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PART 3: THE MAP

CONTROL CENTRE

Here we are with the third and final part of Stu's engine management tutorial.

I HOPE you learnt a little in parts one and two, and that you now have a working understanding of what makes the engine management system tick, and how each separate item plays its role in the whole package.

We've previously discussed the sensors, how they work and what they feed out (issue 247).

We have also discussed the ECU, what inputs it reads and what hardware it actually drives as well as how the two basic configurations differ (Speed Density and Mass Air Flow, covered in issue 248), so what's the missing link?

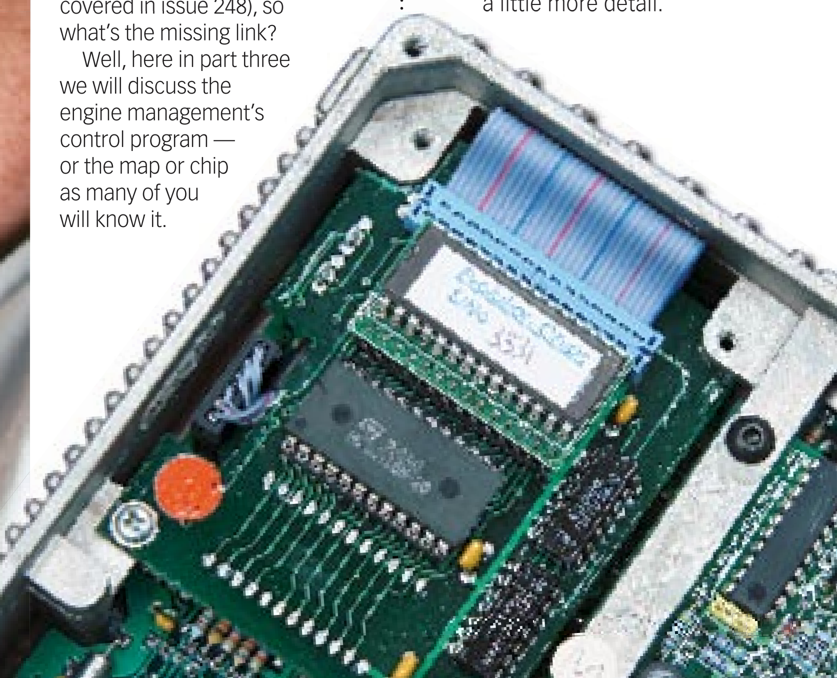
Well, here in part three we will discuss the engine management's control program — or the map or chip as many of you will know it.

OUTPUT CONTROL BRIDGE

The ECU has various inputs from water, air, pressure and speed sensors to name just a few. It also has its outputs such as idle valves, injectors and boost control valves. But how does it decide what to do with its outputs?

Every ECU will have an engine control map programmed within it that allows it to operate its outputs with reasonable intelligence using a system of logical control parameters.

Let's look into this subject in a little more detail.



3 x16 — RPM — Load

RAM2	600	800	1000	1200	1400	1600	1800	2000	2300	2500	2700	3000	3500	4000	4500	5500
4.9	206	206	212	203	208	208	209	209	209	209	215	231	241	251	240	230
4.5	181	181	185	177	181	181	182	182	182	182	189	200	210	214	209	198
4.1	158	158	160	157	156	156	158	159	158	157	164	170	181	179	180	167
3.7	141	141	141	137	135	136	137	140	138	136	142	145	156	150	154	146
3.3	122	122	122	116	114	116	116	119	118	116	120	120	130	125	128	124
2.9	102	102	102	094	094	096	096	099	100	097	100	096	107	103	103	103
2.5	078	078	080	070	071	075	074	076	078	076	078	074	082	078	079	081
2.1	059	059	060	053	054	059	057	058	061	061	062	057	064	060	060	064
1.7	041	041	043	039	040	042	040	040	043	046	045	041	049	044	044	048
1.3	027	026	029	027	027	030	028	028	030	033	030	028	033	029	028	034
0.9	013	012	013	015	016	018	017	017	019	020	015	015	017	013	014	018
0.5	009	008	008	009	010	012	010	010	013	011	012	010	010	007	007	012
0.1	005	006	006	006	005	005	005	005	005	004	004	004	003	002	002	002

