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Lifting the Lid on the mk1 MR2 ECU Part 2

In this part I will show how the UK mk1 MR2 ECU determines the correct amount of fuel to be injected into the engine to get the correct air/fuel mixture for good performance. I have carried out a lot of research into how this ECU operates and can now reveal many of the secrets held within it.

This article will concentrate on the early mk1a MR2 ECU part number 89661-17030.

Some of the words below are based on what I have found by looking at the ECU ROM code and some is based on general theory. The UK mk1 MR2 EMS is based on the 'Speed Density' principle (Toyota call it D Type EFI) and is manufactured for Toyota by Denso. Speed density EFI is very popular amongst car manufacturers as it is simple, cheap and reliable.

Most Electronic Fuel Injection (EFI) management systems strive for an air: fuel mass ratio around 14:1 under steady state driving. This gives low emissions and good economy. At times this ratio needs to be richer (cold starting or during hard driving) and it is the job of the ECU to always provide the optimum air/fuel ratio for any given set of driving conditions.

To work out how much fuel to inject, the ECU must first determine how much air is being drawn into the cylinders at any time. It needs to know the mass of the air (not simply the volume) to get the mixture correct and the ECU uses its sensor inputs to help it predict the air mass. Of course things would be simpler if the MR2 had been fitted with an air mass sensor! As it doesn't have one the MR2 ECU has to do a fair bit of work to predict the air mass accurately. The key word here is 'predict' as the air mass is never physically measured, it is predicted from the results of signals returned from the ECU sensors. As long as the car is not modified or faulty the prediction will be accurate. Once it knows the mass of air, it injects fuel to give a mixture that gives good performance and/or low emissions.

Speed Density Operation

The Speed Density system uses the principle of the Universal Gas Law to operate. This does mean a maths equation but it is a simple one and can be simplified further when applied to speed density. The equation portrays the relationship between the pressure, volume, mass and temperature of a gas. Basically if you know the volume of a canister of gas, you can predict the amount of gas (its mass) within the canister if you can measure the pressure and the temperature of the gas. (Skip this section if you don't like maths!)

Universal Gas Law **P x V = n x R x T**
P = Pressure
V = Volume
R = Gas Constant
n = number of moles. This is an odd chemistry term and is proportional to air mass in this case.
T= temperature

Simplifying the Equation

The MR2 intake has a chamber between the intake valves and the throttle butterfly. So how does this help? Well, if you operate within a known volume, the equation can be simplified to just
P ˜ n x R x T.

This chamber is where the ECU measures the air pressure at the intake. It uses a Manifold Absolute Pressure (MAP) sensor to measure the pressure. (Note that the MAP sensor actually measures the ABSOLUTE pressure referenced to a perfect vacuum. It actually has a tiny sealed 'reference vacuum' built into the sensor! Hence the term 'Manifold Absolute Pressure').

R is a fixed constant and can be ignored and the equation becomes **P ˜ n x T**. (this can be rewritten as: **n ˜ P/T** or **air mass ˜ P/T**).

Simplified Speed Density Equation

So, if you can measure intake chamber pressure and predict the air temperature you can predict the mass of the air passing through the chamber (and therefore into the cylinders). i.e.
air mass ˜ air Pressure/air Temperature.

Now we're getting somewhere!

The ECU predicts the temperature of the air in the chamber by measuring the temperature of the air being sucked into the engine (the sensor is mounted a few inches after the air filter in the mk1b).

Why does the intake pressure change?

This is because the cylinder does not always fill with its full potential of fuel/air on each intake stroke. If you can imagine a piston travelling down and sucking in the fuel/air (like an air pump) it is obvious that it will be less successful at filling the cylinder with a closed or nearly closed throttle (light load). The throttle plate provides a restriction to the airflow and this generates a pressure drop (partial vacuum) in the intake chamber. As you head towards full open throttle (high load) the cylinder can 'breathe' and fill more efficiently (technical term is 'volumetric efficiency', measured in %). The intake vacuum will diminish and will approach local atmospheric pressure when at max throttle/load where the cylinder should 'fill' better. So measuring the strength of chamber vacuum gives a good indication of cylinder filling. It actually fills best when generating peak torque, which is around 5000rpm for the MR2. In theory, this is when the engine will need the most fuel per engine revolution.

To complicate things, the volumetric efficiency versus pressure drop is also affected by engine speed (rpm) and the ECU therefore measures rpm to allow for this. This technique is termed 'speed density' as both the engine speed and air pressure/temperature readings must be used together to begin the air mass prediction in the ECU. Speed refers to engine speed in rpm and NOT vehicle speed in mph.
Phew! As you can see (assume a fully warmed up engine) the ECU has to juggle sensor data for the air temperature, inlet manifold pressure and engine rpm to predict the air mass sucked into the cylinders. Note that, in theory, the throttle position sensor plays no part in the fuel calculation for a speed density system.

A really crude speed density system would simply measure the air temperature, the pressure and the rpm and use the simple formula above to calculate how much fuel to inject. This would work, but the car would not be much fun to drive. It would also be difficult to start, have poor warm up performance and poor throttle response. It would also have to choose a fixed fuel ratio that would be a compromise between performance and economy.

Clearly, a more versatile system is required!

Mk1 MR2 ECU Operation

(This following section is based upon what I have found within the ECU ROM code. Assume for now that the engine is fully warmed up) as hinted at in part 1, the ECU doesn't contain a very powerful microcontroller chip so it doesn't have much time to do any complex maths. It therefore uses a simple series of lookup tables or maps to store the 'answers' to how much fuel is required across all possible engine conditions.

A Simple Mapping System Explained

It's a bit like having a reference library inside the ECU. Imagine having a library with shelves of books, where each book holds a number telling the ECU how much fuel to inject.

The ECU obviously needs to 'find' the right book for each change in driving conditions. How it does this is very simple indeed. It uses the sensor data as 'pointers' to navigate the library. The technical term for the location of each mapping point is 'site' rather than book.

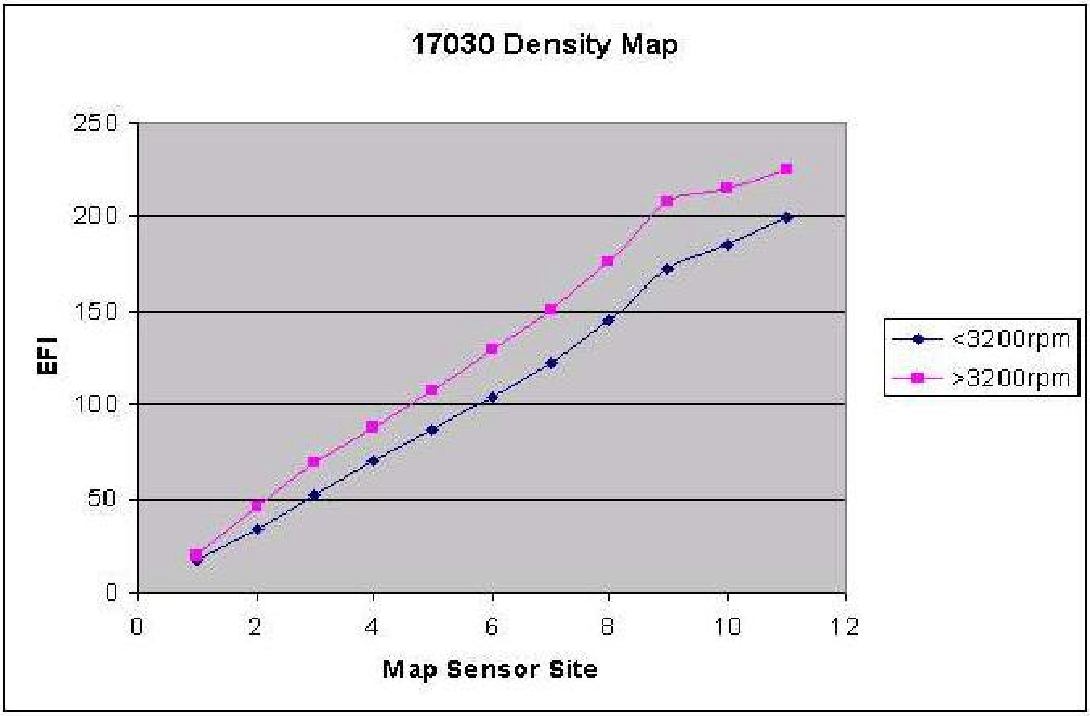
This sensor data can be for the rpm sensor, the pressure sensor or the air temperature sensor etc.

The mapped system affords the ECU tremendous versatility. The UK mk1 MR2 ECU uses a series of fuel maps which club together to provide an overall amount of fuel to inject.

Density Fuel Maps

The first map in the fuel calculation series is a 'density' map (i.e. it is based on intake air pressure).

The ECU reads the MAP sensor and uses the reading to navigate along the density map to arrive at the relevant data site. This gives the ECU a base 16bit value for the fuelling.

