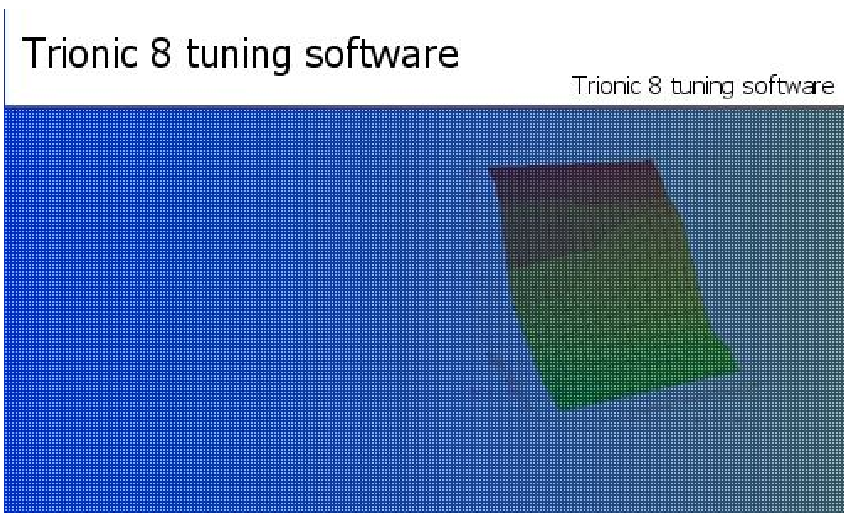
TRIONIC 8



PREFACE

This document is intended for Saab fanatics and engineers who want to start understanding the Saab Trionic 8 motor management system. It will give as much information as possible about the technical part of the system. The only limitation will be the knowledge of the author.

In short the content of this document will enable you to understand Trionic 8 better and give you hands-on information about altering the maps it uses. Prerequisites are minor electronics and computer knowlegde and of course some understanding of how a turbo charged engine works.

Throughout the document the T8Suite software will be referenced. This software will enable you to really "get into" the Trionic. The T8Suite software can be downloaded from the T8Suite website.

http://trionic.mobixs.eu

Acknowledgements

The author would like to thank everyone on ecuproject for their help on getting all this information together. Special thanks go out to Actitis H., General Failure, J.K. Nilsson, Hook, Hma, Vigge, Mackan, Sandy Rus, JKB, L4staero, G-ice, MrAze and Steve Hayes.

These icons are used throughout the document to denote:

References

Advanced technical topics

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HARDWARE

The T8 is build around a Motorola microcontroller (MC 68377). This is a 32 bit controller that handles the entire motor management including fuel injection, ignition timing and boost pressure control.

The processor has a vast 8Mb (1024 kByte) flash memory (29BL802C) to its disposition for fetching program code and maps.

INTEGRATED CIRCUIT LIST

The table below lists almost all IC's on the board. This is just to give you an idea on what to expect.

Partnumber	Function	Usage	# on board
MC68377	Main microcontroller	Everything	1
29BL802C	Flash memory	Program storage	1

DATASHEETS

Datasheets can be found on my website:

http://trionic.mobixs.eu/T8/hardware/MC68377.pdf

http://trionic.mobixs.eu/T8/hardware/29BL802C.pdf

BLOCK SCHEMATIC DIAGRAM

TODO: Insert block schema for T8 here

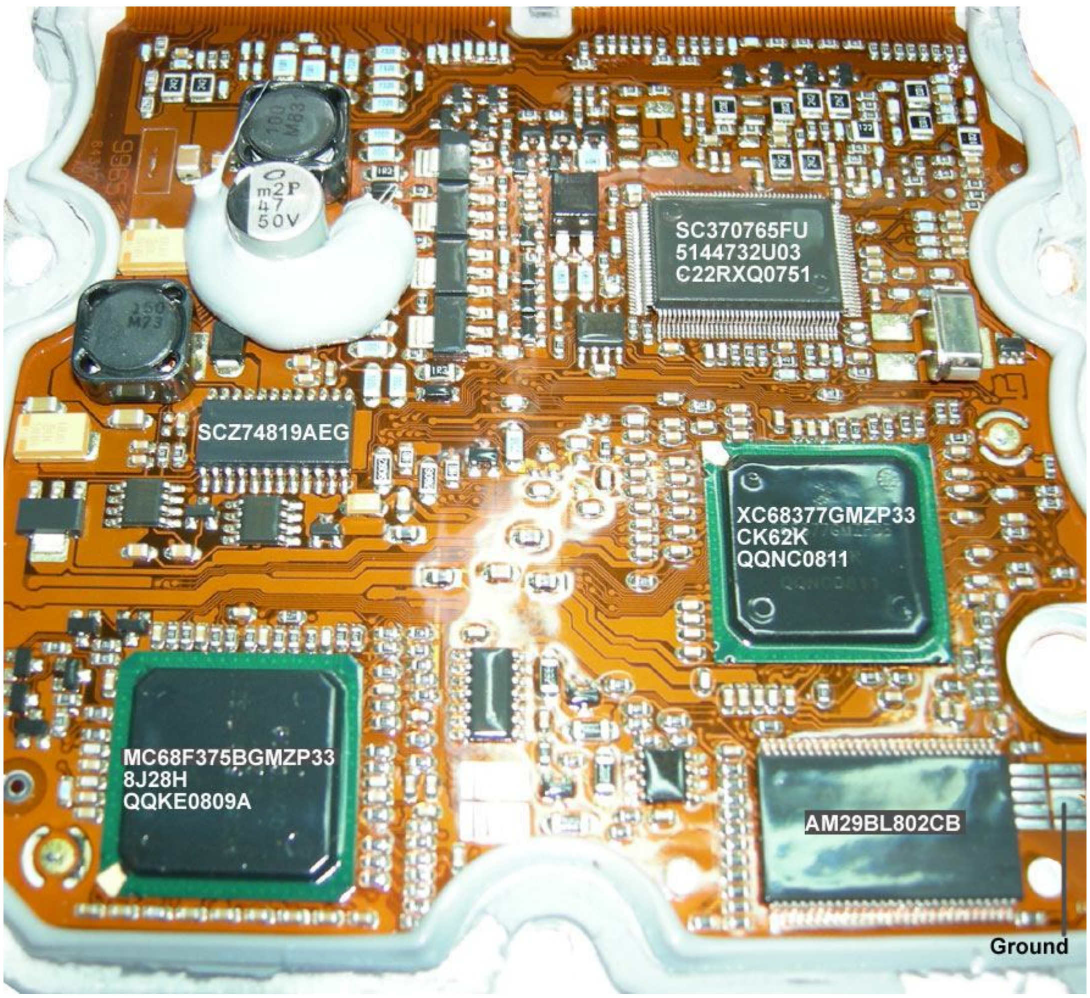
MEMORY ORGANIZATION

```
0x000000 - 0x01FFFF = boot

0x020000 - 0x0BFFFF = Application software

0x0C0000 - 0x0FFFFF = Unknown

0x100000 - 0x108000 = SRAM
```

PCB DETAILS

The PCB layout is not entirely known of course because SAAB did not release details about this, even in the service manuals. Finding out how things are setup is not so very difficult though, once you know what the system should do and what hardware components are on the board.

The image will give you some idea on what is what on the board.



