LAND ROVER
FUEL INJECTION SYSTEM

DESIGN AND FABRICATION

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PROJECT DURATION: Feb to May 2010

Document version – 2.15 – 25th April 2012

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Introduction

The land rover came with a standard induction system consisting of twin 1.75" SU carburettors fitted to a 3.5 litre 9.35:1 compression ratio rover V8 using electronic ignition. The vehicle employed a stainless steel exhaust system coupled with log style exhaust manifolds. However, even after rolling road jetting of the carburettors and with good and tight linkages for both throttle and choke, they were the usual SU horror to drive with. The mixture was generally fairly good on cruise and part throttle – but cold starting was erratic to say the least, and carburettor icing occurred regularly unless the weather was warm. It was quite typical to experience boggy stumbling running when having the audacity to approach traffic lights if the engine was anything other than fully warm and even when fully warm, the engine idle speed was impossible to set with any degree of precision.

Many will disagree, and some off roaders have very good reason to prefer carburetion over fuel injection – but speaking personally, while I admire the elegance of the constant vacuum carburettor, I have had first hand experience of both Stromberg and SU carburettors on three vehicles in my life, and have equally loathed them all.

This paper describes the conversion of the existing carburetion system to a fuel injection system in full and is designed as a maintenance aid.

The conversion project started in February 2010 with an extended period of research. By the end of May the basic injection system was running. Fine tuning was then undertaken over a period of months.

As stated, the primary intention when drafting this document was to have a maintenance aid. However, anyone thinking about attempting the same carburettor to EFi conversion on a Rover engine may find these notes useful even if just for background research – and so I took the decision to make these notes available on the web. If this is your aim - have fun with the conversion. I can say that once it works, it is a vast improvement on even an ideally setup carburetion system.

Overview

When it comes to injection systems there are a number of systems capable of fueling a Rover 216CID small block engine.

A company in the US called FAST have created a system known as EZ-EFi which is a self learning fuel injection system consisting of a large four barrel plenum fitted to a custom manifold. The kit comes with an ECU capable of learning the fuel requirements of broadly any size engine – but the system is costly and very much aimed at larger displacement engines (the CFM capability of the four barrel body is well over 1000CFM). By the time all aspects of system design were considered, the cost became prohibitive as did the injection air flow rates – suggesting poor low speed performance for what would be a low revving four wheel drive vehicle.

Another off the shelf DIY system is known as megasquirt. This consists of an ECU designed along the lines of open-source with enough instructions / help to build a fully working injection system using additional off the shelf sensors, injectors etc. Megasquirt has a significant data logging capability which when coupled with a laptop provides a tremendous degree of flexibility. It is also very popular and clearly is a viable option for this engine. However, it works by referring inputs to a fixed map of fuel requirements. That means that any change to the engine necessitates the rebuilding of fuel maps in order to achieve proper fueling – an aspect that appears only to be a useful asset when selling the product. To the end user it is a potential liability.

There are advantages and disadvantages to these systems – but it is worth factoring into the decision land rover research leading to a flexible, self adaptive system known as the C family and which culminated in the 14CUX. This system has two major advantages. Firstly it is self adaptive because it measures air flow into the engine using a mass air flow sensor – using that to determine the required amount of fuel. The air flow sensor employs a hot wire anemometer to sense air intake – and is consequently known as a hot wire system. Within certain limits, engine changes including displacement changes from 3.9 to 3.5 litre do not significantly alter the 14CUX's ability to correctly fuel the engine. Even aggressive profile cams are well within the range available to a 14CUX – except when the overlap becomes greater than about 12 degrees. The second advantage is that it is a readily available given it was used extensively from 1990 to 1995 on range rovers – many of which are now being retired and broken.

Bosch began the line of development for this system with the 4CU flapper system in 1990 – so called because air flow into the engine was monitored by a moving flap in the air flow. From 1985 to 1989 the 13CU hot wire system was built which used a hot wire system, cooled by incoming air, to detect the precise air flow into the engine. From then on, the hot wire system was the primary line of development leading, in 1990 to 1995, to the 14CU system which culminated in the 14CUX system. The 14CUX included a small degree of diagnostics and was capable of fueling the stricter emission controlled engine requirements of a vehicle running catalytic convertors running in different geographical markets.

Injection systems following on from the 14CUX (including the GEMS land rover system) incorporated fuel injection and per cylinder ignition and so are far more difficult to transfer between vehicles.

The 14CUX system was the one selected for the job of injecting the target engine.

It is important to understand one key feature of the 14CUX system – namely that there is no programming capability and little or no data logging built into the system. Effectively the 14CUX is a closed box. In reality, it is a straightforward microprocessor based system using an EPROM (27128) to hold the program code along with a number of fixed fuel maps for open loop operation. The system is also capable of using lambda sensors in closed loop mode at low speed.

Selected Donor Vehicle

Type: Range Rover 3.9EFi
Registration: Kxxx xxx (VIN confirms the year of manufacture is 1993)
VIN: SALLHAMM3KAnnnnnn
VIN decoded:

- S=Europe region
- A=UK origin
- L=Land rover manufacturer
- LH=Range rover model type
- A=Wheelbase which includes
    - Series III 88”
    - Defender 90” extra heavy duty

    - Range rover classic 100”
    - Range rover (38A) 108”
    - Freelander
- M=Body style which includes
    - Defender 5 door station wagon
    - Range rover classic 5 door
    - Range rover (38A) 5 door
    - Discovery 5 door
- M=Engine 3.9 & 4.0L V8 EFi petrol
- 3=Gearbox – Chrysler 747 3 speed auto RHD
- K=Year of manufacture 1993
- A=Built at: Solihull, UK
- nnnnnn is the vehicle serial number off the line

Donor vehicle parts supplied

The donor vehicle supplied the following parts.

1. Full wiring loom including main and fuel relays and a socket for the air conditioning control relay
2. ECU – stamped 14CUX
3. Intake manifold
4. Air horns
5. Plenum
6. Throttle blade and linkage control
7. Throttle potentiometer
8. Air bypass valve stepper motor
9. Under plenum heater
10. Pipe work linking to mass air flow sensor
11. Mass air flow sensor
12. Air filter housing
13. Air fliter
14. All 8 injectors
15. Fuel rail
16. Fuel rail regulator

Missing parts

Key parts not included (could not be sourced from the donor vehicle)

1. Inertia cut off switch
2. Road speed transducer and twin speedometer cables one leading from gearbox and one leading to the speedometer.
3. Oxygen (lambda) sensors

Project duration

The procurement of parts and research for the project began in February 2010, with the start of the hardware phase commencing on the 12th April 2010 (the day the major bulk of the components arrived). The project technically ended on 30th May 2010 with the resolution of the last bug and the successful firing of the engine – a total of 49 days, but fine tuning and design improvements have been carried out on the system to the present day in order to improve the reliability and operational stability of the design.

The project was split into two parts – refurbishment and fabrication/design

Refurbishment process

Refurbishment involved stripping the received donor parts into individual components while analysing the condition and operation of each to understand function. There were a number of missing components – for example all the fuel system components up to and from the injection rail were missing, as were all the vacuum plumbing components. The throttle cable and all the water plumbing parts were missing – and what made matters slightly more interesting was that the water plumbing was quite different for the new intake manifold compared to the old.

Figure 1 – 1992 3.9EFi donor vehicle parts as shipped

The general condition of the donor parts was good and it was clear that the seller had done a good job of carefully removing the components in order to minimise damage.

Figure 2 – Plenum side view

The idle control system was intact, as was the throttle linkages and the fuel regulator (at the back of the fuel rail). The throttle linkages did however appear to be in a bad state of repair.

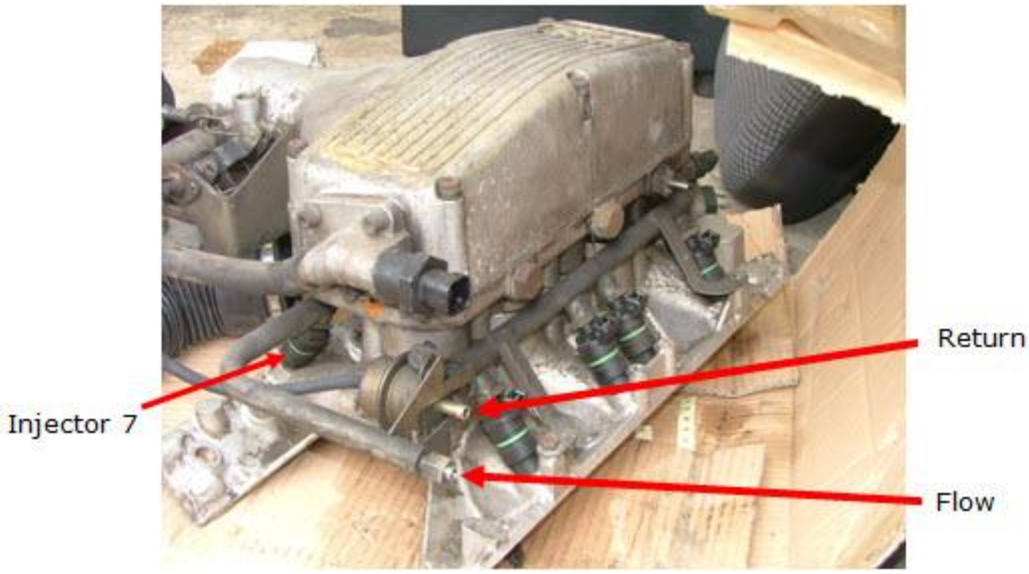


Figure 3 – Plenum rear quarter view – fuel flow and return

In the above photograph, you can see the flow and return feed pipes to the fuel rail, connected to the even bank of injectors (with the injector for cylinder 7 visible at the back left). Note the fuel rail connections – using a standard hose jubilee pipe on the low pressure side of the fuel regulator, but a machined fitment on the input high pressure side. This machined connection was tackled by removing the olive and the free rotating nut and using a standard jubilee clip connection on the rail after soldering a lip onto the pipe.

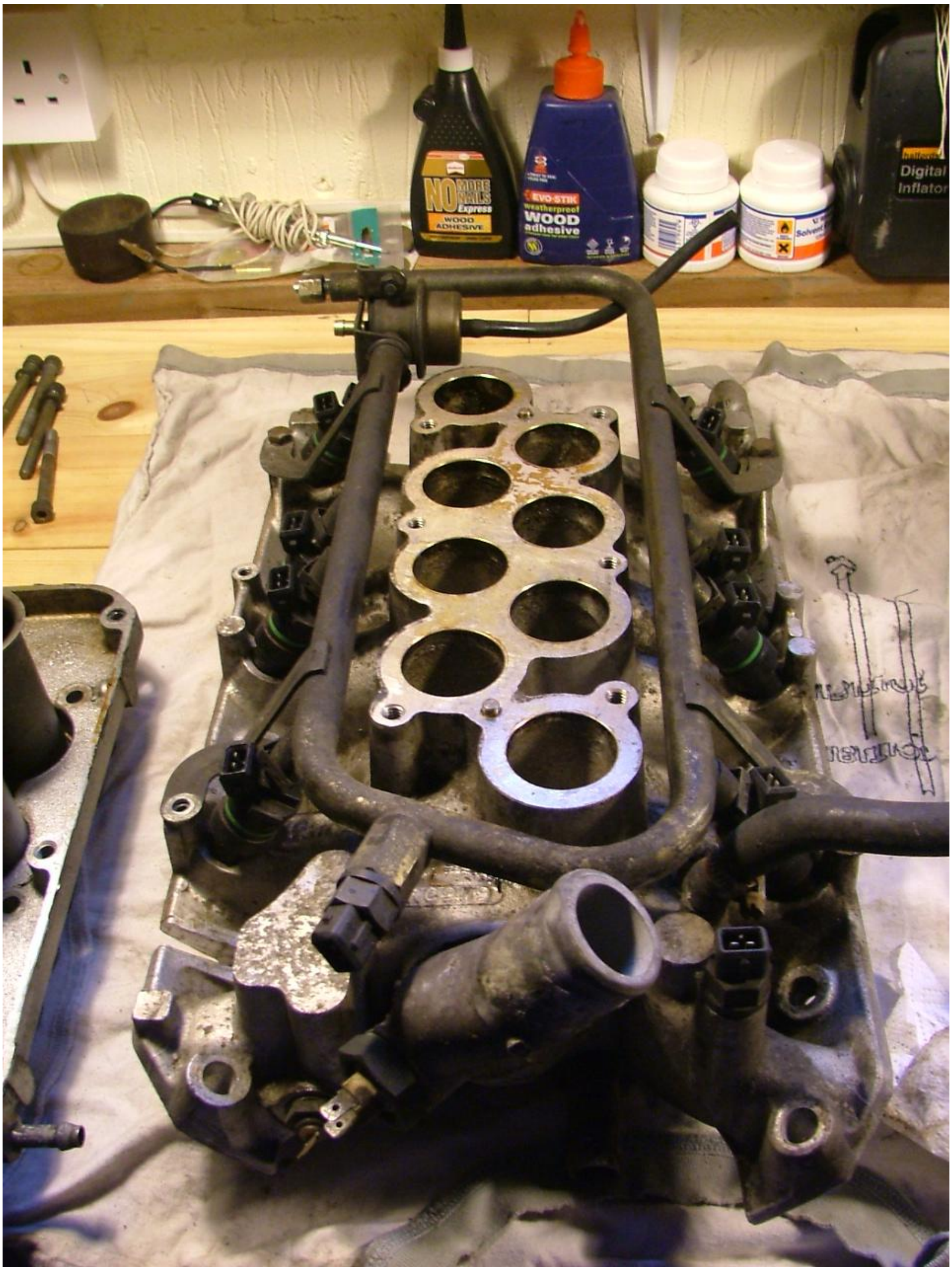


Figure 4 – View of stripped intake manifold

The above photograph details the front of the intake manifold when both the upper plenum and the inner runner manifold have been removed (shown just in shot on the left). Looking at the intake reveals all 8 injectors (the even set of four on the left of the photo, the odd set on the right) connected between the fuel rail and the intake manifold. Note the four bolts (one was missing) fastening the intake to the manifold. You can see the fuel temperature sensor screwed into the front of the fuel rail – and observe that this is not exposed to fuel. The sensor housing is actually brazed to a closed fuel pipe. On the thermostat housing another sensor exists (to drive radiator fans – but which was not employed in my design) and just underneath that is a coolant temp sensor used to drive the dash board gauge. On the front right hand of the manifold you can see the coolant temperature sensor used by the fuel injection system screwed into the manifold. Just above that is a water coolant pipe that feeds hot engine water to the under plenum preheating plate.

At the back of the manifold fuel rail you can see the fuel inlet right at the back coming into the fuel rail, which sweeps round to all 8 injectors exiting into the fuel regulator – with its vacuum hose connected (this hose routes to the vacuum port directly under the idle by pass air valve stepper motor.

Figure 5 – View of Intake runners

The above photo shows the intake runners which bolt to the intake manifold via 6 bolts, and which the upper plenum (shown below) screws to via 6 hex head screws. An important point to note here is that the intake runner platform is actually reversible – and can be mounted either way on the intake manifold – a design advantage that was used to simplify the vacuum pipe routing.

Figure 6 – Underside of plenum.

The underside of the plenum in the figure above and below shows the plenum pre-heater plate with two water hoses and the idle bypass air valve stepper motor as well as the throttle linkages. Note also the cable and plug for the throttle potentiometer sensor.

Figure 7 – Close up of plenum chamber pre-heater

The above figure shows the plenum upside down. The primary metered air entry point is the large round point, and the pre-heater plate is shown above with the two heater hoses.

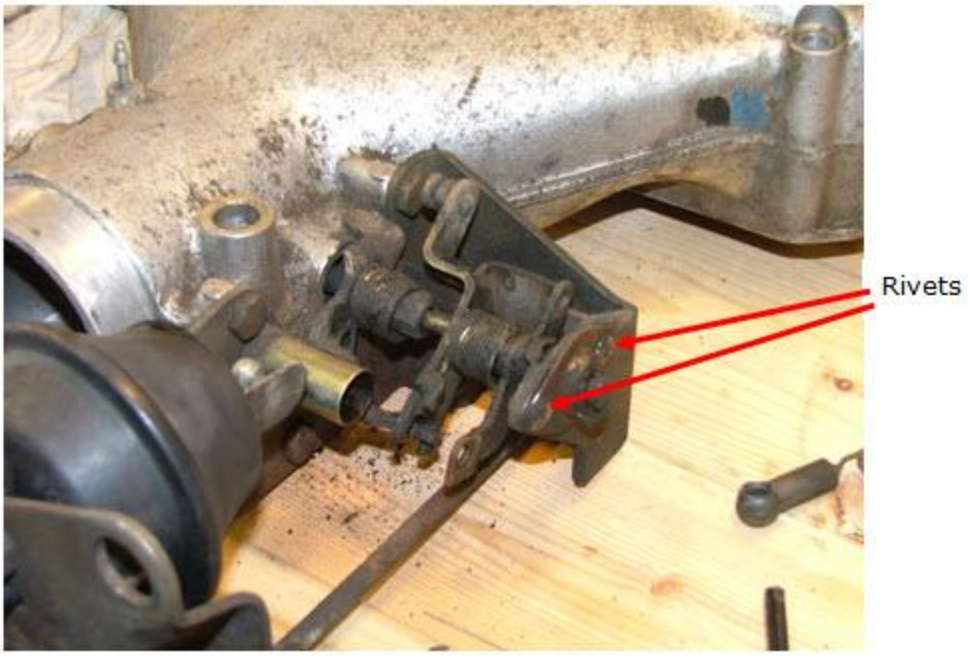


Figure 8 – Close up showing the throttle linkage

The throttle linkage looked in a very bad state during the initial inspection – however after cleaning and refurbishment it quickly became clear that the linkage was in exceptionally good condition with very little wear. Stripping the linkage involved drilling the rivets (shown on the RHS bearing) and replacing.

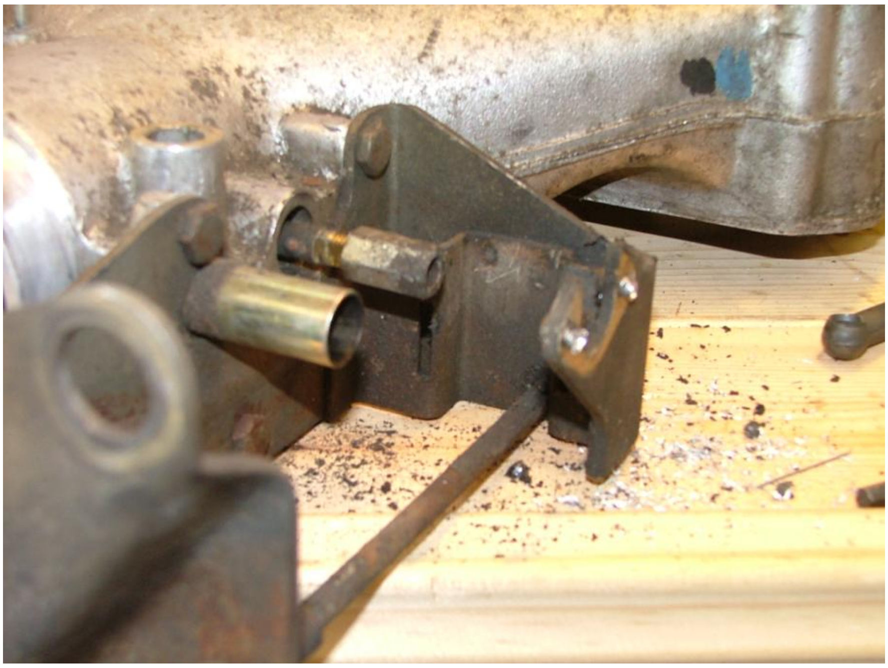


Figure 9 – Drilled throttle assembly rivets

With the degreasing and refurbishment complete, a new coat of paint was required. Matt black was used for everything other than the fuel rail (which was sprayed a bright red colour from Rover).

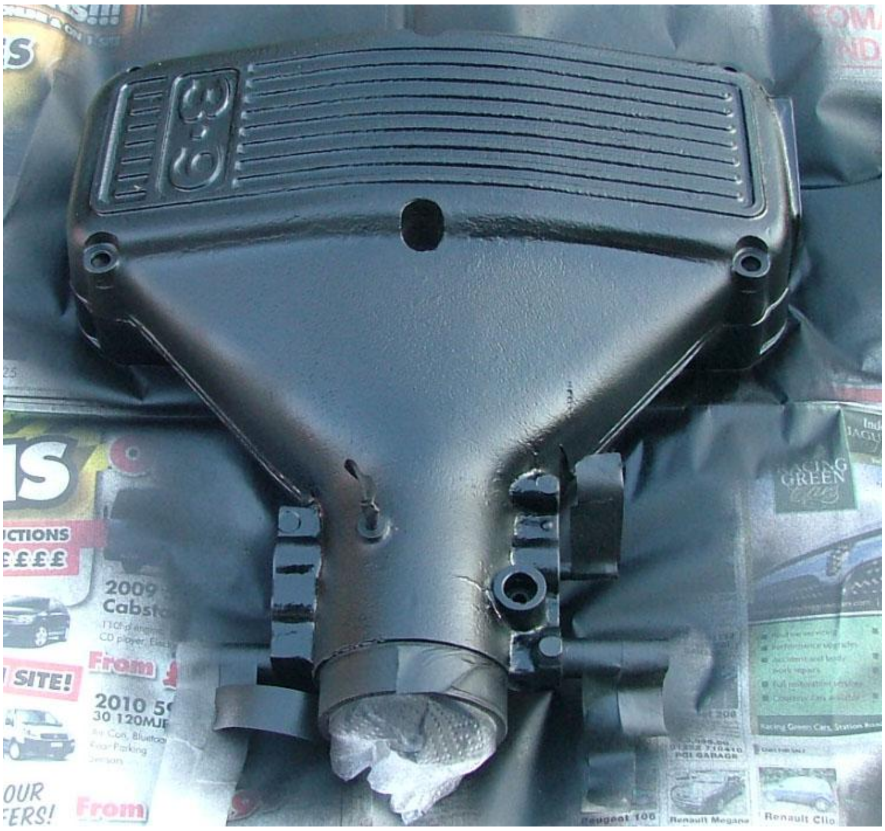


Figure 10 – Painted plenum - minus all ancillary components

Figure 11 – Sprayed idle bypass air valve housing and plenum pre-heater

Figure 12 – Sprayed plenum complete with rebuilt throttle linkages

Meanwhile – all the work required to clear the old carburetion system on the land rover had commenced to the point of leaving the valley clear

Figure 13 – Rover V8 cleared down to the valley

Figure 14 – Left and right views of the V8

A good deal of time was spent carefully cleaning the matting surfaces of the two heads, and also thread chasing all the intake mounting bolts using a stainless steel head bolt cut with a slot (obtained from Real Steel).

Figure 15 – Underside of original carburettor manifold (showing the plumbing)

With the original intake manifold the top and bottom radiator hoses followed a conventional route – although the top hose was interrupted (close to the radiator) by a metal unit holding two temperature switches designed to operate the two electric radiator fans. Closer to the manifold, the water pump had two ports which connected to hoses – one which was about 4" long and which connected to a corresponding metal pipe in the intake manifold front body (shown above as the bottom right hand most pipe). The second connected to a full length metal pipe screwed to the underside of the manifold. At the back of the manifold the screwed pipe and a second metal pipe in the intake manifold rear body acted as the flow and return feeds for the heater matrix.

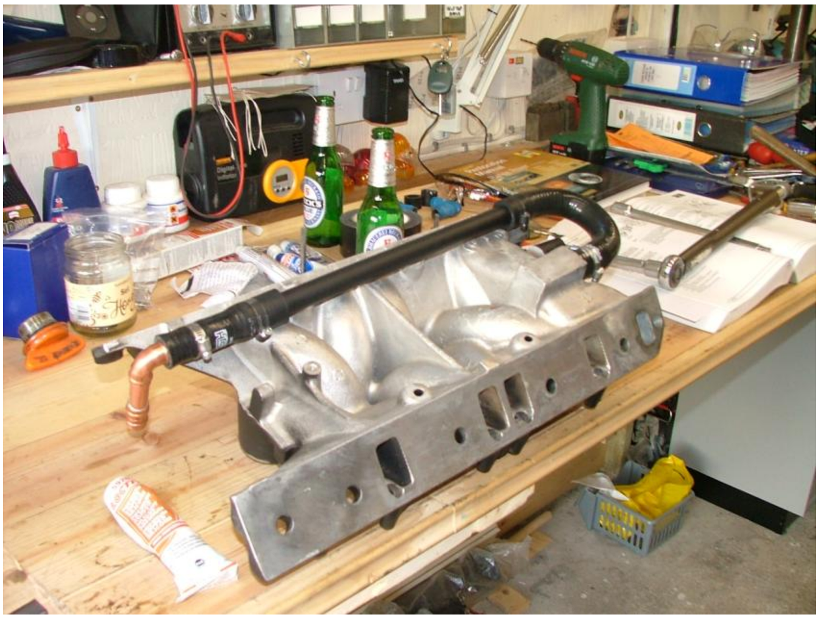


Figure 16 – Underside of injection manifold

The new injection manifold had no full length pipe screwed to the underside and only one port at the front. There was no port at the rear. An additional complication was the fact that the water pump and manifold had 19mm (3/4" fittings) but the heater matrix had 16mm (5/8" fittings). The photo above illustrates one aspect of the plumbing solution adopted.

The existing steel port on the front of the injection manifold was connected to a 19-19mm U bend in silicon, and routed under the intake using a steel metal pipe. Underneath the manifold (towards the rear) the steel pipe connected to a 19mm to 16mm silicon hose reducer (still under the manifold) and the 16mm outlet was then connected via domestic half inch copper to an upright which connected to a 16-16mm right angle in silicon, connecting to the heater control valve (a sluice valve from an early VW Sirocco mounted on the firewall and shown as "V" in the figure below). On the other side of the sluice valve, a short length of 16mm rubber hose connects to the flow side of the heater matrix.