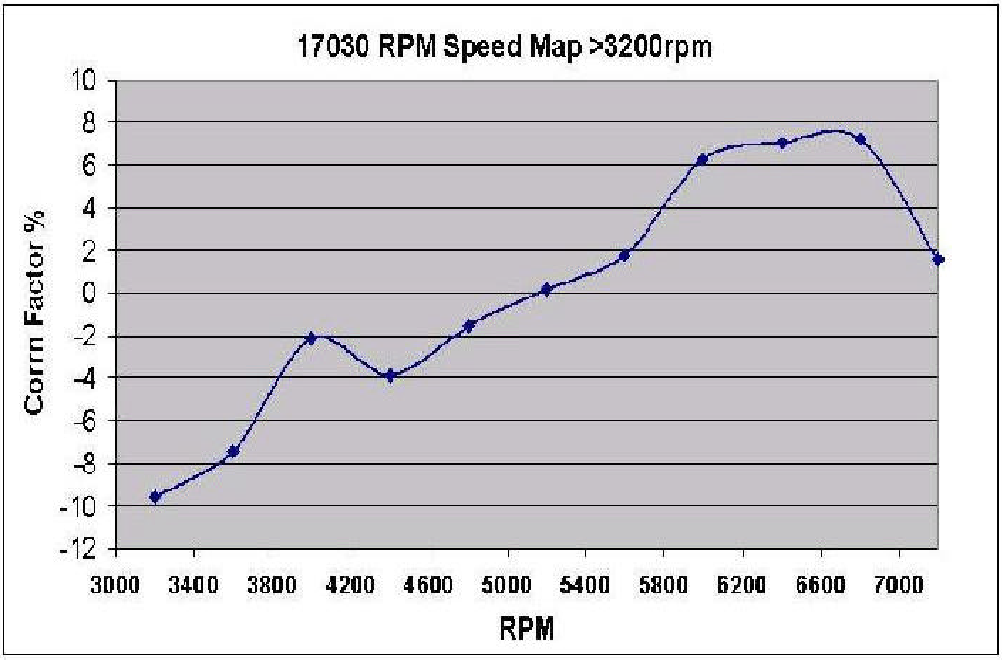


This is a simple 2D graph of MAP sensor vs. fuel duty. This map should be a straight sloping line according to the Universal Gas Law. As you can see from the graph below it IS (nearly) a straight line! The bump in the line close to maximum MAP sensor levels would cause a slight degree of over fuelling at high load, probably on purpose to protect the engine. There are 11 sites in the density map for the mk1a. Site 11 is for least pressure drop (usually full throttle).

There are in fact two density maps, one for when the engine is spinning below 3200rpm and one for when it is above 3200rpm. The reason the density mapping is split into these two ranges is to allow a finer scale map for the lower engine speeds to get more precise fuelling (and emissions?) during urban driving. The density map for speeds above 3200rpm is more biased towards performance.

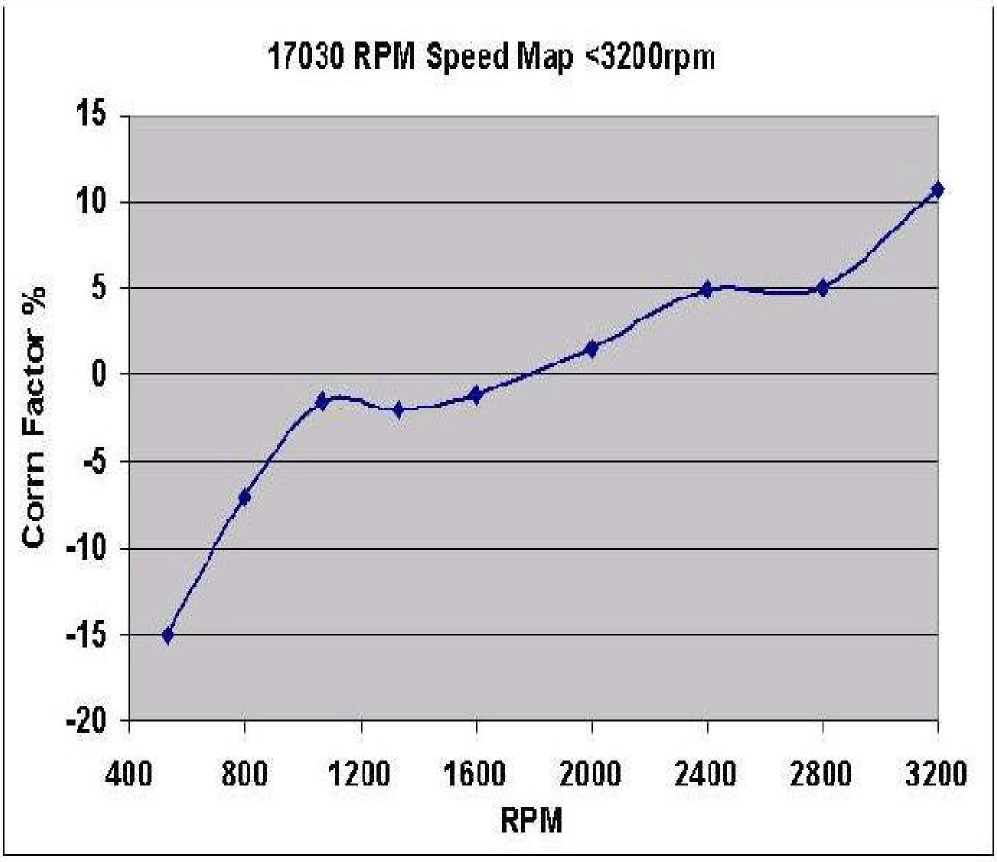
IMPORTANT NOTE: All the remaining fuel maps in the ECU program are merely correction factor maps to this initial 16 bit density value. (I.e. the density map is the 'daddy' map)

Engine Speed Correction…



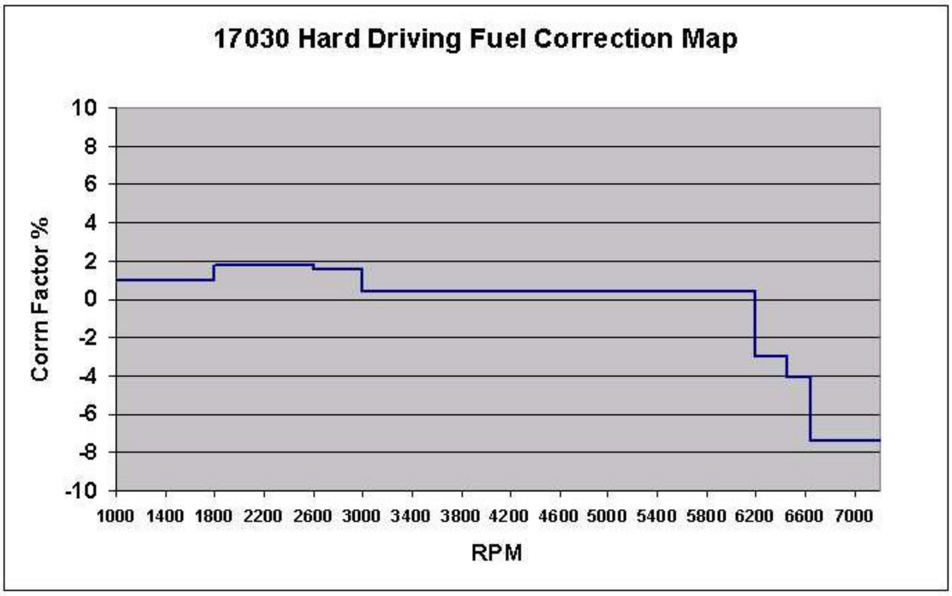
Being a speed density system it is no surprise then that the next fuel map is an engine 'speed' map. This is a map that gets navigated with respect to engine rpm. The higher the rpm, the further along the map the ECU goes. There are two speed maps, one for below 3200rpm and one for above 3200rpm. These maps are twinned with the two density map curves above.

This rpm correction map is a little more interesting! In theory it should show the change in cylinder filling as the rpm changes. This is best at peak torque (5000rpm on the MR2) so this is where the engine should require the most fuel per revolution. As you can see, the ECU continues to add even MORE fuel for engine speeds above 5000rpm. An over rich fuel mixture doesn't really degrade the power unless the mixture is really rich so this is a good way to cool and protect the engine at high engine speed (at the expense of economy). The zero line relates to a zero correction factor which indicates that the engine speed correction factor is zero at around 5200rpm (so maybe the >3200rpm density map was originally created with the engine spinning at 5200rpm?). Note that the correction factor varies between -10% and +8% meaning this map has a limited effect on the fuelling. Note the mini peak at around 4000rpm and the little dip just after this. I have no idea why this is there but I do recall that most torque curves I have seen for the 4AGE engine show a dip at around 4500rpm. This must be a characteristic of this engine!