POWER SUPPLY

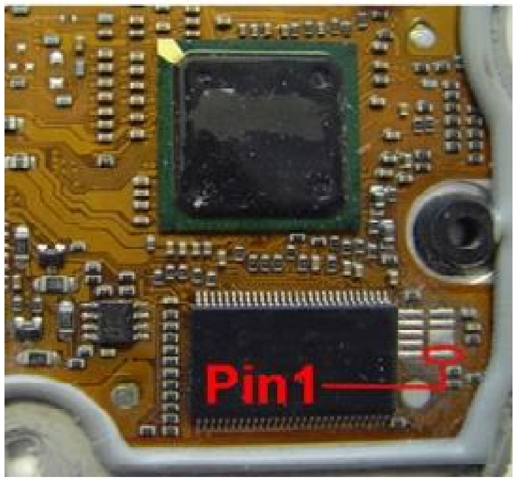
FLASH

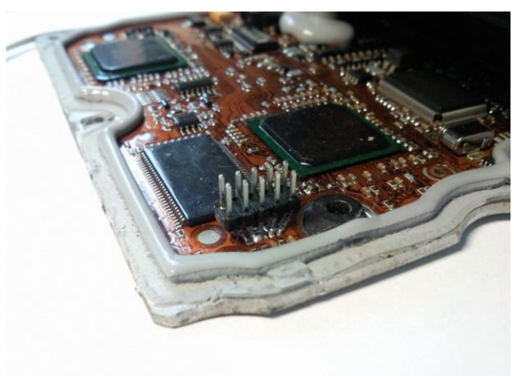
Interesting stuff found in the binary file (needs more investigating to clear up)

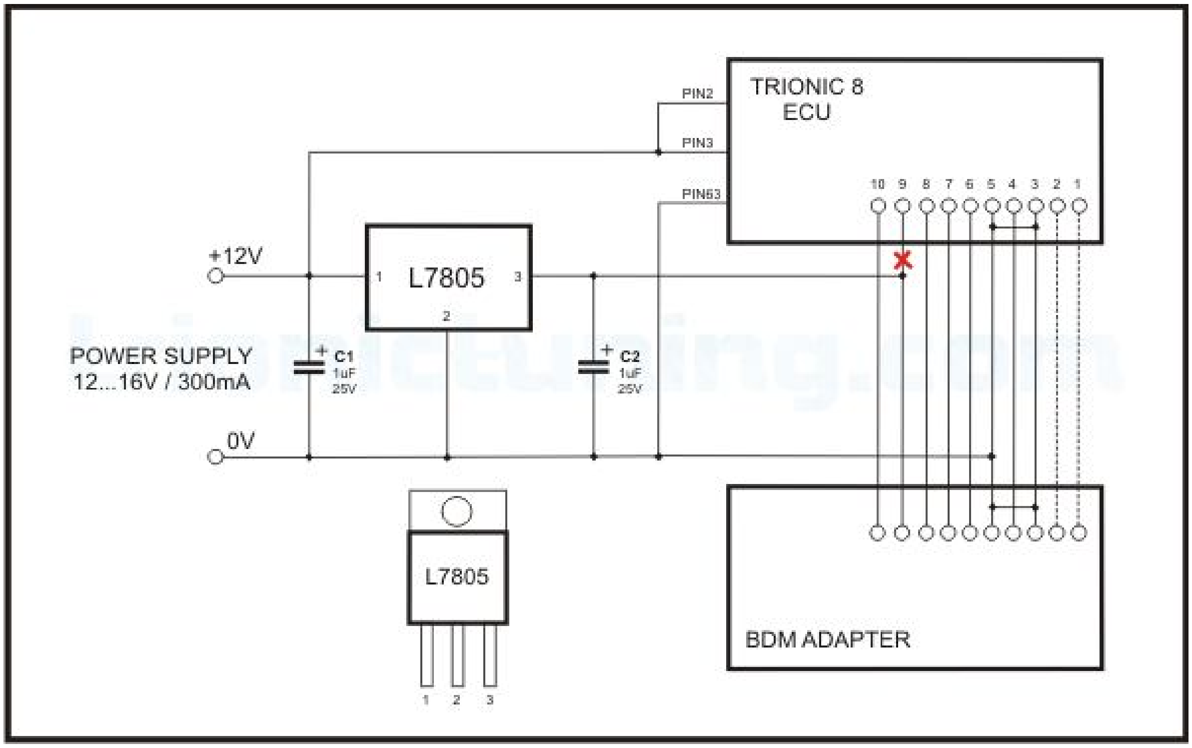
1. GMPT 0100 indicators found at address 0x004141, 0x006142 (in an aero bin). GMPT seems to be short for General Motors Power Train. 0100 might be a version indicator of some sort. Turns out this is an indicator for the hardware (ECU hardware).
2. MFS* indicators found at 0x000E9Ch, 0x000FDC, 0x004000, 0x006000, 0x0104FE, 0x010758, 0x0107CA and 0x010C1E. There seem to be always 8 of these indicators in a T8 file.
3. From 0x004000 (MFS) upto the GMPT 0100 indicator at 0x004141 there seems to be a lot of ASCII information. Also from 0x006000 – the GMPT 0100 indicator at 0x006142 there seems to be a lot of ASCII information in the file. VIN number, part number, software version may be stored here.
4. SAAI indicators found at 0x00800E 0x00945E, 0x020000 and 0x0200DC. The 0x020000 indicator matches the start of one checksum layer area.
5. All symbols seem to be in the area: 0x070000 – 0x0C0000
6. There seems to be some sort of lookup table at or near 0x02C630 – 0x02DEB0 (length ~ 0x1880 = 6272). Each entry seems to consist of 8 bytes to 6272/8, so about 784 entries.

VIN:	YS3FB45F13104xxxx
MOTOR:	ECM
HW:	GPMT 0100
Info:	869060A70952KL2E
	55354002
	12799173
	55352689
	55352573
	55352574
	55352572

Downloading with ECUProjects USB BDM interface






TRIONIC 8
ECU
PIN2
PIN3
PIN63
10 9 8 7 6 5 4 3 2 1
+12V
L7805
1
2
3
POWER SUPPLY
12...16V / 300mA
C1
1uF
25V
C2
1uF
25V
0V
L7805
1 2 3
BDM ADAPTER

CHECKSUM

PREFACE

The Trionic 8 ECU binary images uses several checksums to verify integrity.

Checksum seems to be concentrated at a location given by a pointer @ address 0x20140. It is a 4 byte pointer.

In an example binary we find 0x00 0x0B 0xAF 0x06 at 0x20140.
If we scroll to 0x000BAF06 we find a section that has the checksums (verified by comparing binaries).

```
000baef0h: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ; ................
000baf00h: 00 00 00 00 00 14 5B 56 AF 42 11 A5 E4 9A BD 36 ; ......[V¯B.¥äš½6
000baf10h: C2 39 2A 25 15 F5 92 D0 52 DD 90 96 9B 9F 2B 3B ; Â9*%.õ'ÐRÝ□–›Ÿ+;
000baf20h: 3A 3B 3B 5F E0 8E 8C 96 2B 2B 2B 2B 2B 2B 2B 2B ; :;;_àŽŒ–++++++++
000baf30h: 2B 2B 2B 2B 2B 2B 2B 2B 2B 4D E5 4A 53 4A 69 4A ; +++++++++MåJSJiJ
000baf40h: 4C 57 43 3A 71 4F 14 4C 98 0E 5F 4D 24 2B 2B 53 ; LWC:qO.L˜._M$++S
000baf50h: 0A 3E 3E 3E 3E 42 3F 3C 40 4D 1A 2B 2B 69 53 91 ; .>>>>B?<@M.++iS'
000baf60h: 8A 3E 92 A8 8C A8 91 96 8E 3D A8 41 3E A8 91 92 ; Š>'¨Œ¨'–Ž=¨A>¨''
000baf70h: 8E 91 A8 43 3A 71 2B 2B 2B 2B 2B 2B 2B 4D DE 4B ; Ž'¨C:q+++++++MÞK
000baf80h: 4F 51 E1 36 2B 2B 2B 2B 2B 4F 04 4D 7B 0F 52 4F ; OQá6+++++O.M{.RO
000baf90h: 07 4B 54 B8 51 4F 06 4B 4D 4B 4B 51 61 7B 3E 3B ; .KT¸QO.KMKKQa{>;
000bafa0h: 41 41 3B 5C 55 3D 3B 3B 3F 36 3B 43 36 3A 3D 2B ; AA;\U=;;?6;C6:=+
000bafb0h: 3A 3F 45 3A 3C 45 3C 3F 69 58 91 8A 3E 92 A8 8C ; :?E:<E<?iX'Š>'¨Œ
000bafc0h: A8 91 96 8E 3D A8 A3 A3 A8 A3 A3 A3 A8 A3 A3 A3 ; ¨'–Ž=¨££¨£££¨£££
000bafd0h: 39 7F 76 7B 2B 2B 2B 2B 58 66 9C 7F 6E 71 6A 79 ; 9□v{++++Xfœ□nqjy
000bafe0h: 2B 96 78 7C 7C 6D 6E 7D 70 FF FF FF FF FF FF FF ; +–x||mn}pÿÿÿÿÿÿÿ
```

