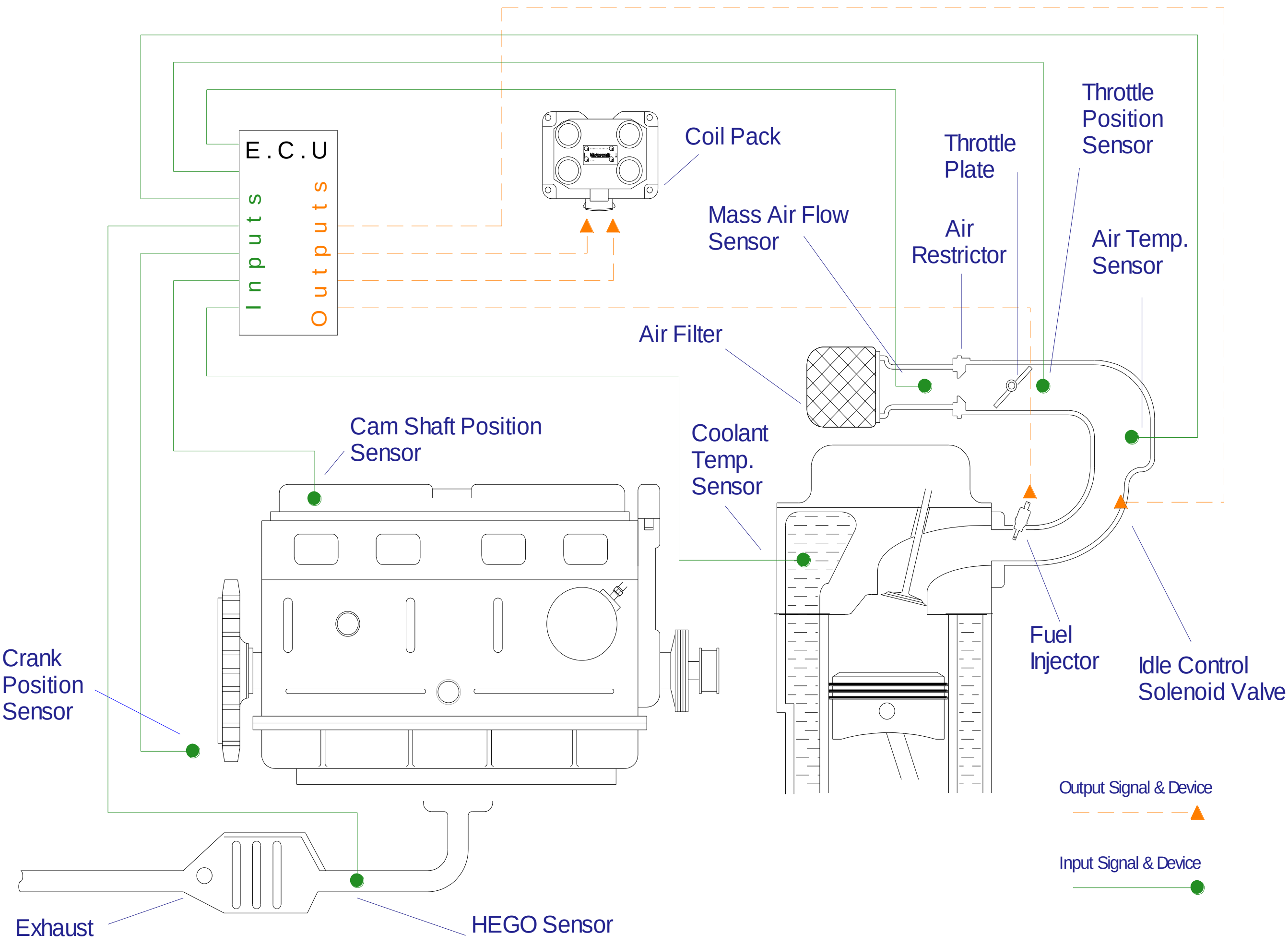
Engine Management Systems

In this article of the technical section we will attempt to explain how the Electronic Fuel Injection (EFI) system of a Formula Ford Zetec works. Prior to the Zetec engine being introduced all Formula Ford's had been powered by either the Kent Crossflow (FF1600) or Pinto (FF2000) engine, both of which utilised traditional carburettor and distributor type systems for fuelling and ignition timing. The Zetec engine was the first power plant to feature full electronic engine management to be used in a Formula Ford and coincided with its wider availability throughout the commercial car market.