10 x 16 — RPM — Load

RAM2	7000	6600	6100	5300	4500	4000	3500	2900	2300	2000	1800	1500	1300	1000	800	600
4.9	6.25°	4.75°	3.75°	4.00°	6.00°	3.00°	2.00°	1.25°	1.25°	0.00°	5.75°	6.25°	7.00°	7.50°	7.50°	9.00°
4.4	11.00°	10.50°	11.50°	9.75°	10.00°	8.00°	5.50°	3.00°	2.25°	2.25°	7.50°	8.50°	9.50°	8.75°	8.75°	9.00°
3.8	16.50°	15.75°	17.50°	15.50°	14.50°	12.50°	10.50°	7.00°	5.50°	5.50°	8.25°	10.00°	11.00°	10.00°	10.00°	9.00°
3.3	22.50°	22.00°	20.50°	18.50°	19.75°	17.75°	17.00°	15.25°	11.75°	11.50°	11.50°	13.50°	12.00°	11.00°	12.25°	9.00°
2.8	24.25°	23.50°	21.75°	20.00°	22.75°	22.25°	21.25°	21.00°	19.50°	18.75°	16.00°	17.00°	14.00°	13.00°	14.75°	9.00°
2.2	25.00°	25.00°	26.00°	25.00°	25.00°	25.00°	25.00°	25.00°	25.00°	23.75°	22.75°	19.50°	14.25°	14.00°	17.00°	15.75°
1.7	25.00°	25.00°	29.50°	25.00°	25.00°	25.00°	25.00°	25.00°	25.00°	25.00°	25.00°	21.00°	15.50°	15.00°	17.00°	20.00°
1.2	25.00°	25.00°	30.00°	25.00°	25.00°	25.00°	25.00°	25.00°	25.00°	25.00°	25.00°	22.00°	16.75°	16.00°	16.00°	20.00°
0.6	25.00°	25.00°	30.00°	25.00°	25.00°	25.00°	25.00°	25.00°	25.00°	25.00°	25.00°	22.00°	17.75°	16.00°	16.00°	20.00°
0.1	25.00°	25.00°	30.00°	25.00°	25.00°	25.00°	25.00°	25.00°	25.00°	25.00°	25.00°	22.00°	19.00°	18.00°	18.00°	20.00°

Top. The base fuel map. Top to bottom is pressure, left to right is engine speed

Bottom. Base spark advance map. Again, top to bottom is pressure, left to right is engine speed

THE BASIC FUEL-INJECTION MAP

Every control map will have a base-fuelling map. This map will have been developed with the engine at full normal operating temperature, — likely on a dyno first of all — for many 10s if not 100s of hours.

This finalised fuel map will cover all manner of throttle/load/speed combinations and will run the engine correctly whether idling at 850 rpm on your driveway or flat out on the Autobahn with 15 lb of boost pressure rushing into it at 8000 rpm.

THE BASIC SPARK ADVANCE MAP

Every control map will also have a base spark advance map. As with the fuel map, this will have been developed over 100s of dyno and road hours and real-life testing. It will be suitable for pretty much any speed and load combination you wish to throw at it mile after mile, day after day.

THE MULTIPLIER MAPS

The problem with the two base maps described is this: they will only ever be correct when the engine is operating in the exact same conditions that the map was developed under. In most cases this is with the intake air at 40 degrees C, and the water temperature in the engine block at around 88 degrees C.

So what happens when these parameters change? Morning, noon and night, Spring, Summer, Autumn and Winter? Yes, the figures you can see in the base maps will be substantially incorrect and the engine would run badly, if at all.

To rectify this, there exists a whole host of additional maps that either add or subtract values from the main base maps depending on input data from your multitude of sensors. This is the way temperature and additional external influences are dealt with in 90 per cent of management systems. Please read on for examples of how the various multiplier maps influence the running of your engine under different conditions.

MAP SENSORS AND AIRFLOW METERS

In our example fuel map, can you see the scale on the left? That scale is essentially load. The scale itself in this example is actually scaled in volts, and it is zero to 4.9 volts out of a MAP sensor. It would be similar for an airflow meter. The more load the engine is under, the higher up that scale the fuel injector switch-on time will be read from at any given rpm — for example, full boost and 5500 rpm will read a value of 230 from the map.

The figure itself equates fuel injector opening time into a decimal number and is of little consequence to this actual discussion, but to oversimplify the system, let's just say it gives the ECU the ability to vary the injector opening time between fully closed and fully open.

In an old fashioned system like a Cosworth you can have anywhere from zero (closed) to 255 (always open), but more modern systems can be 0-255000. So, as you might expect, the 230 in that table is running the injectors quite hard indeed. Imagine what would happen if the MAP sensor only delivered 2.5 volts instead due to a wiring issue, or the pipe leaked due to a missing clip so it didn't get the same boost as the plenum... The management computer would, of course, deliver a totally incorrect amount of fuel from totally the wrong area of its fuel map.