The checksum actually consists of two layers. The first layer is a MD5 hash over the area 0x20000 up to the pointer address (in our case 0x000BAF06). This hash will be 16 bytes in length. All bytes in this array are XOR-ed with 0x21 and 0xD6 is subtracted from that value. This final array is stored in the pointer address + 2 (so, 0x000BAF08 in our example, the large marker in the image).

Once this first layer is correct we can calculate the second layer (not earlier, because the second layer checksum includes the first layers result). This second layer is calculated over 0x100 bytes ranging from the pointer address (0x000BAF06) up to the pointer address + 0x100 (0x000BB006).

All the bytes (256 in total) are added with 0xD6 and then XOR-ed with 0x21. In this coded buffer there will be three values 0xFB, 0xFC and 0xFD with an interval of 6 bytes. For example somewhere in the buffer this sequence will be found.

FB XX XX XX AA AA FC YY YY YY BB BB FD ZZ ZZ ZZ ZZ in which XX and YY are don't cares. Once this index is found the XX values will yield a result we will call "*sum*", the YY values will yield a result we will call "*dimension*" and finally the ZZ values will yield a value that we will call "*fileaddress*".

If the dimension is larger than 0x020000 we will start reading from the binary file at *fileaddress* until we reach the *dimension* address - 4. All bytes read will be added and this will result in a checksum value which we will call "*calculated_checksum*". Finally we also add the byte at location *dimension* – 1 to the *calculated_checksum*.

We do this again to calculated a second checksum called "*calculated_checksum_2*" but now we add a 4 bytes word every time in stead of a single byte word. If the upper 3 bytes of the *calculated_checksum* are unequal to the upper 3 bytes of *sum* we make *calculated_checksum* the same value as *calculated_checksum_2*.

If our *calculated_checksum* does not equal *sum* we have an incorrect checksum an it needs to be updated. This is done by XOR-ing all bytes in *calculated_checksum* with 0x21 and subtracting 0xD6 and writing this result to the XX XX XX XX positions in the previously found buffer. This is save to file.

Special thanks to "Actitis H." for all the provided help!

FIRMWARE

GENERAL

Memory map

```
0x000000 - 0x01FFFF = boot

0x020000 - 0x0BFFFF = Application software

0x0C0000 - 0x0FFFFF = Unknown

0x100000 – 0x108000 = SRAM
```

Disassembling the code

SYMBOL TABLES

GENERAL

Each T8 firmware file contains a symbol table describing data structures in the program. This table is compressed inside the binary and needs to be extracted and decompressed for parsing. We actually need these symbol names because they tell us what a certain memory location means.

To save you the time to lookup all addresses manually the T8Suite application will extract all symbol information in one run. Symbol name, flash address and length will be displayed all together.

The symboltable end address can be found by searching the binary file for the text: "sYMBOLtABLE". Just after this address in the file, we can find a pointer for the start of the compressed symboltable like it is shown in the image below.

```
00080210h: 99 50 F8 76 36 52 C7 2F F6 C8 1B AA F8 8E B0 74 ; ™Pøv6RÇ/öÈ.ªøŽ°t
00080220h: 3C 3B EA 1B 1B 10 18 7F 30 6F 48 C2 73 59 4D 42 ; <;ê....□0oHÂsYMB
00080230h: 4F 4C 74 41 42 4C 45 00 00 04 A8 EA 1B 90 4E 71 ; OLtABLE...¨ê.□Nq
00080240h: 4E 71 4E 71 00 07 57 14 AB 18 00 00 04 01 00 00 ; NqNq..W.«.......
00080250h: 00 00 00 00 00 00 20 00 00 10 5C 30 00 04 00 00 ; ...... ...\0....
```

This *image (2)* will give you an idea of what the symbol table should look like once it has been extracted and decompressed. See appendix I for a complete list of known symbols.

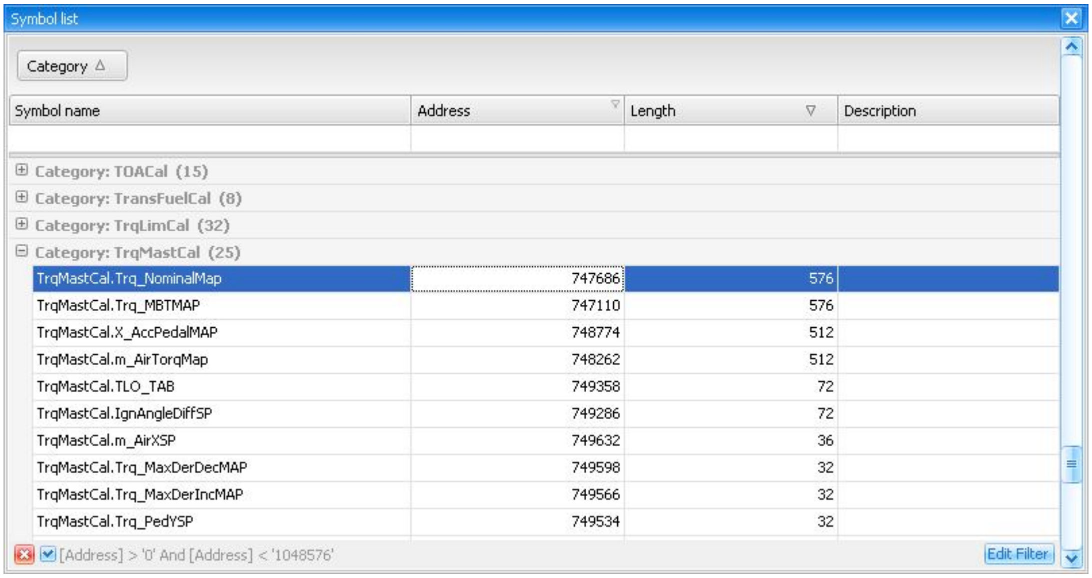
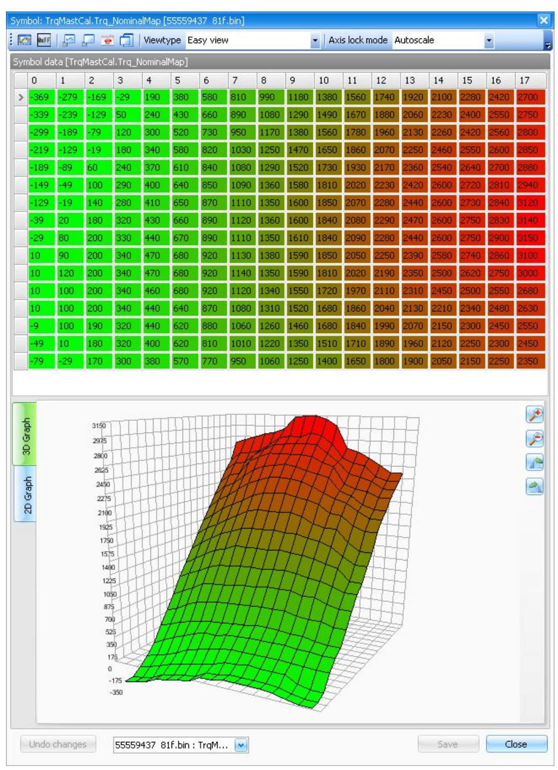


IMAGE 1: SCREENSHOT OF A PART OF THE SYMBOL TABLE

When the user double clicks one of the symbols that has a flash address attached to it, T8Suite will display the corresponding symbol in a viewer. This viewer will display the data in table form was well as in graphical form.



