Understanding ECU Remapping: The Audi TT 1.8T Variants/Bosch Motronic ME7.x

Revision Status
Revision 0 to Revision 1

Section	Status	Description
All	Minor	Minor editorial amendments, including standardizing the translation of 'soll' to 'target' instead of 'requested' or 'desired'. Correction of 'indicated' to 'indexed'.
3.1	Minor	Interpretation of torque pathway from pedal angle to throttle angle in terms of maps and variables added.
4	Minor	Section 4. Reference made to manually translated *funktionsrahmen* modules available on Nefmoto
4.1	Minor	New section 4.1 added to discuss the nature and origin of DAMOS & ASAP2 files. Existing sections renumbered.
5.3.2	Minor	Section 5.3.2. Remarks added for both KFMIRL and KFMIOP to note that (a) these maps are the inverse (complementary, not arithmetic inverse) of each other and changes made to one should be reflected in the other to avoid problematic operation (b) KFMIRL should be adjusted to tune part-throttle torque response. Section 5.3.2. Section on LDRXN revised to compare and contrast with LDRXNZK.
7.2	Minor	Section 7.2. (Motronic German Terms and their Abbreviated Forms) amended

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1. Introduction

1.1. Background

In January 2009, I bought a 2005 Audi 8N TT Quattro Sport 240 PS and initially, I didn't have a strong desire to modify the car, either cosmetically, or for increased performance. However, internet forums soon piqued a strong technical interest in the machine and provided ideas as to how the car could be enhanced such that I ended up spending the best part of £4,000 on it in less than two years. The physical modifications didn't require too much thought because the parts themselves are tangible, the benefit is easy to quantify and the improvement mechanism easy to comprehend. However, I was suspicious of arguably the most popular modification and one which gives the biggest 'bang for buck': an ECU remap.

Some people are quite happy to take information and reputations on trust and submit their cars for various repairs, diagnostic work and electronic tuning in a degree of 'blind faith' and this is fine I suppose, but I'm not one of them. I like to know how things work, especially opaque processes that cost hundreds of pounds. After about 18 months of prevarication, I decided to JFDI and booked into Awesome GTi for an APR Stage 2 remap in October 2010. Between booking the appointment and turning up, Awesome GTi switched technical partners and started offering Revo Technik tuning products, so I ended up with that instead. Nevertheless, I couldn't fully accept that there were no significant disbenefits to remapping, particularly with respect to engine component lifetimes, so I invoked the motto of the RAF No. 1 Parachute Training School: "knowledge dispels fear", and looked into the technical aspects of ECU tuning. I wanted to answer such questions as:

What do maps look like?
How many are there?
What parameters do they control?
Are they easy to understand and modify?
Is developing a tuning strategy a definable, systematic process?
What are the main constraints on, or side-effects of increasing output?
Is a professional remap good value for money?

1.2. Scope and Limitations

This technical article/FAQ doesn't really contain any new information; my intent is simply to share the findings of my own investigations into ECU remapping to allow someone with general technical knowledge and curiosity to understand the processes involved, the difficulties and limitations and what their £300-£500 is actually buying them. I am unable to reveal any proprietary secrets or commercially-sensitive data because I only have access to what is already in the public domain, either free-of-charge or can be acquired for a modest donation. Nor is it my intention to give sufficient detail here to empower any 1.8T owners to become amateur tuners overnight. Commercial remaps do offer good value for money and, if the code is not encrypted, can represent a good starting point for further analysis if you're interested in the topic only from an academic perspective.

It became clear early on in my research that there are good reasons for this. Principally, in the case of Bosch Motronic ME7.x ECUs fitted to many German vehicles,

1. There is binary assembly code in the processor ROM and the external flash chip read/write memory and binary data in the processor ROM, the external flash read/write memory and the external EPROM read/write memory. Specialist software is required to interpret and edit it.
2. The cost of fully-functional versions of tuning software and, in particular, the definition files that enable the ECU information to be interpreted is prohibitive (€1000s) for people with only an amateur interest.
3. Even when professional definition files are available, the maps, tables and constants are only identified in German which adds an extra barrier to understanding. Definition files compiled by amateur tuners are freely available in other languages, primarily English.
4. A large number of inter-dependent variables are monitored and controlled by the ECU.
5. Many hours of work are required to iterate and optimize alterations to parameters such that outputs remain within safe constraints.
6. Specialist technical knowledge, experience and a thorough understanding of engine management control is required.
7. There are relatively few reputable, professional tuners and they are justifiably protective of their intellectual property and capital investment in hardware, software and R&D. Indeed, in the case of the smaller, independent companies with one or two key individuals, their livelihoods depend on protecting a hard-won competitive advantage.

It is worth noting that the tuning process for American (GM and Ford) cars and Asian cars (e.g. Honda, Nissan and Subaru) is relatively open because the professional and amateur community considers that the added value is in the tuner's time and is not vested in a copy of a tuned ECU file (which is often specific to the particular configuration of hardware modifications on a particular vehicle in any case). Non-European tuners focus on custom tuning individual vehicles on inertial or load-bearing rolling road dynamometers and are selling their time and experience. In contrast, European tuners focus on optimizing several stages of tune (usually three) for a particular make and model and then earning revenue from authorized distributors when they upload the tuned file to a customer's car. Since you will be reading this article after having downloaded it from the Nefmoto internet forum, I'm happy to inform you that "this house believes that open sharing of tuning knowledge, information, tips, 'secrets of OEM calibrators', problems, etc. promotes innovation rather than stifles it".

1.3. Due Diligence & Responsibilities of Owners and Tuners

While it is clear that a responsible tuner has a duty of care not to carry out procedures on a vehicle that is obviously in an unfit state for tuning, it is reasonable to expect that the owner of the vehicle has a reciprocal responsibility to not knowingly submit a vehicle for remapping with latent defects that could be exacerbated or cause further damage. As such, it is normal practice to sign a damage waiver before a vehicle's output is measured on a rolling road dynamometer. If the owner is uncertain of their vehicle's state of repair, they should ensure that the tuner is qualified to carry out an inspection or assessment and, if necessary systematic fault-finding, diagnosis and remedial work. This is made much easier by the ready availability of on-board diagnostic interfaces such as the Liquid gauge by Race Diagnostics and software such as VCDS (VAG-COM); a diagnostic scan plus check on the vehicle's maintenance history should be the starting points for any pre-tuning assessment.

1.4. Cost per BHP: Comparing ECU Remapping with Physical Modifications

The main reason why ECU remapping is such a popular aftermarket performance modification is the low cost per bhp compared to physical modifications such as a performance exhaust system, high flow induction kit or front-mounted intercooler. Crude figures are illustrated below for typical Audi TT 8N modifications:

Table 1.1 Approximate Costs per BHP of Performance Modifications

Modification	Expected Gain* (BHP range)	Total Cost	£/BHP
Performance exhaust system with 100-200 cps catalytic converter matrix	10-20 bhp	£800-£1,200	£40-£120
Front-mounted intercooler (FMIC)	10-15 bhp?	£500-£700	£33-£70
Higher flow-rate induction kit	5-10 bhp	£100-£150	£10-£30
Stage 2 remap	40-50 bhp	£300-£400	£6-£10

*Note that the expected gains are complementary, not additive.

As far as European tuners are concerned, ECU remaps come in three flavours, usually referred to simply as Stage 1, Stage 2 and Stage 3. This 'pigeon-holes' the power output into three ranges which are best suited to physical modification of increasing sophistication. Stage 1 tunes are reserved for cars with a basic level of modification which is usually considered to be a sports exhaust system and performance air filter/induction kit. The requirements for Stage 2 build on this and an uprated intercooling system is recommended. A Stage 3 tune is best suited to cars with all the aforementioned kit plus more esoteric modifications which might include some or all of the following: a debaffled charge pipe, a redesigned and optimized intake manifold and/or exhaust manifold and/or downpipe from exhaust manifold to the catalytic converter section(s), larger fuel injectors, a higher pressure fuel pump, etc.

2. Why Remap a Car?

Most manufacturers calibrate their ECUs to optimum emissions, fuel economy, component longevity and safety which can limit performance. It is also logistically simpler and more cost-effective for car manufacturers to produce as few region-specific model variants as possible. Pre-production prototypes are tested in a variety of extreme ambient conditions ranging from Arctic sub-zero to desert heat temperatures in Death Valley, at high altitude and with the low-octane gasoline and low-cetane diesel fuel grades available in developing countries. Therefore, one engine management map is developed with the necessary flexibility to cope with all these limiting constraints. Thus, the 'one-size-fits-all' map that is conservative enough to cope with running low octane fuel at an altitude of over 3,500 m in La Paz, Bolivia will have some scope to be optimized to run at sea level on premium unleaded 99 RON octane fuel in Britain at average ambient temperatures of 15°C.

The improvements are often impressive with a better power spread across the rev range, higher peak torque resulting from increased power at lower engine speeds, better throttle response, quieter and smoother idle and cruising and increased rev and/or speed limit, etc. Perhaps paradoxically, a performance tune can return increased mpg on the extra urban cycle and at steady speeds. This is because OEM calibrations might retard timing and run richer mixtures to safeguard against deviations in the vehicle's maintenance regime or pre-ignition and knock caused by low octane fuel.

A basic appreciation of the combustion process is useful to underpin understanding the remapping process. In a simple model of the four-stroke Otto cycle, the fuel-air mixture is always ignited at piston TDC at full compression. In reality, this is not the case and there is actually a great deal of scope for varying when the fuel/air mixture is ignited. Ignition is timed to occur several 'degrees crank' before TDC (BTDC) for two reasons:

1. Although the engine can speed up, the fuel-air mix takes a finite amount of time to combust, so at higher speeds, the mixture needs to be ignited earlier in the cycle so that peak cylinder pressure is achieved at the optimum crank angle (a few degrees after TDC).
2. To try to lengthen the combustion process to obtain a more controlled burn because the burn rate is influenced by various conditions such as AFR and temperature. I.e., a richer mixture is heavier so will burn more slowly. Similarly, the mixture will be denser at lower ambient temperatures and will also burn more slowly requiring greater ignition advance to achieve peak cylinder pressure at the optimum point in the cycle.

SSP 322 (The 2.0l FSI Engine with 4-Valve Technology) illustrates just how much scope there is for varying these parameters in the context of lean-burn strategies.

In the 'stratified charge mode', a layer of insulating air is created between the ignited mixture and the cylinder wall which reduces the amount of heat transferred via the engine block and thus improves efficiency.

Contrast this with the 'homogeneous mode' in which fuel is injected during the intake stroke (0-180 °crank) and not in the compression phase (180-360 °crank). The fuel-air mixture has more time to mix thoroughly before ignition and fuel evaporation removes some of the heat from the incoming air. Cooling the combustion chamber reduces the tendency to knock and thus increases the engine compression and efficiency.

Contrast this with the turbocharged version of the 2.0 litre FSI engine described in SSP 337. The stratified combustion mode has been designed out and the piston head design (shown in Figure S337_011) is very different.

Table 2.1. Some 'rule-of-thumb' AFR/lambda limits

AFR	lambda	Notes
6.0:1	0.41	Rich run limit
9.0:1	0.61	Low power, black smoke
11.5:1	0.78	Rich best torque at WOT
12.5:1	0.85	Safe best power at WOT
13.2:1	0.90	Lean best torque at WOT
14.7:1	1.00	Stoichiometry (ideal)
15.5:1	1.05	Lean light load, part throttle
16.2:1	1.10	Best economy, part throttle
18-22:1	1.22-1.50	Lean run limit

In general, a lower rate of change of energy transfer from the gas explosion to the piston head enables more useful work to be done. Higher octane fuels are preferred for tuned cars because they have a larger proportion of branched chain hydrocarbons. These burn cooler and more slowly than molecules with fewer branches which makes them less prone to pre-ignition and knock. Pre-ignition is the tendency for the fuel to ignite before the spark event whereas knock is explosive combustion after the spark event. These phenomena result in three extremely undesirable effects: (a) a rapid, uncontrolled increase in cylinder pressure (b) greater than desired peak cylinder pressure and (c) peak cylinder pressure achieved at the wrong time in the cycle. It should be obvious enough why an opposing downward force being applied when the cylinder traveling up towards TDC is a bad thing. As a rule of thumb, the maximum tolerable cylinder overpressure (in bar) is RPM/1000. I.e. 4 bar at 4,000 RPM. This is only useful to OEM calibrators who can measure the cylinder pressure during the initial tuning process with pressure transducers fitted to specially-modified cylinder heads or incorporated into the spark plugs.

3. How Bosch Motronic ME7.x Works in the Context of the Audi TT 8N

The Motronic electronic control unit (ECU) consists of a sixteen bit Siemens C167 microprocessor and a memory. Each 16 bit word contains an executable instruction or a piece of data in binary format. The memory contains a work program with algorithms and data for determining all the primary outputs such as boost pressure, throttle plate angle, injector on-time, ignition angle etc. Sensors provide the microprocessor with information on the amount of intake air, engine speed and crankshaft position as well as the intake-air and engine temperatures for every injection and ignition operation i.e. over 6,000 times per minute. By comparing the program data, the processor calculates the individual requirements for the next injection and ignition operation.

Like many modern cars, the Audi TT 8N has an electronic throttle (i.e. there is no physical connection between the accelerator pedal and the throttle body). Instead, accelerator position is transmitted to the ECU which takes this into account in conjunction with a number of other variables when calculating the throttle plate angle. The system is called Electronic Power Control (EPC) and the details are described in SSP 210. Bosch’s family of Motronic engine management systems (EMS) work by centrally managing the long-term and short-term torque demands in accordance with efficiency constraints and the air fuel ratio (AFR).

3.1 Torque Management

Demands from driver and vehicle inputs are computed, prioritized and converted into outputs for the primary actuators (throttle valve control part, ignition coil packs, fuel injection timing, and the turbocharger waste-gate). The ‘long-term’ torque demand is achieved by controlling the cylinder charge by varying throttle plate angle and turbocharger waste-gate opening. This is limited by throttle response time and transit time through the intake manifold which can be several hundred milliseconds at low engine speeds. The ‘short-term’ (up to 100 ms) torque demand is achieved by varying injection and ignition timing which are referred to as crank-synchronous outputs for obvious reasons. An overview of this process is illustrated in Figure 3.1.

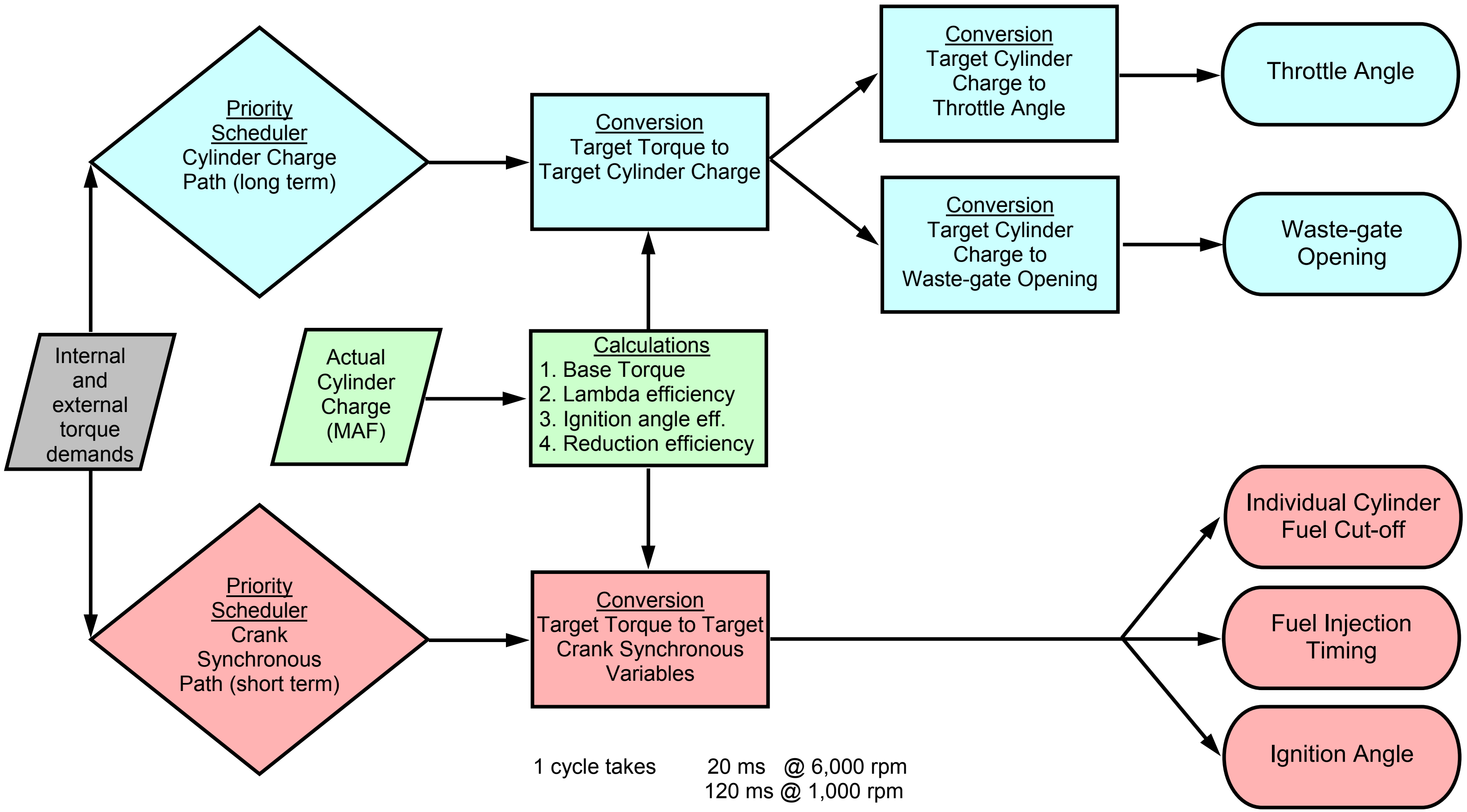
Table 3.1. Summary of Motronic Torque Influencing Functions

Torque Reducing	Torque Increasing
Traction control system	Engine braking torque control
Engine governor	Load change damping (dash pot function)
Speed limiter	Idling speed control
Power limiter	
Cruise control system	
Driving dynamics control systems	

The stages in this pathway (which replaces the mechanical link between throttle pedal and throttle plate) are summarized in *funktionsrahmen* module MSF 4.4 (overview of engine control functions) and in the simplified sequence below. There are only a few key maps (KFPED and KFMIRL/KFMIOP) and two key characteristics (LDRXN/LDRXNZK) involved. These are discussed further in Section 5.

Variable	Main Module	Map	Description
wped_w	MDFAW 12.260	KFPED	Normalized throttle pedal position
mrped_w	MDFAW 12.260	—	Relative driver-requested torque from the throttle pedal
mrfa_w	MDFAW 12.260	—	Relative driver-requested desired torque from throttle pedal and cruise control
mivbeg_w	MDFAW 12.260	—	Indexed driver-requested torque before change limitations
mifa_w	MDFAW 12.260	—	Indexed driver-requested engine torque for air path
milsol_w	MDKOL 10.130	—	Driver-requested torque for cylinder charge
rlsol_w	MDFUE 8.50	KFMIRL	Target cylinder charge
rlfgks_w	FUEDK 21.90	—	Corrected relative target fresh air [air that flows via throttle plate and fuel tank breather]
msndkoos_w	FUEDK 21.90	—	Normalized air mass flow for target throttle angle determination
wdksgv_w	FUEDK 21.90	—	Target throttle plate angle before application interface (filtered)

Figure 3.1. Overview of Bosch Motronic Torque-oriented Functional Structure



The interdependencies between these variables are greatly simplified by introducing two central reference values: optimal ignition advance and optimal internal torque (which is achieved at the optimum ignition advance) when lambda = 1.

Examples of internal torque demands are: starting, idling speed control, catalytic converter heating*, power limitation, components protection and engine governing.
Examples of external torque demands are: driver inputs via accelerator pedal position, inputs from vehicle dynamic sensors and cruise control.

*The 2.0 litre TFSI engine (described in SSP 337) has an interesting rapid catalytic converter heating mode known as dual injection with cold start. A quantity of fuel is injected on the intake stroke at approx 300° crank. The fuel distributes itself homogeneously due to the long gap before ignition. The second injection occurs at approx. 60° crank in the compression phase. The rich mixture that thereby forms around the spark plug means that timing can be retarded to a considerable degree without affecting stability of the engine. Both injection periods result in lambda 1. Since the exhaust valves are already open, the exhaust gas temperature rises rapidly. This brings the catalytic converter to operating temperature (350°C) in a short space of time (30-40 seconds). In addition to the Audi TT BAM and BFV ECU files referenced in the supporting information section, I have uploaded fully defined ECU files in WinOls .ols format for both the VAG 2.0 litre FSI and TFSI engines to the Definition Files section of the Nefmoto forum.

Internal torque is converted to engine output torque by subtracting losses incurred in transferring the kinetic energy of the fuel/air combustion front to kinetic energy in the piston and overcoming friction and inertia in the piston/crankshaft system. Clutch torque is obtained by subtracting the torque required to drive auxiliary components such as the alternator, PAS pump and air conditioning. Wheel torque is obtained by subtracting frictional and inertial losses in the gearbox and differential from clutch torque. N.b. these losses are preset in the ECU by the manufacturer and are not evaluated dynamically.

Target torque is calculated by looking up the optimal torque at lambda = 1 as a function of target cylinder charge and engine speed then reducing this by three scaling factors (lambda efficiency, ignition advance efficiency, and an individual cylinder fuel cut-off). Ignition advance efficiency is the difference between the actual ignition advance and the optimal ignition advance.

3.2. AFR Management
There are three essential components to Motronic’s AFR management strategy, namely:
(a) The basic calibration.
The basic calibration target is lambda = 1 under all operating conditions and this component is designed to eliminate mixture variations caused by systematic errors.

(b) Lambda pilot control
Pilot control changes the target lambda value depending on the operating conditions, enriching the mixture for prompt catalyst heating to reduce emissions during start or warm-up, or running lean for fuel economy.

(c) Lambda limits
Limits are defined by the flammability of the mixture at a given engine load and are used to coordinate the AFR without the need to cross-reference calibration data.