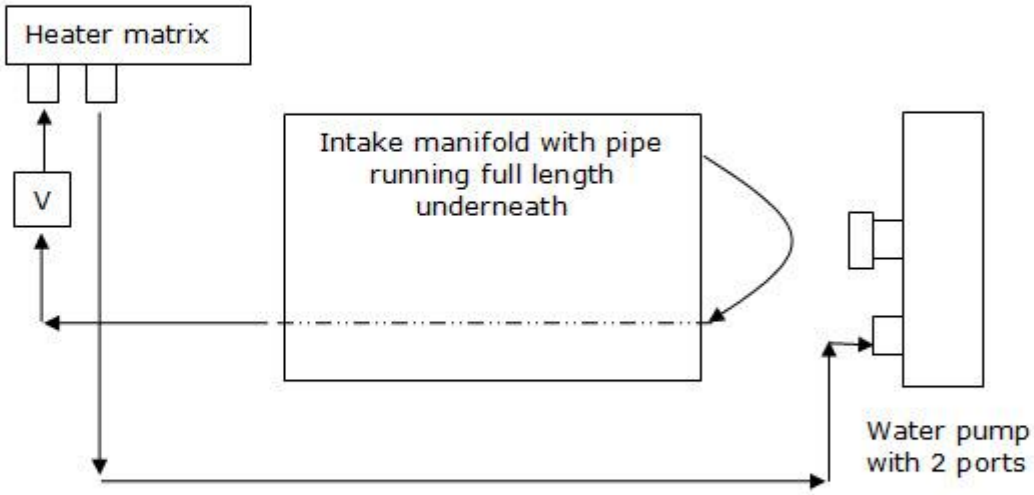


Figure 17 – Cooling plumbing for the heater matrix

The matrix return routed via a long sweeping 16mm hose, clamped just above the throttle linkage and routed from there to a straight 16-19mm reducer in plastic, and from that to the water pump port via a 19-19mm right angle in plastic. The innermost unused water pump port is blocked off.

Each of the water pump ports were odd, in the sense that they had no lips – which meant that when under pressure, even well clamped hoses could theoretically push off. (The author has experienced precisely this occurrence at speed in a vehicle with a small block Chrysler 360CID engine – with the instantaneous loss of all coolant). With that in mind, the pipe work has been fitted in such a way to physically lock each pipe into place on the water pump ports before being clamped with strong jubilee clips.

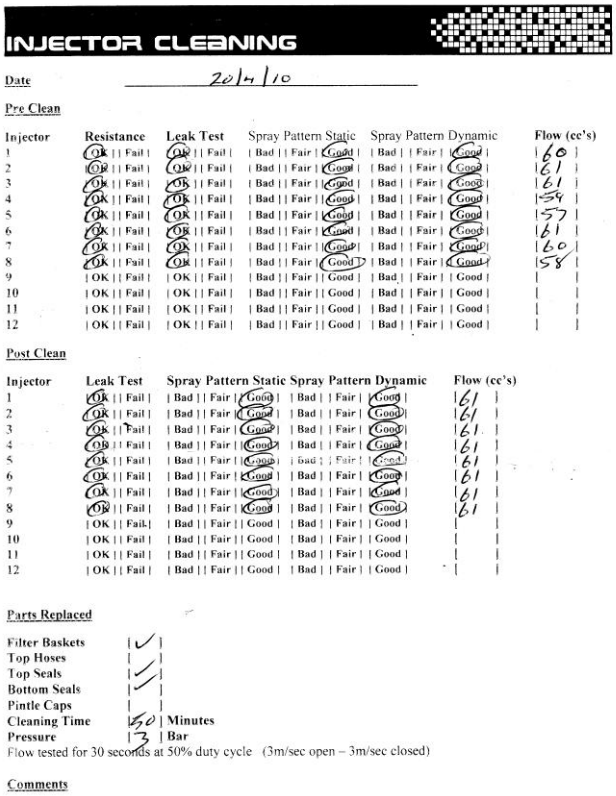
The metal pipe under the manifold was constructed using new steel pipe, with soldered lips at both ends, cleaned and painted matt black. It is not fixed.

There was one other complication with the cooling system involving the thermostat housing. The injection manifold came its own thermostat housing (which included a temp switch sensor). However, offering up the new intake manifold to the engine revealed a fouling problem between the thermostat housing and the distributor advance/retard vacuum actuator. A good deal of time was spent reviewing this problem – including an attempt to swap the original carburettor manifold thermostat housing onto the injection manifold (which failed because the top hose then fouled other components).

The solution involved fitting the housing as close to the manifold as possible by removing the gasket and using silicon to seal, followed by grinding additional clearance into the body of the housing. As it stands, the clearance permits slightly more than 12 degrees BTDC of advance before fouling. It is also relatively easy to remove the housing, albeit tricky to refit while keeping the thermostat locked in an upright position in its recess.

Figure 18 – Intake front and rear view

As part of the refurbishment, all eight injectors were sent to a specialist cleaning company (who also supplied the oxygen lambda sensors). Their injector cleaning service included replacing the pintle heads, all O rings (2 per injector) followed by ultrasonic cleaning and then a testing phase to assess the coil electrically, and to check the flow rating for each injector at 3 bar pressure along with measured leak down loss and spray pattern.



INJECTOR CLEANING

Date 20/4/10

Pre Clean

Injector	Resistance	Leak Test	Spray Pattern Static	Spray Pattern Dynamic	Flow (cc's)
1	OK / Fail	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	60
2	OK / Fail	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	61
3	OK / Fail	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	61
4	OK / Fail	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	59
5	OK / Fail	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	57
6	OK / Fail	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	61
7	OK / Fail	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	60
8	OK / Fail	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	58
9	OK / Fail	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	
10	OK / Fail	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	
11	OK / Fail	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	
12	OK / Fail	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	

Post Clean

Injector	Leak Test	Spray Pattern Static	Spray Pattern Dynamic	Flow (cc's)
1	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	61
2	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	61
3	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	61
4	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	61
5	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	61
6	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	61
7	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	61
8	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	61
9	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	
10	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	
11	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	
12	OK / Fail	Bad / Fair / Good	Bad / Fair / Good	

Parts Replaced

Filter Baskets	✓
Top Hoses	
Top Seals	✓
Bottom Seals	✓
Pintle Caps	
Cleaning Time	50 Minutes
Pressure	3 Bar

Flow tested for 30 seconds at 50% duty cycle (3m/sec open – 3m/sec closed)

Comments

Figure 19 – Injector testing results

Figure 20 – Finalised injection intake base

The figure above shows the fully built injection manifold complete with refurbished injectors and fuel rail – note the converted fuel pipe connection on the rear of the fuel rail - now converted to use a standard hose connection

The injector and fuel rail refit involved the following steps.

1. Oil the manifold injector bores
2. Lightly oil the O-rings on the bases of the injectors
3. Carefully push fit all eight injectors into the bores without damaging the new O-rings and with the electrical connections in the upright position.
4. Lightly oil the injector upper O-rings
5. Place one side of the rail onto the even set of four injectors
6. Using a clamp with rubber jaws, press fit the rail onto all four injectors observing the mount positions to prevent push fitting the rain too far down.
7. Place the odd injector side of the rail onto the remaining four injectors
8. Using a clamp with rubber jaws, press fit the rail onto all four injectors observing the mount positions to prevent push fitting the rain too far down.
9. Move across the rail to ensure it is evenly pressed onto the 8 injectors.
10. Fit all four fuel rail mounting screws and tighten to 10ft/lbs

Fabrication / Design process

Following the refurbishment of the injection hardware, the engine fitting process began.

Broadly this involved the following steps

1. Fitting the intake manifold with new valley gasket and front and rear valley seals.
2. Deciding on the orientation for both the intake runners and the plenum
3. Fabricating and fitting the throttle linkage
4. Fabricating the air intake filter and mass air flow sensor mount
5. Designing the PCV system
6. The fuel system
7. Designing the vacuum plumbing
8. Fitting the electrical wiring loom for the ECU
9. Removing the two down pipes of the exhaust system – and fitting the mount points for both lambda sensors
10. Designing the road speed transducer system
11. Designing the mount for the ECU and main + fuel relays
12. Fitting the ECU
13. Wiring the loom into the ECU
14. Fitting the 14CUX diagnostic reader.

This was the time consuming part of the project and proceeded as follows

Fitting the injection Intake manifold

Fitting the intake manifold was the one area of ambiguity given it was from a different displacement engine. As it happens, the intake fit was fine – although it is worth saying that all mount bolts were extremely tight to get threaded. A full set of new multipoint head stainless steel bolts were available, but the decision was taken not to employ them as the original bolts were in good condition after careful cleaning. With that in mind, one stainless bolt was sacrificed as a thread cleaner and chaser – which given the state of the existing heads was a step well worth taking.

Use caution on the front two intake bolts. They are notorious for rusting and then sheering on removal.

The intake valley gasket was a fabric type (not pressed steel). Silicon sealant was employed on the four water openings (front and back, left and right), on the front and rear valleys and on all four outer valley corners where the head butts into the intake. Silicon was not used around the inlets.

Selection of orientation of plenum and trumpets

The selection of orientation for the trumpets was easy – given it is a reversible section of the intake. The external vacuum ports on the trumpet housing were the deciding factor given the need for the brake servo on one side, and on the other a PCV feed at idle, and the vac gauge. (*Note that the distributor advance/retard is fed from the port on the upper surface of the plenum, and the fuel regulator is fed by the port under the idle bypass air valve stepper motor*).

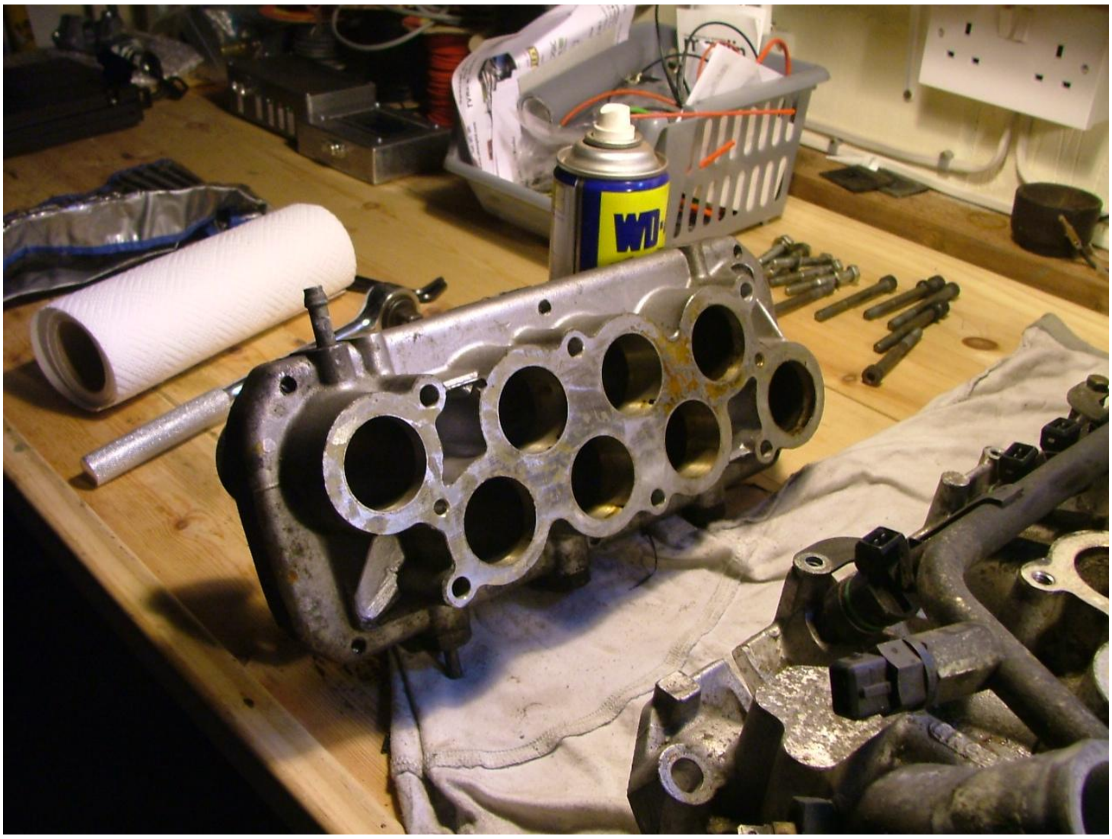


Figure 21 – Underside of plenum intake trumpet housing (note vacuum ports)

The plenum orientation again was an easy choice given it is also reversible. Fitted correctly (ie: with the 3.9 emblem visible at the front) the air intake fouled the land rover wing. Flipping the plenum with the air intake onto the drivers side of the vehicle not only resolved the fouling problem but also meant it was possible to reuse the existing carburettor throttle cable.

The one downside with this arrangement was that the route from the air intake to the logical place for fitting the mass air flow sensor required a tight C shape.

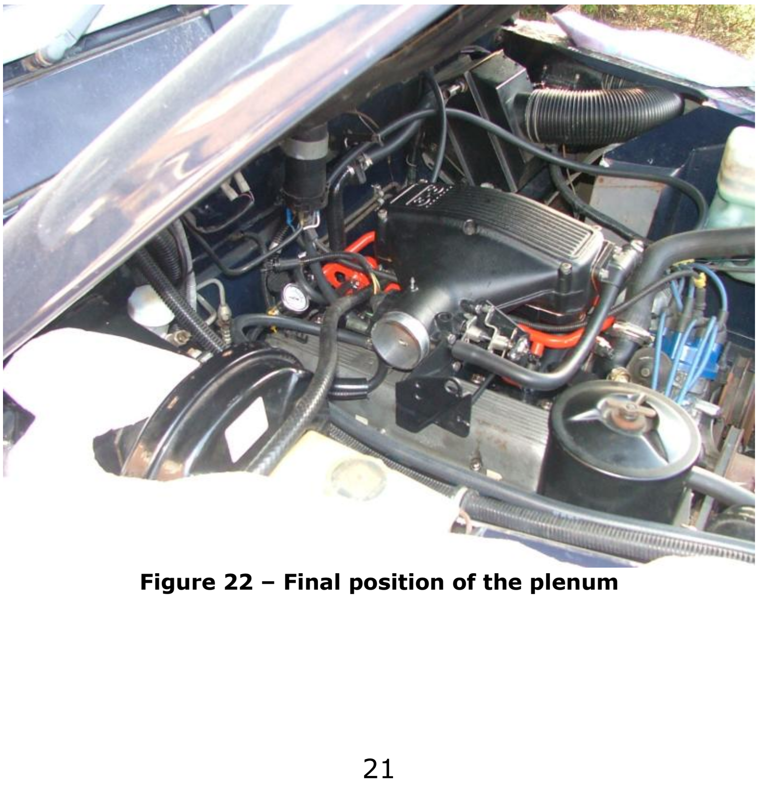


Figure 22 – Final position of the plenum

Throttle linkage

The arrangement of placing the plenum chamber with its air intake towards the drivers side meant that it was possible to reuse the existing throttle cable.

Figure 23 – Throttle fabrication

However, the existing throttle assembly steel frame fouled the intake metal air pipe running from the plenum to the mass air flow sensor assembly and so had to be discarded. The throttle assembly was cut back, and welded strengtheners were added to the existing frame. A bracket was then constructed (see below) and welded to the assembly to accommodate the throttle cable (the mounting bolts were then removed and the holes filed with weld).

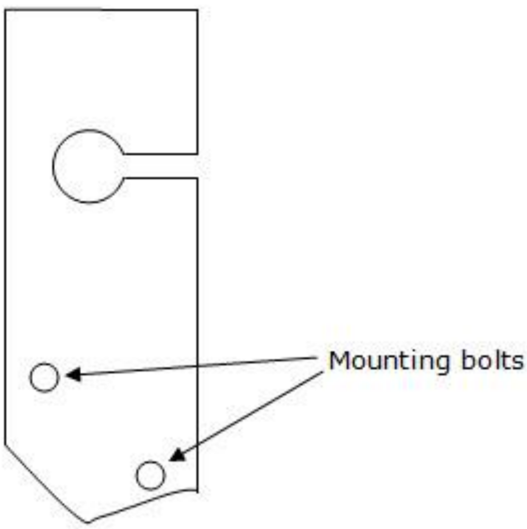


Figure 24 – Throttle cable mount bracket

The arrangement permits ingress of the fine throttle cable through the slot, at which point the whole throttle cable assembly can be moved forward to permit the mount screw thread to enter the main hole shown above. Once in position, the slot does not permit the throttle mount screw to exit.

The throttle linkages on the plenum are sprung at wide open throttle when the back stop is reached. In other words when the throttle blade is wide open, the throttle actuator can be opened slightly wider (by about 5 degrees of rotation). The cable was adjusted so that that springing state is only just engaged – which means that WOT is possible and accommodated accurately by the linkage system.

Mass air flow sensor and air filter

The mass air flow sensor is the electronic unit used to measure the precise amount of air entering the engine. It does this by using two wires in a balanced bridge circuit. One wire is exposed to the air flow entering the engine, and the other is encased and hidden. As air flow passes over the exposed wire, it is cooled, and its resistance alters. The bridge circuit measures the difference between the two wires to determine relative air flow.

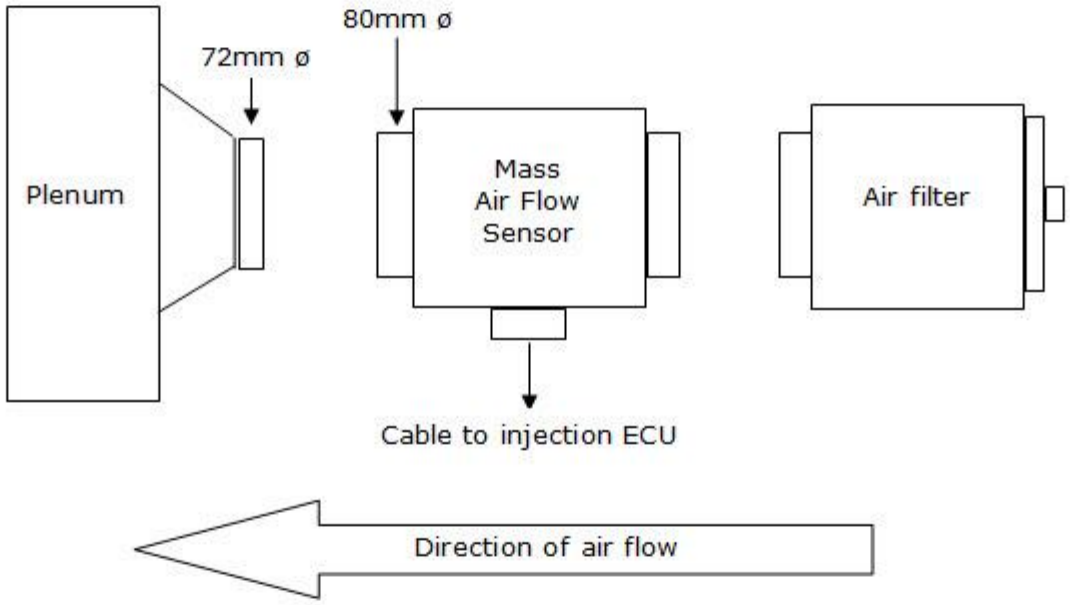


Figure 25 – Mass air flow sensor schematic

Filtered air enters the MAFS unit which is cabled into the injection loom via a four wire connector. A hose connects the outflow side of the MAFS unit directly to the plenum intake.

There is one interesting oddity about the design – which is that the diameter of the MAFS outflow is different to that of the plenum inflow. The MAFS unit is 80mm OD, whereas the plenum is 72mm OD – consequently the standard land rover plenum flexible hose used to make the connection has two different sized ends. 80mm diameter pipe is fairly easy to source, but 72mm is difficult to obtain and so this aspect of the design, coupled with the rather tight almost-but-not-quite C shape and long length has been the most problematic to resolve – all the more so given that it is vital that the hose connection linking the MAFS to the plenum is air tight in order to ensure that all air entering the engine is metered by the MAFS unit.

The solution (which passed through three different unsatisfactory designs) consisted of the following. First, a 20mm deep stainless steel sleeve was manufactured with a 72.1mm inside diameter, and 80mm outside diameter. The sleeve was designed to be an interference fit on the 72mm collar of the plenum chamber. Silicon sealant was then applied to the inside of the sleeve and it was then driven carefully onto the plenum – and left to set for 24 hours.

Two brushed aluminium pipes with 80mm outside diameters were then purchased, one a right angle, and one a 45 degree. Both had been bent using a mandrill press resulting in a smooth inner radius. These two pipes were then cut, dressed and smoothed, and joined to the plenum, at the centre and to the MAFS in three places using silicon 80mm ID soft pipe and large jubilee clips.

One complication to this solution was that the 90 degree radius pipe when fitted fouled the throttle assembly frame. In order to resolve this, the entire throttle had to be disassembled, cut and welded to permit adequate clearance while ensuring it was strong enough not to flex.

Figure 26 – MAFS air path

With the main air intake pipe routing fitted and with clearance ensured all round the intake pipe (especially near the power steering reservoir canister – allowing for engine torque motion) the mount for the MAFS box and air filter was then created.

Figure 27 – MAFS mounting bracket

There are four bolt holes in the MAFS mounting bracket. Two bolts mount the bracket firmly on to the adjustment swing arm used to hold the alternator. An additional two bolts are used to mount the MAFS air filter case to the bracket. It is important to realise that there are two levels of adjustment deliberately built into this bracket. The mount holes for the MAFS air filter case are slotted – permitting the entire MAFS assembly to move. In addition, the left hand curved mount bolt hole (see above – closest bolt to alternator) is also slotted, whereas the right hand lower bolt hole is fixed. That means that the entire assembly can rotate around the right hand lower bolt. The combination of the two adjustments allows the MAFS position to meet the intake pipe, while coping with minor adjustment changes to the alternator position.

During the fabrication phase, some time was spent reviewing adequate air filtration for the MAFS unit with an investigation of K&N filters and other third party units. However, the manufacturers filter case has the significant advantage of being equipped with a strong MAFS coupling which any third party filter would not. In addition the land rover air filters are very much cheaper than after market dress up models, and supply more air flow.

The donor vehicle air filter unit was the standard Land Rover EFi metal canister unit using a solid clip coupling to the MAFS, a main body and a lid with extended nozzle for the raw air intake. There was interestingly no air preheating feature on this unit. The outer canister steel was also badly rusted on the donor part even though the base was in good condition. An elegant temporary solution involved grinding off the outer canister welds leaving a base with proper clip couplings to the MAFS and an elongated bolt fixing mechanism for the air filter (a standard range rover filter).

Figure 28 – Mounted air filter (outer canister removed) clipped to MAFS

While this air cleaner solution worked well in dry conditions it was less than ideal when driving in rain because any rain water passing through the radiator would hit and therefore dampen the paper air filter. This caused the element to loose its shape and its ability to properly seal. A second hand standard land rover air cleaner in fairly good condition was therefore purchased, cleaned and modified to shorten the snorkel so that it didn’t foul the radiator fans. The finished result was then primed and sprayed matt black. See the two figures below for both views of the modified air cleaner.

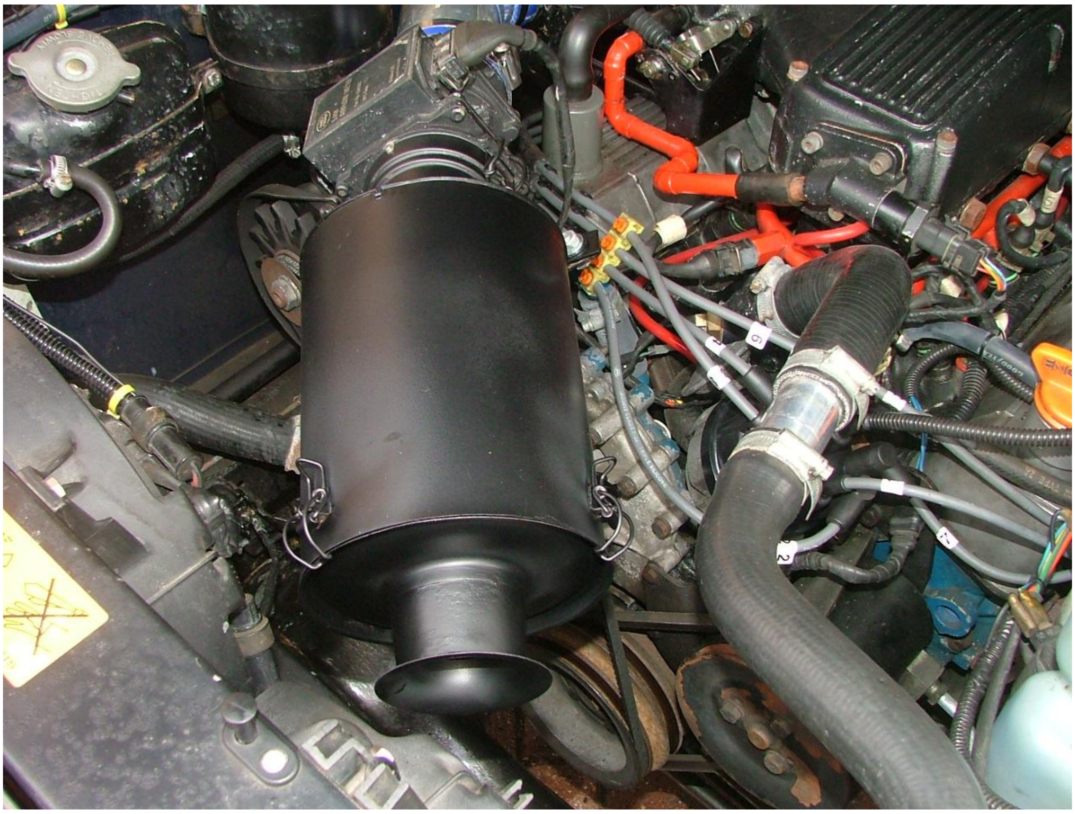


Figure 29 – Modified air cleaner box used to weather proof the intake air filter

Note in the above figure the shortened snorkel (which is much longer on a normal Land Rover air cleaner).

