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Fuel Injection for the 5 Port A-Series

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Version Control

Version	Date	Author	Comments
Draft	December 2009	Paul S	1st Draft
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Purpose of this Guide

This document is intended to provide specific guidance on the application of Fuel Injection to the A Series engine with a 5-port cylinder head using the Megasquirt ECU and the latest MS2/Extra software.

It is not intended to provide general guidance on Fuel injection. There are a number of books on the subject that provide some very useful general information such as Dave Walkers book. It is also recommended that you first read the Megamanual to get a basic understanding of the workings of the ECU.

Basic Principles

So what's different from a carburetor?

Many have tried to fuel inject the A-Series but few have delivered success. The factory first developed the SPi system i.e. Single Point injection and lastly the MPi i.e. Multi Point injection. The term Multi Point refers to port injection which involves a controlled injection of fuel for each cylinder.

To understand the problems of port injecting the A-Series, it is first necessary to understand some basic features of fuel injection:

Fuel is delivered by injectors, fed at high pressure. An Electronic Control Unit (ECU) controls the opening and closing of the injectors to meet the demand of the engine. The ECU calculates the fuel requirements from the speed of the engine, the inlet manifold pressure/vacuum and the air temperature. Hence, the ECU delivers the correct amount of fuel to create the optimum Air Fuel Ratio (AFR) within the cylinder.

The injectors fire slugs of fuel into the inlet manifold, unlike a carburettor that continuously adds fuel to the air stream. This slug of fuel does not have a chance to atomise within the manifold alone and hence does not fully mix with the surrounding air before entering the cylinder.

In a conventional 4 cylinder engine with four inlet ports, the slug of fuel is delivered to each cylinder once every engine cycle: 2 revolutions which include the 4 strokes - intake, compression, combustion and exhaust. Most OEM fuel injection systems fire all four injectors at the same time irrespective of the current stroke of the cylinder. It doesn't really matter as the correct amount of fuel will go into the cylinder, either from this slug, the preceding one or the next. As long as the injectors fire the correct amount of fuel it will get into the cylinder.

The difficulty with port injecting the A Series is that the intake ports are siamesed, so cylinders 1 & 2 share an inlet port as do 3 & 4. Let's call the ports A & B. The firing order of the A Series is 1342 which can be written 2134, same thing. Hence the inlet ports feed two cylinders in quick succession AABB. Each intake port sees two intake strokes, inner cylinder then outer cylinder during a single revolution of the engine and then nothing in the next revolution and so on.

Hence, a slug of fuel fired into the inlet port arbitrarily has a 75% chance of going into the inner cylinder and only a 25% chance of going into the outer cylinder.

It then follows, that the only way to ensure that the outer cylinder gets enough fuel is to deliver the precise amount of fuel over a very short period at a particular point in the engine cycle.

Going back to the conventional engine, the injectors are normally sized to open for up to 80% of the engine cycle i.e. more than 3 of the 4 strokes. The A-Series has only a very short window to inject the outer cylinder, so the injectors need to be rated to deliver in around 20% of the engine cycle, four times larger than normal conventional engines.

To ensure that the fuel enters the cylinder at the precise point, the ECU needs to know at which point of the engine cycle each cylinder is at. This is achieved with a Phase Sensor in addition to the usual crank speed sensor. As the cam rotates at half the engine speed, the cam signal can set the injection point to the correct stroke.

The ECU then needs to be able to time the injection to a precise point, much the same as ignition timing. Very few ECUs have this ability, but the Megasquirt MS2/Extra code now has this facility thanks to the work of Jean Belanger of jbperf.com and the TurboMinis.co.uk forum.

Main Hardware

ECU

The choice of ECU in this instance is the Megasquirt MSII unit. This is because the Megasquirt ECU offers the option of user development of the hardware and firmware to suit specific needs. It is this feature that has enabled code modifications by the TM Forum to suit the specific requirements of the A Series engine.

The specific option selection and build guide are detailed in the Megamanual.

