

Electronic Fuel Injection for Hot Rods

Part 4 – Converting to EFI

A Hot Rod must have that “look” before it is considered a true Hot Rod. While there are many opinions on what the “Hot Rod Look” actually is, one thing is certain – you can’t get it from a factory floor!

Converting to EFI is, to some people, detracting from “The Look”. Having said that, no-one can deny that the classic good looks of the earlier GM TPI, especially if it’s started up with some polishing and an after market air filter. It looks pretty good in any rod, whether you are a “traditional” rodder or not. The same goes for the Ford EEC 3, 4 and 5 EFI setups, although they are a little less symmetrical in appearance. All this is OK, provided you are building a car with these powerplants in mind. More popular every day is the quad cam Toyota V8 and the Nissan V8, especially when the prices are lower than any imported GM/Ford cut-out!

Convert to EFI

But what about the rods that are already on the street, still giving their owners miles and miles of rodding fun, that want to convert to EFI? Sure, you can get a complete drivetrain, but you need the engine, trans, computer, wiring, maybe some changes to the cooling system, the exhaust, not to mention the dollars! Many factory engines have advanced to EFI while still retaining their basic engine block – the SBC and 5.0 Litre Ford come to mind. Chrysler commercial vehicles, too, have the 318/360 EFI systems that still retain their basic LA engine blocks. Get one of these manifolds and you’re halfway to your conversion at half the cost. No need to drill the manifold and build fuel rails, and there’s plenty of imaginative ways to get throttle bodies to look and work right. However, it’s not always that easy, especially if you have one of those engines that doesn’t have a factory EFI manifold at a reasonable price, or if the hi-tech look of the plenum and its associated plumbing is a put-off.

In the US, there are many shops that advertise manifold conversions and throttle body adaptations. Force Fuel Injection, BDS, Jim’s Performance, Rance EFI, Kinsler, Hilborne, just to name a few. But what about here? After sniffing around for my own projects, I was dismayed, at first, that there appeared to be so few, but as I dug a bit deeper, several well-known shops came forward. I found one such company, Inner Active Manifolds in Blacktown, NSW, working closely with Ross Racing up the road, who were only too happy to accommodate me. What’s more, they manufacture their own brand of throttle body adapter, and supply the necessary hardware for the manifold conversion as well, all for a reasonable price. There are several others around, and I’ll mention them as I go so you can choose one closest to you.

Convert to EFI

Conversion from a carb/points car to EFI power using a factory EMS is OK if your donor engine stays stock as a rock. Modifying your engine means you must switch to a programmable EMS like Haltech or maybe you might choose to toss the factory EMS and go GM Delco 808 ECM tuned with Kalmaker. For most of us with existing 4-barrel manifolds and distributors, however, converting the manifold to EFI and using a factory or after-market throttle body is the solution.

If you are fortunate enough to come across a Hilborn or Enderle type stack injector that fits your engine, conversion from constant flow to EFI operation is the same process. Stack injection will give you the ultimate in “Hot Rod” induction with the look of a classic dragster and the street manners of EFI.



Figure 1 - How about this for your Windsor, a stack injection set-up from EFI Hardware (Speed Technology) in Mitcham, Vic. They manufacture IDF/IDA Weber pattern throttle bodies for use on Weber manifolds such as the Windsor featured here. If you have such a manifold, conversion to EFI is easy with these throttle bodies, and they look good, too!

Notice that these options require some machining of the manifold. At the ends of the runners, holes need to be drilled so that injectors can be inserted. With the stack injection, constant flow injectors won't work, and they are much narrower than EFI injectors, so these manifolds need machining, too. Simple enough. And it is, if you know what you are doing, because if you know what you are doing then you know:

- The injectors must point at the back of the intake valve.
- The injectors must all be at the same depth.
- The injectors must all be at the same height so that the fuel rail, which joins them, is level.
- They fuel rails must not leak (the fuel, remember, is at high pressure), and must be secure enough that the injectors don't shift in the event of a backfire.

Before you go any further, take your manifold to Ross Racing and ask Ben Clothier to convert it to EFI for you. For a cost of around \$600 - \$700 (check first, some manifolds may require more work, eg tunnel rams) you get:

- The holes milled and cut for equal depth.
- Injector bungs welded in to the holes.
- Inner runners ground smooth.
- Injector height set correctly by milling the injector bungs flat and square.
- Fuel rails cut and milled.
- Your injectors installed in the rails and secured into your manifold.

I spent some time at Ross Racing, and Ben took me through the entire process. There are plenty of other places around the country that can do this work, just contact any of the businesses I have featured throughout this series and they'll put you on the right track.