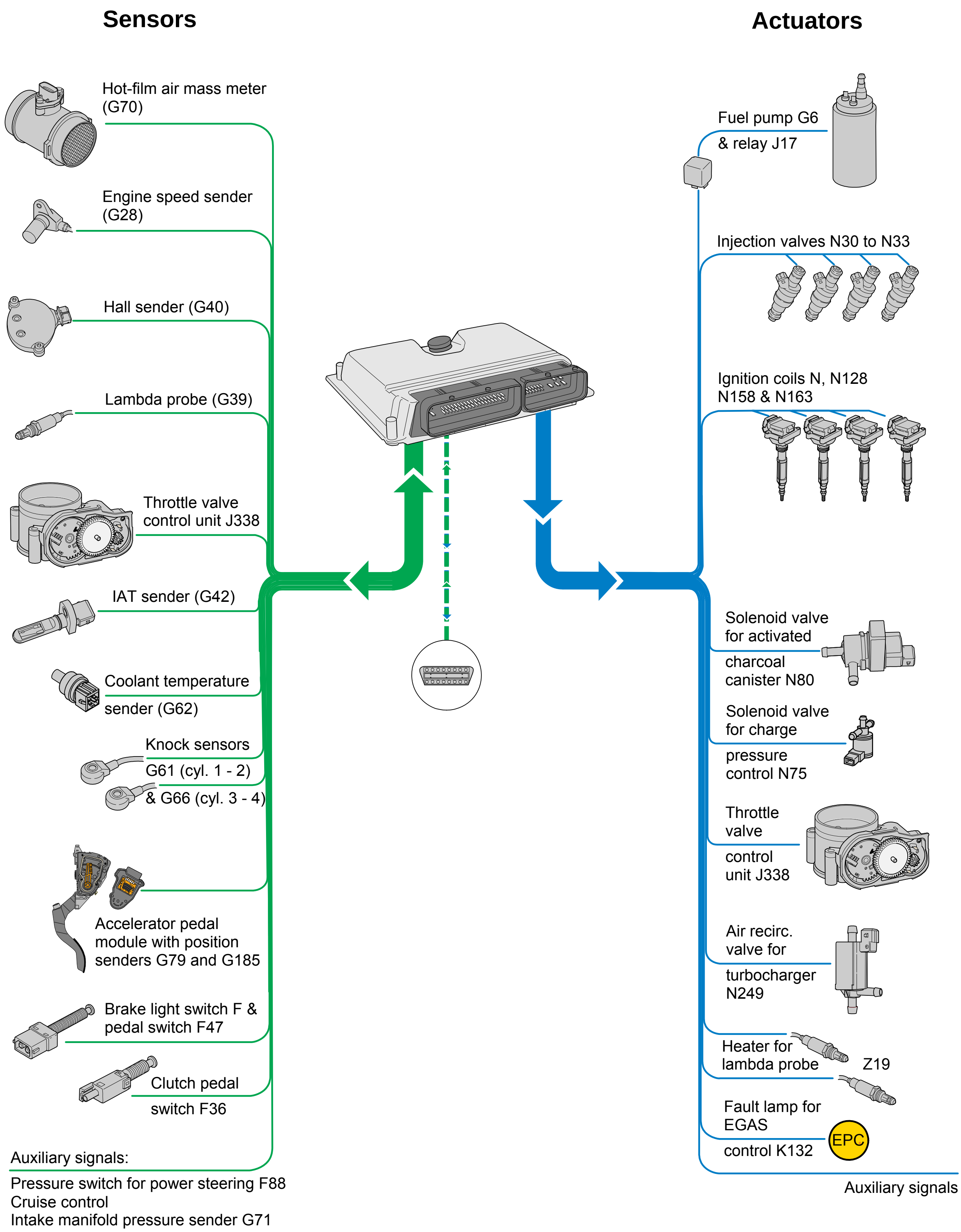
Although the stoichiometric ratio (lambda = 1) is the target, peak flame speed occurs around lambda = 0.9 and at this point, less overall ignition advance is required to achieve peak cylinder pressure. Adding more fuel or more air will slow down combustion. Flame speeds are in the region 18 to 25 m/s so in an engine with a bore of 81 mm like the 1.8T, the flame can travel from a central spark plug to the cylinder wall in only 1.6 to 2.3 ms. At an idle speed of 800 rpm, this equates to approximately 10 degrees of crank angle but increases to 62.5 degrees at 5,000 rpm.

3.3. Cylinder [Fuel] Cut-off
Under certain conditions, fuel delivery is reduced or completely shut off, that is, the ECU reduces the injector pulse width, or does not send the injector activation signals. There are three situations in which this occurs.

(a) Engine speed limit reached or exceeded.
(b) MAP reaches or exceeds the prescribed value (overboost protection).
(c) Deceleration.

Figure 3.2 illustrates schematically the sensors that provide inputs to Bosch Motronic ME7.x ECU and the actuators which the output signals control. Please note that the alphanumeric designations are just reference numbers used in the Self-Study Programs and the electronic workshop manual but are not part numbers.

Figure 3.2. Schematic of Bosch Motronic ECU Sensors & Actuators (Audi TT 8N)



3.4 Conclusions: Bosch Motronic Operating Philosophy

In conclusion from this section, there are a limited number of variables that can be altered during the ECU remapping process: the relative cylinder charge can be increased, the fuel injection timing and quantity, and ignition angle can be altered.

4. Interpreting the Information on a Bosch Motronic ME7.x ECU

Interpreting the information encoded onto a Motronic ECU is no trivial matter, even if you are able to obtain a definition file for the specific ECU version of interest (e.g. from a friendly professional tuner or the internet at large). Several Windows-based software tools are available to assist the user to access and interpret the ECU code.

I opted to use WinOls from EVC (http://www.evc.de/en/default.asp) which is Windows software aimed at professional tuners to allow them to display, modify and administer ECU data. It will automatically recognize some maps and display them as hexadecimal and decimal text and as 2D and 3D plots. A trial version is available to download from their website. It has the same functionality as the full version but you cannot read DAMOS/A2L files, perform checksum correction or export modified files. A screenshot is illustrated in Figure 4.1. TunerPro is another popular software package that offers similar features and functionality.

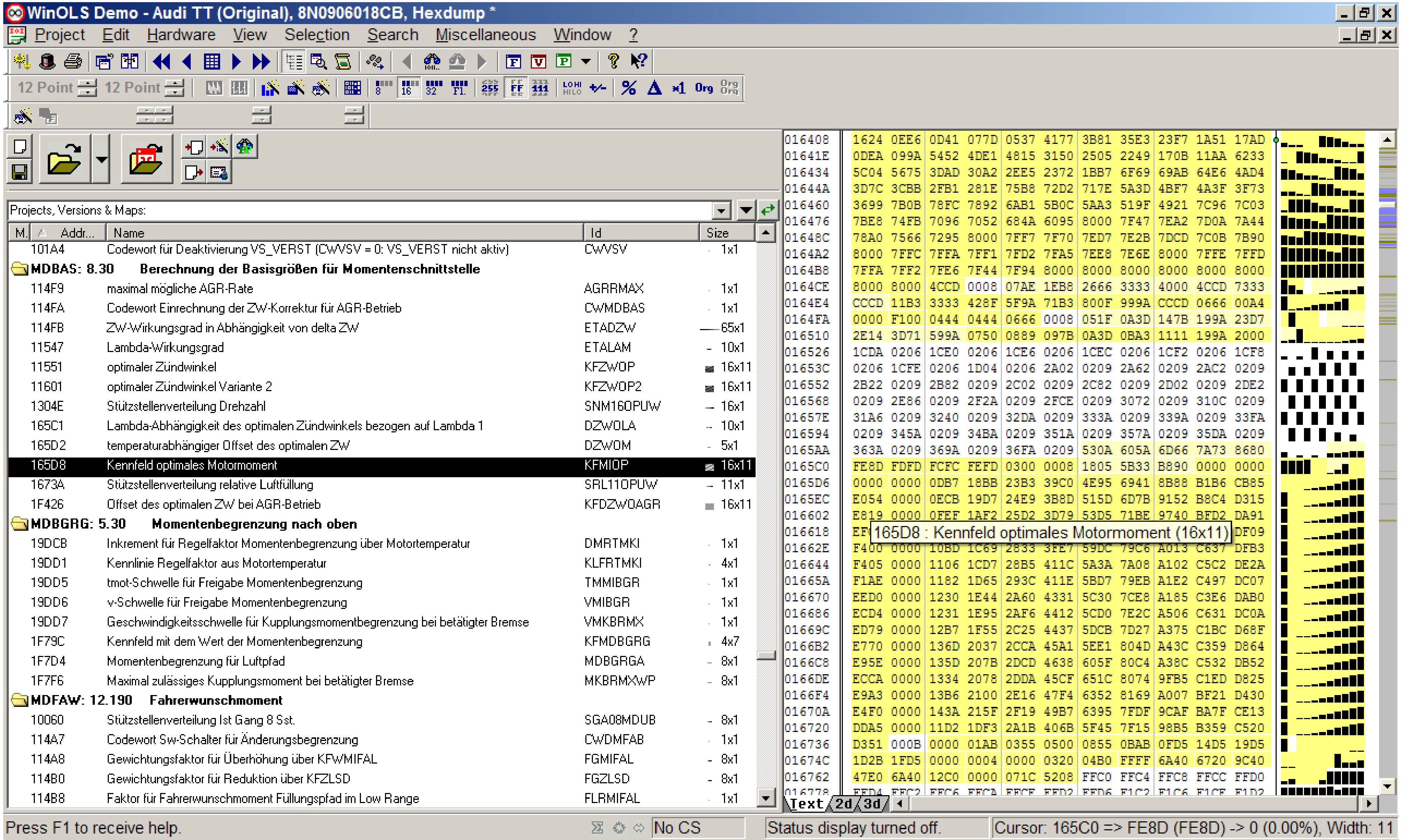
The detailed functional operations of the ECU are described in documents called *funktionsrahmen* (function sheets). The Motronic ME7.5 *funktionsrahmen* PDF file runs to 1885 pages (in German) and is over 20 Mb in size. The Motronic MED9.1 *funktionsrahmen* PDF file for direct injection petrol engines runs to 4860 pages and is over 93 Mb in size. Both of these documents are available to download at Nefmoto. The *funktionsrahmen* describes the discrete operational areas of the ECU in 335 modules; each module has a flow chart describing which 3D maps, 2D characteristics and constants are processed by the ECU to monitor conditions or control particular outputs. I have tried out three internet translation engines (Google Translate, Babylon and dict.cc) during this study and have found Google's effort to be the best all-rounder in that it is relatively competent at recognizing technical terms and interpreting the original sentence structure. Dict.cc has a comprehensive list of technical terms and recognizes many compound words. Between the two resources, it is possible to obtain a meaningful translation quickly. I have manually translated several of the key modules and uploaded them to the relevant thread in the Tuning section of Nefmoto. Presently, these comprise the following modules:

ATM 33.50 (Exhaust Gas Temperature Model)
ATR 1.60 (Exhaust Gas Temperature Control)
FUEDK 21.90 (Cylinder Charge Control [Calculating Target Throttle Angle])
GGHFM 57.60 (MAF Meter System Pulsations)
LAMBTS 2.120 (Lambda for Component Protection)
LDRPID 25.10 (Charge Pressure Regulation PID Control)
MDBAS 8.30 (Calculation of the Basic Parameters for the Torque Interface)
MDKOG 14.70 (Torque Coordination for Overall Interventions)
MDZW 1.120 (Calculating Torque at the Target Ignition Angle)
RKTI 11.40 (Calculation of Injection Time ti from Relative Fuel Mass rk)
ZUE 282.130 (Fundamental Function - Ignition)
ZWGRU 23.110 (Fundamental Ignition Angle)

I will add more in due course as and when I have time to translate them. I have uploaded to the same post on Nefmoto where you obtained this file a definition file for a MY2004 TT 8N with the 225 PS BAM variant engine (part number 8N0 906 018 CB) and a raw binary file for a 240 PS BFV variant engine (part number 8N0 906 018 CA). These can both be read by the test version of WinOls if you're interested in exploring them further for yourself. Although they do not directly support this document, I have also uploaded fully defined ECU files in WinOls .ols format for both the VAG 2.0 litre FSI and TFSI engines to the Definition Files section the Nefmoto forum. If you're interested but don't want to grapple with WinOls, I have transferred a large amount of the information from the BAM file into a Microsoft Excel 2003 spreadsheet. There are various worksheets within the workbook. One contains all 312 maps with fully scaled and offset (i.e. real-world) data values. The parameter description, German name and English translation for each map is given to assist interpretation. Another sheet has all the *funktionsrahmen* module identifiers.

A word of caution if you're using WinOls to peruse the ECU code. Although you will find a total of 312 maps in the full-defined BAM file, WinOls will only recognize 79 of them automatically and this sub-set of automatically-recognized maps doesn't necessarily contain the most relevant or interesting maps or even complete module sets.

Figure 4.1. Screenshot from WinOls with a Fully-Defined ECU File (8N0 906 018 CB.ols)



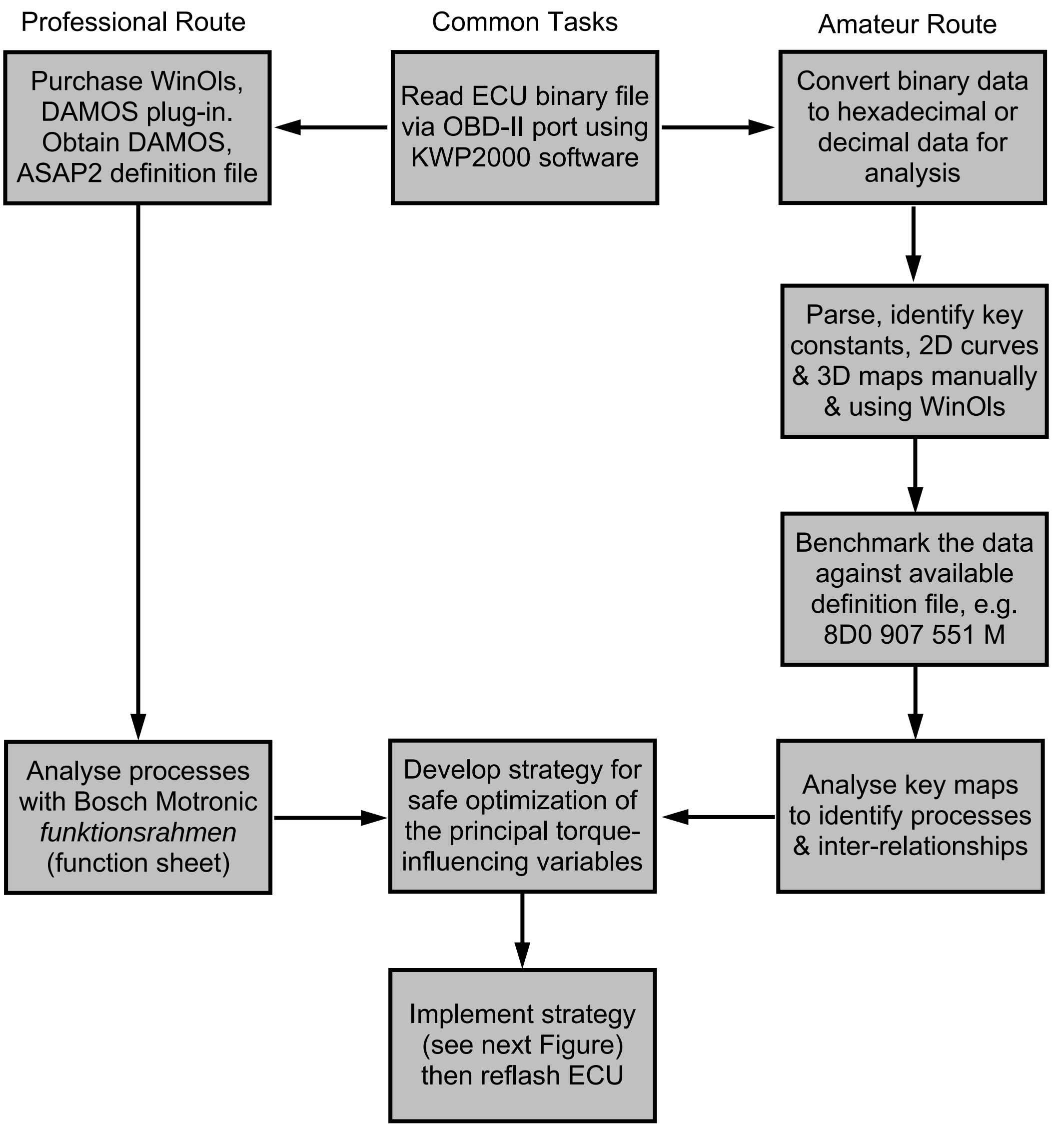
It is relatively easy to locate maps manually using WinOls because the distinctive patterns are displayed graphically in the right-hand pane. Comparing the array size and content with a benchmark aids identification. The techniques are succinctly described at www.motronic.ws. If you don't have an authentic definition file, then it will be necessary to do this. It's a big puzzle and if you enjoy doing Sudoku, then you might enjoy the process. If not, it's best to try to find a proprietary definition file to minimize frustration and heartache. With 312 maps in the 225 BAM file, you can begin to appreciate how much work would be involved in identifying these manually, and why people who have done so are keen not to give away their information freely. Figure 4.2 summarizes the processes described in this section.

4.1 DAMOS and ASAP2 File Formats

It is worth noting the information on EVC's internet site regarding DAMOS and ASAP2 format ECU definition files which I paraphrase below:

The development systems used by vehicle manufacturers to match ECUs to engines will display the constants, 2D characteristics and 3D maps including scaling, sampling points and labels for the OEM calibrators. Only the data contents are stored in the EPROM built in to the ECU. All other information is stored in files which contain the addresses and names of the maps. The DAMOS and ASAP2 file formats are deemed the most suitable for this purpose and are used by almost all German vehicle manufacturers. Only a select few (usually officially endorsed) top-level tuners have the proper contacts to the manufacturers or racing departments to obtain the data file for a certain ECU. For these advanced tuners, the DAMOS/ASAP2 import option was implemented in order for them to be able to use the map information and properties from such a file directly in a WinOls project. For this task, filters and choices are available to sort out only the required map information from the 2,000 to 10,000 maps contained in such a file. EVC do not supply DAMOS/ASAP2 files nor do they have information about how or where to obtain them.

Figure 4.2. Summary of Processes Involved in Interpreting ECU Information



4.2 Why Store Information as Maps?
The information required to control the engine is stored on the ECU as constants (*konstanten*, 1D, x), characteristic curves (*kennlinier*, 2D, x & y) and maps (*kennfelder*, 3D, x, y & z). The latter are simply look-up tables. Data is stored in look-up tables for two very good reasons. 1. There is not necessarily a function that can return the required data because the nature of fluid dynamics is not easily predictable or linear and 2. The processor can operate much more quickly by just looking up values and interpolating between them instead of calculating each one every time a control action is required.

4.3. Error Checking (Checksum Verification)
Because of the harsh conditions (particularly elevated temperature and vibration levels) in which the electronics are required to operate, it is necessary to build in error checking subroutines to the ECU. For Bosch Motronic systems, this is a simple process that involves checksums. The checksum is simply the sum of all the hexadecimal data in a particular region of the code. The ECU adds up the numerical data in each area of code for which there is a checksum then compares it with the checksum. If the two values are different, it is likely that an error has occurred and the Bosch Motronic ECUs will not boot up and the engine will not run. This process is illustrated at www.motronic.ws

5. The Key Maps and Parameters for Tuning
5.1 Introduction
This section is intended to be a fairly basic overview of which ECU parameters can be recalibrated and what changes can be made when developing a tuning strategy. It is based on the S4 wiki which I have cross-checked with information on amateur tuning internet forums to attempt to validate it. I have translated and included some information from the Bosch Motronic ME7.x *funktionsrahmen* (function sheet) where appropriate and have illustrated this section with actual maps from two Audi TT 1.8T variant ECUs for two good reasons. Firstly, because I own a TT with highest output OEM tune (240 PS) and I have also had it remapped (which is the raison d'être for this endeavor). In addition, the Audi TT 1.8T makes a good 'case study' because the basic engine was available with several levels of OEM tune including 180 PS, 225 PS and 240 PS and still has plenty of scope for aftermarket modification and ECU remapping. Another good Motronic ME7.x case study would be the MY2001 Audi S4 and RS4 because both have essentially the same 2.7 litre twin turbo engine, but outputs greatly differ (265 PS for the AGB engine variant) and 380 PS for the ASJ engine variant) and fully-defined ECU files are available for each state of tune. A good non-VAG case study might have been any of the recent Mitsubishi Lancer Evo series 2.0T engines which are also supplied in several levels of OEM tune and have a similarly healthy aftermarket modification and ECU remapping scene.

The content of this section varies greatly in scope. Some sub-sections have a fairly comprehensive technical content if there is information of general relevance in the *funktionsrahmen*, whereas in others, I just present the maps themselves for awareness purposes with no further discussion other than some paraphrased remarks from the S4 wiki. It is difficult to judge what and how much to include, and having to translate the prose from *funktionsrahmen* modules manually as a prerequisite to that judgment isn't conducive to achieving a cogent, flowing narrative.

There does appear to be a vague consensus about what information is key to the main Motronic functions and therefore which should be considered when tuning the ECU. Table 5.1 below is a cross-comparison between the maps three amateur tuners consider to be important and the maps reported to be changed by a professional tuner. The latter column also includes differences observed between the BAM and BFV engine variants (e.g. ignition angle maps).

On the FAQ section of their website, UK-based tuner Emaps state that they *"…change about thirty-five different tables in a standard remap. Load, turbo boost (where applicable), ignition timing, and fuel are all adjusted as well as the variable cam timing. Some tuners change only one table while most others no more than six. By increasing one table it may be indirectly increasing another table and causing it to 'max out' or be at the limit of the table. This effectively leaves this table ineffective in providing necessary data for the control systems."*

Tony at Nefmoto has changed the following maps in his Stage 3 tuned file for a 2001 B5 Audi S4 (ECU part number 8D0 907 551 M) and both the stock binary file and the tuned binary file are available to download on the Nefmoto forum. Apart from the modifications listed in the table, the car is running K04 turbos and the stock 3 barg FPR. Maximum boost is 22 psi.