Electronic sensors and injectors replace the traditional carburettor and distributor in order to mix the required fuel / air ratio and accurately time the ignition spark. An Engine Control Unit (ECU) acts a central control system, using information received from various sensors to calculate the exact fuel and ignition requirements.

There are a total of seven ECU input sensors, which measure coolant temperature, air intake temperature, crank shaft position, cam shaft position, air flow, exhaust gas oxygen content and throttle position. And there are outputs for each of the fuel injectors, the ignition coil pack, idle speed control solenoid and fuel pump relay.



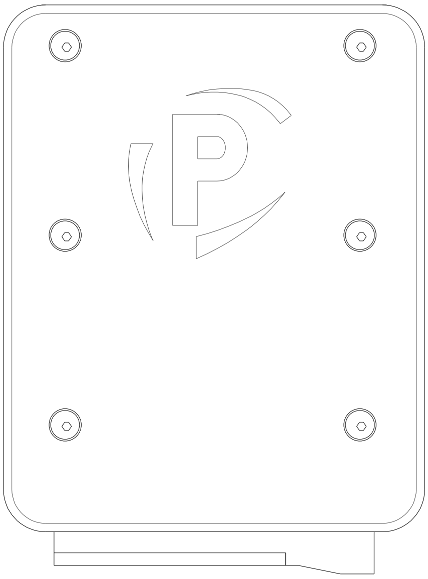
Formula Ford Zetec EFI Sensors & Injectors

Engine Control Unit (ECU)

The engine control unit or ECU is the engine management system's computer. Using data received from all of the engine sensors it performs a series of complex calculations to determine the ideal quantity of fuel to be injected, as well as timing the ignition spark. These calculations are known as "Engine Mapping" and determine how the engine performs and how much power it ultimately produces. Other parameters are also controlled by the ECU such as idle speed, rev limiting and fuel pump cut out.

However, this is not all that the Pectel ECU does, it also provides rudimentary data logging which may be viewed and analysed using special software.

By far the most commonly used ECU is the Pectel T2 (part number MS97FF12A650 AA). These were supplied by Pectel and programmed with a standard engine map especially designed for use with the Formula Ford Zetec engine. There is also a specific wiring loom which must be used. The loom, ECU and mapping may not be modified in anyway.



Pectel T2 ECU

Engine Wiring Loom

The engine wiring loom connects the ECU to all of the sensors, injectors and ignition pack as well as providing power supply and earthing connections to those devices requiring them.

There are basically two parts to the complete engine loom; the main loom, which was manufactured by Pectel and the injector loom, which is a standard Ford part.

The main loom connects the ECU with most of the engine sensors, ignition pack and comm's device (when connected). The injector loom is situated below the inlet manifold and connects the reset of the engine sensors, the injectors and idle speed control solenoid. The main loom and injector loom come together at the twelve way plug called the 'Engine Split'.

There is another large plug located half way down the main loom called the 'Chassis Split', this is where the engine loom is connected to the rest of the vehicles wiring, it is an eight way plug although only five terminals are used. Individual power supplies are brought in on terminals two, three and four for the ECU, ignition pack and lambda heater, (which allows for separate switching and fusing). The tachometer output is on terminal six and the fuel pump relay is brought in on terminal seven.

