

Electronic Ignition & Fuel Injection Systems
Assignment Report.
M4X02197



Bosch fuel injection.

(Image source - <https://www.thoughtco.com/how-does-fuel-injection-work-281577>)

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Electronic Ignition & Fuel Injection Systems Assignment.

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i) Abstract.

The power output, economy, performance and emissions of an engine are dependent on the ratio of air/fuel and ignition timing during combustion. In a modern car engine the management system is dependent on accurate data from sensors relating to mechanical and/or thermal conditions. The sensors convert a thermal, chemical or physical value into an electrical signal and relay it to the engine management system or ECU (Electronic Control Unit). The ECU receives the instructions and acts accordingly by changing fuel/air ratio, ignition timing, power output and other operational commands.

This assignment aims to investigate two types of Electronic ignition/Fuel Injection Systems. An oscilloscope used to test electronic sensors and components and the relevant live data collected to analyse various ignition and fuelling characteristics.

In this research a systems operation test will be carried out on both Bosch Motronic and Bosch LE3 Jetronic systems, each fitted on Vauxhall 2.0 engines. The assignment will aim to collect live data, analyse characteristics of both management systems whilst promoting team-working during researching and recording data. The report will investigate and explain the practical operating conditions of; ignition on, cold engine cranking, engine warm-up and acceleration. It will aim to report on the comparison of main system operational differences and will end by suggesting and justifying any possible modifications to the Bosch LE system.

ii) Acknowledgements.

To Mr Andrew Gibson for his guidance and advice during lectures. And the information available on Moodle/ UWTSD.

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Section 1.

1.1 Introduction

Electronic fuel injection systems successfully entered the marketplace in the late 1970s. The systems gave the ability for engines to develop more power, improve fuel efficiency and economy and lower emissions. Bosch's first generation Jetronic system gained a reputation for being robust and reliable and by the mid 80s, most European manufacturers specified Bosch systems. The two major benefits of Jetronic being improved fuel economy and the potential for increasing engine performance.

In fuel injection engines the fuel/air is mixed in the intake port outside the combustion chamber, the fuel being injected close to the intake valve. When the valve opens, the fuel /air mix is drawn into the combustion chamber. The injectors operate to address the engine's requirements depending on speed, throttle and load conditions.

With electronic control systems, the adjustments and settings of the fuel/air ratio and ignition timing are controlled by an electronic engine management system.

Microprocessors or microcontrollers and relevant programmes or 'maps', interface with an ECU (engine control unit) or command module to determine the correct fuel/air delivery and the ignition timing setting/adjustments. Whilst constantly analysing and responding to the throttle setting, engine load, air temperature and other operating variables. The ECU processes the information received and electronically calculates the required amount of fuel at the correct time, known as injection time (iT).

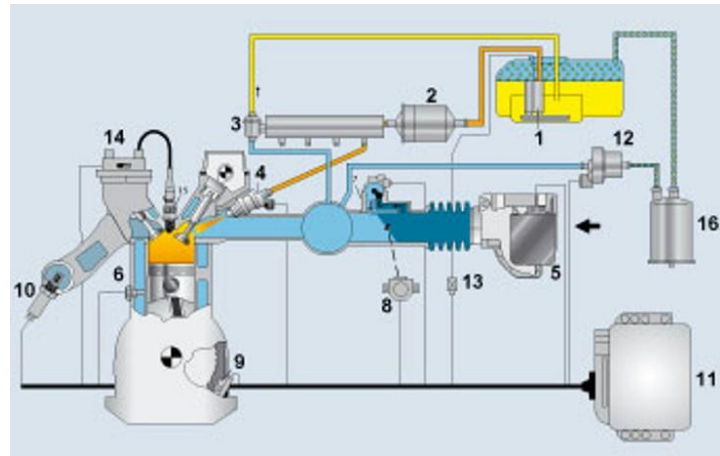
For this assignment, the following two engines were chosen;

- i) a Vauxhall 2.0 fitted with **Bosch Motronic** engine management system, and
- ii) a Vauxhall 2.0 fitted with **Bosch LE3 Jetronic** engine management system.

Fuel delivery for both engines is provided by fuel injectors. Solenoid-operated valves that are opened by an electrical control signal at the proper time in the engine cycle. The exact period is computed by the ECU. These control signals are related to ambient temp, engine coolant temp, air flow, throttle pedal opening, crank position, engine speed, exhaust emissions and ignition timing.

Fig 1.
Bosch Motronic engine management system.

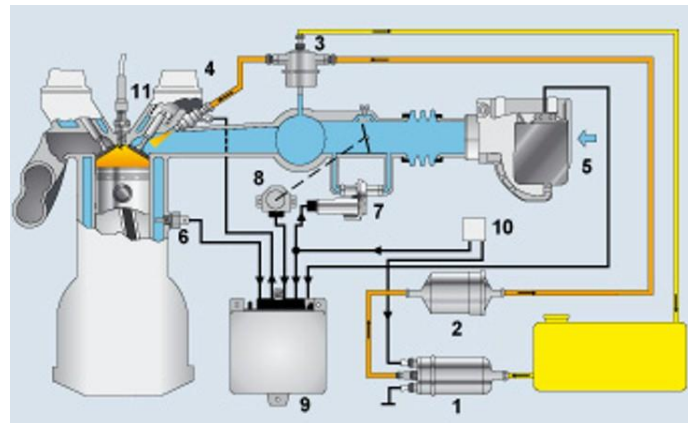
- 1 - Fuel pump
- 2 - Fuel filter
- 3 - Pressure gauge
- 4 - Injection valve
- 5 - Air flow meter
- 6 - Temperature sensor
- 8 - Butterfly potentiometer
- 9 - Rotation Sensor
- 10 - Lambda Probe
- 11 - Command unit (injection + ignition) of the tank
- 12 - Tank ventilation valve
- 13 - Command relay
- 14 - Ignition coil
- 15 - Spark plug
- 16 - Canister



(Info source - http://br.bosch-automotive.com/en/internet/parts/parts_and_accessories_2/motor_and_sytems/benzin/injection_system/motronic/)

Fig 2.
Bosch Le Jetronic engine management system.

- 1 - Fuel pump
- 2 - Fuel filter
- 3 - Pressure gauge
- 4 - Injection valve
- 5 - Air flow meter
- 6 - Temperature sensor
- 7 - Air injector
- 8 - Butterfly switch
- 9 - Command unit
- 10 - Command relay
- 11 - Spark plug



(Info source - http://br.bosch-automotive.com/en/internet/parts/parts_and_accessories_2/motor_and_sytems/benzin/injection_system/motronic/)

The injection side of both systems feature the same principles and share the same types sensors. However, the sensors on the Motronic system run on a supply of approx 5 volts while the LE system runs on 12volts.