MAPS

GENERAL

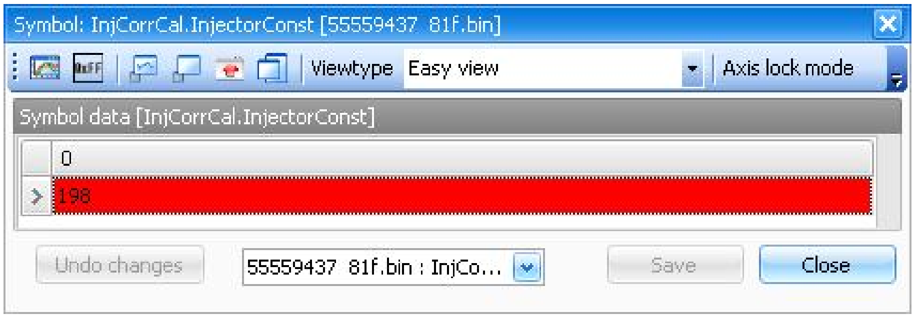
A lot of maps in the T8 are not only made up of a piece of raw data. It also includes x-axis and y-axis information. T8Suite will automatically display all known axis information when a map is opened. In Trionic 8 most symbol have an English name (Trionic 5 has lots of Swedish names) that explains lots about its function. Also, the symbols are caterogised by name, which makes browsing the symbols much easier. All torque calibration symbols start with "TrqMastCal.". T8Suite groups all symbols by their respective category by default.

FUEL

Fuel calculation in Trionic 8 is based on the airmass entering the engine. In rough steps this seems to be the calculation's flow:

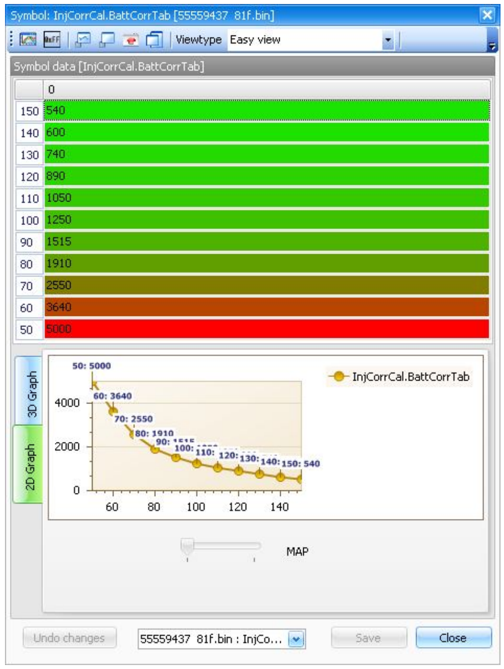
	Description	Explaination
1	Basic calculation of fuel quantity per combustion	The current air mass/combustion is divided by 14.7 and sent to box 2. The unit is now in mg fuel/combustion
2	Compensation	In case of a cold engine, shortly after starting, rapid load changes, knocking or high loads, the current value is multiplied by a compensation factor
3	Closed loop	The closed loop value is used as a multiplier. The value is then sent to box 4
4	Correction for purge	Multiply by the value for purge adaptation. The value is sent to box 5
5	Multiplicitive adaptation (long term fuel trim)	The multiplicitive adaptation value is used as a multiplier and the new value is sent to box 6
6	Additive adaptation	The additive adaptation value is added and the new value is sent to box 7
7	Starting fuel quantity	If the engine has not yet started, starting fuel is selected. The value is sent to box 8
8	Fuel quantity per combustion to be injected	The fuel quantity per combustion is the amount of petrol to be supplied to the engine. The value is sent to box 9
9	Injector opening duration	Converts the value to the time during which the injector must be open and the new value is sent to box 10
10	Injection twice per combustion	Injection takes place twice per combustion until the camshaft position has been found. Injection duration is divided by two. The value is sent to box 11
11	Voltage dependant needle lift duration added (battery correction)	Adds the injector time delay, which is voltage dependant. The value is sent to box 12
12	Fuel cut	The value is sent to box 13 unless fuel cut is active
13	Activation of injector	At a DETERMINED crank shaft angle, the microprocessor will control the transistor for the injector that is next in the firing order

The basic fuel quantity is calculated based on Airmass and Injector constant. This injector constant is called InjCorrCal.InjectorConstant.

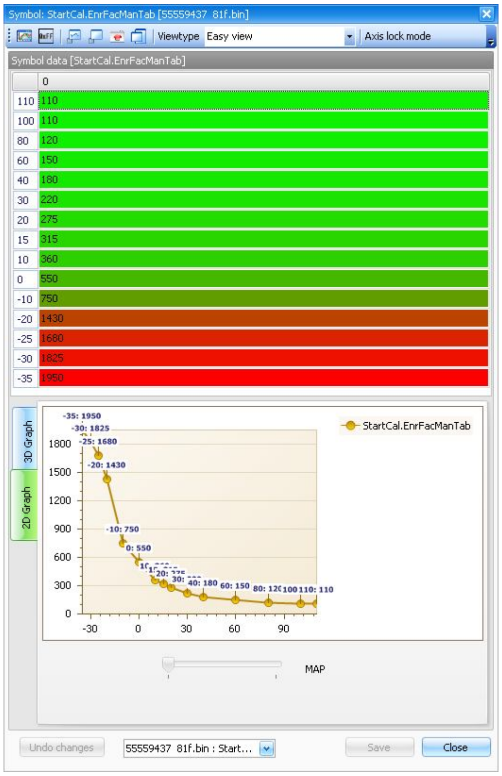


TODO: Insert fuel correction maps here

Battery correction values for injector latency



Water temperature correction


Symbol: StartCal.EnrFacManTab [55559437 81f.bin]
Viewtype Easy view
Axis lock mode
Symbol data [StartCal.EnrFacManTab]
0
110 110
100 110
80 120
60 150
40 180
30 220
20 275
15 315
10 360
0 550
-10 750
-20 1430
-25 1680
-30 1825
-35 1950
3D Graph
2D Graph
StartCal.EnrFacManTab
MAP
Undo changes
55559437 81f.bin : Start...
Save
Close