Choosing a Manifold

Before we look at the engineering side of things, here's some advice from George and Terry at Performance Engineering in Queanbeyan, NSW, on manifold choice:

A single plane manifold (eg, victor jr., torker, etc) works best, although the split plenums (eg,

performer) will also work. A tunnel ram is ideal, but must be the type that has individual runners so that air is directed to the port. Boat type tunnel rams are completely open at the manifold base and flow way too much air, so stay away from them.

Notice that I only refer to aftermarket aluminium manifolds when it comes to modifying them for multi point EFI use. That's because cast iron manifolds are too hard to machine and weld compared to the aluminium alloy types. To retain your 4 barrel cast iron manifold, you would have to build a Throttle Body Injection (TBI) setup as opposed to multi point. There are a few TBI throttle bodies around that will bolt straight on to a 4 barrel manifold, such as those manufactured by EFI Hardware, who I mentioned earlier. You might also consider some of the 2 barrel weber type TBI throttle bodies, or use a GM TBI adapter plate such as those available in the US (for example, CFM-Tech¹) but these are "Wet Manifold" systems that we haven't got space for here. Suffice to say, it is a good alternative for some of the more obscure engines, such as early Cadillacs, Nailhead Buicks, Ford Y-Blocks, etc where aluminium manifolds are either too scarce or don't exist.

Making the Manifold

After visiting Ross Racing, it was obvious that sticking my manifold in to my drill press at home and drilling holes in it would have resulted in failure (don't laugh, I was going to do it – I have a very good drill press!). I also would have spent far more than necessary on things like fuel rails, injector bungs, and aluminium welding. In addition, Ben has all the measurements and settings for just about every type of alloy manifold there is.



Figure 2 – Ben Clothier is setting up the milling machine to drill the holes in my Mopar hi-rise manifold. It's a 2 stage process - a hole is drilled, then milled to the correct size using a cutter.

¹ <http://www.cfm-tech.com/catalog/>



Figure 3 - The drill is fitted and ready to roll.



Figure 4 - We'll drill one side, then cut the same side before we flip the manifold around to do the other side.



Figure 5 - Now the cutter is used to shape the hole exactly so that we can fit the injector bosses.



Figure 6 - All done on this end.



Figure 7 - The manifold has been done, now we need to make the fuel rails. Again, this is a precise operation, and you need to know what you are doing. The fuel rail is supplied in bulk form, and is cut to size. The holes are drilled to the injector O ring size.

