Words: Stewart Sanderson
Photos: Michael Whitestone

WHAT IS MAPPING?

This month Stu gives us the first of his master class series on the theory behind mapping and why your Ford might need it.

Having worked as a tuner for 17 years, Stewart 'Stu' Sanderson is one of the most-respected names in the business.

A Level 5-trained fuel-injection technician, in the past Stu has worked for a Ford Rallye Sport dealer, a well-known fuel-injection specialist and various tuning companies.

Then seven years ago he joined forces with Kenny Walker and opened up Motorsport Developments near Blackpool (01253 508400, **www.remapping.co.uk**), specialising in engine management live remapping, as well as developing a range of Evolution chips which are now sold all over the world.

He's also jointly responsible with Webmaster, Petrucci for www.passionford.com. Started in 2003, it's grown rapidly from a few friends contributing, to one of the biggest Ford communities on the web.

Stu's enviable knowledge of the workings of modern-day Ford performance engines means that every month he's just the man to explain how and why things work, and most importantly how they can be improved.

As most of you will know, what we actually specialise in at Motorsport Developments is all forms of Original Equipment and aftermarket engine management system live mapping. Since this is often thought of as some form of black art I figured it was high time that I explained in some depth just what mapping actually is and why you as an enthusiast need it for your modified Ford.

MAPPING? WHAT'S THAT?

Mapping is the term given to the act of changing an engine management system's calibration file.

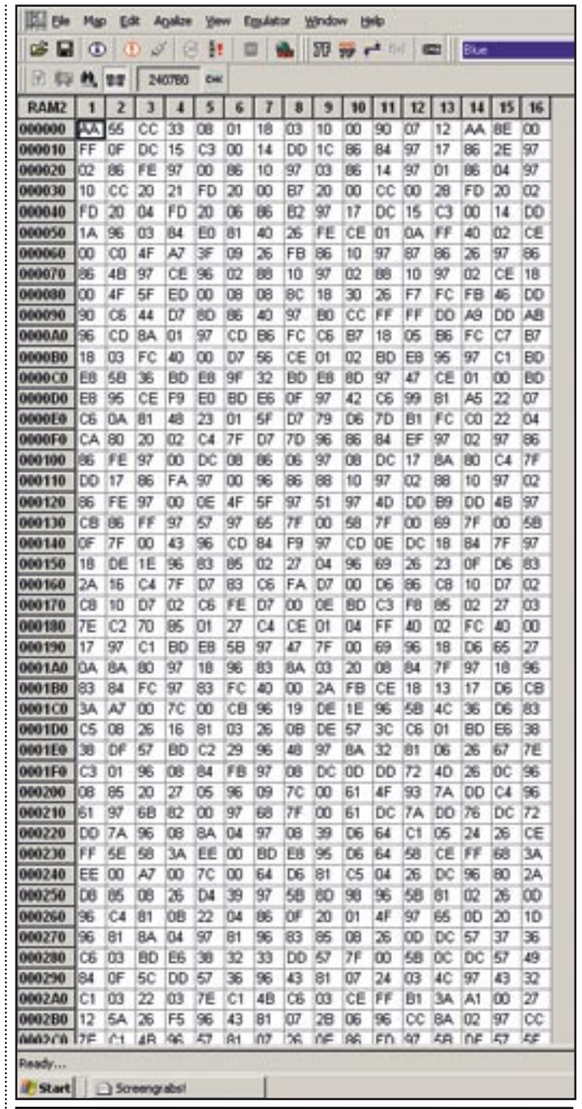
Now that is all well and good if you happen to know what a calibration file (or map as it is commonly known) actually is, but if like 90 per cent of the motoring population you actually don't, then read on...

THE MAPS

All electronic fuel-injected engines are controlled by an electronic control unit (ECU for short), which is constantly hooked up to sensors that feed it live data telling it everything there is to know about the engine's dynamic conditions such as water, air and fuel temp, throttle angle, engine speed, air density and manifold pressures.