Constant, Characteristic Curve or Map	Comment
KRKTE (Conversion factor: relative fuel mass rk to effective injection time te)	Rescaled injection time Siemens Deka IV 630 cm^3/min injectors.

KVB (Constant for fuel consumption display)	Rescaled fuel consumption factor for Siemens Deka IV 630 cm^3/min injectors
TVUB (Voltage correction)	Values for TVUB and KRKTE are iterated by carry out logging runs then reviewing the long term idle and partial load adaptation.
KFLAMKRL (Enrichment during ignition angle retard)	None
KFLAMKR (Weighting factor for enrichment during ignition angle retard)	None
KFMLDMX (ML-threshold for B_maxflr-diagnosis HFM/HLM)	None
MLHFM (Linearization of MAF sensor output)	Rescaled for 85 mm Hitachi MAF housing
EDLDRP (Control error threshold for diagnosing charge pressure control positive deviation)	None
KFLDHBN (Charge pressure control: altitude limit, maximum compressor pressure ratio)	None
LDORXN (Maximum cylinder charge E_ldo LDR during overboost error)	None
KFLDIMX (Map for charge pressure control integral control limit)	None
LDDIMNN (Safety margin for charge pressure control integral controller negative limit)	None
KFLDRQ2 (Charge pressure control map: control parameter Q2)	None
LDRXN (Maximum cylinder charge)	See later discussion
LDRXNZK (Maximum cylinder charge during continuous knock)	See later discussion
KFMIRL (Map for calculating target cylinder charge)	None
CDKAT (Codeword for catalyst diagnosis)	Disabled catalytic converter efficiency diagnosis
KFZW (Map for ignition angle in camshaft state 1)	See later discussion
KFZW2 (Map for ignition angle in camshaft state 2)	See later discussion
NLLM (Target idle speed)	Raised idle speed to help with misfires
KFMRESK (Idle control: basic torque reserve during idle and near idle range, clutch depressed)	Raised base idle torque with clutch depressed to help with misfires
KFMRES (Idle control: basic torque reserve during idle and near idle range)	Raised base idle torque without clutch depressed to help with misfires

Table 5.1. Cross-comparison of Key Maps for Motronic Operation & ECU Tuning

Key maps, tables & constants in S4 Wiki	Amateur tuning website 1	Amateur tuning website 2	Maps, tables & constants modified by a professional tuner
FBSTABGM✓			
			FFLDIMX
			FNSA
			FQTEFR
KFDLBTS✓			
KFFDLBTS✓			
			KFHSTT
KFLBTS✓	KFLBTS✓	KFLBTS✓	
KFLDHBN	KFLDHBN	KFLDHBN	
KFLDIMX✓		KFLDIMX✓	
	KFLF✓		KFLF✓
KFDLULS✓			
KFLDRL✓	KFLDRL✓		
KFKHFM✓			
			KFMDST✓
KFMIRL✓	KFMIRL✓	KFMIRL✓	KFMIRL✓
	KFMIOP✓	KFMIOP✓	KFMIOP✓
	KFNWEGM		
KFPBRK✓			
KFPBRKNW✓			
KFPED✓	KFPED✓		
KFPRG✓			
KFTARX✓		KFTARX✓	
KFURL✓			
KFZW/KFZW2✓	KFZW/KFZW2✓		KFZW/KFZW2✓
KFZWOP/KFZWOP2✓	KFZWOP/KFZWOP2✓		KFZWOP/KFZWOP2✓
KRKTE✓			
LAMFA✓	LAMFA✓		
LDIATA✓		LDIATA✓	
			LDORXN
			LDPBN
LDRXN✓	LDRXN✓	LDRXN✓	LDRXN✓
LDRXNZK			LDRXNZK
			NMAXDVG
			RLDKTSO
			RLKRLDA
			RLLRTMO
			RLVMXN
			RLVSMXN
			TLDOBAN
VAVMX			VAVMX
VMAX			VMAX

✓ = discussed in this section

In the maps that illustrate the information that follows, indigo values refer to the 225 PS BAM engine variant (ECU part number 8N0 906 018 CB) and dark red values to the 240 PS BFV engine variant (ECU part number 8N0 906 018 CA).

5.2 AFR Control

The S4 wiki cautions that due priority should be given to reviewing fuelling adjustments because incorrect specifications can cause physical damage to the engine components. It further cautions that tuners should not attempt to increase any other parameters towards the limits of their operating envelope until AFR control is satisfactory. Fortunately, unlike some models, the TT has a wideband lambda sensor which is necessary for accurate tuning.

5.2.1. Metered Air Intake Calibration (GGHFM module)

MLHFM (*Linearisierung der Heißfilmspannung*, Linearisation of MAF voltage)
Comprehensive instruction on how to calibrate the MAF transfer function can be found in Greg Banish's book. Note that the TT MAF sensor 'pegging' limit is around 292 g/s so this should give scope for power increases up to 365 bhp, i.e. well into big turbo conversion territory. The S4 wiki notes that this characteristic with 512 values compensates for MAF housing diameter and that using a non-stock MAF housing (to extend the functional metered flow range) requires this to be adjusted to ensure that intake air mass is correctly metered. It is recommended that long-term fuel trim (LTFT) should be logged at various part throttle positions, engine speeds, loads, and gears to determine where the MAF readings need adjusting. The short-term fuel trim (STFT) is too variable to be of much use in this case.

KFKHFM (*Korrekturkennfeld für Heißfilmspannung*, correction map for MAF).
Units (x,y,z): % load, RPM, ratio.
This map allows a tuner to correct for the differences in volumetric efficiency at different loads and engine speeds due to load and speed dependent air turbulence in the MAF sensor which influences the air flow readings. Ideally, the MAF sensor should be located in a straight section of pipe to minimize these turbulent flow effects but this is not always possible in a cramped engine compartment. Thus correction factors are required. Some set-ups incorporate a Helmholtz resonator device to damp out unwanted turbulence.

	5	13	17	25	35	47	60	70	80	90	107	135	150	185
1000	1.000	1.000	0.977	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1480	1.000	1.000	1.000	1.000	1.000	1.000	0.977	0.977	0.984	1.000	1.000	1.000	1.000	1.000
1720	1.000	1.000	0.992	1.000	0.992	0.977	0.969	0.977	0.969	0.992	1.000	1.000	1.000	1.000
2000	1.000	1.000	1.000	1.000	1.000	0.992	0.977	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2200	1.000	1.000	1.008	1.008	1.000	1.000	0.977	0.969	0.992	0.984	1.000	1.000	1.000	1.000
2520	1.000	1.000	0.992	1.000	0.977	0.969	0.992	0.992	0.977	0.992	0.992	1.000	1.000	1.000
3000	1.000	1.000	1.000	1.000	0.977	0.969	0.977	1.008	0.969	0.969	1.000	0.969	1.000	1.000
3520	1.000	1.000	0.969	0.961	0.969	0.977	0.992	0.977	1.000	1.000	0.992	1.008	1.000	1.000
4000	1.000	1.000	0.977	0.977	0.953	0.977	0.969	0.984	0.977	0.969	0.969	0.992	1.000	1.000
4520	1.000	1.000	1.000	0.961	0.969	0.977	0.992	0.969	0.961	0.969	0.977	0.984	1.000	1.000
5000	1.000	1.000	0.992	0.969	0.977	0.977	0.969	0.922	0.953	0.969	1.000	1.000	0.992	1.000
5520	1.000	1.000	0.961	0.961	0.969	0.969	0.953	0.961	0.961	0.969	0.969	1.000	1.000	1.000
6000	1.000	1.000	0.977	0.961	0.961	0.969	0.961	0.961	0.953	0.977	1.000	1.000	1.000	1.000
6520	1.000	1.000	0.961	0.977	1.000	1.000	1.023	1.031	1.031	1.023	1.000	1.000	1.000	1.000

5.2.2. The RKTI module and Fuel Injector Calibration

The RKTI module calculates the effective injection time before fine tuning (tevfa_w or tevfa2_w) from the relative fuel mass (rk_w or rk2_w) and the factor frkte. With an ideal fuel supply system, tevfa_w + tvu_w or tevfa2_w + tvu_w should result in lambda of 1.0 in the combustion chamber, with pilot control to lambda = 1.0 and neutral values of all mixture adaptations. In practice, a deviation in lambda may occur due to injector nonlinearities or pulses in the fuel system. This deviation is corrected using the map FKKVS as a function of engine speed (nmot_w) and effective injection time (tevfa_w or tevfa2_w). The corrected effective injection time is te_w or te2_w. By adding the battery voltage correction for the injectors, the injector actuation time is calculated thus: ti_b1 = te_w + tvu_w.

The correction for fuel supply systems where the reference pressure of the fuel pressure regulator is ambient pressure is calculated using the expression:

FRLFSDP = √[pdr_evmes/(pdr_akt + (pu – ps))]

Where:

pdr_evmes = absolute pressure in the fuel system before the injectors at the injector constant (Qstat) (generally 3 bar)
pdr_akt = actual fuel system pressure
pu = ambient pressure
ps = intake manifold pressure

For systems that take their reference pressure from the intake manifold pu – ps = 0 is used in the calculation above and the expression reduces to:

FRLFSDP = √(pdr_evmes/pdr_akt)

For a fuel pressure of 3 bar, the results for FRLFSDP (where dpus = pu – ps) are as follows:

Naturally-aspirated Engine		Turbocharged Engine	
dpus/mbar	FRLFSDP	dpus/mbar	FRLFSDP
0	1.0000	-1200*	1.2990
100	0.9837	-1000	1.2247
200	0.9682	-800	1.1678
300	0.9535	-600	1.1180
400	0.9393	-400	1.0742
500	0.9258	-200	1.0351
600	0.9129	0	1.0000
700	0.9005	200	0.9682
800	0.8885	400	0.9393
		600	0.9129
		800	0.8885

*Boost pressure = 1800 mbar, ambient pressure = 600 mbar

KRKTE (*Umrechnung Relative Kraftstoffmasse RK in Effektive Einspritzzeit TE*, conversion of relative fuel mass, RK to effective injector on time, TE).
Value: 0.08356 ms/% cylinder charge.
This is a constant which converts the required fuel mass to be injected into a duration in milliseconds which the fuel injectors are to be switched on for (IPW). This value is calibrated for the stock fuel injectors and fuel pump so if uprated injectors are fitted, it will need to be recalibrated. The value is derived thus:

$$\begin{aligned}\text{KRKTE} &= (\rho_{air} \times V_{hcyl}) \div (100 \times 14.7 \times 1.67 \times 10^{-5} \times 1.05 \times Q_{stat}) \\ &= (50.2624 \times V_{hcyl}) \div Q_{stat}\end{aligned}$$

Where:

ρ_{air} = air density (1.293 g/dm^3 at 0°C and 1013 mbar)
V_{hcyl} = Volume of a cylinder hub in dm^3
Q_{stat} = injector constant with *n*-heptane (density 0.6795 g/cm^3)
1.05 = injector correction factor for petrol (density 0.7135 g/cm^3)
14.7 = Stoichiometric air quantity at lambda = 1.0
1.67×10^{-5} = conversion factor minutes to milliseconds.

When recalibrating KRKTE for different fuel injectors, it is important to check that the units of Q_{stat} are appropriate and the normal operating pressure is the same as will be deployed in the vehicle. Q_{stat} values are normally quoted in grams per minute in Europe and lbs/hr in North America with a standard fluid, usually *n*-heptane which has a density of 0.6795 g/cm^3. Note also that the air density is quoted at 0°C, not STP. Iterating the required Q_{stat} for a V_{hcyl} of 1.786 litres ÷ 4 gives an injector size of 267.8 g/min (375.4 cm^3/min) at 3 bar. ELSAWin specification is 358 ± 28 cm^3/min.

A straightforward physical solution to increasing fuel supply across the board is to fit a higher pressure fuel pump (4 bar compared to the stock 3 bar is popular). According to the Bernoulli equation, increasing the supply pressure will increase the flow rate by the square root of the ratio of the pressures so in this case there will be an approximately 15% increase in mass flow rate. Therefore, the ECU will have to be recalibrated to take account of this increase because there is the potential for over-fuelling during any enrichment regime, e.g. catalyst heating at start and component protection. Some owners who have carried out this modification without ECU recalibration have reported rough running during cold start and warm-up. Presumably, also gas mileage will suffer, but the bonus is that unwanted enrichment is always better than unwanted enleanment.

The Bosch Fuel Injection and Engine Management (Technical Including Tuning & Modifying) manual by Charles Probst notes that:

"A positive side-effect of increased fuel pressure... is that forcing the fuel through the same injector at a higher pressure tends to improve fuel atomization. This will tend to improve fuel distribution and combustion efficiency, and may contribute to improved fuel economy.

The benefits of higher pressure are accompanied by some additional concerns, the main one being safety. With fuel lines and connections being subjected to higher pressure, there naturally is an increased risk of leaks or outright failure. To ensure reliability, the standard Bosch parts are rated for pressures well above the normal operating range..."

5.2.3. Lambda for Component Protection (LAMBTS & ATR Modules)

The purpose of these important functions is to protect key components such as the exhaust manifold, turbocharger and catalytic converter. The principle of operation is the reduction of high exhaust temperature by enriching the air-fuel mixture. Excess (unburned) fuel evaporates cooling the cylinder walls, thus the exhaust temperature decreases. The ignition angle efficiency decreases as EGT increases but mixture enrichment can counteract this (see sub-function DLAMBTSZW).

The maps KFLF (*Lambdakennfeld bei Teillast*, map for lambda under partial load conditions) and LAMFA (*Lambda Fahrerwunsch*, driver-target lambda) with units (x,y,z): % load, RPM, AFR determine lambda. Although professional tuners do appear to adjust KFLF, it is part of the basic fuel injection module ESGRU 23.30 *Grundeinspritzungen*. This states that the map KFLF should not be used for mixture intervention because the map KFPU (which compensates for MAF sensor pulsations and signal interruptions) aligns the relative cylinder charge (rl) for the engine's requirements. The S4 wiki notes that these tables are not very useful for fine tuning high load fuelling. It was noted earlier that target lambda is 1.00 under 'normal' conditions, and if you look these tables up using WinOls in the files provided, you will see that they consist mostly of unity entries. LAMFA is only implemented when another AFR protection map is not overriding it and some tuners suspect that the LAMFA table implementation in the ECU may contain bugs.

The map KFLBTS which specifies lambda values as a function of engine speed and cylinder charge controls enrichment of target lambda. This only activates when several variables which represent <u>modelled</u> temperatures (a) at the exhaust manifold, (b) in the catalytic converter, (c) near the catalytic converter (d) at the cylinder head or (e) near the lambda probe, in a sub-function LAMBTSENABLE have exceeded their threshold and a start-up delay time has expired. Apart from the cylinder head temperature which is 200°C, these values are typically 900-950°C.

KFLBTS (*Kennfeld für Lambdasoll für Bauteileschutz*. map for target lambda for component protection). Units (x,y,z): RPM, % load, AFR

	800	1000	1480	1720	2000	2200	2520	3000	3520	4000	4520	5000	5520	5800	6040	6520
25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
34.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
47	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
60	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
70	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
107	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**0.98**	**0.97**	**0.98**	1.00	1.00	1.00
135	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
150	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
165	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
179	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
191	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Lambda for component protection = KFLBTS + (KFDLBTS x KFFDLBTS).

KFDLBTS (*Kennfeld für Delta Lambdasoll für Bauteileschutz*, map for the change in target lambda for component protection). Units (x,y,z): RPM, % load, ∆AFR

	1000	3000	5000	6000
2.5	0.000	0.000	0.000	0.000
3	0.000	-0.023	-0.023	-0.023
6	-0.023	-0.117	-0.117	-0.117
10	-0.070	-0.203	-0.203	-0.203
15	-0.125	-0.258	-0.258	-0.258
20	-0.180	-0.313	-0.313	-0.313
30	-0.281	-0.375	-0.375	-0.375

40	-0.375	-0.375	-0.375	-0.375

Enrichment can be deployed in desired areas, attenuated or eliminated by means of the map KFFDLBTS (*Kennfeld für Faktor Delta Lambdasoll für Bauteileschutz*, map for the multiplication factor for the change in target lambda for component protection) with units (x,y,z): RPM, % load, multiplication factor.

	800	1000	1480	1720	2000	2200	2520	3000	3520	4000	4520	5000	5520	5800	6040	6520
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.25	0.19	0.52	0.76
34.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.30	0.20	0.13	0.25	0.55	0.52	0.75	1.00
47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.55	0.48	0.70	0.74	1.37	1.65	1.89	1.99
60	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.51	0.66	0.66	0.91	1.25	1.83	1.85	1.37	1.28
70	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.61	0.66	0.80	0.96	1.69	1.80	1.43	1.43	1.20
90	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.65	0.73	0.91	1.08	1.38	1.30	1.30	1.16	1.11
107	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.82	0.91	1.08	1.13	1.06	1.16	1.15	1.34
135	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	0.85	0.83	1.08	1.12	1.19	1.35	1.00	1.23
150	1.00	1.00	1.00	1.00	1.00	0.78	1.00	1.00	1.00	0.86	1.07	1.12	1.19	1.04	0.92	1.00
165	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
179	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
191	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

FBSTABGM (*Faktor Bauteileschutz abhängig von model Abgastemperatur*, Multiplication factor for component protection subject to the model EGT)

°C	700	820	860	900
Ratio	0	0	1	1

In addition to LAMBTS, the ATR module controls the general enrichment at high load and speed (full load enrichment). EGT control is applied only if the controlled enrichment is insufficient (which improves fuel economy). Unlike LAMBTS which uses modelled temperatures, ATR takes an actual temperature input from the EGT sensor. The set point for EGT regulation in the ATR function is given by constant TABGSS (*Sollwert Abgastemperatur für Abgastemperaturregelung*) which has the value 920°C.

The data I obtained on my own car post-remap during third gear and fourth gear WOT logging runs illustrates how difficult it can be to balance all the stipulated constraints when exploring the limits of the tuning envelope and the dramatic effects on individual cylinder corrections of ignition angle and output of using lower octane fuel than the remap is formulated for. Discussion follows at the end of the four data tables 5.2 to 5.5 in which excessive values are highlighted in red type, derived or calculated parameters are in blue type and peak values in bold type.

Table 5.2. Engine Parameters During Third Gear WOT Logging Run with 99 RON Premium Unleaded Fuel (Ambient Temperature +2.5°C).

Time Index	RPM	Load	Inj. On Time	IDC	MAF	Calc BHP	Cyl1	Cyl2	Cyl3	Cyl4	ECU Torque
Seconds	/min	%	ms	%	g/s	MAF/0.8	°KW	°KW	°KW	°KW	lbft
0.9	1480	27.1	2.72	3.4	7.58	9.5	0.0	0.0	0.0	0.0	14.2
1.8	1560	80.5	7.48	9.7	26.0	32.5	0.0	0.0	0.0	0.0	34.7
2.7	1840	96.2	8.50	13.0	36.4	45.6	0.0	0.0	0.0	0.0	108.9
3.6	2240	128.6	11.90	22.2	60.3	75.4	0.0	0.0	0.0	0.0	148.4
4.5	2760	188.0	17.00	39.1	110.9	138.6	0.0	0.0	0.0	0.0	221.0
5.4	3520	191.7	21.08	61.8	141.9	177.4	0.0	0.0	0.0	0.0	**265.2**
6.3	4280	191.7	21.42	76.4	181.5	226.9	0.0	0.0	0.0	0.0	**265.2**
7.2	5000	191.7	20.74	86.4	204.5	255.7	0.0	0.0	0.0	0.0	**265.2**
8.1	5640	191.7	19.72	92.7	217.7	272.2	0.0	0.0	3.0	0.0	249.4
9.0	6200	186.5	18.02	93.1	221.9	277.4	0.0	0.0	3.0	0.0	230.4
9.9	6680	174.4	16.66	92.7	222.3	277.8	0.0	0.0	2.3	0.0	202.0
10.8	7040	167.7	16.66	97.7	223.3	**279.2**	0.0	0.0	2.3	0.0	189.4

Table 5.3. Engine Parameters During Third Gear WOT Logging Run with 95 RON Unleaded Fuel (Ambient Temperature +13.5°C).

Time Index	Speed	Load	Inj. On Time	IDC	MAF	Calc BHP	Cyl1	Cyl2	Cyl3	Cyl4	ECU Torque
Seconds	RPM	%	ms	%	g/s	MAF/0.8	°KW	°KW	°KW	°KW	lbft
0.6	1000	71.4	6.5	5.4	13.9	17.4	0.0	0.0	0.0	0.0	75.7
1.5	1120	75.9	6.8	6.3	17.5	21.8	0.0	5.3	3.0	3.0	82.1
2.4	1320	80.5	6.8	7.5	21.6	27.0	0.0	5.3	3.0	3.0	94.7
3.3	1520	86.5	7.5	9.5	26.4	33.0	3.0	4.5	2.3	2.3	101.0
4.2	1760	94.0	8.2	12.0	32.7	40.9	3.0	4.5	2.3	2.3	118.4
5.1	2040	107.5	9.2	15.6	44.7	55.9	2.3	3.8	1.5	2.3	132.6
6.0	2400	136.1	12.2	24.5	68.1	85.1	2.3	3.8	4.5	1.5	172.1
7.0	2880	191.7	17.0	40.8	114.4	143.1	1.5	3.0	7.5	4.5	225.7
7.9	3520	191.7	20.7	60.8	148.6	185.8	4.5	3.0	7.5	4.5	255.7
8.8	4200	191.7	20.4	71.4	173.4	216.7	4.5	6.0	6.8	7.5	252.5
9.7	4760	191.7	19.4	76.9	184.6	230.8	7.5	6.0	6.8	7.5	**258.9**
10.6	5280	191.7	19.0	83.8	193.0	241.3	7.5	6.0	6.0	7.5	236.8
11.5	5720	184.2	18.0	85.9	198.6	**248.2**	7.5	5.3	6.0	6.8	221.0
12.4	6120	167.7	16.3	83.2	193.3	241.7	6.8	5.3	6.0	6.8	198.8
13.3	6480	146.6	14.6	78.9	188.7	235.8	6.8	5.3	5.3	9.8	164.2
14.2	6760	142.1	14.3	80.4	183.0	228.7	6.0	4.5	5.3	9.8	164.2
15.1	7000	134.6	13.3	77.4	183.8	229.8	6.0	4.5	8.3	9.0	157.8
16.0	7200	139.8	14.3	85.7	183.4	229.2	6.0	4.5	8.3	8.3	140.5

Table 5.4. Engine Parameters During Fourth Gear WOT Logging Run with 99 RON Premium Unleaded Fuel (Ambient Temperature +2.5°C).

