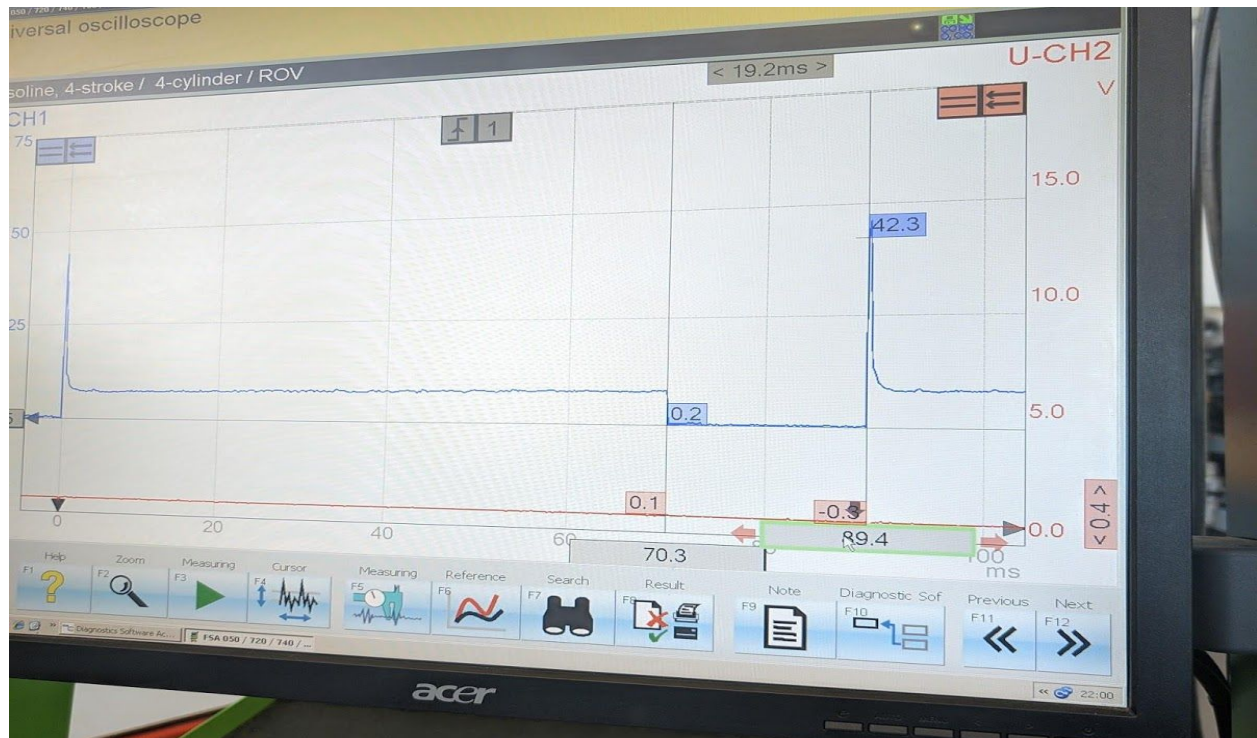


Engine Control Systems

# Electronic Ignition & Fuel Injection Systems

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## Introduction

This report will cover two types of engine management systems, a Vauxhall 1.5 Motronic system and a LE3 Jetronic system developed by Bosch. As part of a group, the tests were carried out in controlled live laboratory conditions on their respective rigs using a 'Bosch FSA 740 - Vehicle Systems Analysis' setup. Having carried out the tests on both systems, they will then be compared and evaluated with further improvement for the respective engine management system. Data such as injection on time, ignition time. Using a multimeter, resistance values of the pins on the air temperature sensor, fuel injector valve and auxiliary air valve sensor are among the systems that were tested. As the tests were carried out on live engines, relevant information was noted at 10°C increments up to 70°C with an initial temperature of 19.2°C on the jetronic engine.

Use of suitable PPE (personal protection equipment) such as eyewear and lab coats were employed to reduce the risk of injury.

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## Research

### Vauxhall 2.0 litre Motronic 1.5 injection/ignition system

The 'Bosch developed Motronic 4.1 engine management system was first introduced in early 1987 later revised to 'version 1.5' in the early 1990s. The Motronic 1.5 allows for open and closed-loop control being managed in once ECU. The Motronic 1.5 is a multipoint system which incorporates both the fuel injection and ignition in one ECU. The LE3-Jetronic system only controls injection timing. The Motronic system uses fuel injection valves for each cylinder whereas the LE3-Jetronic is a mono-point system that has one injector which feeds into the other cylinders

A lambda sensor has also been fitted in the Motronic system to determine the air-to-fuel ratio, a Stoichiometric ratio of 14.7:1 is ideal. If the engine is running 'lean' or 'rich' along with emissions output data to meet EU standards. An engine running 'lean' is referring to the air-to-fuel mixture being supplied to the combustion chambers. A lean mixture is a result of excess air being supplied in ratio to fuel into the combustion chamber through the inlet valves, this can cause increased friction which will lead to engine overheating. When an engine is running 'rich' this effectively means that excess fuel is being injected into through each valve.

The Bosch 1.5 Motronic system uses electronic injection which reduces pollution through the use of a tank ventilation valve which allows for toxic fuel vapours to be reused. This system also makes use of a catalytic converter to reduce harmful emissions such as hydrocarbons.

*(Lecture notes, bosch-automotive.com, Bosch Automotive handbook 10th edition)*

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## **LE3 Jetronic**

The 'Bosch' developed LE3-Jetronic is an analogue, open-loop control system that does not allow for emissions to be regulated as they would be on the Motronic system as it lacks a lambda sensor and a catalytic converter. The ECU receives signals from the ignition circuit, which activates the fuel injectors to set off simultaneously.