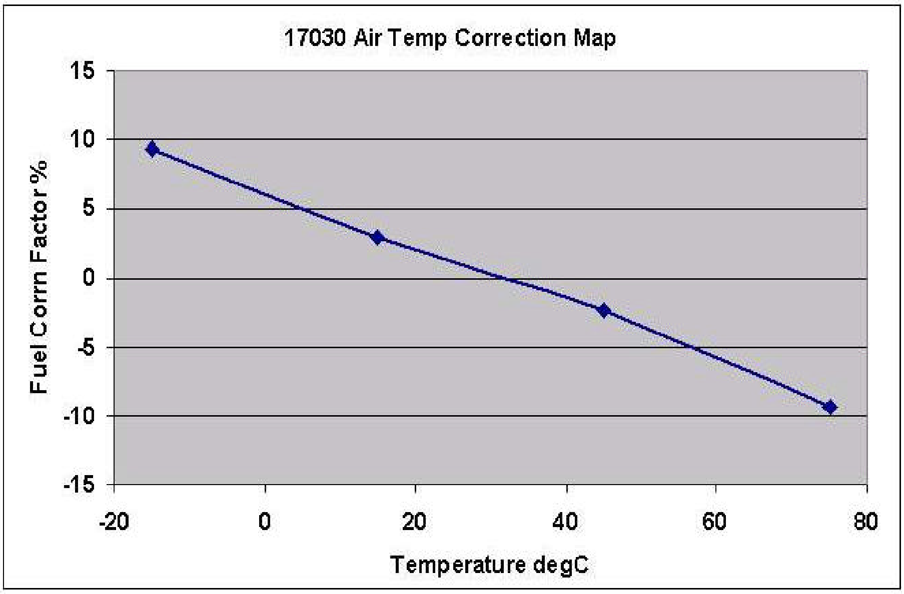
Here's the speed map for engine speeds below 3200rpm. Note how the fuelling leans off quite markedly below 900rpm. I assume this is done to make the engine prefer to rev up above 900rpm to improve the idle. It does look quite alarming though! If the revs ever drop below 800rpm it would appear the mk1a engine would be prone to stalling.

Hard Driving Correction Map



At high load AND rpm well above idle the ECU then consults an extra rpm correction map. On the mk1a this has mapping points at 1800, 2600, 3000, 6200, 6450, 6650 and >6650 rpm. This odd looking map is shown. This provides tighter control of the fuelling when driving the car really hard. As you can see it actually reduces the fuelling above 6200rpm. You can also see how crude this correction map is as it does not interpolate between map points which leads to the 'staircase' effect. As you can see, it only affects the fuelling by +2% at 2000rpm and by -7.5% at >6650rpm. Therefore, this correction map has only a minor effect.

Air Temperature Correction



As mentioned earlier, intake air temperature affects the air mass for a given volume so the ECU needs to correct the fuelling still further. This is the next map in the series to get consulted by the ECU. The cooler the air the more dense the air is so the more fuel should be added. According to theory this map should be a straight line and it is! I was expecting a slightly steeper slope to the line in theory BTW. I may have to recheck my air temperature sensor calibration.

Secret Treasure Map

Next, the ECU has a 'secret' engine speed fuel correction map in the code. This map always gets jumped over in the stock UK MR2 ECU program code. You have to mod a logic level inside the ECU to enable it (Note: A secret alternative 3D ignition timing map gets selected at the same time). For this reason I have not shown this map here. I would guess these maps are for different cams or a different fuel grade. It may well be for different cams because the secret fuel map is an engine speed map which implies a change in volumetric efficiency rather than a change of fuel grade. I'll publish the secret fuel and ignition maps in a later article.

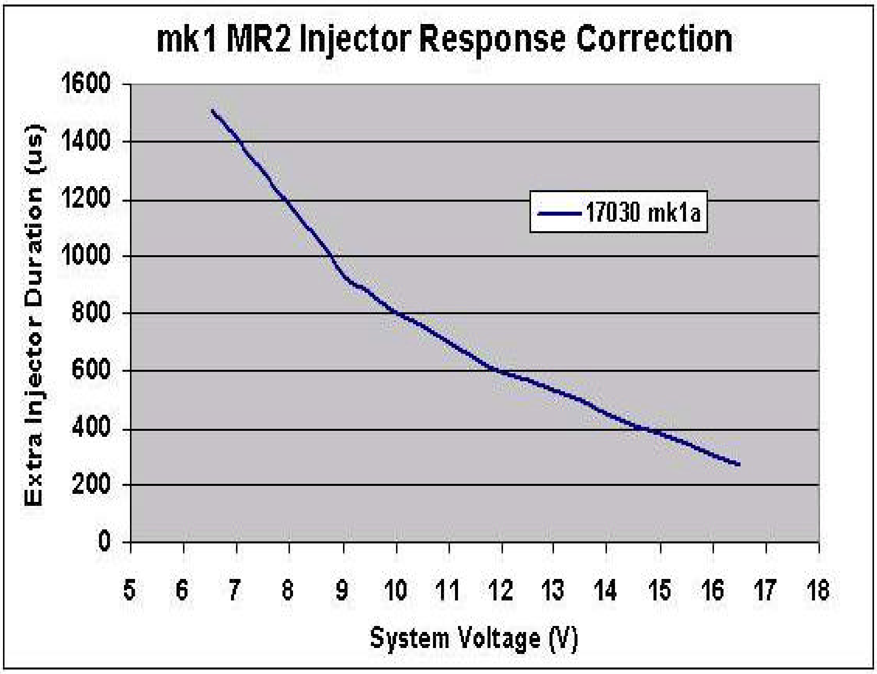
Global Correction Factor

Next up, the ECU uses a correction factor held in memory to correct the fuelling still further.
This correction factor gets calculated in a different part of the ECU program code to the fuel mapping section.
It actually contains several correction factors rolled into one. It is affected by coolant temperature (this correction factor is most significant during warm up) and also contains a throttle response 'transient' fuel correction factor. It also contains a correction map that switches in at high rpm and very high load AND high throttle. According to the ROM code this kicks in at 6300rpm and richens the fuelling curve by a fixed offset. This tends to cancel out some of the effect of the hard driving map mentioned previously.
I will write more about this global correction factor in a later article.

Mixture Screw Correction

The ECU then looks to see if it should include the manual mixture screw correction. For the mixture screw to have an effect the engine must be spinning below 3600rpm and the engine must be at a light or medium load setting (e.g. urban driving conditions)
If the mixture screw is set to its mid range value then the mixture screw gives a zero correction and therefore has no effect on the fuelling anyway. I will write more about the mixture screw mapping in a later article.

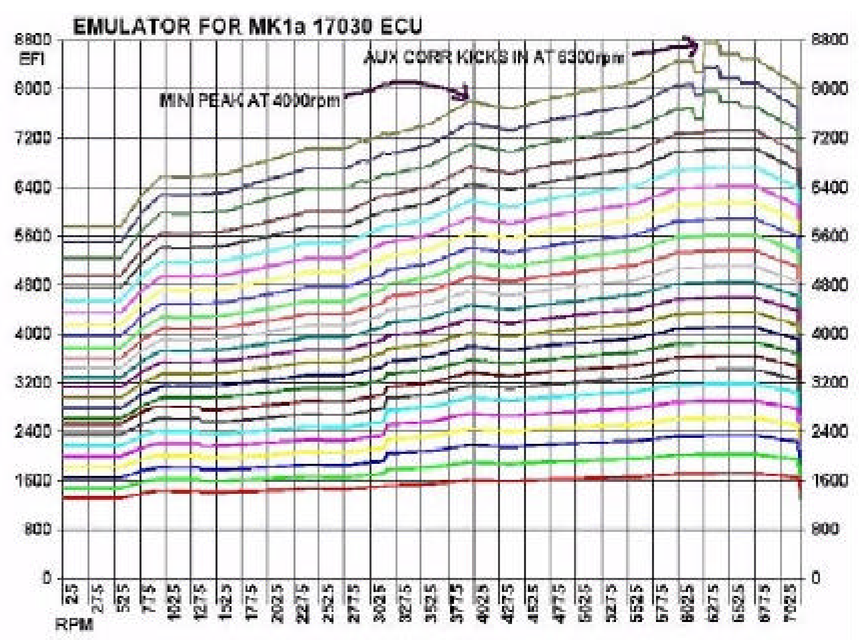
Voltage Correction



The fuelling calculation is almost done! Just before outputting the final fuel value the ECU has one more sensor test to make. It reads the system voltage (i.e. the alternator voltage). It does this because the fuel injector response time is affected by system voltage. See the graph. It shows how the injector duration correction (in microseconds) increases with lowering system voltage. This correction is significant during idling (a narrower injector duration is more susceptible to variations in injector response time) and also during starting as the volts can dip quite a lot.

Virtual AW11 ECU?