Time Index	RPM	Load	Inj. On Time	IDC	MAF	Calc BHP	Cyl1	Cyl2	Cyl3	Cyl4	ECU Torque
Seconds	/min	%	ms	%	g/s	MAF/0.8	°KW	°KW	°KW	°KW	lbft
0.01	1000	14.3	1.7	1.4	3.1	3.9	0	0	0	0	88.4
0.9	1080	77.4	7.48	6.7	17.1	21.3	0.0	0.0	0.0	0.0	101.0
1.8	1200	85.0	7.82	7.8	21.0	26.3	0.0	0.0	0.0	0.0	110.5
2.7	1320	88.7	8.16	9.0	23.4	29.3	0.0	0.0	0.0	0.0	113.7
3.6	1480	93.2	8.84	10.9	27.8	34.7	0.0	0.0	0.0	0.0	121.6
4.5	1640	100.0	9.52	13.0	33.9	42.3	0.0	0.0	0.0	0.0	138.9
5.4	1880	108.3	9.86	15.4	41.1	51.4	0.0	0.0	0.0	0.0	164.2
6.4	2080	129.3	11.90	20.6	56.2	70.3	0.0	0.0	0.0	0.0	208.4
7.2	2360	164.7	15.30	30.1	81.2	101.5	3.0	3.0	3.0	0.0	265.2
8.2	2720	191.7	19.38	43.9	115.8	144.8	3.0	3.0	3.0	0.0	265.2
9.1	3160	191.7	20.40	53.7	135.3	169.1	3.0	2.3	2.3	0.0	**269.9**
10.0	3600	191.7	20.74	62.2	144.9	181.2	3.0	2.3	2.3	3.0	**269.9**
10.9	4040	191.7	21.08	71.0	173.8	217.2	3.0	2.3	2.3	3.0	268.3
11.8	4400	191.7	20.74	76.0	185.4	231.8	2.3	1.5	5.3	3.0	257.3
12.7	4800	191.7	20.40	81.6	193.6	242.0	2.3	1.5	5.3	3.0	257.3
13.6	5160	191.7	20.74	89.2	202.6	253.3	1.5	1.5	4.5	2.3	251.0
14.5	5440	191.7	20.40	92.5	210.9	263.6	1.5	0.8	4.5	2.3	236.8
15.4	5760	191.7	20.40	97.9	216.3	270.4	1.5	3.8	3.8	2.3	227.3
16.3	6000	189.5	19.72	98.6	218.1	272.6	1.5	3.8	3.8	1.5	211.5
17.21	6240	184.2	20.06	104.3	217.7	272.2	0.8	3.0	3.8	1.5	198.8
18.11	6480	179.7	22.78	123.0	217.7	272.2	0.8	3.0	3.0	0.8	195.7
19.02	6640	177.4	23.12	127.9	224.2	**280.3**	0.8	2.3	3.0	0.8	184.7
19.92	6840	172.9	23.46	133.7	221.6	277.0	0.0	2.3	2.3	0.8	175.2
20.83	7000	157.9	22.44	130.9	222.9	278.6	0.0	2.3	2.3	0.8	175.2

21.73	7160	169.9	24.82	148.1	221.6	277.0					

Table 5.5. Engine Parameters During Fourth Gear WOT Logging Run with 95 RON Unleaded Fuel (Ambient Temperature +13.5°C).

Time Index	RPM	Load	Inj. On Time	IDC	MAF	Calc BHP	Cyl1	Cyl2	Cyl3	Cyl4	ECU Torque
Seconds	/min	%	ms	%	g/s	MAF/0.8	°KW	°KW	°KW	°KW	lbft
0.6	880	71.4	6.5	4.7	12.5	15.7	0.8	4.5	0.0	1.5	3.2
1.5	1000	72.9	6.1	5.1	14.6	18.2	0.8	4.5	0.0	3.8	80.5
2.4	1120	76.7	6.8	6.3	17.1	21.4	0.0	3.8	3.0	3.8	78.9
3.3	1240	81.2	7.1	7.4	21.2	26.5	3.0	3.8	3.0	3.8	91.5
4.2	1360	85.0	7.5	8.5	24.1	30.1	3.0	3.0	2.3	3.8	102.6
5.1	1480	87.2	7.5	9.2	24.5	30.6	3.0	2.3	2.3	3.0	107.3
6.0	1640	93.2	7.8	10.7	30.4	38.0	2.3	2.3	1.5	3.0	113.7
6.9	1800	97.7	8.5	12.8	36.1	45.1	2.3	1.5	1.5	3.0	126.3
7.8	1960	108.3	9.2	15.0	42.3	52.9	2.3	1.5	3.8	3.0	137.3
8.7	2200	127.8	11.2	20.6	56.3	70.3	1.5	7.5	3.8	6.0	165.7
9.6	2440	159.4	14.6	29.7	80.8	100.9	4.5	7.5	6.8	9.0	208.4
10.5	2760	191.7	18.4	42.2	121.3	151.6	4.5	6.8	6.8	9.0	247.8
11.4	3080	190.2	17.7	45.4	112.6	140.8	4.5	6.8	6.8	9.0	251.0
12.3	3440	188.7	17.7	50.7	127.1	158.9	3.8	6.0	6.0	8.3	249.4
13.2	3760	191.7	17.7	55.4	138.2	172.7	6.8	6.0	6.0	8.3	252.5
14.1	4080	191.7	18.0	61.3	151.6	189.5	6.8	6.0	5.3	7.5	**254.1**
15.0	4400	191.7	18.4	67.3	159.6	199.5	6.8	5.3	5.3	7.5	246.2
16.0	4680	185.7	18.4	71.6	165.5	206.8	6.0	5.3	5.3	6.8	239.9
16.9	4960	186.5	18.4	75.9	174.5	218.1	6.0	5.3	8.3	6.8	232.0
17.8	5200	182.0	18.0	78.1	181.9	227.4	6.0	4.5	8.3	6.8	219.4
18.7	5440	178.9	18.0	81.7	184.4	230.6	8.3	7.5	7.5	6.0	214.6
19.6	5680	171.4	17.7	83.7	182.3	227.9	8.3	7.5	7.5	6.0	203.6
20.5	5920	162.4	17.0	83.9	179.0	223.8	8.3	7.5	7.5	6.0	195.7
21.4	6040	157.1	16.3	82.1	181.7	227.1	7.5	6.8	6.8	5.3	167.3
22.3	6240	148.9	15.3	79.6	184.5	230.6	7.5	6.8	6.8	5.3	172.1
23.2	6360	155.6	16.7	88.3	184.4	230.5	6.8	6.0	6.0	5.3	168.9
24.1	6480	152.6	16.7	90.0	187.4	**234.3**	6.8	6.0	6.0	5.3	164.2
25.0	6600	142.1	15.3	84.2	180.4	225.5	6.8	6.0	6.0	4.5	145.2
25.9	6680	136.1	15.6	87.1	170.6	213.3	6.0	5.3	5.3	4.5	126.3
26.8	6800	130.8	15.0	84.8	172.0	215.0	6.0	5.3	5.3	3.8	132.6
27.7	6880	130.8	15.3	87.7	173.8	217.2	5.3	4.5	5.3	3.8	126.3

Remarks

(a) Individual cylinder corrections to the overall ignition angle advance are significantly greater with the lower grade fuel which reflects the expected ECU response when the fuel has a greater tendency to pre-ignite and knock. Because of the lower overall ignition angle advance, peak cylinder pressures will be lower and therefore less favourable to achieving best torque. A positive side-effect of the lower achievable torque output is that now less fuel is required both for stoichiometric burning and component protection enrichment regimes. Thus IDCs remain within target for a safe tuning strategy (i.e. not more than 85 to 90%).

(b) The combination of low ambient (and therefore intake air) temperature and high octane fuel mean that there is plenty of oxygen available for stoichiometric combustion and the ECU can operate at a highly favourable overall ignition advance to achieve high torque outputs. Therefore, component protection regime is working hard by enriching the mixture to keep temperatures within limits; so much so that IDCs at the end of the fourth gear WOT run with premium fuel are much greater than 100% indicating that the injectors are effectively static above 6,200 RPM.

(c) The peak MAF is 11 to 16% lower on the standard octane fuel (discounting any power reduction due to the ~10°C temperature difference).

(d) load doesn't exceed 191.7 which is the maximum value on one axis used to specify optimum torque in the map KFMIOP (illustrated later).

Clearly, this remap is designed to extract the maximum potential torque for relatively short durations at full load (i.e. up to around 15 seconds) which ought to be quite reasonable for typical European driving conditions, for instance to enable swift overtaking on single-carriageway trunk roads. Although it's not my scene, this timescale should also comfortably accommodate a standing quarter mile drag race without the owner experiencing enleanment issues such as excessive EGT.

Remapping specialists of course recommend the higher rated fuel because its reduced tendency to knock allows the ECU full access to early ignition angles. This in turn allows for the optimum fuel-air mixture burn time and achieving peak cylinder pressure at the correct angle in the cycle (just after TDC on the power stroke) and thus maximum commanded torque. The price differential between standard and premium unleaded fuels in the U.K. (between £3.00 and £4.80 per 60 litre tank) and the fact that the majority of my driving is at steady cruise with gentle acceleration meant that I was not experiencing the benefits of using premium fuel and therefore opted to use standard 95 RON unleaded fuel to save money. However, this does somewhat hamper the ability to extract the car's full performance potential if the opportunity arises.

5.3. Torque Control via Relative Cylinder Charge

5.3.1. Torque Demand Management Overview (MSF Module)

We learned in Section 3 that Motronic ME7.x with EGAS doesn't influence charge pressure directly. Instead, the direct torque demand from the driver (external) via the accelerator pedal position is evaluated into a cylinder charge. As a rule-of-thumb, boost pressure is approximately 10 × (relative cylinder charge) + 300 mbar.

The basic torque functional structure is illustrated diagrammatically in Appendix 1 with a table describing the variables used. The structure consists of a series of functions that impose torque demands such as: driver commands (MDFAW), minimum torque for start and idle speed control (MDMIN), exhaust/catalytic converter functions (AK), driver comfort function through anti-judder (ARMD), traction control (ASR), transmission control and ancillary functions for engine speed and vehicle speed (NMAXMD, VMAXMD).

The coordination of these control functions occurs in the function MDKOL for the air pathway and in MDKOG for the overall coordination. The function MDBAS largely represents those engine torque models available, such as optimum engine torque, optimum ignition angle, etc. MDIST sets the actual adjusted indexed torque.

5.3.2. Maps Relating to Charge Pressure Control (LDRLMX & LDRUE Modules)

The charge pressure regulation functional structure is illustrated diagrammatically in Appendix 2 with a table describing the variables used. The boost pressure regulation function controls target load 'plsol' (or target MAP, 'pssol') upstream of the throttle 'pvdkds'. Boost pressure regulation is air mass based, i.e. the primary charge is set by a pressure level. This confers very good fail-safe, guaranteed behaviour (for example, in the case of a non-critically blocked catalytic converter) since boost pressure remains constant.

The maximum permissible charge 'rlmax_w' under full load is generated by LDR and the available torque structure. All charge-influencing variables (relative fuel mass, IAT, overboost, etc.) are included in 'rlmax_w'. Without any torque intervention, the target charge under full load 'plsol_w' is equal to 'rlmax_w'.

The required charge pressure is generated by selecting the appropriate intake manifold pressure from a parametric linear equation in the FUEDK module then dividing by the target pressure ratio 'vpsspls_w' to give the target charge pressure value 'plsol'.

This pressure ratio depends on the driving conditions such that there is a trade-off between good efficiency on the one hand and a good pressure build-up response characteristic at part-loads within defined practicable limits on the other hand.

The LDRLMX module calculates the allowed maximum cylinder charge. In the main path, the engine speed dependent maximum cylinder charge is determined by the characteristic LDRXN (*Maximalfüllung LDR*, maximum cylinder charge for charge pressure control). There is a similar maximum specified charge profile during continuous knock: LDRXNZK *(Maximalfüllung LDR bei Dauerklopfen)*. These values are shown in the table below.

BAM | BFV

RPM	LDRXNZK (%)	LDRXN (%)	LDRXNZK (%)	LDRXN (%)
1000	97.0	97.0	99.0	99.0
1720	128.1	128.1	129.8	129.8
2000	139.9	140.6	148.5	148.5
2100	143.6	147.4	154.5	154.5
2200	145.6	146.7	160.5	155.3
2520	148.5	140.8	176.3	166.5
3000	148.2	138.3	176.3	166.5
3520	146.5	140.9	176.3	166.5
4000	148.2	144.0	182.3	166.5
4520	159.4	151.8	188.3	177.0
5000	160.2	151.7	183.0	185.3
5520	157.7	157.7	168.8	171.8
5900	155.8	155.3	162.0	168.8
6000	153.2	153.0	153.8	160.5
6400	142.3	142.3	141.0	148.5
6800	130.1	130.1	135.0	144.0

Remarks for LDRXN: these maps contain the most significant differences between the two states of tune (BAM & BFV) of any of the primary maps discussed so it seems reasonable to assume that adjusting these profiles will bring about the most noticeable effect. Note that the peak in LDRXN is around 5500 to 5700 rpm which corresponds to the point at which peak power is achieved in the BAM and BFV engines. LDRXN can be set to near maximum by some professional tuners as a means of sacrificing some safety margin in the pursuit of higher output. Although this represents the short-circuit of a safety feature, it is perhaps deemed sufficient for only timing to be retarded during knock rather than both timing to be retarded and charge pressure to be reduced. However, considering that the output profile I logged on my car using lower octane fuel than the remap was designed for is actually close to stock (peaking at only 234 bhp), it appears likely that a reasonable safety margin has been retained.
Remarks for LDRXNZK: It is noted in module LDRLMX 3.100 that the values should be set about 15% lower than LDRXN which would be reasonable from an intuitive understanding; i.e. overall ignition advance is reduced during knock so maximum allowable cylinder charge should also be reduced. However, in these examples, the values in LDRXNZK are actually higher from around 2,300 to between 5,000 and 5,500 rpm. The only plausible explanation is that a slightly larger cylinder charge is allowed to counteract the sub-optimal peak cylinder pressure and consequential loss of torque that would result from sub-optimal ignition timing due to knock. Otherwise, the driver would feel a noticeable step-change in power during the onset of knock. If in doubt, don't try to second-guess the OEM calibrator; follow the advice in the *funktionsrahmen* and set the values in LDRXNZK a bit lower than LDRXN.

The characteristic field KFTARX (*Kennfeld Maximalfuellung Tans Korrekturfaktor*) corrects the 'rlmx' path by a multiplication factor as a function of engine speed and IAT. Notice that up to and including an IAT of 30°C, the correction factor is 1.00, between 30°C and 70°C, a slight charge pressure increase is applied to counteract the loss of power resulting from warmer, lower density intake air then above 70°C, the charge pressure is progressively reduced for safety. I observe typical IATs of 8-11°C above ambient air temperature during normal driving conditions so in the U.K., even at the height of summer, IATs are unlikely to rise above 45°C, therefore Motronic will be applying minimal charge pressure correction. For this reason, there ought to be no strong requirement to adjust these IAT correction maps.

KFTARX (*Kennfeld Maximalfüllung Temperatur Ansaugluft Korrekturfaktor*, Map for IAT correction factor to maximum charge). Units (x,y,z): °C, RPM, ratio

	-10	10	30	50	70	80	90	110	130	143
1000	1.00	1.00	1.00	1.000	1.000	0.95	0.85	0.75	0.75	0.75
1700	1.00	1.00	1.00	1.000	1.000	0.95	0.85	0.75	0.75	0.75
2000	1.00	1.00	1.00	1.036	1.012	0.95	0.85	0.75	0.75	0.75
2200	1.00	1.00	1.00	1.051	1.042	0.95	0.85	0.75	0.75	0.75
2520	1.00	1.00	1.00	1.056	1.056	0.95	0.85	0.75	0.75	0.75
3000	1.00	1.00	1.00	1.026	1.061	0.95	0.85	0.75	0.75	0.75
3520	1.00	1.00	1.00	1.023	1.060	0.95	0.85	0.75	0.75	0.75
4000	1.00	1.00	1.00	1.010	1.059	0.95	0.85	0.75	0.75	0.75
5000	1.00	1.00	1.00	1.043	1.039	0.95	0.85	0.75	0.75	0.75

5500	1.00	1.00	1.00	1.008	1.023	0.95	0.85	0.75	0.75	0.75
6000	1.00	1.00	1.00	1.004	1.023	0.95	0.85	0.75	0.75	0.75
6500	1.00	1.00	1.00	1.000	1.000	0.95	0.85	0.75	0.75	0.75

	-10	10	30	50	70	80	90	110	130	143
1000	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.97	0.97	0.97
1700	1.00	1.00	1.00	1.00	1.00	0.97	0.95	0.93	0.93	0.93
2000	1.00	1.00	1.00	1.00	0.97	0.95	0.90	0.78	0.78	0.78
2200	1.00	1.00	1.00	1.00	0.90	0.80	0.79	0.76	0.76	0.76
2520	1.00	1.00	1.00	0.95	0.92	0.80	0.76	0.67	0.67	0.67
3000	1.00	1.00	1.00	0.98	0.94	0.81	0.75	0.65	0.65	0.65
3520	1.00	1.00	1.00	1.00	0.93	0.82	0.74	0.60	0.60	0.60
4000	1.00	1.00	1.00	1.02	0.94	0.82	0.73	0.57	0.57	0.57
5000	1.00	1.00	1.00	0.92	0.88	0.78	0.71	0.53	0.53	0.53
5500	1.00	1.00	1.00	0.92	0.90	0.77	0.70	0.52	0.52	0.52
6000	1.00	1.00	1.00	0.95	0.90	0.77	0.69	0.51	0.51	0.51
6500	1.00	1.00	1.00	0.87	0.79	0.76	0.68	0.50	0.50	0.50

Remarks: the S4 wiki notes that if the tuning strategy results in high charge pressures, and it is presumed that maximum performance is desired at all times, there is no point in varying boost as ambient temperature changes. Also, as IAT rises, even with uniform KFTARX and LDIATA maps, the charge pressure will still increase because the ECU must achieve a higher pressure ratio to maintain the target cylinder charge. To compensate, it is advisable to taper KFTARX values as IATs rise to keep boost pressure at an acceptable level. Maximum boost pressure is slightly above the maximum MAP (presumably to account for pressure drop across the charge air coolers between the turbocharger and intake manifold). Undesirable effects can occur in control loops if the MV cannot meet DV.

KFPED (*Relatives Fahrerwunschmoment aus Fahrpedal*, relative driver-target torque via throttle pedal). Units (x,y,z): RPM, %pedal travel, %torque

	600	1000	1480	2000	2100	2520	3000	4520	5000	5520	6000	6520
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	20.9	10.8	3.2	1.8	1.8	1.4	1.4	1.4	1.0	0.9	0.9	0.7
7	31.0	18.2	8.0	4.8	4.4	3.9	3.5	2.7	2.3	1.9	1.6	1.9
12	41.8	30.6	19.6	12.8	12.1	11.1	9.9	7.2	5.9	4.9	4.4	4.5
18	53.9	41.3	29.3	20.6	19.2	18.5	17.1	12.4	10.9	9.0	8.4	7.8
24	66.7	55.1	42.0	28.9	27.2	26.4	24.9	19.1	17.3	15.2	14.5	13.8
30	77.9	66.4	52.5	38.3	35.9	34.8	33.8	28.0	27.1	25.1	23.7	22.4
36	86.3	76.9	63.1	48.8	46.0	45.9	45.0	39.5	39.0	36.5	34.2	32.8
42	92.0	84.8	73.0	59.7	56.9	57.5	56.7	52.7	52.2	50.3	47.8	46.3
50	96.1	91.9	83.4	72.0	69.0	70.4	69.2	64.9	64.4	61.0	58.9	57.3
60	98.9	96.0	91.0	83.4	81.4	83.1	82.3	78.4	78.4	75.3	73.0	71.0
70	100.0	98.9	96.9	92.8	91.6	92.5	92.3	88.8	89.0	85.6	83.5	81.5
80	100.0	99.6	99.1	97.4	96.5	97.5	97.3	94.5	94.8	93.5	92.2	90.7
87	100.0	100.0	100.0	99.9	99.8	99.7	99.2	98.0	98.0	97.8	96.8	96.6
93	100.0	100.0	100.0	100.0	99.9	99.9	99.8	99.4	99.4	99.4	98.9	98.9
100	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Remarks: there is no difference between the BAM & BFV maps for relative driver-target torque via throttle pedal. This map can be used to fine tune how aggressive/benign the torque delivery is compared to the throttle pedal position, but note that part-throttle torque output should be tuned by modifying KFMIRL and WOT output should be tuned by modifying LDRXN (see later).

KFMDST (*Startmoment*, starting torque). Units (x,y,z): °C, λ?, % torque.

	-30	-20	-7	0	20	90
0.00	13.3	13.3	11.7	11.7	11.7	9.4
0.20	13.3	13.3	11.7	11.7	11.7	9.4

0.35	13.3	13.3	11.7	11.7	11.7	9.4
0.70	13.3	13.3	11.7	11.7	11.7	9.4
0.70	13.3	13.3	11.7	11.7	11.7	9.4
0.87	13.3	13.3	11.7	11.7	11.7	9.4
0.88	-70.2	-70.2	-70.2	-70.2	-70.2	-70.2
0.90	-98.3	-98.3	-98.3	-98.3	-98.3	-98.3

KFMIRL (*Kennfeld für Berechnung Sollfüllung,* map for calculating target cylinder charge). Units (x,y,z): % torque, RPM, % charge.