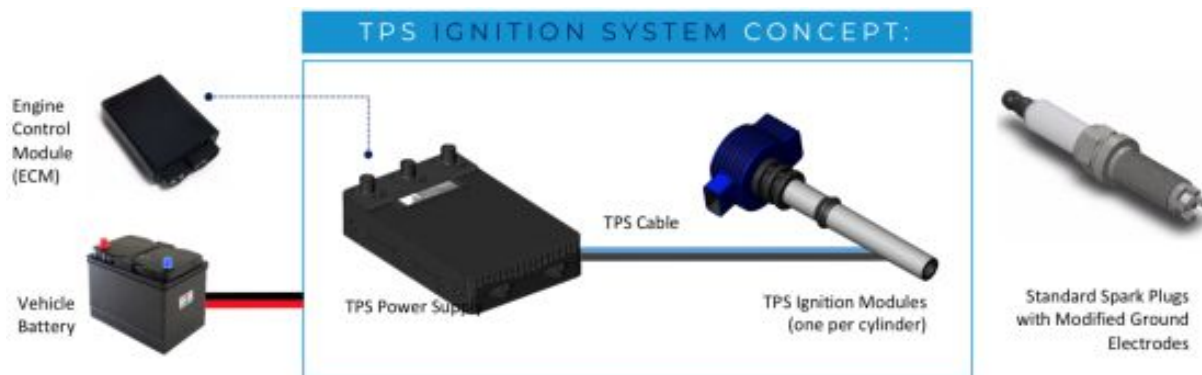
The system uses electrical signals to operate, its job is to inject the right amount of fuel into the intake manifold. The system is able to meter the fuel and inject it at an appropriate time by processing electrical signals being sent from other sensors such as temperature sensor, speed and load sensor along with air injector. This information is processed by the ECU to determine the injection-on period.

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## Alternative Ignition systems

One of the main ways of improving engine efficiency is ensuring the complete burning of the air-fuel mixture in the combustion chamber. Most ignition systems in use are coil-on-plug that use high voltages in order to produce a spark every few milliseconds to ignite the mixture. The flame front propagates from the location of the spark. Alfa Romeo has a 'twin spark' engine where 2 sparks aid complete burning of the fuel however not all manufacturers are able to accommodate their vehicle engines for such a venture. The TPS system takes the spark plug and improves on it. A car with spark-ignition at cold cranking would dump lots of hydrocarbons' into the atmosphere however as the TPS system has faster flame ignition and propagation, this will reduce emissions being produced by the vehicle in-line with EU legislation on emissions control.

### Transient plasma Ignition



A startup company out of California has developed a new plasma-based ignition system. Plasma is electronically charged gas. The system is based on fast pulse low temperature that works using low energy but still delivering high power. The system initiates ignition by producing a high voltage pulse under 100ns that sets off the fuel

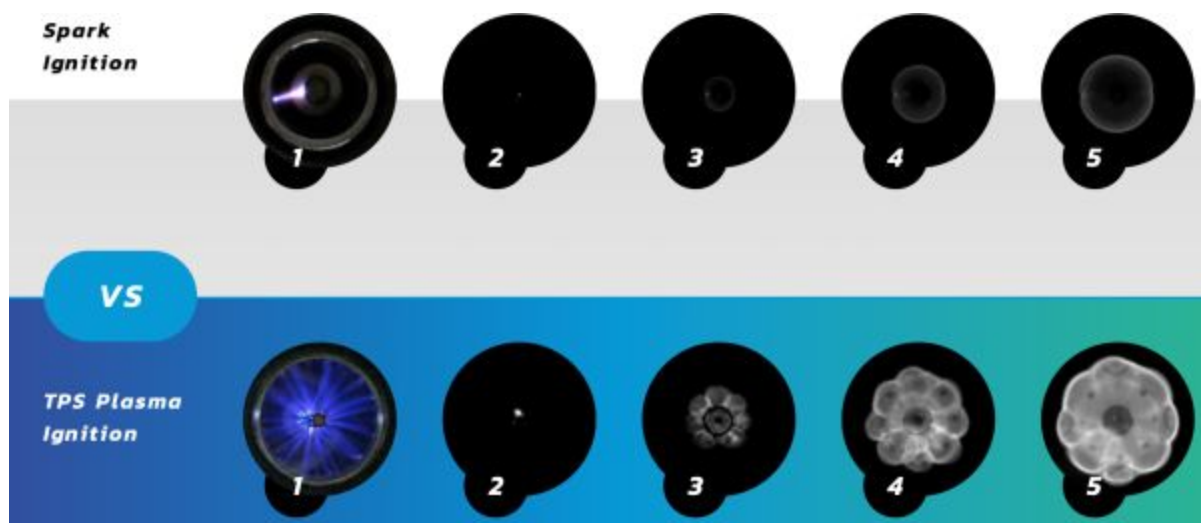
Research by 'Transient plasma systems' has shown that this technology will increase fuel efficiency by 20% in cars and trucks which will increase the life of the engine. The

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plasma-based system has shown to enhance lean-burn capabilities as well which would benefit in reducing HC, CO and NOx.

One of the biggest problems of alternative ignition systems is design and manufacturing that car companies would have to do in order to integrate the systems however with 'TPS' the system is a coil-on-plug type which means that cars can be retrofitted with the system which would see an immediate increase in fuel efficiency and ignition timing.

To prove a point, a test was done where a match was exposed to the plasma, the match stayed unlit because of its low temperature however the same system ignited fuel faster than a spark based system.



From the image, it is evident that the transient plasma ignition (TPI) is better than spark ignition. The flame propagation triggered by the TPI system is a lot further along whereas at the spark initiated flame front is still expanding.

In the image, one can observe detonations occurring in multiple locations from a single pulse which is one of the main ways the system is able to deliver higher engine efficiency as more of the fuel is being fully combusted. For this reason, the TPI system also enjoys less engine knock, further improving engine life.

(Greencarcongress.com, <https://pulsedpower.usc.edu>, [asmedigitalcollection.asme.org](https://asmedigitalcollection.asme.org))

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## Methodology

In order for testing to take place, 4-hour sessions had been booked for the engine testing lab. PPE Personal Protective Equipment was worn prior to entering the live testing zone, this is in line with government legislation - The Personal Protective Equipment at Work Regulations 1992 Act, following PPE procedures will prevent potential harm. Testing teams consisted of 4-5 students each who all had tasks in order for testing to be efficient and clear. The 'live-engine' tests are great as they allow for tangible data that can be measured and compared. The purpose of this report is to compare the Motronic engine to the LE3-Jetronic engine and suggest improvements where necessary for the respective engine. Live testing is an excellent way of knowing if the engine is behaving how it should at different operating conditions such as temperature and how injection on-time is addressed to meet the needs of the vehicle. This data may contain errors as this was the first time the students had carried out such testing and multiple tests had not taken place which could also affect the data that was recorded for this report.