1.2 Sensors

Sensors measure physical actions such as vibrations, movement or temperature or electrical actions such as current, resistance or power. They can be self-acting, where they generate their own energy supply or passive by receiving input from another source such as the ECU. Speed or position sensors can be magnetic, optical or capacitance generated. They are usually used in gearboxes, flywheels, pulleys and throttle potentiometers. Temperature sensors react to heat and cold and are used in cooling systems, transmission systems or air intakes. Gas sensors are found in exhaust systems and measure excess oxygen or unburnt fuel.

Fig 1. Table. Engine sensors.

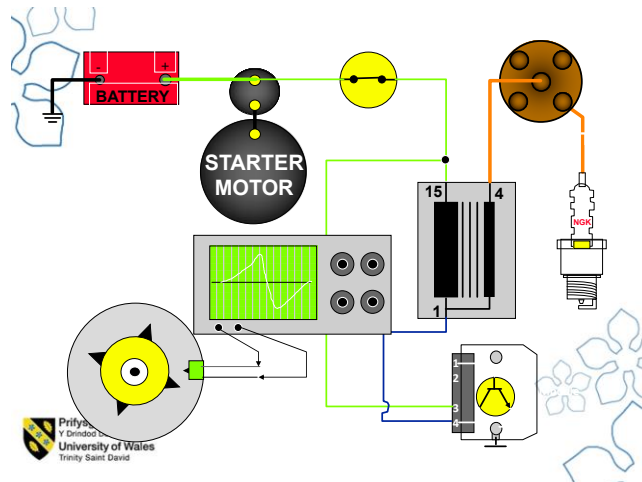
Sensor	Task	Purpose
Airflow meter/ Air temp sensor.	Measures airflow into engine/ Intake air temperature.	To establish load/engine requirements. Adjust fuel/air mixture and timing corrections.
Water temp sensor.	Measures engine coolant temp.	For correct fuel delivery / timing corrections/ set idle speed.
Throttle switch.	Identifies idle or high load positions of pedal.	Corrects / adjusts fuel requirements as required.
Throttle position sensor. (Potentiometer)	Accurately identifies full movement/positions/ setting of throttle pedal.	Provides exact indication of requirements/load to adjust fuel/ignition.
Crankshaft sensor.	To establish/provide reference to crank position/ engine revs.	To adjust ignition timing and provide 'trigger' reference for injection settings.
CO adjuster.	Relays CO settings in air box (in prox to air flow meter) to ECU .	To adjust fuel injection settings (weak/rich mixture) as required.
Lambda Probe. (As fitted on Motronic only.)	Measures oxygen content of exhaust gases, sends data to ECU.	ECU calculates/determines the ideal air/fuel at combustion. To ensure optimum engine efficiency and low emmissions.

Section 2.

Systems Operation Tests.

Fig 2.

Diagnositic Testing



(image source UWTSD-Moodle)

2.1 Equipment

A full systems test was run on both electronic ignition systems. A digital multimeter and a diagnostic oscilloscope were used as effective means of analysing. Together with suitable hand tools. Both electronic ignition system components have certain resistance value ranges, showing voltage output signals and output pulse waveform ranges. A multimeter and oscilloscope were used to measure the resistance or the output voltage and the waveform of these signals. An oscilloscope is able to examine how an electrical circuit functions by measuring voltage waves and presenting the information on a screen. It is able to analyse these complex wave forms produced by the dynamics of electrical systems. Signals can be either analogue or digital. Analogue signals hold continuous values with a smooth transition between changes. Digital signals have a definite set of values that change or 'jump' instantaneously.

2.2 Systems Test

The test sequence was based on checking the connection, correct battery voltage present, the voltage supply and earth, and that the variable signal output was as per manufacturers specification. The tests focused on the set-up of an oscilloscope to measure settings, waveform interpretation and analysis. The differences between analogue and digital signals were considered. The tests highlighted the importance of understanding the operation of the component examined and measuring how sensors can send/modify a signal to and from an engine's management system. The tests examined current, resistance, voltage, frequency and duty cycle of injectors. Analysing and understanding the wiring diagrams for the two engines was an important aspect for team work and group discussion during the following tests;

Fuel injection signal duration test –to analyse the injector 'on-time', the duration of time or 'pulse width' when the fuel injector delivers fuel. An oscilloscope with a millisecond m/s scale was used to check the injection duration.

Airflow meter operation test – airflow and temperature readings were analysed and established by checking resistance between the meter terminals.

Water temperature sensor test – changes in temp of the engine coolant were analysed by the change in resistance.

Crank sensor test - was connected, to analyse 'trigger source' and engine speed which lead on to analysing waveforms.

Idle Speed Control Valve test – to establish operation and examine idle speed control wave form.

Fig 3. Table. Systems Test.

(Test, operation and source location / points).

Test.	Operation. /	Motronic. Source location	LE Jetronic. Source location
Secondary Voltage Wave pattern.	Ignition. ('spark duration' or burn time.)	Coil 'King' HT Lead	Coil 'King' HT Lead
Signal Ref for Fuel / Injector Pulse	Injector time / operation	Pin 16 Pin 17	Pin 5
System Ignition. NTC 2	Ignition system	Pin 27 Pin 2	Pin 3 supply Pin 5 Earth
Simultaneous Injection	Fuel Injection system	Pin 16 Pin 17	
Amps Primary	Ignition system		Pin1
Throttle / Airflow	Engine revs.	Pin 7 Pin 53	
Spark Advance signal/Primary	Spark operation / duration	Pin 1	Pin 4 Pin 1
Crankshaft Signal	Engine revs		Pin 12
Injector idle	Idling Speed.		Pin 3
Deceleration	Engine revs /deceleration	Pin 16	Pin 3
Acceleration	Engine revs / acceleration	Pin 16	Pin 3
Fuel / Emissions	Lambda	Pin 28	
Engine speed	Engine revs	Pin 49	

2.3 Health and safety.

The high voltage output from ECUs, live engine management systems and diagnostic equipment may cause serious harm or injury. Voltages on modern electronic ignition systems can often be as high as 90,000 Volts. Care was taken when working on electronic ignition/injection equipment and consideration towards health, safety and welfare was made during engine testing. Audible warnings were issued before starting up of engines. A risk assessment was carried out to identify and address any probable hazards and risks that may have caused harm during the test procedures. Students were protected from anything that would have caused harm through the effective control of any risks to health or injury. Danger of injury from moving engine parts, pulleys, belts and the risk of electrocution from test equipment. The effective control, management and disposal of engine exhaust emissions, especially from cold or intermittently run engines, as these contain a slightly higher concentration of harmful exhaust gases. Limiting harm or injury from excessive engine noise and ensuring there were no trip hazards on the floor caused by loose/hanging equipment cables.

