puts a message onto the CAN bus when an event occurs.

In our system, when the horn switch is pressed, for example, the ECU on Node B transmits the message: **ID 5 D0 1** and, when released, sends the message :**ID 5 D0 0**



Over to you:

1. You are now going to investigate the message structure. Complete the table opposite for all switches and sensors, writing down the ID and D0 value for each of the 'on' (switch pressed) and 'off' (switch released) messages.
2. Discuss how D0 is used to indicate switch status.
3. Carry out a similar exercise for the fuel and other sensors in the system. How is D0 used to give an indication of the quantity being measured?

Sensor	ID	D0
Side lights (A1) switch on	8	1
Side lights (A1) switch off	8	0
Full beam (A2) on		
Full beam (A2) off		
Left (A3) on		
Left (A3) off		
Right (A4)		
Right (A4) on		
Horn (A5) on		
Horn (A5) off		
Wiper (A6) on		
Wiper (A6) off		
Reverse (B1) on		
Reverse (B1) off		

Sensor	ID	D0
Fuel level empty		
Fuel half full		
Full fuel tank		
Wiper half speed		

Worksheet 3

Receiving Messages

CAN bus systems and operation



iStock_000003887872Small.jpg

You have seen that when a switch is pressed or released, or when a sensor value changes, the corresponding ECU sends an appropriate message to other parts of the system so that they can react.

In this assignment, we test an ECU's ability to receive messages. In our simplified system this is easy because we can see a light flashing, the horn comes on etc. However, we can also use the Scan/fuse Node to allow us to send messages to the

Over to you:

1. Set the voltage on the power supply to 13.5V.
2. Switch on and check that the power LED on each MIAC is lit.
3. On the Scan/fuse Node, use the up / down keys to select the `Send message` option.
4. Construct a 'switch horn on' message by setting `ID=5` and `D0=1`.
5. Press the 'OK' button to send this message.
6. What happens?
7. Press and release the horn switch on node B. Notice what happens.
8. Look up the codes to turn the brake lights on and off. Use the Scan/fuse node 'Send message' feature, to make the brake lights go on and off.
9. Turn the fuel sensor potentiometer to the 'full' position.
10. Use the Scan/fuse node 'Send message' feature to send a message

In this exercise you fooled Node A into believing that the horn switch on Node B was pressed. In doing so, you showed that Node A is receiving messages correctly.

We all know that computers are stupid. They do only what they are told. This also applies to ECUs. If they get the wrong message, they carry out the wrong action.

Good system design can - to some extent - prevent this.

Worksheet 4

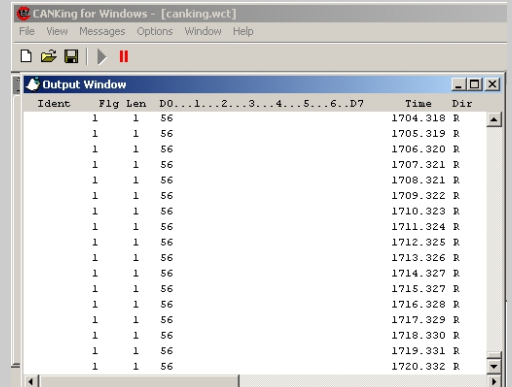
System Monitoring and 'Pinging'

CAN bus systems and operation

In worksheet 2, you used the Scan/fuse Node to monitor messages on the CAN bus. This method has a major limitation - it only shows one message at a time.

In this exercise you are going to use a different approach which will show **all** the messages over a period of time.

This uses the Kvaser CAN bus Analyser, connected to a computer. The Kvaser Analyser gives a detailed breakdown of the sequence of messages sent on the bus and shows the order in which they were sent.



Over to you:

1. Set the voltage on the power supply to 13.5V, but do not switch on yet.
2. Connect the Kvaser Analyser into the CAN H and CAN L connections on Node C using the adaptor cable provided.
3. Start the CANKing software using the 'Kvaser Analyser Setup' page to help.
4. Switch on and check that the power LED on each MIAC is lit.
5. Wait a few seconds and then press 'F2' on each MIAC in turn, leaving Node C till last.
6. The first operation in the system is the Startup routine, which you looked at earlier. Node C first sends a message to Node A to ask if Node A is present. Node A replies. This dialogue is often known as a 'ping'. Node C then pings Node B, then Node D.

In the table, note down the ID and D0 values that correspond to the two parts of the 'ping' message, for each of the nodes.

7. Switch off.
8. Remove the CAN connections to node A.

Message	ID	D0
Are you there Node A?	40	0
Node A status - node missing		
Are you there node B?		
Node B status - node present		
Are you there node D?		
Node D status - node present		

Message	ID	D0
Are you there Node A?	40	0
Node A status - node present	40	1
Are you there node B?		
Node B status - node present		
Are you there node D?		
Node D status - node present		

9. Switch on and repeat step 5.
10. In the second table, note down the new ID and D0 values that appear on the CAN bus.
11. What do these messages mean?

This sequence demonstrates how an automotive system is able to check that each part of the system is in place.

This can be taken a step further: in automotive ECUs each node will also check the status of some of the sensors and actuators that are connected to it and report this status.

Worksheet 5

System Faults

CAN bus systems and operation

You have seen that CAN bus messages can transmit the status of sensors and control actuators and lamps. Here is a new use of the CAN bus message system - to report faults - current or historical.



Over to you:

In the last exercise, the fault light lit on Node B, the instrument panel, when you switched on again after removing the CAN bus wires from Node A.