The following operating conditions that the engines will be testing on are:

- (a) Ignition on, engine not running. (b) Engine cranking (from cold). (c) Engine warm-up.
- (d) Acceleration. (e) Deceleration. (f) Idle speed (engine at operating temperature)

The Bosch FSA 740 system had a high-performance oscilloscope which allows users to capture lots of live data. The oscilloscope shows wave patterns on the monitor which can also be paused, features like zoom are also available, this allows the user to attain high-resolution data that can also be measured using the software.

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***How injection on-time is addressed to meet the following operating conditions:***

**Ignition on, engine not running**

Motronic - turn the ignition on. Using a multimeter take voltage readings of the ignition/fuelling ECU by inserting the multimeter probe into the correct pin locations.

**Engine cranking from cold**

To ensure personnel safety, a call "clear, cranking" is said loudly every time so that team members stay clear of any exposed moving parts such as the radiator fan. Link the 'Bosch' engine analysis system making sure the voltage and time scales are appropriate for the test, then connect via the correct pins on the engine, take a reading by pausing live scope patterns of injection-on time. To address cold cranking, the injector ECU pumps an increased amount of fuel into the combustion chamber to increase the chance of spark plug igniting the homogenous mixture. The thermostat will remain closed until the engine has reached a set point. (lecture notes)

**Engine Warm-Up**

The recommended starting temperature for the engine is 20°C however as the tests were carried out in an uncontrolled lab environment, aspects like ambient temperature could not be controlled. The engine's operating temperature is increased by 10°C increments up to 70°C with an initial temperature of 17.8°C on the Motronic engine. The engine is left idle to reach the next 10°C increments. NTC 2 cables are also linked to check the resistance of the cooling temperature sensor. The Motronic scope patterns show an injection on time of 6.29ms which is appropriate as the engine is warming up.

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## **Acceleration**

When the engine is at the proper operating temperature, with the 'Bosch FSA 740' linked, the oscilloscope will show scope patterns. Accelerate the engine so there is a visual change in the scope patterns and immediately pause the scope and observe injector on-time. Take readings. The Motronic unit, pin 16 - a voltage of 12.1v can be observed, this is a potential voltage that will be grounded by the ECU once the engine is cranked.

Timing-advance occurs under acceleration. Engine components like air-fuel injectors, spark plugs and pistons are all impacted by timing-advance i.e. the spark plugs in a car will start to fire off earlier as the acceleration is increased. One of the methods used to increase the performance of a car is tuning the injector ECU, this will improve timing-advance however that may lead to overheating if the engine is kept under constant load at high speeds. (*Bosch Automotive handbook, Hillier 6th edition*)

## **Deceleration**

While the engine is decelerating, timing-retardation occurs which means that the injector valves stay open for longer and the spark plug fires off inline with deceleration. Pause the oscilloscope as the engine slows down having just accelerated.

## **Idle Speed at Operating Temperature**

When the engine has reached operating temperature the fuel injection at idle speeds will be around 2.5 to 3ms however pin 4 - Motronic unit shows an ignition on time of 4.46ms, this is not within factory specification which would suggest a potential fault with the injection ECU combined with the temperature sensor.

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***The legislation(s) that apply upon entering the testing zone are:***

- The Personal Protective Equipment at Work Regulations 1992
- The Workplace (Health, Safety and Welfare) Regulations 1992

As the name suggests 'The Personal Protective Equipment at Work Regulations 1992' refers to the use of proper safety equipment for the situation. Overall the testing area was safe however prior to entering the workshop it was still necessary to put on a lab coat and protective eyewear which were provided per the legislation.

'The Workplace (Health, Safety and Welfare) Regulations 1992' also applied to the testing conditions as the engine rigs would need to be cranked; it was necessary to ensure that exhaust fumes were not circulating the room as they were extremely hazardous. Under the Act, it is mandatory to have adequate ventilation. Use of extractor was employed, the extractor was manually secured to the exhaust of the engine rig.

(<http://www.legislation.gov.uk>)

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## Live Testing

In order to carry out the live tests, the use of an aforementioned 'Bosch FSA 740' - Vehicle Systems Analysis/ diagnostics machine was employed along with multimeters to measure resistances and voltages circulating around the engine control systems. Lecturer supplied schematic diagrams were also used

To start the tests, the Bosch FSA 740 has to be linked to the engine properly in order to see the scope patterns. In order to ensure proper results from the start, the engine's starting temperature should be 20°C which is an approximate room temperature.

Resistance values of the throttle switch, injectors and coolant temperature are taken using a multimeter as it is the best handheld tool for such testing. The data recorded is compared to factory specification from the engine manual provided to ensure all sensors are within resistive and voltage range and operating properly.

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## Live Test Results - Motronic

Figure 1 - Engine Temperature vs. Pins

|                      | Pins | 45 ( $\Omega$ ) | 45 (V) | 16 (ms) | 4% | 5   | 28 (lambda) |
|----------------------|------|-----------------|--------|---------|----|-----|-------------|
| Temp( $^{\circ}$ C ) | 20   | 1528            | 3      | 3.6     | 43 | off | off         |
|                      | 30   | 1028            | 2.5    | 3.8     | 43 | off | off         |
|                      | 40   | 647             | 2      | 2.7     | 40 | off | on          |
|                      | 50   | 460             | 1.6    | 2.7     | 42 | off | on          |
|                      | 60   | 334             | 1.2    | 3.0     | 41 | off | on          |
|                      | 70   | 242             | 1      | 2.8     | 41 | on  | on          |
|                      | 80   | 240             | 1      | 2.9     | 44 | on  | on          |

(Multimeter probes had a resistance of  $0.2\Omega$  thus any resistance reading will need to minus 0.2 off the value)

At first start 'cold crank' the engine temperature was  $17.8^{\circ}\text{C}$ , an injection on-time of 19.2ms was observed using the scope. The long injection-on time is necessary as the engine needs enough fuel and air to overcome any moisture and other residual matter that has accumulated in the combustion cylinders.

From the table, it can be observed that the resistance in **pin-45 ( $\Omega$ )** decreases as the engine temperature increases.

**Pin-45 (v)**, it can be observed that voltage decreases as the engine temperature increases however as the engine approaches operating temperatures around  $70\text{-}80^{\circ}\text{C}$  the voltage stays the same.

**Pin-16** shows the fuel injection-on time. From the table, it can be observed that injection-on time decreases to maintain idle speeds.