2.4 How injection on-time is addressed to meet certain conditions.

Fuel injection systems play an important role in the majority of today's automotive management systems. Their primary function is to deliver the correct amount of fuel at the correct time to an engine, prioritising fuel-efficiency and reducing exhaust emissions and pollution. The primary purpose of any electronic engine management system is to regulate and control the ignition timing and fuel to air mixture. Injection on-time, or 'pulse width' refers to the controlled delivery of the correct amount of fuel to the engine when the injectors are in operation. Whether on/off or pulsed rapidly. When an engine needs more fuel to meet increased loads, the injection time increases accordingly and during deceleration, decreases accordingly.

(info source <http://www.hurstinjectorservice.com/faqs.html>)

Injector timing is controlled and managed by the engine ECU. Measured in milliseconds (ms), injection on-time refers to the duration of time or 'pulse width' when the fuel injector delivers fuel (stays open) during the intake cycle. An engine at idle at the normal operating temp would have a typical injector on-time of between 2.5 and 3.5 ms. When an engine needs to increase revs and develop power, the management system increases the injection on-time or pulse width accordingly.

(Info source <https://www.thoughtco.com/what-is-fuel-injector-pulse-width-85366>)

Rather than just instantly opening and closing; *"it takes a small amount of time for the coil to fully energize and open the pintle or disk depending on the voltage, fuel viscosity, fuel pressure, etc. It also takes a small amount of time for the injector to close once current stops*

flowing through the coil.” When calculating the injector on time / pulse band, this additional time is calculated by the ECU/command unit.

(info source <http://www.ecmtuning.com/injector-duty-cycle>)

Injector Duty Cycle.

The degree of time that an injector output is held ‘on’ is measured as a percentage of its whole duty. *“An injector open for 8 m/s then closed for 10 m/s has a duty cycle of 80%”*. Should an injector reach or exceed 100% duty cycle then it has reached its full delivery potential and the limit of its ability to supply more fuel.

(<https://www.lloydspecialistdevelopments.co.uk/wp-content/uploads/2018/01/Canems-Injection-Manual-1.pdf>)

The ECU receives signals of engine position, speed, coolant temperature, air temperature. The function of an engine management system is complex. It interfaces fuelling and ignition timing to address engine speed and load requirements. At the same time allowing for differing conditions in engine and ambient temperatures, pressures and acceleration conditions and requirements.

With the ignition on and the engine not running.

The state ‘ignition on and the engine not running’ creates a primary current within the coil. However, the voltage in the coil will only be released to the HT leads / spark plugs at the correct point in the ignition cycle. Voltage is supplied to the tank fuel pump and injection relay, but this circuit will only be energised once cranking takes place.

Engine cranking from cold.

During cold cranking the fuel injection on-time is dependent on the readings sent from the coolant temp sensor and engine speed. The fuel is often enriched during cranking to aid firing. An AC voltage is generated and released in the coil and stroke ignition occurs in the compression/ignition cycle. The control unit determines the correct cylinder charged with compressed air/fuel mixture for ignition. The fuel injection relay is energised. *(“In the Motronic the enrichment factor is increased during cold cranking, in order to compensate for the condensation of fuel on the cold cylinder walls.”)(“In the LE-Jetronic system, the injection valves spray the fuel simultaneously, they are all driven at the same time.)*

” Info source [http://br.bosch-](http://br.bosch-automotive.com/en/internet/parts/parts_and_accessories_2/motor_and_sytems/benzin/injection_system/le_jetronic_1/le_jetronic.html)

automotive.com/en/internet/parts/parts_and_accessories_2/motor_and_sytems/benzin/injection_system/le_jetronic_1/le_jetronic.html

“Info source Moodle. Andrew Gibson.”

Engine during warm up.

Upon completion of the starting process, injection time increases. The ECU, as a result of receiving data from the engine sensors, calculates the correct injector pulse time right

across the temp range. While the engine reaches optimum operating temperature. Dependent on temp reading, revs and load. Ignition timing is also corrected depending on engine temp. The warming up settings are dependant on engine speed and load in order to provided smooth running of the engine for 'drivability'.

"Info source Moodle. Andrew Gibson."

Engine at idling speed (at operating temperature).

Injection time depends on engine speed and idling speed regulator, dependent on the signal from engine coolant temp sensor / throttle position sensor. Idle speed mode is activated in order to allow the engine to run as low an rpm as possible without stalling. An engine at idle speed of around 500-700rpm at normal operating temp would have a typical injector on-time of between 2.5 and 3.5 ms.

"Info source Moodle. Andrew Gibson."

<https://www.thoughtco.com/what-is-fuel-injector-pulse-width-85366>

<https://www.sciencedirect.com/topics/engineering/idle-speed-control>

Engine under acceleration.

Opening the throttle results in a sudden intake of air and the management system compensates through fuel enrichment based on throttle position. Therefore, Injection on time increases, causing fuel enrichment resulting from signals from the air-flow meter. The exact degree of acceleration enrichment is established as a result of the engine revs, engine load, throttle setting, engine coolant temp and increased air-flow. The antiknock sensor signals the ECU /command module and ignition timing is adjusted accordingly. This prevents 'acceleration knock' or preignition as a result of enriched fuel. *"Knocking starts -ignition retarded in 3 degree steps. Knocking starts – ignition advanced in 0.7 degrees).*

The fuel/air ratio is then rebalanced as the engine revs rise.

"Info source Moodle. Andrew Gibson."

Engine under deceleration.

Crankshaft speed will decrease below the threshold speed set by the ECU due to the added load. The crankshaft position sensor will send the lower engine speed signal to the ECU, which will then either increase or decrease injection time dependent on engine load. Thus sending longer/shorter pulses to the injectors, adding more fuel or decreasing fuel to compensate for the increased/decreased load. The ignition timing adjusted accordingly. A smooth deceleration rate of revs is achieved by a steady decrease in the injection on time and the reduction in the amount of fuel burnt.

Section 3.

Practical Measurement and Interpretation of Data Sheets.