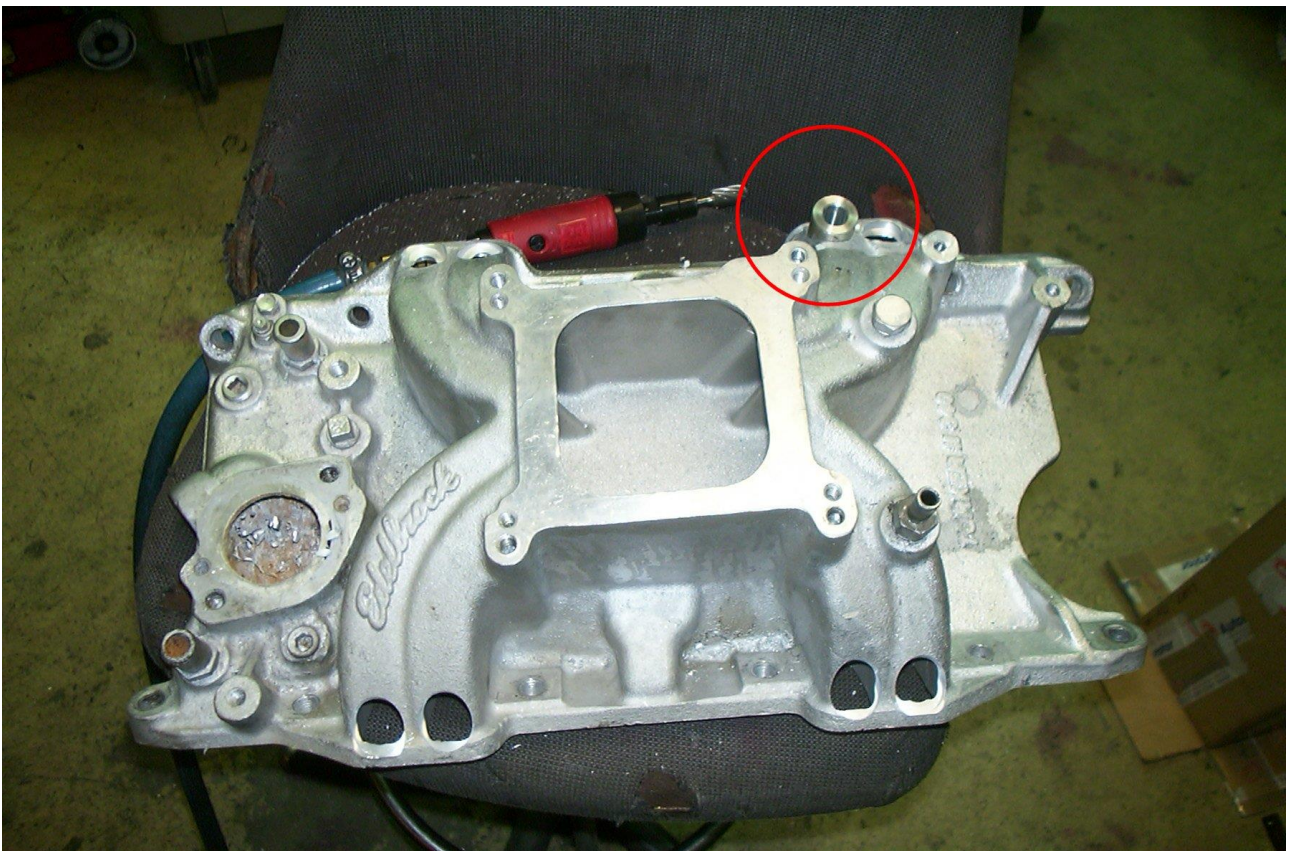


Figure 8 - My manifold, ready for the injector bungs to be welded in. The first bung has been pressed in (circled). Once they are all welded in, the tops of the bungs are milled flat and square to ensure they are all exactly the same height from the deck.



Figure 9 – Ross Racing also make their own barbed fuel rail ends and weld them into the fuel rails. Alternatively, you can have the ends threaded for standard fuel barbs.



Figure 10 - Ready to weld in the first injector bung. Notice how close the two ports are on the Mopar manifold. Small block Chevs are the same, making it difficult for a novice welder to get a good seam.



Figure 11 - One down - seven to go!

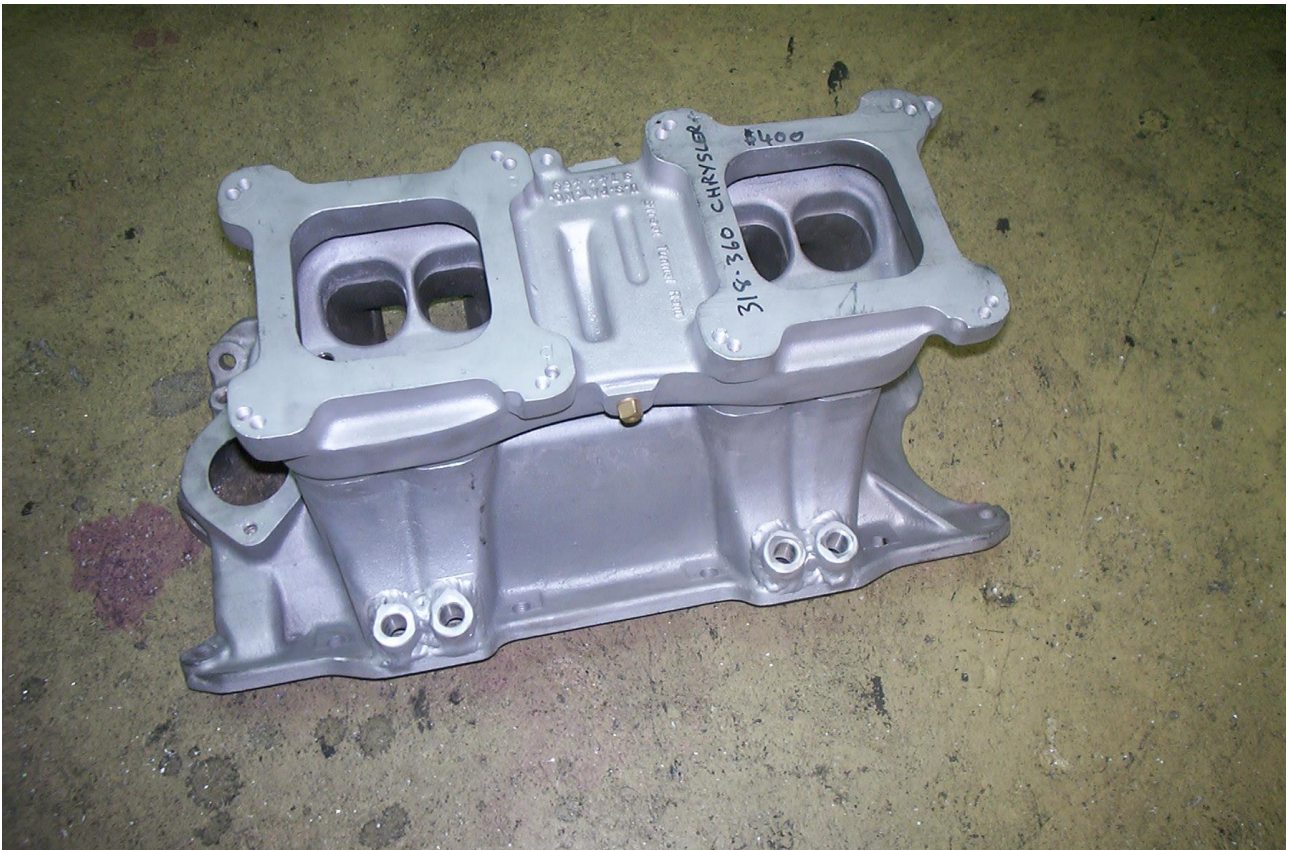


Figure 12 - That looks familiar! Sitting on the floor was my tunnel ram that I had sent in a week earlier. All finished and waiting for the fuel rails.