1. Switch off.
2. Reconnect node A to the system
3. Switch on. Is the fault light on Node B still on?

The answer should be 'Yes'. The system has remembered that there was a fault. In practice this is useful for technicians who need to know that a fault has occurred, especially when the fault is intermittent .

Over to you:

1. Next you need to clear the fault. From the Scan/fuse Node menu use the up / down keys to select 'Release flts'.
2. You will then see a sub menu:
 - Get fault info
 - Clear all faults
3. Select the 'Get fault info' option, and make a note of the fault in the table.

Fault description	ID	D0

4. Next, select 'Clear all faults.' The fault light on Node B will go off.
5. Power the system down, and remove the fuse for Node A.
6. Power up. Press 'F2' on each MIAC in turn, leaving Node C till last.
7. Use the Scan/fuse MIAC to get the fault message and the fault **ID** and **D0** values. Record them in the table below.

Fault description	ID	D0

8. Clear the fault and replace the fuse.
9. Repeat steps 5, 6 and 7, removing the fuses for Nodes B and D. Again, record your results.

Worksheet 5

System Faults ...continued...

CAN bus systems and operation

Over to you:

10. Switch off.
11. Unplug the CAN wires from Node A, but leave the CAN connection between the Scan/ fuse Node and Node B in place.
12. Switch on.
13. Press 'F2' on each MIAC in turn, leaving Node C until last, as usual.
14. Record the fault information.

Fault description	ID	D0

15. How does this compare to the fault information when you removed the fuse for Node A?
16. Reset the fault and restore the circuit.
17. Remove the 0V line from Node A, but make sure 0V is connected to all other nodes.
18. Record the fault information.
19. How does this compare to the fault information when you removed the fuse for Node A?

Clearly this system is not perfect! It can tell us that Node A was faulty but can not necessarily tell us exactly what the fault is. There could be several reasons for the same fault - fuse blown, CAN bus connection down, ECU faulty, etc

Worksheet 6

Circuit Faults

CAN bus systems and operation

Clever design of the ECU and associated circuit can help in fault diagnosis and ensure that 'mission critical' systems are monitored adequately.

Over to you:

1. Switch off
2. Rebuild the system and check it works.
3. Press and then release the brake switch.
4. Note the Kvaser Analyser codes in the following table:

Kvaser sequence	ID	D0
Brake (B2) switch on	8	1
Left brake bulb on verified		
Right brake on verified		
Brake switch off		
Left brake bulb off verified		
Right brake off verified		

5. Remove a brake bulb.
6. Repeat steps 3 and 4. Record the codes in the following table:

Kvaser sequence	ID	D0

Here is a new fault code on the CAN bus! The resistors in series with the brake lights on Node D produce a small voltage each time a brake light comes on. If the ECU cannot detect that small increase in the voltage, it transmits a fault code. The system designer chooses which components need this close monitoring.

7. Note the CAN bus messages relating to faults on both the left and right brake lights in the next table.

Kvaser sequence	ID	D0
Left brake light fault		
Right brake light fault		

Our system designer wanted to check the brake light performance each time they were used. In practice many systems check circuitry only on Startup. For the fuel, oil pressure, and engine temperature sensors, additional resistors are included in the sensor to help verify sensor performance. Additional connections to the ECU are also needed.

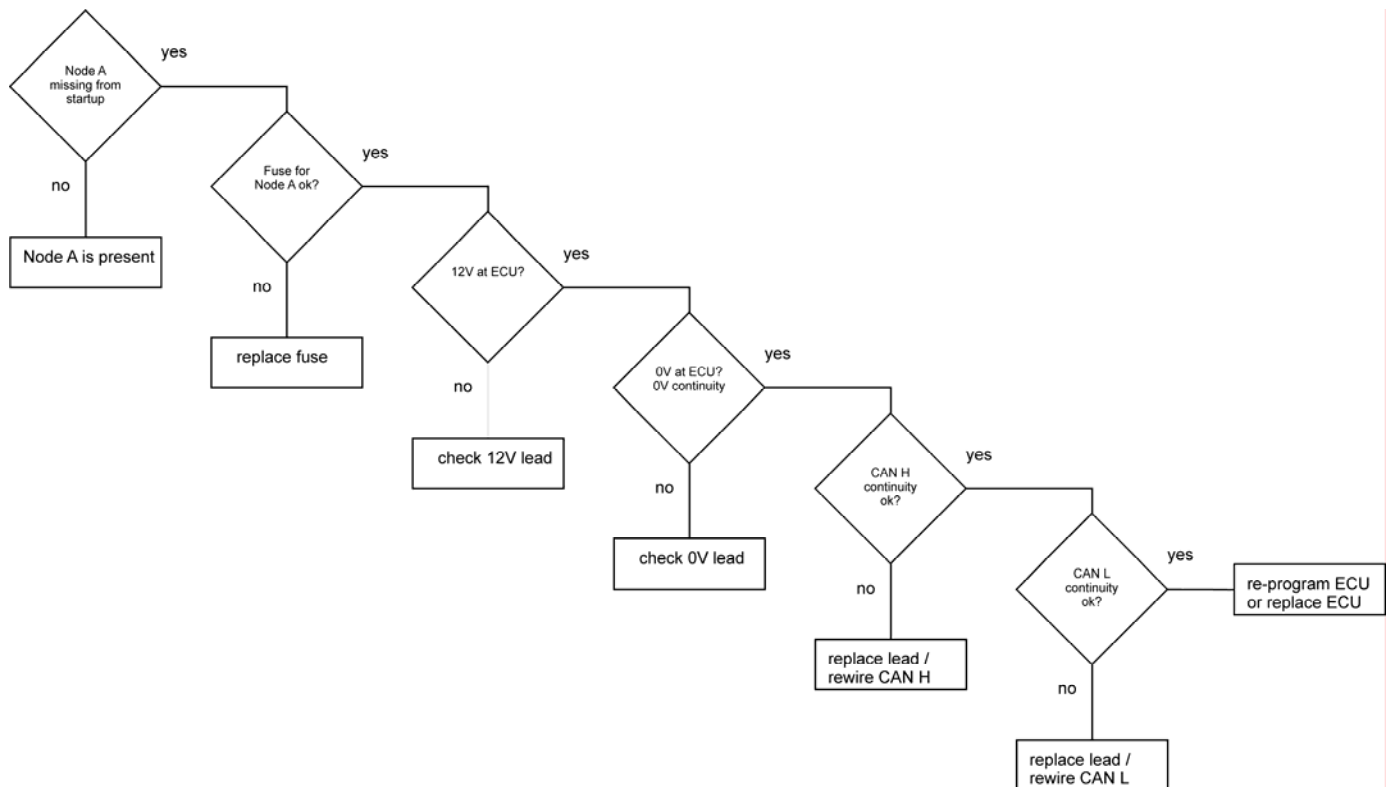
8. For the Oil Pressure and Engine Temperature sensors, short circuit the sensor output - first to ground and then to +V.
9. Use the Kvaser Analyser and the Scan/fuse Node to find the CAN bus fault information.
10. Fill in the table.