	0	5	10	15	20	25	30	35	40	45	50	60	70	80	90	100
600	0.0	9.4	20.8	32.4	44.1	56.0	68.3	80.3	92.3	103.7	114.9	136.1	156.1	176.0	195.7	217.6
800	0.0	8.6	19.8	31.3	42.6	54.1	65.8	77.3	88.7	99.8	110.5	131.3	150.8	170.2	189.7	211.1
1000	0.0	8.0	18.8	30.5	41.3	52.3	63.7	74.8	85.5	96.2	106.4	126.7	145.7	164.7	183.9	202.1
1240	0.0	7.8	18.2	29.5	40.3	51.0	61.6	72.1	82.2	92.4	102.4	122.4	141.8	161.2	180.6	197.3
1520	0.0	7.7	17.6	28.5	39.3	50.1	59.9	69.8	79.8	89.8	99.9	119.9	140.0	160.2	180.3	198.3
1740	0.0	7.5	17.3	28.1	38.6	49.1	59.3	69.5	79.6	89.6	99.6	119.3	139.9	160.8	181.8	200.3
2000	0.0	7.3	16.8	27.6	38.3	49.1	58.7	68.3	78.8	89.4	99.6	118.8	140.0	162.0	183.8	204.3
2520	0.0	7.1	16.1	26.7	37.1	47.4	57.7	67.9	77.8	87.6	97.5	118.5	140.4	162.8	185.3	209.1
3000	0.0	7.0	16.0	26.3	36.6	46.8	57.0	67.4	77.2	86.8	96.4	116.2	137.8	161.0	184.5	210.0
3520	0.0	6.8	15.4	25.5	35.9	46.5	56.7	66.7	76.9	87.1	97.2	117.3	140.6	165.6	190.0	212.1
4000	0.0	6.6	14.8	24.9	35.2	45.5	55.7	65.8	75.6	85.2	94.8	116.1	139.4	164.0	188.2	212.8
4520	0.0	6.6	14.8	24.4	34.4	44.9	55.0	64.8	74.6	84.5	94.4	116.4	138.9	161.9	185.2	210.9
5000	0.0	6.7	14.8	24.4	34.5	45.1	54.5	62.6	71.2	82.9	94.6	119.1	142.1	164.8	188.0	210.3
5520	0.0	6.5	14.4	24.1	34.0	43.9	53.5	62.9	72.6	83.2	93.8	118.7	143.5	168.0	189.0	209.3
6000	0.0	6.3	14.1	23.6	33.1	42.7	52.4	62.3	72.5	83.8	95.1	121.8	147.7	173.7	194.8	218.0
6800	0.0	7.2	16.4	27.0	38.2	49.6	58.0	66.3	75.6	85.7	96.1	126.0	154.8	183.7	204.0	222.0

Remarks: the map KFMIRL is used in the *funktionsrahmen* module MDFUE 8.50 with inputs of engine speed and the target torque for the charge pathway, recalculated at lambda = 1 and zwopt (misopl1_w) to calculate the target cylinder charge. Note that the higher values are greater than 191.0% in KFMIOP and greater than the maximum of 185.3% in LDRXN for the BFV engine which places an upper limit on the KFMIRL output via the variable rlmax. There is no difference between the BAM & BFV maps for calculating target charge. KFMIRL should be used to tune part-throttle torque response. Please note that **it is stated in module MDFUE 8.50 Application Notes that the map KFMIRL is the inverse of the map KFMIOP in module MDBAS. Therefore, any changes made to KFMIRL should be reflected in KFMIOP and vice versa. If the difference is too large, problematic operation/torque intervention will be experienced.** Inverse in this sense is assumed to mean ‘complementary’, not the exact arithmetic inverse.

KFMIOP (*Kennfeld optimales Motormoment*, map for optimum engine torque). Units (x,y,z): % load, RPM, % torque

	0	10	20	30	50	70	95	125	155	175	191
600	0.0	5.4	9.7	13.9	22.6	30.7	41.1	54.5	69.4	79.5	87.6
800	0.0	5.8	10.1	14.4	23.3	31.8	42.8	56.8	72.2	82.5	90.7
1000	0.0	6.2	10.5	14.8	24.0	32.7	44.4	59.1	74.9	85.4	93.7
1240	0.0	6.4	10.8	15.2	24.5	34.0	46.3	61.3	76.8	87.1	95.3
1520	0.0	6.5	11.1	15.7	25.0	35.1	47.6	62.5	77.4	87.4	95.3
1740	0.0	6.6	11.3	15.9	25.4	35.2	47.7	62.9	77.2	86.8	94.4
2000	0.0	6.8	11.5	16.1	25.4	35.9	47.6	63.2	76.8	85.9	93.3
2520	0.0	7.1	11.8	16.6	26.2	36.0	48.8	63.1	76.5	85.4	92.5
3000	0.0	7.1	11.9	16.8	26.6	36.3	49.3	64.5	77.4	86.0	92.8
3520	0.0	7.3	12.2	17.2	26.6	36.6	48.9	63.9	75.7	83.8	90.4
4000	0.0	7.6	12.6	17.5	27.2	37.1	50.1	64.2	76.3	84.5	91.2
4520	0.0	7.6	12.7	17.9	27.4	37.6	50.3	63.9	77.0	85.7	92.5
5000	0.0	7.5	12.7	17.9	27.3	39.5	50.2	62.4	75.8	84.4	91.3
5520	0.0	7.7	12.9	18.0	28.1	38.8	50.6	62.5	74.7	82.9	89.4
6000	0.0	7.9	13.0	18.4	28.8	38.9	49.9	61.2	72.9	80.5	86.6

6800	0.0	7.0	11.7	16.4	25.2	37.2	49.6	59.7	70.1	77.0	82.5

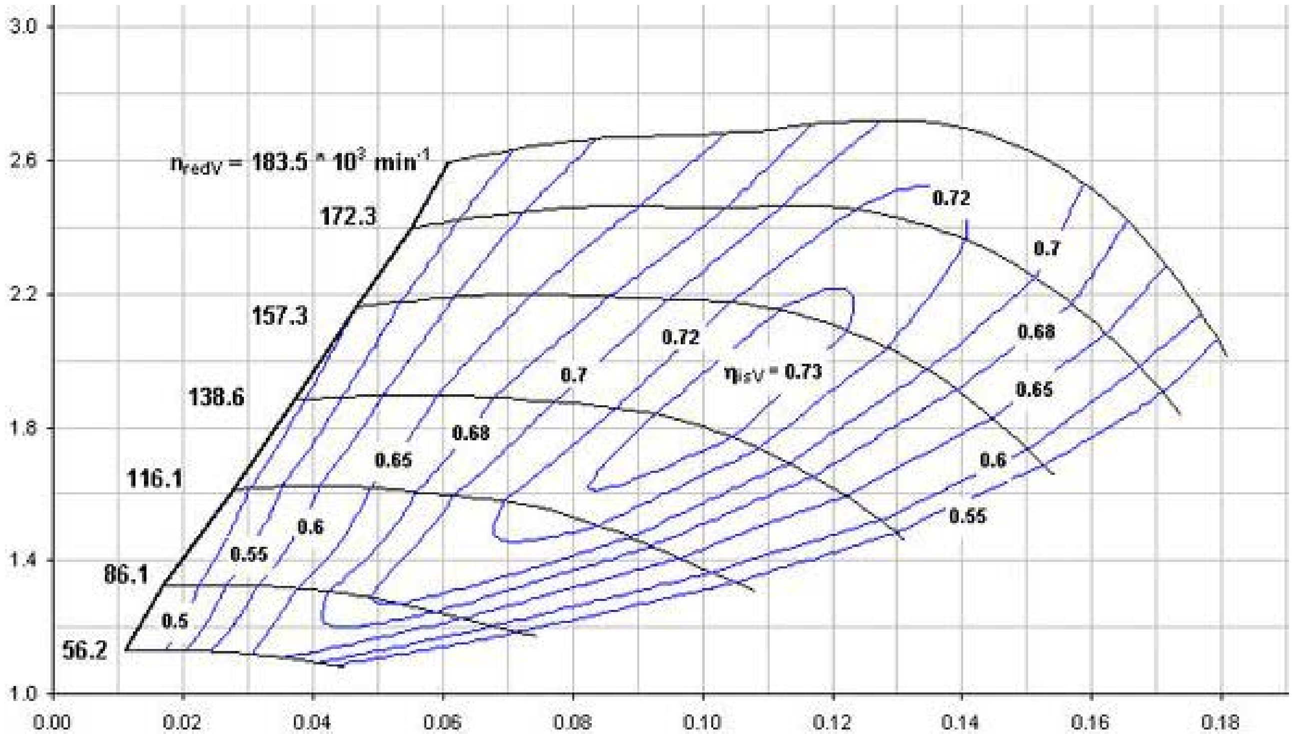
Remarks: the map KFMIOP is used in the *funktionsrahmen* module MDMAX 1.40 with inputs of engine speed and maximum allowed cylinder charge to calculate the maximum allowed indexed torque mimax_w. It is also used in MDBAS 8.30 with inputs of engine speed and relative cylinder charge to calculate the optimum torque variable 'mioptl1_w' at lambda = 1. The optimum torque is corrected for the influence of lambda by multiplying by the lambda coefficient variable 'etalab'. The lambda efficiency is obtained from the characteristic line ETALAM. The basic torque variable 'mibas' is obtained by multiplying by the ignition angle. This corresponds to the indexed torque produced if the combustion takes place with the basic lambda variable 'lambas' and the basic ignition angle variable 'zwbas'. There is no difference between the BAM & BFV maps for optimum engine torque. **It is stated in module MDFUE 8.50 Application Notes that the map KFMIRL is the inverse of the map KFMIOP in module MDBAS. Therefore, any changes made to KFMIOP should be reflected in KFMIRL and vice versa. If the difference is too large, problematic operation/torque intervention will be experienced.** It is accepted that this can be achieved by scaling the load axis instead of altering individual table addresses. Inverse in this sense is assumed to mean 'complementary', not the exact arithmetic inverse.

KFLDHBN (*LDR-Höhenbegrenzung max. Verdichterdruckverhältnis*, charge pressure control: upper limit [compressor pressure ratio]). Units (x,y,z): °C, RPM, ratio

	–9.75	10	30	50	70	90	110	120
1000	2.41	2.41	2.38	2.33	2.30	2.22	2.14	2.11
2000	2.42	2.42	2.39	2.34	2.30	2.22	2.14	2.11
2520	2.48	2.48	2.45	2.41	2.34	2.22	2.14	2.11
3000	2.56	2.56	2.56	2.52	2.38	2.22	2.14	2.11
5000	2.50	2.50	2.50	2.44	2.28	2.13	1.98	1.95
5520	2.38	2.38	2.38	2.36	2.22	2.06	1.89	1.86
6000	2.25	2.25	2.25	2.23	2.11	1.91	1.70	1.66
6520	2.19	2.19	2.19	2.17	2.06	1.89	1.70	1.66

Remarks: the S4 wiki notes that on a WOT run, the charge profile will follow LDRXN but because K03 and K04 turbochargers have significant flow limitations, unlike big turbochargers, charge pressure should peak before the engine speed limit then taper off. The compressor map for these turbochargers is shown in Figure 5.1. The ECUxPlot software has a pressure ratio/flow plotter that can be used use to compare against a turbo's compressor map. The DTC 17963 "Charge pressure: Maximum limit exceeded" will result if boost deviation is too high. There is no difference between the BAM & BFV maps for charge pressure upper limit (compressor pressure ratio).

Figure 5.1. Compressor Map for K04 Turbocharger



X axis: Volumetric flow rate in m^3/s. Y axis: compressor ratio. Z axis: ?

If you would like to learn more about turbochargers, three excellent tutorials at the basic, advanced and expert levels, a FAQ and glossary of terms can be found at Garrett's website.

http://www.turbobygarrett.com/turbobygarrett/tech_center/tech_center.html

KFDLULS (*Delta Druck für Überladeschutzdiagnose*, pressure change for overboost protection diagnosis). Units (x,y,z): mbar, RPM, mbar

	800	1400	1500	1600	1700	1800	1900	2000
800	1200	800	600	500	400	400	400	400
1000	1200	800	600	500	400	400	400	400
1520	1200	800	600	500	400	400	400	400
2000	1200	800	600	500	400	400	400	400
3000	1200	800	600	500	400	400	400	400
4000	1200	800	600	500	400	400	400	400
5000	1200	800	600	500	400	400	400	400
6000	1200	800	600	500	400	400	400	400

Remarks: The S4 wiki notes that if charge pressure is significantly higher than stock, or changes have been made to the boost PID control parameters, then consideration should be given to increasing these limits to avoid overboost protection activating at too low a threshold. The most unsophisticated way would be to simply set all the values in the table to maximum but since this will short-circuit an important safety feature, it is better to spend time iterating and optimizing appropriate values.

5.3.3. Charge Pressure PID Control (LDRPID Module)

PID control philosophy is ubiquitous in industrial processes and is simply a way of ensuring that a controlled variable (e.g. a temperature, pressure or flow but in this case charge pressure) remains at the 'desired value' (DV), 'target' or 'set point' requested by a computer or human operator when conditions change. It is described in detail on Wikipedia but for this purpose, the hot water analogy is sufficient. Proportional control is 'how much for how much': turn the tap on a little for warm water and fully open for hot water and responds to the present error. Integral control is 'how fast for how much' and responds to the past errors: if hot water is not supplied quickly, you turn the tap on more. But what if it overshoots and you get a sudden burst of scalding hot water? That's no good so derivative control is introduced to damp out anticipated future oscillations.

The Motronic ME7.x charge pressure control scheme uses a type 3PR2 (three parameter controller with two output parameters to be optimized) PID controller with adaptive pilot-operated integral control. The integral component takes the form of min/max limitation within an applicable tolerance band to give adaptive tracking of duty cycle during steady-state running. To use the entire duty cycle range (very different gradients) it is necessary to linearize the control system software, so that the PID-controller gives a linear response. This is achieved with the map KFLDRL, which closely regulates the N75 duty cycle by applying an opposing non-linearity so that the regulator-controlled system appears linear.

KFLDRL (*Kennfeld zur Linearisierung Ladedruck = f(TV)* (map for linearization of charge pressure = function of duty cycle). Units (x,y,z): % charge, RPM, % charge

	0	10	20	30	40	50	60	70	80	95
1000	0.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0
1500	0.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0
1750	0.0	19.1	25.5	31.4	36.8	41.5	45.4	49.2	68.6	95.0
2000	0.0	27.1	38.2	45.2	51.4	56.8	63.2	70.0	81.1	95.0
2200	0.0	35.4	47.9	57.0	61.8	67.0	72.7	77.0	84.7	95.0
2300	0.0	39.5	52.2	59.5	65.0	70.2	74.3	78.4	84.8	95.0
2520	0.0	42.6	55.2	61.6	67.3	72.4	75.7	79.0	83.7	95.0
3000	0.0	45.1	56.8	64.4	69.4	73.8	77.1	79.8	83.7	95.0
3520	0.0	44.1	55.8	63.7	69.7	73.6	76.9	80.2	84.2	95.0
4000	0.0	43.3	55.6	63.1	69.5	73.2	77.0	80.2	85.7	95.0
4520	0.0	42.1	54.6	62.5	69.5	73.0	77.0	80.4	86.4	95.0
5000	0.0	42.0	54.2	62.2	68.8	73.2	76.9	80.7	87.5	95.0
5520	0.0	41.7	53.5	61.5	68.6	72.9	76.5	81.1	88.1	95.0
5800	0.0	41.6	53.1	61.3	68.2	72.4	76.4	80.9	87.9	95.0
6000	0.0	41.4	52.7	60.4	67.7	71.8	75.9	80.0	87.5	95.0
6500	0.0	41.6	51.6	58.6	65.4	71.3	75.2	79.1	86.5	95.0

The S4 wiki comments that KFLDRL can be used to get open-loop type behavior for operation past the MAP and boost limit by making the output duty cycle unresponsive (flat) to uncorrected duty cycle (from the PID) at various engine speeds and/or duty cycle values.

There are basically two distinct operating modes:

1. Quasi steady-state operation with PI control which gives a relatively weak control action. Derivation of the control parameters is carried out using an engine dynamometer test according to the Ziegler-Nichols tuning method.

2. Dynamic performance with PID control which gives a strong control action. Derivation of the control parameters is carried out using the transient oscillation method using an engine dynamometer.

These operating states are distinguished via the MV/DV error, i.e. above a positive deviation threshold, the dynamic control action is activated and only stopped at the change of sign of the deviation (DV > MV). The S4 wiki notes that if actual boost is not meeting target boost, the PID integral limit between 2200 and 5000 RPM for 850 and 1000 mbar might need to be increased.

The charge pressure profile ‘pvdkds’ as a function of duty cycle is determined on an engine dynamometer. This procedure is performed starting at 1500 RPM in 500 RPM steps to the maximum engine speed. The necessary linearization values at any given speed are subsequently determined graphically (or calculated) as follows. In the diagram 'pvdkds' which is a function of 'ldtvm', the first measuring point (0%) and the last measuring point (max. 95%) lie on a straight line. Then, at 10% duty cycle for instance, the corresponding pressure value is determined from the line and then the pressure associated with this value from the measurement curve ‘ldtvm’. This 'ldtvm' value is now addressed into the map KFLDRL at the corresponding interpolation point (here, 10%).

Key maps in the charge pressure PID control function are:

KFLDIMX (*Korrektur I-Begrenzung LDR PID Regler als Funktion von Temperatur ansaugluft,* Charge pressure control: integral control limit IAT correction). This specifies the steady-state duty cycle integral control limit.

KFLDIOPU: specifies the duty cycle correction as a function of ambient pressure.
KFLDRQ0, KFLDRQ1 & KFLDRQ2 (*Kennfeld LDR-Reglerparameter Q0, Q1 & Q2*, maps for charge pressure PID control parameters). Units (x,y,z): mbar, RPM, % per 100 mbar.
LDIATA: specifies the duty cycle correction as a function of ambient temperature.

KFLDIMX (*Kennfeld LDR I-Reglerbegrenzung*, map for charge pressure control: integral control limit). Units (x,y,z): mbar, RPM, % charge

	0	50	100	200	400	600	800	1000
1000	0.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0
1500	0.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0
1750	0.0	78.7	95.0	95.0	95.0	95.0	95.0	95.0
2000	0.0	13.4	26.7	58.6	95.0	95.0	95.0	95.0
2200	0.0	5.8	11.6	24.6	53.0	71.8	93.2	95.0
2300	0.0	4.1	8.2	18.9	37.2	51.6	68.6	81.8
2520	0.0	3.8	7.7	15.3	31.9	48.5	63.1	77.1
3000	0.0	3.6	7.3	14.6	31.1	48.9	62.2	75.5
3520	0.0	3.8	7.5	15.1	32.1	51.0	64.2	77.4
4000	0.0	4.0	8.0	15.9	34.4	53.6	66.9	81.0
4520	0.0	4.3	8.5	17.0	37.2	56.8	70.6	86.4
5000	0.0	4.6	9.1	18.2	40.3	60.4	74.8	91.7
5520	0.0	5.0	10.1	20.7	43.4	64.8	81.7	95.0
5800	0.0	5.6	11.2	22.3	45.3	67.6	86.1	95.0
6000	0.0	5.7	11.5	23.6	46.5	69.5	89.9	95.0
6500	0.0	6.9	13.7	27.4	50.4	75.3	94.4	95.0

The S4 wiki comments that it is worth considering setting all the values in LDIATA to zero. However, in the 225 PS BAM map, the values are already zero. This is also the case with the ambient pressure correction map (KFLDIOPU).

KFLDRQ0 (*Kennfeld LDR-Reglerparameter Q0*, map for charge pressure proportional control term Q0). Units (x,y,z): mbar, RPM, % per 100 mbar.

	100	200	400	700
1000	22.10	22.10	22.10	22.10
1240	22.10	22.10	22.10	22.10
1520	22.10	22.10	22.10	22.10
1760	22.10	22.10	22.10	22.10
2000	22.10	22.10	22.10	22.10
2240	21.85	21.85	21.85	21.85
2520	20.70	20.70	20.70	20.70
2760	18.90	18.90	18.90	18.90
3000	17.15	17.15	17.15	17.15
3520	14.30	14.30	14.30	14.30
4000	12.35	12.35	12.35	12.35
4520	10.65	10.65	10.65	10.65
5000	9.40	9.40	9.40	9.40
5520	8.00	8.00	8.00	8.00
6000	6.85	6.85	6.85	6.85
6520	5.65	5.65	5.65	5.65

KFLDRQ1 (*Kennfeld LDR-Reglerparameter Q1*, map for charge pressure integral control term Q1). Units (x,y,z): mbar, RPM, % per 100 mbar.

	100	200	400	700
1000	2.00	2.00	2.00	2.00
1240	2.00	2.00	2.00	2.00
1520	2.00	2.00	2.00	2.00

1760	2.00	2.00	2.00	2.00
2000	1.75	1.75	1.75	1.75
2240	1.50	1.50	1.50	1.50
2520	1.25	1.25	1.25	1.25
2760	1.00	1.00	1.00	1.00
3000	1.00	1.00	1.00	1.00
3520	0.75	0.75	0.75	0.75
4000	0.75	0.75	0.75	0.75
4520	0.75	0.75	0.75	0.75
5000	0.75	0.75	0.75	0.75
5520	0.75	0.75	0.75	0.75
6000	0.75	0.75	0.75	0.75
6520	0.75	0.75	0.75	0.75

KFLDRQ2 (*Kennfeld LDR-Reglerparameter Q2*, map for charge pressure differential control term Q2). Units (x,y,z): mbar, RPM, % per 100 mbar.