Figure 30 – Modified air cleaner box rear view (note MAF sensor clips)

Positive crank case ventilation (PCV)

The standard PCV system is designed to draw un-burnt hydrocarbons resulting from blow-by past the piston rings, into the combustion process. This process removes hydrocarbons from the engine where they would otherwise reduce lubrication efficiency increasing wear (and emissions from the engine) while also creating a mild depression inside the engine to assist the gasket sealing process.

The original carburettor PCV system employed a filter (actually a plastic fuel filter) free standing and connected via a hose to a metal pipe on the rear of the engine valley. Additional hoses connected half inch ports on both rocker covers separately to a pair of flame traps and from there to vacuum ports on each carburettor. This design applied engine vacuum to both rocker covers – while drawing fresh air into the crankcase via the small plastic filter.

The design may have been adequate for a 1970's vehicle, but it is all but unusable for a fuel injected engine. PCV acts as a secondary source of air entering the system, and so considerable care is required to meter the precise amount of air it passes, while ensuring that it functions as a self contained system of crankcase ventilation.

The standard PCV system designed by Rover for a fuel injected engine requires the use of different rocker covers (a new set had to be sourced from eBay). The key features of the new rocker covers are a built in PCV breather metered orifice (see (c) below), a screw thread capable of accommodating the oil separator (see (D) below), and a separate screw thread fixed in a raised tower for oil entry. A schematic of the final PCV plumbing is shown below.

Note that the oil entry screw thread on the passenger side rocker cover isn't shown and that the original pipe on the back of the valley is blocked off and sealed.

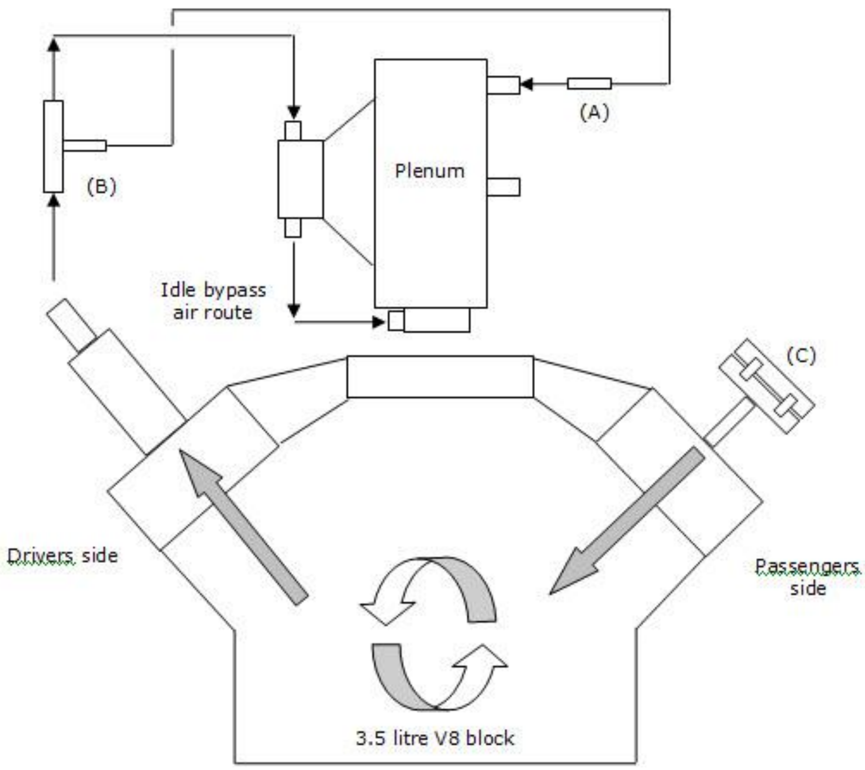
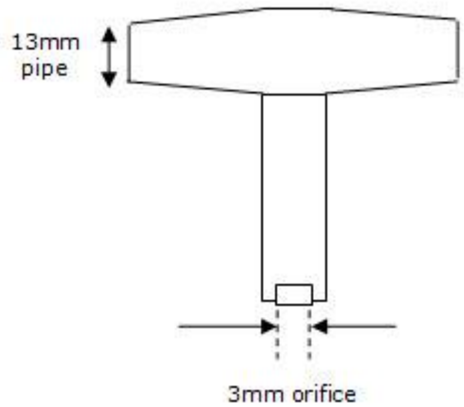


Figure 31 – PCV schematic

The passenger side rocker cover is fitted with a fixed small round metal T piece raised above the cover by perhaps 1cm (see (C) above). The stem of this T is drilled with a small 0.5mm hole passing into the inside of the rocker cover. A plastic shroud encases a gauze filter which clips onto the top of the metal T piece. Metered airflow draws into the engine via this filtered path and from there passes through the head into the main crankcase where it combines with oil and any hydrocarbons. It is then drawn out of the driver side rocker cover via a screw-in oil separator (see (D) above) which as the name suggests allows oil in the air flow to drain back into the engine while also acting as a flame trap in case of backfire. Airflow from the oil separator is drawn into the plenum via a T shaped plastic connector (supplied by Rover) and hose pipes.



A large diameter hose (13mm ID) connects the oil separator directly to the large 13mm side of the plastic T piece. A second 13mm hose connects the other 13mm side of the T piece to a port on the plenum on the atmospheric side of the throttle housing. This path will only apply engine vacuum to the oil separator when the throttle is off idle – with the amount of airflow largest at wide open throttle.

Figure 32 – Rover PCV coupling "T" piece

The plastic T piece has a third metered orifice (a 3mm hole) which is connected to an engine vacuum port on the plenum, via hose pipe. This path is designed to provide a metered amount of vacuum to the PCV system when the engine is idling, with the throttle shut. It is worth noting that the amount of air flow is substantial, even with this metering orifice – a fact which has a bearing on the engine idle speed as the PCV system behaves as an alternate source of air flow into the engine at idle. The implementation includes an additional copper pipe in the path (see (A) in the PCV schematic figure) which further reduces the air flow via a 2mm drilled solder restriction.

The image below shows the PCV hose run from the oil separator to one side of the plastic T piece.

The close up below shows the routing from the rear of the T piece to the plenum port (via a 15mm copper U bend painted red). The third vacuum pipe leaving the plastic T piece is just visible heading down under the plenum chamber.

Figure 33 – View of the PCV system pipe routing

The fuel system

Fuel injection relies on high pressure fuel being delivered to the injector rail under all conditions. When the injectors open, the high pressure fuel instantly atomises into a fine spray and this effect greatly eases the traditional problem of vaporising fuel prior to combustion.

The 14CUX system requires the following fuel circuit

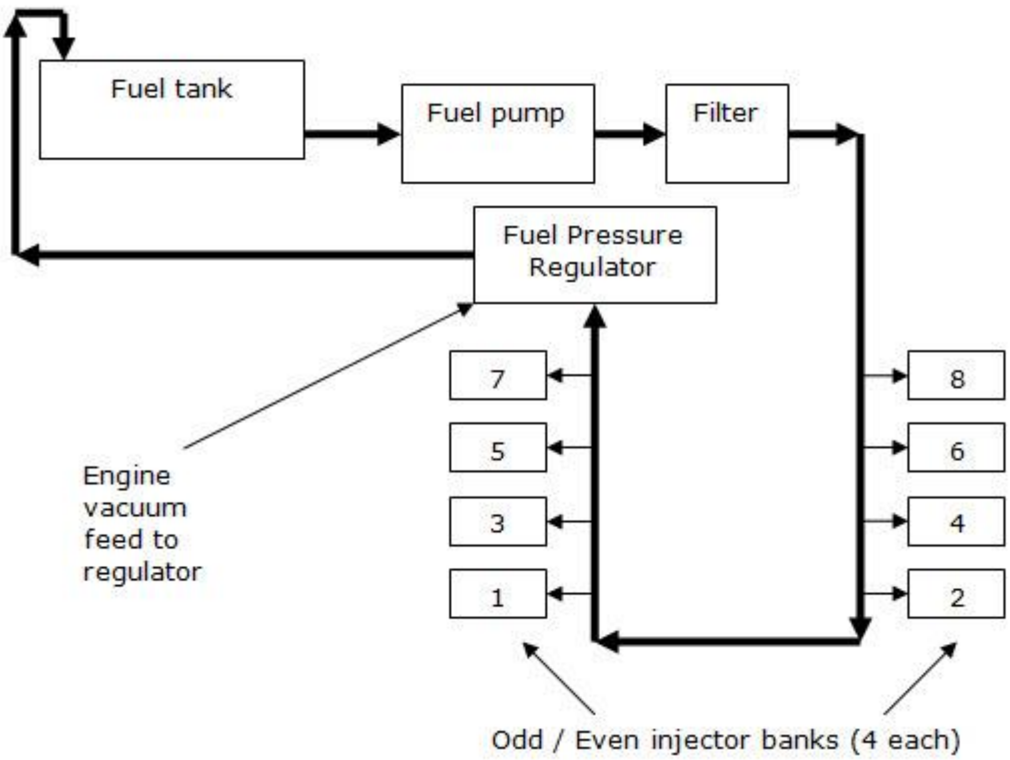


Figure 34 – Fuel system schematic

14CUX production implementations generally employed wet fuel pumps mounted inside the fuel tank along with non-serviceable gauze intake filters. The pump pressurises fuel to about 3 bar and delivers it to an inline replaceable filter and onto the fuel rail – connecting to all 8 injectors. At the distant end of the fuel rail, the pipe connects to the inlet of a fuel pressure regulator designed to regulate the pressure between 24 and 36 psi, relative to engine vacuum (the higher pressure obtained when vacuum is lowest and demand is greatest). The outlet of the fuel regulator returns excess fuel via a return pipe to the tank (at relatively low pressure).

For the initial implementation of this system, a dry fuel pump was employed. The petrol fuel tank on this Series 3 Land Rover – Short Wheel Base vehicle was fitted with flow and return pipes (8mm OD) as well as a fuel level sender. One of the tank pipes was employed to feed a Jaguar XJ6 fuel pump rated at 3 bar and which was mounted on the front of the mid horizontal chassis rail of the vehicle (just behind the gearbox). The output of this pump fed fuel at high pressure to an inline fuel filter (taken from a Katterham Seven vehicle). The output of the filter connected to hard pipes running up the firewall to supply the fuel injection rail. The plumbing around this chassis mounted pump was worthy of note due to the odd mix of pipe sizes.

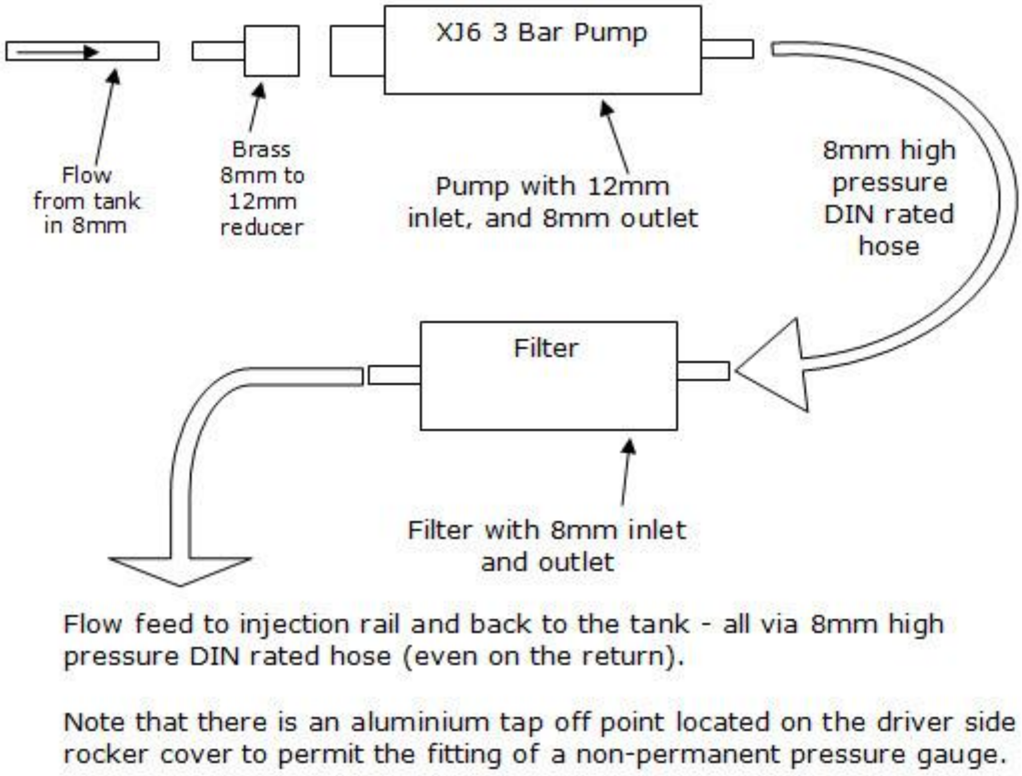


Figure 35 – Fuel pump and plumbing schematic

The fuel circuit was plumbed using predominantly 8mm fuel hose (rated to DIN standards for fuel injection). A small amount of 12mm hose was used to couple the inlet of the fuel pump.

The fuel line ran up the firewall to the rear of the engine – and then connected to an aluminium block threaded with three holes – two designed to accept 8mm hose ends, and a third tapped to suit a 1/8th NPT non-permanent fuel gauge. After testing this gel filled gauge was removed and replaced with a threaded block plug.

Figure 36 – Fuel pressure tap off point

Some months after testing was complete, the aluminium fuel pressure tap off point was permanently removed.

An alternative – wet fuel pump solution

The dry pump solution described above had previously failed in August 2010 (due to an electrical fault inside the pump). In early April 2011 (after a chilly winter), inspection of the system revealed that the jubilee clips and hoses had deteriorated on the underside of the vehicle – mainly due to salt exposure (they are mounted on the front of the mid-cross member just behind the gearbox). An additional irritant has always been pump noise. Even allowing for the cacophony of gear noise generated by a Land Rover Series 3 gearbox fitted with overdrive, the external fuel pump was audible to some degree in all gears but was particularly noticeable at idle when stationary.

Manufacturers generally employ wet pump systems, where the fuel pump is mounted inside the tank and submerged in the fuel – and with good reason. Wet pumps are quieter and smaller than an external pump because cooling occurs as a result of being immersed in fuel. They are arguably safer because liquid fuel will not ignite, and are consequentially protected from the elements. A wet design also results in the entire fuel system (from the tank to the engine) holding pressurised fuel, which eliminates vapour lock, especially when engine bay temperatures are high (fuel under pressure has an increased boiling point and is therefore far less likely to flash into vapour if external temperatures are high).

Range rover classic EFi vehicles (1986 to 1992) use a wet pump with part number PRC8318. An example is shown below.

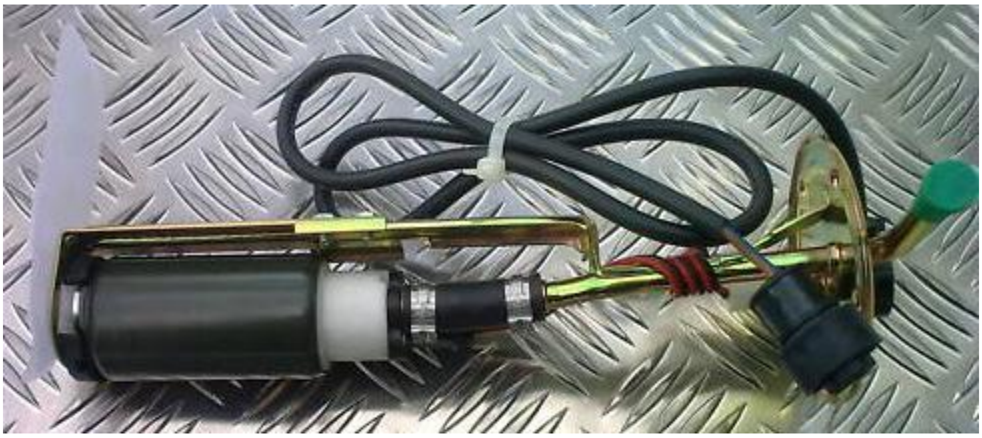


Figure 37 – Web pump for range rover classic (part number PRC 8318)

The mount flange plate (right hand side plate in the above figure) includes a fuel resistant electrical plug with cabling leading down to a two pin locking connector on the pump body, and a short angled support brace for the 8mm pipe.

On the left side, the pump assembly consists of a white plastic porous filter allowing fuel to pass into a small but powerful, 3 bar pump via an 8mm opening. The pump output is coupled by a short hose to the 8mm pipe extending out through the cover mount flange plate complete with protective green cap. The lower end of the pump is supported by an L shaped steel bracket secured with two nuts (each having a small degree of adjustment) mid way up on its long side. The bracket is not secured to the bottom of the pump. Instead it fits over small extrusions on a rubber collar (see the black part below, sandwiched between the pump and the metal bracket). The fit is lose, but in such a way that the pump is cushioned (which helps reduce noise), supported vertically, and can't rotate

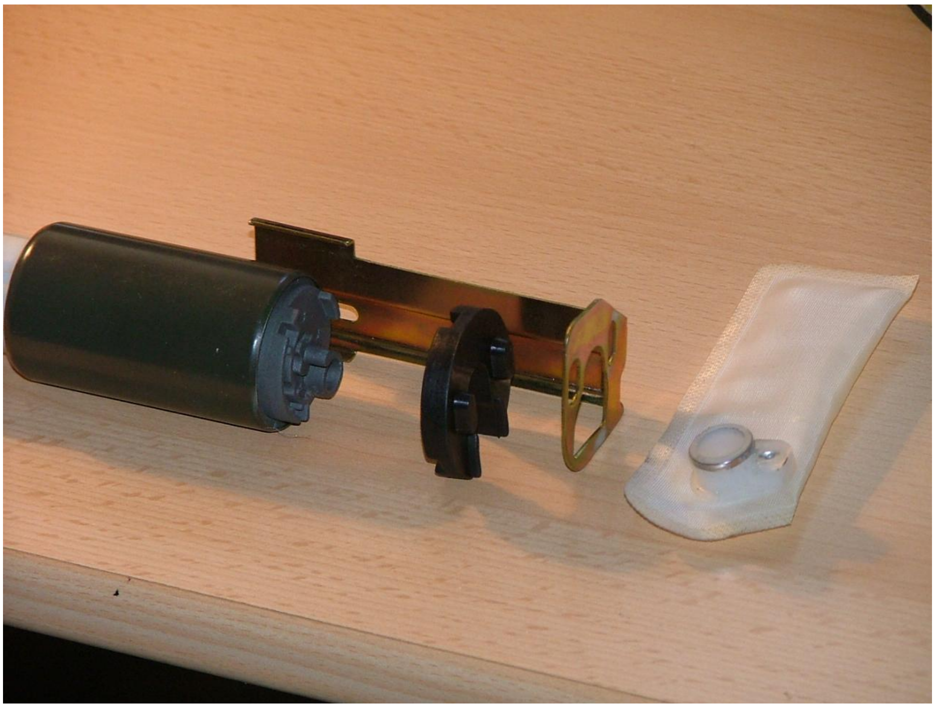


Figure 38 – Wet pump deconstructed

The design of this assembly hides some subtle but important design qualities.

The pump support bracket is electrically earthed, and surrounds the fuel intake filter – providing an effective earth screen for incoming fuel, while also serving to physically restrain the pump. Hazardous fuels are often electrically screened to eliminate the build-up of static electricity as fuel flows into a rotary pump. This may seem like an esoteric safety feature, but over large production runs, especially when fuel tank levels become relatively low (giving rise to large volumes of air in the tank), there is a strong incentive to minimise any build up of static electricity.

It may be tempting to consider supporting the pump body by the rubber hose alone (a fact that would make fitting the pump into the narrow opening of a Series 3 SWB fuel tank easier). However, an unsecured pump (ie: one secured merely by its hose) will swing in the tank due to vehicle motion and also rotate due to motor torque twist whenever the pump was started and/or stopped. Over an extended period, this continual motion would inevitably result in hose failure.

The first attempt to design a web pump solution for this Land Rover Series 3 SWB fuel tank involved direct modifications of a PRC8318. However, the attempt revealed a number of key problems – including the rather obvious lack of a fuel tank level sender. Inspection of the flange plate revealed a strengthening ridge pressed into the flange along the midline of the *five* mounting screw holes. Although the diameter of the mounting flange is a good match for the Series 3 tank aperture, the PRC8318 flange isn't flat. It also must be drilled to accommodate the six mounting screws of the Series 3 land rover fuel tank. Even after careful gasket design, and sealing all five original mount holes (using epoxy), the resulting mounting plate flange with six screw holes was entirely unable to seal the fuel tank – and it still needed a fuel level sender!

As this engineer learned the hard way, part number PRC8318 is not easily modified to fit a Land Rover Series III SWB fuel tank.

The reader will perhaps forgive a statement of the obvious – namely that a wet pump has to operate in a particularly dangerous environment. Poor design resulting in any electrical condition of high resistance on the relatively high current fuel pump feed (either on the +ve or the –ve side) would all too easily result in an arc or spark capable of vapour ignition when the fuel level drops below a certain level. Given that the fuel tank on a Land Rover Series 3 SWB vehicle is positioned directly underneath the drivers seat, it would be fair to say that the designers mind was somewhat… focussed on these risks, while working through the design.

Turning to the standard fuel sender for a SWB land rover Series 3 fuel tank – a new replacement fuel gauge sender has part number 90560612. A picture of the part from a land rover supplier is shown below. As can be seen from the photo below, this is actually a generic part, where the float arm is supplied as two components. The owner calibrates the float arm length using the two arms, and then solders one to the other.

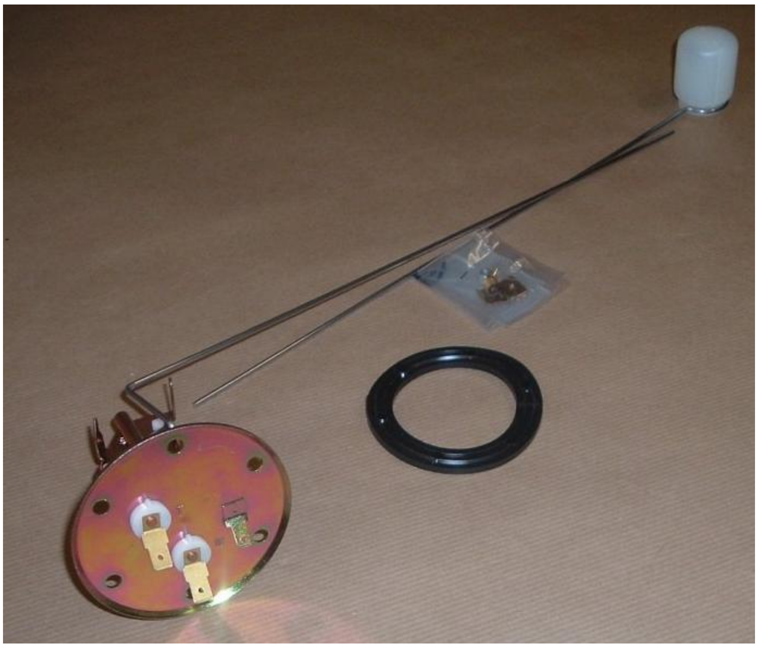


Figure 39 – Series III SWB petrol tank sender (part number 90560612)

There are two insulated spade terminals and a smaller earth spade terminal (shown on the right of the round mounting flange plate in the figure above). One of the insulated terminals is used by the variable fuel gauge. The other is a low fuel level switch which is connected to ground by the sender once the tank is very close to empty. Having these two insulated connectors makes a perfect base for a wet fuel pump design, given that the existing fuel gauge connector can remain as is, and the original "low fuel" tank feed can instead be used to supply the +12v side of the wet fuel pump (the pump connects direct to earth on its –ve side). Both of these insulated terminals are designed to be resistant to fuel, leak proof and are fixed into position (they cannot be removed) – but the reader should note that they are plastic. Any attempt to heat the mounting flange plate (in order to solder the fuel feed pipe as it passes out to the outside world) is guaranteed to result in the two terminals melting.

Regardless of the fact that these terminals are intolerant of heat, the metal contacts are physically wide enough to accommodate significant current carrying capacity and are therefore well suited to supplying the pump. One part number PRC 8318 was purchased for £38 – providing the pump, the intake filter, the 2 section mounting bracket and the 2 pin electrical plug and petrol resistant cable (note: PRC8318 parts can sometimes sell for ludicrous prices – such as £243.12 plus £48.62 of UK VAT on one particular web site – so its worth shopping around). In addition, two fuel senders (part number 90560612) priced at £11.99 each were also purchased – one to act as a donor, and the other as a base for the final assembly.

Inspecting one of these complete 90560612 assemblies reveals that the electrical module for the fuel level gauge is a self contained box – consisting of a back plate, a clipped on module cover, and the float arm. The back plate is spot welded to a small L shaped bracket, (which is itself spot welded to the underside of the main mounting flange (ie: the plate with 6 holes). The entire fuel level module can be removed as one unit by drilling two spot welds.

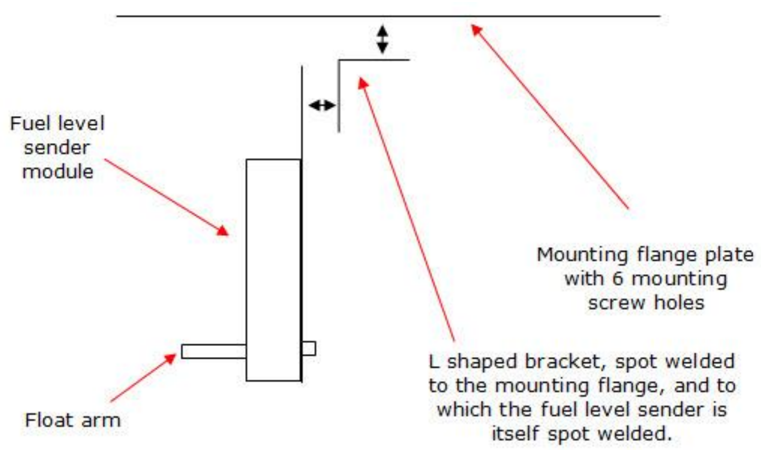


Figure 40 – Fuel level sender side profile (part number 90560612)

For the sake of the following discussion, let us refer to the two purchased fuel senders (with part number 90560612) as assembly A (the donor) and assembly B.