Fault	ID	D0
Oil pressure short to ground		
Oil pressure short to +V		
Engine temp. short to ground		
Engine temp. short to +V		

Worksheet 7

Fault Diagnosis Using Charts

CAN bus systems and operation



Fault diagnosis is often carried out using a flow chart. In this section we are going to look at this in more detail.

In worksheet 5 you found that a number of faults can lead to the same error message, in this case 'Node A missing'.

It would be helpful to have a flow chart that listed the items to check, and detailed the remedies, for each kind of fault.

Many manufacturers produce flow charts that are designed for this purpose.

The flow chart shown above is an example of this approach.

Over to you:

1. Your instructor has the ability to introduce faults into the CAN bus system.. These could be in the components, the wiring, the ECU or the ECU software.
2. Using your knowledge of CAN bus, the Kvaser Analyser, the Scan/fuse node, and multimeters, find out where the fault lies.
3. For each fault, construct your own fault diagnosis chart to show the checks you have made.

Good luck!

Worksheet 8

Build Your Own Car!

CAN bus systems and operation

A complete panel of automotive parts, like the one shown, can be connected to, and be controlled by, the CAN bus system you have been studying.



Over to you:

The aim of this exercise is to rewire parts of the CAN bus system using real components from a car. Your instructor will provide some light clusters and steering wheel controls.

1. Use a multimeter to find out as much as possible about how each component and its connector are wired.
2. Connect each component to a switch and power supply. Measure the current taken by the component. Note down the current requirements of the components you are using. The MIAC ECU is limited to around 500mA from the transistor outputs on the MIAC and around 8A on the relay outputs. You may need to use additional relays to boost output current.
3. Once you fully understand the connectors and current requirements of a component, connect it to the appropriate MIAC ECU terminal on the CAN bus system.
4. Connect the CAN bus system to a real car battery, or one of the Locktronics high current power supplies. Make sure that fuses are in place and are correctly rated.
5. Switch on and test the modified CAN bus system.
6. Troubleshoot any faults using the flow charts you developed during the previous exercise.

Instructor Guide

CAN bus systems and operation

About this course

Introduction

This course uses Locktronics and MIAC equipment to give students hands-on experience of CAN bus systems, their operation and troubleshooting.

The distinctive, possibly unique, approach starts by allowing students to investigate the system, through a series of structured exercises. This slowly builds their understanding of what CAN bus systems can do. This is in contrast to the traditional approach of immersing students in masses of theory about CAN bus, and then expecting them to apply this to real systems and situations.

Aim

The course aims to introduce pupils to the CAN bus protocol and how it can be used to control and monitor the electrical components in a motor vehicle. The Kvaser CAN bus Analyser is introduced as a CAN bus monitoring and diagnostic tool.

Prior Knowledge

It is recommended that pupils have completed the following courses, or have equivalent knowledge and experience of electrical circuits and sensors:

- 'Electricity Matters 1';
- 'Electricity Matters 2';
- 'Sense and Control'.

Learning Objectives

On successful completion of this course the pupil will have learned:

- the advantages offered by CAN bus over traditionally connected components:
 - reduction in size, complexity and weight of wiring loom;
 - extra functionality - troubleshooting, monitoring, control;
- how to create nodes within the vehicle electrical system, each controlled by its own ECU;
- how to connect together a number of nodes using the CAN bus system;
- to describe the message structure, consisting of ID and data, used within CAN bus;
- how to create and send messages to control components
- how to terminate the CAN bus network correctly;
- the need for separate fuses for each node ECU;
- the function of the Start up routine;
- the benefits of using a CAN bus analyser such as the Kvaser Analyser, in troubleshooting;
- how intelligent design can be used to trap faults in systems
- how to fault find CAN bus systems
- how to interpret a range of fault codes, and to release them;
- how to create and read a fault-diagnosis flowchart to troubleshoot a particular fault;
- to connect real vehicle components to a CAN bus network.