Fuel injection correction map for knock conditions

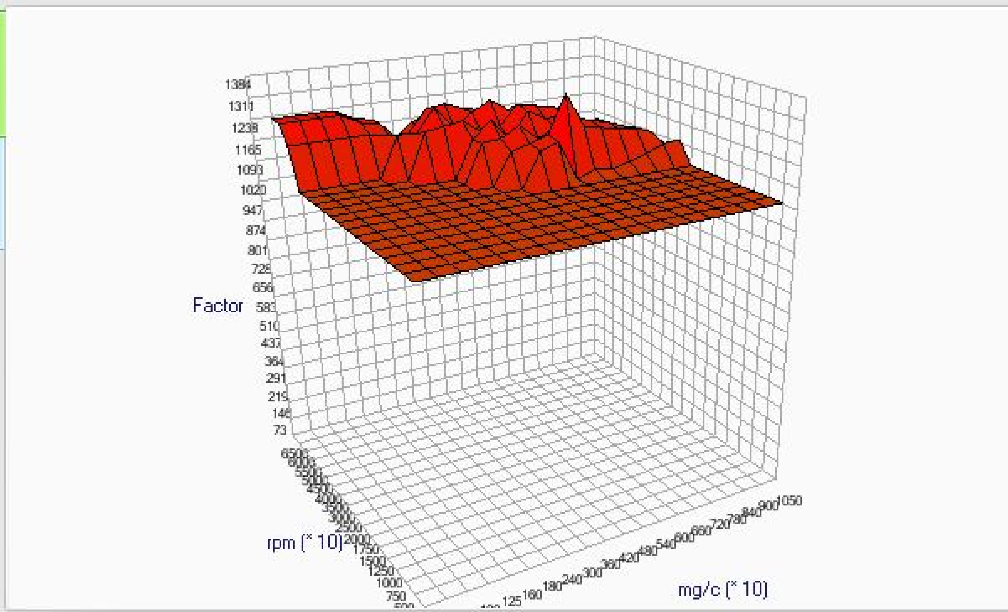
Symbol: KnkFuelCal.EnrichmentMap [55559437 81f.bin]

Viewtype Easy view | Axis lock mode Autoscale | Mathematics

Symbol data [KnkFuelCal.EnrichmentMap]

	75	100	125	160	180	240	300	360	420	480	540	600	660	720	780	840	900	1050
6500	1229	1229	1229	1193	1178	1096	1152	1167	1167	1106	1101	1106	1060	1024	1044	1024	1024	1024
6000	1229	1229	1229	1193	1178	1096	1152	1167	1167	1106	1101	1106	1060	1024	1034	1024	1024	1024
5500	1167	1167	1167	1167	1152	1152	1229	1239	1213	1198	1172	1132	1121	1080	1050	1039	1024	1024
5000	1024	1024	1024	1024	1172	1167	1251	1167	1213	1249	1203	1137	1126	1101	1085	1050	1034	1024
4500	1024	1024	1024	1024	1024	1188	1198	1208	1157	1172	1239	1224	1213	1167	1142	1106	1034	1024
4000	1024	1024	1024	1024	1024	1024	1024	1157	1219	1137	1229	1193	1198	1167	1162	1116	1075	1024
3500	1024	1024	1024	1024	1024	1024	1024	1162	1167	1203	1147	1178	1203	1183	1167	1142	1075	1024
3000	1024	1024	1024	1024	1024	1024	1024	1024	1137	1157	1178	1311	1188	1172	1157	1152	1126	1060
2500	1024	1024	1024	1024	1024	1024	1024	1024	1024	1147	1167	1024	1050	1039	1055	1075	1100	1105
2000	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024
1750	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024
1500	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024
1250	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024
1000	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024
750	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024
500	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024

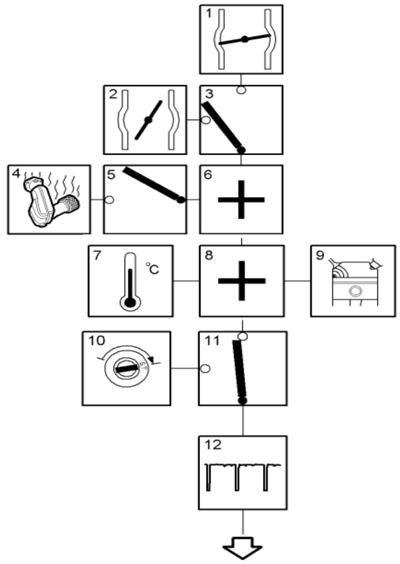
3D Graph
2D Graph



Undo changes | 55559437 81f.bin : KnkF... | Save | Close

IGNITION

	Description	Explaination
1	Idling speed ignition timing	With idle speed control active, the timing is adjusted to stabilize idle engine speed. The value is sent to box 3
2	Normal ignition timing	When idle speed control is inactive, the ignition timing is read from a load and engine speed depeding matrix. The value from the matrix is optimized for lowest fuel consumption (best engine torque) and sent to box 3
3	Selection of ignition timing	One of the ignition timing calculation is selected depending on which function is active. The value is sent to box 6
4	Catalytic converter heating timing	In order to heat up the catalytic converter as fast as possible after start, the ignition will be retarded. This is a compensation matrix that is added to the value in box 3. The matrix is dependent on load and engine speed
5	Engagement of catalytic converter heating timing	The function is active when coolant temperature is above -10 degrees celcius and below +64 degrees celcius
6	Total	The value from box 5 is added to the value of box 3
7	Compensation	The ignition timing is corrected depending on engine coolant temperature and intake air temperature. The value is sent to box 6.
8	Knock control	If knocking occurs, a timing retardation will be calculated. The value is sent to box 6
9	Total	The compensation angle and knock retardation are totalled to give the current ignition timing. The value is sent to box 7
10	Selection of ignition timing	Starting ignition timing is selected when the engine has not been started. The value is sent to box 9
11	Starting ignition timing	Starting ignition timing is selected when the engine has not yet been started. The value is sent to box 9
12	Activate relevant trigger	At the calculated crackshaft angle, the microprocessor controls the transistor for the trigger that is next in firing order



IGNITION COILS

Trionic 8 cars don't use a DI cartridge like T5 and T7 do. It uses seperate ignition coils for each cylinder.

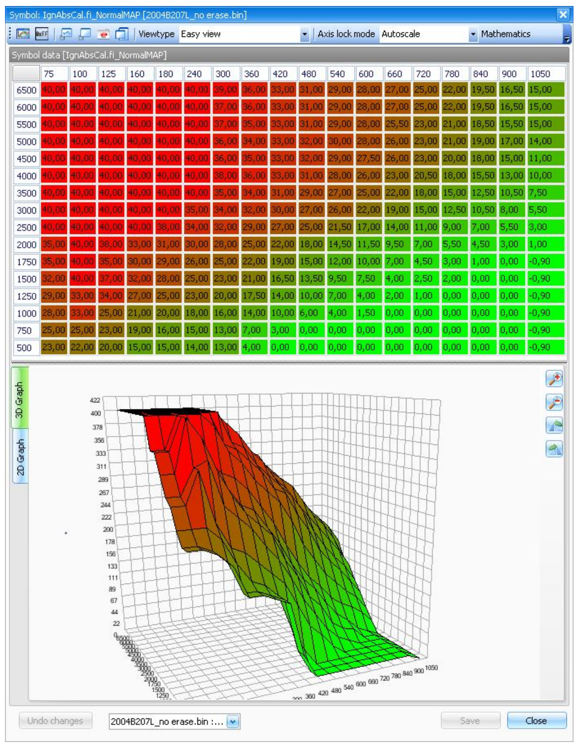
Pin	Description
1	B+ (positive supply voltage)
2	B- (negative supply voltage, ground)
3	Ignition trigger signal from ECU
4	Ionization voltage (knock, combustion and missfire detection)