The ECU uses this input data in conjunction with a reference program to see what exactly it needs to do, such as what fuel injector duration to supply, or maybe when to fire the spark plug, to name just the two most critical factors.

These tables also tell it when to do a number of other engine control related things such as how to idle, what cam timing to run, what boost pressure to run the turbo at and even when to vent fumes from the fuel tank into the engine for nice clean emissions, not to mention when to disable your lovely air



RAM2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
000000	AA	55	CC	33	08	01	18	03	10	00	90	07	12	AA	BE	00
000010	FF	0F	DC	15	C3	00	14	DD	1C	86	84	97	17	86	2E	97
000020	02	86	FE	97	00	86	10	97	03	86	14	97	01	86	04	97
000030	10	CC	20	21	FD	20	00	B7	20	00	CC	00	28	FD	20	02
000040	FD	20	04	FD	20	06	86	B2	97	17	DC	15	C3	00	14	DD
000050	1A	96	03	84	E0	81	40	26	FE	CE	01	0A	FF	40	02	CE
000060	00	C0	4F	A7	3F	09	26	FB	86	10	97	B7	86	26	97	86
000070	86	4B	97	CE	96	02	B8	10	97	02	B8	10	97	02	CE	18
000080	00	4F	5F	ED	00	08	08	BC	18	30	26	F7	FC	FB	46	DD
000090	90	C6	44	D7	8D	86	40	97	B0	CC	FF	FF	DD	A9	DD	AB
0000A0	96	CD	8A	01	97	CD	B6	FC	C6	B7	18	05	B6	FC	C7	B7
0000B0	18	03	FC	40	00	D7	56	CE	01	02	BD	E8	95	97	C1	BD
0000C0	E8	5B	36	BD	E8	9F	32	BD	E8	8D	97	47	CE	01	00	BD
0000D0	E8	95	CE	F9	E0	BD	E6	0F	97	42	C6	99	81	A5	22	07
0000E0	C6	DA	81	48	23	01	5F	D7	79	D6	7D	B1	FC	C0	22	04
0000F0	CA	80	20	02	C4	7F	D7	7D	96	86	84	EF	97	02	97	86
000100	86	FE	97	00	DC	08	86	06	97	08	DC	17	8A	80	C4	7F
000110	DD	17	86	FA	97	00	96	86	88	10	97	02	B8	10	97	02
000120	86	FE	97	00	DE	4F	5F	97	51	97	4D	DD	B9	DD	4B	97
000130	CB	86	FF	97	57	97	65	7F	00	58	7F	00	69	7F	00	5B
000140	0F	7F	00	43	96	CD	84	F9	97	CD	0E	DC	18	84	7F	97
000150	18	DE	1E	96	83	85	02	27	04	96	69	26	23	0F	D6	83
000160	2A	16	C4	7F	D7	83	C6	FA	D7	00	D6	86	C8	10	D7	02
000170	C8	10	D7	02	C6	FE	D7	00	0E	BD	C3	F8	85	02	27	03
000180	7E	C2	70	85	01	27	C4	CE	01	04	FF	40	02	FC	40	00
000190	17	97	C1	BD	E8	5B	97	47	7F	00	69	96	18	D6	65	27
0001A0	0A	8A	80	97	18	96	83	8A	03	20	08	84	7F	97	18	96
0001B0	83	84	FC	97	83	FC	40	00	2A	FB	CE	18	13	17	D6	CB
0001C0	3A	A7	00	7C	00	CB	96	19	DE	1E	96	5B	4C	36	D6	83
0001D0	C5	08	26	16	81	03	26	0B	DE	57	3C	C6	01	BD	E6	38
0001E0	38	DF	57	BD	C2	29	96	48	97	8A	32	81	06	26	67	7E
0001F0	C3	01	96	08	84	FB	97	08	DC	0D	DD	72	4D	26	DC	96
000200	08	85	20	27	05	96	09	7C	00	61	4F	93	7A	DD	C4	96
000210	61	97	6B	82	00	97	68	7F	00	61	DC	7A	DD	76	DC	72
000220	DD	7A	96	08	8A	04	97	08	39	D6	64	C1	05	24	26	CE
000230	FF	5E	58	3A	EE	00	BD	E8	95	D6	64	58	CE	FF	68	3A
000240	EE	00	A7	00	7C	00	64	D6	81	C5	04	26	DC	96	80	2A
000250	D8	85	08	26	D4	39	97	5B	8D	98	96	5B	81	02	26	00
000260	96	C4	81	0B	22	04	86	0F	20	01	4F	97	65	0D	20	1D
000270	96	81	8A	04	97	81	96	83	85	08	26	0D	DC	57	37	36
000280	C6	03	BD	E6	38	32	33	DD	57	7F	00	5B	0C	DC	57	49
000290	84	0F	5C	DD	57	36	96	43	81	07	24	03	4C	97	43	32
0002A0	C1	03	22	03	7E	C1	4B	C6	03	CE	FF	B1	3A	A1	00	27
0002B0	12	5A	26	F5	96	43	81	07	2B	06	96	CC	8A	02	97	CC
0002C0	7F	C1	4B	96	A7	81	07	26	0E	A6	F0	97	5A	0F	57	5F