Throttle Bodies

One of the cheapest ways to get a throttle body for a 4 barrel manifold is to use a carb base. The drawback is the *Throttle Position Sensor* and the *Idle Air Control* valve – where do you mount them?



Figure 13 - Twin Holley carb bases are used as throttle bodies on this converted tunnel ram. A TPS needs to be installed as does an IAC valve. You also need to adapt an air filter, but a couple of aluminium or phenolic spacers will do the job.

The TPS solution can be to mount it on the accelerator shaft. This has the added advantage of hiding the TPS and its associated wiring. The IAC problem, too, can be easily overcome with a remote IAC valve. All you need is a vacuum line.



Figure 14 - Remote IAC Valve. The only source for these items I could find was in the US at Fuel Air Spark Technology (FAST²) and Full Throttle Performance³. Inner Active Manifolds in Blacktown offer a similar setup for their Twin Tech throttle body adapters. Image courtesy of Full Throttle Performance.

An easier way is to use an after-market four-barrel throttle body, which has the TPS, IAC and air filter mount installed. EFI Hardware⁴ in Mitcham, Vic, have a version which costs about the same as a new carb.

² <http://www.fuelairspark.com/catalog/components.asp>

³ <http://www.fullthrottleperf.com/index.htm>

⁴ <http://www.speed-technology.com>

EFI Hardware, a division of Speed Technology. 7 Monomeeth Drive, Mitcham, Vic Phone (03) 9873 5400