Typically, the ECU would be configured with two ignition drivers, cam sensor input and dual wideband input. Options for injector drivers are detailed below.

Inlet Manifold

The simplest induction arrangement is a dual runner and plenum style manifold configured to accommodate the injectors, sensors and controls. However, at the time of writing, these are not commercially available.

A solution for naturally aspirated or low boost turbo applications could be to use the Rover MPi manifold, suitably modified to accommodate Megasquirt compatible sensors and controls.

For a custom build manifold consideration should be given to the number of injectors required to deliver sufficient fuel for the required power output. Also runner length should be chosen to suit the engine application. Shorter runner lengths will suit race engines, whereas longer runners will help in delivering peak torque at lower revs.

The manifold should also allow the fitment of the Manifold Air Temperature sensor and have sufficient tapings to provide vacuum/boost signals for the various components. The Idle Air Control Valve can also be direct mounted to the manifold.

Throttle Body

Any simple cable operated throttle body in the size range of 45-60mm with provision for a Throttle Position Sensor (TPS) will suffice.

Suitable units are fitted to Ford or Rover models although there are many other options.

Jenvey Style Throttle Bodies

An option, as yet untried, would be to use dual Jenvey style throttle bodies on a DCOE style manifold. These can be purchased with dual injector bosses, thereby providing adequate injector capacity fitment for moderate output.

Sensors

Throttle Position Sensor (TPS)

The ECU needs to know the throttle position. Generally Throttle bodies come fitted with a TPS, however, sometimes these are just switch type devices. The TPS needs to be of a type that will give a 0-5v signal relative to throttle position.

Bosch make a range of throttle position sensors that are suitable and can be adapted to fit a Throttle Body relatively easily.

Connectors are three pin mini-timer type.

Coolant Temperature Sensor (CLT)

The ECU adjusts fueling during engine warm-up in a similar manner to an automatic choke. It therefore needs to know the engine temperature.

Many sensors are available however, these need to be 2500 ohm NTC type sensors. These generally come with two pin mini-timer type connectors.

Whichever sensor you use, you will need to know the range of temperature/resistance values. You can either use published values or measure the sensor resistance when immersed in water of a known temperature.

Inlet Air Temperature (IAT)

The ECU adjusts the fueling depending on the temperature of the air in the inlet manifold. The MAT sensor provides this information.

The sensors are very similar to the CLT sensor with the exception that the measuring element tends to be an open element. This is so that the sensor can react quickly to rapid temperature changes.

A readily available sensor that is known to work is the one fitted to the MPi Mini. It has a green hexagonal body.

Crank Position Sensor (CPS)

The ECU needs to know the crank position in order to control ignition and injection event timing. The normal method is to use a VR sensor and a 36-1 toothed wheel on the crank pulley.

The pulley can either be a separate bolt on wheel or a machined front pulley. The missing tooth is usually at TDC. The sensor should be positioned 90 degrees before the missing tooth with the engine at TDC. Other wheel configurations can be used.
The sensor is usually a VR sensor from a Ford EDIS system as used with Megajolt. In this instance the VR sensor is connected directly to the ECU.

Phase Sensor (PS)

As the ECU needs to know the crank position in engine cycle terms, a phase sensor is used. As the cam rotates at half engine speed ie once per engine cycle, a phase sensor monitoring the cam rotation can provide a signal so that the ECU knows if cylinder No, 1 is on the induction stoke or the power stroke.

The phase sensor can be fitted to sense each revolution of the cam, either directly off the cam/sprocket or fitted into a modified distributor body.

Phase sensors can be either VR, Optical or Hall type sensors, however, if a VR sensor is used, such as installed on the MPI engine as standard, a separate VR conditioner board (another of Jbperf.com's boards) will be required.

The choice between a Hall switch and an opt-switch for the phase sensor will probably be more down to what you are going to build to house it and where. An aftermarket Hall switch will probably be a 12V device so need additional power wiring whereas an opto-switch can be set to operate at 5V so can use the same supply wiring as the TPS, CLT, IAT. They will both feed through an opto-isolator on the MS2 PCB so the 12v (usually considered bad practice near a CPU) is not an issue. One switches low, the other high so there will be differences required in the MS2 internal wiring, but neither require an additional board.