Instructor Guide

CAN bus systems and operation

What the students will need:

To complete this course each student group, (up to 10 students,) will need the following equipment (Order codes are included to assist the instructor.):

Node A

1	Baseboard	LK8900
13	Connecting links	LK5250
6	Automotive lampholders	LK5287
4	MES bulb 12V, LED, white	LK6841
2	MES bulb 12V, LED, yellow	LK6822
1	12V motor	LK6706
1	Buzzer, 12V	LK3246

Node B

1	Baseboard	LK8900
13	Connecting links	LK5250
1	Press switches	LK6207
5	On/off switches	LK6209
1	10K potentiometer	LK6630
2	LEDs, 12V, red	LK6430

Node C

1	Baseboard	LK8900
15	Connecting links	LK5250
2	Press switches	LK6207
2	10K potentiometer	LK5214
4	1K resistors	LK5202
1	560ohm resistor	LK6219
1	8V2 Zener diode	LK5254

Node D

1	Baseboard	LK8900
8	Connecting links	LK5250
1	10K potentiometer	LK5214
2	1K resistors	LK5202
7	Automotive lampholders	LK5287
1	MES bulb 12V, LED, white	LK6841
2	MES bulb 12V, LED, yellow	LK6822
4	MES bulb 12V, LED, red	LK6749
2	68R resistors	LK5217

Scan/fuse Node

1	Baseboard	LK8900
3	Connecting links	LK5250
5	Automotive fuse holders	LK4786
1	On/off switches	LK6209
1	12V relay	LK5280

Other components

7	Lead, red, 500mm	LK5603
11	Lead, red 100mm	LK5598
8	Lead, black, 500mm	LK5604
23	Lead, blue, 500mm	LK5609
23	Lead, yellow, 500mm	LK5607
5	MIAC controller	MI0245
5	Shallow plastic tray	HP2045
8	Tray lid	HP4039
3	Deep tray	HP5540
3	62mm daughter tray	HP9564
3	Daughter tray insert foam	HP7750
1	Flowcode 3	TEFLCSI3
1	Kvaser CAN bus analyser	EL239
1	D-type to 4mm lead	LK5695
4	International power supply	HP5328
1	15V power supply, 25A	HP0056
4	Lead, red, 2000mm	LK6574
1	USB lead	HPUAB
1	15V, 25A power supply	HP0056
1	Curriculum pack CD ROM	LK6492

Fault components

Fault components are supplied in working order. You will need to make them faulty, and then store them separately.

1	1K resistors	LK5202
1	Automotive fuse holder	LK4786
1	Lead, red, 500mm	LK5603
1	Lead, black, 500mm	LK5603
1	Lead, blue, 500mm	LK5609
1	Lead, yellow, 500mm	LK5607

2 spare links (LK5250) are also included in the pack.

Programs

CAN bus program LK8900
This program is contained on the LK6492 CD ROM.

Instructor Guide

CAN bus systems and operation

Using this course: A suggested pathway:

- Create the student groups. As there are five nodes to construct separately, and then wire together, it is suggested that a group consists of five students.
- Distribute copies of the following to each student:
 - 'Introduction' (page 3) (to keep)
 - 'Overview' (page 4) (to keep)
 - 'Building Node A' (page 5) (not to keep)
 - 'Building Node B' (page 6) (not to keep)
 - 'Building Node C' (page 7) (not to keep)
 - 'Building Node D' (page 8) (not to keep)
 - 'Building the Scan/fuse Node' (page 9) (not to keep)
 - 'Wiring It All Up' (page 10) (to keep)

In this way, everyone in the group has a record of the functionality of each node.

- Allocate tasks to each member of the group. For example:
 - where the group consists of five students, allocate to each student a particular node;
 - where there are ten students in the group, split it into five pairs and allocate to each pair one of the nodes. Within each pair, designate one to carry out the construction, and the other to run the testing of the node.
- While it may be tempting to present the group with a pre-assembled CAN bus system, it is much more productive, educationally, to allow the students to build the nodes for themselves. Only where time is critically short should the pre-assembled option be considered.
- To make it easier to recognise what is happening, the students should label the switches, sensors and output components. Similarly, the group should be given a large print out of the whole CAN system, (provided on the page 33 of this manual.)
- Once all nodes are built and tested, the designated constructors go on to link together the nodes to form the CAN bus system.
- At this point, distribute copies of worksheets 1 to 8, for the students to complete and keep.

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CAN bus systems and operation

Using this course: A suggested pathway continued...:

Each worksheet has:

- an introduction to the topic under investigation;
- step-by-step instructions for the investigation that follows, in a section titled 'Over to You';

Their results are recorded in tables in many cases. The instructor should check these and discuss their significance with the student to ensure that appropriate learning is taking place. The timings provided in the Scheme of Work that follows do not take into account this reinforcement of learning.

This format encourages self-study, with students working at a rate that suits their ability. It is for the instructor to monitor that students' understanding is keeping pace with their progress through the worksheets. One way to do this is to 'sign off' each worksheet, as a group completes it, and in the process have a brief chat with them to assess their grasp of the ideas involved in the exercises it contains.

Time:

It will take the group between five and seven hours to complete the course. It is expected that a similar length of time will be needed to support the learning that takes place as a result.