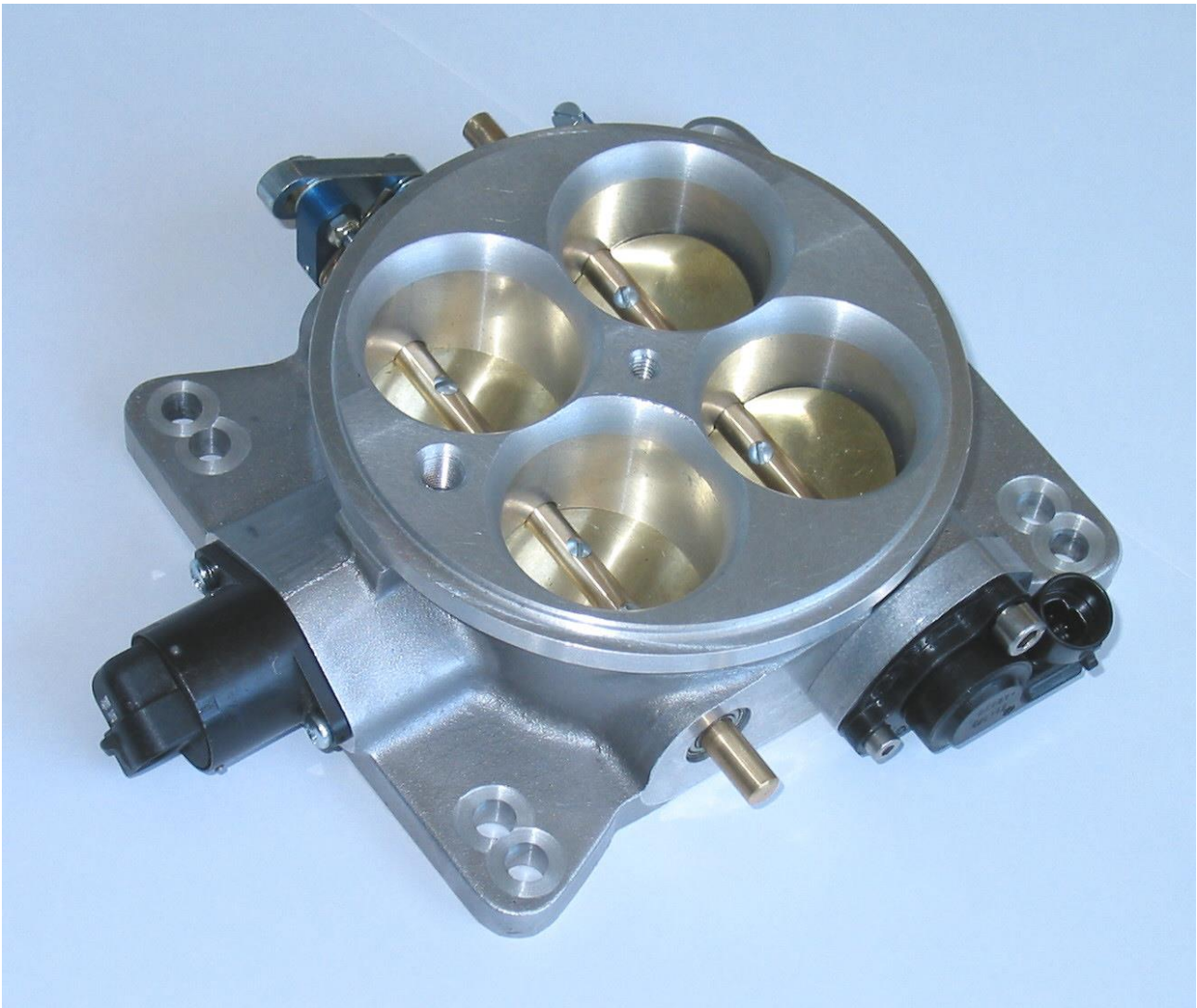


Figure 15 – Billet 4 bbl Throttle Body from EFI Hardware. TPS, IAC and standard 4-Barrel air filter are all accommodated. They are similar in design to the Holley, Edelbrock and MSD variants, but at half the cost. And it's an Aussie made product! In addition, they have adapters for common VN Commodore TPS and IAC. They also have billet TBI throttle bodies.

In Part 3 of this series, we looked at the Twin Tech throttle body adapter. By using two VN Commodore throttle bodies linked together, you can use the IAC and TPS from one of the throttle bodies (keep the others as spares). The Twin Tech is inexpensive (around the \$200 mark) and VN Commodore Throttle Bodies are very cheap (from around \$40 at wrecking yards or anywhere from \$10 at swap meets). New components are readily available from GM spares outlets. For cramped engine bays, you might consider using the Ecotech throttle bodies from the VL onwards. They are much shorter than the earlier VN throttle bodies, but retain the same mounting base and TPS.



Figure 16 - Use a Twin Tech adapter from Inner Active Manifolds in Blacktown, and bolt on a couple of cheap Commodore throttle bodies. TPS and IAC are accommodated on one throttle body.



Figure 17 - The other side has the throttle cable spool. The two throttle bodies are joined at the centre shaft by an adapter, also supplied by Inner Active.

Programming your EMS for Engine Modifications

Mass Air systems such as the 86 – 89 GM TPI will give you a lot of leeway when modifying your engine. You can build your 350 with a lumpy cam, alloy heads, balance, port jobs even plonk a blower on, and the factory ECM will adjust accordingly without any intervention by you. Provided that the injectors will flow enough, the ECM will only see that the engine is ingesting a larger amount of air than normal, increasing injector pulse width accordingly. Later models are speed density and combinations of speed density and mass air. More importantly, the ECM is programmed with more specific data, which relies on engine specifications remaining constant.

Fortunately for us, the GM factory computer can be re-programmed with Kalmaker to complement engine modifications. In fact, Kalmaker can deploy the common 808 Delco ECM for use with any engine. See part 3 of this series for more Kalmaker information.

If you are not using a Commodore computer and Kalmaker, your choice will be one of the many Programmable Engine Management Systems on offer. These systems have far fewer maps to calibrate, thereby making tuning an easy process, either by way of a hand held controller (supplied) or using software (supplied) on your lap top computer. Prices vary, but they start at around \$1400. A VN Commodore 808 Delco computer can be picked up from a wreckers for about \$100. I have bought them from swap meets for \$40. Kalmaker tuners (see part 3) will charge a nominal fee, but you must provide them with all the relevant information on your engine so that they can select a mapping that can act as a starting point. Kalmaker tuners have paid for the *Real Time* computer, so

they can use it to tune your EFI engine, copy the data to a chip and replace your factory chip with your individually modified version. Talk to your Kalmaker tuner first.

Modifying your EFI Engine

Firstly, let's get one thing perfectly clear – for most naturally aspirated engines operating on pump fuel, the only way to achieve real power gain is by increasing airflow through the engine. If you are going to install a factory EFI engine into your Hot Rod or Street Machine, then “fiddle” with the electronics to get it to go hard, think again! *Chips cannot do this*. A Chip is simply an electronic component known as an Integrated Circuit (IC) - an EPROM, a Monostable Multivibrator (or “Flip-Flop”), a Multiplexer, a De-Multiplexer, a Buffer, yadda-yadda-yadda. Not interested? Me neither. They are just “Chips”. Aftermarket chips that you plug into a stock, factory ECU have been re-programmed to richen the mixture slightly at full throttle and/or advance ignition timing, but at the expense of lowering the safety margins for detonation and emissions set by the factory.