Oxygen Sensor(s) (O2)

To correctly adjust the injection system it is advisable to use a pair of wideband O2 sensors. It is not absolutely necessary to provide the sensor output to the ECU, however, it does provide a simple method to monitor and log.

Any wideband sensor controller/gauge will suffice as long as it can be configured to give an analogue output that can be connected to the ECU.

To fit the second wideband signal to the ECU will need some additional circuitry. Details can be found in the Megamanuals.

Fuel System

Injectors

Injector options are as follows:

(a) high z or low z injectors.
(b) normal or staged injection.
(c) number of injectors (per port/runner) required.

(a) high z injectors are generally more expensive especially for high flow capacity but only require simple driver circuitry whereas low z injectors can be cheaper and may have slightly faster opening times but need more complicated drive circuitry. Recently the availability and pricing of high capacity high z injectors has been improving

(b) Because the Siamese code works by timing the injection only when the inlet valves are open, they operate on a very low duty cycle compared to a normal engine so their flow capacity has to be much larger for a given BHP. Large capacity injectors give poor idling so a solution is to have one "small" injector per runner and one (or more) larger ones staged in at higher power levels. 1000cc injector capacity per port is probably the largest that would give an acceptable idle and will limit power to ~120BHP. So for greater than 120BHP or to be able to use a smaller injector for better idling, multiple injectors and staging will be required.

(c) Whether to make the required capacity (irrespective of staging) from more than one injector. Using the example above, 1000cc per port un-staged could be achieved with 2 off 500cc injectors. A more likely scenario would be a relatively small injector for idle and low power with either one large or two medium sized ones staged in later.

These choices combined make the most fundamental difference as to how the MS2 will be built in terms of the injector drive circuitry. Low z injectors require special circuitry to provide a high initial current to open them and then a low "hold" current or they would overheat. Because of the high initial current, the power transistor part of the drive circuitry can only cope with a single injector. The standard Megasquirt achieves the lower hold current by Pulse Width Modulation (PWM) but ties up two additional CPU outputs to generate the PWM – these additional channels are the ones that, under the Siamese code become available for staged injection (with a small modification to the daughterboard). So, if you want more than 2 low z injectors, or if you want staged injection then all of the standard drive circuitry is omitted and replaced by one (or more) of Jbperformance.com's dedicated driver boards.

The additional boards are available in two versions for low z or high z, the low z one usually being referred to as a "Peak and Hold" (P&H) board. There is also a difference in how the ignition circuitry is dealt with on these boards (see later).

To summarise;

Injector drive circuitry	Injection options
Standard Megasquirt	Maximum of 2 low.z injectors (one

	per port/runner). NO staging Multiple high z injectors in each port/runner but still no staging
Jbperf.com's 4 channel Injector driver board	Multiple high z injectors and staging available. No low z option
Jbperf.com's P&H board (one only)	Maximum of 4 low z injectors (2 per port/runner). So either increased capacity without staging or staged injection but without multiple injectors in either stage.
Jbperf.com's P&H board (two off)	Maximum of 8 low z injectors (4 per port runner). So either increased capacity and/or staged injection with multiple injectors in either stage.

Injector capacity is determined by amount of time available during the intake stroke to inject the fuel. At 6000rpm the intake stroke takes just 5mS. Latest testing suggests that a maximum of 4mS can be achieved.

The following table gives indicative injection capacity required for a given power output:

HP	Injector capacity (cc/min)
100	1714
150	2571
200	3428
250	4285
300	5142

Fuel Rails

You need to source suitable fuel rails to feed your particular choice of injectors. These are unlikely to be available commercially; hence these need to be fabricated to suit. Options are to either machined from solid or built up from fabricated components welded, brazed or screwed together.