Instructor Guide - Scheme of Work

CAN bus systems and operation

Page	Notes for the Teacher	Timing
	<p>Pages 3 to 10 give the student an overview of the course, and details of what each node does in the CAN bus system.</p> <p>Once the system is built, then there is a series of eight worksheets, exploring what the system can do.</p>	
3	<p>This introduces the CAN bus protocol, and describes the hardware used in the course to simulate a CAN bus system. It is important that students have a grasp of what ECUs do in a motor vehicle.</p> <p>Each student should have, and should read through pages 3 to 10, even though they will be principally concerned with the construction and testing of only one node. This will allow them to appreciate what is happening in the full CAN bus system.</p> <p>Students should be encouraged to compare and contrast the use of a CAN bus and ECUs, with the alternative of a wiring loom, consisting of current-carrying cables to dozens of electrical components in a car. CAN offers savings in weight, complexity, and maintenance time. In addition, close monitoring and predictive maintenance of each component is possible with CAN, but not possible with the conventional wiring loom.</p> <p>The instructor should provide additional time and resources to allow the students to carry out individual research into CAN bus systems.</p>	10 - 15 minutes
4	<p>This gives an overview, in the form of a wiring diagram, of the full system. The five nodes that make up the CAN bus system used in the course are described.</p> <p>Students should be encouraged to study this information carefully, and relate it to the layout of components in a typical motor vehicle.</p>	5 - 10 minutes
5	<p>This gives details on how to construct and test Node A. While only one student, or pair of students may be responsible for carrying this out, all students should study this sheet carefully.</p> <p>The lamps on this node mimic the various lamps on the front ECU: side lights, main beam and indicators. The motor mimics the windscreen wiper motor. Its speed is dictated by other parts of the system. The buzzer mimics the horn.</p> <p>For this course, all MIAC units are programmed with the same Flowcode program, called LK8902. Users then choose the function of each MIAC unit from a menu offered on power up. Instructions for downloading programs to the MIAC are given in the MIAC 'Getting Started' guide.</p>	<p>Reading time 5 - 10 minutes</p> <p>Construction and testing time 15 - 25 minutes</p>

Instructor Guide - Scheme of Work

CAN bus systems and operation

Page	Notes for the Teacher	Timing
6	<p>This gives details on how to construct and test Node B. While only one student, or pair of students may be responsible for carrying this out, all students should study this sheet carefully.</p> <p>The switches on this node control (left to right) side lights, full beam, left indicator, right indicator, horn and wipers, found on nodes A and D.</p> <p>The potentiometer controls wiper speed.</p> <p>The left hand LED is the fault light, which will illuminate whenever a fault is detected. It will not go off until the fault is reset using the Scan/fuse node. The LED on the right mimics the low fuel warning light.</p>	<p>Reading time 5 - 10 minutes</p> <p>Construction and testing time 15 - 25 minutes</p>
7	<p>This gives details on how to construct and test Node C. While only one student, or pair of students may be responsible for carrying this out, all students should study this sheet carefully.</p> <p>The switches on this node mimic (left to right) the reverse switch in the gearbox, and the brake switch on the brake pedal.</p> <p>The two potentiometers mimic the engine temperature sensor and the oil pressure sensor. (The 560ohm resistor and the 8V2 zener diode are used to provide an exact voltage for these two sensors to allow MIAC to make precise measurements.)</p>	<p>Reading time 5 - 10 minutes</p> <p>Construction and testing time 15 - 25 minutes</p>
8	<p>This gives details on how to construct and test Node D. While only one student, or pair of students may be responsible for carrying this out, all students should study this sheet carefully.</p> <p>The lamps on this node mimic the various lamps controlled by the rear ECU: side lights, indicators, brake lights and a reversing light.</p> <p>The potentiometer represents the fuel level sensor.</p>	<p>Reading time 5 - 10 minutes</p> <p>Construction and testing time 15 - 25 minutes</p>
9	<p>This gives details on how to construct and test the Scan/fuse node. While only one student, or pair of students may be responsible for carrying this out, all students should study this sheet carefully.</p> <p>The instructor should emphasise that this node may not exist on real motor vehicle CAN systems. Its job is to show students what is happening on the CAN bus, and allow them to intervene. On a vehicle, these functions are not needed. A mechanic may use similar tools when troubleshooting the system during maintenance or repair, in which case (s)he would use a CAN bus analyser like the one studied in worksheet 4, the Kvaser Analyser. This would be connected to the vehicle CAN bus during servicing.</p> <p>Continued on next page ...</p>	<p>Reading time 5 - 10 minutes</p> <p>Construction and testing time 15 - 25 minutes</p>