It is very difficult to visualize how all these 2D maps combine to provide the overall fuelling for the mk1a. To overcome this me carefully rewrote all the ECU ROM assembly code for the fuelling (complete with all the above maps) across to Intel 8086 assembly code so I could emulate the ECU fuelling program on a PC. The PC CPU therefore runs the same routines as the ECU and emulates it exactly. This took a while to do but it provides an insight into the overall (final) ECU fuelling for MAP sensor vs. rpm. It also has inputs for throttle and air temperature and assumes a fully warm engine. See the graph below which shows the PC emulator output.
This shows how the 16bit fuelling increases with increasing engine load whilst at high throttle.

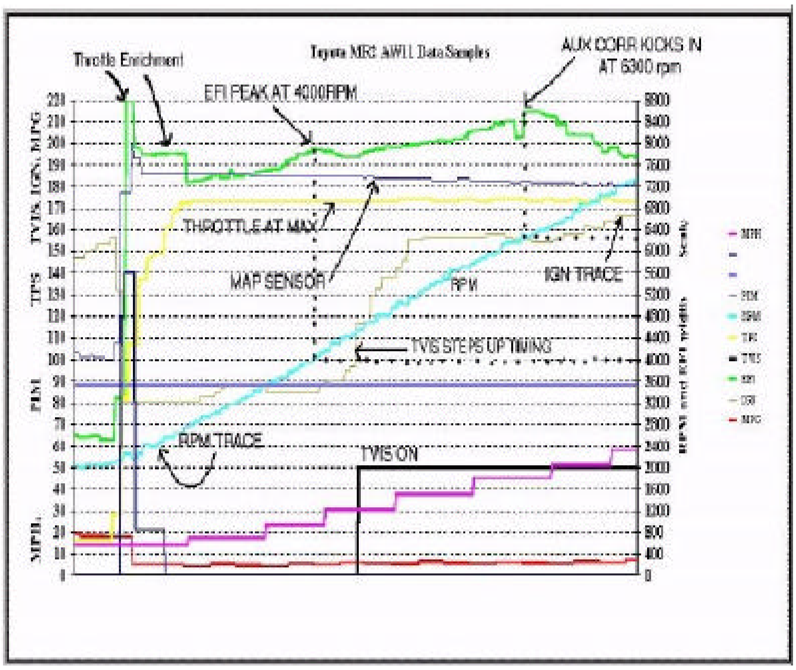


The PC ECU emulator shows the fuelling as a series of curves. Each point on each curve represents a complete fuelling calculation running the same code as the ECU. The emulator includes all the fuel maps and corrections and assumes a fully warm engine with medium to high throttle and 27degC air temperature.

The lowest curve is at low load (the MAP sensor is used to measure load) and the highest curve is at max load. Try to see it more as a flowing relief map rather than a series of curves as the emulator could have produced even more curves within the curves.

At low throttle the whole set of curves fall because the global correction factor has a lower value once the throttle falls below about two thirds. I have not included the lower throttle emulation graphing.

The top 3 curves show where the high load (crude) correction map kicks in and you can see the fuelling change above 6000rpm. At 6300rpm the global (AUX) correction factor can clearly be seen to suddenly 'lift' the curve. I guess the question is "why bother with this funny fuel mapping above 6000rpm?" Perhaps that sudden dip down and step up of fuel at around 6100-6400rpm serves some important purpose. To me it hardly seems worthwhile!



Theory vs. Practice

With my ECU data I am able to test drive the MR2 and data log the final 16bit fuelling over time onto a laptop. I fitted an mk1a 89661-17030 ECU to my t(rusty) 'test' mk1b, F61 LCH and in the graph below you can see the results of me flooring the throttle at low rpm and letting the car rev through to 7200rpm in second gear. This causes max engine load and in theory the data logged EFI trace (the top green trace) should look similar to the top trace on my emulator output. As you can see, it's pretty close! Also note the sub 10mpg fuel economy (bottom trace) when at full throttle in second gear. Trackdayers take special note!!

The data logged fuel curve is not quite as steep as the top emulator curve, but this is explained by the fact the MAP sensor can be seen to gradually tail off on the (real) data logged results which tends to gradually mute the gradient of the fuel curve. This gradual pressure drop with increasing rpm could be due to the hideous mk1b air intake plumbing! However the general EFI curve shape is correct, with the mini peak at 4000rpm and the 'odd' fuelling at above 6000rpm. It's good to see theory and practice agree and it proves I'm not just making this all up…

Notice also how the rpm trace sags a bit at around 6300rpm. This shows that the car loses acceleration at this point. It seems to pick up again once the fuel leans off above 6600rpm. I would guess the over fuelling at 6300rpm is robbing the engine of power. (Remember though, this is a mk1a ECU run in a mk1b) At the left end the EFI trace can be seen to briefly go off the scale at around 2400rpm. This is due to the ECU's response to my flooring the throttle suddenly. It briefly enriches the fuelling with a narrow spurt of fuel to improve throttle response (i.e. it massively increases the global correction factor for a brief spurt). More about this in a later article! Once this settles the EFI trace follows the same shape as the emulator.

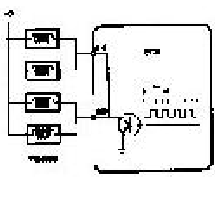
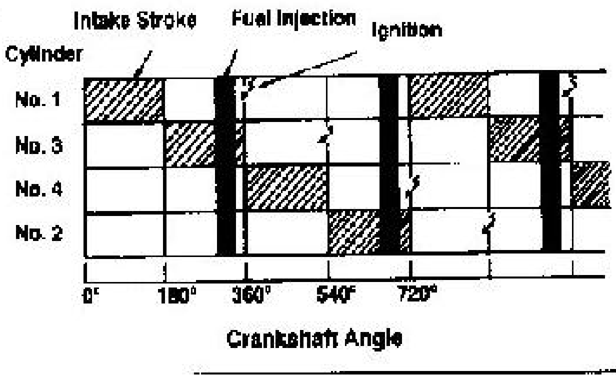
Injecting the Fuel

After consulting its maps the ECU knows how much fuel is needed. It controls how much fuel sprays from the injectors by controlling how long the injectors are held open for. This is all done electronically. Typically the injectors are held on for periods between 1.5 and 7 milliseconds. Injector flow rate is also affected by fuel pressure but this is presumably held constant by the fuel pressure regulator.

The fuel is injected simultaneously in two 'shots' each of which contains half the amount predicted by the ECU. It may come as a shock to some readers that the UK mk1 MR2 NA uses this simultaneous fuel injection. This is a system where half the amount of fuel is injected EVERY engine revolution from all four injectors at the SAME TIME. As there are two revolutions per complete engine cycle for a 4 stroke, only half the fuel is injected each revolution. This means the fuel spray has to 'hang around' behind the intake valves waiting for them to open. Mind you, at 3000 rpm it doesn't have to hang about long as 1 revolution only takes 20milliseconds!

Tech Stuff

I should point out that the final 16bit value for the fuelling relates directly across to the fuel injector pulse width in microseconds. The ECU micro has an internal digital timer that is clocked every microsecond (1MHz). The micro uses the final 16bit fuel number (with all corrections) to set the timer to create a pulse width (duration) exactly as wide as the 16bit number itself. E.g. a final 16bit fuel number of 4500 (decimal) will give fuel injector duration of 4500 microseconds (4.5 milliseconds). This method is really neat and is very efficient. It also makes the fuel data logging easy to calibrate!

Injection Pattern	Injection Timing	Engines
Simultaneous 		4K-E, 4A-FE 2S-E, 3S-FE, 5S-FE (GEN 1) 4M-E, 5M-E, 5M-GE, 3Y-E, 4Y-E 22R-E, 22R-TE 3VZ-E, 3F-E 3E-E

Some readers may initially dispute the simultaneous injection claim as the electrical wiring shows the 4 injectors wired in pairs. The ECU has two outputs feeding each pair hinting at a grouped injection system. Sadly those two outputs are actually strapped together inside the ECU! There is only one driver transistor inside the ECU to control all 4 injectors in parallel. I'm afraid it really is a simultaneous system. I think some Jap and US mk1 variants have grouped injection.

The 6000rpm effect

On both the mk1a and the mk1b a strange thing happens as the revs hit 6000rpm and above. The ECU alters the injection pattern! Instead of pulsing all four injectors every engine revolution, it pulses all four every OTHER revolution. To keep the fuel delivery the same, it doubles the calculated injection duration accordingly (However, according to the ROM code, the injector response correction factor is not

doubled). I think it does this to reduce the stress on the injectors. You see, at 6000rpm the engine spins 1 rev in 10 milliseconds (10ms) and at full load the EFI injector duration can exceed 8ms. This means the injectors are only off for 2ms each revolution. By altering the pattern the injectors pulse at HALF the normal rate and they are OFF for twice as long. Despite the fact they are ON for twice as long, this may well make the injectors run cooler. Anyone know the real reason for the 6000rpm effect? It may also be the reason for the odd step down/up fuelling above 6000rpm shown in the graphs but I can't really explain why!
To keep the data logging and emulator looking sensible I have chosen not to display the >6000rpm doubling effect on them as the net fuel delivery is the same anyway.