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The table shows that between engine temperatures of 20-30°C the lambda sensor does not switch on, this is because the lambda sensor needs to reach a minimum temperature to be fully operational. The table shows the lambda sensor starts operating at 40°C.

*The Motronic engine ECU - all 55 pins were all individually measured for voltage with ignition off/on. - Figure 2 - Motronic ECU pins*

| Pin testing | V - Ignition off | V - Ignition On | Function                          |
|-------------|------------------|-----------------|-----------------------------------|
| pin         | Ignition off     | Ignition on     |                                   |
| 1           | 0                | 12.27           |                                   |
| 2           | 0                | 0.03            | Earth                             |
| 3           | 0                | 12.1            |                                   |
| 4           | 0                | 9.8             |                                   |
| 5           | 0                | 12.04           |                                   |
| 6           | 0                | 11.35           |                                   |
| 7           | 0                | 0.31            | Air-flow                          |
| 10          | 0                | 0               | Earth                             |
| 12          | 0                | 5.06            | Air flow/<br>throttle<br>position |
| 13          | 0                | 10.13           |                                   |
| 14          | 0                | 0.02            |                                   |
| 16          | 0                | 12.03           | Fuel injector                     |
| 17          | 0                | 12.03           | Fuel injector                     |
| 18          | 12.4             | 12.05           |                                   |
| 19          | 0                | 0.02            | Earth                             |
| 22          | 0                | 0.91            |                                   |
| 24          | 0                | 0.03            | Earth                             |
| 26          | 0                | 0.06            | Air-flow/Earth                    |

---

|    |      |       |                                   |
|----|------|-------|-----------------------------------|
| 27 | 0    | 12.17 |                                   |
| 28 | 0    | 0.45  | Lambda                            |
| 32 | 0    | 11.34 |                                   |
| 36 | 12.1 | 0.3   |                                   |
| 37 | 0    | 12.06 |                                   |
| 40 | 0    | 0.06  |                                   |
| 41 | 0    | 0.06  |                                   |
| 42 | 0    | 0.03  |                                   |
| 34 | N/A  | N/A   |                                   |
| 44 | 0    | 3.78  | Air-flow/<br>Throttle<br>position |
| 45 | 0    | 3.81  | NTC 2 -<br>coolant temp           |
| 46 | 0    | 5.06  |                                   |
| 48 | 0    | 0.06  |                                   |
| 49 | 0    | 0.1   |                                   |
| 53 | 0    | 0.63  | Throttle<br>position              |
| 55 | 0    | 11.02 |                                   |

**Figure 3 - Throttle Position Sensor**

| Technical data            | Manual - $\Omega$ | Recorded - $\Omega$ | Throttle |
|---------------------------|-------------------|---------------------|----------|
| Pins - 1 and 2 - Throttle | 1900 - 2000       | 1990                | closed   |
| Pins - 1 and 3            | 1000 - 2000       | 2,550               | open     |
| Pins - 2 and earth        | 0,12 - 1,22       | INFINITY            | closed   |
| Pins - 2 and earth        | 3,90 - 4,95       | INFINITY            | open     |

**Figure 4 - Air Flow Sensor**

| Technical data | Manual - $\Omega$ | Recorded - $\Omega$ |
|----------------|-------------------|---------------------|
| Pins - 4 and 2 | 8 - 2500          | (1)INFINITY         |
| Pins - 4 and 3 | 300 - 550         | 0.03                |
| Pins - 4 and 1 | 270 - 520         | 0.56                |

**Figure 5 - Coolant Temperature Sensor - NTC 2**

| Temperature (°C) | Manual - $\Omega$ | Recorded - $\Omega$ |
|------------------|-------------------|---------------------|
| 0 (Ambient)      | 4800 - 6600       | n/a                 |
| 20               | 2200 - 2800       | 1528                |
| 40               | 1000 - 1400       | 647                 |
| 80               | 270 - 380         | 240                 |