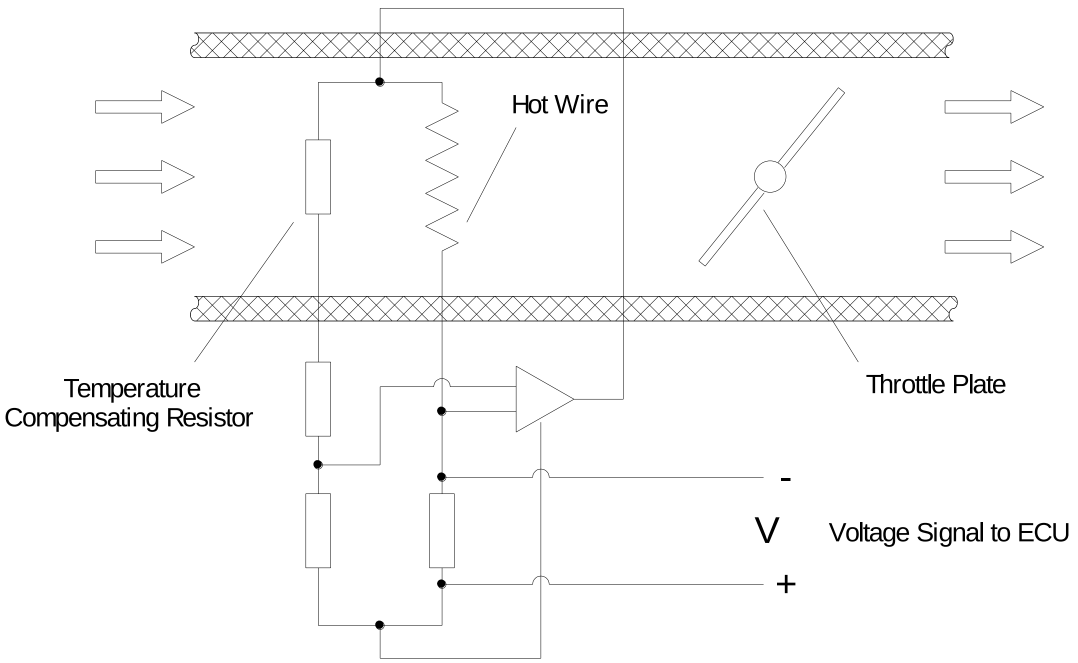
Mass Air Flow (MAF) Sensor

The most critical parameter that needs to be measured before the ECU can begin calculating the fuel required is the mass of air entering the engine. The Mass Air Sensor is situated in the air intake and is sometimes mounted on or inside an intake plenum.

The sensor works by heating a thin platinum wire (usually around 70µm) suspended inside a tube located in the air stream. This wire is heated by an electric current to a constant temperature. The incoming air has a cooling effect on this wire meaning more current is required to maintain its temperature. This current is sensed by a bridging circuit from which an output voltage signal can be derived and sent to the ECU. The mass of air entering the intake is directly proportional to the voltage output.

Unlike other devices the MAF Sensor is not affected by changes in air density caused by atmospheric pressure, altitude or the effects of forced / ram induction as denser air has a proportionally greater cooling effect.

The MAF sensor automatically compensates for changes in ambient temperature with a separate platinum film resistor located in the tube. Compensation for changes in air temperature is achieved since both the resistor and the 'Hot Wire' are equally affected by changes in ambient temperature, but only the 'Hot Wire' is affected by its mass flow rate.



MAF Sensor Schematic (Typical)

Air Intake & Coolant Temperature Sensors

The air intake and coolant temperature sensors are both simple two wire thermistor type devices. The electrical resistance of the probe changes significantly according to temperature. The value of resistance (measured in ohms) reduces proportional to increases in temperature.

The temperature sensors are also used to set the engines idle speed. At low ambient temperature the target idle speed will be around 1500 – 1600 rpm. As the engine heats up this will reduce to a minimum of 800 – 900 rpm.

Crank Shaft & Cam Shaft Position Sensors

Position of the crank and cam shafts is sensed with separate magnetic pickups. The crank position sensor is very important and the engine will not run without it. It is mounted at the left hand side the engine block facing towards the back of the flywheel. As the flywheel turns a frequency is created and sent back to the ECU and used to calculate engine rpm and activate the ignition spark. Like a distributor, the ECU advances and retards the ignition in relation to engine speed and load.

The crank shaft position sensor picks up on 36 circular holes machined into the reverse of the fly wheel, it sends back a frequency signal proportional to the number of holes seen per second. Since the ECU has been programmed with correct number of holes rpm can be calculated.

Throttle Position Sensor (TPS)

The throttle position sensor is located to the side of the throttle body and is actuated by the throttle spindle. It is simply a rotary potentiometer which operates a bridge circuit to derive an output voltage that is directly proportional to the percentage of throttle opening. This voltage signal is then sent to the ECU.