When looking at the spark map, the same is true, the more load an engine is put under, the less advance is normally required.

As many of you will know, too much advance can spell death to any petrol engine, so it is very important that the correct figures are delivered to ensure good performance and engine life.

ENGINE SPEED SENSOR

You see the scale on the top of our example fuel base map? OK, as you have likely guessed by now, that is the scale used to determine how much fuel is added to the engine at different rotational speeds.

Due to the fact an engine's volumetric efficiency (VE) value is different at virtually every different rotating speed, the fuel level injected into the cylinder at low speed can be very different to the requirements at high speed. Conversely, as an engine's speed increases so does its advance requirements, so it's important that the speed signal is correct to avoid us over or under-advancing the engine, especially as the former can be deadly.

Hopefully, it is easy for you to see how a malfunctioning crankshaft speed sensor can create havoc with your fuelling and spark advance maps.

WATER TEMPERATURE MULTIPLIER

One of the biggest variables on a modern engine is its actual temperature. This is measured on almost every engine by the simple water temperature sensor screwed into the cylinder head or surrounding areas.

I should mention in case you don't know, that the colder an engine actually is, the more fuel it requires to make the same power. So, when the engine is at -5 degrees C, it will require far more fuel to idle than it will after it has been running for 30 minutes and the water is up at 90 degrees C.

So, how does the ECU actually work out how much fuel to add and when? Well, there will be a map inside the ECU that graphs the water temperature separately in degrees and each reading (or breakpoint as we call it) will have a multiplier figure for the fuel map.

In the example shown here we have what is essentially the following instruction. "If the water temperature is 5 degrees C, multiply the fuel map by 1.52 (adding some 52 per cent more fuel)."

So, if for argument's sake our base fuel map adds 1 millisecond of fuel at idle speed with the engine fully hot, the warm-up map changes that to 1.52 milliseconds if the water is at 5 degrees C. Typically it will be fully mapped from -55 C to +125 C.

The same situation is true for spark advance; it has its own water temperature-based multiplier map that allows more advance on a cold engine as this is what gives best results. Once again, incorrect application here can spell death, too. Do you see how this system works? Good, onto air...

AIR TEMPERATURE MULTIPLIER

Arguably the second biggest variable is the air temperature. This is because air is actually denser when it is cold than when it is hot. For argument's sake let's pretend our air is at 5 degrees C — it actually carries more oxygen at this temperature than air at 40 degrees C did when the base fuel map was made, and thus it requires more fuel adding to it to keep the air fuel ratio correct in the combustion chamber. Again, it normally has a side map almost identical to the water temperature one that simply adds and subtracts from the base fuel map to keep the mixture correct for all air temperatures. Typically it will be mapped from -55 C to +125 C.

Due to this air density change, the spark advance requirement also changes with the temperature of the air, cooler air requiring a different advance figure than hot air to generate peak cylinder pressure at the same point. Naturally, this map being accessed incorrectly could either retard the engine and lose lots of power, or over-advance the engine and destroy it completely.

BATTERY VOLTAGE MULTIPLIER

You may be wondering what battery voltage has got to do with the fuel map. You would be forgiven for not knowing as it's not the most obvious thing in the world. It is extremely important and one of the least-understood things in the modifying business.

The injectors at 13.8 volts operate at a certain speed, going from closed to open, and from open to closed. As the voltage drops, the time taken to open and close increases, and therefore, they must be held open for a longer time than in the normal fuel map due to the fact the injector will have spent more of its given allowance actually opening and closing.

Let's elaborate: if, for example, we are at idle and the injector is being told to open for 1 millisecond (ms), it will actually spend about 0.2 ms of that time opening and 0.2 ms of that time closing, so the fuel required to idle smoothly is actually injected in 0.6 ms. Understand that? OK, so now let's say we drop the battery voltage down from its nominal 13.8 to 11 and discover the injector nozzle now takes 0.4 ms to open and 0.4 ms to close. This means we now only have 0.2 ms to inject fuel, which we have already established is not enough, so the solution is? Yes, you guessed it; we need to open the injector for 1.4 ms if the batter voltage is this low to account for the dropped opening and closing speed.