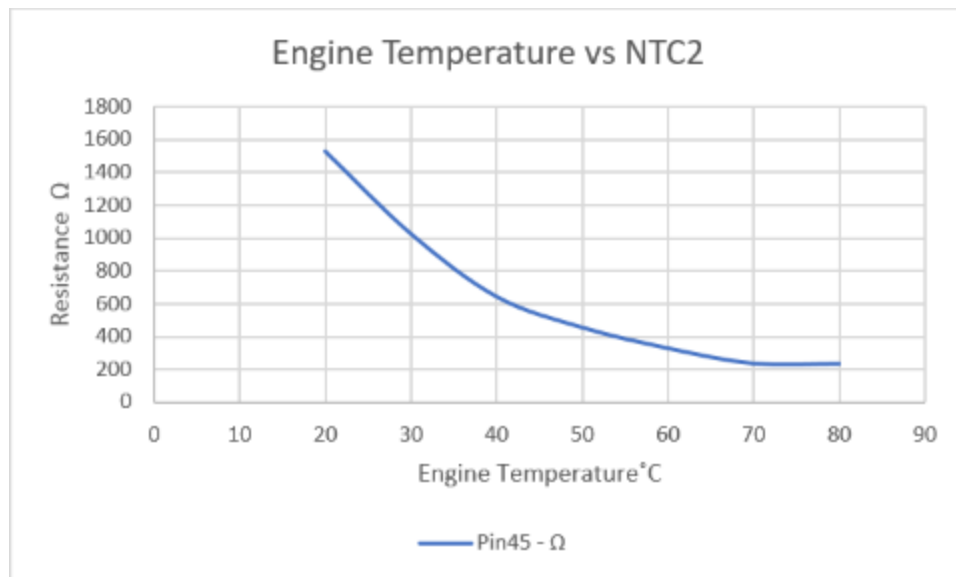


**Figure 6 - Engine temperature vs NTC2 - ( $\Omega$ )**

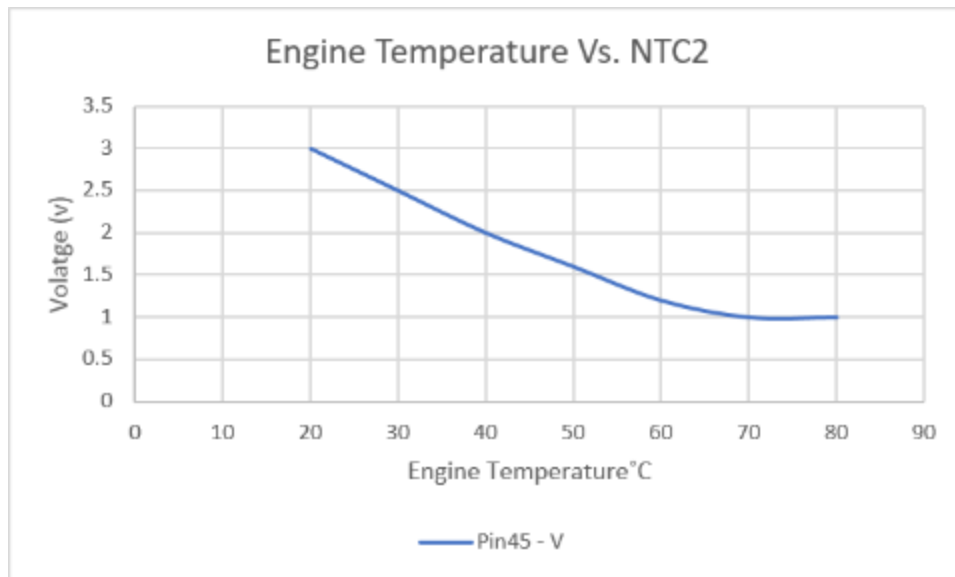


**Figure 7 - Engine temperature vs NTC2 - (v)**

Higher resistance value would indicate that the air-fuel mixture is rich whereas a low resistance value would indicate otherwise. The injection ECU will send and receive signals from the lambda sensor in-order to meter the right amount of air and fuel so that a Stoichiometric ratio of 14.7:1 is achieved.

**Figure 8 - Air Temperature Sensor**

| Temperature (°C) | Manual - $\Omega$ | Recorded - $\Omega$ |
|------------------|-------------------|---------------------|
| 15 - 30          | 1500 - 3300       | 2180                |

**Figure 9 - Idle speed control valve**

| Technical data | Manual - $\Omega$ | Recorded - $\Omega$ |
|----------------|-------------------|---------------------|
|                | 8                 | 0                   |

Data from the idle speed valve was not measured however as the rest of the ECU systems are working properly, this would suggest that the idle valve is also functioning correctly.

---

**Figure 10 - Injector Valves**

| Technical Data | Manual - $\Omega$ | Recorded - $\Omega$ |
|----------------|-------------------|---------------------|
| 1              | 15-17             | 16.1                |
| 2              | 15-18             | 16.1                |
| 3              | 15-19             | 16.1                |
| 4              | 15-20             | 16.1                |

In the vehicle manual, the resistance of the injector sees an increase per valve however all injector valves showed the same 16.1 $\Omega$  of resistance when tested.

**Figure 11 - HTC leads**

| Technical Data | Recorded - $\Omega$ |
|----------------|---------------------|
| Lead - 1       | 19650               |
| Lead - 2       | 18550               |
| Lead - 3       | 15250               |
| Lead - 4       | NO READING          |

The readings were taken using a multimeter. As can be seen, the resistance decreases per lead however there was no reading from the fourth lead shown by reading, this could suggest a fault with the wire or the engine.

---

## Live (static) Test Results - LE3

Pin identities can be found in the appendices

Battery voltage – 12.48V

Resistance on multimeter leads – 0.2Ω

**Figure 12 - Engine Temperature vs Injection on time**

| Temperature         | Injection on time (ms) |
|---------------------|------------------------|
| Cold crank - 19.2°C | 13.7                   |
| Idle at - 20°C      | 11                     |
| 30°C                | 4                      |
| 40°C                | 3.1                    |
| 50°C                | 2.9                    |
| 60°C                | 2.8                    |

The table above shows the engine starting from cold-cranking to operating conditions at 60°C. As expected, the injection-on time is shorter as the engine temperature increases. At 60°C the injection-on time is 2.8ms which would suggest that the engine is in good condition. This can be seen in the scope patterns provided where a voltage change from 0.91 to 4v can be observed in the air-flow meter suggesting acceleration.

---

The **fuel ECU** consists of 15 pins of which pins 6/7/9/11/13 are empty. Voltages were taken using a multimeter. Engine not running. **Figure 13 - Fuel ECU**

| Pin | Ignition off (V) | Ignition on (V) |
|-----|------------------|-----------------|
| 1   | 0                | 010             |
| 2   | 0                | 0.8             |
| 3   | 0                | 0               |
| 4   | 0                | 003             |
| 5   | 0                | 005             |
| 8   | 0                | 145             |
| 10  | 0                | 025             |
| 12  | 0                | 0.8             |
| 14  | 0                | 844             |
| 15  | 0                | 004             |

The table shows '0' volts across all pins when the ignition is off, seeing voltage readings other than '0' could mean complications in the system or the lack of memory control in the injection system,

**Figure 14 - Ignition ECU Voltages - Pins 4/9 are empty**

| Pin | Ignition off (V) | Ignition on (V) |
|-----|------------------|-----------------|
| 1   | 0                | 005             |
| 2   | 0                | 005             |
| 3   | 0                | 0.8             |
| 5   | 0                | 010             |
| 6   | 0                | 007             |
| 7   | 0                | 227             |
| 8   | 0                | 165             |

---

|    |   |     |
|----|---|-----|
| 10 | 0 | 005 |
| 11 | 0 | 005 |
| 12 | 0 | 010 |
| 13 | 0 | 023 |
| 14 | 0 | 853 |
| 15 | 0 | 026 |

**Figure 15 - Amplifier**

| Pin | Ignition off (V) | Ignition on (V) |
|-----|------------------|-----------------|
| 1   | 0                | 1               |
| 2   | 0                | 003             |
| 3   | 0                | 1               |
| 4   | 0                | 023             |

The table shows that the amplifier sees no change in voltage when the ignition is off as there aren't signals being sent from the ECU however the amplifier pins showed readings when the ignition was turned on.

**Figure 16 - Throttle Switch**

| Pins   | Manual - Ω | Recorded Ω | Throttle |
|--------|------------|------------|----------|
| 2 & 18 | 0          | 0          | Closed   |
| 3 & 18 | 1          | 1          | Closed   |
| 2 & 18 | 1          | 1          | Open     |
| 3 & 18 | 0          | 0          | Open     |

---

**Figure 17 - Injector Valves**

| Cylinder | Recorded - $\Omega$ |
|----------|---------------------|
| 1        | 16.1                |
| 2        | 16.1                |
| 3        | 16.1                |
| 4        | 16.1                |

All injector valve pins showed the same resistance of 16.1 $\Omega$  suggesting the injectors are operating properly as they are within factory specification which puts the resistance values between 15-17 $\Omega$  for each cylinder.