3.1 Procedures adopted when carrying out the test.

A period of time was allocated in order to carry out a full practical investigation on a vehicle fitted with the engine management systems in respect to their operation and features. The test equipment available in the automotive workshop used for the investigation and the necessary voltage waveforms were recorded. Circuits were tested by measuring the voltage drop, the current and resistance. The units of measurement being – *the potential energy of an electrical supply measured in Volts (V) , the flow of electrical charge in Amps (A), the ability of the component to prevent or resist the flow, or resistance in Ohms (Ω).*

(info source –page 212. Hillier's Fundamentals of Automotive Electronics Book 2 , 6th Edition)

The oscilloscope was connected to various points in the test procedures, the 'pin' or terminal numbers of the sensor or system have been listed. Most of the testing was carried out on the corresponding ECU pins , with some measurements taken on the sensors. When testing the injectors the positive probe connected to the injector's pin (16) and the negative probe to earth. Voltage levels differ in the two systems tested. The Motronic ECU supplies 5 volts to its sensors whilst the LE Jetronic runs on a board voltage of 12 volts. The resistance values are similar in both.

3.2a Motronic Test Readings. Signal Waveforms.

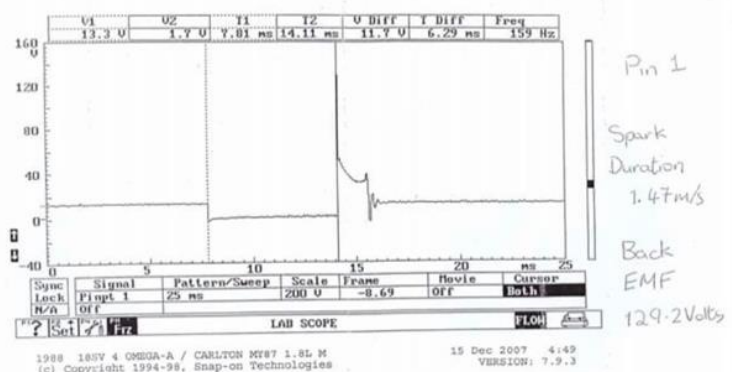
Graph M1.

Motronic. Pin 1 - Spark Duration – 1.47s.

Negative side of coil.

Back EMF. – 129.2 Volts

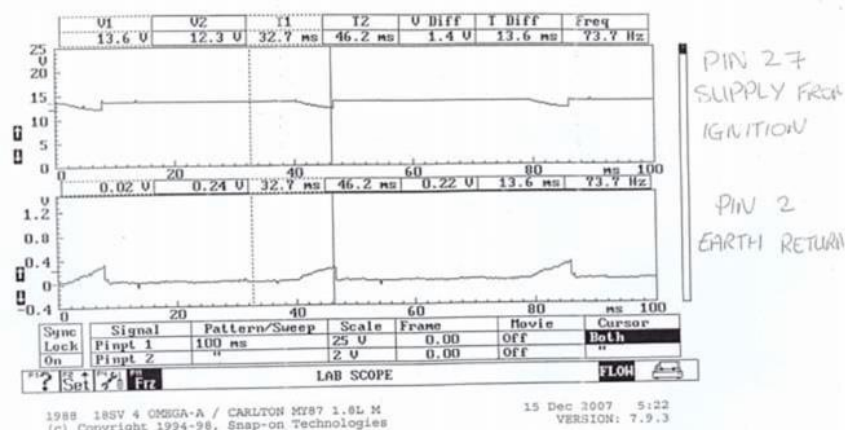
Ignition coil signal.



Waveform shows voltage that creates spark ignition.

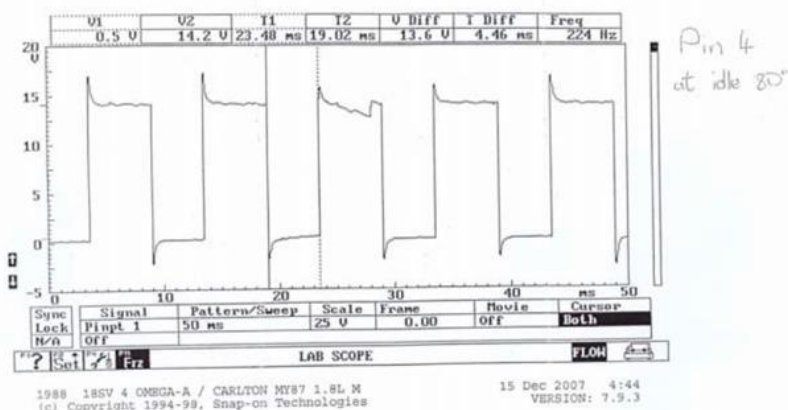
Graph M2.

Motronic.
Ignition On.
Pin 27 - Supply from
ignition.
Pin 2 – Earth return.



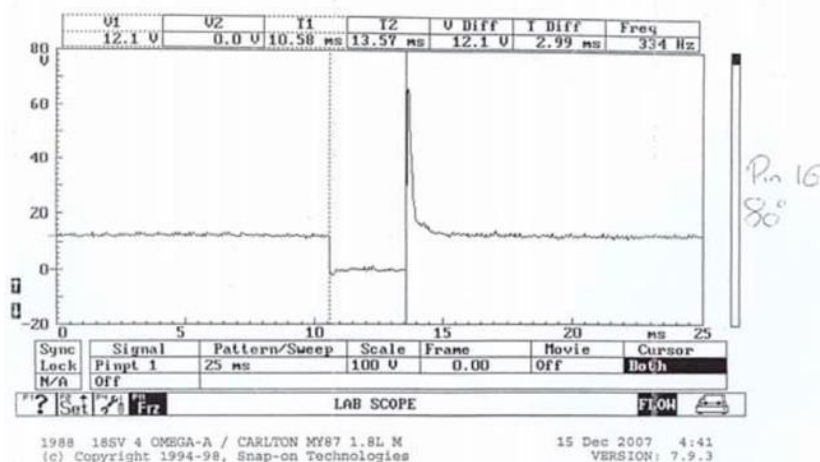
Graph M3.

Motronic.
Pin 4 – Pulse side of
Rotary Idle Valve . At idle.
Temp 80°



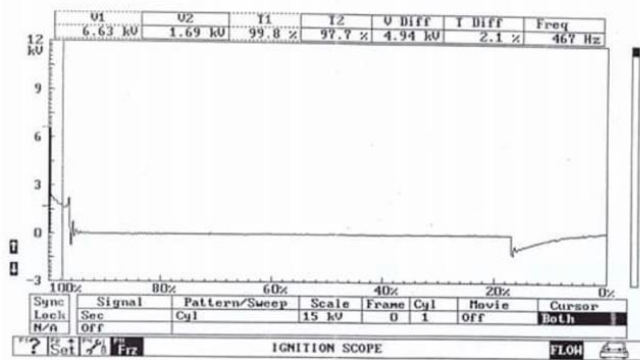
Graph M4.