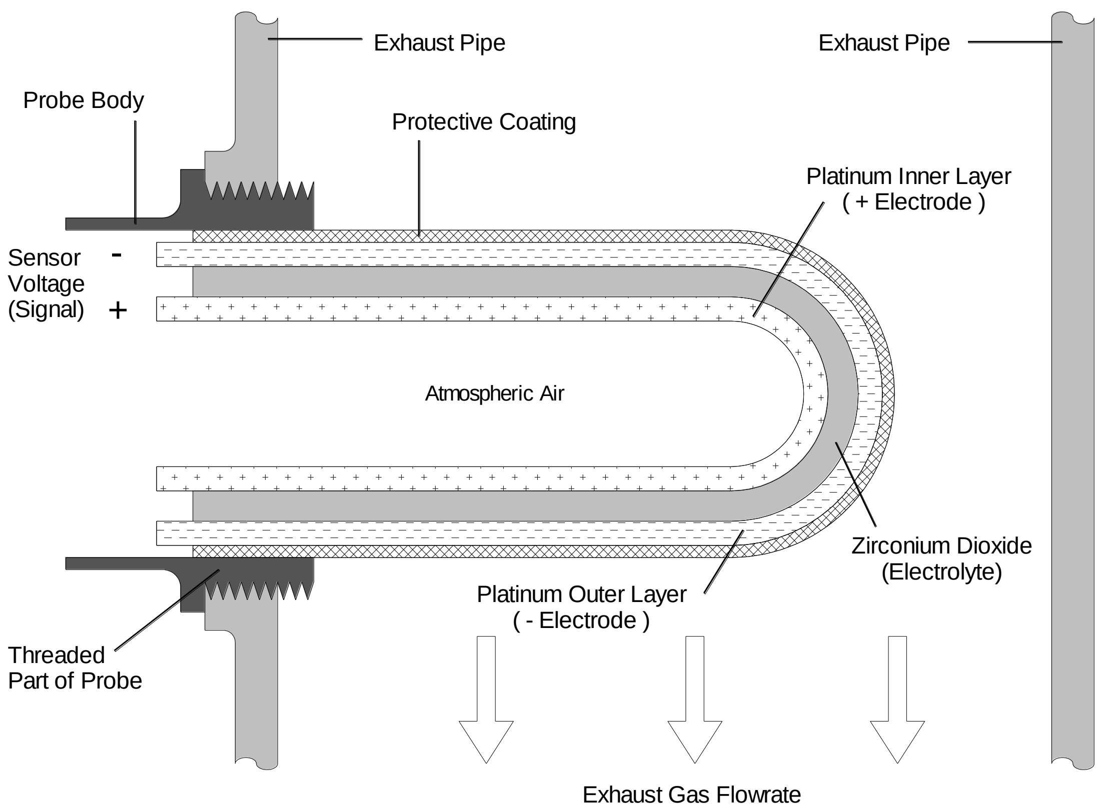
Heated Exhaust Gas Oxygen (HEGO) Sensor or Lambda Sensor

Using sensors to measure various parameters and performing calculations to predict the fuel required is all well and good, but what would happen if the system relied entirely on these predictions?

Variations between engine components, the finite calibration of sensors and injectors as well as wear of the valve gear and piston rings mean that you would be constantly altering the engines mapping to maintain peak performance and economy. This type of control system would be considered ‘Open Loop Control’.

Located in the exhaust system, somewhere between the exhaust collector and the catalytic convertor is the solution to this problem, the Heated Exhaust Gas Oxygen (HEGO) Sensor.

The HEGO sensor consists of a thimble shaped probe made of Zirconium Dioxide and covered inside and out with a layer of platinum. The probe screws directly into the exhaust through a threaded boss. The outside of the probe is exposed to the flow of exhaust gases whilst the inside is exposed to ambient air.



Lambda Sensor Diagram (Typical)