**Figure 18 - Auxiliary Air Valve - Resistance taken with engine off**

| Pin | resistance - $\Omega$ |
|-----|-----------------------|
| 1   | 45.8                  |

**Figure 19 - Catering Coil**

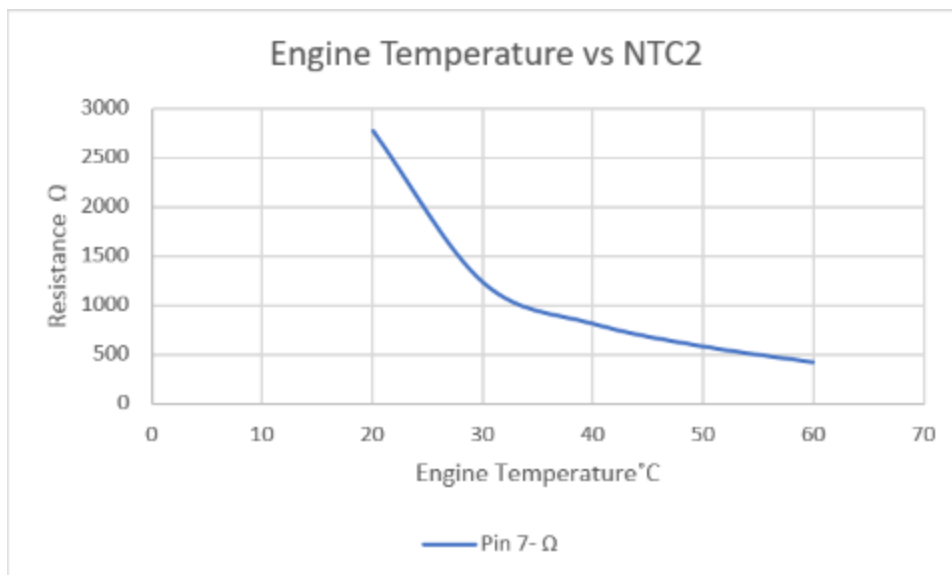
| Technical data                  | Resistance - $\Omega$   |
|---------------------------------|-------------------------|
| Primary(range of 200 $\Omega$ ) | 1 - 0.2 for wires = 0.8 |
| Range (20k $\Omega$ )           | 7.45                    |

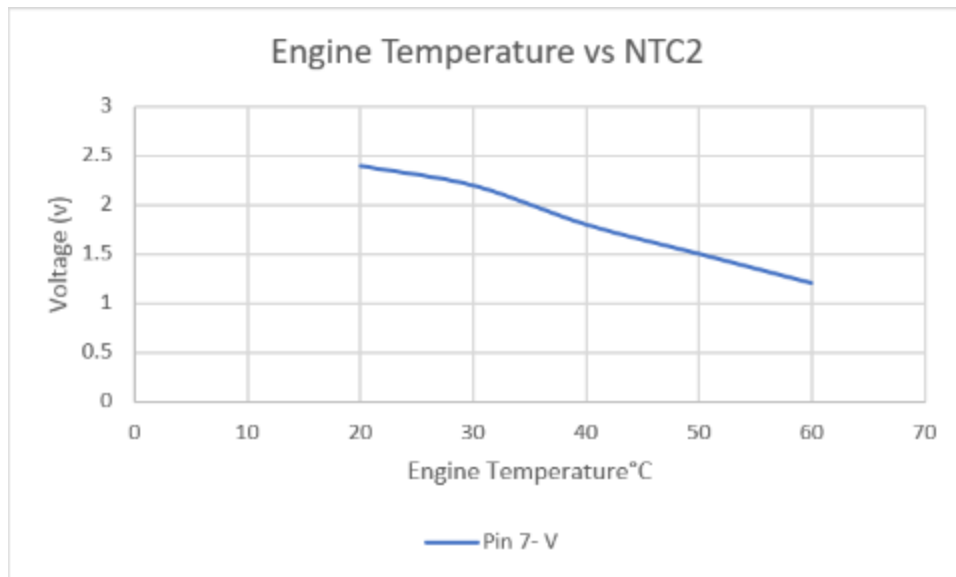
**Figure 20 - HTC Leads**

| Plug | Resistance - $\Omega$ |
|------|-----------------------|
| 1    | 8360                  |
| 2    | 8580                  |
| 3    | 7410                  |
| 4    | 5630                  |

**Figure 21 - Water Temperature Sensor - NTC2**

| Temperature°C | Pin 7- $\Omega$ | Pin 7 - V |
|---------------|-----------------|-----------|
| 20            | 2,770           | 2.4       |
| 30            | 1,230           | 2.2       |
| 40            | 810             | 1.8       |
| 50            | 580             | 1.5       |
| 60            | 420             | 1.2       |





As can be seen from the graph, as the engine temperature increases, the resistance and voltage values see a decrease, this is because the NTC2 sensors are made using semiconductors material 'silicon'. This metalloid allows for such high demand voltage and resistive operations to take place otherwise the whole system would overheat resulting in circuit failure. (*Hillier 6th edition*)

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## Analysis

### Motronic Oscilloscope Data - Signal waveforms - Provided

**(Pin 1 - Negative side of Ignition Coil)** - The scope shows the Motronic system to have a spark duration of 1.47ms and a dwell period of 14.11ms can also be observed. The resulting is a back EMF of 129.2 volts.

**(Pin 27 - Supply from ignition)** – A voltage of 13.6V is shown on the scope pattern information bar, this would suggest that the engine is running.

**(Pin 2 - Earth return)** – the voltage returns to complete the circuit. This takes 13.6ms with a difference of 0.22V.

**(Pin 4 - Pulsed side of rotary valve)** At idle 80°C, - The injection on time is observed to be 4.46ms however at operating temperatures the injection on time should be around 2.5ms. This could suggest that the throttle switch has been configured incorrectly.