Nonsense? No. This calibration file or map can be read by the ECU

BEFORE STARTING...

The first rule of working on cars and using tools of any kind is don't ever skimp on decent protection. Goggles, gloves, ear defenders, masks and a set of overalls should be in your garage. Use them.

When using power tools, protective gear is essential — grinders and welders can make a real mess of your soft skin and bone if you get it wrong.

Never work under a car without supporting it using axle stands. A car falling on you is not something you'll be laughing about down the pub.

fasttech

The ECU takes its information from maps, usually stored on an EPROM or chip. On this 4x4 Cosworth ECU, the chip has been removed, but would be located in the lower right-hand corner

conditioning to save bhp when you need it most.

This information truly does just scratch the very surface of a modern engine management calibration, but hopefully you will all remember my past articles on engine management computers and the sensors that are used to feed them with the vital information they require to perform their duties. We have also covered the sensors own related ECU maps in the past too, so if you missed them, please grab back issues 247, 248 and 249 for a very in-depth explanation of how these management systems work. Now, back to mapping...

WHY DO I NEED MY CAR MAPPING?

Since the ECU contains all the parameters for your fuel injection system to deliver its goods, if you make any modifications to the engine that change the amount of fuel required, or changes the amount of spark advance required, you will have to get the management system remapped to ensure it does what it's supposed to do with regards sparking the plugs and delivering fuel from the injectors — not to mention how to drive the idle valve for best idle stability and cold running. In short, your engine modifications will probably not actually have the desired effect until you reprogram the ECU so it knows the mods are there and what it needs to do about them.

As a simple and very common example: if you fit a nice ported cylinder head to your car, you can reasonably expect it to flow more air at high revs due to the new bigger inlet and exhaust ports, but you must never forget that this extra air requires extra fuel if it is to make any extra power. In fact, without the extra fuel you will normally lose power due to the fact you have leaned out what was once a perfectly good fuel mixture. There is of course always the danger that if you lean it out too far, you will melt the pistons.

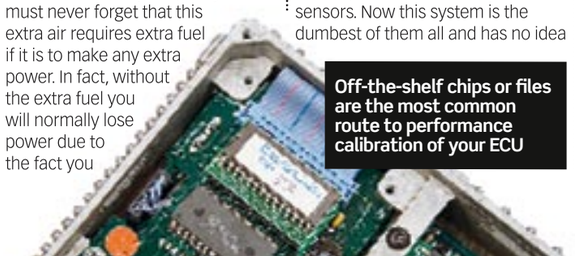
The reason for this is quite simple but may not be quite as obvious if you who don't understand ECUs and management, so I will try to explain what happens if you modify your engine beyond the scope of the ECU calibration.