OK, what about the so-called “Custom Chips”?

Chip companies sell *Custom Chips* for modified engines. This is fine if your engine has the same modifications as the engine used on the chip company's dyno – that's what the chip was developed for. In the US, some performance parts warehouses like Summit sell a complete package – cam, pistons, heads, headers, throttle bodies and chip. However, if your cam, heads, exhaust, injectors or throttle body are different, the chip will not work correctly in your engine. The only way to get EFI to work right on a modified engine is to take your engine to someone with the right facilities and get a custom chip burnt for it. This is a process that starts by measuring all your engine parameters on a chassis dyno, transferring the data to your ECU, then testing on the road. Repeat until it's perfect. You can do this at home if you have the patience, a long stretch of deserted highway and you are computer savvy. Being a propeller head is an advantage.

So where does that leave the majority of us?

Referring back to Part 2, your choices are to use an aftermarket Programmable Engine Management System (eg, Haltech, Motec, etc) or a Commodore 808 ECM and have it re-programmed using Kalmaker. No matter whether your engine is a souped-up 1999 LT1 or a 390 Caddy, they can all be electronically managed in this way.

That's aGOOD thing!

Wiring, RFI and EMI

Radio Frequency Interference (RFI) and Electro Magnetic Interference (EMI) are important things to consider when installing an engine management system. RFI not only affects your stereo system, but can also interfere with the operation of the computer. EMI, while a different form of interference, can have devastating affects on electronic components of your car. Both forms of interference can be treated in the same manner by using care when wiring up your project vehicle and by the placement and mounting of your ignition trigger system and ECM.

RFI is the spurious radiation of radio frequencies, which are harmonics of much lower frequencies like the firing of spark plugs. If your V8 engine is running at 3,000 rpm, the frequency of the ignition is $3,000 \times 8 = 24,000$ hertz (cycles per second) or 25Khz (kilohertz). This frequency is of little consequence, but it carries with it all the *Harmonics* of that frequency. A *Harmonic* is a multiple of that frequency, but as you get further away from 24Khz, the harmonic level decreases substantially (the technical term is *Intermodulation Products* (IP)). With today's powerful ignition systems, however, the level of dangerous harmonics can be high enough to cause problems, mostly minor, but easily prevented.

EMI is the interference caused by the rapid expansion and contraction of an Electromagnetic Field (EMF). Your alternator is constantly generating an EMF, but is easily suppressed with a simple capacitor (suppressor) at its output and a well-grounded casing. Your thermo fan, starter motor,

heater motor, even the tailshaft, generate EMFs, but the EMI they produce is suppressed by the motor's casing which is grounded to the negative terminal of the battery. On fibreglass bodies, grounding is even more important than on steel bodied cars.

Some RFI/EMI is created by external forces that you have no control over, such as mobile phones, CBs, taxi radios, power lines, etc, and have been known to cause air bags to deploy or anti-lock braking systems to fail. RFI/EMI is easily suppressed, but if it is not treated properly it can cause engine misfires, sporadic and intermittent failure of sensors and/or modules and a horrible squawking on your stereo. Every project is different, but here are a few rules that you should follow when installing any electrical/electronic device in your car to suppress RFI/EMI:

- Mount the ECM away from the engine, preferably separated by the firewall. Look at where the factory cars have their ECM.
- Make sure the casing grounds are clean and tight, offering as much contact surface area as possible.
- Mount the ignition trigger box away from the ECM, also ensuring that it is well grounded.
- Never use solid core ignition wires.
- General wiring of electrical components should be of a high quality. I use and recommend Painless Wiring kits.
- Grounds, grounds, grounds. This cannot be overstressed.
- Shielding is the metal casing around electronic components such as stereos, digital gauges, the casing on the alternator, etc. Make sure they are all grounded.
- Use good quality spark plugs and don't let them wear out to the point that the electrodes start to pit and chip.
- Use good quality ratchet-style crimping tools when making your wiring system.
- Don't use solder on your wiring harness, it will crack and corrode at the joint.

Tuning the Engine Management System

All of the after-market Programmable Engine Management Systems are fairly easy to program (tune) yourself. With these systems, you program the values into it that will make the engine start, idle, warm up, cruise, accelerate and run at wide open throttle. With some systems, you may need the services of a dyno. If not, the deserted road and a lap-top computer will help to properly tune your system, much like the way we used to get Holley carbs to work right – a straight road and a handful of jets and power valves.

The following description is a generic overview of how the EMS is tuned. I have elaborated on the operation in an attempt to describe the functioning of a typical EMS. In the real world, much of the following is a no-brainer, because the software does it for you. In fact, many of the programmable engine management systems on the market tune themselves, but it's important to have an understanding of the process so you have complete control over your project.