**(Pin 7 - Load signal output from air-flow meter)** - The change in voltage from 0.91v to 4v would suggest the vehicle is under acceleration which sends signals to the ECU back to the injector switch to open for longer. This type of voltage change may occur at lower

**(Pin 53 - Output from throttle potentiometer)** - The provided schematic shows Pin-53 leads to the Automatic Transmission ECU. This sensor is only triggered when the gear stick is in drive position.

**(Pin 16 - Pulsed side of injectors, bank of two)** - In this scope pattern, an injection-on time of 3ms can be observed at idle, this suggests that the vehicle is functioning properly at operating temperatures.

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**(Pin 17 - Pulsed Side of if injectors, bank of two)** - The Motronic system uses simultaneous injection. The ECU sends a signal to injectors to inject half the fuel required per revolution at the crankshaft which would equate to a full amount of fuel per cycle which would result in lower emissions. This ensures the complete burning of fuel aids performance. This allows for smaller engines to still be able to meet performance requirements yet maintaining a smaller footprint on the environment when compared to sequential injection.

**(Pin 16 - Pulsed side of injectors, bank of two)** – The Oscilloscope data shows the injection on time to be 2.99ms while idling at 80°C. This is within its operating conditions suggesting a good function of the injector ECU.

**(Pin 16 - Pulsed side of injectors, bank of two)** - This data from the oscilloscope shows the engine to have 7.95ms of injection on time. As the engine experiences snap acceleration, the engine will see an increase in injection-on time as the vehicle needs to overcome resistances in-order to start moving.

**(Pin 16 - Pulsed side of injectors, bank of two)** - This scope reading shows the engine to be decelerating, a voltage of (v1) -2.1v can be observed whereas the v2 is 12.5v suggesting good earth after the injection cycle has completed.

**(Pin 28 - Output from lambda sensor)** - This scope reading shows the lambda sensor functioning, the sensor is essential in establishing engine efficiency. A properly functioning lambda sensor is crucial in order to know if the engine is running rich or lean. The readings show oscillations between (v1) 708mV & (v2) 79mV at 0.170Hz as the engine is running suggesting a constant change in the homogenous mixture.

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**(Pin 49 - Speed Sensor/Output from crankshaft sensor)** - This scope shows the data from the speed sensor. A voltage difference of 0.4v. The time it takes for the flywheel ring to move to the next is 1.25ms. Every revolution, one engine RPM is recorded. The sensor then takes an average speed of the flywheel therefore a more accurate sensor could be employed to improve the overall engine performance.

### **Secondary wave pattern**

This scope shows the voltage that is operating within the sparkplug in-order to make the 'spark' jump from the central electrode tip to the ground electrode to complete the 'ignition' part of the 4 stroke cycle. The scope shows an initial voltage of 6.63kV and final voltage of 1.69kV, this drop shows that a spark has occurred.

## **LE3 Oscilloscope Data - Signal waveforms - provided**

**(Graph L1 - Pin 3 - supply)** - The top signal waveform shows the supply voltage on CH1 to be 12.25v, correspondingly the bottom signal waveform is showing the voltage being earthed. An observation can be made here, the earth is more or less the inverse of the supply signal.

**(Graph L2 - Pin 1 - RPM counter/ primary voltage)** - This graph shows the primary voltage to reach a peak of

**(Graph L3 - Pin 3 - injector idle)** - From the scope pattern, one can observe voltage frequency which would indicate that the injectors are operating at idle speeds.

**(Graph L4 - Pin - Secondary Voltage Cyl 1)** - This scope pattern shows a voltage build-up of 9.2kV. The Spark duration shows a spark duration of 1.7ms. The peak after the 'spark' part of the signal shows the burning of hydrocarbons. Coil oscillations can also be observed at the end of the signal.

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**(Graph L5 - Pin - Pin 4 – Spark advance signal)** - Upon receiving signals from the crankshaft, the ignition ECU starts to advance the signal. The scope pattern shows the individual coil charge and spark.

**(Pin 1 – Primary Earth)** - This scope pattern shows how the voltage from the spark advance pin 4 is being grounded.

**(Graph L6 - Pin 3 - Acceleration)** - From this scope pattern, it is easy to know that the engine is under acceleration as there is an increase in signal waveform frequency. The scope shows the spark duration of 6 individual sparks taking place within 100ms. The amplitude of the wave remains the same however, the frequency changes with engine RPM.

**(Graph L7 - Pin 3 - deceleration)** - The signal waveform from this scope shows the signal has 'flatlined' after a period of acceleration - this is because the injectors have stopped as the engine is no longer cranking.

**(Graph L8 - Pin 3 - Engine crankshaft signal)** - This scope pattern shows the signal voltage from the crankshaft, its frequency in 'ms'. The amplitude of the crankshaft signal waveform reaches a high of 12.5v where it is then immediately grounded as there are as many 'crests' as there are 'throughs',

**(Graph L9 - Pin 5 - Speed/signal ref for fuel)** - This scope pattern shows voltage to be zero however when the ECU receives signals from the crankshaft ECU, a voltage of 12.5v can be observed for approximately 20ms. The voltage is again grounded for 10ms where the voltage returns to 0v and the signal then repeats itself in the same manner 4 times.

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## Evaluation

Electronic engine control systems like injection and ignition have experienced exponential development since their introduction, however, the adoption of electronic controlled systems was not well received by the general public as there were reliability issues and injection systems like 'carburettor' did a better job in comparison. As technology has progressed the use of electronic sensors for managing air-fuel mixture and 'spark' timing has become widespread as they are now more reliable than their counterparts.

The LE3 engine has become outdated along with the different ECUs that are on the engine when compared to the Motronic engine setup. The LE3 lacks a lambda sensor along with a catalytic converter, both are very important as they play a key role in regulating emissions, for those reasons the LE3 system is just not as efficient as the Motronic. The Motronic system has one ECU for both injection and ignition whereas the LE3 has two separate ECU's that have send and receive signals in order to function properly, this could be problematic on a micro-scale as signals from the injection/ignition take longer as the electrical signal has to travel a short distance.