Assembly A - part number 90560612 (1 of 2)

The soldered connections (one wire, and one copper strip) were removed from the fuel sender module on assembly A. Then the two spot welds fixing the fuel sender module to the L shaped bracket were drilled to remove it as an electrically complete fuel level sender module – see below.

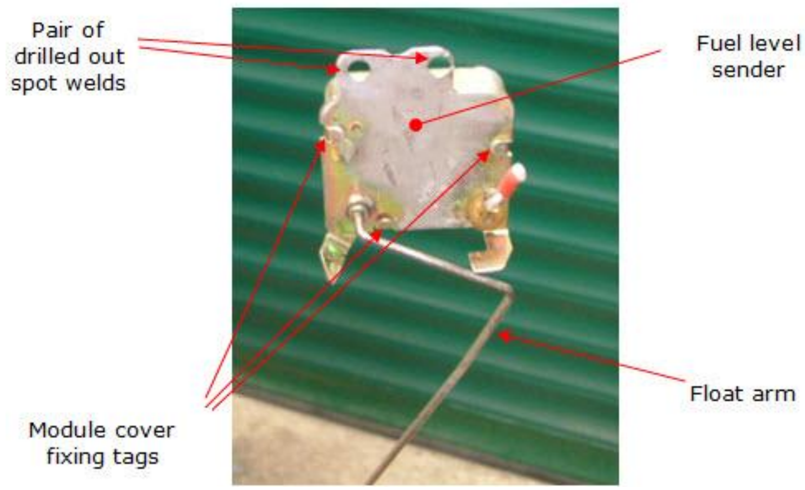


Figure 41 – Fuel level sender module – removed from Assembly A

Note that the fuel level sender module is simply a potentiometer, with its slider connected to the float. As the float moves with the height of the petrol in the tank it converts the fuel level into a proportional electrical signal sent (via the red wire) to the fuel gauge on the dash board. The sender in the above figure has a uniquely desirable float arm because its construction facilitates the fitting of the entire assembly into the tank.

Observe that the fuel level sender module has a metal cover secured to its back plate by three fold-over fixing tags (refer to the above figure).

The remainder of assembly A was then discarded.

Assembly B - part number 90560612 (2 of 2)

The three fixing tags securing the fuel level sender module cover to the back plate on assembly B were levered upright. The cover of the module was removed, along with the arm to the float, and both were discarded. This left the mounting flange plate (ie: the plate with six holes), the spot welded L shaped bracket, and the spot welded back plate of the fuel level sender module. Two small brass rivets fixed a small plastic strip to the module back plate. The plastic strip was wrapped with many turns of fine wire designed to act as the track of the now discarded fuel level potentiometer. The two small brass rivets were drilled out to remove the plastic board - leaving an entirely bare metal assembly plate.

This bare back plate was then cut into a V shape using a hacksaw (refer to the figure below). *The V shape is required so that the complete fuel level sender module taken from assembly A can later be mounted flush on the V shaped back plate of assembly B. It must be as flush as possible in order to provide the maximum possible clearance between its float arm, and the new 8mm copper pipe (fitted next)*.

An 8mm hole was drilled into the mounting flange plate of assembly B. The centre of the hole was positioned just 4mm above the fuel sender back plate (so that the side wall of the 8mm copper pipe would rest directly on the back plate when inserted). It is important to position the 8mm pipe so that when the pipe is inserted in the hole, the body of the pipe clears the hole of the M4 nut that will later be required to fix the fuel level sender module (see M4 note in the figure below).

An 8 inch length of 8mm OD copper pipe was then prepared. The pipe was cleaned, straightened, and then had a smooth right angle curve bend formed at the top – after which the L shaped piece was pushed through the mounting flange hole. The fit through this hole will be tight, but it is far from an interference fit (fuel would leak past this hole – see later notes).

When fully inserted, the lose pipe was then bent inbound starting at the bottom of the back plate (see "Gentle kick bend" in the figure below below) to ensure it cleared the fuel sender float arm when at the fuel tank empty position.

The entire assembly, complete with loose copper pipe, was then turned upside down and placed into a bath of cold water to fully immerse the two electrical connections and therefore protect them from the heat of soldering. With the connectors protected, the copper pipe was then soldered to the back plate (see "solder fixing" above) to mechanically (and electrically) fix the pipe into position.

Preparation involved cleaning with meth spirit, gentle abrasion of the area, and light fluxing prior to soldering with a blow lamp. Both sides of the pipe were soldered to the back plate.
The figure below shows the final result.

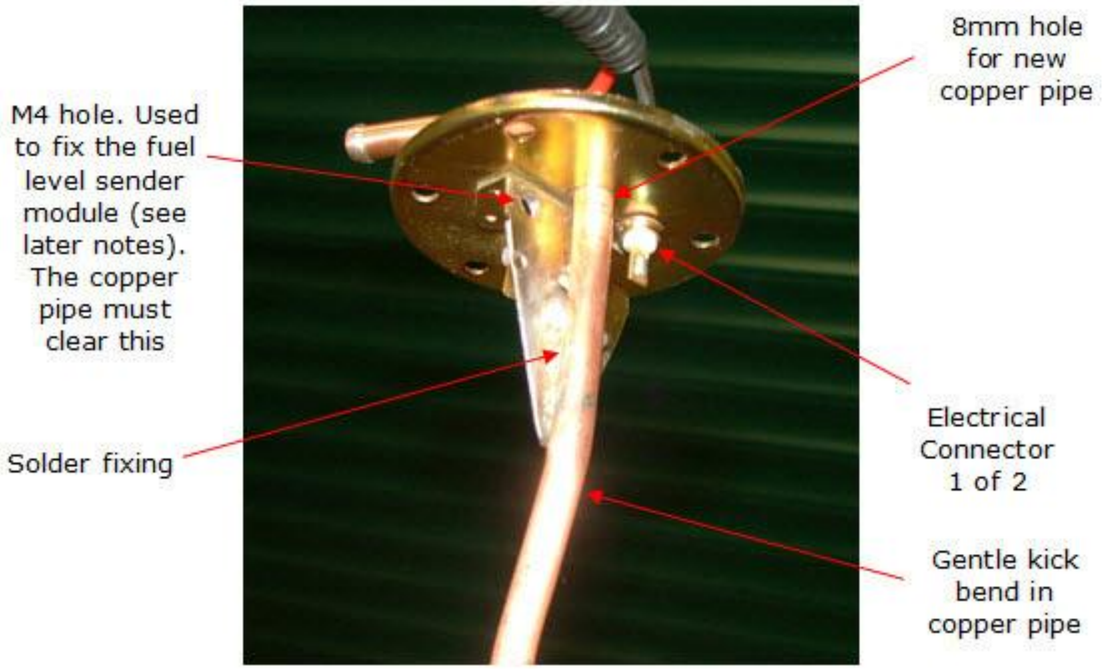


Figure 42 – Bare mounting flange, right angle plate and soldered feed pipe

As stated above, the copper pipe at the bottom of the back plate was bent with a "gentle kick bend" to ensure that the pump assembly would clear the float arm when at the tank empty position. The bend extends for roughly 2 inches at which point the pipe was again bent the opposite way to straighten - so that it dropped straight down into the tank.

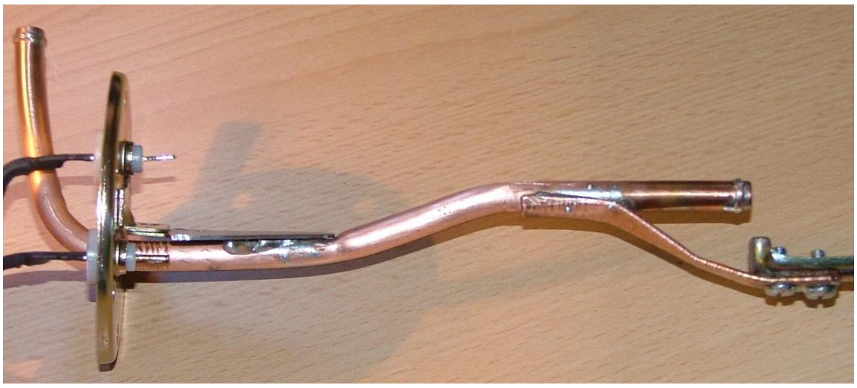


Figure 43 – Pipe bend layout (ignore the brace shown on the bottom right)

The distance from the bottom of a SWB series 3 fuel tank to the top surface of the mounting flange on the outside of the tank is exactly 12.75 inches (323.85mm). The length of the copper feed pipe must be left as long as possible to ensure that the pump intake filter is as close to the bottom of the tank as possible (ie: brushing the bottom) whilst allowing sufficient room for a pair of jubilee clips and a short length of high pressure DIN rated fuel hose to adequately couple the pump to the copper pipe. For this implementation, the coupling hose was 2.75 inches long. The lower end of the copper pipe was then cut to length and two lips were soldered onto both pipe ends (making it suitable for hose connections) using wrapped solid core wire, soldered and then filed and brushed with wire wool to form a neat round lip. The result is shown above (ignore the brace, shown bottom right – which is described next)

With the pump height established, a lower brace was then constructed using flattened 8mm copper pipe. This was formed into a C shape to match the copper pipe and then soldered to the feed pipe at one end, and the lower bracket of the pump at the other. This brace ensured that the pump is adequately anchored and electrically screened. It was soldered to the fuel feed pipe, and screwed (and the screws were then soldered to ensure mechanical stability and electrical continuity) to the existing brace used in part PRC 8318. The result is as shown below.

Note the orientation of the fuel intake filter, compared to the float arm. An angle of about 112 degrees (refer to the figure showing a bottom up view further down) helps to ease the problem of inserting the complete assembly into the tank while at the same time ensuring that the filter doesn’t foul anything in the tank.

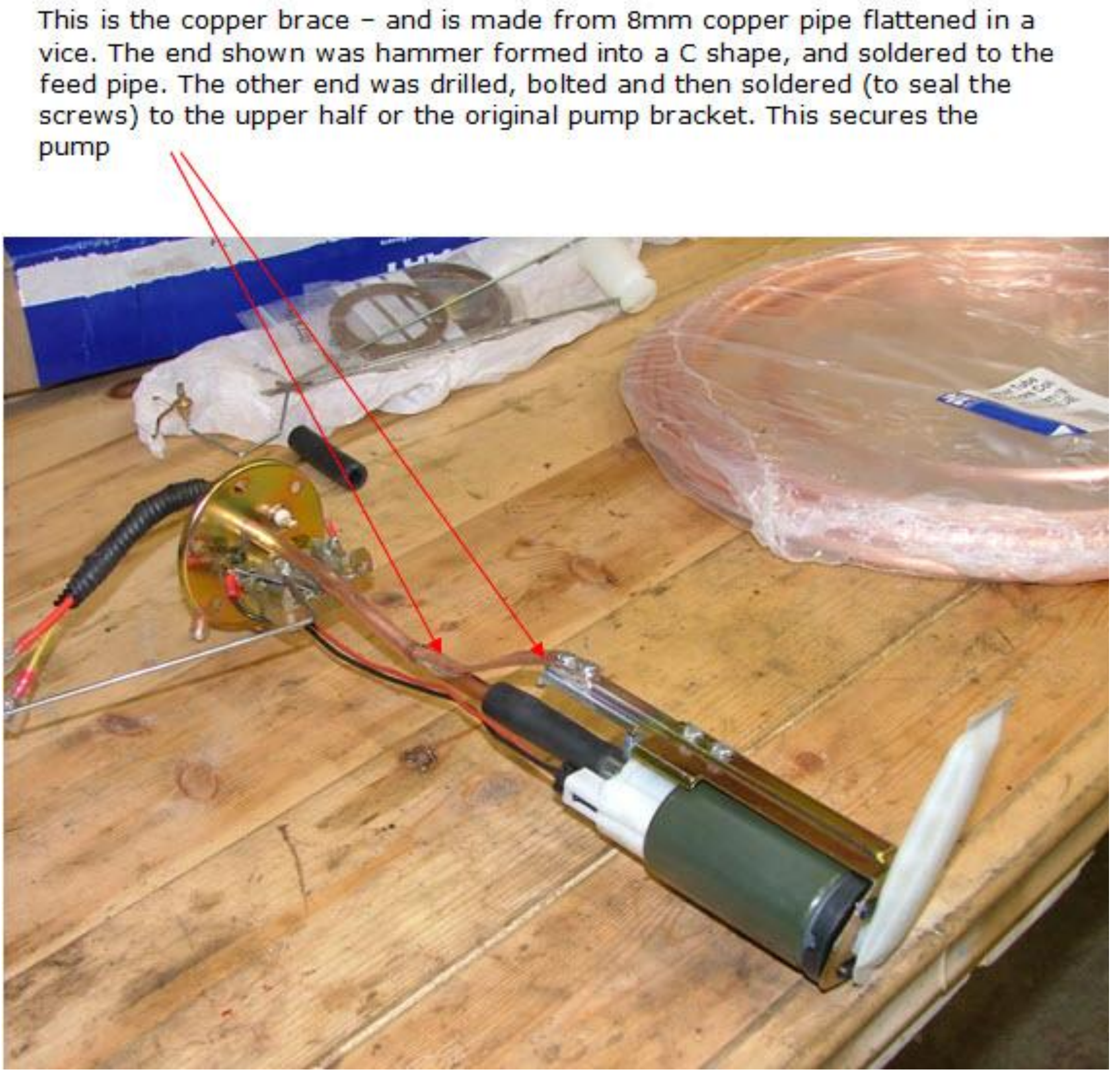


Figure 44 – Final complete assembly of the wet fuel pump design

The 8mm copper feed pipe passes through the mounting flange plate via an unsealed hole. Petrol and vapour will leak through this hole and it can’t be soldered, because the heat would sacrifice the two electrical (plastic) sealed connectors. In addition, the new fuel level sender module taken from assembly A will be fixed to the back plate of assembly B using one M4 nut at the top which ensures electrical continuity, but it must also be secured lower down.

Epoxy resin was the obvious choice for both problems – but which type should be employed?

The choice of epoxy adhesive

Shop bought Araldite (typically known as "ARALDITE rapid" or "Quick set adhesive" and the longer cure 24 hour type known as "ARALDITE Precision") have been used for many years by this engineer in and out of vehicles. They are stable, easy to use, very strong, and resistant to both petrol and oil.

However, there was a degree of uncertainty in their ability to cope adequately when submerged in petrol, or exposed to high fume levels of petrol. Product data sheets from the manufacturer appear somewhat contradictory – with statements that oil and petrol resistance is good coupled with veiled warnings not to use the adhesive inside Carburettors. After much reading, the general consensus was that it may not be worth taking the risk of employing these types of epoxies in the closed, and harsh environment of a fuel tank.

Araldite 2022 has a different composition than standard Araldite available at DIY stores. It is characterised as having particularly strong resistance to petrol and was therefore the selected epoxy of choice. The reverse side of the new assembly shows the bare mounting position for the replacement electrical module – as shown below.

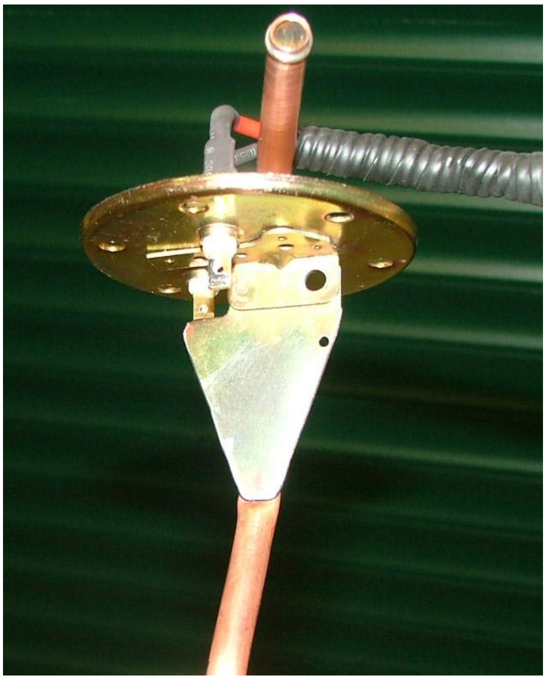


Figure 45 – Module side of the new assembly

The hole in the mounting flange through which the 8mm copper pipe passed was then cleaned with acetone on both sides (note that neither mentholated spirit nor petrol should be used for this purpose). Likewise the rear of the fuel level module, and the back plate were cleaned using acetone after being roughened using sand paper. Care was taken round the copper pipe to remove any/all flux, and both the pipe and the plate were roughened with course scratches.

The electrical module taken from assembly A was then fixed to the back plate. A thin layer of mixed Araldite 2022 was applied to both surfaces and the two metals were brought together. Then an M4 bolt was fitted with locking and scratch washers to ensure electrical continuity. The M4 bolt was new (ie: not pre-stretched) and was tightened firmly. Epoxy was then used to seal both sides of the copper pipe as it passed through the main mounting flange. 24 hours were allowed to pass before the assembly was moved.

Figure 46 – Electrical module fixed onto the back plate

On the top outermost side of the unit there was one risk that some unsuspecting engineer could connect the pump feed to the gauge wire given two identical male spade terminals were exposed. This could be rather dangerous, because the design would permit the mechanic to connect the pumps high current +12v feed to a wire wrapped potentiometer, which would in all probability glow cherry red inside the fuel tank as soon as the ECU powered the unit up. As such, the spade terminals on the top of the mounting plate have been soldered, and hard wired to male and female spade connectors on colour coded wires. The metal terminals in the mounting flange were then surrounded with heat shrink to prevent any direct connection. The sex of the connections ensures that the wiring cannot be accidentally reversed.

Fitting the wet fuel pump into the tank

Some care is required to fit the pump assembly into the tank. Be aware that it is not easy to do. The complete unit cannot be dropped into the tank without obstruction and yet it does have to be inserted as a complete unit. The key to successfully installing the complete assembly lies in the initial approach.

Start with a trial run designed to verify that the pump and pump support bracket can be inserted into the tank aperture. Insert the pump filter into the tank and then check that the pump and bracket can be inserted. It will almost certainly be necessary to grind off a small lip on the support bracket prior in order to fit. The end result will still be tight even with this lip removed – but it will be possible.

With that step completed, start the installation process.

1. Have a dry powder fire extinguisher in easy reach.

2. Clear the entire area of any unwanted tools, items etc.

3. Avoid wearing synthetic clothes (to reduce the risk of static)

4. Physically tie back the loom near the tank so that it is out of the way

5. Make sure the tank flange opening is clean.

6. Lightly grease both sides of a new mounting flange gasket and leave to one side.

7. Next prepare the complete assembly…
    a. Tighten the pump hose jubilee clips (x2)
    b. Fully insert the electrical connector and ensure that it is locked into the pump. Make sure that the two pump cable solder connections are secure, and that the sender wire is secure at both ends.
    c. Tighten the two locking screws on the pump securing bracket
    d. Make sure that the white plastic fuel pump intake filter is secured (it is a simple push fit)

8. Make sure the M4 screw securing the sender to the entire assembly is tightened.

Next - draw the float arm as close to the bottom of the pump as possible effectively going beyond a completely empty fuel tank. You can do this by wrapping your hand around both the float arm and the pump and by drawing your hand tight. This action deliberately fights against the natural spring tension of the float arm leaving it locked tight against the sender back stop. It is therefore important that the back stop be visually checked to ensure that it doesn’t deflect as a result (which could allow the float arm to move too far counter clockwise, potentially misshaping the slider contacts inside the sender).

Viewing bottom up, the complete assembly would appear as follows:-

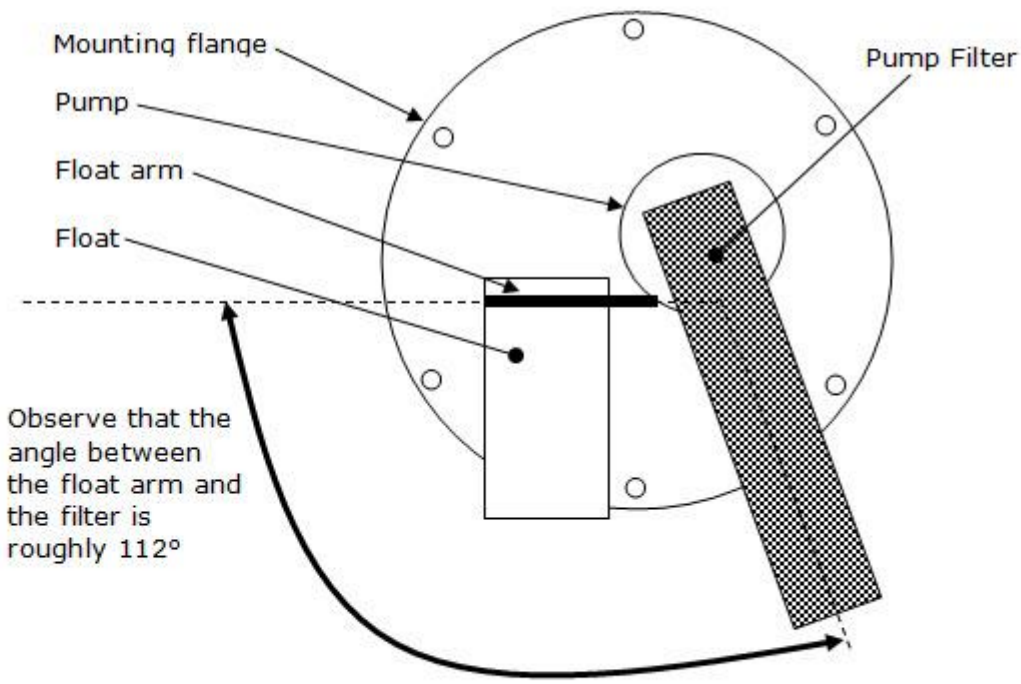


Figure 47 – Bottom up view of the full assembly (float drawn to the pump)

With the float as close to the pump as can be physically achieved, gently insert the fuel pump intake filter through the greased flange gasket followed by the float. Pull the gasket up to the underside of the mounting flange and bring the entire assembly to the tank.

Touch an earth point on the vehicle to discharge any static

Tilt the assembly until the float plastic head can be inserted fully inside the tank. Then tilt the assembly the other way (taking advantage of the fact that the intake filter is flexible) and gently insert the end of the filter into the tank. Making sure that the pump intake filter isn't dislodged in the process, insert it up to the base of the pump and gently push the base & bracket into the tank.

Lower the entire assembly into the fuel which will release the pressure on the float arm. Check that the float arm moves freely – and if so, use a multimeter to ensure that the sender is functioning electrically (typical values will be closed circuit when the tank is full, and about 200 ohms when empty).

The 6 screws on the outside of the main flange can then be tightened, and the electrical connections made. Note that on two of the six mounting flange screws at opposite sides of the mounting flange, earth wiring eye connectors were fitted along with scratch washers. This is a belt and braces solution designed to prevent future corrosion causing any deterioration of the electrical earth signal. The object being to ensure that the assemblies earth is a low resistance, good quality connection.

With the assembly secured to the tank, attention turned to the pipe supplying fuel from the assembly to the first inline filter mounted on the passenger side of the front of the mid cross member. The existing dry pump had been removed from the vehicle along with its mounting bracket which had been bolted to the cross member with three bolts. The bracket was stripped of the pump mounts, and drilled to accept a set of new 8mm P clips. A length of 8mm copper pipe was then prepared by cleaning and carefully bent into shape so that the outlet of the tank could be directly connected to one end, and the other connected to the inline filter. The new pipe had two solder lips prepared at both ends (to secure the hoses) and both cut ends (cut by a copper pipe cutter) were opened out using a countersink. The pipe was then P clipped using five P clips (three on the old pump bracket, and two on the Land Rover seat box).

The assembly was then connected to the new vehicle fuel pipe using a short length of hose and two jubilee clips and the other pipe end was connected to the inline filter. Checks were made to ensure there was no fouling.

The entire system was carefully tested, by turning the ignition to start, but not run. The pump could be heard to quietly spin up for roughly 2 seconds or so. Three such bursts were sufficient to pressurise the fuel system causing a noticeable change in the tone of the pump. The pipe work was checked for leaks.

After that the vehicle was started. Subsequent tests ensured that the tank gasket adequately sealed the tank aperture when the tank was filled to capacity (it did). This doubles as a test of the gaskets ability to seal fuel vapour whenever fuel is at low levels in the tank.

The end result is an elegant design solution. The pump is protected from the elements and from accident damage. It is almost inaudible when running, even when the vehicle is stationary and has improved flow characteristics simply because the input pipe restriction is removed and there is no risk of vapour lock.

Vacuum plumbing design

Connections to the engine intake are used by a number of key engine components. There are five vacuum ports on the engine…

1. Primary vacuum feed for the brake servo
2. Advance / retard vacuum feed for the distributor
3. Vacuum feed for the fuel pressure regulator
4. Vacuum feed for the PCV (crankcase ventilation system) from two sources.
5. Vacuum feed for a dash board gauge.

The brake servo connects directly to a driver side port screwed into the plenum intake runner manifold using silicon hose. It is exposed to engine manifold pressure with no restrictions.

The passenger side of the plenum intake runner manifold has three ports screwed into the side, two of which have piped ports (one of which is fabricated in copper). All these ports are exposed to engine manifold vacuum without restriction.

The port nearest the firewall connects to a 10mm copper U bend to a hose. The hose connects to a small 10mm copper pipe blocked and drilled with a 2mm metering orifice the other side of which connects to the white plastic PCV "T" piece. This is designed to provide metered engine vacuum to the PCV system when the throttle is closed.

The second intake runner port (located in the middle of the manifold) connects to the dash vacuum gauge via a reducer.