Instructor Guide - Scheme of Work

CAN bus systems and operation

Page	Notes for the Teacher	Timing
9	<p>Continued from previous page ...</p> <p>The software tools provided on this node allow students to see CAN messages on the system. They use these to build up a datasheet listing all the message transactions and their meaning</p> <p>The Scan/fuse node offers five options on the main menu: Change node / Msg monitor / Msg interpret Insert fault / Release flts / Send message</p> <p>You can use the up / down keys on the keypad to select these options.</p> <p>The Change node function allows you to change the node that the MIAC mimics.</p> <p>The Msg monitor function displays CAN message ID and data.</p> <p>The Msg interpret function shows the message ID and data, but in addition shows the equivalent function on the CAN bus.</p> <p>The Insert fault function allows you to insert one of two faults to mimic a faulty ECU: Relay output 1 on Node A not working ECU node D failure</p> <p>Release flts resets the fault recorder in node C and releases any faults set on any ECU. If you find Node D is not working then remember that the fault could have been inserted!</p> <p>Send message allows individual ID and data messages to be generated.</p> <p>The hardware attached to this node represents a basic fuse box. The first fuse limits the current into the overall system, and each additional fuse limits the current for one particular node. It is convenient to use the main switch for power up/down.</p>	<p>Reading time 5 - 10 minutes</p> <p>Construction and testing time 15 - 25 minutes</p>
10	<p>This gives details on how to wire together all five nodes using a CAN bus. Again, not all students will be actively involved in doing this, but all students should study this sheet carefully.</p> <p>Students should appreciate that, although the system they have created looks like a complex array of wires, when installed in a motor vehicle, the ECUs are more spread out. The only wires linking them are power cables and CAN bus connections.</p>	<p>Reading time 5 - 10 minutes</p> <p>Final wiring time 15 - 25 minutes</p>
11	<p>Worksheet 1 - the Startup Routine</p> <p>One advantage of the CAN bus over the traditional wiring loom is that it can check whether all components are present and communicating. This is done by the Startup routine.</p> <p>Only one node needs to run this check, in this case Node C. That is why all other nodes need to be initialised before Node C. (Students may be familiar with server-client computer networks, where all administration and checking is done by the server. The CAN bus system has no server. All nodes have equal status, like a peer-to-peer computer network.</p>	<p>20 - 30 minutes</p>

Instructor Guide - Scheme of Work

CAN bus systems and operation

Page	Notes for the Teacher	Timing
12	<p>Worksheet 2 - Seeing the Messages</p> <p>The extensive capabilities of the CAN bus system rely on the messages that flow between nodes. These monitor and control the components in the system. The protocol allows each message to carry eight bytes of data. In this way, a message could contain the engine temperature, or oil pressure, or seat position, or fuel level etc.</p> <p>The aim of this course is to illustrate the working of the CAN bus system. For simplicity, only one of the eight bytes of data, called D0, is used. Nevertheless, this can carry 256 ($= 2^8$) different messages.</p> <p>The worksheet introduces the students to this message system, by having them capture a number of messages on the Scan/fuse Node. These messages contain an identifier, unique to the source of the message, and data. The data may amount only to an 'On' or 'Off' signal.</p>	20 - 30 minutes
14	<p>Worksheet 3 - Receiving Messages</p> <p>This exercise has two aims. It checks that an ECU will receive, recognise and react to a CAN message aimed at a component under its control. Secondly, it shows that the Scan/fuse Node can initiate messages.</p> <p>An important function of the ECU is to filter messages present on the CAN bus, so that only those relevant to the components attached to its node are acted on.</p> <p>These messages are always trusted. In this case, the true state of the fuel level is overwritten by the Scan/fuse Node, and the ECU on Node B reacted accordingly.</p>	20 - 30 minutes
15	<p>Worksheet 4 - System Monitoring and 'Pinging'</p> <p>As pointed out earlier, the Scan/fuse Node does not exist on a CAN bus in a real motor vehicle. Instead, mechanics can use CAN analysers to investigate the system.</p> <p>The exercise here introduces the student to one such device, the Kvaser Analyser. Attached to Node C in this case, it reads and interprets messages from the CAN bus.</p> <p>The reference to 'pinging' comes from the world of computer networks, where small 'packets' are sent to remote devices, to check connectivity. The remote device returns ('echoes') the packet to demonstrate that a connection exists. ('Ping' is an abbreviated form of 'Packet Internet Groper'.)</p>	20 - 30 minutes

Instructor Guide - Scheme of Work

CAN bus systems and operation

Page	Notes for the Teacher	Timing
16	<p>Worksheet 5 - System Faults</p> <p>It is important that the system recognises fault conditions, and has a way of communicating them to the vehicle driver, and also to the mechanic servicing the vehicle.</p> <p>To do this, it must remember that a fault occurred even if the fault disappears temporarily. This ability is investigated here. One outcome is the recognition that several causes can result in the same fault message. Careful CAN system design can minimise this effect, but in the end, the mechanic is not made redundant by this system! Someone has to investigate exactly what is causing the fault, and correct it.</p>	20 - 30 minutes
18	<p>Worksheet 6 - Circuit Faults</p> <p>This exercise demonstrates the ability of CAN bus to recognise when a component such as a light bulb fails. However, the system designer must decide which components to monitor for failure, and when to monitor them. In other words, some components are regarded as more critical than others to the operation of the vehicle.</p> <p>Some component monitoring is carried out during the Startup routine. Obviously, the engine should not be started if the oil pressure sensor is malfunctioning.</p> <p>Students can be given the task of deciding which components should be monitored during Startup, and which should be monitored continually for failure. They should consider the consequences of component failure on the operation of the vehicle.</p>	20 - 30 minutes