Motronic. Pin 16 - Pulsed
side of injectors
(bank of 2) – Temp 80°



Graph M5.

Motronic. Secondary Wave Pattern.



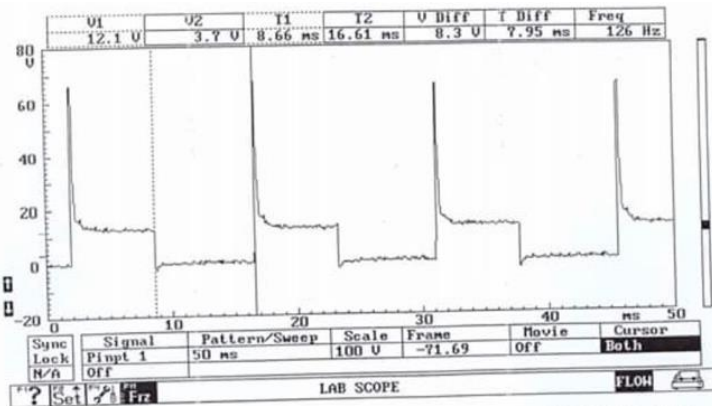
1988 18SV 4 OMEGA-A / CARLTON MY87 1.8L M
(c) Copyright 1994-98, Snap-on Technologies

16 Dec 2007 17:45
VERSION: 7.9.3

Secondary Wave Pattern

Graph M6.

Motronic
Pin 16 – Pulsed side of
Injector.
(bank of 2)
Engine under Acceleration



1988 18SV 4 OMEGA-A / CARLTON MY87 1.8L M
(c) Copyright 1994-98, Snap-on Technologies

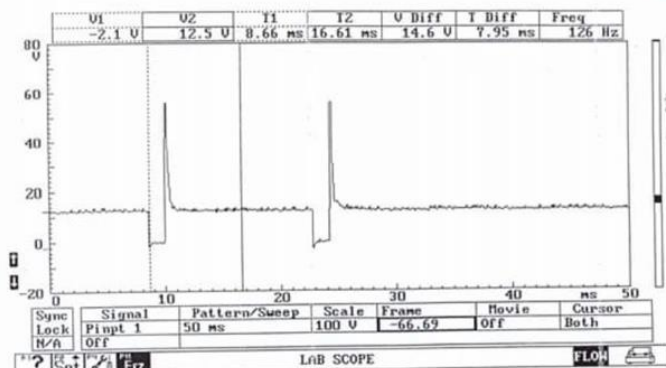
15 Dec 2007 5:09
VERSION: 7.9.3

*PIN 16
ACCELERATION*

Graph M7.

Motronic

Pin 16 – Pulsed side of Injector.
(bank of 2)
Engine under Deceleration



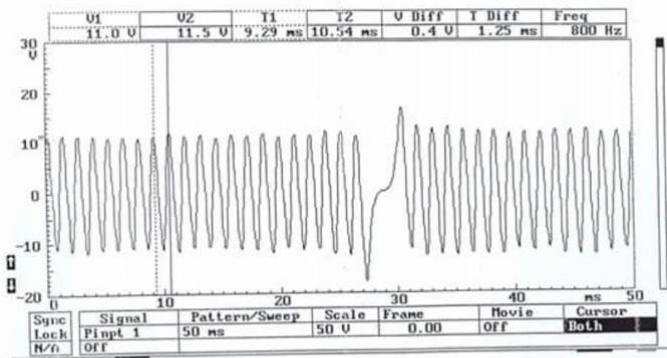
1988 18SV 4 OMEGA-A / CARLTON MY87 1.8L M
(c) Copyright 1994-98, Snap-on Technologies

15 Dec 2007 5:11
VERSION: 7.9.3

*PIN 16
DECELERATION*

Graph M8.

Motronic
Pin 49 - Speed Sensor.

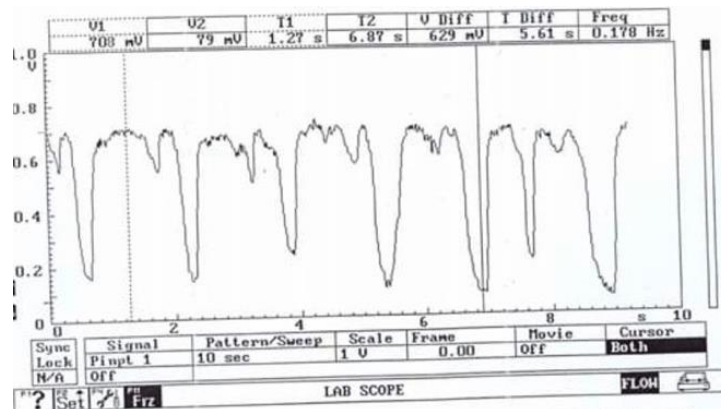


PIN 49
SPEED SENSOR

Graph M9

Motronic
Pin 28 - Lambda Sensor/ Probe

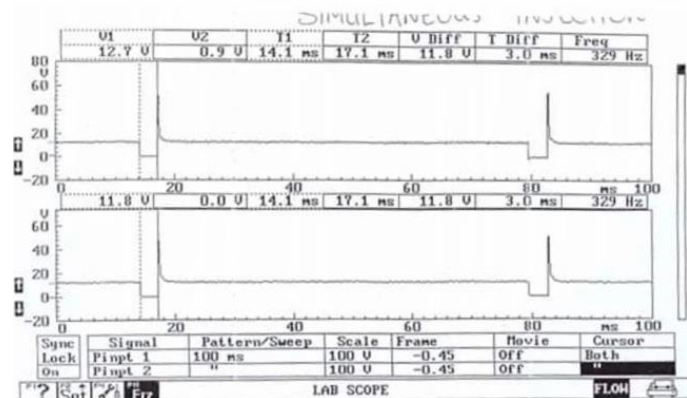
Exhaust gas analysis



PIN 28
LAMBDA SENSOR

Graph M10

Motronic
Simultaneous Injection
Pin 16 - Pulsed side of injection bank
Pin 17 - Pulsed side of injection bank