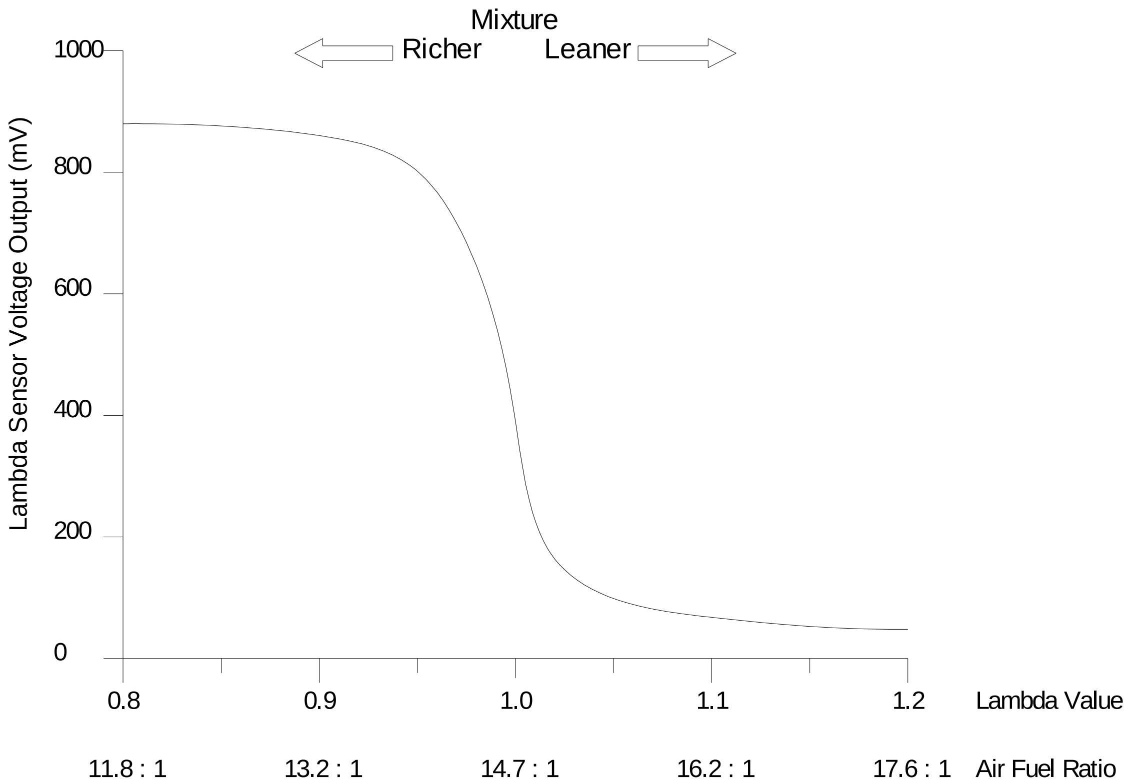
The Zirconium Dioxide which is sandwiched between the two layers of platinum acts as an electrolyte allowing a voltage (potential difference) to be generated between the two platinum layer. The inner layer is exposed to the 21% oxygen of the ambient air. Whilst the outer layer’s oxygen exposure will be significantly less as some is used up during the combustion process and will vary slightly according to the performance of the engine. It is the difference in oxygen content each layer is exposed to which creates the output voltage.

The presence of excess oxygen in the exhaust gasses indicates that the engine is running lean, whilst a lack of oxygen indicates the mixture is too rich.

We can express the oxygen content of the exhaust gas as a relative value known as Lambda. Where Lambda equals 1.0 the air / fuel ratio is considered to be 14.7 : 1, that means for every 14.7 grams of air taken in 1 gram of fuel is being burnt. For production cars this value represents pretty much the ideal fuel ratio. Lambda values less than 1.0 are considered to be richer than ideal and values greater than 1.0 weaker than ideal.

The sensor’s voltage output is relative to the remaining oxygen level, however as you can see from the graph is far from linear. When the engine is running rich, potential difference will be around 900mV. This drops off very sharply to approximately 50mV when a weak air / fuel mixture is encountered.

In reality the sensor works more like an on-off switch constantly switching between rich and lean as the ECU tweaks the engine mapping to maintain an average control voltage and hence desired air / fuel ratio.



Lambda Sensor Voltage Graph (Typical)

The Zirconium Dioxide doesn’t actually become conductive until it reaches approximately 300 degrees C, even at this temperature the probe can take several seconds to react to changes. It isn’t until the material reaches nearly 600 degrees C that performance is optimised and reaction times can be just a few hundredths of a second.