Instructor Guide - Scheme of Work

CAN bus systems and operation

Page	Notes for the Teacher	Timing
19	<p>Worksheet 7 - Fault Diagnosis Using Charts</p> <p>Here the students are tasked with solving faults in the whole system.</p> <p>To facilitate this, we have provided spare components which you can make faulty. These are supplied as working components, to avoid any initial confusion. Once you have 'broken' these components please keep them separate. You have a choice of faults - either open or short circuit. Clearly leads would need to be made to be open circuit to be faulty. Faulty 1K resistors can be used to make introduce faults into sensors.</p> <p>By using these components, and / or by simply altering wiring, you should test students on the following faults:</p> <ul style="list-style-type: none"> CAN bus (H) - short to ground; CAN bus (L) - short to +V; CAN bus (H and L) - short to each other; CAN bus - open circuit; CAN bus - partial open circuit; Fuel sensor - short to +V; Fuel sensor - short to ground; Fuel sensor - +V open circuit; Fuel sensor - faulty at start of journey; Fuel sensor - faulty mid journey Fuse - 'blown' on path to Node B Power lead - open circuit on Node C Ground lead - open circuit on Node D ECU - motor failure on Node A ECU - relay failure on Node D <p>This is a time consuming exercise - but students will enjoy being challenged.</p>	45 - 60 minutes
20	<p>Worksheet 8 - Build Your Own Car!</p> <p>This is more of a project than a worksheet!</p> <p>You will need to provide a selection of car parts - light clusters, indicator stalks etc. Whilst Locktronics can help students to understand CAN bus systems in automotive systems, we believe that only with practice on real automotive components will students really believe that this is real technology as used in real automotive systems.</p> <p>Students will really enjoy this task, which allows them to combine elements of learning from this and the Sense and Control course, and apply theory to practice.</p> <p>Help sheets on each component should be made available in case students struggle to identify the relevant inputs and outputs.</p> <p>The instructor will need to observe how students set up power distribution for the system. It is likely that fuse values and possibly the power supply itself, may need to be changed.</p>	45 - 60 minutes

Instructor Guide - Codes used

CAN bus systems and operation

These tables show all of the codes used in this system.
Students can be given a copy of this sheet to help them with worksheet 7.

Action codes

Message	ID	D0
Are you there Node A?	40	0
Node A status - node present	40	1
Are you there node B?	41	0
Node B status - node present	41	1
Are you there node D?	42	0
Node D status - node present	42	1

Sensor	ID	D0
Side lights (A1) switch on	8	1
Side lights (A1) switch off	8	0
Full beam (A2) on	2	1
Full beam (A2) off	2	0
Left (A3) on	3	1
Left (A3) off	3	0
Right (A4) on	4	1
Right (A4) off	4	0
Horn (A5) on	5	1
Horn (A5) off	5	0
Wiper (A6) on	6	1
Wiper (A6) off	6	0
Reverse (B1) on	7	1
Reverse (B1) off	7	0
Brake (B2) on	1	1
Brake (B2) off	1	0

	ID	D0
Left brake bulb on verified	20	0
Right brake bulb on verified	21	0
Left brake bulb off verified	20	1
Right brake bulb off verified	21	1
The fault code is:	22	FLT
What is the fault code?	22	0
Reset fault code	23	0

	ID	D0
Fuel level	9	Fuel
Oil pressure level	10	Pressure
Temperature level	11	Temp
Wiper speed	12	Speed

Fault codes

	ID	D0
Oil pressure short to ground	52	0
Oil pressure short to +V	52	1
Engine temp. short to ground	50	0
Engine temp. short to +V	50	1
Node A missing	47	1
Node B missing	48	1
Node C missing	49	1
Left brake lamp fault	21	255
Right brake light fault	20	255

Instructor Guide - Kvaser analyser setup

CAN bus systems and operation

The Kvaser CAN Analyzer comes with set up instructions, documentation and software on the accompanying Kvaser CD. Please refer to that documentation for details on installing and setting up the software.

Using the Kvaser CANLeaf analyzer

Connect the CANLeaf Analyzer to the CAN bus using the cable that converts from D-type to 4mm 'banana' leads. Note that the yellow lead connects to CAN L and the blue lead to CAN H.

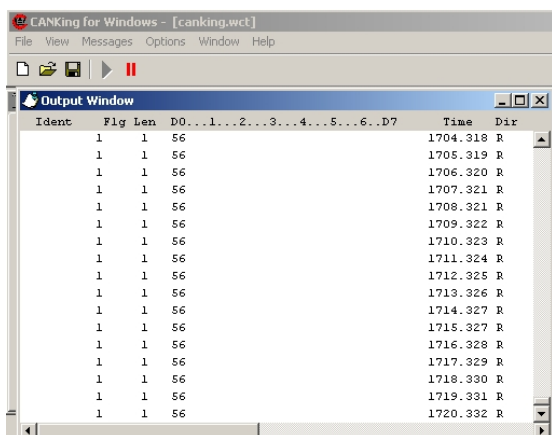
The CAN Analyzer program is called CANKing. You can find this program on the LK6492 CD ROM supplied with your kit in the 'Software' directory.

Once installed, CANKing will be listed in your All Programs menu .

Open CANKing. The most interesting parts, at this stage, are the Start and Pause buttons and the Message screen. The Start and Pause buttons allow you to start, pause and restart the analysis.

The Output Window displays all the messages on the CAN network.

The Message ID, data length, data items, time sent are displayed (along with other information for some codes.) This can help you track down problems caused by missing data, wrong ID's etc., and to check that a malfunctioning node is actually receiving the right information. You can also insert custom messages onto the network for testing and debugging. The analyzer makes life much easier and should be used as a matter of course when programming.



To clear this window, move the cursor over it, right mouse click and select 'clear'.