IDLE CONTROL

TODO: Insert ignition idle control map here

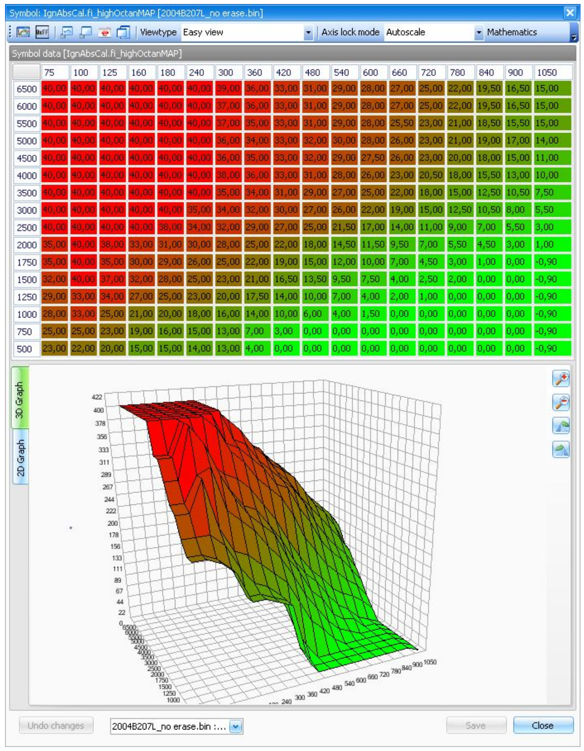
NORMAL MODE IGNITION

Ignition is normally controlled by the main ignition matrix: IgnAbsCal.fi_NormalMAP



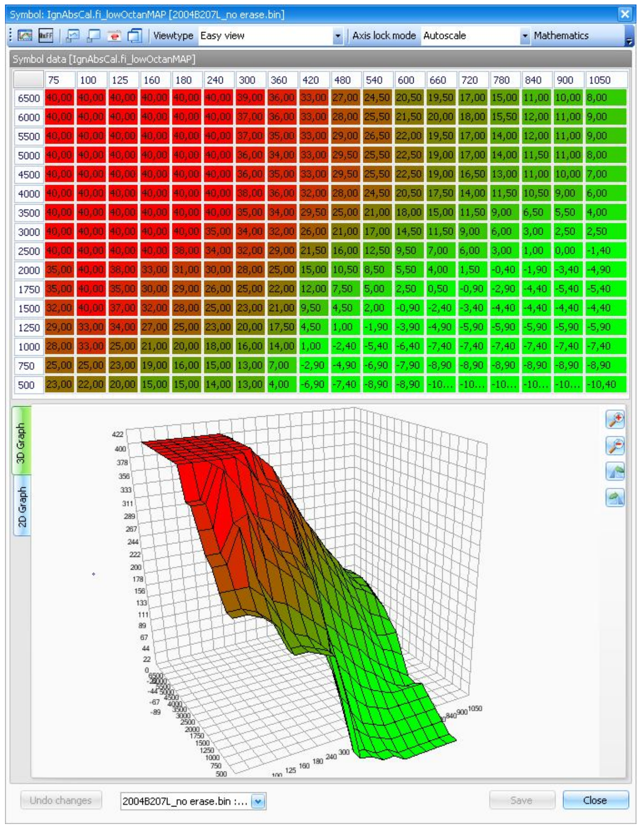
	75	100	125	160	180	240	300	360	420	480	540	600	660	720	780	840	900	1050
6500	40,00	40,00	40,00	40,00	40,00	40,00	39,00	36,00	33,00	31,00	29,00	28,00	27,00	25,00	22,00	19,50	16,50	15,00
6000	40,00	40,00	40,00	40,00	40,00	40,00	37,00	36,00	33,00	31,00	29,00	28,00	27,00	25,00	22,00	19,50	16,50	15,00
5500	40,00	40,00	40,00	40,00	40,00	40,00	37,00	35,00	33,00	31,00	29,00	28,00	25,50	23,00	21,00	18,50	15,50	15,00
5000	40,00	40,00	40,00	40,00	40,00	40,00	36,00	34,00	33,00	32,00	30,00	28,00	26,00	23,00	21,00	19,00	17,00	14,00
4500	40,00	40,00	40,00	40,00	40,00	40,00	36,00	35,00	33,00	32,00	29,00	27,50	26,00	23,00	20,00	18,00	15,00	11,00
4000	40,00	40,00	40,00	40,00	40,00	40,00	38,00	36,00	33,00	31,00	28,00	26,00	23,00	20,50	18,00	15,50	13,00	10,00
3500	40,00	40,00	40,00	40,00	40,00	40,00	35,00	34,00	31,00	29,00	27,00	25,00	22,00	18,00	15,00	12,50	10,50	7,50
3000	40,00	40,00	40,00	40,00	40,00	35,00	34,00	32,00	30,00	27,00	26,00	22,00	19,00	15,00	12,50	10,50	8,00	5,50
2500	40,00	40,00	40,00	40,00	38,00	34,00	32,00	29,00	27,00	25,00	21,50	17,00	14,00	11,00	9,00	7,00	5,50	3,00
2000	35,00	40,00	38,00	33,00	31,00	30,00	28,00	25,00	22,00	18,00	14,50	11,50	9,50	7,00	5,50	4,50	3,00	1,00
1750	35,00	40,00	35,00	30,00	29,00	26,00	25,00	22,00	19,00	15,00	12,00	10,00	7,00	4,50	3,00	1,00	0,00	-0,90
1500	32,00	40,00	37,00	32,00	28,00	25,00	23,00	21,00	16,50	13,50	9,50	7,50	4,00	2,50	2,00	0,00	0,00	-0,90
1250	29,00	33,00	34,00	27,00	25,00	23,00	20,00	17,50	14,00	10,00	7,00	4,00	2,00	1,00	0,00	0,00	0,00	-0,90
1000	28,00	33,00	25,00	21,00	20,00	18,00	16,00	14,00	10,00	6,00	4,00	1,50	0,00	0,00	0,00	0,00	0,00	-0,90
750	25,00	25,00	23,00	19,00	16,00	15,00	13,00	7,00	3,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,90
500	23,00	22,00	20,00	15,00	15,00	14,00	13,00	4,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,90

For high octane fuel the map IgnAbsCal.fi_highOctaneMAP will be used



	75	100	125	160	180	240	300	360	420	480	540	600	660	720	780	840	900	1050
6500	40,00	40,00	40,00	40,00	40,00	40,00	39,00	36,00	33,00	31,00	29,00	28,00	27,00	25,00	22,00	19,50	16,50	15,00
6000	40,00	40,00	40,00	40,00	40,00	40,00	37,00	36,00	33,00	31,00	29,00	28,00	27,00	25,00	22,00	19,50	16,50	15,00
5500	40,00	40,00	40,00	40,00	40,00	40,00	37,00	35,00	33,00	31,00	29,00	28,00	25,50	23,00	21,00	18,50	15,50	15,00
5000	40,00	40,00	40,00	40,00	40,00	40,00	36,00	34,00	33,00	32,00	30,00	28,00	26,00	23,00	21,00	19,00	17,00	14,00
4500	40,00	40,00	40,00	40,00	40,00	40,00	36,00	35,00	33,00	32,00	29,00	27,50	26,00	23,00	20,00	18,00	15,00	11,00
4000	40,00	40,00	40,00	40,00	40,00	40,00	38,00	36,00	33,00	31,00	28,00	26,00	23,00	20,50	18,00	15,50	13,00	10,00
3500	40,00	40,00	40,00	40,00	40,00	40,00	35,00	34,00	31,00	29,00	27,00	25,00	22,00	18,00	15,00	12,50	10,50	7,50
3000	40,00	40,00	40,00	40,00	40,00	35,00	34,00	32,00	30,00	27,00	26,00	22,00	19,00	15,00	12,50	10,50	8,00	5,50
2500	40,00	40,00	40,00	40,00	38,00	34,00	32,00	29,00	27,00	25,00	21,50	17,00	14,00	11,00	9,00	7,00	5,50	3,00
2000	35,00	40,00	38,00	33,00	31,00	30,00	28,00	25,00	22,00	18,00	14,50	11,50	9,50	7,00	5,50	4,50	3,00	1,00
1750	35,00	40,00	35,00	30,00	29,00	26,00	25,00	22,00	19,00	15,00	12,00	10,00	7,00	4,50	3,00	1,00	0,00	-0,90
1500	32,00	40,00	37,00	32,00	28,00	25,00	23,00	21,00	16,50	13,50	9,50	7,50	4,00	2,50	2,00	0,00	0,00	-0,90
1250	29,00	33,00	34,00	27,00	25,00	23,00	20,00	17,50	14,00	10,00	7,00	4,00	2,00	1,00	0,00	0,00	0,00	-0,90
1000	28,00	33,00	25,00	21,00	20,00	18,00	16,00	14,00	10,00	6,00	4,00	1,50	0,00	0,00	0,00	0,00	0,00	-0,90
750	25,00	25,00	23,00	19,00	16,00	15,00	13,00	7,00	3,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,90
500	23,00	22,00	20,00	15,00	15,00	14,00	13,00	4,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,90