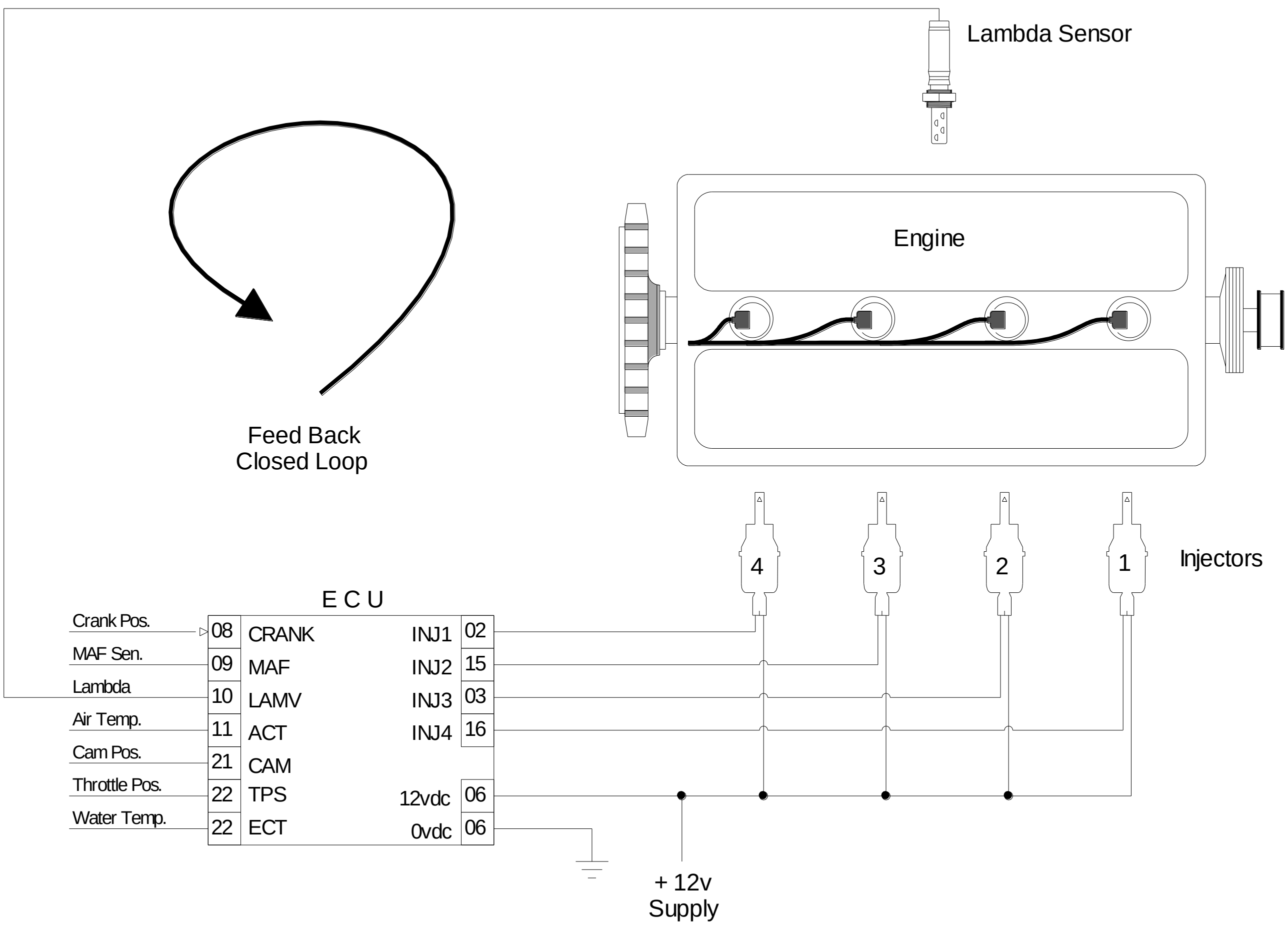
The Ford Zetec HEGO sensor has an inbuilt self regulating heater element which helps during start up and idle speeds when the exhaust is at its coolest. The heater is fed from the vehicles normal chassis wiring via terminal 3 of the chassis split connector. The heater is permanently powered, however regulates the current required to maintain temperature. In ambient conditions the heater will initially draw a current of between 2000mA and 1500mA although this will quickly drop to around 500mA as the element warms up and once the engine is running at full operating temperature little or no current will be drawn. If possible it is good practice to incorporate a fuse in the heater supply of 5Amps.

Injectors

Each cylinder has an individual fuel injector situated just above the intake port. The injectors are signalled by the ECU to spray fuel for a specific length of time just as the inlet valve opens during each cycle of the engine. This period of time is unknown as the 'Injector Pulse Width'.

Fuel pressure is supplied to the fuel rail and is controlled by a regulator which is referenced to the inlet manifold pressure, therefore as the injector opens, fuel is delivered at a known rate. The ECU determines the required 'Injector Pulse Width' based on the results of the engine mapping calculations and will make minor alterations due to the signal it receives from the Lambda probe, in what is known as 'Closed Loop Control'.

There is a common 12vdc power supply to each of the injectors and the ECU switches the negative side of the circuit to operate each injector individually.