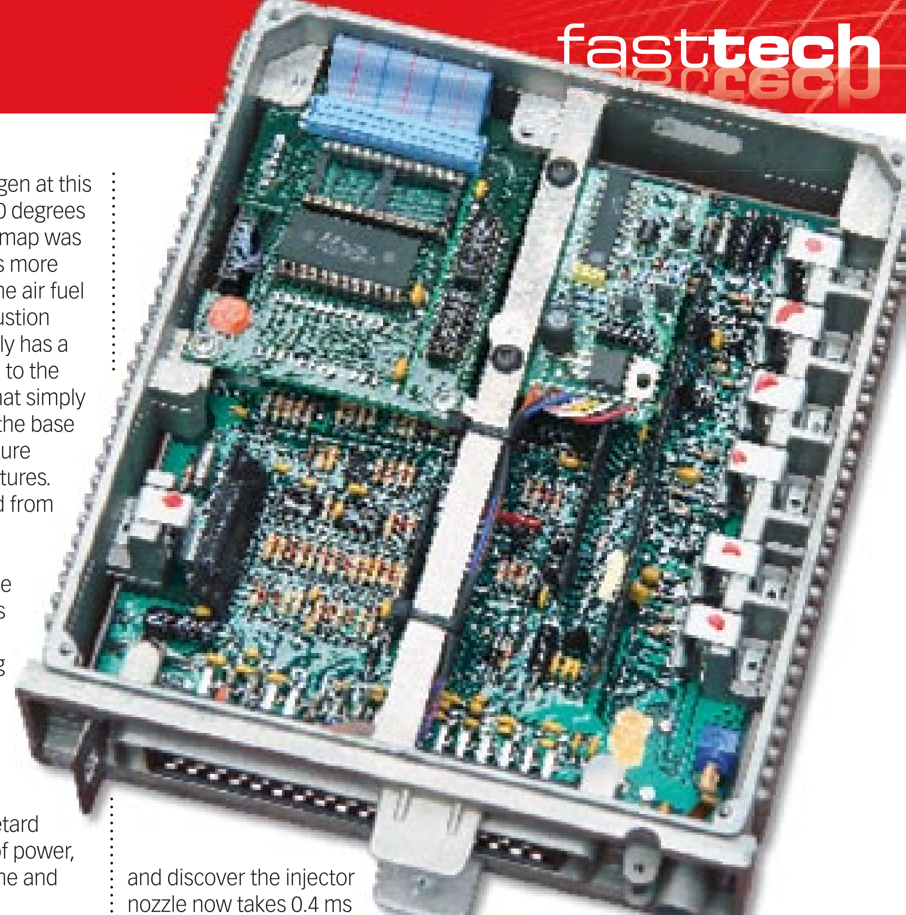
This is infinitely variable so also has its own table, normally spanning around 9-15 volts in very small increments. Interestingly, what do you think would happen to a highly-tuned car when flat out on the motorway and the alternator starts to die due to your massive high-power stereo draining it to death? Yes, I have seen many engine failures attributable to this. Take care out there music lovers...

THROTTLE POSITION MULTIPLIER

Throttle position has various multiplier maps connected to it, the most common one being injection at wide open throttle (WOT). This map, as its name suggests, actually alters the amount of fuel injected when you go to wide open throttle. It can be mapped in many different ways, but most commonly you find that the main fuel map is erred slightly towards generating maximum power and the wide open throttle multiplier adds a little more to keep a check of the exhaust gas temperatures generated under hard-use conditions.

It is also used to control many transient fuel correction parameters which take care of unusual things like fuel hesitations when you move the throttle from one place to another, and other very complex things related to fluid dynamics that this article just doesn't have enough room to deal with.

Again, given that extra fuel is needed at wide open throttle, the sensor failing to inform the ECU of



Top. Fuel enrichment multiplier. More fuel is added when cold, and gradually decreases as engine warms up

Bottom. Wide Open Throttle map. This is the map that adds extra fuel when you mash your foot to the floor. At 5500 rpm we have 1.24 x the fuel listed in the base map

1 x 16 — Temp — Load

RAM2	-55	-43	-31	-19	-7	+5	+17	+29	+41	+53	+65	+77	+89	+101	+113	+125
100	183	186	186	178	167	152	136	126	119	112	106	101	100	100	100	100

1 x 16 — RPM — Load

RAM2	600	800	1000	1200	1400	1600	1800	2000	2300	2500	2700	3000	3500	4000	4500	5500
100	101	101	109	108	108	110	112	114	119	119	120	121	127	131	130	124

1 x 16 — Temp / Load

RAM2	-55	-43	-31	-19	-7	5	17	29	41	53	65	77	89	101	113	125
100	100	092	088	081	070	061	052	043	037	029	018	001	000	000	000	000