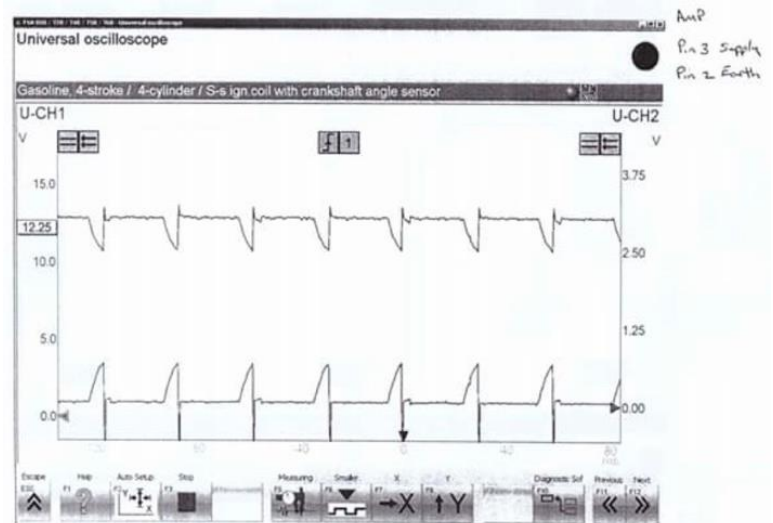
PIN 16

PIN 17

3.2b Test Readings LE3 LE System

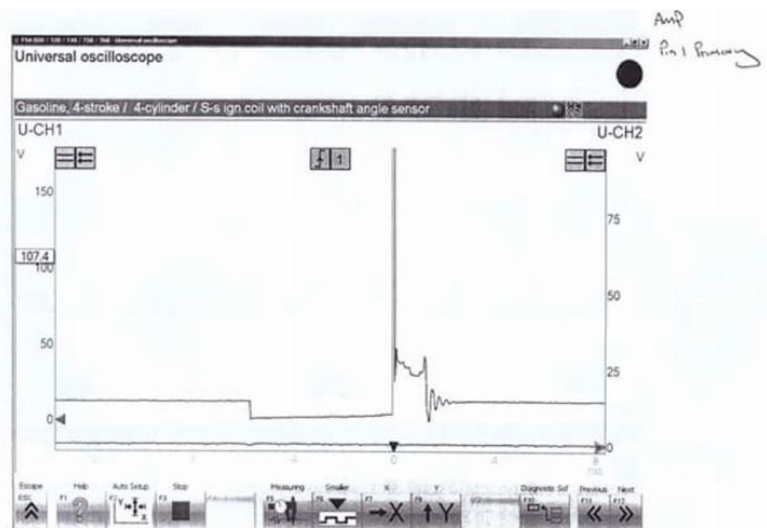
Graph L1

LE3. NTC2
System Ignition
Pin 3 supply
Pin 2 NTC2 Earth



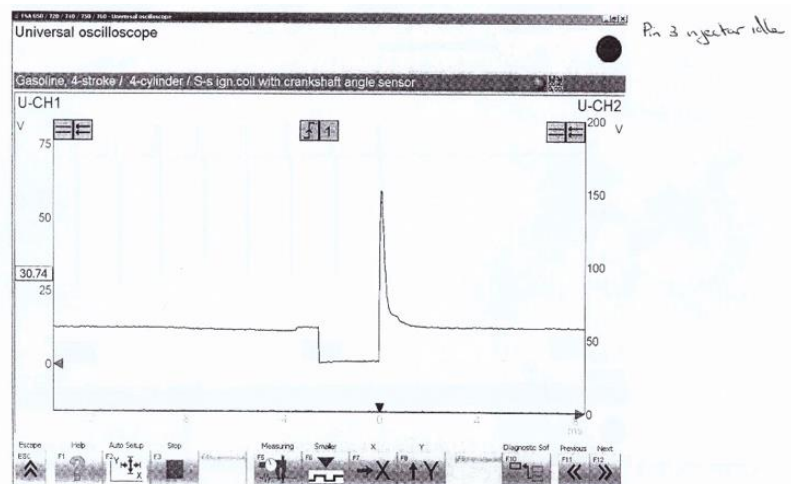
Graph L2

LE3
Pin 1 – RPM counter /
Primary Voltage.