The vacuum feed to the fuel pressure regulator is taken from the plenum upper chamber port located directly under the bypass air stepper motor valve and which is exposed to engine manifold vacuum without restriction. This feed uses red silicon hose.

The advance / retard feed for the distributor is taken from a metered port directly on the top of the plenum throttle body. This feed also uses red silicon hose.

Engine cooling

The plumbing used for engine cooling has been covered in the intake manifold section of these notes however there are a number of related issues worthy of note.

As the vehicle was delivered (running twin SU carbs) there was roughly 4-6 degrees of static advance and the engine was fitted with a 74 degree C thermostat.

If an owner asked for a standard thermostat for an EFi Range Rover they would typically receive an 88 degree C thermostat. However running an 88 degree thermostat in this particular engine caused it to run very warm as confirmed both by the coolant and oil temperature. The vast majority of modern V8 engines are designed to run somewhere between 80 and 90 degrees C. Most American V8's such as the Pontiac / Olds big block 400, Pontiac 455 and the small blocks such as the Chrysler 360 and Chevy 350 run with 195 degrees Fahrenheit thermostats (90.5 degrees C). Even pre-emission high compression engines (prior to 1971) typically run at the same temperature because that temperature is ideal for helping to minimise emissions while ensuring that the crankcase oil is at the ideal temperature for lubrication. Running an engine at that temperature is always conditional on three aspects of engine operation.

- The engine static timing should be advanced as far as safely possible before detonation occurs. Advanced timing always ensures an engine runs cooler simply because more of the heat of combustion is converted into useful work, as opposed to useless heat which must then be absorbed and dissipated by the cooling system. Given a well maintained engine a minimum static timing advance of 9 to 10 degrees should be possible, even allowing for the relatively poor quality fuel available nowadays.

- The ignition system must be running properly, so that the risk of detonation through mistimed ignition for example, or failed ignition due to weak spark is eliminated

- Accurate metering of fuel must be occurring consistently through the rev range and especially under load when preignition is most likely to occur.

A 74 degree thermostat will cause the Rover engine to run too cool resulting in greater wear and tear of the mechanics of the engine due to the lower temperature of the oil coupled with a rich mixture generated by the injection system which is itself merely responding to a constantly lower than ideal coolant temperature. Rover V8 engines can be run at a temperature of 82 degrees – and so an 82 degree thermostat was employed to elevate the running temperature as high as possible. The thermostat didn’t have a joggle hole – but it did have the traditional V pressed into the body casing designed specifically to pass a small amount of fluid which reduces the risk of air locks.

The engine static timing has been set to 9 degree BTDC and the engine (even under load) copes comfortably. Advancing the timing from 5 degrees to 9 degrees resulted in a noticeably more responsive engine, and one that ran cooler and with increased gas mileage.

Note that two minor consequences of fitting the higher temperature thermostat were firstly that the thermostat housing suffered some leaks, and secondly that the overflow from the expansion tank used to expel some coolant – especially if a 15 PSI radiator cap was used. The leak problem was resolved by fitting a paper gasket using hylomar blue as the sealant. The expansion tank issue was resolved by replacing the old 9 PSI radiator cap with a new one, and fitting a catch tank (which rarely if ever collects any fluid).

Note that the radiator fan switch sensor was recalibrated to cope.

Radiator fans

The original carburetted engine had the engine fan removed and replaced by twin electric fans switched by a pair of sensors in the top coolant hose. In warm ambient conditions the arrangement was prone to overheating especially following a stop after long soak conditions because the sensors were set to switch on at greater than 90 degrees coupled with the use of a 74 degree thermostat. In fact the previous owner had gone to great lengths to source fan switching sensors with the lowest possible switching temperature threshold – but these were far from ideal in practise.

Both of these sensors were replaced by a digital, adjustable sensor in the top hose and which is calibrated to switch the fans on at roughly 85 degrees C.

Coupled with the 82 degree thermostat, and a cool running engine the arrangement works extremely well even in very hot ambient weather conditions.

Figure 48 – Digital radiator fan sensor in top hose (control relay behind)

Note that the cooling system does include a warm water feed to the chamber directly under the injection plenum. This assists engine operation by increasing the temperature of the plenum during cold conditions – which increases the ability to vaporise fuel as the air passes into the combustion chamber at the sacrifice of some fuel density. The water supply is taken from the engine intake manifold (front, passenger side close to injector 1) and the return feed is connected via a hose directly to a port on the radiator.

Idle control system

The notorious weakness of the 14CUX system is its idle control. The system is intended to operate as follows:

1. Assume the engine is running and then switched off, at the instant of switch off - the 14CUX withdraws the idle air valve stepper motor fully, which opens the port on the plenum chamber leading to a port on the atmospheric side of the throttle (B) via a half inch hose. In effect, the full amount of air flow can then pass by this route the next time the engine is started and as the air flow is metered (remember it is being drawn from the atmospheric side of the throttle and is therefore being metered by the mass air flow sensor) the 14CUX will provide an appropriate air/fuel mixture. The temperature sensors are involved in the precise metering of fuel – as when starting a cold engine the injectors are actively opened for a longer duration in order to provide a rich enough mixture. Once the engine catches, the injection system runs through a purge fast idle cycle which holds the engine at about 1800RPM for a few seconds in order to smooth out the engines running (by gaining maximum air flow through the intake, and thereby purging any excess fuel which may have wetted the intake runners).

2. With the cold engine now running, the coolant temperature sensor showing a slow rise in temperature the 14CUX will test the rev speed of the engine and if too high will close the stepper motor by a predetermined amount. It will then pause for a short while and retests the engine speed to repeat the process. The objective is to slowly reduce the engine idle speed to about 720RPM in line with cold operation – a process known as hunt idling.

3. The 14CUX uses two slightly different idle speeds. The lowest (720RPM) is employed only when the vehicle road speed falls below a threshold of roughly 3MPH. At road speeds higher than this threshold, the 14CUX employs a higher idle speed of roughly 1200RPM when the throttle is

released. This is designed to minimise wear and tear in the drive train during gear changes.

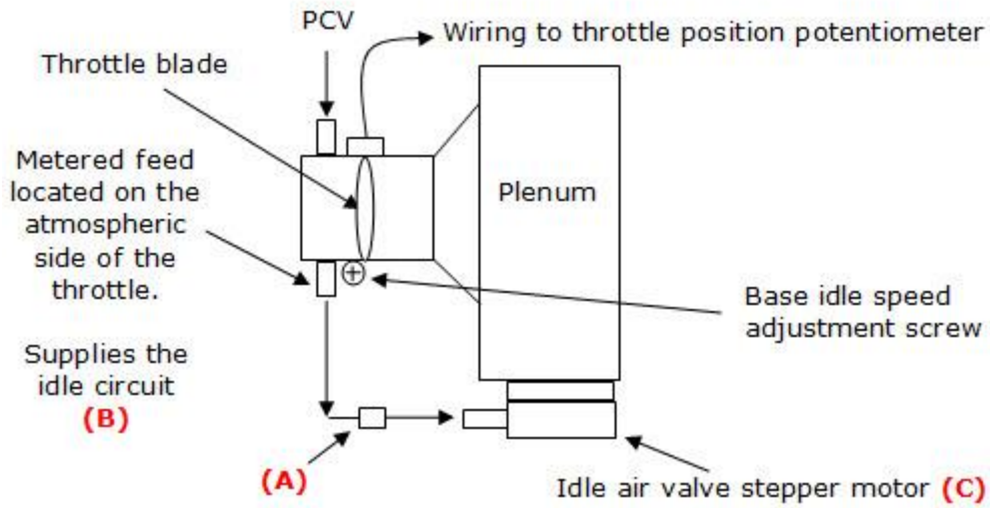


Figure 49 – Idle control system

There were multiple problems with the idle speed system on this vehicle – resulting in no hunt to idle, or a too fast idle speed when warm. An additional complication was that the normal method of connecting the plenum port to the idle air valve stepper motor housing (ie: (B) to (C)) involved using a soft L shaped rubber hose. However, after adding the new rocker covers (with PCV oil separator at the front of the driver side rocker) and with the plenum orientated as shown, the idle air rubber hose fouled the PCV oil separator.

The first problem was that the unadjusted base idle speed for the injection system was much too high. The base idle is the speed the engine will run at when the throttle is closed and the fuel injection idle circuit is disabled. It is specified by Land Rover as 520RPM (+/-25RPM).

It is absolutely vital that the base idle speed is checked on a new installation.

In order to set the base idle, the engine is first run up to full working temperature. The engine is then stopped and the hose connecting (B) to (C) is removed. The two exposed ends (at end (B) and end (C)) are then blocked and made air tight. The engine is then restarted – but this time with the throttle initially opened by hand. The throttle is then slowly allowed to close in order to allow the engine speed to slowly reduce to its base speed. With the throttle closed, the resulting idle speed is adjusted to 520RPM by turning the base idle speed adjustment screw (via an Allen key) in the plenum. This allen key can be protected by a tamper proof plug – which must be removed if fitted. Once the base idle speed is set, hose (A) can be refitted.

As the plenum was delivered, base idle was in the order of 1100RPM – which is reasonable given it was being used on a larger displacement engine.

The second problem was that both the throttle potentiometer and idle stepper motor were faulty (see TPS notes below). The throttle potentiometer fault meant that the system always thought it was off idle (it was stuck set to about 80% open throttle) – which rather nicely demonstrates the value of an air flow metering system given that even with this fault, the system was safe and driveable. The idle valve fault was caused by a stuck stepper shaft – which is an extremely common fault with this design (given that the stepper motor shaft is exposed to engine blowby gasses and oil).

The third problem (as stated above) was that the standard Land Rover hose linking (B) to (C) fouled the new position of the PCV oil separator. The hose was therefore discarded, and replaced with two short rubber hose joiners, and a neatly bent 10mm copper pipe with soldered 10mm to 15mm reducers on both ends (all painted red). These reducers were a snug fit in the rubber hose pipe.

Figure 50 – Idle air supply pipe (red) – no longer used

While this solution did resolve the problem of the original hose fouling the PCV oil separator, it came with the disadvantage that the amount of air entering the idle circuit was proportionally reduced due to the smaller diameter of the copper pipe. Testing revealed a low idle speed – typically 200RPM lower than expected by the 14CUX, and so the ECU routinely reported fault code 17.

The idle air flow pipe was therefore reconstructed using half inch copper painted red (but with no restrictions) as shown below. The rubber hose ends coupling to the plenum and the idle air valve body were, again, ends cut from the standard hose.

Figure 51 – Idle air supply pipe (red) – finalised

The figure above shows the two rubber joining hoses coupling a red 15mm copper pipe formed to avoid fouling the PCV separator.

There are two more general observations that follow

1. The first is that the engine management switch to hunt mode is directly linked to the output from the transmission road speed transducer. As stated above, the 14CUX employs a higher idle speed (roughly 1200RPM) when the throttle is released but when the road speed is above a fixed threshold of normally 3MPH. If the throttle is released when the road speed is lower than this threshold, then the 14CUX uses the lower idle speed Refer to the road speed transducer notes which address this issue.

2. The second is that the ability of the injection system to properly control idle speed is directly linked to the cleanliness of the idle air bypass stepper motor shaft. It is possible to clean this part (as shown in Ginetta notes at http://www.g33.co.uk/fuel_injection.htm) and it is suggested that this step be taken on a fairly regular basis.

Multiple Code 17's – Throttle Position Sensor (TPS) Fault

These notes were written in Nov 2010

Since the Fuel Injection system had been fitted, one problem has repeatedly occurred – and with very predictable characteristics.

Assume that the vehicle is in fourth gear, cruising at a relatively constant 50MPH. If the throttle is eased back the engine will stumble. If the throttle is immediately depressed, the engine will resume normal operation. The same problem can occur at traffic lights, when the vehicle comes to a stop. The engine may stumble without stalling. Again, depressing the throttle will cause the engine to correct and run well.

The fault (when it occurs) is always accompanied by a permanent code 17 on the ECU – which is described as…

17	Throttle sensor out of range	Sensor needs adjustment, is faulty, or has wiring fault. This can cause low speed misfires and can also prevent the system setting low idle speed.

As soon as the ECU reports code 17, the idle speed will raise to 1500 RPM until the fault condition is cleared. Note that the ECU must be disconnected for the fault to clear.

The logical starting point was to replace the Throttle Position Sensor (TPS) for a brand new part. Given that these parts are nearly £100 each, the reader will appreciate the consternation when the new part didn't fix the problem at all. A number of alternative theories for the cause of this problem resulted in a good deal of work, which did appear to fix the problem (but without any reasonable explanation of the cause). A couple of weeks later the fault re-occurred just a couple of days before an MOT test was due.

TPS parts are actually standard linear 4K potentiometers, but with a sweep of roughly 135 degrees. There is no clever technology in these parts (regardless of what nonsense you may read on the web) and they do wear out.

In the old 14CU injection system, the TPS devices had slots for their screw mounts so that the potentiometer could be rotated through a small angle before being fixed to the plenum. The mechanic fitting a new TPS would monitor the voltage on the wiper arm (connected to ECU pin 20) and rotate the TPS before tightening the screws to get that voltage to meet the target idle position specification. Effectively – this fixed the voltage sent by the TPS to the ECU at idle.

The 14CUX system uses a different approach in the sense that the ECU software measures the TPS output when it is first powered up and assumes that this is the normal idle position voltage. Internal algorithms deal with subsequent variations in the TPS output, while at the same time coping with the situation where the user starts the vehicle with their foot on the throttle. The 14CUX can therefore cope with variations in the TPS output over time, and for this reason the TPS on a 14CUX system is not fitted with adjustment screw mount slots.

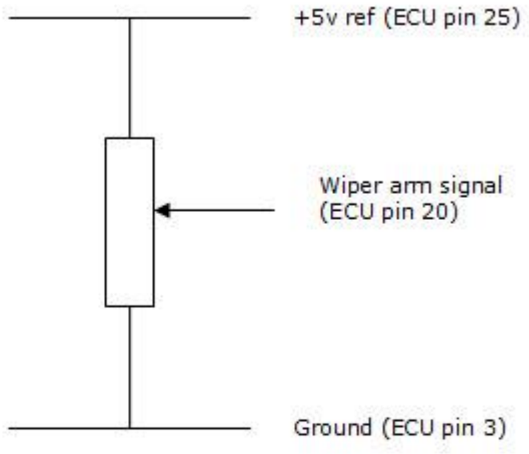


Figure 52 – TPS equivalent circuit

The workshop manual diagnostic tests designed to check the voltage of the wiper arm with the vehicle stopped all passed on the subject vehicle – although it is worth noting that obtaining a reliable volt meter connection by poking wires into the back of the TPS plug is difficult to achieve in practice without using a breakout cable of some sort.

Note: If the ignition is switched on, and the engine is not started, the +5v reference voltage on ECU pin 25 is continuously fed – which means that (once connected reliably) the wiper voltage can be monitored very easily.

Armed with a break out cable (for all three TPS wires), a volt meter was connected between ground and the wiper arm signal and the vehicle was driven to dynamically monitor the returned voltage. At that point, the cause of the fault became all too clear. Whenever the engine stumbled, the voltage from the wiper track dropped to zero. Usually it was such a fast drop out that the engine barely missed a beat (no ECU errors would be reported) – but at other times it was a long enough drop out to cause a noticeable stumble and to provoke a code 17 error on the ECU display.

The possibility that the +5v regulated reference voltage (on ECU pin 25), or the ground (ECU pin 3) were causing the fault was eliminated given they were both stable whenever the fault occurred.

Attention then turned to the TPS itself.

The TPS was first removed from the plenum, and a volt meter used to monitor the TPS wiper voltage as its shaft was rotated by hand. It was found that reliable operation could only be obtained when the TPS shaft was pressed into the body of the TPS by roughly 1mm, as it was being rotated. In effect, the wiper wasn't making reliable contact with the track until the shaft was physically pressed home.

It is a frankly astonishing fault – begging all sorts of questions about the quality of these ridiculously expensive parts! The fault was observed on two TPS parts – both less than 1 month old, and both sourced from different companies.

The condition did suggested the possibility that this was a deliberate design characteristic – and that perhaps the plenum shaft was somehow recessed too far towards the throttle (leaving too big a gap). But that couldn't be the case given the throttle shaft is held in position by a rotating butterfly and so can't move left or right assuming the butterfly is capable of opening/closing.

Measurements were then made to compare the length of the TPS shaft with the depth of its female counterpart in the plenum. With the TPS fully screwed home in the plenum, a gap between the two surfaces of 1.08 to 1.23mm was found. If that gap was reduced to zero, the shoulder of the plenum would ride on the shoulder of the TPS shaft. Two washers were then fabricated, in such a way that they locked onto the TPS shaft, and resulted in a gap of -0.74 to -0.59mm (ie: the TPS shaft was pushed into the body of the TPS unit by 0.59 to 0.74mm when screwed into the plenum with these two washes on the shaft).

This fixed the problem – and it has never occurred since

Another plenum, and TPS device (given it may come from a different source) may well be different – but if this fault occurs, observe the voltage of the TPS dynamically and if the problem of drop out can be seen, measure the relative gaps between the TPS and plenum for a potential fix.

Cold Engine – Surge Hunt problem

These notes were written in Jan 2012

After the engine temperature was modified by increasing the temperature of the thermostat from 74 to 82 degrees one running problem has occurred, and in an oddly repeatable way. If the vehicle is driven for about 3 miles in relatively mild conditions (say 6 degrees C) and then brought to a halt, the engine speed will oscillate relatively quickly between about 800 and 1500 RPM. It feels like the EMU is trying to stabilise the speed, but is overcompensating. After perhaps 2 seconds of this odd oscillation, the idle circuit will bring the hunt/surge under control after which the engine will idle correctly.

This felt like a variant of a known 14 CUX problem and which Land Rover main deals were forced to tackle as part of warrantee work. Their fix was to place a 10K resistor directly across the coolant temperature sender in such a way as to fool the 14CUX into thinking the engine was warmer than it actually was.

In fact, the effect of this modification is tapered, having a much greater effect when the engine is cold compared to virtually no effect at all when the engine is hot. The typical CTS resistance at 9 degrees C ambient (engine off overnight) is somewhere round 4K, and when hot this reduces to something in the range of 200-400 ohms. Clearly 10K in parallel will reduce 4K to 2.85K (a big difference) but would reduce 300 ohms to 291 ohms (a much smaller difference) when hot. The mod is designed to prevent an overly rich mixture – and oddly works quite well.

The specific modification places a quarter watt 10K R, about 3 inches down from the CTS connector. The loom wiring is covered in self amalgamated tape and the connections are shrink wrapped.

Exhaust and Lambda sensors

The 14CUX engine management system used in 1992 range rover vehicles has a tune resistor option fitted to the wiring loom permitting the selection of different modes of operation based on the emission legislative requirements of the geographical location of the vehicle when sold. The loom simply contains a half watt resistor in a plastic case. The value of the resistor defines the mode of operation – with the following options …

- 180 ohms – Australia rest of world
- 470 ohms – UK and Europe non catalyst
- 910 ohms – Saudi non catalyst
- 3900 ohms – USA and Europe catalyst

Non catalytic operation is much simpler in the sense that no extra exhaust sensors are required – but this mode of operation has the significant disadvantage that the system is unable to self compensate for any changes in air flow. In effect, the 14CUX will operate using a static fueling map, and any engine changes that tend to fall outside of the assumptions built into that map will result in substandard performance.

By contrast, catalytic operation requires the use of two oxygen sensors (lambda probes) one fitted into each exhaust down pipe, but this mode of operation does provide the 14CUX with a mechanism to monitor the combustion effectiveness of the engine by assessing its exhaust oxygen content levels. In effect, catalytic mode of operation allows the 14CUX to operate as a closed loop feedback system.

The vehicle employs catalytic operation requiring lambda probes in the exhaust system and therefore uses a 3.9K tune resistor.

The lambda probes were purchased online – complete with plugs for the range rover donor vehicle (it is possible to purchase cheaper variants of the probes without connectors – and this needs to be checked at the time of ordering). Price was roughly £70 each. The threads of the standard lambda probes are M12 with a 1.25mm pitch thread. The two down pipes were marked up for suitable lambda sensor positions and then fully removed from the engine, separating them from the back pipe at the split point under the gearbox. It was fortunate indeed that the exhaust system was relatively new and constructed from stainless steel. Penetrating oil and some sharp blows from a hammer at the joint was all that was required to separate the unions. Once on the bench the construction work for each down pipe began as follows

1. The down pipe was cleaned and punch marked at the hole location
2. A 13mm hole was drilled into the exhaust pipe at the punched location. The hole was dressed and cleaned and then roughened in preparation for welding.
3. An M12-1.25mm thread stainless steel nut was ground down to lose roughly a quarter of its height. The grind was curved to match the curve of the stainless steel exhaust pipe.
4. A MIG welder was fitted with 0.8mm stainless steel welding wire, and set to a high carbon argon gas feed in preparation for 1mm welding.
5. The nut was G clamped to the stainless steel exhaust pipe, and then tack welded into position.
6. Final checks were made that the position was correct and that the lambda sensor could thread and appear in the exhaust stream correctly.
7. The nut was then seam welded round the lower edge directly sitting on the pipe. The weld was allowed to cool and then the area above the weld (leading up to the high point of the nut) was welded.
8. The excess weld was ground down, smoothed and dressed to provide a gas tight seal.
9. Copper grease was used in the nut thread and the lambda sensors were checked for clearance.

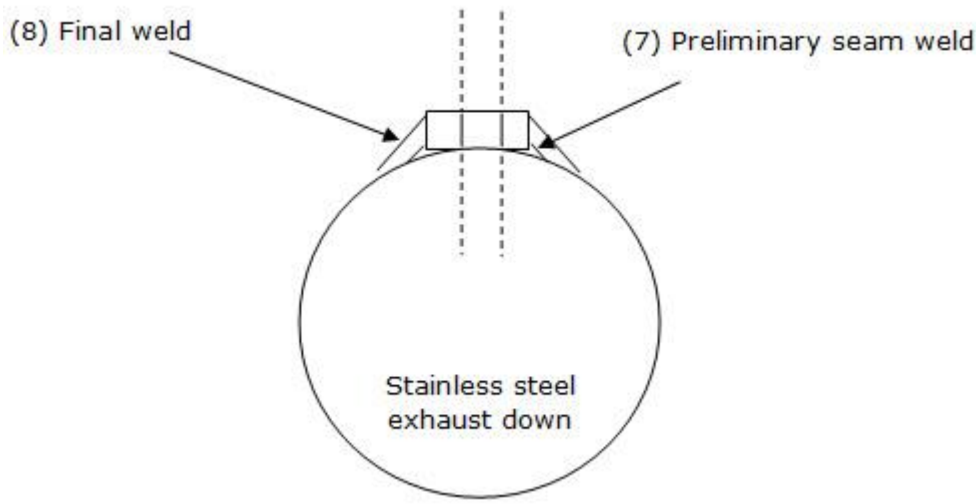


Figure 53 – Welding lambda sensor threads into the exhaust downpipes

Bench testing the electrical wiring loom for the ECU

The wiring loom taken from the donor vehicle was in generally good condition. Nonetheless, a number of wires close to the 14CUX harness plug had been cut, and some signal lines were broken perhaps due to the flexing incurred in removing the loom as one complete piece. Both main and fuel relays had been included in the loom along with the primary connector used to link the injection system to the vehicle (normally located behind the dash).

Before any of the loom was fitted to the vehicle it was assessed on the bench primarily to electrically test the loom for continuity and to repair any damage. Two other reasons made this step essential. Firstly it was necessary to understand precisely how each connector was wired (so that faults could be diagnosed when fitted in the vehicle). Secondly it was necessary to re-route some of the loomed cabling due to the reversal of plenum orientation (certain plugs had to be moved from the passenger side engine bank to the drivers side and from the rear of the engine to the front).
During bench checking a full set of hand drawings were used to record the wiring connections and layout. These are copied in the following set of figures.

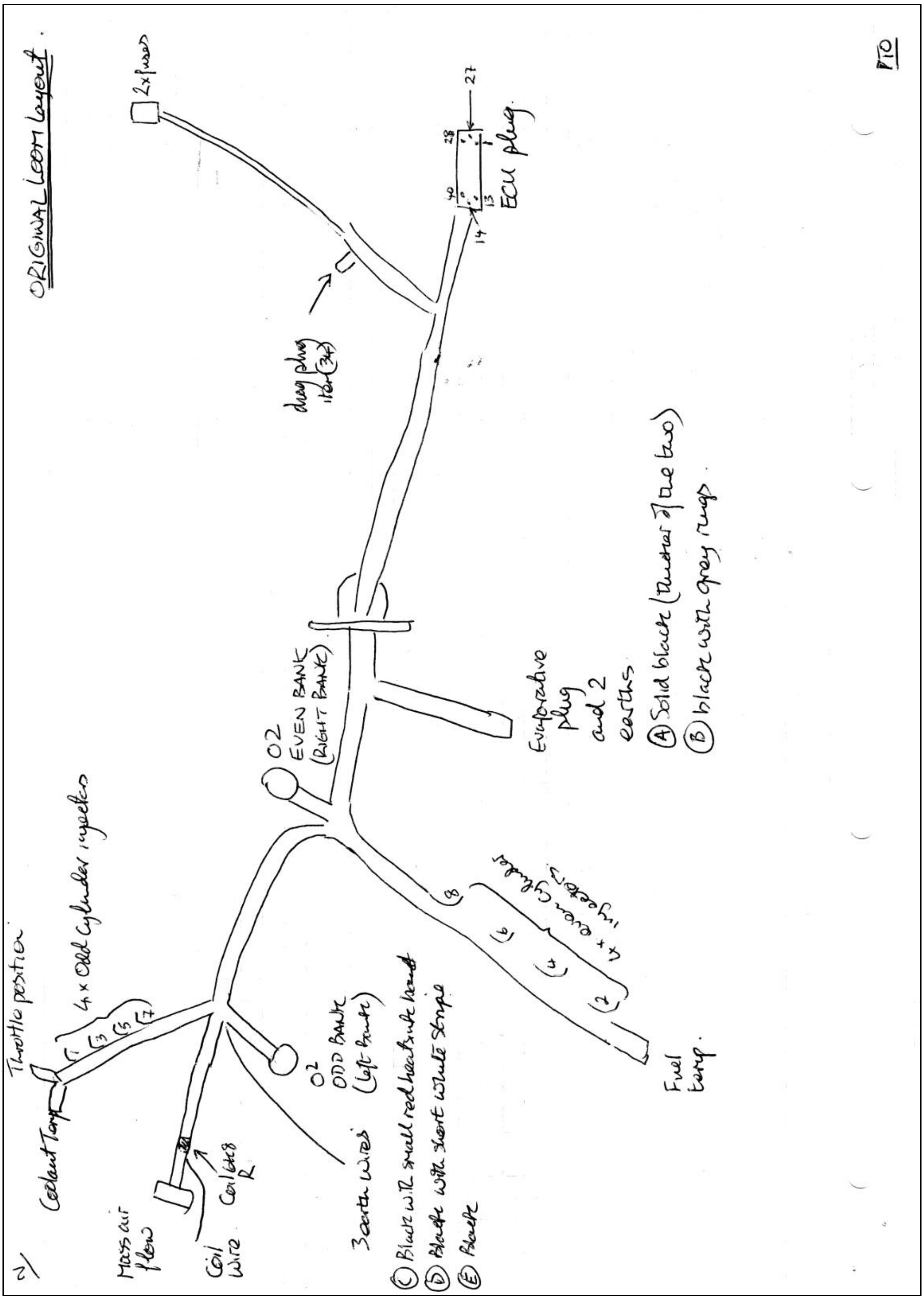


Figure 54 – Original loom connector layout in donor vehicle

The original layout reflected the needs of the donor vehicle. Due to the changes in orientation of the plenum, these changed when fitted to the target vehicle.