More Limitations

The MR2 speed density EFI works well as long as you don't modify anything! It totally relies on the subtle relationship between the intake vacuum and the engine rpm to provide the main steer towards the air mass prediction. Anything you change that affects the intake vacuum versus rpm versus volumetric efficiency will have an effect on this, with subsequent consequences for the fuelling and ignition timing. This is most significant with modified (longer timed) intake camshafts as the volumetric efficiency gets much improved with the modified cams. This is because the cylinder gets more 'time' to fill with air. The system cannot compensate for this. The ECU speed/density maps would ideally require full remapping to get everything optimized. The more air (with correct fuel mixture) you can get into the cylinder the more torque you will get! This is how hotter cams work. The longer timed cams can also adversely affect the vacuum in the chamber and the vacuum can become severely affected by reverse pulses of air back out of the cylinders which creates havoc with the whole speed/density process. This typically causes very poor low speed running/idling. I have read that changes to the exhaust system affect the volumetric efficiency too.

Changes to the air intake upstream of the throttle, e.g. air filter mods are less of a problem as the system interprets the better breathing as if the throttle is slightly more open. This will reduce the pressure drop which is then reported by the MAP sensor and the ECU should give the extra fuel accordingly.

Fuel Cut

During deceleration from high rpm with a closed throttle (overrun) the ECU ignores the fuel calculation and simply keeps the injectors switched completely off. This is done to improve fuel economy and emissions. The fuel is also cut when the engine hits the rev limiter threshold. I will write more about the rev limiter in a later article.
That's about it for the fuelling part of the ECU program. There are a few other details like the throttle enrichment, the idling maps and the starting/warm up mapping but these can wait for a future article.

Lifting the Lid on the mk1 MR2 ECU Part 3

In part 2 of this article I briefly explained how the MR2 ECU uses lookup tables (maps) to help it determine the fuel injection duration. I will now go into some more detail about how the ECU determines the correct ignition timing for the mk1 MR2. This applies to the mk1a MR2 with the 89661-17030 ECU.

Ignition Timing Theory

It is important to time the ignition spark correctly in order to get good performance and also to prevent damage to the engine.
For maximum engine efficiency, the air/fuel mixture in the cylinder should be ignited a short time Before Top Dead Centre (BTDC) such that maximum combustion pressure occurs around 12degrees AFTER top dead centre. It's a bit like bouncing a ball. It feels best if you start to contact the ball with your palm on its way up and allow the ball to continue up and then start to really press down with your hand just after it is on the way down again. If you press down hard too early the ball makes a noise (and it hurts your hand!) and the bouncing loses its smoothness. Press down too late and the ball won't bounce as high.
The same principle applies to the internal combustion engine. The fuel/air mixture doesn't 'explode' when ignited by the spark; rather it burns at a progressive rate and gradually builds up pressure. It is this pressure that turns the engine round. Just like bouncing the ball, this pressure should reach its peak just past the point of top dead centre.

Cylinder Filling

To complicate things, the rate at which the fuel/air mixture burns is affected by how well filled the cylinders is. At light throttle settings, not much fuel/air mixture gets sucked into the cylinders. This small charge burns quite slowly. Therefore when the car is being driven lightly the ignition will need to be sparked quite early because it will take a while for the burn pressure to build to maximum. So for best efficiency the ignition timing will need to be well advanced (to spark early) under these light throttle conditions.
For harder driving (with more throttle) the cylinders will fill better with more fuel/air mixture. This larger charge has a faster burn rate and if the timing was left as above (i.e. well advanced) the pressure would build too early in the engine rotation and this would cause rough running and a nasty noise (pinking).
So under harder driving the ignition timing will need to be retarded in order to get the maximum burn pressure at the sweet spot just after TDC.

Engine Speed

There is another major factor involved as well. This is engine speed. At high rpm the piston obviously moves much faster than it does at low rpm!
If the piston is moving faster then the ignition needs to be sparked earlier because the burn rate doesn't speed up in sympathy with the rpm. So at low rpm the ignition timing can be quite retarded, but at high rpm it will need to be well advanced.

Mixture Ratio

The fuel: air mixture ratio also affects the burn rate. Richer mixtures tend to burn slower so require more ignition advance. The ECU richens the fuel: air mixture during warm up so more ignition advance is needed during this time.

In the Old Days…

In the days before MR2s and ECUs, cars used to achieve the correct ignition timing by mechanical means. The distributor had a pair of devices inside it that affected the ignition timing. One device was affected by cylinder filling, and the other was affected by engine speed.
The first device of the pair was a vacuum advancer. This connected the distributor to the engine intake via a rubber hose. As outlined in part 2, the cylinder filling is inversely proportional to the strength of the intake vacuum. At light throttle settings there is a strong intake vacuum (poor cylinder filling) and this gets fed to the distributor via the hose and the timing will be set well advanced by the vacuum advancer mechanics in the distributor to suit the slow burning charge. When driving the car harder the vacuum reduces and the timing will start to retard in order to prevent pinking etc. Crude, but effective!
The other device was a centrifugal advancer that advanced the ignition timing with increasing rpm. This was a simple mechanical device that spun and splayed out as the rpm got higher. As it splayed, it advanced the timing. Also crude but effective.
The combination of these two devices gave the required ignition timing control in older cars. Because these old fashioned devices were mechanical they were prone to wearing out over time and were also slow to respond during periods of rapid engine acceleration.
So even in the old days, engines had ignition timing that was able to change in order to get reasonably ideal ignition timing across all combinations of cylinder filling and engine speed. Without these crude mechanical devices in the distributor, the timing would have to be set at a fixed position and this would mean a serious compromise would have to be made to the performance of the engine.

MR2 ECU

The MR2 has no mechanical advance devices in the distributor. Instead, it controls the ignition timing electronically within the ECU. This means there are no moving parts to wear out and also the ignition timing can be controlled in a more versatile manner.
Just as in the old days, the ECU has to monitor both engine speed (rpm) and the degree of cylinder filling in order to determine the optimum ignition timing.
On the UK mk1 MR2 the ECU gets the engine speed by measuring the pulses coming back from the ignitor/distributor. As outlined in part 2 the ECU determines the cylinder filling by using a Manifold Absolute Pressure (MAP) sensor connected to the intake manifold.

Mk1a MR2 3D Ignition Timing

17030 ECU 3D Ignition Table

17 RPM Sites

17	7200	207	196	178	168	162	166	158	151
	6800	207	200	179	162	160	150	155	145
	6400	207	203	186	161	161	151	144	141
	6000	207	205	183	164	157	147	149	145
	5600	207	196	188	169	163	143	150	144
	5200	207	191	187	174	152	163	149	144
	4800	207	198	183	170	154	139	126	122
	4400	210	185	168	161	149	132	107	96
9	4000	213	183	168	156	141	128	98	85
	3600	213	190	167	162	159	126	105	85
	3200	213	195	173	163	161	128	96	90
	2800	213	199	167	158	151	142	105	81
	2400	212	178	165	149	134	116	90	81
	2000	209	179	140	129	123	113	83	81
	1600	205	184	160	134	121	96	73	68
	1200	201	158	132	109	107	69	54	43
1	800	192	147	107	97	90	37	23	11
		1	2	3	4	5	6	7	8

8 MAP Sensor Sites
Cylinder filling →

So how does the ECU determine the ignition timing? Well, it could hardly be simpler! In common with other manufacturers, the MR2 ECU uses a lookup table (or map) to store all the optimum values for the ignition timing across all combinations of rpm vs. cylinder filling (MAP Sensor). On the mk1a 17030 ECU the engine speed is represented by a lookup 'site' every 400rpm from 800rpm through to 7200rpm. The mk1a ignition map therefore has 17 rpm sites and these are at: 800, 1200, 1600, 2000, 2400, 2800, 3200, 3600, 4000, 4400, 4800, 5200, 5600, 6000, 6400, 6800 and 7200rpm.

The cylinder filling is represented by 8 sites from low MAP sensor reading through to high. Therefore, the basic ignition map for the mk1a MR2 consists of a lookup table with a total of 17 x 8 = 136 possible ignition timing settings. It is stored in the ECU micro chip memory (ROM) as a table of 8 bit numbers meaning each entry in the table can have a value from 0 to 255. The higher the value stored, the more advanced the ignition timing will be.