Graph L3

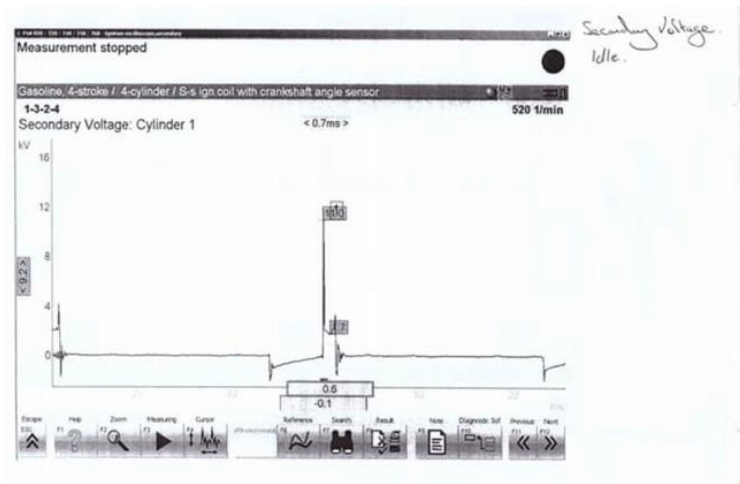
LE3
Pin 3 – Supply /Injector Idle



Graph L4

LE3

Secondary Voltage Cyl 1

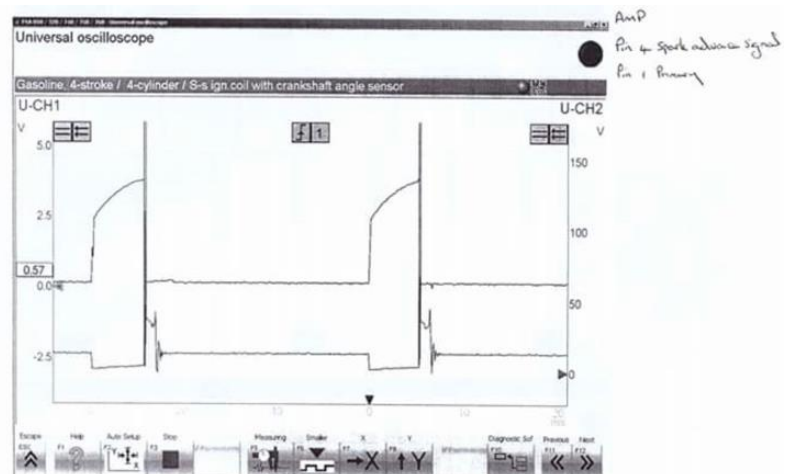


Graph L5

LE3

Pin 4 – Spark advance signal

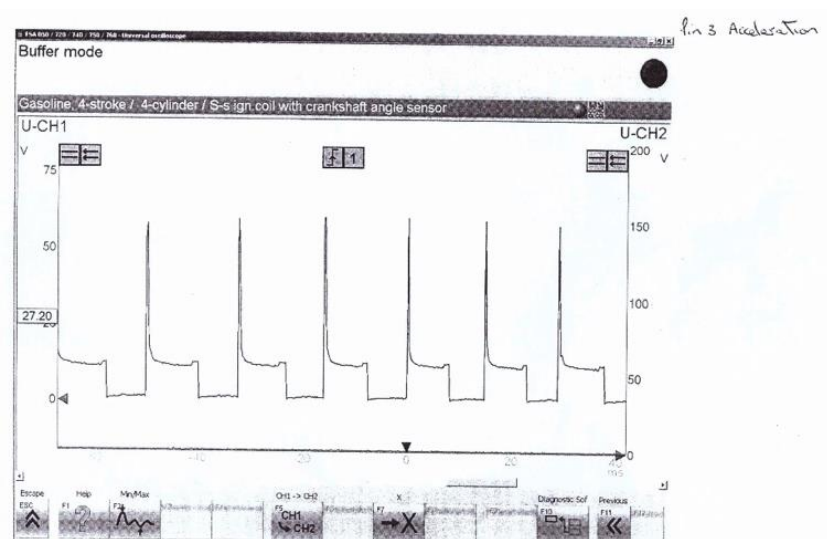
Pin 1 – Primary Earth



Graph L6

LE3

Pin 3 Crank Sensor
Engine under acceleration.

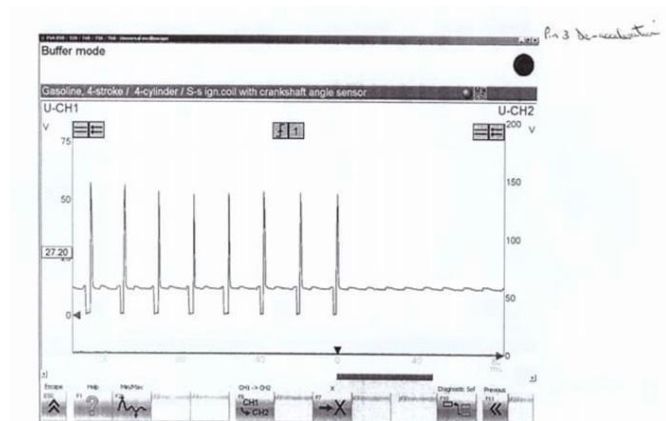


Graph L7

LE3

Pin 3 Crank sensor

Engine under deceleration.

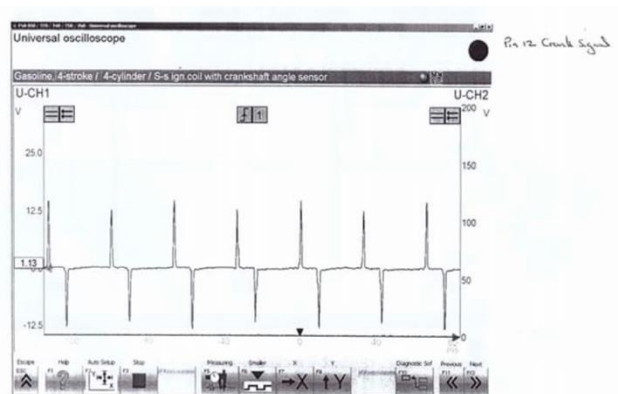


Graph L8

LE3

Pin 3 Crank sensor

Engine crankshaft signal.

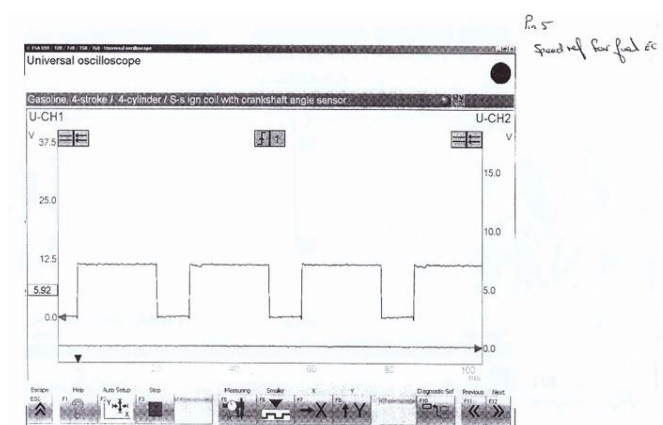


Graph L9

LE3

Pin 5

Speed/signal ref for fuel



3.3. Reasons for choice of test equipment.

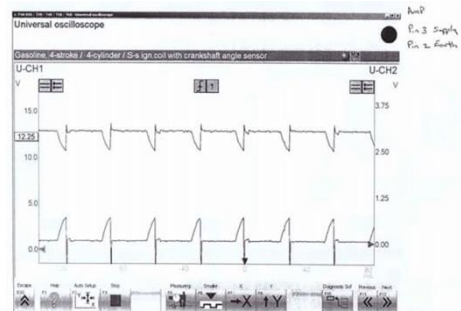
An oscilloscope and multimeter was considered as the ideal test equipment for engine management analysis test. The equipment provided the opportunity to investigate and analyse the different waveforms, in order to interpret signals from the various sensors. The readings were shown on the screen in a graphing trace format, with up to a minute across the screen.

3.4 Safe working practices.

The testing of engines can be dangerous unless basic checks and risks are observed and considered. Before running any engine, all levels should be checked and topped up if required. A relevant fire extinguisher should be suitably located together with a knowledge of fire exit points. Attention drawn to possible hazards and risks from rotating pulleys, drive belts and other moving parts, also the safe collection and disposal of engine exhaust emissions.

3.5 NTC2 Graph

LE3 System Ignition Screen.
Pin 3 + supply
Pin 2 earth (NTC2)



A negative temperature coefficient resistor (NTC) is an engine temperature sensor switch where the resistance varies in relation to the temperature. The hotter the engine coolant temperature, the less resistance. The resistance is higher when coolant temp cold, this setting initiates cold start enrichment. Available in many different resistant values from 1 ohms to 10 ohms, they perform in many applications of engine thermostat circuits.

(Info source <http://www.giangrandi.ch/electronics/ntc/ntc.shtml>)

The ECU is able to analyse the engine coolant temperature and activates the cooling fan circuit when engine temperature increases to high levels and functions as an input signal to calculate injection on time.

(Info source Hillier's Fundamentals of Automotive Electronics Bk 2 6th Ed)

Section 4

Main system operational differences.