There needs to be facility to secure the fuel rails to prevent fuel and boost pressure from separating the injectors from the fuel rail or manifold.

Fuel Pump

The fuel pump needs to be sized to provide sufficient fuel flow to match your power expectations. Normal EFi systems operate at 3 Barg fuel pressure.

There are many OEM fuel pumps available as well as aftermarket units such as FSE or Walbro.

If you want to use an OEM pump, select one from a car of a similar horsepower.

You will need to mount the pump so that it has a positive suction pressure.

An alternative is to use the SPi or MPi tank and fit a larger, higher pressure pump. Walbro do a pump specifically for this application and will provide sufficient flow and pressure for up to 300hp.

Fuel Filter

The fuel filter is generally fitted after the fuel pump. It needs to be sized to suit the maximum anticipated fuel flow, although as long as the connections are an adequate size it should flow sufficient fuel.

Again there are many OEM filters available or they can be sourced from FSE etc.

Fuel Pressure Regulator (FPR)

The fuel pressure regulator controls the fuel pressure in the fuel rails to 3 Barg above manifold pressure. Hence it needs to be vacuum/boost referenced.

It is fitted after the fuel rail unlike carburetor regulators.

Ignition

EDIS is not required

As the ECU needs precise information regarding crank angle, the crank position sensor has to be connected to the ECU. Hence, it is not possible to use the EDIS controlbox normally associated with Megajolt and early MS/Extra configurations.

Coil Pack

Typically the coil pack of choice would be the Ford EDIS coilpack as used with Megajolt. These require only two ignition driver chips which can usually be fitted onto the standard heatsink of the MS board. They will be driven from the ECU. As noted above, the EDIS module is no longer used. If the jbperformance 4 channel board is being used for injection, they could be installed there instead.

Coil On/Near Plug

Many modern production cars use coils mounted directly on the plug. As these are four individual coils they need four separate driver chips and will require the jbperf.com 4 channel board,

Logic Level Coils

Some CNP coils, such as the GM LS2 coils have built in drivers so there is no need for the ignition driver chips. However they require a “logic level” output from the MS2 which will involve building some additional circuitry in the proto area of the PCB.

Idle Air Control

Idle Air Control Valve (IACV)

The MS2 ECU has the circuitry to drive a stepper motor type Idle Air Control Valve (IACV). There are four outputs on the ECU to drive a bipolar 4-wire valve.

The MPi IACV is a uni-polar valve and is therefore not compatible. However the Rover housing can be used to mount 4-wire valves of a similar pattern.

Suitable valves can be found on 90s petrol engined Peugeot or Rover vehicles. Any 4-wire valve should be useable.

The valve can either be mounted in the throttle body or in a suitable housing. The housing provides a seat for the valve and inlet/outlet ports, If required the valve and housing can be mounted on the bulkhead and connected to the inlet manifold by a rubber pipe.