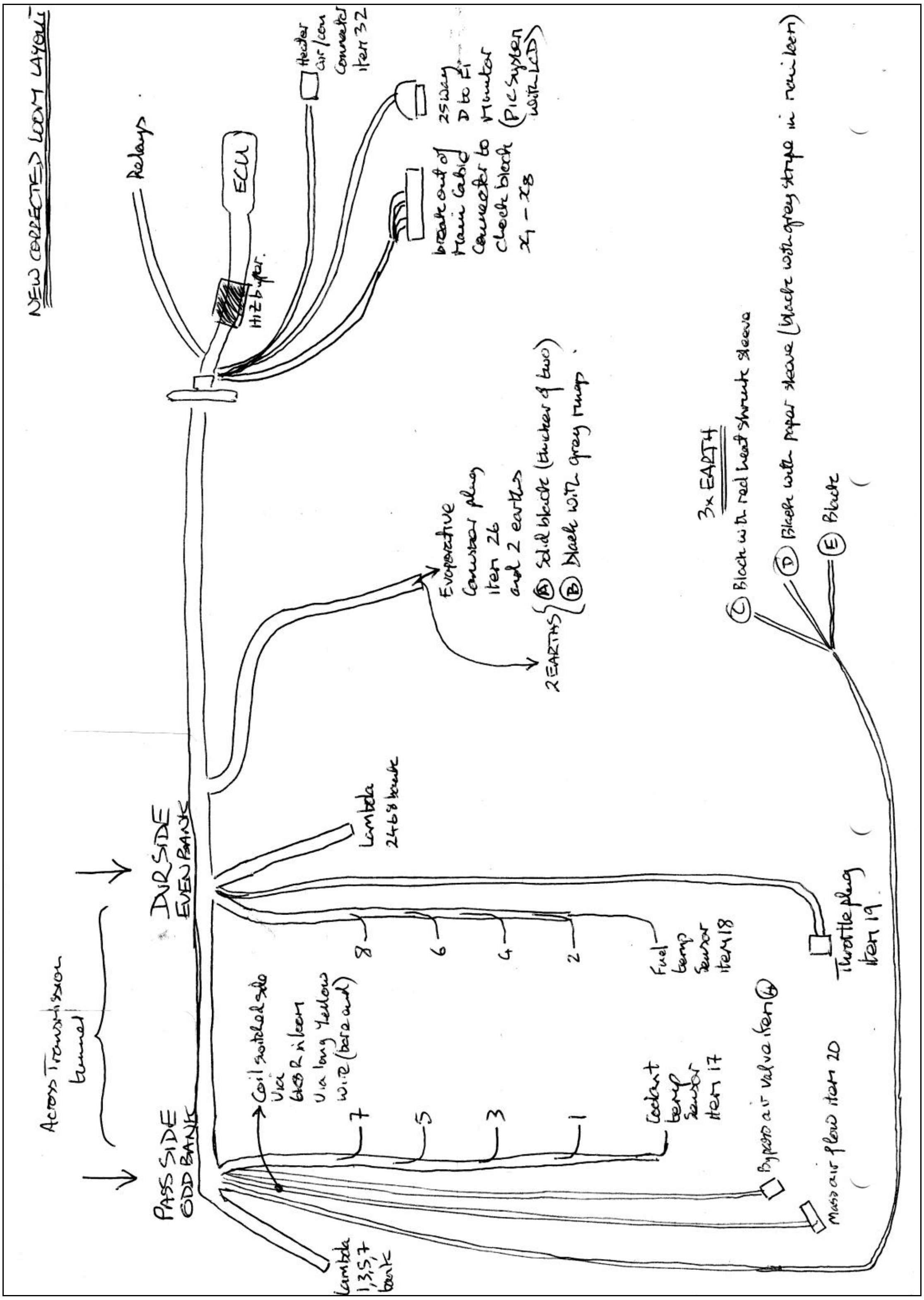


Figure 55 – New loom layout suited to the target engine bay

The new layout was ideally suited to the target vehicle. Exposed loom sections were rewrapped using self amalgamated tape.

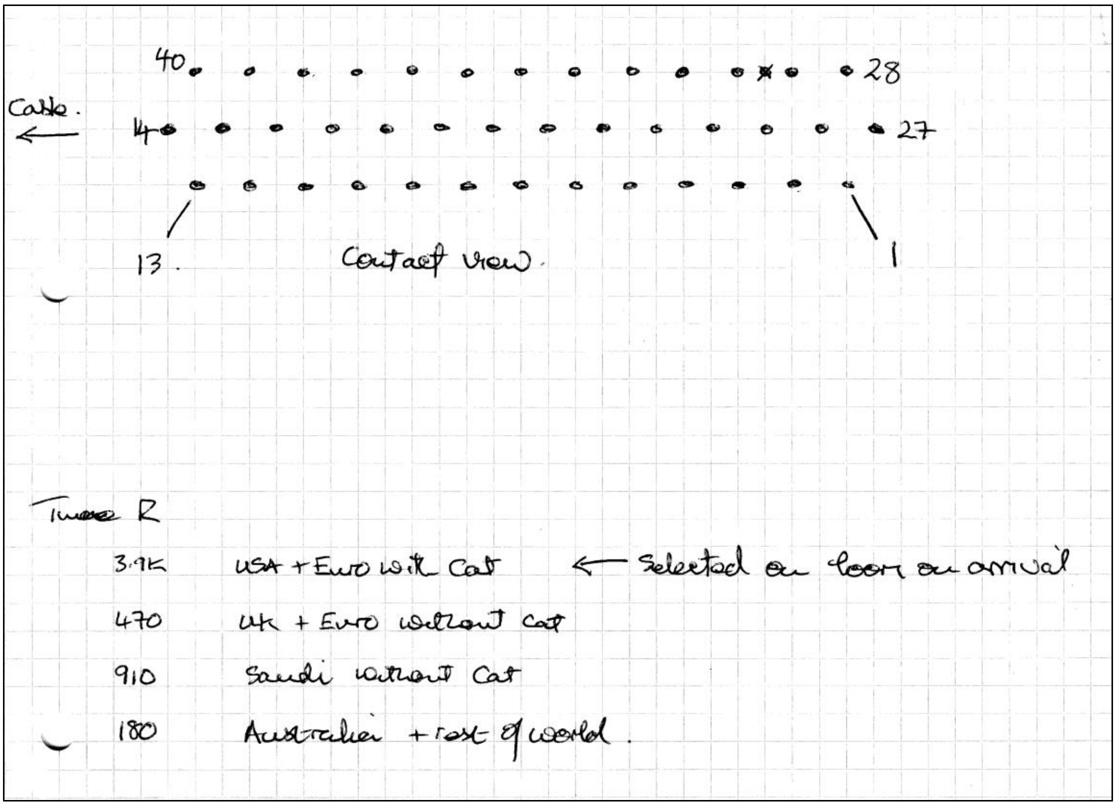


Figure 56 – ECU Connector layout and numbering (and tune R)

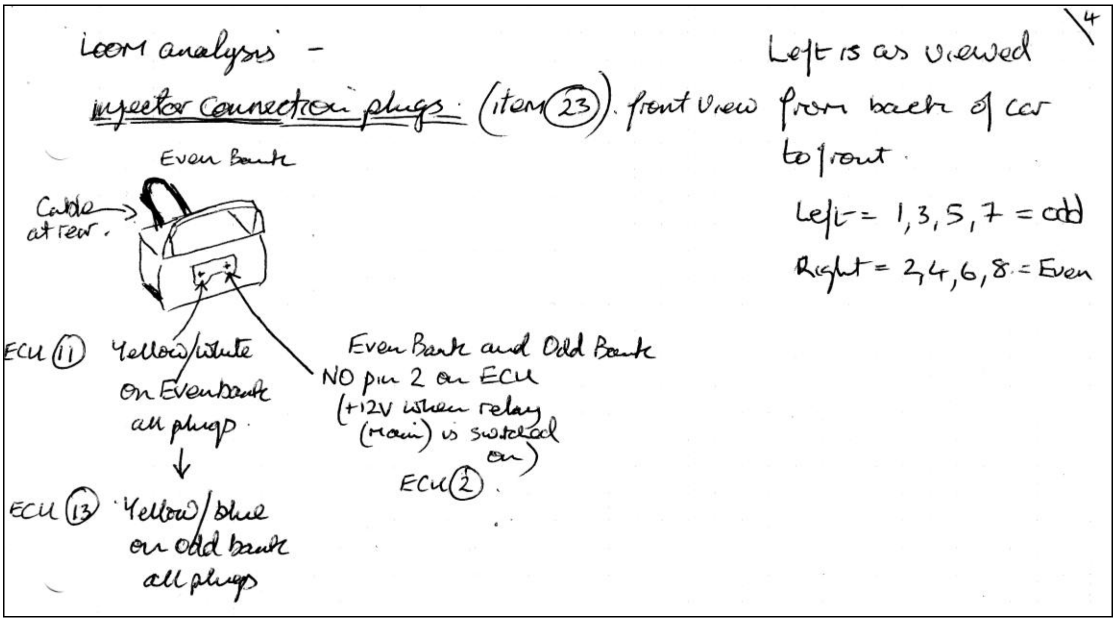


Figure 57 – Injector electrical connectors

Injector wiring is banked as two banks of four (one bank on the passenger side of the engine, and one on the driver side).

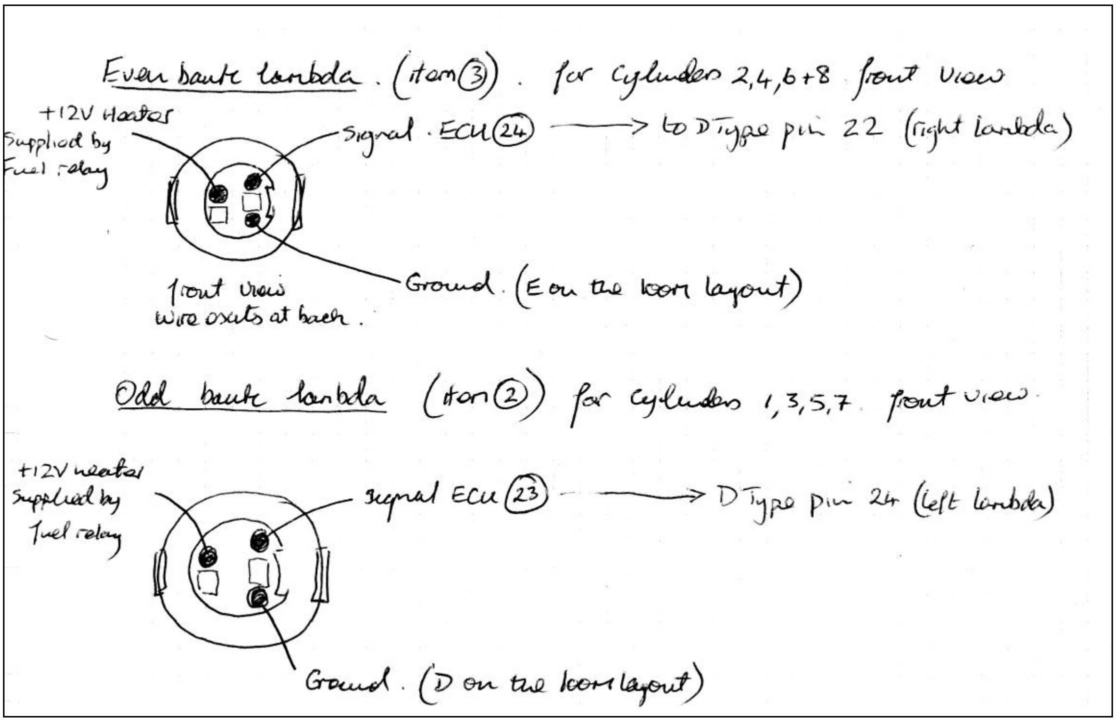


Figure 58 – Exhaust Lambda electrical connectors

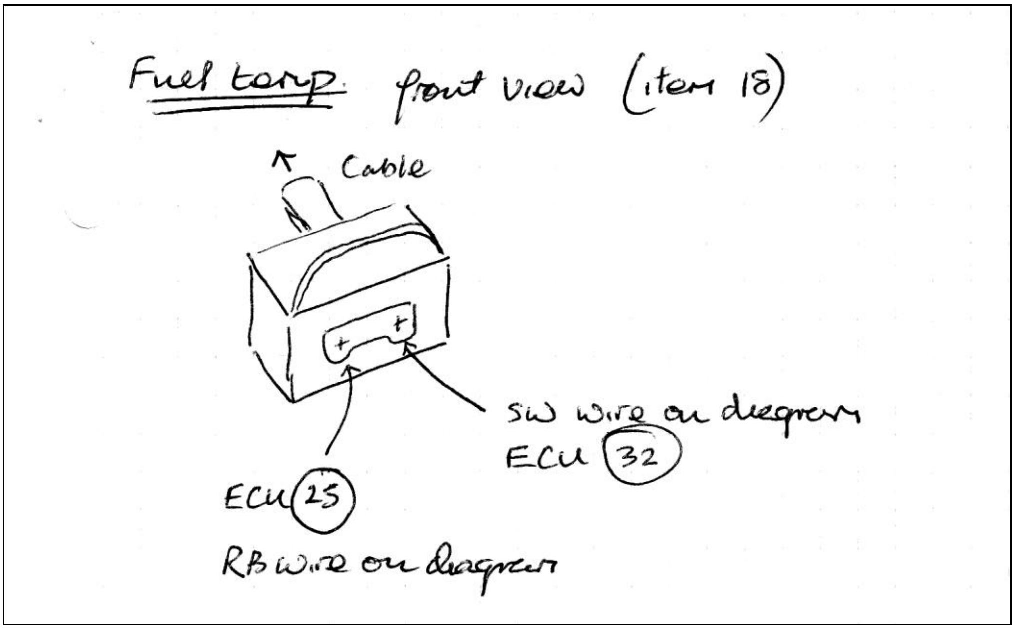


Figure 59 – Fuel temperature sender electrical connector

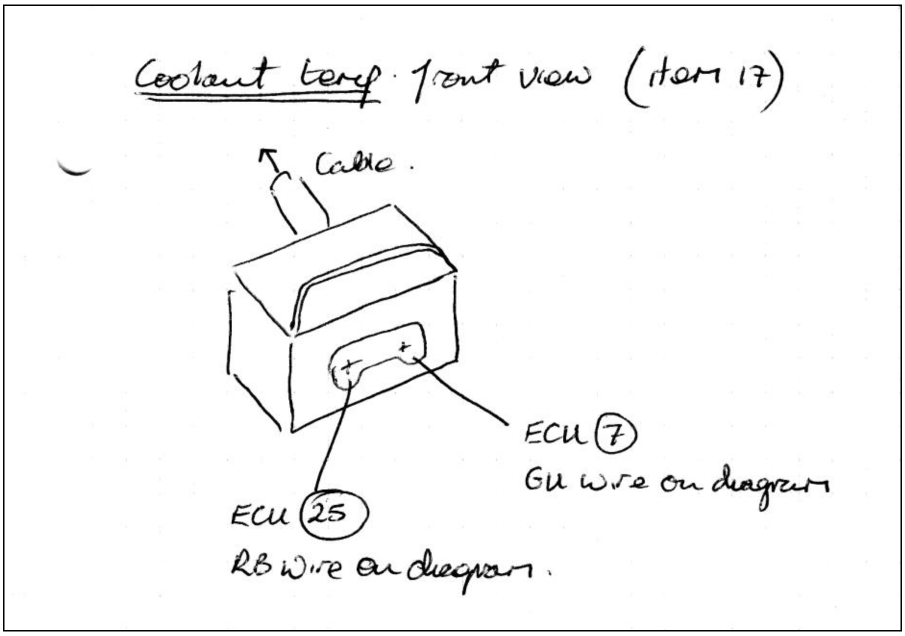


Figure 60 – Coolant temperature sender electrical connector

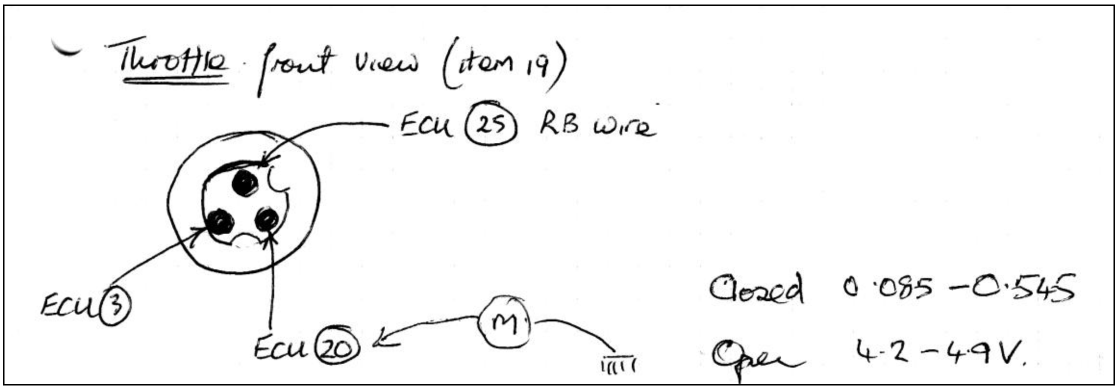


Figure 61 – Throttle position sensor (potentiometer) electrical connector

Note it was found to be difficult to electrically connect to the ECU(20) wire on the back of the throttle plug – therefore a short external wire has been added to the loom extending the red ECU (20) wire to an exposed (but insulated) spade connector just behind the throttle plug. Testing the throttle voltage is then a matter of measuring the voltage between the spade terminal and ground. The test results (after replacing the throttle potentiometer) were 0.45v with the throttle closed, and 4.8v when open – ie: within spec. Note that a code 17 fault will be reported if this test is carried out – requiring an ECU power down to clear.

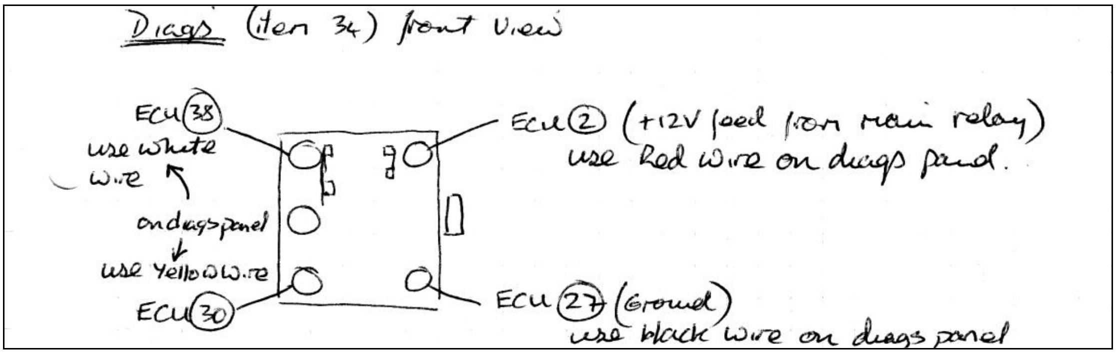


Figure 62 – Diagnostics plug (item 34 in workshop manual) electrical connector

The diagnostic display (located inside the cab) is coupled to this plug.

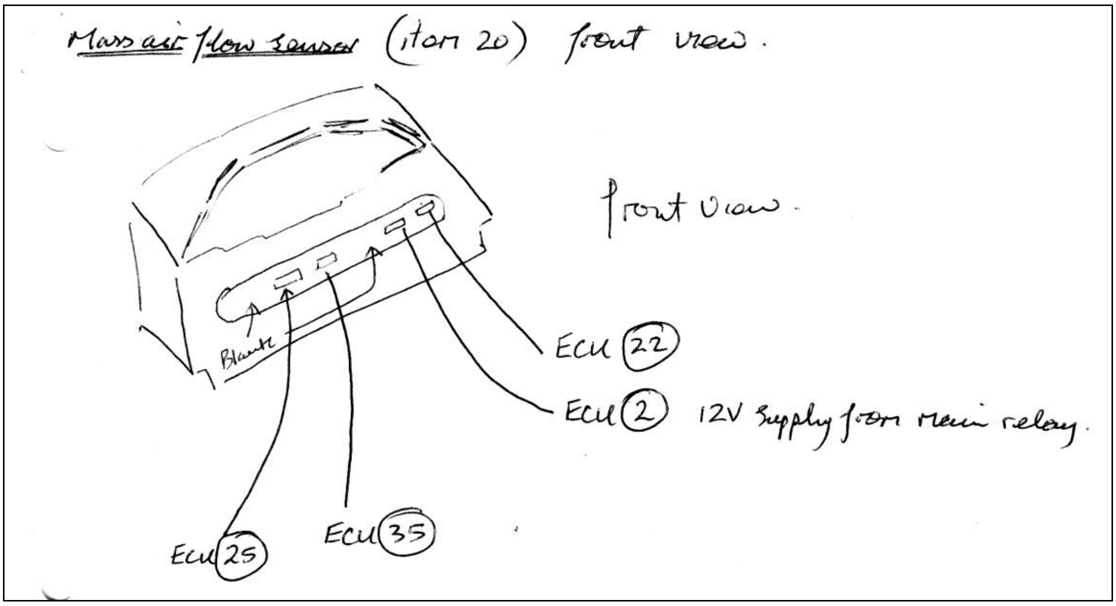


Figure 63 – Mass air flow sensor electrical connector

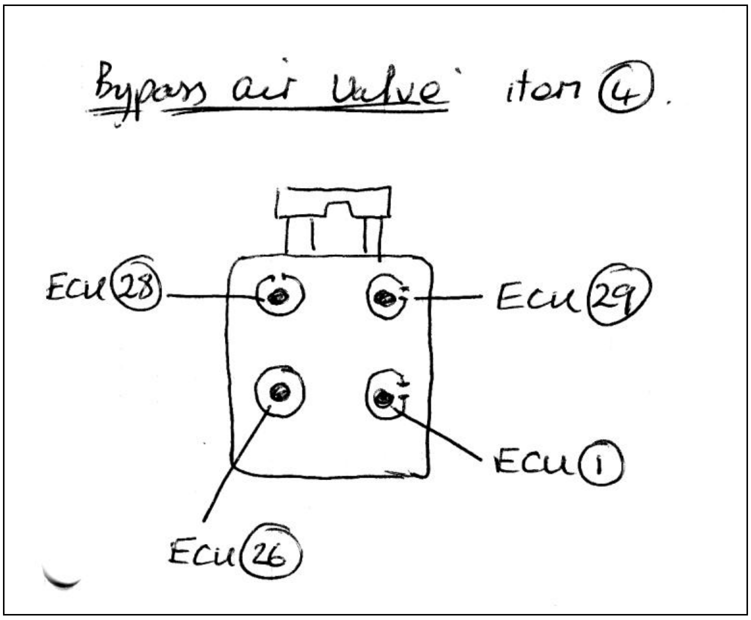


Figure 64 – Bypass air valve electrical connector

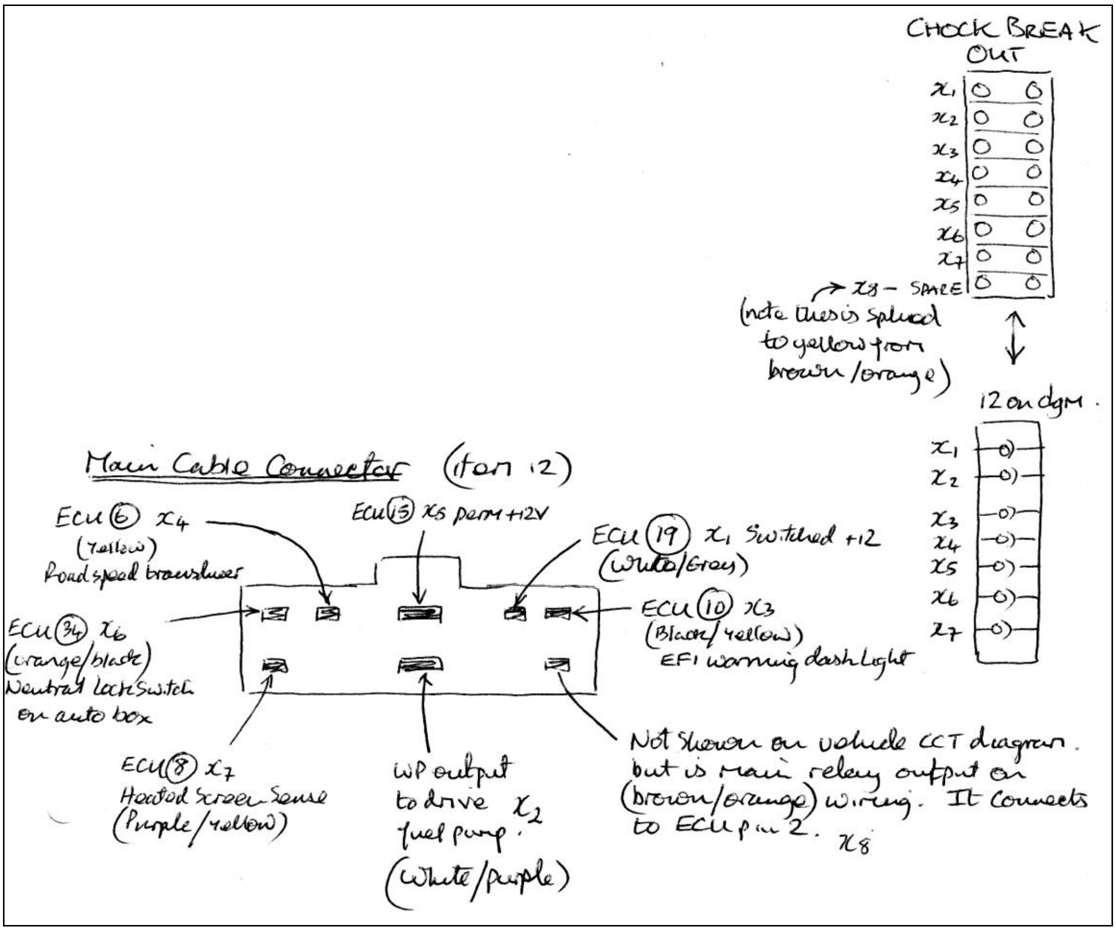
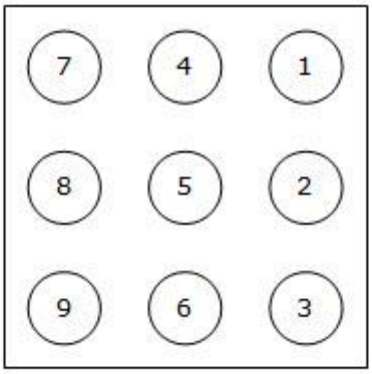


Figure 65 – Main cable connector linking loom to vehicle

The main cable connector was the primary method used to connect the injection loom to the original donor vehicle electrical system. This plug was removed and a new female 9 pin multicore plug fitted as shown below.