4.1 Bosch's Motronic fuel injection/ignition management system.

First introduced in 1979 with advancements in 1987, 1989 and 1990. 'Motronic' referring to the fact that the system is controlled by the one ECU which controls both the fuel injection and ignition.

The system is 'multi-point' in that each cylinder has its own fuel injector. Motronic 4.1 has a single output for the injectors, which results in simultaneous injection with all injectors firing at the same time.

The Motronic slightly differs from the LE Jetronic in that the electronic ignition system incorporated in the command unit and it features a Lambda Probe Sensor connected to the ignition system and mounted within the exhaust pipe measuring the exhaust gases.

The Motronic's digital system is equipped with 'adaption memory' and malfunction 'engine code' warning light which enables the system to 'memorise' fault codes. These codes can be retrieved or 'interrogated' by a compatible fault code reader/code analyser. Should a sensor circuit develop a fault, the ECU will pick up on this and run a basic ignition/injection programme, referred to as 'limp mode' or 'get you home' mode. Where defective information from relevant sensors are by-passed and the engine operates up to certain basic settings and revs.

In addition, the Motronic System incorporates a 'Tank ventilation valve' which allows the reuse/reburn of toxic fuel vapours. Aimed at reducing pollution.

The sensors in both ignition systems are similar and provide accurate timing information by the ECUs. However, while the Motronic system operates on a supply rating of 5v, the LE system runs on 12v.

4.2 The LE-Jetronic system.

Launched in 1967 as the world's first mass-produced electronic fuel injection system and further improved in 1979 and 1985. Electronically commanded, airflow-controlled and operates by injecting the fuel directly into the intake manifold. It provides the correct amount of fuel necessary to address the engine's working requirements. The command unit receives input signals from various sensors that send information regarding engine operation requirements/conditions. For example, denser air needs less fuel, therefore starting in cold

ambient temperatures require more fuel. The command unit processes the information received and calculates the required 'fuel injection time' electronically. Also known as injection time (iT).

The system has injection valves that spray the fuel simultaneously as they are all driven at the same time. It differs slightly in that the LE injection command unit controls only the fuel system. Also, as the LE system is analogue it is unable to store a memory of 'engine faults' and does not feature 'limp mode' capability or an engine fault warning light.

(Info source http://br.bosch-automotive.com/en/internet/parts/parts_and_accessories_2/motor_and_sytems/benzin/injection_system/le_jetronic_1/le_jetronic.html#)

Both systems are fitted with similar electronic sensors.

Section 5. Conclusion.

Conclusion

The management system of a fuel injected electronic ignition engine must dictate the delivery of the correct quantity and ratio of fuel/air to be ignited at the correct time. In order to meet this requirement, it must measure the amount of air, analyse engine load and sense crankshaft position. These three factors contribute towards the timing of the injection and ignition in order for the engine to address it's workload and other conditions or requirements. The oscilloscope is able to display wave form patterns that represent the operation of correctly functioning components of the system, for example a pulse generator that produces a signal to trigger the spark at the spark plug at the correct time. This waveform gives information on the ignition system and also the fuel injection side. Because the voltage needed to ignite a fuel/air mixture is dependent on other aspects such as ignition timing, air-flow, air temperature and spark plug gap the analyser can do this because the voltage required to fire a petrol/air mixture in an engine is affected by many different variables including air-fuel ratio, cylinder compression, ignition timing, ignition polarity, spark plug gap and condition etc, etc. The oscilloscope proved to be useful in testing and analysing sensors, solenoids, primary and secondary ignitions. Capable of visualizing the ignition spark sequence, also the observation of output signals coming from inductive sensors, current waveforms, analogue and digital signals.

Section 6.

Possible enhancements to the LE Jetronic system.

Based on the information gained from the test, there are a number of possible enhancements that could be carried out to the LE system.

- i) Improve air flow sensor. To replace the hot wire mass sensor in the air intake with a volume sensor. Short journeys (average of less than 10 miles a week) do not allow the hot wire to 'glow' and burn off the dust and 'rubbish' matter. This builds up and prevents the wire from functioning correctly.
- ii) To consider the use of adaptive control measures, where solenoid plungers allow better control of more or less airflow especially during warm up, thus enhancing air values and improving better start up, fuel efficiency.
- iii) Removal of auxiliary air valve. Less fuel used during idling creates less heat and better fuel efficiency.
- iv) LE3 system is not digital and therefore not equipped with fault code memory facility in ECU. Memory would improve diagnostic procedure should faults occur.
- v) During cold start up of LE3, lambda probe sensor was not switching therefore not registering the amount of unburnt fuel. Causing an over enrichment when cold.
- vi) To improve throttles response. Repositioning the airflow meter nearer to the throttle-body. The closer the distance, the faster the meter analyses any changes in airflow, resulting in a quicker response to throttle movement.*
- vii) *"In the LE-Jetronic system, the injection valves spray the fuel simultaneously, they are all driven at the same time."*^{**} Changing the timing of the injection system from 'all' to 'sequential' fuel injection would providing improved fuel efficiency, lower exhaust emissions and better throttle response.

(*Info source -<http://users.telenet.be/jov/opeltuners/aboutfi/ciccosinjection.html>)

(** “ Info source-

http://br.boschautomotive.com/en/internet/parts/parts_and_accessories_2/motor_and_sytem/s/benzin/injection_system/le_jetronic_1/le_jetronic.html)

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Section. A. Appendices.

A.1. Results

LE3 ECU - Spreadsheets showing readings taken / LE Jetronic.

The following data was analysed and recorded into an Excel document to create the following tables.

	Amplifier	
Pin Number	Ignition Off	Ignition On
1	0V	11.99V
2	0V	00.02V
3	0V	11.95V
4	0V	00.13V

		Book		Engine
Throttle Switch	Terminals	Resistance (Ohms)		
	2&18 Throttle Closed	0		0
	3&18 Throttle Closed	Infinity		Infinity

Coolant Temperature Sensor	Temperature (°C)	Resistance (Ohms)		
	-10	7000-116000		
	20	2100-2900		
	80	270-390		

Injector Valves	Resistance Between Terminals	15-17 Ohms	Injector Number	
			1	15.7 Ohms
			2	15.7 Ohms
			3	15.7 Ohms
			4	15.8 Ohms

Auxiliary Air Valve	Resistance Between Terminals	40 Ohms		45.7 Ohms
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	Pin Number		
Temperature (°C)	8	8	3
20	1974	1.6	3.9
30	1105	1.1	3.1
40	747	0.9	3
50	512	0.6	2.6
60	548	0.6	2.5

**Cold Crank 17°C –
Injector On Time = 27M/S**