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## Recommended improvements for LE3-Jetronic

*The following is a breakdown of recommended changes for the LE3-Jetronic engine.*

As the LE3-Jetronic ECU only manages the injection of fuel, it would be ideal to **merge the injection and ignition ECU's**. This will reduce overall costs as there is one ECU rather than two. The combined ECU's will result in faster and precise data sharing as the electrical signals have less distance to cross to deliver input from the driver, this will increase the accuracy of spark/injection period and allow for better performance characteristics. *(Hillier 6th edition)*

An overall way of improving engine efficiency is by installing a '**Lambda**' sensor and integrating it with the ECU. The electronic sensor will deliver the atomised air-to-fuel ratio into the intake manifold and also send signals back to the ECU reporting if the engine is running 'lean' or 'rich'. Lambda sensors are on every new car per stringent EU emissions control regulation. *(Bosch Automotive Handbook 10th edition)*

As the LE3-Jetronic lacks a **catalytic converter** due to its age, one should be integrated to meet EU emissions control legislation. Exhaust gasses enter the catalytic converter, they are exposed to rare-earth metal coatings such as palladium and rhodium. The gasses are converted into harmless components through the special inner coating. Palladium is used for its inherent ability on HC and CO gasses as it accelerates oxidation whereas rhodium is used to decrease NOx levels coming from the exhaust. The gasses are converted into harmless components effectively meeting regulations. *(Bosch Automotive Handbook 10th edition)*

Engine '**knocking**' takes place within the combustion chamber during the compression/ignition phase. Essentially, knocking is a form of vibration caused by an increase in pressure and temperature which sets off a smaller explosion in any one corner of the cylinder, the explosion collides with the main flame front caused by the upward stroke of the piston combined and spark plug. A knock sensor works by

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detecting noises occurring from the 'knock', the sensor sends electrical signals to the engine ECU which in turn retards the ignition timing to counter it. (*Hillier 6th edition*)  
(*Bosch Automotive Handbook 10th edition*)

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## **Conclusion**

This report has covered 2 engine management systems, they have been compared and reasons have been given for why the Motronic system is better than the LE3. A clear methodology has been produced so that if need be, this test could take place again by someone who is unfamiliar with the systems. Resistance and voltage readings off all the ECU's were taken, first with the ignition off and then on. Scope patterns have been analysed for both engines and a list of improvements for the LE3 engine have been stated that will improve the overall engine efficiency and bring it into modern times.

The data consistently shows that the Motronic is a better system because of sensors like lambda that aid the engine's efficiency.

## **Recommendations for testing - next time**

Tests should have been carried out after having familiarised with the equipment used such as the Bosch FSA machine. The tests were carried out in an uncontrolled environment which could have affected how the engine behaved from the initial cold crank. As resistance and voltage readings were only taken once, they could contain errors which could be attributed to human error or equipment malfunction, which is why it is important to carry out multiple tests in different environments in-order to really know how the engine systems behave.

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## Appendices

### Pin Identification

The **Motronic 1.5 ECU** consists of a total of 55 pins of which 14 pins are empty. The table below has been correctly labelled and pins that are missing are not on the table.

| Pin | Function                                             |
|-----|------------------------------------------------------|
| 1   | Negative side of coil                                |
| 2   | Earth                                                |
| 3   | Control Circuit for fuel pump (from relay pin (85B)) |
| 4   | Pulsed side of Rotary idle valve                     |
| 5   | Pulsed side of Tank Vent Valve                       |
| 6   | 4WD ECU – A/T ECU – Fuel Tell-Tale Lamp              |
| 7   | Load Signal from air-flow meter                      |
| 9   | Speedo, mileage frequency sensor                     |
| 10  | Earth                                                |
| 12  | 5V supply to air-flow meter & throttle potentiometer |
| 13  | Diagnostic socket supply                             |
| 14  | Earth                                                |
| 16  | Pulsed side of injectors (bank of two)               |
| 17  | Pulsed side of injectors (bank of two)               |
| 18  | Permanent live – keep alive memory                   |
| 19  | Earth                                                |
| 20  | Earth. (for vehicles fitted with catalyser)          |
| 21  | Earth. (for vehicles fitted with A/T)                |
| 22  | Engine tell-tale warning light                       |

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|    |                                                                       |
|----|-----------------------------------------------------------------------|
| 24 | Earth                                                                 |
| 26 | Earth Via ECU                                                         |
| 27 | Ignition Feed                                                         |
| 28 | Output from lambda sensor                                             |
| 32 | Output to on-board computer                                           |
| 34 | A/T ECU                                                               |
| 36 | Control Circuit for supply to auxiliaries and ECU (from relay pin 85) |
| 37 | Supply to ECU & to on-board computer                                  |
| 40 | A/C                                                                   |
| 41 | A/C                                                                   |
| 42 | Earth from manual transmission only                                   |
| 43 | Output from CO potentiometer – not fitted with catalyser              |
| 44 | Output from NTC 1                                                     |
| 45 | Output from NTC 2                                                     |
| 46 | Octane plug input                                                     |
| 47 | Earth for vehicle fitted with 4WD                                     |
| 48 | Output from crankshaft sensor                                         |
| 49 | Output from crankshaft sensor                                         |
| 51 | A/T ECU                                                               |
| 53 | Output from throttle potentiometer                                    |
| 55 | Earth for diagnostic socket                                           |

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## Pin Identities - LE3

### *Ignition ECU Pin Number functions*

| Pin | Function                                                  |
|-----|-----------------------------------------------------------|
| 1   | Earth                                                     |
| 2   | Earth for NTC 2                                           |
| 3   | Ignition supply voltage                                   |
| 5   | Speed reference for speed ECU                             |
| 6   | Idle control for throttle switch                          |
| 7   | NTC 2                                                     |
| 11  | Earth crank sensor                                        |
| 12  | AC output                                                 |
| 13  | Sends signal to the amplifier                             |
| 14  | Other side of throttle switch – wide open throttle output |
| 15  | Load reference                                            |

### *Amplifier Pack Pin Number & Meaning*

| Pins | Function                 |
|------|--------------------------|
| 1    | Primary Wave Form        |
| 2    | Earth                    |
| 3    | Supply for the amplifier |
| 4    | Signal from pin 13       |

### *Fuel ECU Pin Number functions*

| Pin | Function        |
|-----|-----------------|
| 1   | Speed reference |
| 2   | Supply          |

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|    |                                             |
|----|---------------------------------------------|
| 3  | Injectors                                   |
| 4  | Earth                                       |
| 5  | Earth                                       |
| 8  | Oil NTC                                     |
| 10 | Load reference for ignition                 |
| 12 | Tachometric relay grounded when running     |
| 14 | Snap acceleration (wide open throttle fuel) |
| 15 | Idle                                        |