	100	200	400	700
1000	17.00	16.00	15.00	13.00
1240	16.60	15.75	14.75	12.75
1520	16.00	15.25	14.30	12.15
1760	15.45	14.60	13.70	11.60
2000	15.00	14.00	13.00	11.00
2240	14.50	13.50	12.50	10.50
2520	14.00	13.00	12.00	10.00
2760	13.50	12.50	11.50	9.50
3000	13.00	12.00	11.00	9.00
3520	12.40	11.00	10.10	8.30
4000	11.90	10.20	9.20	7.70
4520	11.40	9.30	8.30	7.00
5000	11.00	8.40	7.40	6.40
5520	10.00	6.60	5.60	4.60
6000	9.40	5.40	4.40	2.90
6520	8.50	3.50	2.50	1.50

The control algorithms are defined thus:

Proportional component	ldptv	= (LDRQ0DY (or LDRQ0S) − KFLDRQ2 (or 0)) × lde
Integral component	lditv	= lditv(i−1) + KFLDRQ1 (or LDRQ1ST) × lde(i−1)
Derivative component	ldrdtv	= (lde − lde(i−1)) × KFLDRQ2 (or 0)

where lde is the charge pressure control error, i.e. (set point - process value) or (DV − MV)

5.4 Camshaft State Change: Effect on Relative Cylinder Charge

The S4 wiki notes that Motronic changes relative cylinder charge depending on camshaft position. While it may seem like a good idea in theory, in practice, abrupt changes in boost pressure near the MAP limit can perturb the boost PID controller. When logging, you may see a dip in boost pressure between 3000 and 4000 RPM. These maps cause that dip.

KFPBRK (*Korrekturfaktor für Brennraumdruck*, correction factor for combustion chamber pressure). Units (x,y,z): % charge, RPM, ratio

	10	20	30	45	70	90	107	120	150	165
800	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2200	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2520	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

4000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
5000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**0.973**	1.000
5520	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**0.992**	**1.016**	1.000
6000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**1.031**	**1.016**	1.000

KFPBRKNW (*Korrekturfaktor für Brennraumdruck bei aktiver NWS* (correction factor for combustion chamber pressure when cam shaft control active). Units (x,y,z): % charge, RPM, ratio

	10	20	30	45	70	90	107	120	150	165
800	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2000	1.000	1.000	1.000	1.000	1.000	1.000	**0.972**	**0.962**	1.000	1.000
2200	1.000	1.000	1.000	1.000	1.000	1.000	**0.979**	**0.985**	1.000	1.000
2520	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**1.007**	1.000	1.000
3000	1.000	1.000	1.000	1.000	1.000	1.000	**1.009**	**1.015**	**0.984**	1.000
4000	1.000	1.000	1.000	1.000	1.000	1.000	**0.985**	**0.985**	**0.983**	1.000
5000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
5520	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
6000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

KFPRG (*Interner Abgaspartialdruck abhängig von NW-Verstellung bei sumode=0*, internal exhaust partial pressure dependent on cam adjustment when sumode=0). Units (x,y,z): RPM, °crank, mbar

	800	1000	2000	2500	3000	4000	5000	5500	6000	6500
0	56	47	40	47	49	56	40	41	46	50
2.5	56	47	40	47	49	56	40	41	46	50
5	56	47	40	47	49	56	40	41	46	50
17	95	78	68	52	39	41	40	41	46	50
19.5	95	78	68	52	39	41	40	41	46	50
22	95	78	68	52	39	41	40	41	46	50

KFURL (*Umrechnungsfaktor von PS to RL abhängig von NW-Verstellung bei sumode=0,* conversion factor for PS to RL dependent on cam adjustment when sumode=0). Units (x,y,z): RPM, °crank, mbar

	800	1000	2000	2500	3000	4000	5000	5500	6000	6500
0	0.08288	0.08529	0.08889	0.08938	0.09172	0.09125	0.09005	0.08773	0.08467	0.08237
2.5	0.08288	0.08529	0.08889	0.08938	0.09172	0.09125	0.09005	0.08773	0.08467	0.08237
5	0.08288	0.08529	0.08889	0.08938	0.09172	0.09125	0.09005	0.08773	0.08467	0.08237
17	0.08405	0.08529	0.08713	0.08528	0.08703	0.08832	0.09005	0.08773	0.08467	0.08237
19.5	0.08405	0.08529	0.08713	0.08528	0.08703	0.08832	0.09005	0.08773	0.08467	0.08237
22	0.08405	0.08529	0.08713	0.08528	0.08703	0.08832	0.09005	0.08773	0.08467	0.08237

5.5. Ignition Angle Control (ZWGRU, ZWMIN & ZWOB Modules)

As with the optimum torque KFMIOP, the optimum ignition angle at lambda = 1 is obtained from the map KFZWOP in the *funktionsrahmen* module MDBAS. Additive corrections to lambda, depending on the exhaust gas recirculation rate (not applicable to most Audi TT 8N engine variants) and the engine temperature are made. The resulting ignition angle variable 'zwopt' forms the basis for the ignition angle efficiency calculation. Motronic has a two point variable cam timing system; there is a table for each cam timing state (KFZWOP & KFZWOP2). N.b. there are no differences between the BAM & BFV maps for optimum ignition angle in camshaft state 1 or 2. The ignition angle efficiency is calculated using the characteristic ETADZW, the input value is formed by the difference between variables 'zwopt' and 'zwbas'. This is followed by an averaging of the basic efficiency across all cylinders resulting in the basic efficiency variable 'etazwbm'.

KFZWOP (*Kennfeld für optimaler Zündwinkel*, map for optimum ignition angle in camshaft state 1). Units (x,y,z): % load, RPM, °crank

	0	10	20	30	50	70	95	125	155	175	191
600	21.75	21.00	21.00	21.00	18.00	14.25	10.50	6.75	6.00	6.00	5.25
800	31.50	29.25	26.25	24.00	20.25	17.25	14.25	11.25	11.25	11.25	11.25

1000	42.00	37.50	32.25	26.25	22.50	20.25	18.00	15.75	16.50	16.50	16.50
1240	45.00	40.50	35.25	29.25	25.50	23.25	21.75	21.00	20.25	19.50	19.50
1520	45.00	40.50	36.00	32.25	28.50	27.00	25.50	24.00	21.75	20.25	19.50
1740	42.75	39.00	34.50	31.50	28.50	27.00	26.25	24.00	21.75	20.25	19.50
2000	42.75	38.25	34.50	31.50	29.25	27.75	26.25	24.00	22.50	21.00	20.25
2520	48.75	44.25	39.75	35.25	31.50	30.00	28.50	27.75	25.50	24.00	23.25
3000	52.50	48.75	44.25	39.00	34.50	33.00	30.75	30.00	28.50	27.75	27.00
3520	46.50	43.50	40.50	39.00	34.50	33.00	31.50	30.00	29.25	28.50	27.75
4000	41.25	39.75	38.25	36.75	33.75	32.25	30.75	30.75	29.25	28.50	27.75
4520	42.00	40.50	38.25	36.75	34.50	33.00	31.50	30.75	30.00	29.25	28.50
5000	42.75	41.25	39.75	38.25	34.50	33.00	32.25	30.75	30.00	29.25	29.25
5520	42.75	41.25	39.75	38.25	35.25	33.75	32.25	31.50	30.00	30.00	29.25
6000	42.75	41.25	40.50	39.75	36.75	35.25	34.50	33.75	33.00	32.25	32.25
6800	48.00	47.25	46.50	45.75	39.75	37.50	36.75	37.50	37.50	38.25	38.25

KFZWOP2 (*Kennfeld für optimaler Zündwinkel*, map for optimum ignition angle in camshaft state 2). Units (x,y,z): % load, RPM, °crank

	0	10	20	30	50	70	95	125	155	175	191
600	78.75	65.25	51.75	37.50	20.25	17.25	15.00	9.00	1.50	-3.75	-8.25
800	76.50	63.75	51.00	39.00	24.00	20.25	16.50	10.50	3.75	-0.75	-4.50
1000	74.25	62.25	51.00	39.00	27.00	23.25	18.00	12.00	6.75	3.00	0.00
1240	71.25	60.00	49.50	38.25	29.25	24.75	20.25	14.25	11.25	9.00	7.50
1520	68.25	58.50	48.75	38.25	30.75	27.75	23.25	19.50	18.00	15.75	15.00
1740	65.25	56.25	48.00	39.00	32.25	29.25	26.25	23.25	21.00	19.50	18.00
2000	63.75	55.50	48.00	39.75	33.00	30.75	27.75	25.50	23.25	21.00	19.50
2520	60.75	53.25	46.50	39.75	32.25	30.75	29.25	27.75	25.50	23.25	21.75
3000	64.50	57.00	50.25	43.50	36.00	34.50	31.50	30.75	28.50	27.00	25.50
3520	73.50	66.00	58.50	50.25	40.50	36.75	33.00	31.50	29.25	27.75	26.25
4000	66.75	60.00	53.25	45.00	37.50	34.50	32.25	30.00	29.25	28.50	27.75
4520	54.00	48.00	42.00	37.50	33.00	31.50	30.75	28.50	27.75	27.75	27.00
5000	52.50	47.25	42.00	36.00	31.50	30.00	30.00	30.00	28.50	28.50	27.75
5520	54.00	48.75	42.75	37.50	33.00	32.25	31.50	30.75	30.75	30.00	30.00
6000	56.25	51.75	46.50	40.50	33.75	33.00	33.75	33.75	33.75	34.50	34.50
6800	62.25	57.00	52.50	48.00	38.25	35.25	35.25	37.50	39.75	41.25	42.75

Remarks: the maps KFZW and KFZW2 provide the basic ignition angle for each of the two camshaft states. The partial function ZW_NWS takes into account any camshaft timing. The variable 'fnwue' switches seamlessly between the maps KFZW and KFZW2. The engine temperature dependence is considered in the module ZWWL. The maps KFZW, and KFZW2 are applicable when the engine is warm for the respective camshaft position 1 or 2, exhaust gas recirculation (EGR) inactive (not applicable for most TT 8N engine variants) and lambda = 1. In the case of variable camshaft timing where there is a dependence on the overlap angle 'wnwue', an ignition angle correction DZWNWSUE is added to KFZW. Should the engine not knock, the optimum ignition angle is used.

KFZW (*Kennfeld für Zündwinkel*, map for ignition angle in camshaft state 1). Units (x,y,z): % load, RPM, °crank

	10	20	30	45	60	70	90	107	135	150	165	185
800	25.50	23.25	21.00	18.75	15.75	12.75	7.50	3.75	3.00	2.25	0.75	-0.75
1000	28.50	27.00	24.00	21.00	18.00	14.25	9.75	6.00	4.50	3.00	0.75	-0.75
1480	33.75	32.25	30.00	27.00	22.50	18.75	15.00	9.75	5.25	3.00	0.75	-0.75
1720	34.50	33.00	30.75	28.50	25.50	21.75	16.50	12.00	6.00	3.75	1.50	-0.75
2000	35.25	34.50	31.50	29.25	27.00	23.25	18.00	14.25	8.25	5.25	3.00	0.00
2200	35.25	34.50	32.25	30.00	27.75	25.50	19.50	15.00	10.50	6.00	3.75	0.75
2520	36.00	36.00	34.50	32.25	30.00	27.75	23.25	18.00	13.50	9.00	5.25	1.50
3000	36.00	36.00	36.00	33.75	31.50	30.00	27.00	22.50	16.50	11.25	7.50	3.75
3520	36.00	36.00	36.00	35.25	33.00	31.50	29.25	27.00	23.25	18.75	13.50	6.00

4000	36.00	36.00	36.00	35.25	33.75	32.25	30.00	27.75	24.00	19.50	15.00	11.25
4520	36.00	36.00	36.00	35.25	33.75	33.00	31.50	27.75	24.00	19.50	16.50	13.50
5000	36.00	36.00	36.00	35.25	33.75	33.00	31.50	28.50	22.50	18.75	15.75	14.25
5520	36.75	36.75	36.00	35.25	33.75	33.00	31.50	27.75	22.50	18.00	15.75	15.00
5800	37.50	37.50	36.75	35.25	33.75	32.25	31.50	27.00	21.75	18.00	15.75	15.00
6040	37.50	37.50	36.75	35.25	33.75	32.25	31.50	27.00	22.50	18.75	17.25	15.75
6520	37.50	37.50	37.50	35.25	34.50	32.25	31.50	27.75	23.25	21.75	20.25	18.00

	10	20	30	45	60	70	90	107	135	150	165	185
800	25.50	23.25	21.00	18.75	15.75	12.75	7.50	3.75	3.00	2.25	0.75	-0.75
1000	28.50	27.00	24.00	21.00	18.00	14.25	9.75	6.00	4.50	3.00	0.75	-0.75
1480	33.75	32.25	30.00	27.00	22.50	18.75	15.00	9.75	5.25	3.00	0.75	-0.75
1720	34.50	33.00	30.75	28.50	25.50	21.75	16.50	12.00	6.00	3.75	1.50	-0.75
2000	35.25	34.50	31.50	29.25	27.00	23.25	18.00	14.25	8.25	5.25	3.00	0.00
2200	35.25	34.50	32.25	30.00	27.75	25.50	19.50	15.00	10.50	6.00	3.75	0.75
2520	36.00	36.00	34.50	32.25	30.00	27.75	23.25	18.00	13.50	9.00	5.25	1.50
3000	36.00	36.00	36.00	33.75	31.50	30.00	27.00	22.50	16.50	11.25	7.50	3.75
3520	36.00	36.00	36.00	35.25	33.00	31.50	29.25	27.00	**21.00**	**16.50**	**12.75**	**5.25**
4000	36.00	36.00	36.00	35.25	33.75	32.25	30.00	**27.00**	**22.50**	**18.75**	**14.25**	**10.50**
4520	36.00	36.00	36.00	35.25	33.75	33.00	31.50	**28.50**	**23.25**	**22.50**	**19.50**	**14.25**
5000	36.00	36.00	36.00	35.25	33.75	33.00	31.50	**28.50**	**24.75**	**21.00**	**17.25**	**15.00**
5520	36.75	36.75	36.00	35.25	33.75	33.00	31.50	**29.25**	**26.25**	**23.25**	**19.50**	**16.50**
5800	37.50	37.50	36.75	35.25	33.75	32.25	31.50	**29.25**	**28.50**	**23.25**	**21.75**	**17.25**
6040	37.50	37.50	36.75	35.25	33.75	32.25	31.50	**29.25**	**28.50**	**22.50**	**22.50**	**18.75**
6520	37.50	37.50	37.50	35.25	34.50	32.25	31.50	**29.25**	**27.00**	**21.75**	**21.00**	**17.25**

KFZW2 (*Kennfeld für Zündwinkel*, Map for ignition angle in camshaft state 2). Units (x,y,z): % load, RPM, °crank

	10	20	30	45	60	70	90	107	135	150	165	185
800	25.50	23.25	21.00	18.75	15.75	12.75	7.50	3.75	3.00	3.00	0.75	-0.75
1000	28.50	27.00	24.00	21.00	18.00	14.25	9.75	6.00	4.50	3.00	0.75	-0.75
1480	36.75	36.00	33.00	28.50	22.50	18.75	15.00	9.75	5.25	3.00	0.75	-0.75
1720	36.75	36.00	33.75	30.00	24.75	20.25	16.50	12.75	7.50	3.75	1.50	-0.75
2000	36.75	36.00	34.50	30.75	27.00	23.25	18.75	14.25	8.25	5.25	1.50	0.00
2200	37.50	36.75	34.50	31.50	28.50	24.75	19.50	15.75	10.50	6.00	1.50	0.00
2520	38.25	37.50	35.25	32.25	29.25	27.00	23.25	20.25	14.25	10.50	3.75	0.00
3000	39.75	39.00	36.75	35.25	32.25	30.75	28.50	25.50	18.00	14.25	8.25	3.75
3520	39.75	39.75	37.50	36.75	35.25	33.00	30.00	28.50	21.75	18.00	12.75	8.25
4000	39.75	39.75	38.25	37.50	35.25	33.00	30.00	28.50	23.25	19.50	15.00	11.25
4520	39.00	39.00	38.25	37.50	34.50	33.00	30.00	27.75	24.75	20.25	18.00	14.25
5000	38.25	38.25	37.50	36.75	33.75	31.50	29.25	27.75	25.50	24.00	21.75	18.75
5520	37.50	37.50	36.75	35.25	32.25	30.75	29.25	27.75	25.50	24.00	21.75	19.50
5800	37.50	37.50	36.75	34.50	32.25	30.75	30.00	28.50	25.50	24.00	22.50	20.25
6040	37.50	37.50	36.75	34.50	32.25	31.50	30.75	30.00	26.25	24.75	22.50	20.25
6520	37.50	37.50	37.50	35.25	33.00	32.25	31.50	30.75	26.25	24.75	22.50	20.25

	10	20	30	45	60	70	90	107	135	150	165	185
800	25.50	23.25	21.00	18.75	15.75	12.75	7.50	3.75	3.00	3.00	0.75	-0.75
1000	28.50	27.00	24.00	21.00	18.00	14.25	9.75	6.00	4.50	3.00	0.75	-0.75
1480	36.75	36.00	33.00	28.50	22.50	18.75	15.00	9.75	5.25	3.00	0.75	-0.75
1720	36.75	36.00	33.75	30.00	24.75	20.25	16.50	12.75	7.50	3.75	1.50	-0.75
2000	36.75	36.00	34.50	30.75	27.00	23.25	18.75	**15.75**	8.25	5.25	1.50	0.00
2200	37.50	36.75	34.50	31.50	28.50	24.75	19.50	**16.50**	**11.25**	**7.50**	**5.25**	**1.50**
2520	38.25	37.50	35.25	32.25	29.25	27.00	23.25	**21.00**	**13.50**	**10.50**	**9.00**	**4.50**
3000	39.75	39.00	36.75	35.25	32.25	30.75	28.50	**25.50**	**17.25**	**14.25**	**13.50**	**9.00**
3520	39.75	39.75	37.50	36.75	35.25	33.00	30.00	**27.75**	**21.00**	**18.75**	**16.50**	**10.50**

4000	39.75	39.75	38.25	37.50	35.25	33.00	30.00	**27.75**	**22.50**	**20.25**	**18.00**	**13.50**
4520	39.00	39.00	38.25	37.50	34.50	33.00	30.00	**28.50**	**24.00**	**20.25**	**17.25**	**14.25**
5000	38.25	38.25	37.50	36.75	33.75	31.50	29.25	**28.50**	**24.75**	**21.75**	**18.75**	**16.50**
5520	37.50	37.50	36.75	35.25	32.25	30.75	29.25	27.75	25.50	**23.25**	**20.25**	**19.50**
5800	37.50	37.50	36.75	34.50	32.25	30.75	30.00	28.50	25.50	24.00	22.50	20.25
6040	37.50	37.50	36.75	34.50	32.25	31.50	30.75	30.00	26.25	24.75	22.50	20.25
6520	37.50	37.50	37.50	35.25	33.00	32.25	31.50	30.75	26.25	24.75	22.50	20.25

Remarks: note that, as expected, the higher output tune generally has increased ignition angle advance at higher loads and engine speeds. The S4 wiki notes that when running increased boost on regular fuel, it will be necessary to reduce target ignition angle to prevent timing retard. Individual cylinder correction factors should be constrained to <10° crank and ideally up to 6° crank. Further, knock sensor voltages should be monitored carefully when adjusting ignition timing. If the MAF was not fully corrected in map KFKHFM, it advises that thorough logging is carried out to see where the various load points are and how much ignition angle is retarded due to knock activity. It is likely, that the entire map will have to be adjusted. If the MAF was properly corrected, ignition angle adjustments will not be required, except at very high load.

The module ZWMIN calculates the latest possible ignition angle 'zwspae' and the latest ignition angle efficiency 'etazwmn' for the ignition angle limit.

The latest possible ignition angle is calculated either from the combustion limit map (KFZWMN) which contains the absolute latest ignition angle which can be tolerated. a special catalyst heating map (KFZWMNKH) or engine protection map which yields the latest possible ignition angle at which misfire occurs.

During start and post-start, clearly audible bangs are detectable in the exhaust system with the ignition angles in KFZWMN. This long post-combustion period with a cold engine and poor mixture conditioning is offset by the map KFZWMNST. In cold temperatures afterburning occurs in the exhaust system more frequently, so an early displacement of the latest ignition angle with a cold engine is often useful. The shift of the latest limit with engine temperature takes place via DZWSPM.

Particularly in turbocharged engines, the ignition angle can be temporarily advanced during the middle of the speed range with continuous load. The possible change in ignition angle is addressed in the map KFDZWOB. The values in the map KFTZWOB switch the integrator from 1 to 0 and vice versa to determine how long the ignition correction is effective and how long the engine recovery phase lasts. However, both these maps contain zero values for the 225 PS BAM engine indicating that change of ignition angle during overboost conditions is not required.

5.6. Other Maps & Characteristics of Interest

KFWDKMSN (*Kennfeld für Drosselklappen-Sollwinkel*, map for throttle plate angle). Units (x,y,z): RPM, kg/h, % open.

	1000	2000	3000	4000	5000	6000
0	0	0	0	0	0	0
10	3	3	2	2	2	3
21	5	5	5	5	5	5
34	9	7	7	7	7	7
48	13	10	10	10	10	10
63	17	13	12	12	12	12
85	21	17	15	15	15	15
111	26	20	19	18	18	18
212	36	29	29	28	28	26
325	44	38	36	36	36	33
463	50	47	44	43	43	39
560	54	51	49	47	46	41
635	57	54	52	50	48	42
749	61	59	57	56	54	48
1227	77	77	76	76	76	75
1978	100	100	100	100	100	100

KFWDKMSX (*Maximaler Solldrosselklappenwinkel*, maximum throttle plate angle). Units (x,y,z): λ, RPM, % open.