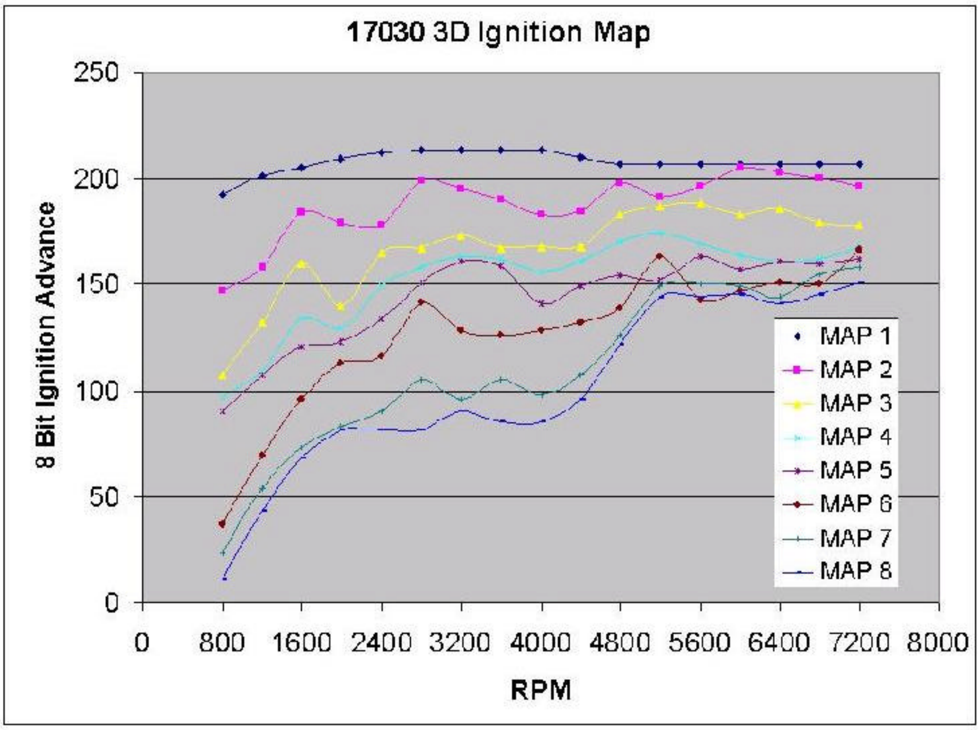
Imagine this table as 8 columns of boxes in a row (each column is 17 boxes tall). Each box holds an 8 bit value for the ignition timing. If the MAP sensor reports an engine cylinder filling factor of 6 (out of 8) and the rpm is 4000rpm, then the ECU navigates along the row of 8 MAP sensor columns until it comes to the 6th one. Shown by the red arrow. It then navigates up 9 (out of 17) rpm boxes (i.e. to the 4000rpm box, shown by the blue arrow) and gets the basic timing from the value stored in the box which happens to be 128 in the above table. If the rpm then increased to 4400rpm the ECU would get the new ignition timing from the 10th box in the column (= 132, slightly more advanced).

IMPORTANT NOTE: The timing advance is shown as the 8 bit value stored in the ROM and NOT in degrees BTDC!

The ECU can do this simple task in a tiny fraction of a second. This means the ignition timing gets constantly updated and ensures that the optimum ignition timing is always achieved even when the engine is accelerating rapidly.

Easy, huh? The versatility of this system is there for all to see. If an engine tuner only wanted to alter the ignition timing at 4000rpm whilst at a moderate MAP sensor reading, then the tuner simply alters the value in the relevant part of the lookup table but the timing will remain as standard under all other engine conditions. With 8 bit resolution, the timing can be tuned in fractions of a degree BTDC.

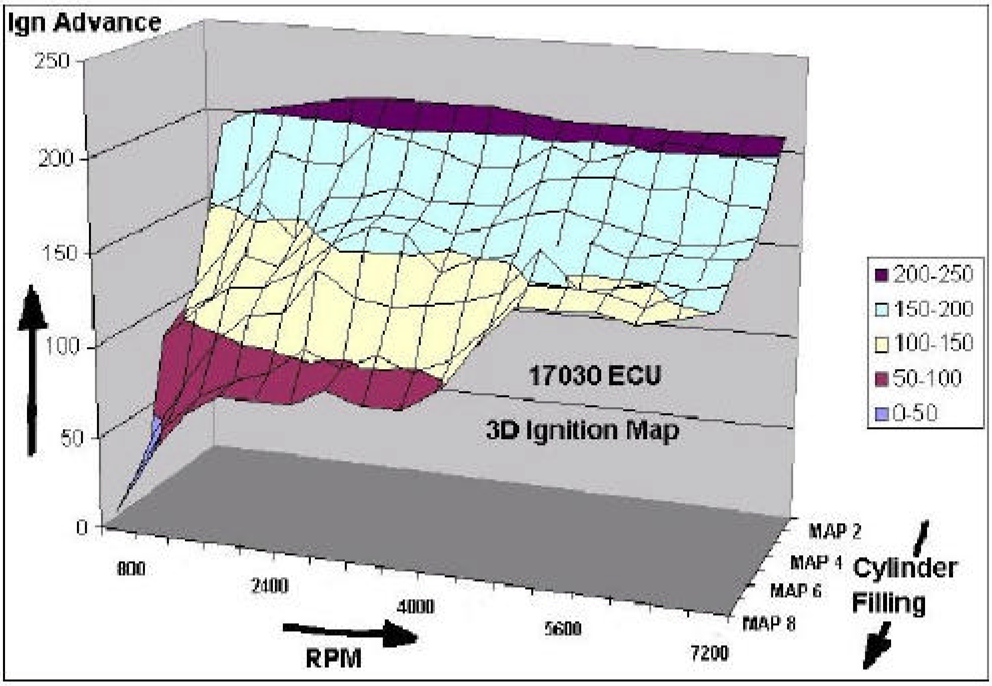
See the picture below which shows the above table in graphical format for the mk1a ECU. There are 8 curves in the graph, one for each column in the table. The MAP 8 profile (bottom curve on the graph) is the profile used when the car is being driven hard and cylinder filling is at the highest. See how the ignition timing tends to advance with increasing rpm and how it retards for the higher MAP sensor curves where cylinder filling is good.



There are one or two odd peaks and troughs in the ignition curves! Try and see the above curves as a relief map rather than a series of curves as the ECU is clever enough to interpolate between points on the graph and smoothly fill in the gaps between the curves.

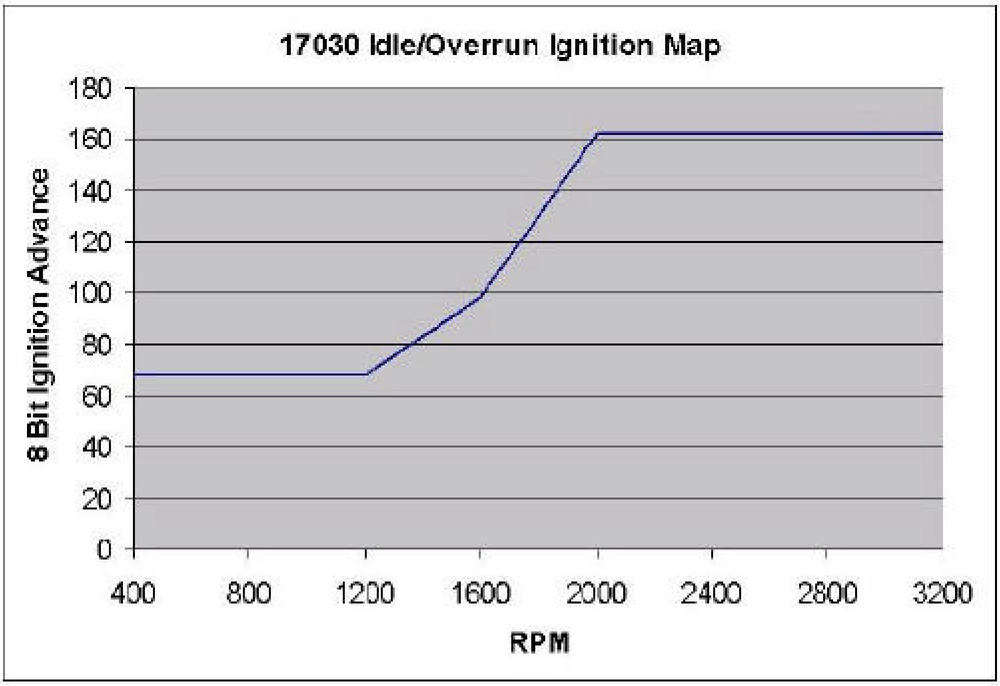
In other words, to get smooth mapping, the MR2 ECU interpolates between adjacent lookup values. So if the engine is at 4250rpm the ECU would use the data stored in the 4000rpm and 4400rpm sites and would predict the value at 4250rpm. The ECU does the same trick for the MAP sensor sites.

To illustrate this point, the 3D graph below attempts to portray the same 8 curves in the format the ECU treats them if you include the interpolation between mapping points. Imagine the ECU skating across the surface of this relief map. Where it skates depends on the engine rpm and the cylinder filling (indicated by the MAP sensor). Wherever it is on the map, at any point in time sets the ignition timing. You can clearly see how the ECU is able to fill in the gaps between curves and provide really smooth mapping. (In other words, the ECU can skate anywhere on the colored surface, not just on the gridlines)



You can clearly see how technically advanced this system is compared to the mechanical advance/retard mechanisms in older vehicles. The engine tuner has complete control over the shape of this 3D map and can alter any section of it by changing a few values in the 3D table. This allows precise control to find the optimum setting for the ignition timing across all combinations of cylinder filling and engine rpm. Being electronic, the response time for this system is way faster than the old mechanical system also which adds to the crispness of the engine. Not bad for a 20 year old ECU!