And for low octane fuel the map IgnAbsCal.fi_lowOctaneMAP



	75	100	125	160	180	240	300	360	420	480	540	600	660	720	780	840	900	1050
6500	40,00	40,00	40,00	40,00	40,00	40,00	39,00	36,00	33,00	27,00	24,50	20,50	19,50	17,00	15,00	11,00	10,00	8,00
6000	40,00	40,00	40,00	40,00	40,00	40,00	37,00	36,00	33,00	28,00	25,50	21,50	20,00	18,00	15,50	12,00	11,00	9,00
5500	40,00	40,00	40,00	40,00	40,00	40,00	37,00	35,00	33,00	29,00	26,50	22,00	19,50	17,00	14,00	12,00	11,00	9,00
5000	40,00	40,00	40,00	40,00	40,00	40,00	36,00	34,00	33,00	29,50	25,50	22,50	19,00	17,00	14,00	11,50	11,00	8,00
4500	40,00	40,00	40,00	40,00	40,00	40,00	36,00	35,00	33,00	29,50	25,50	22,50	19,00	16,50	13,00	11,00	10,00	7,00
4000	40,00	40,00	40,00	40,00	40,00	40,00	38,00	36,00	32,00	28,00	24,50	20,50	17,50	14,00	11,50	10,50	9,00	6,00
3500	40,00	40,00	40,00	40,00	40,00	40,00	35,00	34,00	29,50	25,00	21,00	18,00	15,00	11,50	9,00	6,50	5,50	4,00
3000	40,00	40,00	40,00	40,00	40,00	35,00	34,00	32,00	26,00	21,00	17,00	14,50	11,50	9,00	6,00	3,00	2,50	2,50
2500	40,00	40,00	40,00	40,00	38,00	34,00	32,00	29,00	21,50	16,00	12,50	9,50	7,00	6,00	3,00	1,00	0,00	-1,40
2000	35,00	40,00	38,00	33,00	31,00	30,00	28,00	25,00	15,00	10,50	8,50	5,50	4,00	1,50	-0,40	-1,90	-3,40	-4,90
1750	35,00	40,00	35,00	30,00	29,00	26,00	25,00	22,00	12,00	7,50	5,00	2,50	0,50	-0,90	-2,90	-4,40	-5,40	-5,40
1500	32,00	40,00	37,00	32,00	28,00	25,00	23,00	21,00	9,50	4,50	2,00	-0,90	-2,40	-3,40	-4,40	-4,40	-4,40	-4,40
1250	29,00	33,00	34,00	27,00	25,00	23,00	20,00	17,50	4,50	1,00	-1,90	-3,90	-4,90	-5,90	-5,90	-5,90	-5,90	-5,90
1000	28,00	33,00	25,00	21,00	20,00	18,00	16,00	14,00	1,00	-2,40	-5,40	-6,40	-7,40	-7,40	-7,40	-7,40	-7,40	-7,40
750	25,00	25,00	23,00	19,00	16,00	15,00	13,00	7,00	-2,90	-4,90	-6,90	-7,90	-8,90	-8,90	-8,90	-8,90	-8,90	-8,90
500	23,00	22,00	20,00	15,00	15,00	14,00	13,00	4,00	-6,90	-7,40	-8,90	-8,90	-10...	-10...	-10...	-10...	-10...	-10,40

TORQUE

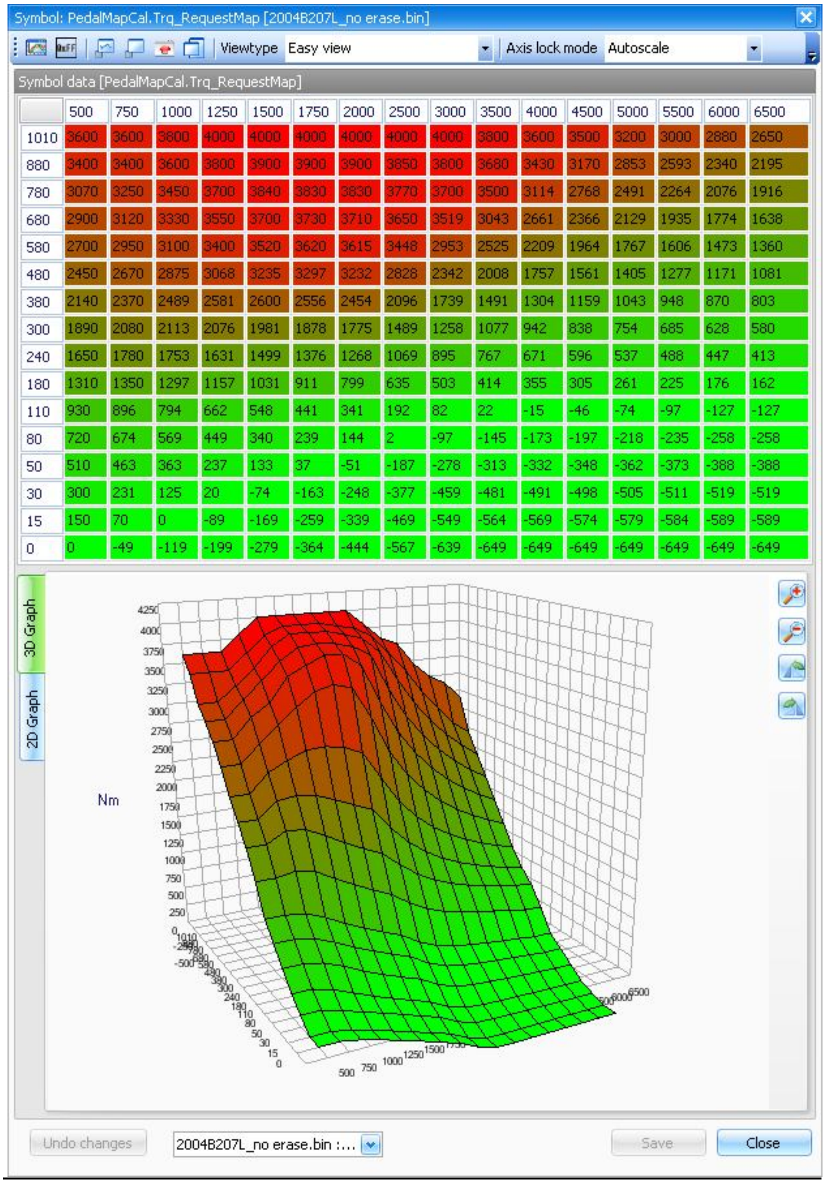
Trionic 8 is a torque/airmass request system in stead of a boost request system like Trionic 5 is.

The basic procedure for the airmass controller is like in the table below.