	0.80	0.90	1.00
720	25	25	25
1000	44	44	44
1280	60	60	60
1520	70	70	70
1760	80	80	80
2000	86	86	86
2520	95	95	95
3000	100	100	100
4000	100	100	100
6000	100	100	100

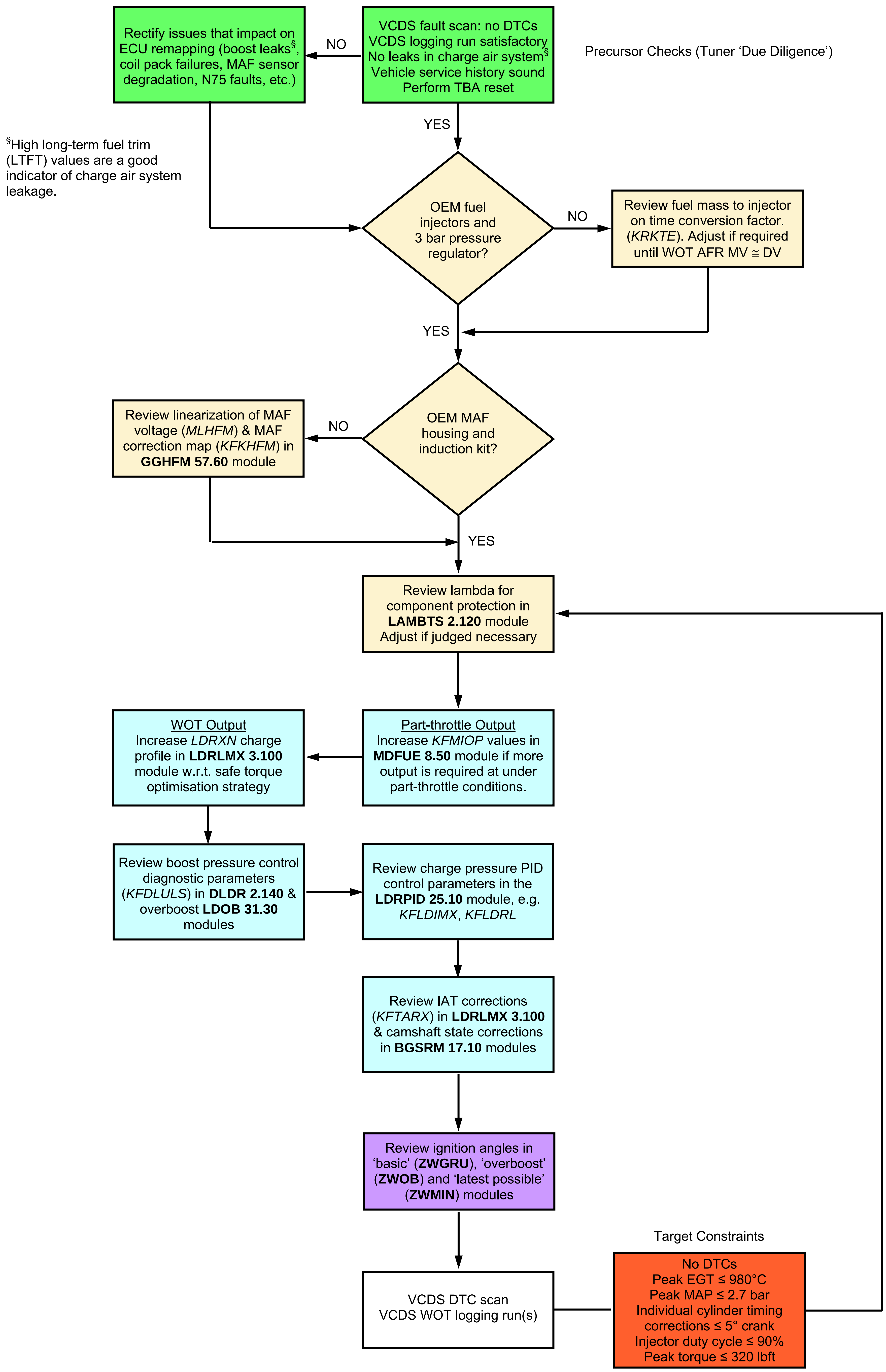
KFLAMKRL & KFLAMKR. Enrichment on ignition retard (set to 1.00 for all addresses).
KFFLLDE (*Faktor für langsamen Ladedruckeingriff auf rlmax durch KR*, factor for slow LDR intervention of maximum charge via KR). Units (x,y,z): °crank, RPM, factor.

	1.5	2.25	3	3.75	4.5	6	7.5	11.25
1000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.86
1720	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.86
2000	1.00	1.00	1.00	1.00	1.00	0.97	0.94	0.83
3000	1.00	1.00	1.00	1.00	1.00	0.96	0.90	0.80
5000	1.00	1.00	1.00	1.00	0.98	0.94	0.87	0.77
5500	1.00	1.00	1.00	0.98	0.95	0.91	0.85	0.77
6000	1.00	1.00	0.98	0.96	0.93	0.89	0.83	0.77
6500	1.00	0.98	0.96	0.93	0.90	0.86	0.80	0.76

KRALH (*Klopfregeladaption Lasthysterese*, knock control adaption load hysteresis). This adjusts how quickly timing will be restored as load changes. Value 3%.
KRANH. (*Klopfregeladaption Lasthysterese*, knock control adaption engine speed hysteresis). This adjusts how quickly timing will be restored as RPM changes. Value 120 RPM.
KRFKLN (*Spätverstellung pro Klopfereignis bei Langsamer Frühverstellung*, Ignition retard per knock event in slow early adjustment). Value is –3 °crank at all engine speeds.
NLLM. Idle RPM.
NMAX. RPM limiter
KFNWEGM (*Wiedereinsetzdrehzahlkennfeld*, reset speed map). Function of engine temperature and gear; prohibits the gear-dependent overrun fuel cut by raising the reset speed.
VAVMX/VMAX. Speed limiter

5.7. Section Conclusions: Tuning Strategy
Figure 5.2 summarizes the basic functional areas and modules that a tuner might review when developing a tuning strategy as discussed in this section. To recap: the objectives of the article were to examine some of the key maps involved in Motronic operation that might concern a professional tuner and that's what I've tried to provide here, even if it now seems to occupy the uneasy no-man's land between a story and a reference work you would dip into occasionally to check something.

Figure 5.2. Flow Chart Summarizing a Basic Tuning Strategy



6. Overall Conclusions and Discussion

This article was originally intended to be a much smaller document, but it became obvious that it wasn't possible to discuss all the issues pertaining to tuning without going into some technical detail where appropriate. To complete the picture, I offer up some hard data in the form of output graphs from a commercial rolling road dynamometer, results of third and fourth gear logging runs with the Ross-Tech VCDS suite and some in-gear acceleration figures I measured myself in real-world conditions to illustrate the difference a remap makes.

Stock map with physical modifications, cleaned MAF & air filter. Ambient temperature 10-12°C
30-50 mph (3rd gear): 3.3, 3.3, 3.7 s (average 3.4 s). Audi Driver July '05 test (OEM): 3.2 s
30-50 mph (4th gear): 4.7, 5.0, 5.3 s (average 5.0 s).
30-50 mph (5th gear): 7.7, 7.9 s (average 7.8 s).
50-70 mph (4th gear): 4.3, 4.3 s (average 4.3 s). Audi Driver July '05 test (OEM): 4.0 s
50-70 mph (5th gear): 5.1, 5.1, 5.3, 5.6 s (average 5.3 s). Audi Driver July '05 test (OEM): 4.5 s
50-70 mph (6th gear): 7.6, 7.6, 7.7, 8.3 s (average 7.8 s). Audi Driver July '05 test (OEM): 7.0 s
40-80 mph (4th gear): 8.1, 8.5 s (average 8.3 s).
40-80 mph (5th gear): 10.3, 10.7 s (average 10.5 s).
40-80 mph (6th gear): 14.4, 14.7, 14.8 s (average 14.6 s).

Revo Technik Stage 2 remap with physical modifications. Ambient temperature 5-7°C
30-50 mph (3rd gear): not enough data to get a meaningful average but sub 3 s looked easily achievable
30-50 mph (4th gear): 4.7, 4.9, 4.9 s (average 4.8 s)
30-50 mph (5th gear): 6.8, 7.3, 6.9, 7.1 s (average 7.0 s)
50-70 mph (4th gear): 3.7, 3.8, 4.0, 4.2 s (average 3.9 s)
50-70 mph (5th gear): 5.0, 5.2, 5.2 s (average 5.1 s)
50-70 mph (6th gear): 6.7, 7.0, 7.2, 7.3 s (average 7.1 s)
40-80 mph (4th gear): 7.2, 7.4 s (average 7.3 s)
40-80 mph (5th gear): 9.4, 9.7 s (average 9.6 s)
40-80 mph (6th gear): not enough data to get a meaningful average but looked about the same as stock.

The biggest benefits are seen when accelerating or overtaking. The torque increase is largest in the 2500-3000 rpm range (50-55%). From 3,000-4000 rpm the torque increase is ≅ 20-30% then 15-20% from 4,000 to 4,500 rpm. All the shorter durations are probably subject to too much percentage error from reaction time to start and stop the timer, but there is a genuine 1 second decrease on the 40-80 mph times in 4th and 5th gear.

Manufacturers, tuners and car enthusiasts prefer to quote peak or headline output figures but just as with 0-60 mph acceleration times and top speeds, these only give limited information on the performance envelope; it's a case of 'lies, damned lies and statistics'. I have attempted to quantify the change before and after the Revo Technik Stage 2 remap carried out on my own car in October 2010. The data was measured manually from a paper printout from Awesome GTi's Dyno Jet Research brand rolling road dynamometer. Although their rolling road can measure the output of four-wheel drive vehicles, the normal method for Haldex 4WD systems is to remove the fuse supplying the Haldex clutch pack and do runs in FWD only. This removes the transmission losses through the prop shaft, rear differential and driveshafts from the equation and thus makes the measurement more realistic of available clutch power and torque.

Although it is generally accepted that logging runs via the OBDII port carried out on the same section of straight, level road give the most representative output results, a dynamometer at least offers the advantage of a standard platform with reproducible conditions in a controlled environment. It is presumed that commercial dynamometers are checked and calibrated on a regular basis such that systematic errors are minimized and random errors are within acceptable levels to allow a meaningful comparison to be made between different vehicles. Some rolling road dynamometer installations have large fans to mimic the cooling and 'ram air' effects of air resistance in a moving vehicle, but those that don't have the drawback of potentially elevated IAT from heat soak in the engine bay.

Figures 6.1 and 6.2 show the power curve and clutch torque curve before and after the remap. Clutch torque is derived by estimating drive train losses during rundown of engine speed and then adding these to the measured wheel torque.

Figure 6.1. Rolling Road Dynamometer Power Curve Before and After Revo Stage 2 Remap

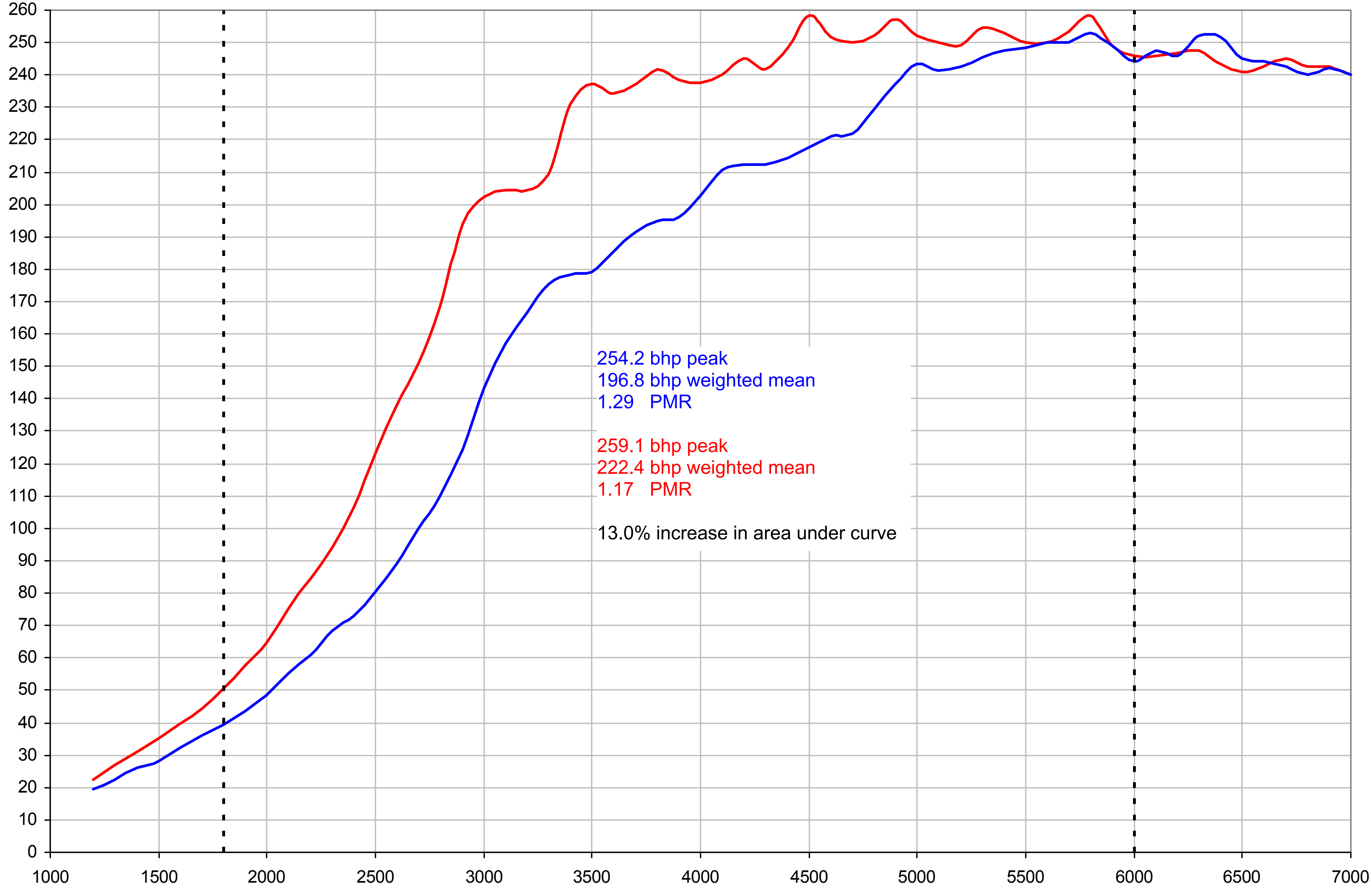
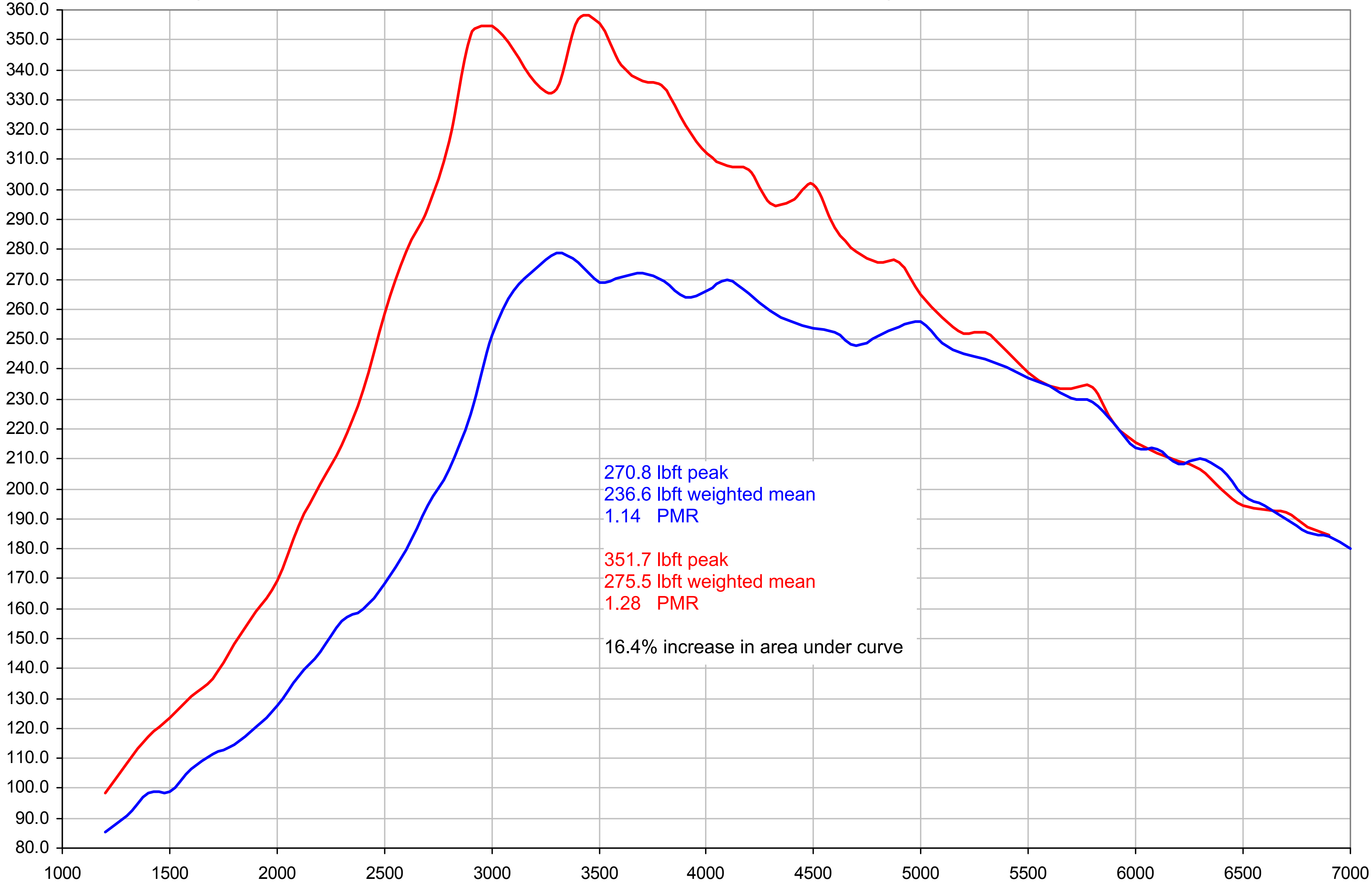


Figure 6.2. Rolling Road Dynamometer =Torque Curve Before and After Revo Stage 2 Remap



You can see that the peak power barely increased at all which, superficially, looks disappointing. However, to better quantify the improvement, I've calculated a few very simple derived parameters:

1. Increase in area under the curve
2. Weighted mean of the power (or torque) over a nominal engine speed range (say 1000 + warm idle RPM) to (redline RPM – 1000)
3. Relative 'peakiness' or 'flatness' of the curve (a simple ratio of the peak to the weighted mean) or PMR.

This data, charts and calculations are included on the Microsoft Excel 2003 workbook entitled Quantification of Changes to the Output Before & After Tuning.xls

A theoretically ideal engine might produce the peak power all the way across the rev range so the PMR would be 1.00. In an extreme actual case (say a 2.0 turbo rally car), the power would most likely come in a relatively narrow rev band (say a peak of 450 bhp with the same weighted mean power of 200 bhp). This would yield a PMR of 2.25. So a PMR closer to 1.00 indicates a relatively flat power/torque curve and further away from one indicates a peaky curve.

7. Common Acronyms and Abbreviations

7.1. General Abbreviations Related to Engine Management and Tuning

AFR	Air-Fuel Ratio (lambda)
BTDC	Before top dead centre
CAN	Controller Area Network
ECU	Electronic Control Unit
EGAS	Electronic Gas Pedal
EGR	Exhaust Gas Recirculation (not deployed in TT 8N BAM & BFV variants)
EGT	Exhaust Gas Temperature
EMS	Engine Management System
EPROM	Electronically Programmable Read-Only Memory
FMIC	Front Mounted Intercooler
FPR	Fuel Pressure Regulator
HDR	High Data Rate. Crank sensing method used by the ECU to determine engine speed and position which uses a signal derived from a multi-toothed wheel fixed to the crankshaft or flywheel of the engine. The passing teeth are picked up by a variable reluctance sensor and the output signal is fed to the ECU.
IAT	Intake Air Temperature (not to be confused with Integral Action Time in PID control)
IDC	Injector Duty Cycle. (IPW x RPM)/1200
IPW	Injector Pulse Width (injector on time)
LDR	Low Data Rate. Crank sensing method used by the ECU to determine engine speed and position using a signal provided by an Optical or Hall Effect switch and segmented disc mounted within the distributor. The switch will give a positive or negative going trigger signal at a point before the maximum advance position (45 degrees) for each cylinder. The other switching edge of the segmented disc is often at TDC. Beware of confusion with the Motronic German abbreviation LDR which is the abbreviated form of *lädedruck* (charge pressure).
MAF	Mass Air Flow
MAP	Manifold Absolute Pressure
MY	Model Year
OBD	On-Board Diagnosis
OEM	Original Equipment Manufacture/Manufacturer
PID	Proportional/Integral/Derivative (Control)
TB	Throttle Body
TDC	Top Dead Center
WOT	Wide Open Throttle

7.2. Some German Abbreviations used in the Funktionsrahmen

German Abbreviation	**Translations**
AGR	Exhaust gas recirculation *(Abgasrückführung)*
ASR	Traction control system (Antriebsschlupfregelung)
ATL	Exhaust gas turbocharger *(Abgasturbolader)*
BDE	Petrol Direct Injection *(Benzin-Direkteinspritzung)*
BTS	Component protection *(Bauteileschutz)*
DK	Throttle plate *(Drosselklappen)*

DV-E	Throttle-adjustment facility *(Drosselverstell-Einrichtung)*
FGR	Vehicle speed limiter *(Fahrgeschwindigkeitsregelung)*
GS	Transmission protection *(Getriebeschutz)*
LLR	Idle control *(Leerlaufregelung)*
MSR	Traction control *(Momentenschlupfregelung)*
SAWE	Overrun fuel cut-off/reinstatement *(Schubabschalten/Wiedereinsetzen)*
SG	ECU *(Motorsteuergerät)*

8. References, Supporting Information and Further Reading

8.1. Supporting Information

The following information is provided to support the discussion in this review:

(a) Microsoft Excel 2003 workbook (1.13 Mb) with worksheet content as follows:
- Sheet 1. Listing of all 312 fully scaled and offset 3D maps in the BAM ECU file
- Sheet 2. Limited listing of key 2D characteristics & 1D constants
- Sheet 3. Limited listing of BAM & BFV maps with processor addresses
- Sheet 4. Full listing of the 335 modules covered in the *funktionsrahmen*.
- Sheet 5. Long listing of approximately 6,700 automotive and technical terms with German to English translations

(b) WinOls .ols format file for the 225 BAM ECU (part number 8N0 906 018 CB) containing all maps, characteristics and constants organized into the 335 discrete functional modules covered in the *funktionsrahmen*. Audi TT 8N0906018CB.ols (4.05 Mb).