CALCULATIONS

When an ECU calculates how much fuel to add to the air, it does so in one of two ways. The simplest is the speed density calculation using a combination of manifold pressure, throttle, air and water temperature sensors. Now this system is the dumbest of them all and has no idea about airflow at all, and can only do what its calibration tells it to do. As an extreme example for illustration purposes let's look at this scenario.

A Cosworth Sierra had 204 bhp as standard with 8 psi of boost at around 6000 rpm on a T3 turbocharger. However, a Cosworth with a nicely-ported cylinder head and some sensible camshafts, allied to a Garrett GT35 turbocharger can make over 350 bhp with the same 8 psi of boost at the same 6000 rpm. The problem is, if you were using the same ECU calibration as the standard car, the ECU will only inject enough fuel for 204 bhp, as that is all the standard calibration program is telling the ECU to do when it sees 8 psi and 6000 rpm.

That is heavily over-simplified but I hope it makes sense and illustrates how an ECU can only do what it is told to do when it was calibrated. In a nutshell, because we have changed how much air flows through the engine with any given engine's planned power output. Extra air from this point on just leans the system out as the calibration is not programmed to see it.



Off-the-shelf chips or files are the most common route to performance calibration of your ECU

The second big problem with MAF calibrations is usually created by camshafts with long duration. These long duration cams tend to create a lot of overlap that plays havoc with gas speeds. This means the gas speed can drop massively and in turn, the airflow meter can no longer see the airflow. Worse still, you can generate backflow with high overlap camshaft figures and that means air going through the mass meter the wrong way!

The MAF meter isn't direction conscious, so it presumes the air is going into the engine and it adds more fuel... Instant rich condition and poor driveability are the only result. Expert mapping can correct all these conditions and of course many more we haven't even touched upon.

Custom chips are based on off-the-shelf items, but the maps are tweaked to suit your engine

MY ENGINE NEEDS MAPPING, WHAT ARE THE OPTIONS?

There are various ways to go about having your maps changed to better suit your mods and all vary in both price and effectiveness.

1. OFF THE SHELF

Option one is to have what we call an off-the-shelf program. This is a performance calibration for your management system that will remove various compromises written into the software by the manufacturer and has basic performance mods. These include leaning off excessive rich mixtures that the OEMs use and running a little more advance due to the fact that as an enthusiast you will be using better fuel than the garbage they had to program it for, just in case you put it in there after you bought the car. Sometimes the rev or speed limiters are increased or removed too.

These files can be installed in EPROM form just like the old days, or 'flashed' in via the car's diagnostic port which leaves no tell-tale signs of modification. These files are basically programmed all the same for each type of car/ECU and engine combination, so if it doesn't really do much for your car, it's tough. It may work for some and not others due to the fact all engines tend to vary somewhat.

2. CUSTOM MAP

Option two is a custom map. This is a performance calibration for your pressure, we have to inform the ECU and program in what is required of fuel, spark and so on.

The second common system seen on your Ford is the mass airflow system.

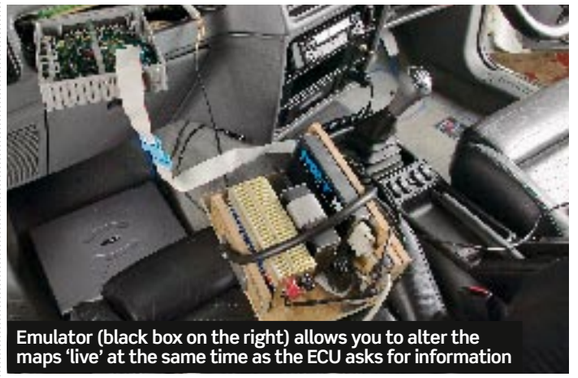
This system is a lot better with regards self-compensation as it uses a MAF (Mass Air Flow) meter to give the ECU some idea about actual airflow, and not just pressure as per the speed density system. With this system you can flow a little more air and still be OK, but two things commonly create big problems for it. Firstly, you may increase the flow so much you get to the point where Ford had no longer programmed any further. This is quite easy to do with a good cylinder head and sensible cams.