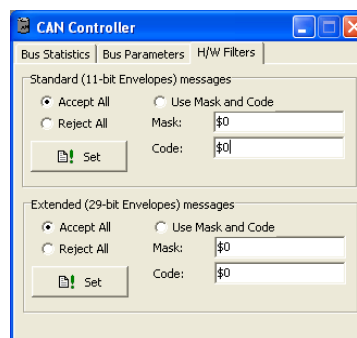
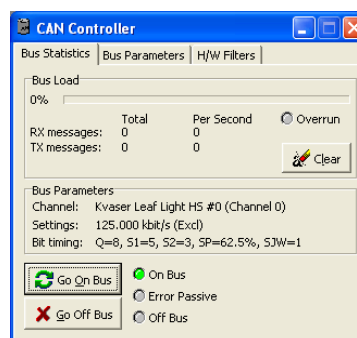
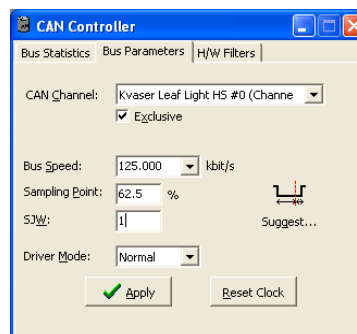
Analyzer network settings

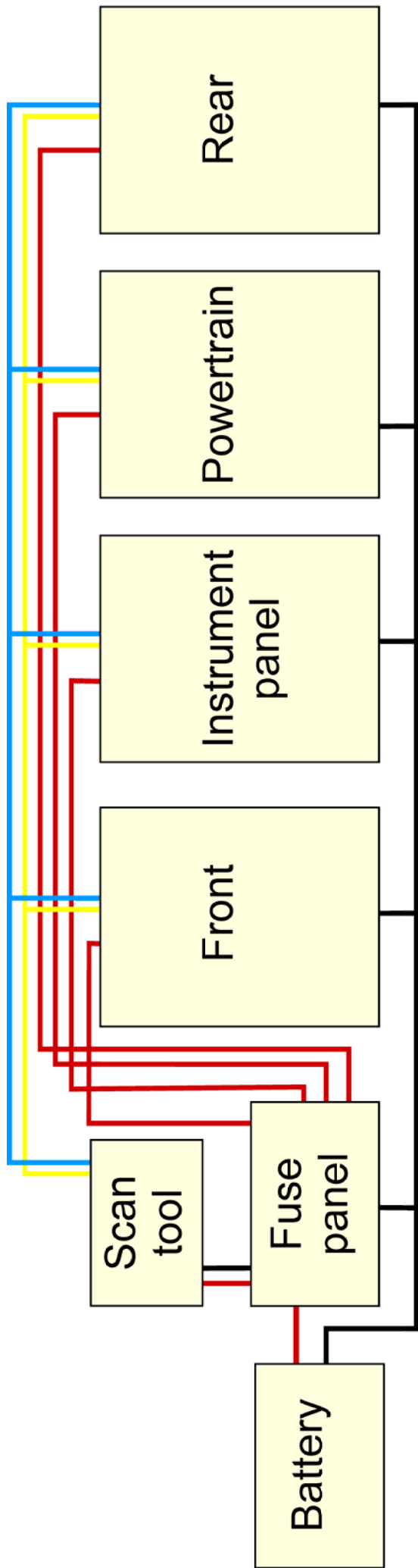
The bus parameters must be set up correctly so that the analyzer works correctly on the network. These should match up already if you have used the suggested settings for the CAN component . Should you need to change them, they are found on the Bus Parameters tab of the CAN controller window.

Statistical details and the current bus status are found on the Bus Statistics page, along with the On/Off Bus connection buttons.

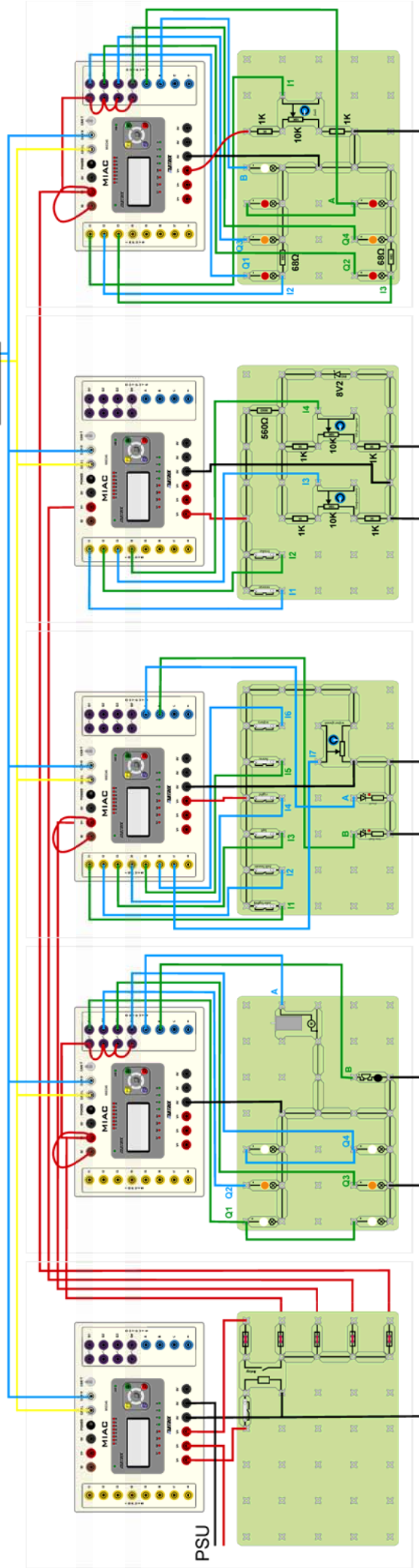
The suggested settings are:

- CAN Channel:** Select USB CANLeaf options
- Exclusive:** On
- Bus speed:** 125 kbps
- Sampling Point:** 62.5%
- SJW:** 1
- Driver mode:** Normal





Analyser



Scan/fuse (A) Front (A) Instrument panel (B) Powertrain (C) Rear (D)