Toyota and Denso would have spent many hours with a 4A-GE engine on a dyno optimizing the basic 17x8 ignition map lookup table for best overall performance. They would then have 'softened' the performance to allow for variations in fuel quality, engine production tolerances and driving conditions. They would then have stored this softened ignition map as standard into all mk1a MR2s. Often the best performance gains on a car are to be had from playing with the standard ignition mapping rather than the fuelling.



The ECU uses this basic ignition map whenever the car is being 'driven', i.e. when the throttle is being pressed. If the driver lifts off the throttle then the car reverts to a much smaller idle ignition map. This crude map only has 3 rpm sites at 1200, 1600 and 2000rpm. It is unaffected by cylinder filling. If the car is at high rpm when the throttle is lifted off (overrun) then the ECU uses the value in the 2000rpm site. As the fuel is cut off during overrun this ignition timing is fairly academic anyway! I assume this idle map has been designed to give optimal warm up idling with the throttle closed. The UK MR2 tends to idle up at 2000rpm when started from cold and it takes a while for the revs to fall down to 1000rpm. This high idle (when cold) is caused by the waxstat air bleed valve located in the throttle body.

TVIS and Ignition Timing

When the TVIS is enabled the ECU also advances the ignition timing with a sudden step. This adds to the TVIS 'kick'. The ECU allows a short delay before stepping the timing to allow time for the TVIS to open. On the mk1a the TVIS opens at 4350rpm and closes when the revs fall back below 3950rpm. Figures for the mk1b are 4650 and 4250rpm respectively. I obtained the above TVIS threshold info simply from studying the ROM code and it appears to agree with various technical articles I have read for the mk1a and mk1b.

Warmup

During warm up, the ECU consults a warm up correction factor map for the ignition timing. This is solely driven by the coolant sensor and it adds a value to the value obtained from the basic map. In other words, the ignition timing starts off quite advanced when the engine is cold and gradually this extra advance gets pared off as the engine warms up (richer mixtures tend to burn slower). When the car is fully warm, the correction value is small and constant and can be ignored.

Too Hot to Handle

If the ECU detects that the coolant temperature is getting hotter than normal then it switches in an 'over temperature' correction map for the ignition timing. Presumably this map reduces performance in an attempt to reduce the possibility of engine damage.

Idle Stability

The ECU does a trick with the ignition timing to help maintain a steady idle rpm (throttle must be fully closed for this to activate). At idle the timing is quite retarded (see above simple idle/overrun map). If the idle ever falters slightly the ECU can sense this and it quickly advances the ignition timing with a sudden step. This causes the rpm to rise. Once it senses the rpm has recovered, the step in ignition timing slowly decays away back to the normal value. There are map values in the ECU for the attack/decay time of this idle stability as well as for the maximum amount of extra advance it can add.

Self Learning

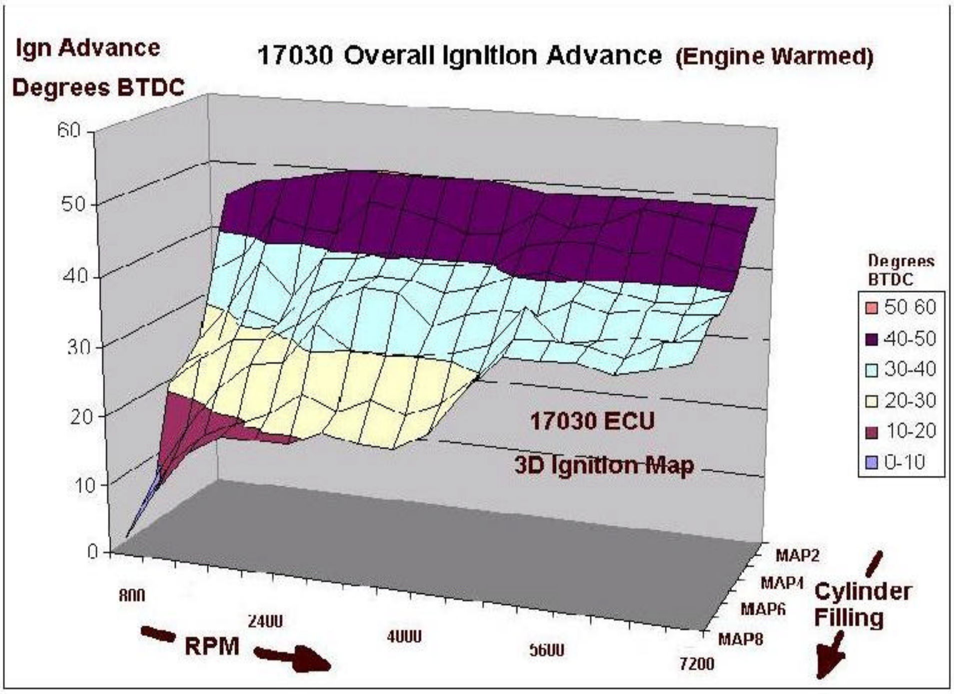
Please note that the ECU in the UK mk1 MR2 has no self learning capability as it has no oxygen sensor. It simply gets the basic ignition timing (and fuelling) from the same old look up tables regardless of driving style, previous driving history or engine age. In fact, the only thing the UK mk1 MR2 'remembers' about previous journeys is if there are any ECU fault codes stored in the micro RAM!

More ECU Secrets

As mentioned in part 2 the ECU has a secret fuel map. It also has a secret 3D ignition map. When the secret map is selected by modding the ECU, the main 3D ignition map above gets discarded and a whole new 17x8 3D ignition map is selected.

IGF Signal

After the ECU sends out the signal to the igniter to trigger a spark it monitors the IGF signal for a confirmation echo from the ignitor unit. The ignitor sends a signal down the IGF wire to the ECU to confirm if a spark has occurred successfully. According to Toyota literature this IGF signal is used to protect the catalytic converter on some overseas models. The exhaust cat can be damaged by being flooded with unburnt fuel. If the IGF signal says no spark has occurred then the ECU cuts off the fuel



injectors to protect the catalytic converter from any unburnt fuel. As the UK mk1 MR2 does not have a cat, this function seems obsolete but it is still there in the ROM code and it does cut the fuel if no spark occurs (it actually waits until there are several failed sparks before cutting the fuel).
Here is a 3D graph showing the ignition advance in degrees BTDC for the 89661-17030 ECU assuming the following conditions: Engine is fully warm, car is being 'driven' i.e. throttle being pressed.

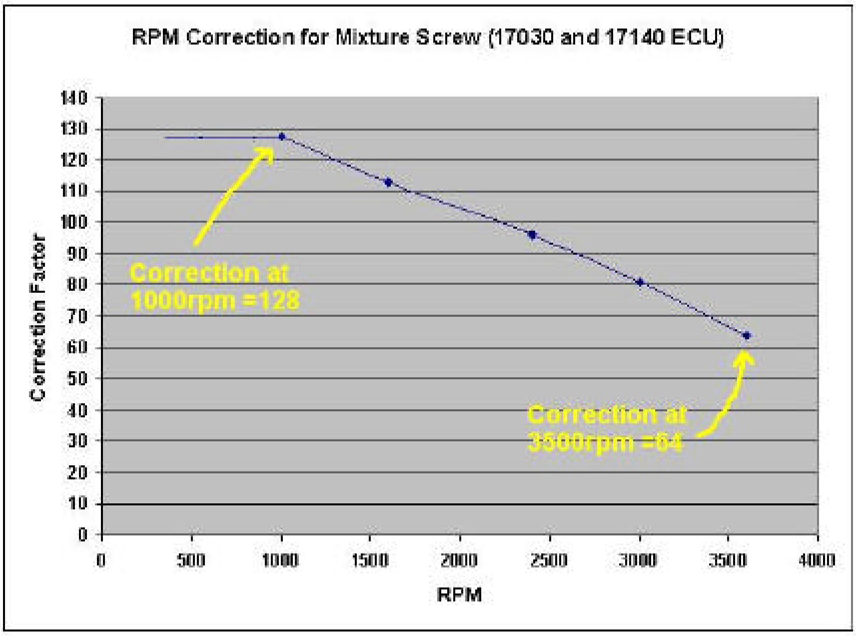
Lifting the Lid on the mk1 MR2 ECU Part 4

In this part I have tried to write something with a broader appeal that would be of interest to quite a few mk1 owners. It concerns the fuel mixture screw that is fitted to the UK mk1 MR2. Setting this screw correctly could improve your mpg!
As most owners are aware, the UK mk1 MR2 has the facility for manual fuel mixture adjustment. This adjuster is located under the engine cover, and is bolted to the top rear of the engine compartment, just behind the TVIS logo. It takes the form of an adjustable resistor that is adjusted using a flat bladed screwdriver. Turning the screw clockwise (mk1b MR2 with 89661-17140 ECU) richens the fuel mixture and turning it anti clockwise weakens it. This screw often gets tweaked at MOT time if your MR2 fails to meet the emissions test. The screw is protected with a black dust cap, but most mk1s will have lost this cap years ago!
The popular belief is that this screw only affects the mixture whilst at idle, and that it has no effect on fuel economy or emissions when actually driving the car. After studying the ROM code in the ECU micro I have found that things are a little more complicated than this!