ECU

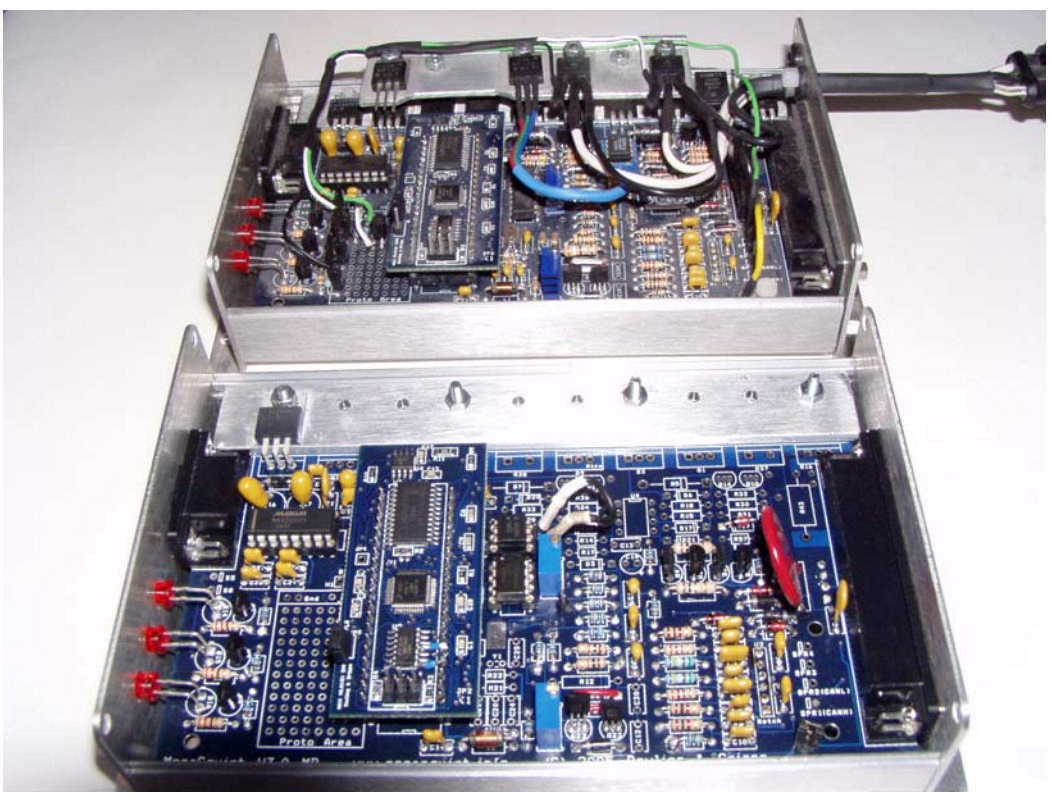
Build Guide

As noted in the preceding sections, all but the most basic setup will require additional small PCBs from Jbperf.com and, for staged injection, a small modification to the daughterboard. So by now, you will have decided on

(a) high z or low z injectors.
(b) normal or staged injection.
(c) number of (and size of) injectors (per port/runner).
(d) coilpack, coil on plug (COP) or coil near plug (CNP).
(e) phase sensor - hall switch, opt-switch or MPI built in VR pickup.

So you will now know how many additional boards (if any) you require. These additional boards come as bare boards or kits direct from Jbperf.com but, at time of writing, they are not available fully assembled.

As for the MS2 itself, it can be purchased as a partial kit, a full kit or assembled but, (again at time of writing) none of our more advanced options for staged injection or multiple low z injectors are available fully built. The only fully built version available is “standard” but with two ignition drivers for a coilpack. Also, a fully built version has a significant number of redundant components that simply waste space and some that MUST be removed to allow the daughterboard modification for staged injection. So at present, it’s a choice of how much you want to solder or how much to unsolder as well.



The top one is “standard” build for two low z un-staged injectors and coil pack (plus a couple of other MS-Extra features hence the additional heat sink) and the lower one is built for multiple high z injectors with staged injection using a Jbperf.com 4 channel injector driver board (not on view in photo). Note the number of components omitted from the top right of the MS2 PCB and below the bottom right of the daughterboard and note that the heatsink is virtually bare.

The difference between a partial kit/bare board and a full kit is lack of components. The MS2 partial kit is the bare PCB plus the MS2 assembled daughterboard and a MAP sensor, nothing else, even the case/heatsink is purchased separately. The full kit contains all the components including many that are not required for the advanced builds but ironically still only has one ignition driver. For the JBperf.com items, a bare board is just the PCB, and a kit is everything except connecting wire. Also when ordering your choices, note the potential missing pins for the “Extra” features on the standard pre-built wiring loom.

Wiring

Relays

It is recommended that a relay is used, switch by the vehicle ignition, to provide a supply to the ECU. Another relay is required to drive the fuel pump, this relay is grounded by the ECU.

It is also advisable to use a relay to provide a power supply to power hungry instruments such as the O2 sensors.

Fuses

As well as fuses to protect the ECU and fuel pump, fuses are required to provide a protected power supply to the injectors and coil pack.

http://www.msextra.com/doc/general/ms2external.html