(c) Raw binary file for the 240 PS BFV ECU (part number 8N0 906 018 CA). AUDI TT 1.8T 240HP 0261208086 375111.bin (1.00 Mb)

(d) PDF file "A New Approach to Functional and Software Structure for Engine Management Systems - Bosch ME7". Technical paper 98P-178 (49) for the Society of Automotive Engineers. J. Gerhardt, H. Honninger and H. Bischof. Robert Bosch GmbH. (456 kB).

8.2. References and Background/Further Reading

Specific references consulted for this guide are listed below in order of section. The most useful single technical reference is "Engine Management: Advanced Tuning" by Greg Banish. CarTech Inc (2007). ISBN-13 978-1-932494-42-6. Although the author's experience as an OEM calibrator is largely on U.S. vehicles, and the terminology used and examples given are U.S.-specific, the basic principles behind modern ECU operation on both normally aspirated and forced induction engines are very well covered and there are plenty of useful tips and inside information. It should really be read thoroughly and fully understood before attempting to understand ECU operation and any amateur tuning.

Another useful reference work is "Bosch Fuel Injection and Engine Management (Technical Including Tuning & Modifying)" by Charles Probst, Robert Bentley publishers (20 Oct 1989). ISBN-10: 0837603005. ISBN-13: 978-0837603001 aid understanding of the basic principles of Bosch fuel injection systems, fault finding and tuning.

Section 2
http://www.volkspage.net/technik/ssp/ssp/SSP_322.pdf
http://www.volkspage.net/technik/ssp/ssp/SSP_337.pdf
Section 3
"A New Approach to Functional and Software Structure for Engine Management Systems - Bosch ME7". Technical paper 98P-178 (49) for the Society of Automotive Engineers. J. Gerhardt, H. Honninger and H. Bischof. Robert Bosch GmbH.
http://www.bosch.com/content/language2/html/3074_3184.htm
Section 4
http://www.evc.de/en/default.asp
http://www.motronic.ws/
http://www.andywhittaker.com/ECU/BoschMotronicME71/tabid/68/Default.aspx

Funktionsrahmen. Audi R4-5V T Quereinbau 132kW ME7.1. 5/4019.00;35

http://www.nefariousmotorsports.com/forum/index.php?action=dlattach;topic=400.0;attach=359
Section 5
http://s4wiki.com/wiki/Tuning
http://www.audizine.com/forum/showthread.php/269322-Tuning-your-Motronic-ECU-(ME7.1)
http://www.stealth316.com/2-calc-idc.htm

Garrett, the turbocharger manufacturers have a very informative technical resource on the website:
http://www.turbobygarrett.com/turbobygarrett/tech_center/tech_center.html

The following sections (all of which can be downloaded as Adobe PDF files) are particularly useful technical background material in increasing degrees of sophistication:

Troubleshooting symptoms/causes matrix

Turbo Tech 101 (Basic) covers
- How a Turbo System Works
- Turbocharger Components
- Other Components
- Oil & Water Plumbing
- Which Turbocharger is Right for Me?
- Journal Bearings vs. Ball Bearings

Turbo Tech 102 (Advanced) covers
- Turbocharger wheel trim topic coverage
- Understanding turbine housing A/R and housing sizing
- Different types of manifolds (advantages/disadvantages log style vs. equal length)
- Compression ratio with boost
- AFR tuning: Rich v. Lean, why lean makes more power but is more dangerous

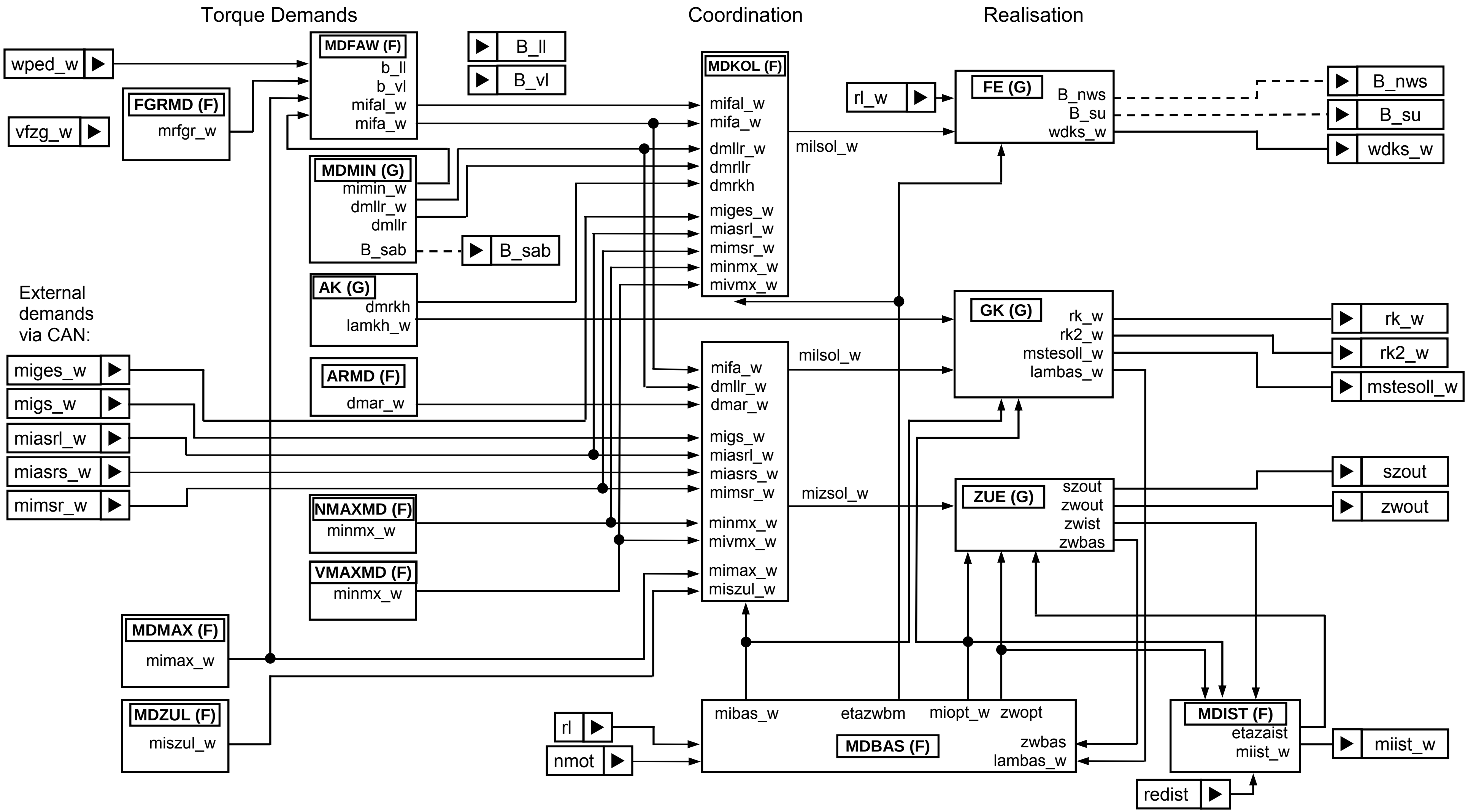
Turbo Tech 103 (Expert) covers
- Parts of the Compressor Map (pressure ratio, mass flow rate, surge line, the choke line, turbo speed lines, efficiency islands, plotting your data on the compressor map)
- Estimating the required air mass flow and boost pressures to reach a horsepower target.
- Calculating the required MAP required to meet the horsepower, or flow, target:

Turbo Optimisation section covers:
- Application information
- Turbo matching
- System components (air filter including how to determine the correct air filter size, oil supply & drain, water lines, charge tubing & charge-air-cooler, BOV and wastegate
- Common Causes of Oil Leakage
- System testing and monitoring
- 11-point checklist

8.3 Recommended Software

WinOls by EVC (Entwicklung Vertrieb Communication) electronic:
http://www.evc.de/en/
Nefmoto ME7 ECU flashing software:
http://nefariousmotorsports.com/forum/index.php/board,33.0.html

Appendix 1. Functional Overview: MSF Module (Engine Torque Control)

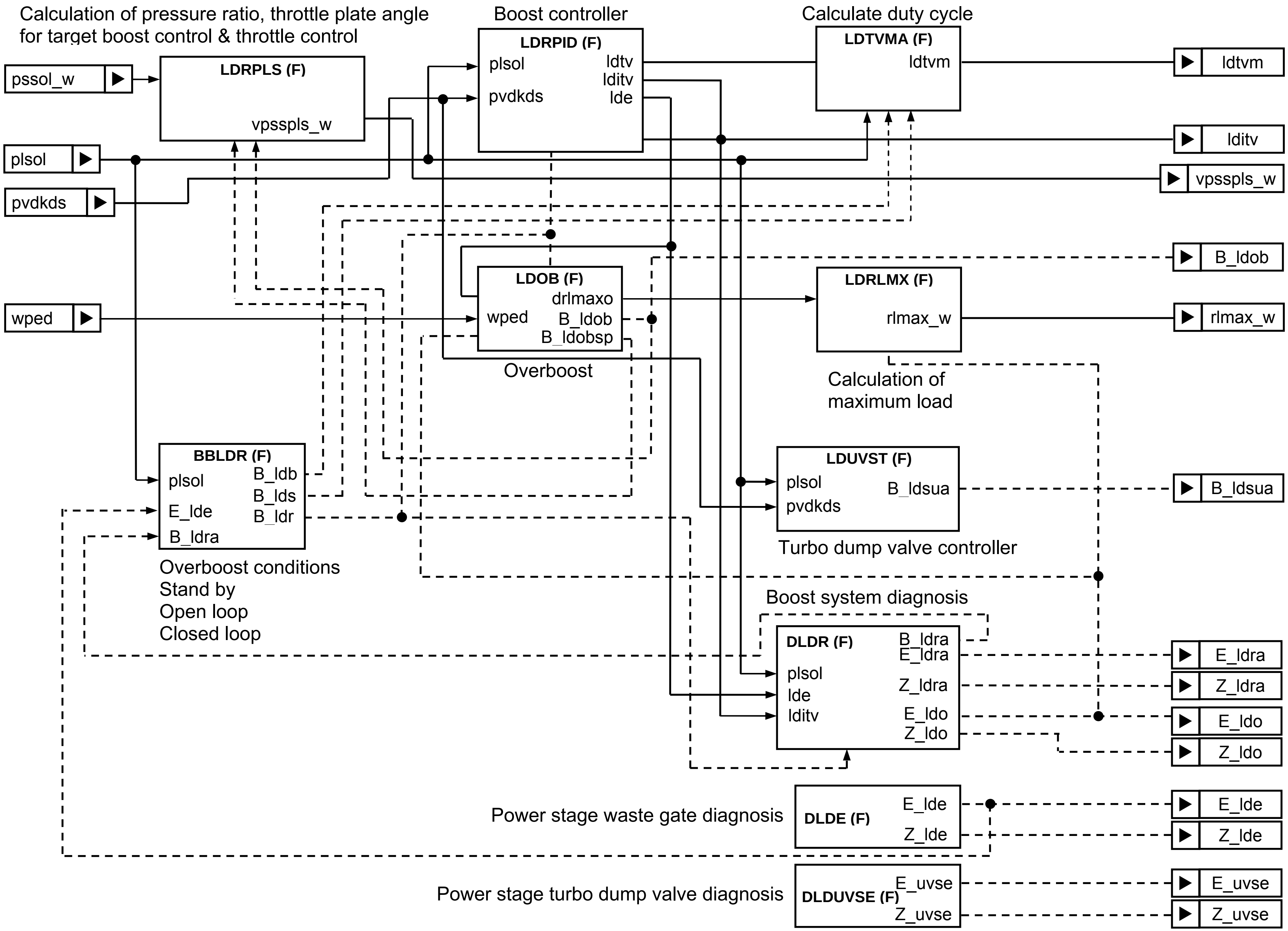


Appendix 1. Functional Overview: MSF Module (Engine Torque Control)

Explanation of Variables

Variable	Description
B_LL	Idle term
B_NWS	Camshaft control term
B_SAB	Overrun fuel cut-off standby term
B_SU	Inlet manifold changeover term
B_VL	Full load term
DMAR_W	Delta engine torque for anti-judder
DMLLR_W	Required engine torque adjustment from idle control (PD-components)
DMRKH	Torque reserve for catalyst heating
DMRLLR	Torque reserve for idle regulation
ETAZAIST	Actual cylinder suppression efficiency
ETAZWBM	Average ignition angle efficiency of the basic ignition angle
LAMBAS_W	Lambda basic value (word)
LAMKH_W	Lambda engine target with catalyst heating (word)
MIASRL_W	Indexed target engine torque during traction control, long-term intervention
MIASRS_W	Indexed target engine torque during traction control, short-term intervention
MIBAS_W	Indexed basic torque
MIFAL_W	Indexed driver-target torque for torque coordination charge
MIFA_W	Indexed driver-target engine torque
MIGES_W	Indexed target engine torque for gear protection
MIGS_W	Indexed target engine torque for transmission protection, short-term intervention
MIIST_W	Indexed engine torque high pressure phase actual value
MILSOL_W	Driver-target torque for cylinder charge
MIMAX_W	Maximum allowed indexed torque
MIMIN_W	Minimum engine torque
MIMSR_W	Indexed target engine torque (traction control)
MINMX_W	Torque demand from the speed limiter
MIOPT_W	Optimum indexed torque
MISOL_W	Indexed resulting target torque
MISZUL_W	Maximum allowed indexed torque
MIVMX_W	Indexed target torque for maximum vehicle speed regulation
MIZSOL_W	Indexed resulting target torque for ignition angle intervention
MRFGR_W	Relative torque demand from cruise control
MSTETARGET_W	Fuel tank breather mass flow into the inlet manifold, target value
NMOT	Engine speed
REDIST	Actual reduction stage
RK2_W	Relative fuel mass (cylinder bank 2)
RK_W	Relative fuel mass (cylinder bank 1)
RL	Relative cylinder charge
RL_W	Relative cylinder charge (Word)
SZOUT	Closing time
VFZG_W	Vehicle speed
WDKS_W	Target throttle plate angle, based on (lower) stop
WPED_W	Normalised throttle pedal angle
ZWBAS	Basic ignition angle
ZWIST	Actual ignition angle
ZWOPT	Optimum ignition angle
ZWOUT	Ignition angle output

Appendix 2. Functional Overview: Module LDRUE (Charge Pressure Regulation)

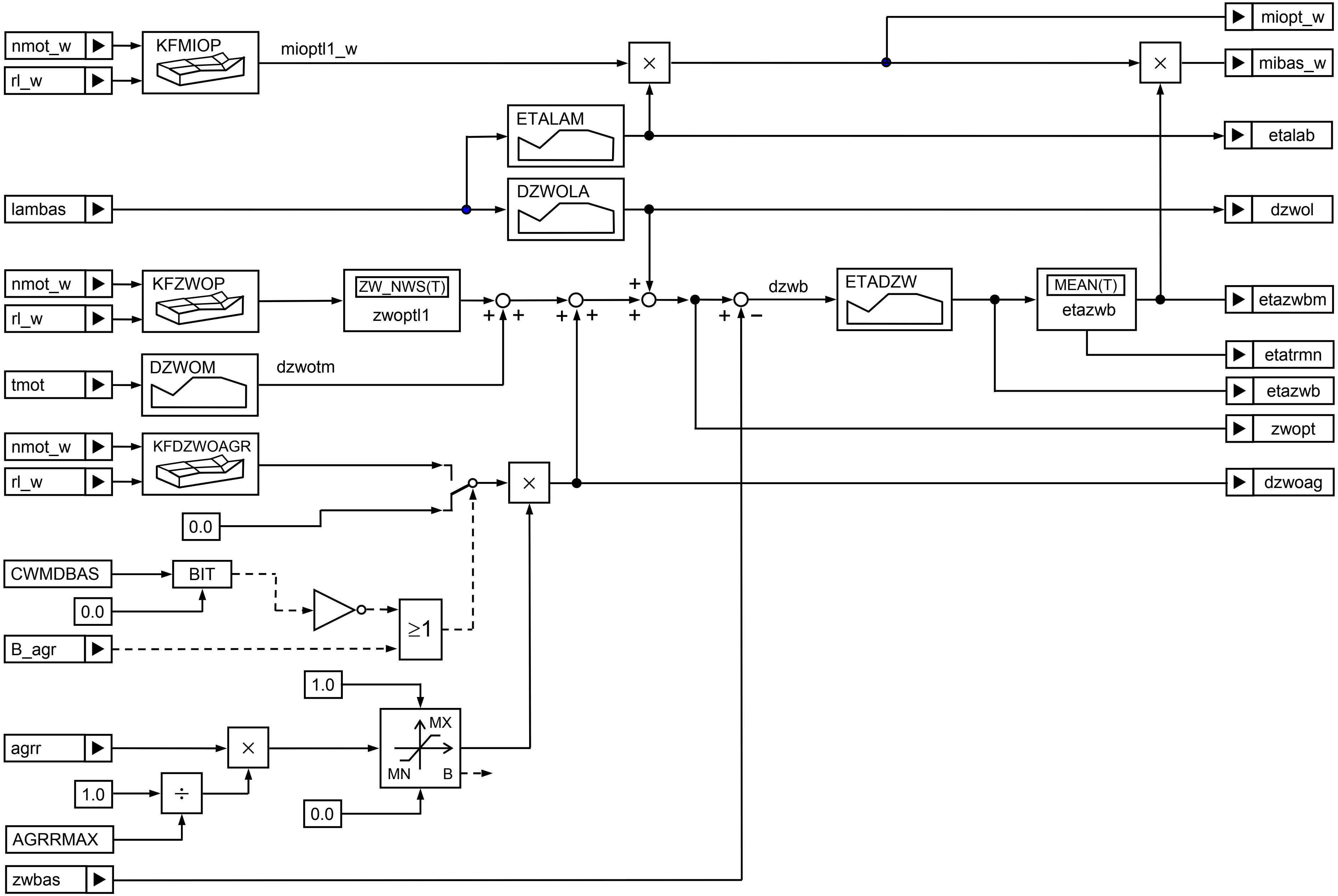


Appendix 2. Functional Overview: Module LDRUE (Charge Pressure Regulation)

Explanation of Variables

Variable	Description
B_LDB	Condition for boost pressure control standby
B_LDOB	Overboost active condition
B_LDOBSP	LDR overboost within off-time condition
B_LDR	Flag for LDR active condition
B_LDRA	Condition for alternative measure E_LDRA
B_LDS	Flag for LDR control condition
B_LDSUA	LDR diverter valve active (open) condition
DRLMAXO	Change in maximum charge during overboost
E_LDE	Error flag: charge pressure control valve (final stage)
E_LDO	Error flag: charge pressure characteristic; upper value exceeded
E_LDRA	Error flag: charge pressure control abnormality
E_UVSE	Error flag: Final stage turbocharger air diverter valve
LDE	LDR-control abnormality (target value – actual value)
LDITV	Charge pressure, duty cycle vom integral control
LDTV	Charge pressure duty cycle
LDTVM	Charge pressure, modulated (final output value)
PLSOL	Target boost pressure
PSSOL_W	Target inlet manifold pressure
PVDKDS	Pressure from throttle plate from pressure sensor
RLMAX_W	Maximum permissible charge from turbo
VPSSPLS_W	Ratio of target MAP over target boost pressure
WPED	Normalisation of accelerator pedal angle
Z_LDE	Cycle flag: Boost pressure control valve (final stage)
Z_LDO	Cycle flag: Boost pressure characteristic; upper value exceeded
Z_LDRA	Cycle flag: Boost pressure control abnormality
Z_UVSE	Cycle flag: Final stage turbocharger air diverter valve

Appendix 3. Functional Overview: MDBAS Module (Calculation of the Basic Variables of the Torque Interface)



Appendix 3. Functional Overview: MDBAS Module (Calculation of the Basic Variables of the Torque Interface)

Explanation of Variables

Variable	Description
AGRR	Exhaust gas recirculation rate
AGRRMAX	Maximum permissible exhaust gas recirculation rate
B_AGR	Condition for exhaust gas recirculation
CWMDBAS	Codeword: Calculation of the ignition angle correction for exhaust gas recirculation operation
DZWNWSUE	Change in ignition angle depending on camshaft state (NWS)
DZWOAG	Exhaust gas recirculation rate dependent correction for the optimum ignition angle
DZWOL	Lambda-dependent correction for the optimum ignition angle
DZWOLA	Lambda-dependent optimum ignition angles based on lambda = 1
DZWOM	Temperature-dependent offset for the optimum ignition angle
DZWOTM	Temperature-dependent correction for the optimum ignition angle
ETADZW	Ignition angle efficiency dependent on the change in ignition angle
ETALAB	Lambda efficiency without intervention, based on optimum torque at lambda=1
ETALAM	Lambda efficiency
ETATRMN	Minimum value of cylinder efficiency
ETAZWB	Ignition angle efficiency of the basic ignition angles
ETAZWBM	Average ignition angle efficiency of the basic ignition angles
FNWUE	Inlet valve camshaft state (NWS) weighting factor
KFDZWOAGR	Offset for the optimum ignition angle during exhaust gas recirculation operation
KFMMIOP	Map for optimum engine torque
KFZWOP	Optimum ignition angle in camshaft state 1
KFZWOP2	Optimum ignition angle in camshaft state 2
LAMBAS	Basic lambda
MIBAS_W	Basic indexed torque
MIOPTL1_W	Optimum indexed engine torque at lambda = 1
MIOPT_W	Optimum indexed torque
NMOT_W	Engine speed
RL_W	Relative air charge (word)
R_SYN	Synchro-grid
SY_NWS	System constant for camshaft control: neither 2-state or steady
TMOT	Coolant temperature
WNWUE	Camshaft overlap angle
ZWBAS	Basic ignition angle
ZWOPT	Optimum ignition angle