8 x 16 — Load / RPM

RAM2	100	94	88	81	75	69	63	56	50	44	38	31	25	19	13	6
2500	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
3000	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
4000	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
5000	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
5800	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
6000	253	253	253	253	253	255	255	255	255	255	255	255	255	255	255	255
6500	230	239	252	253	253	255	255	255	255	255	255	255	255	255	255	255
6800	200	217	236	246	253	255	255	255	255	255	255	255	255	255	255	255

Top. The idle speed control map. This map shows how the valve is told to open more, the colder the engine is, giving you the raised cold idle speed

Bottom. The boost map. Top to bottom is rpm, left to right is load. This map controls your boost control solenoid and thus your boost curve

this position can be deadly, and one reporting it too early can cause big over fuelling problems.

KNOCK SENSOR MAPS

The map attributable to the knock sensor on most system is based on load and rpm. When knock is detected by the sensor it looks up its load and speed position in the table and retards the timing by the amount dictated there or until the knock stops.

The knock table is essentially a table that dictates how severe the retard is. This table exists as it will require less retard to make the engine safe at low rpm/low load than it does at high rpm/high load. Some more modern systems are now fully active and constantly advance or retard the ignition, keeping the engine on the verge of knock where maximum power can always be found.

Obviously when the knock sensor reports knock that doesn't exist we end up with a retarded and non-responsive engine. Conversely, when it fails to report knock that is actually present we can end up with an over-advanced or totally-destroyed engine.

LAMBDA CORRECTION MAPS

Since 1992 pretty much all engine management systems in the world are operated in closed-loop mode with the help of a Lambda sensor. The output of the Lambda is monitored and when fuelling is not at the chemical correct ratio of 14.7 parts air to 1 part fuel — the ECU automatically richens up or leans off the mixture to compensate. How much it does so varies according to these Lambda correction maps. Low load only requires low correction and higher loads require more drastic correction.

These correction maps are essential to stop the ECU over compensating and getting stuck in a rich-lean loop it cannot correct. When the Lambda sensor input is faulty the ECU will try to compensate based on the information it is given, leading to a too rich or too lean situation.

IDLE SPEED COMPENSATION MAPS

The idle speed control valve is often a source of problems on many old Fords.

This valve is controlled by a map in the ECU, that essentially dictates what pulse width is sent to the valve. The pulse width at the valve controls how much air is allowed to flow, and this controls the idle speed directly. The map is normally based primarily on temperature; when the engine is cold the idle speed needs to be higher to maintain a stable idle speed, so the ECU looks at the temperature and takes the required pulse width out of the map that will give the correct idle speed.

Typically, as the engine warms up the map delivers less and less pulse width to the point the valve has no effect at all. Some systems also work the valve in other situations such as when heavy loads are applied to an engine that may stall it, such as air conditioning activation at idle. Naturally, a faulty valve can lead to stalling of the engine or too high an idle speed, but conversely so can any sensor error that causes the idle speed map to drive the valve incorrectly, such as a coolant sensor error telling the idle map that the engine is in fact hot when it is really cold.

BOOST MAPS

The boost pressure on virtually all production turbocharged engines is controlled by a boost pressure solenoid. This solenoid, as you will no doubt have guessed is controlled by its own map in the ECU.

This map (or more commonly maps) can be controlled by a multitude of things such as load, engine speed, throttle position and air temperature, not to mention barometric pressure, gear selection and road speed; either way, the map works in a similar way to the idle speed control valve, essentially controlling a pulse width output to the valve itself that in turn controls how much air reaches the wastegate actuator, or how much air is bled away from it, depending on whether the system is a bleed-on or bleed-off design.

Faults with this valve normally mean a lack of, or too much boost pressure, and faulty sensors can cause the pulse width delivered by the ECU to be incorrect, such as an air temperature sensor reporting extremely hot air, or a knock sensor reporting detonation. As you are no doubt aware by now, everything is very tightly interlinked.

Well, that about covers the basic maps that we deal with everyday as an ECU mapper, but there are literally many 100s more maps in a modern ECU — yes, 100s more.

You would probably be quite shocked if I were to show you every map in a modern ECU, but suffice to say that the ones I have shown you are the mere basics and don't even scratch the surface of a modern engine control system.

But they are still the foundation maps upon which all management control programs are built.

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NEXT MONTH

Cylinder heads: how valve and port sizes affect power, plus how much difference can they really make?