For starters, you simply enter a list of known values, such as cam duration, lift, engine displacement, compression ratio, transmission ratios, rear end ratio, tyre size, etc and the software calculates the essential data for you. The software may be embedded in a hand-held controller or installed on your laptop, but this initial exercise populates the appropriate tables with the data, and it's usually enough to get you cruising. A little fine-tuning is all that's left to do. Of course, all systems are different in many ways, so to describe a particular one in detail shall have to wait for another issue.

Having said that, you'll be pleased to know that the basics of tuning are pretty standard throughout

– at different steps (from idle, through cruise and at WOT) you make adjustments to supply the correct amount of fuel, and then fire the spark with the correct amount of advance. You start from a *Base Idle* condition where the Engine Management System supplies the basic fuel and ignition data to start and run the engine. The EMS software then looks for extra data supplied by the sensors, which is stored in *Lookup Tables* – so called because the software “looks up” the value. You already know what the data from the sensors *should* be – in fact, the EMS software may already have populated the *Lookup Tables* with the most likely readings, so all you need to do is adjust the value slightly to get the best response from the engine. This is where a Dyno comes in handy, but it’s not essential. If the software is doing its job, the engine will run close to stoichiometric (14.7:1) with “seat of the pants” tuning.

The data in the *Lookup Tables* is used to correct the base injector pulse width and base ignition advance until the engine is running at 14.7:1 A/F ratio. You do this at increments of engine speed, measured by degrees of throttle position (these increments are called *Load Points*). At each *Load Point*, you can make corrections that deliver the most power, the best economy and/or the best emissions – you can choose your priority. You lock your adjustments in by saving the data to the computer. You do this for every sensor at the specified number of *Load Points* (determined by the software). All the measured data is stored in *Lookup Tables* for the individual sensors.

Once you have tuned the EMS, the software does its job by comparing the sensor reading with its associated data in the *Lookup Tables* (sometimes called *Maps*). If the O2 sensor, MAP or MAF, Knock Sensor, MAT, CTS, etc. are all working properly, the engine will hum along nicely. If a sensor’s input to the ECM does not match its value in the *Lookup Table* for the particular engine speed, timing and/or fuel is adjusted until it does. Remember, too, that all this happens thousands of times per second.

Data maps in aftermarket programmable EMS are kept to a minimum for the purpose of simplicity. Features such as closed loop idle, closed loop cruise, accelerating or decelerating using a Vehicle Speed Sensor (VSS) may be ignored. They may not include air temperature, manifold air temperature, water temperature or barometric pressure in their calculations, again, to provide for ease of installation and setup. The number of load points, too, will be far less than those for factory ECUs. What this means is that there are refinements that may or may not be available, such as:

- Tuning out backfiring/popping condition when slowing down/backing off.
- Timing adjustments that prevent pinging on hot days yet still make maximum power on cold days.
- A steady reliable idle regardless of the conditions.
- Starting first time, every time without touching the throttle, whether the engine is hot or cold.
- Low speed, first gear driving without surge or having to ride the clutch.

To put this in perspective, the best programmable EMS is capable of addressing up to 20 maps. The Commodore ECM has about 300 maps! While that sounds daunting, remember that the Kalmaker software was developed primarily to address each and every map possible, with a view to improving efficiency and power by fine tuning the Engine Management System. I asked Alan Gibbs (Kalmaker distributor in Perth) and Ken Young (the owner and developer of the Kalmaker software) what improvements could be made to a stock Commodore by simply fine tuning the ECU, and figures of 20% to 50% increases in output were not uncommon. For Hot Rodders, apply that to high performance/modified engines, and there’s no telling what you can accomplish!