Rear view (cable entry side) of the 9 pin female connector.

Numbers are annotated on the connector shell

Pin	Description
1	Ignition switched +12v (input to EFi)
2	Drive to fuel pump (Output from EFi)
3	EFi warning lamp (output from EFi)
4	Road speed transducer signal (Input to EFi)
5	Permanent +12v (Input direct from battery)
6	Gearbox neutral switch (Input to EFi)
7	Heated front windscreen sense (Input to EFi)
8	Not used (ECU Pin 2)
9	N/C

Figure 66 – Main EFi 9 pin connector

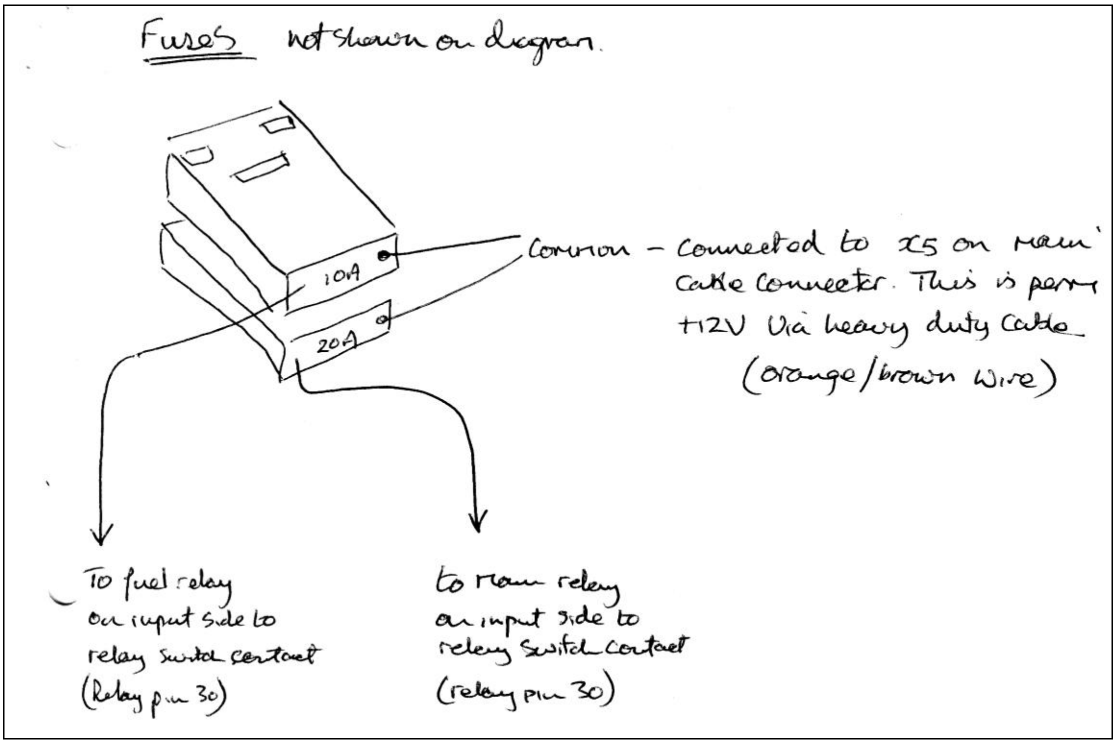


Figure 67 – Original loom fuse arrangement

The original donor vehicle injection loom fuses were heavily oxidised and were replaced using new water proof connectors. Both old and new employed spade style fuses. All connections were soldered.

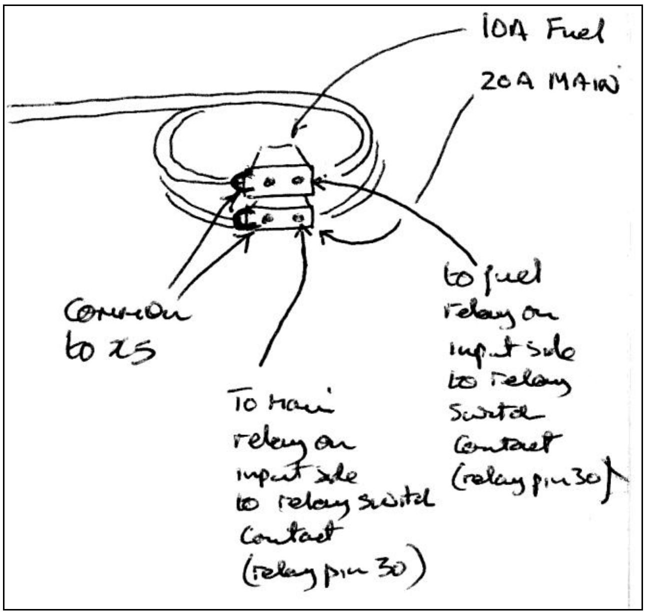


Figure 68 – New loom fuse arrangement

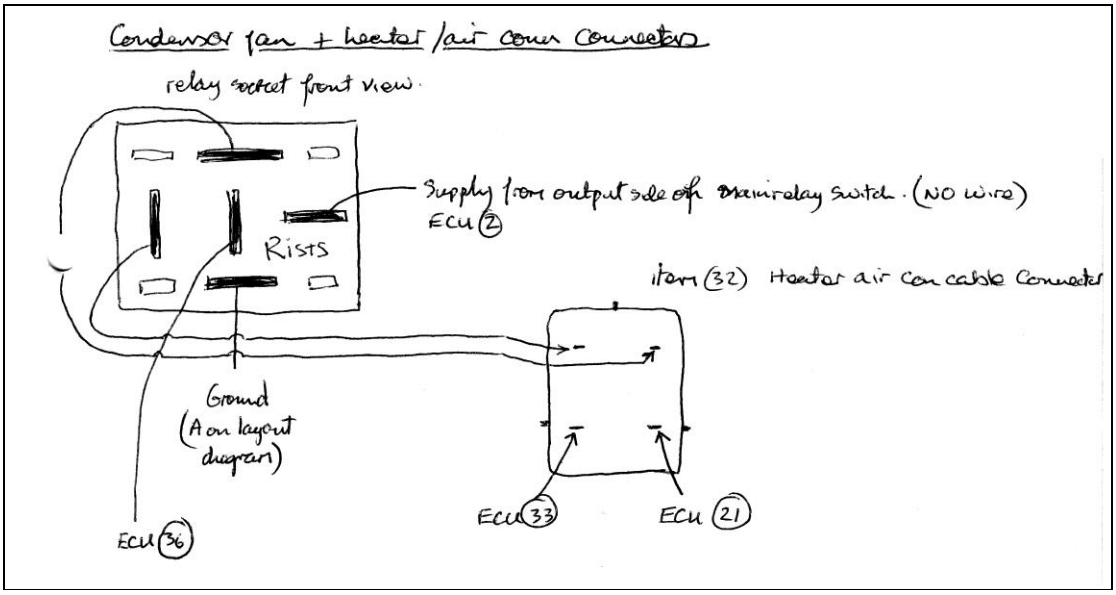


Figure 69 – Condenser fan and heater/air conn electrical connectors

The original wiring loom included a relay and connector to drive and interface to the air conditioning system. The primary motive for linking the two systems is to enable an increase in engine speed when the extra running load of the air conditioning compressor is enabled. As the target vehicle does not employ air conditioning – this circuit is entirely unused. Nevertheless the connections are shown above.

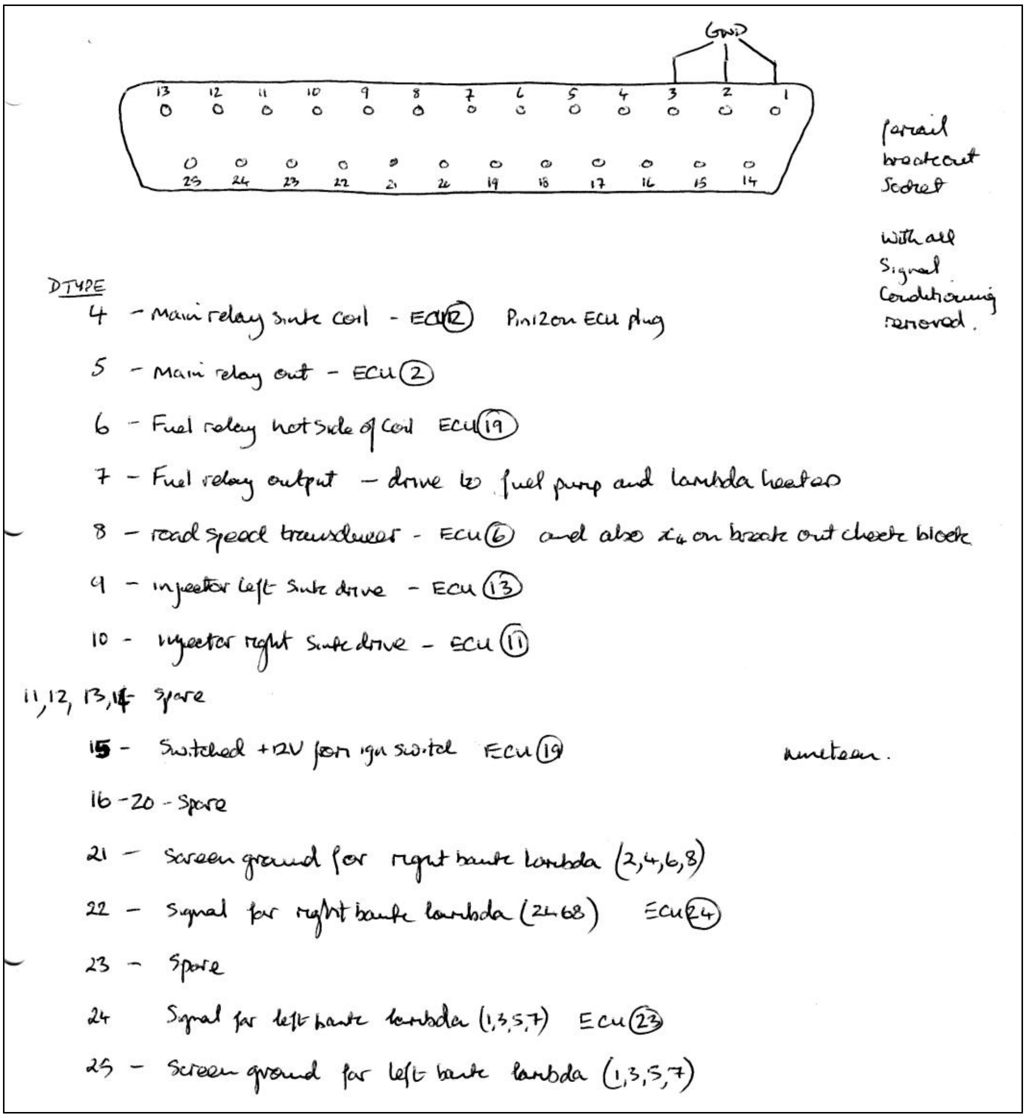


Figure 70 – Break out cable (close to ECU) wiring of 25 way female D

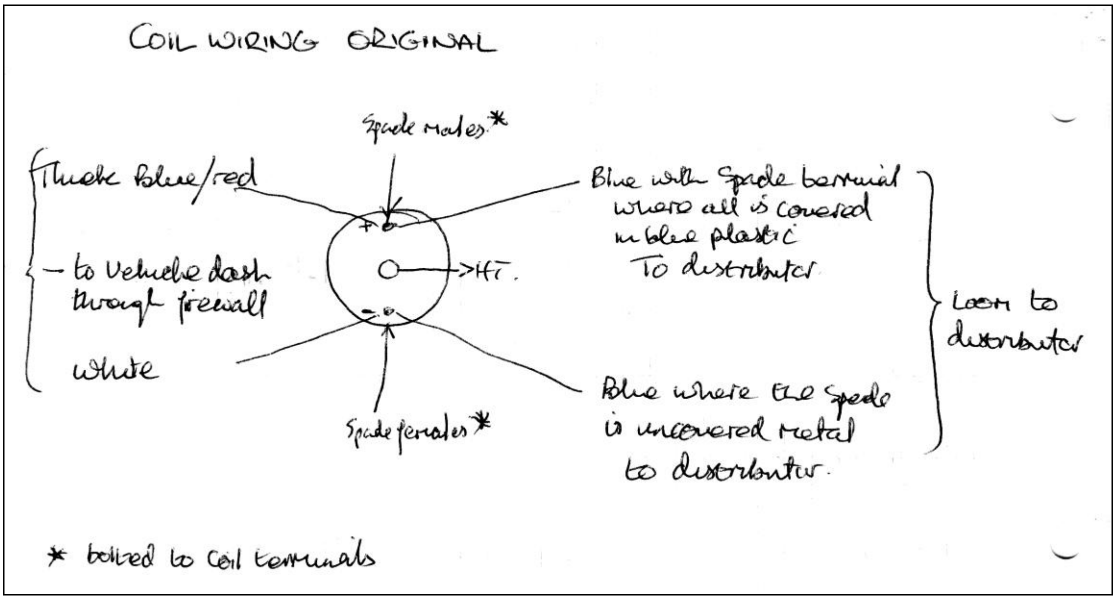


Figure 71 – Original coil wiring (when mounted on firewall)

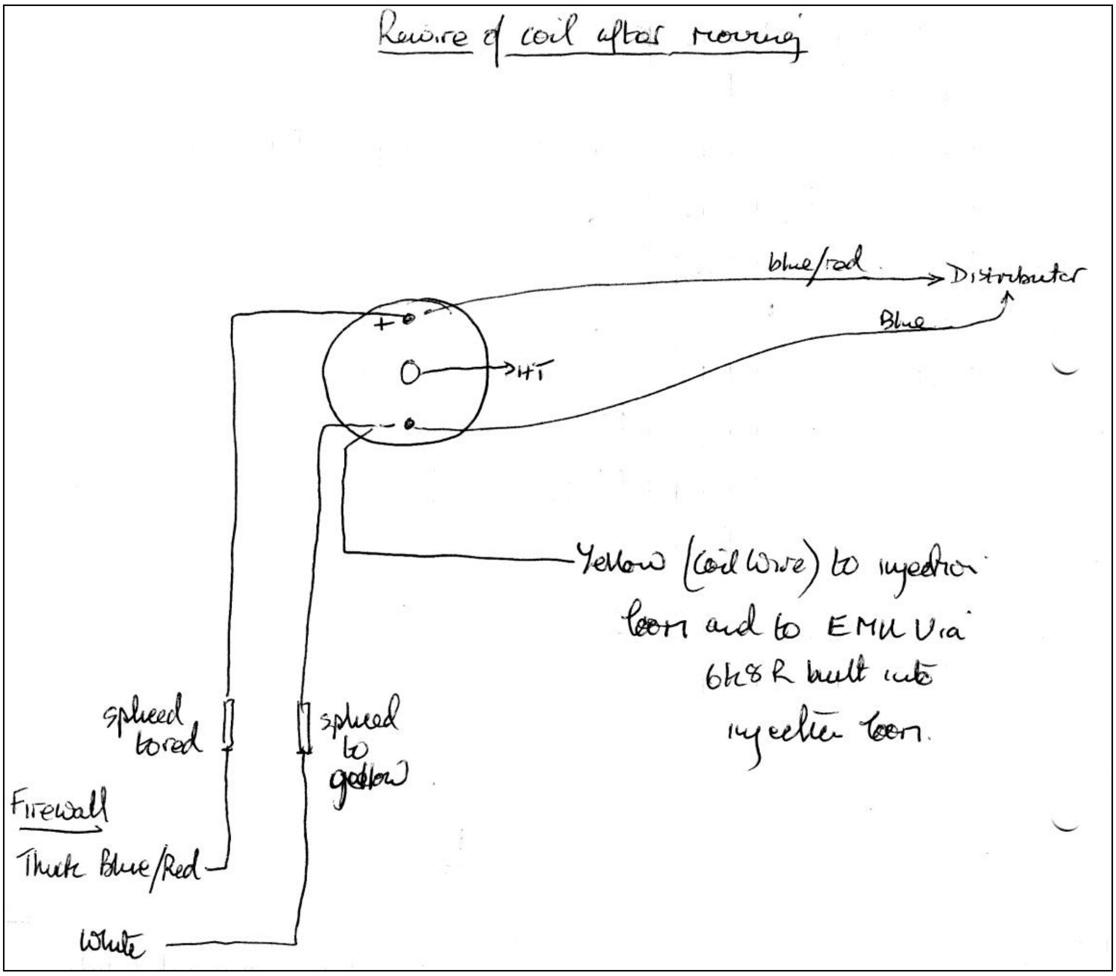


Figure 72 – New coil wiring (when mounted on passenger side fender)

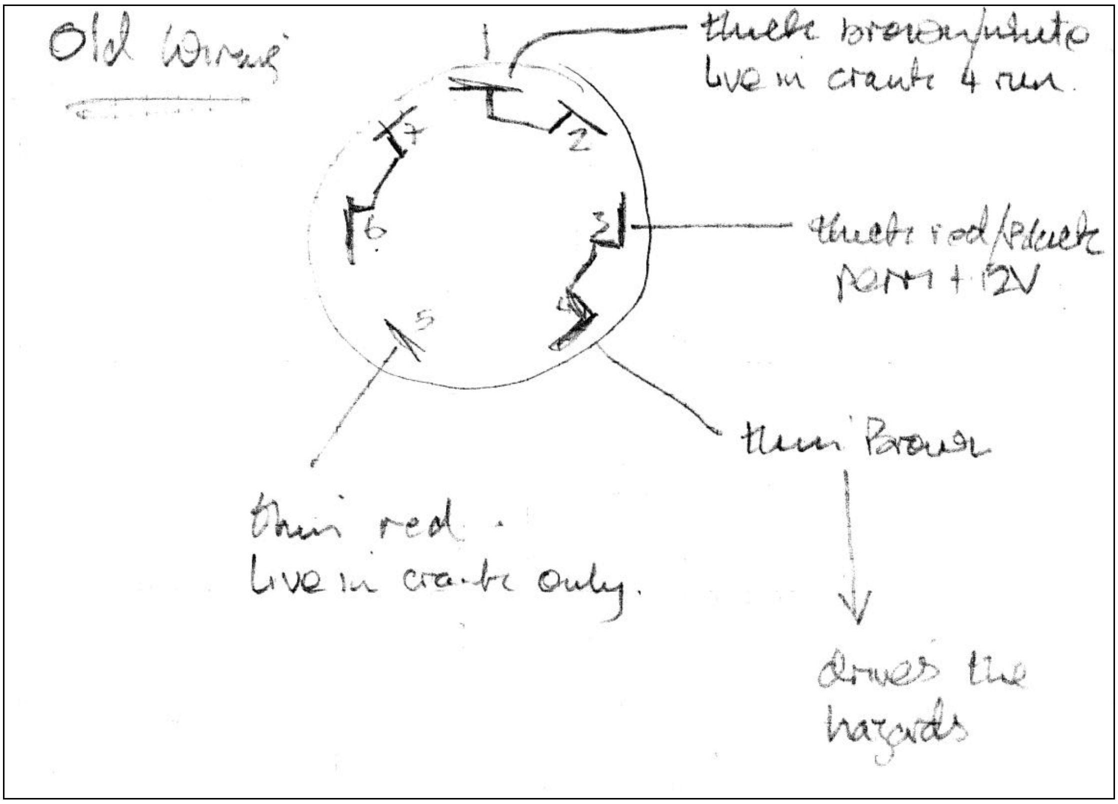


Figure 73 – Original ignition switch wiring

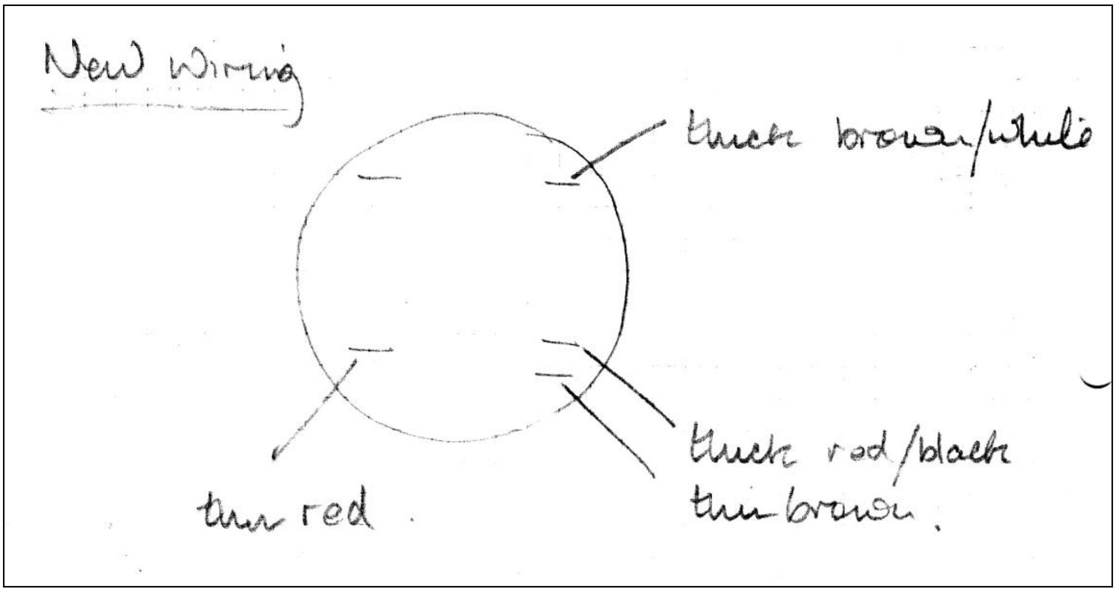


Figure 74 – New ignition switch wiring

Loom analysis results

The bench testing revealed only a small number of problems. The lambda sensor wiring was open circuit (both sides). Also the two active feed wires (not the common feeds) to the injectors had been deliberately cut close to the ECU. It was assumed that the injector wiring had been spliced in the donor vehicle with an immobiliser.

The lambda fault was traced to a splice that had been made in the original loom again close to the cut injector wiring. All four faults were repaired with fresh wiring, and heat shrink. At the same spot, there were a total of six additional wires which had at some time in the past been cut and extended. However, some of the wire joints pulled apart because the soldering was poor quality, and some of the insulation was frayed and damaged. All of this wiring was rejoined using fresh soldered wiring and heat shrink insulation.

After testing had confirmed end to end continuity, the loom plastic outer sheath was removed in order to permit the movement of sensor positions to cope with the new plenum orientation. The main parts of the loom remained intact, but the following items were moved.

1. Throttle position connector was moved from odd to the even bank wiring
2. Coil wiring (with the built in 6k8 R in the loom) was extended
3. Mass air flow connector wiring was extended to the front of the engine

After which the loom was re-taped using self amalgamated tape and small link sections of sticky PYV insulation tape. At the end of that process, continuity was again tested end to end.

Road speed transducer system

The 14CUX uses a road speed transducer module to determine if the vehicle is moving – and if so at what speed. It sits inline with the speedometer cable between the gearbox and the speedometer in the dash binnacle. There are two reasons why this module appears to be required. The first is so that the system can determine if the vehicle is stationary (at which point the lowest idle speed is used). The second is to allow the injection system to limit the top speed of the vehicle.