This scenario means it goes very lean up in the power area as the ECU is of course only programmed up to a certain limit, above which it was deemed unnecessary to do any more programming work as they were already beyond the production management system that is far better than the simple off-the-shelf calibration but not at all as accurate as a live map, so a compromise.

With custom mapping, you basically start with an off-the-shelf chip as explained above, and it is then tweaked time and time again to get the best out of your engine. The tuner would test drive the car, make notes on paper as to what rpm/throttle etc problem arises, and then modify the map on a computer, program another chip, fit this to the ECU, then go out again and see what difference it has made. This is basically repeated until the tuner is happy with the outcome.

This is the option normally chosen by people with not quite enough cash to get the car mapped live, but want more than an off-the-shelf program for their cherished chariot. It's worth noting that this is quite often the only way a tuner can work if they haven't got the necessary expensive equipment to live map, so they painstakingly tune this way.

Some systems cannot be live mapped, such as Pectel hardware-equipped IAW P8 systems. Good results are certainly possible



Emulator (black box on the right) allows you to alter the maps 'live' at the same time as the ECU asks for information

Wide-band air/fuel ratio monitor is essential kit when live-mapping

Det cans (usually bolted to an inlet manifold stud) are needed to listen for detonation while live-mapping

from custom mapping but it is very hard and time consuming to perfect anything in this way, as it is so drawn out and long winded, not to mention a little inaccurate by its very nature. A great middle ground though as long as you use a competent professional.

3. LIVE MAP

Option 3 is a live map — the daddy of the mapping world. Live mapping is a little like custom mapping but on a far grander scale. With a live map you have your chip completely removed and a laptop is connected in its place via a piece of hardware called an emulator.

Once this system is installed the maps can be accessed live and altered at the same time as the ECU is asking for the information. This means if for example you have a hesitation at 50 mph in fourth gear, you can drive the car to that speed and easily see and access the point in the map that is wrong so you can correct it there and then, whilst driving the car using that current data.

This allows you to literally feel the result of map changes as you perform them whilst simultaneously watching the fuelling on your wide-band fuel monitor, watching boost levels etc and listening for detonation. There is no substitute for live mapping. It is the ultimate way to tune an ECU. Period.

This list of maps and switches on a Focus RS ECU is just for the fuel injectors alone...

WHAT DO THE MAPS CONTAIN?

Each system is different but your average Ford EEC IV and V ECU calibration contains over 300 end-user controllable maps and calibration switches. Everything from fuel and spark to maps that adjust things based on coolant and air temperature, as well as battery voltage and barometric pressure.

Modern ECUs also have adaptive tables that allow the ECU to learn how to fuel your engine correctly as it wears out, meaning less tuning to be done and less time for the car off the road.

Every map is dedicated to at least one individual running factor, such as spark control, but this factor may require over 50 different maps and calibrations to make it work to the satisfaction of the original manufacturer. The levels of accuracy built into modern ECUs is mind blowing, and the average aftermarket ECU like Motec and DTA can only dream of being even close to as good.

HOW DOES A MAP WORK?

Let's take two of the most common maps from two of the most common systems, and look at how they work and then it may give you some idea of what's going on within the ECU and how the information ends up being wrong after you have tuned your engine.

1. Speed density system
2. MAF System

The way they both work is quite simple to explain:

The left column is the engine's load. On the speed density system this is calculated using the map sensor, on the MAF system it is calculated using actual air travelling through the engine and worked out as volumetric efficiency.