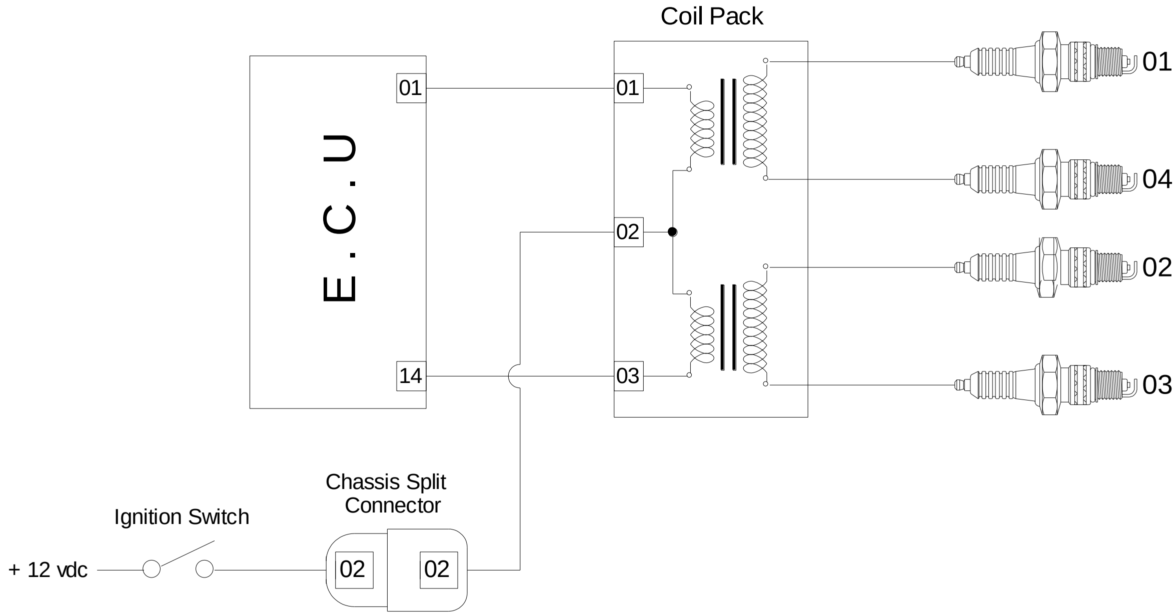
Fuel Injector Wiring Diagram

Ignition Coil Pack

The ignition pack replaces the distributor and ignition coil of a traditional system where timing and distribution is achieved by mainly mechanical means. The coil acts like a step up transformer, with a primary and secondary winding. Due to the difference in the size of the windings, when current flows through the primary a greater voltage is induced in the secondary. This is how the ignition pack transforms 12 volts from the battery into the 30'000 volts necessary for the electrical current to jump across the spark plug gap.

The ignition pack has a pair of coils which ECU signals via terminals one and fourteen. A separate power supply is required via terminal two of the chassis split. This allows the ignition to switched and fused separate to the ECU, (although it doesn't have to be).

The Ford Zetec ignition system is a 'Wasted Spark' design where just pair of coils drive all four spark plugs. However, since the other cylinder which fires at the same time does so during the exhaust stroke, no harm is done.



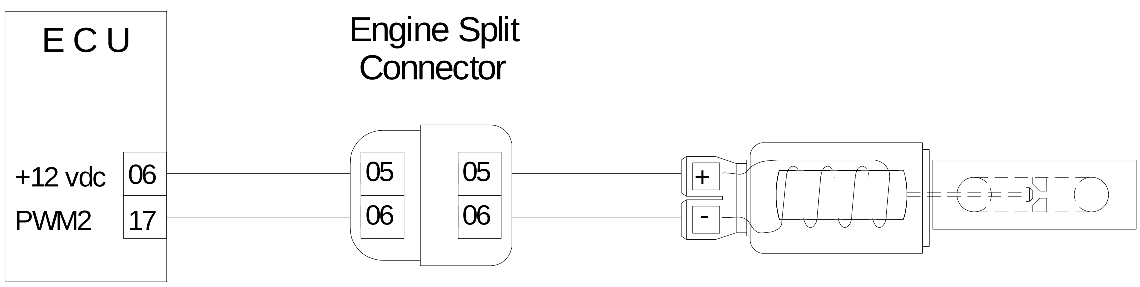
Ignition Coil Pack (Typical)

Idle Speed Control Solenoid Valve

Located just below the throttle position sensor is the Idle Speed Control Solenoid Valve. This is necessary as when the throttle is closed and the engine idles not enough air is being drawn in to maintain effective combustion and the engine would stall. The solenoid operated valve opens to bypass air around the throttle plate raising the tick over speed.

The valve is simply a spring loaded plunger, the barrel shaped part with the electrical connections is the solenoid coil. It is essentially an electro magnet and consists of a wire coil wrapped around an iron core. When electrical current is allowed to flow the magnetic field created pulls the plunger across, opening the valve.

Like the injectors the coil is supplied with voltage and the ECU switches the coil down to earth when it wants to trigger the solenoid.