The 1992 Range Rover application uses a simple chopper disc transducer in a metal module connected inline with the speedometer cabling running from the gearbox to the vehicle dash speedometer gauge. The unit has two electrical wires, which are open circuit, but for every one revolution of the speedometer cable, the wires go low resistance 8 times (400ohms). When correctly calibrated, and fitted into the speedometer cable of a Range Rover vehicle, the road speed transducer *should* produce 6 pulses for every single rotation of the road wheel.

The equivalent circuit of a road speed transducer requires a 4K7 R on one of the wires to ground simulating the loading of the 14CUX input.

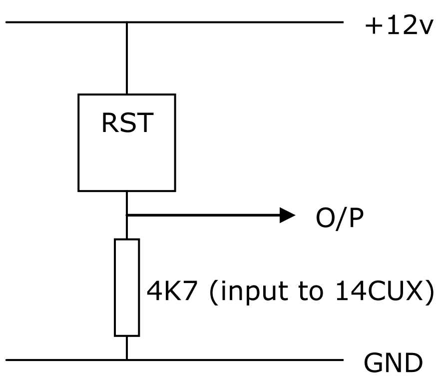


Figure 75 – Road Speed Transducer (RST) Equivalent Circuit

The resulting output signal is remarkably clean, and square with very little bounce extending from the vehicle 12v down to ground. It can be sampled digitally by monitoring edge changes (low to high for example) – and the results are very consistent.

The transducer itself is readily available – but it should be remembered that the unit normally works in a Range Rover Vehicle with a Range Rover gearbox – so the Series III gearbox in the target vehicle does present some challenges. For example new speedometer cables had to be fabricated. The road speed transducer was therefore posted to Speedy Cables Ltd along with the existing single speedometer cable and an explanation of the pair of new cables required. Within 2 weeks the parts arrived.

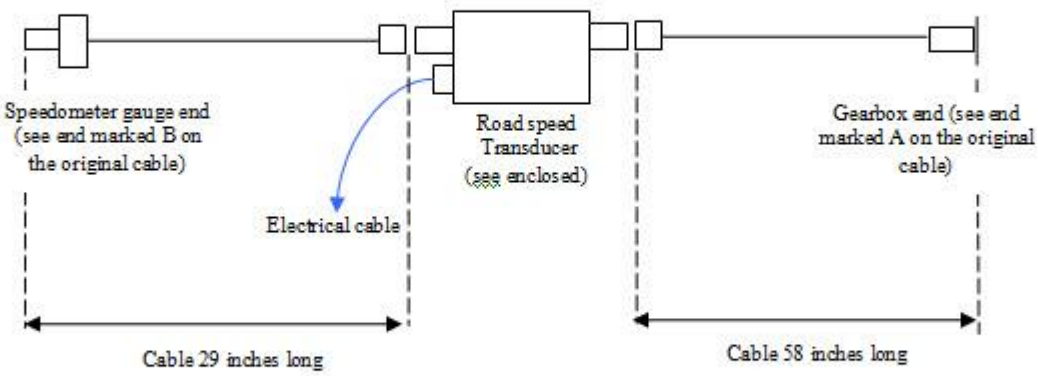


Figure 76 – Road speed transducer speedometer cable layout

Fitting was straightforward with the road speed transducer cable tied to the wiring loom running about 10 inches up the firewall on the drivers side.

Road Speed Transducer Accuracy

After the vehicle injection system had been successfully running for a number of weeks, it didn't take long to realise that there was a subtle problem with vehicle operation. The particular symptom of the problem occurred when the vehicle was slowing – and could be reproduced by cruising at 30MPH on a quiet road and then simply releasing the accelerator and waiting. One would expect the vehicle engine revs to reduce, with a consequential reduction of vehicle speed, ending (eventually) with the vehicle in a fairly slow crawl forward at the lowest idle speed.

Instead, the engine revs remained higher than expected (at about 1200RPM) until the vehicle had to be brought to a dead stop by the driver applying the brakes. The idle speed would only drop from 1200RPM to 800RPM some 2 to 3 seconds *after* the vehicle was physically stopped. In order to slow the vehicle, the driver had to apply the brakes – effectively fighting the engine.

A conjecture for the cause of this problem centred on the accuracy of the road speed transducer – with the most likely cause being that it was misreporting the vehicle speed (too high) to the 14CUX. The 14CUX has a characteristic where engine rev speed will be maintained at higher than the slow idle speed in order to minimise wear and tear during downward gear changes while the vehicle is still moving. It also should reduce the engine speed to its normal slow idle at a threshold road speed of roughly 3MPH or slower. Assume for arguments sake that the vehicle is cruising / decelerating at 40MPH in fourth with the accelerator released. When the driver engages the clutch to change down to 3rd gear, the 14CUX will reduce the revs, but only to the lower limit of 1200RPM, and not to the slow idle speed of 750RPM. This is a compromise in the sense that while it should reduce wear and tear in the drive train, it removes some of the advantage of engine braking. In the case of the subject vehicle – the fault (occurring at walking speed) represents a highly unwelcome characteristic.

The 14CUX testing data sheet confirms that when the road wheel is rotated one time a total of 6 road speed sensor pulses should occur. Knowing the size of the tyres, the circumference can be calculated using 2∏r – which came out to be roughly 92 inches (checked with measuring tape round the tyre).

The vehicle was jacked up at the back and placed securely on two axle stands. The engine was turned on, the hand brake released and first gear gently engaged to rotate the road wheels. A digital speedometer was separately employed to monitor road speed – which at cold idle engine revs was reported at 7-8MPH. An oscilloscope was then connected to the road speed transducer output and the signal measured as follows:-

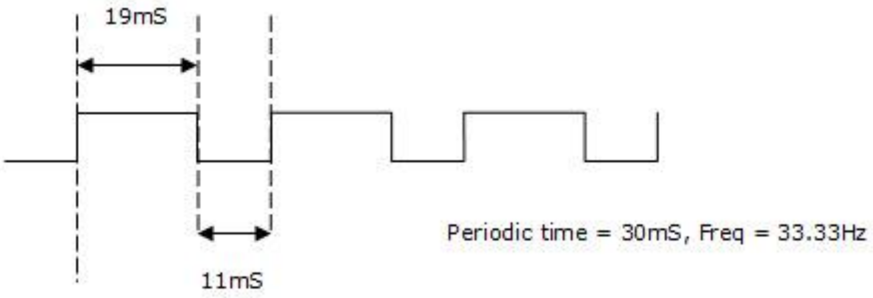


Figure 77 – Road Speed Transducer output at 7-8MPH

The measurement wasn't totally clean – given there was some jitter, but over the course of about 30seconds with a constant engine speed, a periodic time of 30mS was repeatedly measured. The frequency being reported by the road speed transducer at 7-8 MPH was therefore 33.33Hz.

The question then was does a road speed transducer frequency of 33.33Hz correspond to 6 pulses per wheel revolution as the 14CUX testing data says it should, at a road speed of 7-8 MPH?

We know that the road speed sensor is reporting 33Hz, or 33 pulses per second. And we separately know that the actual speed should be 7-8MPH. If we assume that we should expect 6 pulses per wheel revolution, then the wheel is revolving 5.55 times per second (ie: 33/6 - which incidentally looked much faster than was observed).

1. Wheel circumference is approximately 92"
2. There are 63360 inches per mile
3. With 5.5 revs per second, we get 92 x 5.5 = 506 inches per second of forward travel for the vehicle
4. Or 30360 inches per min
5. Or 1821600 inches per hour
6. Or 1821600/63360 = 28.75 MPH

Given that we know the vehicle speed should be 7-8MPH (lets assume 7.5MPH), then 28.75 / 7.5 = 3.83 – which means that the road speed transducer is misreporting the vehicle speed too high, by a factor of 3.8 times.

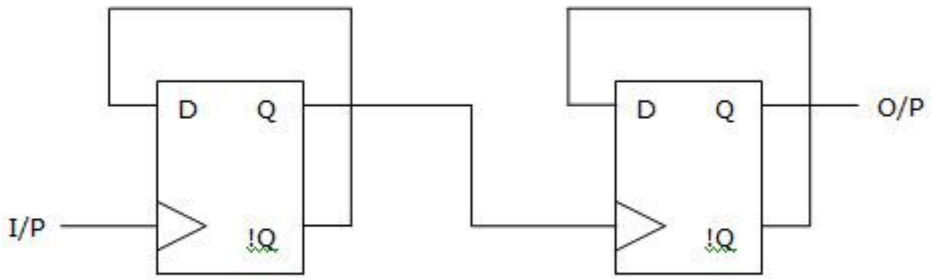
This certainly did explain the problem.

To check our calculations, work the problem the other way round. Assume the vehicle is travelling at 7MPH, how many wheel revs per second should we expect?

1. At 7MPH, the vehicle is travelling at 7 * 63360 = 443520 inches per hour
2. Or 443520/60 = 7392 inches per min
3. Or 7392/60 = 123.2 inches per second.
4. Knowing the wheel circumference is 92 inches, then 123.2/90 = 1.3391 wheel revs per second.
5. Knowing that we should expect 6 pulses per wheel rev, then we should expect to see a pulse frequency of 1.3391x6=8.03Hz.

Instead, we're measuring a pulse frequency of 33Hz – ie: again, a 4x error.

So – in order to fix the problem, we have to take the existing road speed transducer output, and interrupt it by passing through a black box capable of dividing the signal frequency by 4, and then pass that out to the 14CUX. As it happens that was much easier than it might sound. A divide by 4 circuit is trivial requiring just two D type flip flops eg:



A possible solution based on a TTL 7474, which would require a regulated 5v rail, input conditioning and a Darlington pair driver for the output.

Figure 78 – A possible divide by 4 solution

On the project vehicle, a small monitor system had been already constructed by the author consisting of two electrically linked diecast boxes. The first box houses a microprocessor with high impedance input conditioning circuitry and which is connected to the injection wiring loom via the connector shown in figure 57. A second 9 way screened cable connects the first processor box to a second box which is mounted close to the driver to the left of the dash board and which contains a backlit LCD panel with a character display (21 chars wide and 8 lines high).

The CPU used in the processor box is a PIC 16F877 selected primarily for its large I/O capability. The box includes voltage regulation, some TTL glue logic, and 8 op amps designed to present high input impedance to the signals on the injection loom.

The hardware and software on the monitor was constructed entirely by the author, and was designed to monitor a number of aspects of the injection system including the state of both lambda probes, the state of the main and fuel relay, and the road speed.

The CPU operating environment is interrupt driven based on a master oscillator frequency of 8Mhz. Processor interrupts occur every 1.024mS, and the I2C bus used to drive the LCD panel uses a base frequency of 100Khz, which works well over the 2.5mtr screened cable leading up to the dash. The system takes inputs from the left and right injector sink sources, but actually doesn't display any information on those two signals. It reads assorted relay signals, both lambda probe signals (via two screened cables) and the road speed sensor signal.

The ability to monitor the state of both of the 14CUX lambda signals turns out to be one of the best indicators of overall engine operation. It is, without doubt a very useful pair of signals to be able to see.

The solution to the misreported road speed signal therefore involved the following steps.

1. The wire from the road speed transducer was cut from the normal 14CUX loom, and connected to the existing road speed transducer input in the monitor box, but using a new previously unused pin 13 of the 25 way D type shown in figure 57.

2. The monitor box reads the road speed sensor and uses edge detection to calculate the speed of the vehicle and display this as a MPH value

3. Now, in addition to the MPH display, the software also employs a mod 4 counter to divide the road speed signal frequency by four – driving an output on processor I/O pin RD0.

4. RDO is connected via a darlington pair transistor driver to pin 8 on the 25 way D type shown in figure 57 – which off course connects to the road speed signal in the loom – thereby feeding the 14CUX with a new modified road speed frequency.

The darlington pair circuit is simply a very high gain amplifier. It is used to convert the 5V swing of the CPU, to a full +12v (actually nearer 13.8V once the alternator is running) voltage swing suitable for input to the 14CUX. The circuit is shown below.

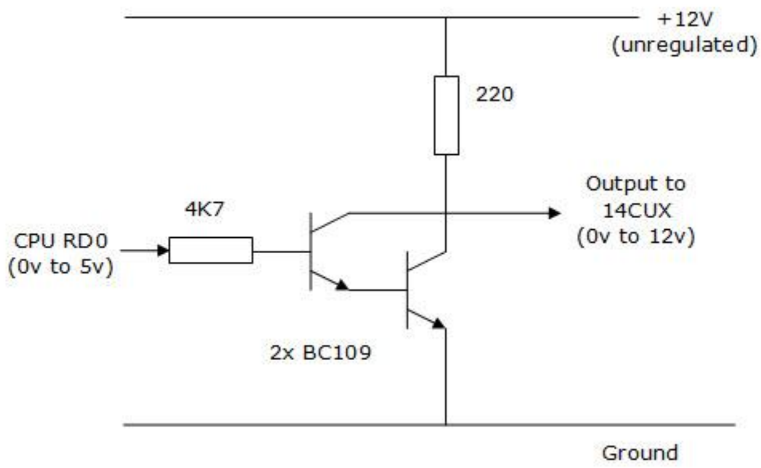


Figure 79 – Darlington pair high gain amplifier

Initial tests were good. On the initiation of a road test, it became clear that the 14CUX now treats a road speed of 3MPH as a threshold below which engine idle speed will reduce to slow idle. This eliminates the odd delay in reducing engine idle whenever the vehicle was brought to a stop. The system now operates as it should.

However, even with this threshold correctly set, the vehicle still *feels* less than optimal. It is all too easy to cruise to a stop at a set of traffic lights at say 5 or 6MPH, only to be faced (again) with the need to brake to overcome an engine revving slightly too high, because the road speed threshold has not yet been reached. It continually reminds the driver that the threshold may be in fact too low. During one test the land rover happily sat at a speed of 5-6MPH in 1st gear with no acceleration on a private road going up hill for 100 yards. It felt decidedly odd.

It is not abundantly clear why this 3MPH threshold is built into the 14CUX system. Few, if any fuel injection systems behave the same way. The Bosch approach may be in part due to the relatively slow operation speed of the idle circuitry – or it may be a reasonable compromise to cope with production variation across a large production base. After some testing, it was found that switching to low speed idle would better occur whenever the road speed reduced below a threshold of 12MPH instead of 3MPH. As the divisor required to correct the road speed sensor was currently 4, an extra division by 4 (a total divide by 16) would be suitable. The system monitor box counts low to high edges incoming from the road speed transducer. Now, whenever the count reaches 8, the control unit asserts the signal to the 14CUX road speed input. Similarly, whenever the count reaches 16 the control unit negates the signal fed to the 14CUX and also restarts the edge counter. In this way – the 14CUX road speed receives a further division by 4, which means that it will think the vehicle is moving at 3MPH when in fact it is at 12MPH. The solution is under test now but preliminary results are rather good, with a much more intuitive seat-of-the-pants feel to vehicle operation.

One final comment is worth making. A reader investigating this problem will inevitably stumble across a number of Internet comments suggesting that the road speed sensor can either be eliminated or replaced by a fixed frequency pulse unit when installing a 14CUX system. Unfortunately, neither suggestion is true.

The 14CUX does require a road speed input (it will error if it does not get a suitable road speed signal). However, during normal operation, the 14CUX splits the available range of frequencies incoming from the road speed sensor into three bands – which are…

1. Road speed below the threshold (usually 3MPH) – the 14CUX employs a slow idle whenever the throttle is released.
2. Road speed above the threshold (usually 3MPH) – the 14CUX employs a high idle whenever the throttle is released.
3. Road speed is above a second high speed threshold (ie: at the top end of the speed range of the vehicle) – in which case the injection system limits the overall top speed.

With the above 3 points in mind, a possible solution (adopted by TVR) would be to provide a fixed pulse frequency of say 30Hz or thereabouts (satisfying the second and third requirements), but which only actually generates a signal when the road speed exceeds 3MPH. At a road speed below 3MPH, the signal would cease (either remaining low (ground) or high (+12v) – makes no difference).

Mounting ECU and main + fuel relays

A metal structure was constructed from sections of narrow gauge steel and angle iron to form a base in which the injection control box could tightly sit. This was screwed to mounting positions in the battery box under the passenger seat. The 14CUX frame clears the positive terminal of the battery by roughly 2 inches. Both main and fuel relays are mounted to the box frame using thin strip aluminium.

Fitting the wiring loom

The fitting process took just under a day to complete. The wiring required some clamps and supports to be fabricated, and copper ties were used in the exposed areas under the chassis. With the 14CUX mounted under the passenger seat, the loom wiring exits the battery box via a grommet lined large diameter hole. It then passes over the top of the gear box and on to the driver side of the vehicle where it turns sharp left to head towards the engine. As it passes under the chassis before the firewall it is clamped via two copper ties until it reaches the firewall. At that point it heads directly upwards while being tied tightly to the wall (in order to avoid the exhaust components). At the top of the firewall at roughly the same height as the rear of the drivers side engine rocker cover, the loom splits into three sub parts. The first is the wiring used to drive the even bank of injectors and which runs straight down the plenum side. The second is the even bank lambda sensor connector which hangs at that point with roughly 10 inches of cable slack, and the third is the wiring used to pass over the transmission tunnel.

That third section of the wiring extends for about 12” as one solid loom as it passes over the transmission tunnel before itself splitting into two further sub parts. The first is the odd bank lambda sensor connector which again hangs at that point with roughly 10 inches of cable slack, and the second is the section of wiring used to drive the odd bank of injectors.

The arrangement of the cabling round the injectors and various sensors is cable tied where appropriate.

Fitting the 14CUX diagnostic reader

The 14CUX does have a limited diagnostic capability. It is capable of driving a two digit display in order to announce fault codes. If the display is empty – the system is running correctly.

The 14CUX system on the donor vehicle did not include a fault display and unfortunately, Land Rover no longer manufacture these units. However, a company called Steve Heath Engineering Ltd does manufacture very good quality readers which saved the time required to analyse and interface to the serial communications link from the 14CUX control unit.

The Heath Engineering display is shipped with a cable employing an inline connector which breaks out to four push fit pins designed to insert directly into the standard 14CUX diagnostics plug as follows:-

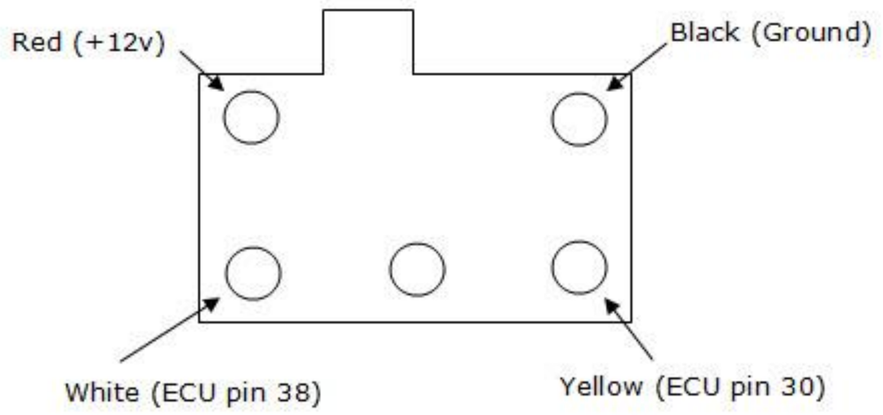


Figure 80 – Wiring the diagnostic display into the loom plug

Using the diagnostic reader

First the reader must be used in “connect” mode by pushing the switch away from you. Turn on the ignition, at which point the status LED (the DP on the seven segment display) will illuminate. If any error code is stored by the 14CUX it will be displayed now.

You can easily simulate a code 15 error by disconnecting the fuel temperature sensor.

Clearing error codes can be done in two ways. The ECU can be powered off by disconnecting the main harness connector. This will reset the ECU and clear all fault information. A second method will clear the current fault and then display the next one (when there are multiple faults). The procedure is repeated until no more codes are displayed. The procedure is as follows:-

1. Disable the immobiliser
2. Switch the ignition on
3. Disconnect the fault code reader by throwing the switch on the box. The status LED and any code will go out. Wait 5 seconds, and then reconnect the box by throwing the switch into the connect position.
4. Switch the ignition off and wait for the main relay to drop out (a good 5-10 seconds).
5. Disable the immobiliser
6. Switch the ignition on
7. The display will either display the next fault code, OR will be blank (when all fault codes have been shown). Repeat steps 3 to 6 until all codes have been seen.

If a fault causing a code isn’t rectified, then the code will continue to be seen. On first sight it may seem that the code isn’t being cleared – whereas it actually is being cleared but the 14CUX is continuing to see and report the same fault code.

It is also worth understanding that some codes can’t be cleared by anything other than a full power down (removal of the main harness plug).

Fuel cut off – inertia switch

The injection system relies on a constant fuel pressure feed rated at approximately 3 bar. In terms of open flow rate, that equates to 135 litres of fuel flowing per hour, or 2.25 litres per minute. The risk of an accident rupturing the fuel lines but leaving the fuel pump powered represents an obvious threat. As a result Range Rovers were fitted with inertia switches mounted inside the vehicle, on a solid part of the frame. In the event of an accident exhibiting sufficient levels of stopping G force, the inertia switch activated and disconnected the fuel pump.

If the inertia switch false triggers, it is a simple matter to push in the activation button in order to reset it. This switch is wired directly in line with the fuel pump.

The target vehicle employs the same precaution using an inertia switch specified for the donor vehicle.

A range rover inertia switch has been bolted to the B pillar directly behind the front passenger seat back rest. It is mounted button up with its back surface parallel to the side of the vehicle. It is wired in line with the supply feed to the fuel pump and interrupts that connection if a sufficiently violent impact occurs.

Appendix A – 14CUX Fault Codes

Code	Meaning	Comments
02	Live +12v supply to ECU has been disconnected	Normal code that appears whenever the ECU is first reconnected. Code 02 will clear when ignition is switched off, the main relay is allowed to release and the ignition is switched on again.
03	Stored data corrupted since last trip	No useful information available. Test drive and try again
13	Air flow meter out of range	Possible air leak or wiring fault
14	Coolant thermistor out of range	Faulty sensor or wiring
15	Fuel thermistor out of range	Faulty sensor or wiring
17	Throttle sensor out of range	Sensor needs adjustment, is faulty, or has wiring fault. This can cause low speed misfires and can also prevent the system setting low idle speed.
18	Throttle sensor output too high when air flow low	Large air leak between throttle butterfly and A/F meter or faulty throttle sensor or A/F meter
19	Throttle sensor output too low when air flow high	Faulty A/F meter or throttle sensor
21	Tune resistor out of range	Check tune resistor and wiring
23	Low fuel pressure	Blocked fuel filter or faulty pump or pressure regulator. Valid for cat cars only
25	Misfire at full load	Faulty plugs, leads, electronic ignition unit, distributor or coil, low fuel pressure or valve or head gasket leak. Valid for cat cars only. The lambda sensors have detected an emission fault which could be caused by almost anything in the ignition and injection system. If this is code 40 or 50 it will indicate which side of the engine the fault is (but be aware this can be misleading if the lambda sensors are faulty).
26	Very lean mixture	Lean or misfire condition. Probable causes are a faulty low or out of range lambda sensor or an ignition fault causing a misfire. This code is generally only used on the jaguar implementation of the 14CUX and is generally not listed under the Range Rover fault codes.
28	Air leak	Check for air leaks in the following areas • Hose, air flow meter to plenum • PCV • Brake servo hose • Distributor advance/retard pipe • Injector seals • Any other joints and seals
29	Checksum error	ECU has failed its internal self test. If detected, any other codes are unreliable.

		Try powering the ECU off. If the fault continues, then the ECU must be replaced.
34	Fueling fault in nearside injector bank	Injector or lambda sensor wiring fault, faulty injectors, air leak at injector seals or intake manifold, blocked injectors. Valid for cat cars only on cylinders 1,3,5 and 7
36	Fueling fault in offside injector bank	Injector or lambda sensor wiring fault, faulty injectors, air leak at injector seals or intake manifold, blocked injectors. Valid for cat cars only for cylinders 2,4,6 and 8
40	Misfire on nearside bank	Misfire has occurred on cylinders 1,3,5 and 7. Valid for cat cars only (see code 25 for more details and suggestions)
44	Nearside lambda sensor out of range	Faulty or lead-poisoned lambda sensor. Valid for cat cars only. If codes 45 and 45 appear then the likely cause is the heater wiring for both lambda sensors.
45	Offside lambda sensor out of range	Faulty or lead-poisoned lambda sensor. Valid for cat cars only. If codes 45 and 45 appear then the likely cause is the heater wiring for both lambda sensors.
48	Stepper motor (bypass air valve) fully open below 500RPM or fully closed above 750 RPM	Sticking stepper motor valve, incorrect base idle speed adjustment, air leak on non cat cars, incorrect stepper motor adjustment, incorrect throttle butterfly adjustment, rough running (due to fuel, ignition or mechanical faults) and finally a faulty road speed transducer can cause this problem. Note that low fuel pressure can cause this problem especially if it causes the engine to stumble at idle or very low speed.
50	Misfire on offside bank	Misfire has occurred on cylinders 2,4,6 and 8. Valid for cat cars only (see code 25 for more details and suggestions)
58	ECU unable to distinguish between faults 23 and 28	Fault occurred for an insufficient time for ECU to correctly diagnose.
59	Fuel thermistor our of range	Fuel thermistor fault – but be aware that in some documentation code 59 is described as code 58.
68	Road speed sensor output too low at medium RPM and high air flow	Possible sensor or wiring fault. Valid for cat cars only
88	Power up check	Two interpretations for this. For non cat cars, the code is shown on power up but isn’t a code. For cat cars it is used to show that there is a purge valve fault with the evaporative emissions carbon canister system.

Appendix B – Final notes, comments and links

- Engine thermostat must be a 74 degrees C part with no joggle hole
- Engine air filter is standard range rover 1992 part number RTC 4683
- Bypass air valve is standard 1992 range rover part
- Throttle potentiometer is standard 1992 range rover ETC 8495 part
- As described above the PCV system connects to the plenum vacuum source via a 2mm drilled orifice. This is additional to the plastic PCV T piece supplied by land rover which has a 3mm restriction orifice.
- 14CUX workshop manual link: www.conehead.org/landrover/14cux_fuel_injection.pdf