The top row is RPM. This is hopefully self explanatory to you all? So, at any given load and rpm, the ECU simply takes the value at that juncture and uses it to deliver fuel to the engine. The speed density system inputs fuel based on pure manifold pressure as explained earlier, so if you changed the amount of air your engine could flow at X RPM and X LOAD, you would have to change the number in that table to a bigger number or it would run lean. Simple eh?

The MAF system is a little more complex as it is far more intelligent, but it uses all its inputs to calculate actual engine volumetric efficiency and the fuel table is displayed as a lambda ratio. We can input a lambda figure as a target and the ECU will calculate what fuel to deliver to achieve that AFR.

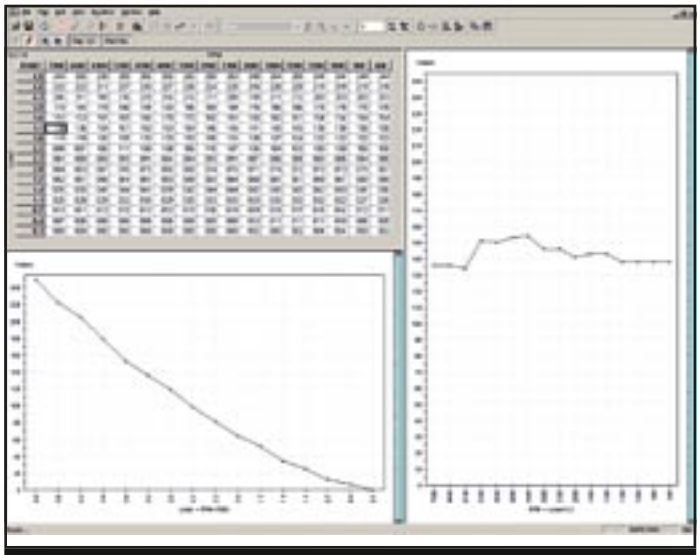
This all goes wrong if you put cams in the engine as the airflow reading at the MAF tends to go wrong. It also runs into problems if you max out the MAF as once its flow is maxed out at 4.9 volts, it is blind and can no longer do any further calculations.

So, there you have it, that is just two of the maps from two of the systems. If I showed you them all we would fill the next two or three years' editions.

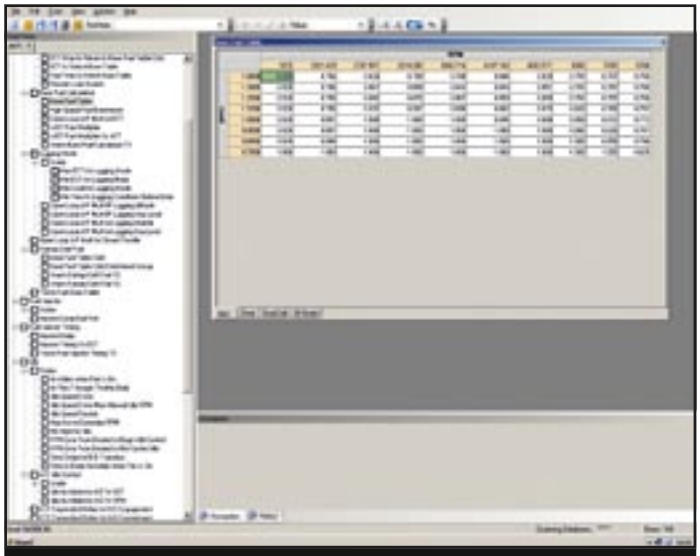
However, we are going to look at these two systems in some more depth next month, so stay tuned for part two.

NEXT MONTH

Mapping in the real world: what does the mapper actually do with your car on a live-mapping day?



Speed density system: fuel map from an Escort Cosworth P8 ECU



MAF system: base fuel map from a Focus RS ECU