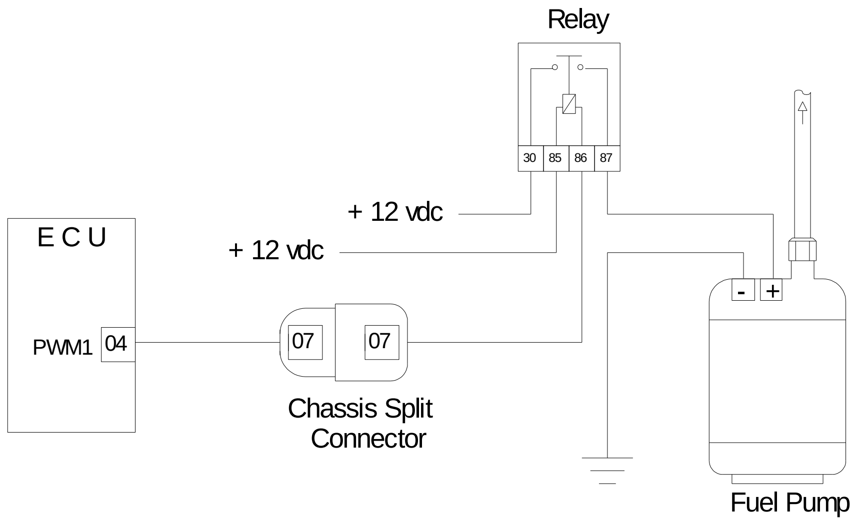
Idle Speed Control SOV & Wiring Diagram

The ECU will determine a suitable target idle speed based on engine temperature (which will be as low as possible without risk of stalling). It will signal the ECU in pulses to vary the amount of air being bypassed and control the rpm as close as possible to the target. As the engine warms up the rpm will drop (so as not to burn excessive fuel). When up to full temperature the engine should tick over at 800 – 900 rpm.

Fuel Pump Relay Control

The wiring for the fuel pump and it's on/off control is fairly straight forward. The ECU actually switches the pump on and off via a relay. This is mainly a safety feature so that when the engine stops, the fuel pump shuts down, which happens regardless of whether the engine stalls or the ignition is turned off. When the ECU is switched on for the first time the fuel pump will run, but only for around 10 seconds, if the engine is not started, then the pump cuts out. Only when the ECU detects that the engine is running will the pump continue to run.

Switching of the pump must be done using a suitable relay. This is to prevent the ECU from having to switch all of current drawn by the pump, an action which could damage its sensitive electronics. A relay rated for at least 30 amps is mandatory.



Fuel Pump Wiring Diagram

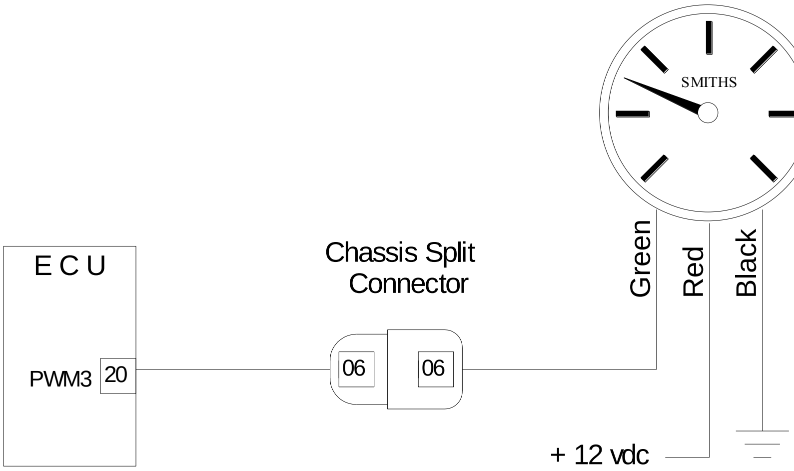
Like all of the outputs the ECU switches the negative side of the circuit. The relay coil must be supplied with 12volts, via the vehicles ignition switch. The other side of the relay coil must be connected to terminal seven of the 'Chassis Split' connector.

The wiring for the relay circuit can be made in 0.5mm² wire. The power supply for the pump can come from the main isolator and should be made in 1.5mm² wiring in order to cope with the larger current drawn by the pump and to minimise voltage drop at the pump connections.

Tachometer Drive Output

The ECU also provides a tachometer output that can be used to drive either a conventional gauge style tachometer or as an input to a modern digital type display system. Terminal 6 of the 'Chassis Split' connector should be connected to the instruments input / signal wire.

The ECU sends out two voltage pulses per revolution (four per engine cycle) so the tachometer / display should be configured for a standard four cylinder engine.



Tacho Drive Output Diagram