Lifting the Cap on the AW11 Mixture Screw

Here's how it works on the 89661-17030 and 89661-17140 ECUs. Towards the end of the fuelling calculations the ECU decides whether or not to include the mixture screw correction. It looks at two conditions. First, the engine must be spinning below about 3600rpm. Second, the engine load (indicated by the MAP sensor voltage) must be at a light to medium load setting. Typically these conditions are met when driving the car fairly gently on a light throttle as in an urban environment.

Crunching the Numbers



The ECU reads in the mixture screw resistor setting and converts it to an 8 bit number. This will be in the range 0 to 255. It then compares this reading with the 'mid range' value of 128 to get an initial mixture correction factor. For example, if the ECU reads 155 for the mixture screw setting it subtracts 128 from 155 to get an initial correction factor of +27 (i.e. make it richer). If the reading had been 100 then the factor would be 100-128 = -28 which would weaken the mixture. If the mixture screw was set to give a reading of 128 then the correction factor would be 128-128 = zero. The ECU then consults a further correction map to correct for engine rpm. This is shown below. The map for the 89661-17030 ECU is identical.

This correction map effectively sets the sensitivity of the mixture screw with respect to rpm. As you can see the sensitivity of the mixture screw is mapped to diminish as the rpm increases such that by 3500rpm it has about half the correction compared to 1000rpm.

So what do these numbers really mean? Well, it is actually possible to relate them directly across to fuel injector duration in microseconds.

Let's do a real world example. We'll set the mixture screw to give an ECU reading of 148 and assume the engine is ticking over at 1000rpm.

As indicated above, the mixture correction factor for the screw setting would be 148 - 128 = +20 meaning that this will make the mixture richer. Let's call this factor MX1.

Next we need to get the rpm correction factor from the graph above. Looking at the graph the rpm map points to a correction value of around 128 when at 1000rpm. Let's call this factor MX2.

The ECU then does a quick sum on these two MX numbers as below:

The CHANGE in fuel injector duration would be (MX1 x MX2) divided by 32000

in this case this would be (+20 x 128) divided by 32000 = +0.08 milliseconds (+80 microseconds). By turning the mixture screw up to +20, the injectors will stay on slightly longer and will allow more fuel into the engine. Typically, the total injector duration at idle is around 1.6 milliseconds for a warm engine, so turning up the screw to +20 would increase the fuel injector duration to about 1.68 milliseconds. With this mixture setting you would be using 5% more fuel when sitting at the traffic lights at idle. Quite a sobering thought!

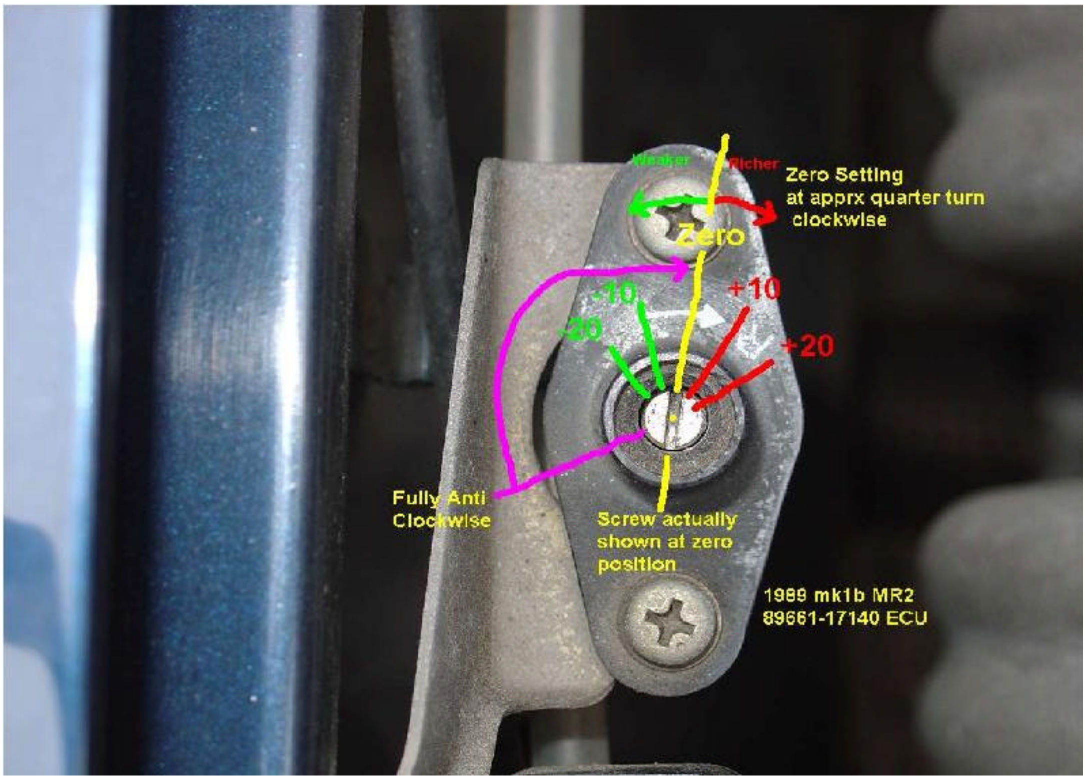
If the rpm is then increased to 3500rpm the extra injector duration correction will be smaller as the graph value of MX2 is only 64 at 3500rpm. This is calculated as:

(+20 x 64) divided by 32000 = 0.04 milliseconds for the same mixture screw setting. Typical injector duration at 3500rpm (light to medium load) is around 3 milliseconds, which means the mixture screw is only adding about 1.3% more fuel at 3500rpm with the screw set to +20. As stated above, once the rpm exceeds 3600rpm this mixture screw correction gets ignored by the ECU.

The number 32000 in the above equation is a fixed division factor used by the ECU to give the correct injector correction in microseconds.

If you use light throttle settings and keep the rpm well below 3400rpm then the setting of the mixture screw has a part to play in the fuel economy of your MR2! I have set mine to read 128, which is zero correction. At the next MOT it will be interesting to see where it gets tweaked to for best emissions.

Join in the Fun!



If you want to know where the zero setting is for the 89661-17140 ECU, then I have included a picture to show where it is on my mk1b. In fact both of my mk1bs show the zero position in the same place visually. First, note where the screw is at present in case you want to put it back where it was. Then turn it fully anti-clockwise. Then turn it just over a quarter turn clockwise and it should be as in the picture below. The picture also shows the +10, +20, -10, and -20 settings. If you go below the -20 setting your MR2 won't tick over too well as the mixture will be too weak.

I noted whilst playing with the mixture screw on both my mk1bs that they appear to have a 'get you home' function built in! If you set the screw fully clockwise or fully anticlockwise (or within a screw slot width of either) the ECU senses this and ignores the mixture screw resistor and sets the correction factor to be spot on zero. The laptop display of the mixture screw setting jumps to zero too. If you ever think your mixture screw has gone dodgy then simply turn it to either end stop position to get a zero mixture correction. Those Japs think of everything…

Crossed Wires

As mentioned in a previous article the wiring for the mixture screw appears different for the various mk1 types. The 89661-17140 mk1b uses a different ECU input pin number for the mixture screw. Although I don't have access to the other mk1 types (to look at the wiring) it appears that the 89661-17030 and 89661-17070 ECUs use a different input pin. This means that the ECUs are not 100% interchangeable and I would guess the wiring looms will differ in this respect too. If I put a 17030 or 17070 ECU in my 17140 mk1b then the mixture screw will not work. The car runs OK otherwise.

89661-17070 Mixture Mapping

Please note that the 89661-17070 ECU mapping is different, it has a 'flat' (rpm graph correction factor always =128) correction map for mixture screw vs. rpm right up to 3800rpm, meaning the mixture screw has equal effect right from idle through to around 3800rpm. This makes the setting of the mixture screw MUCH more important with respect to urban fuel economy if you have an mk1 with this ECU fitted. With the screw set on the rich side you could be needlessly burning excess fuel right up to 3800rpm! As hinted at in previous articles, the 17070 ECU is a bit of an oddball (nothing to get alarmed at though) and I actually wonder if this ECU was really aimed at a different part of the World with a different climate to the UK.
I'll do an article on this ECU later in the year to explain why.