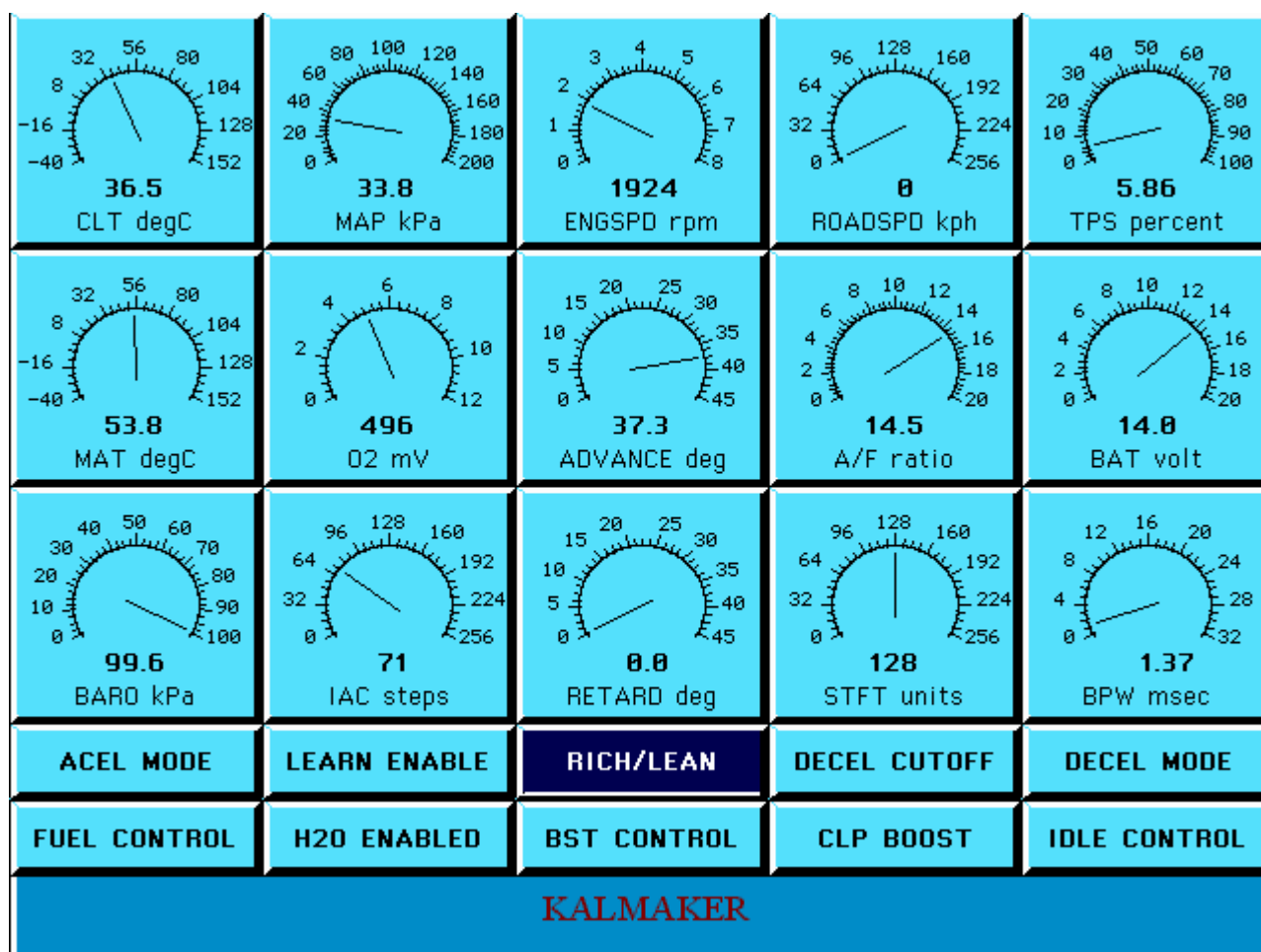


Figure 18 - This is one of the Kalmaker screens that the Kalmaker tuner uses to "tweak" the Commodore 808 ECM. This screen is called the "gauges" screen, and displays the condition of the engine in "Real Time". The engine has just been started and is running at part throttle. Looking at the "gauges", starting at top left, you can see that the temperature is cool (normal is about 90 C). Next to it is MAP which varies with engine load, followed by RPM, speed in KPH and TPS (throttle position), which is currently at 5.86%. The next row starts with MAT (Manifold Air Temp), then O2 sensor voltage, followed by Advance. The A/F ratio is 14.5, but as the engine approaches its normal temperature range, it will settle on 14.7 stoichiometric. A/F drops to around 12.1 under full throttle for maximum power. The bottom gauges of importance are Idle Air Control (IAC) and Retard, which reads out degrees of timing when the Knock Sensor detects detonation.

Concluding

The purpose of these articles is to shed some light on the complexities of computer controlled engines. That's one thing that there's no denying – Electronic Fuel Injection is, indeed, complex, far more so than the carbs and points that powered our cars for so many years. So why change? Emissions, crap fuel and economy all come to mind, but the most important reason is increased engine efficiency. Far more reliable horsepower per pound of fuel can be coaxed from an EFI engine than a carburetor engine. Not only that, but reliability is increased by a factor that was never thought possible twenty years ago. It's an expensive conversion, but well within the average rodder's reach, both economically and technically, and it will pay for itself in low maintenance costs and be environmentally friendly to boot!

While I've thoroughly enjoyed this exercise, I feel that there's more to come. I believe that EFI (and EGI, Electronic Gas Injection) is going to make rodding more fun than it already is, and I look forward to seeing more and more injected power plants at rod runs and shows. If you would like to contact me to ask a question or point me to an Australian business/manufacture of EFI components that I haven't mentioned, or if you are a manufacturer or seller of EFI components, email me at:

choco@hotrodhandbooks.com.au or visit my Web at **<http://www.hotrodhandbooks.com.au>**