	Description	Explaination
1	Driver request	The control module reads pedal potentiometer 1 and converts the voltage to air massper combustion (mg/c). The value is sent to box 3
2	Cruise control request	When cruise control is active, the air mass per combustion required to maintain the set speed is calculated. The value is sent to box 3
3	Select highest value	The control module selects the higest of the two values (box 1 or box 2). The value is sent to box 5
4	Engine torque limitation	The maximum permissable air mass per combustion varies depending on the engine type. During operation, the maximum permissable mg/c must also be limited to protect the engine, gearbox, brakes and turbo
5	Select lowest value	The control module selects the lowest value and sends it to box 8
6	Compensation request	When the AC comprressor is on, and when the heated rear window or radiator fan is on, the mg/c required to compensate for the increased load is calculated. The value is sent to box 8
7	Other air request	The control module calculates the mg/c required for idle speed control. The value is sent to box 8
8	Totalling values	The control module totals all the values. The total is sent to box 9
9	Total requested mg/c	
10	Total airmass request	
11	Trottle control	The requested mg/c is converted to requested voltage for throttle position sensor 1. The charge air pressure and intake air temp are used to correct this conversion. The throttle motor rotates the throttle until the current voltage for throttle position sensor 1 corresponds with the reqested voltage
12	Current mg/c	The requested mg/c is also compared with the current mg/c (MAF reading). If needed the requested voltage for throttle position sensor 1 is finely adjusted
13	Turbo control	If mg/c is too high for throttle alone the turbo control will take over. The excess is converted to a PWM which controls the charge air control valve. The absolute pressure sensor is used to correct the conversion
14	Current mg/c	The req mg/c is compared to current mg/c and the charge air control vale PWM is finely adjusted if required

TORQUE REQUEST

So, if the driver (or cruis control for that matter) pressed the accelerator pedal he actually requests a certain torque from the system. This value is fetched from the PedelMapCal.Trq_requestMap shown below.

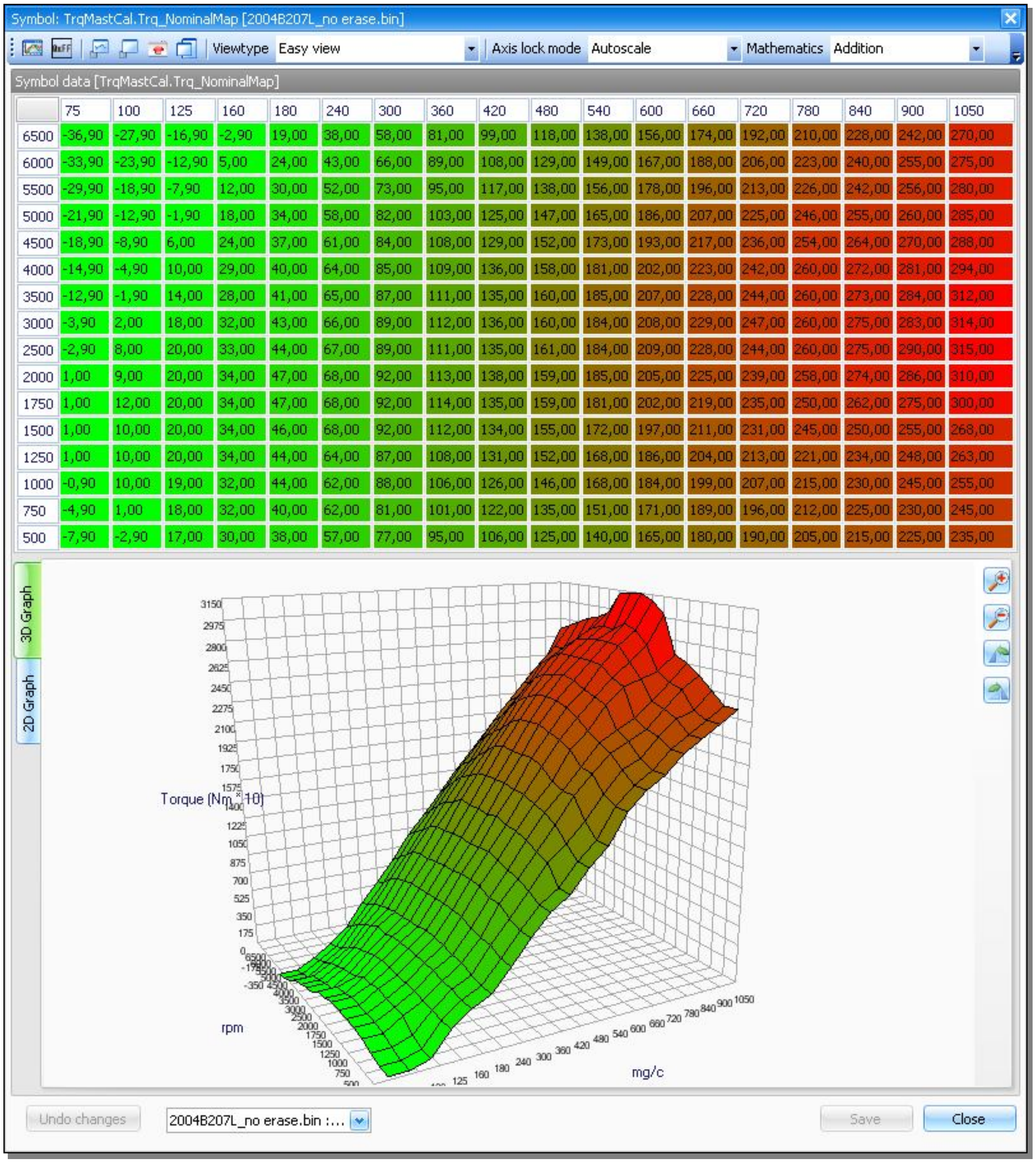


	500	750	1000	1250	1500	1750	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500
1010	3600	3600	3800	4000	4000	4000	4000	4000	4000	3800	3600	3500	3200	3000	2880	2650
880	3400	3400	3600	3800	3900	3900	3900	3850	3800	3680	3430	3170	2853	2593	2340	2195
780	3070	3250	3450	3700	3840	3830	3830	3770	3700	3500	3114	2768	2491	2264	2076	1916
680	2900	3120	3330	3550	3700	3730	3710	3650	3519	3043	2661	2366	2129	1935	1774	1638
580	2700	2950	3100	3400	3520	3620	3615	3448	2953	2525	2209	1964	1767	1606	1473	1360
480	2450	2670	2875	3068	3235	3297	3232	2828	2342	2008	1757	1561	1405	1277	1171	1081
380	2140	2370	2489	2581	2600	2556	2454	2096	1739	1491	1304	1159	1043	948	870	803
300	1890	2080	2113	2076	1981	1878	1775	1489	1258	1077	942	838	754	685	628	580
240	1650	1780	1753	1631	1499	1376	1268	1069	895	767	671	596	537	488	447	413
180	1310	1350	1297	1157	1031	911	799	635	503	414	355	305	261	225	176	162
110	930	896	794	662	548	441	341	192	82	22	-15	-46	-74	-97	-127	-127
80	720	674	569	449	340	239	144	2	-97	-145	-173	-197	-218	-235	-258	-258
50	510	463	363	237	133	37	-51	-187	-278	-313	-332	-348	-362	-373	-388	-388
30	300	231	125	20	-74	-163	-248	-377	-459	-481	-491	-498	-505	-511	-519	-519
15	150	70	0	-89	-169	-259	-339	-469	-549	-564	-569	-574	-579	-584	-589	-589
0	0	-49	-119	-199	-279	-364	-444	-567	-639	-649	-649	-649	-649	-649	-649	-649

The table holds airmass values for each position of the accelerator pedal and each rpm site. Trionic now looks up the estimated engine output (torque) based on airmass and rpm. This is done through map "TrqMastCal.Trq_NominalMap" as shown next.

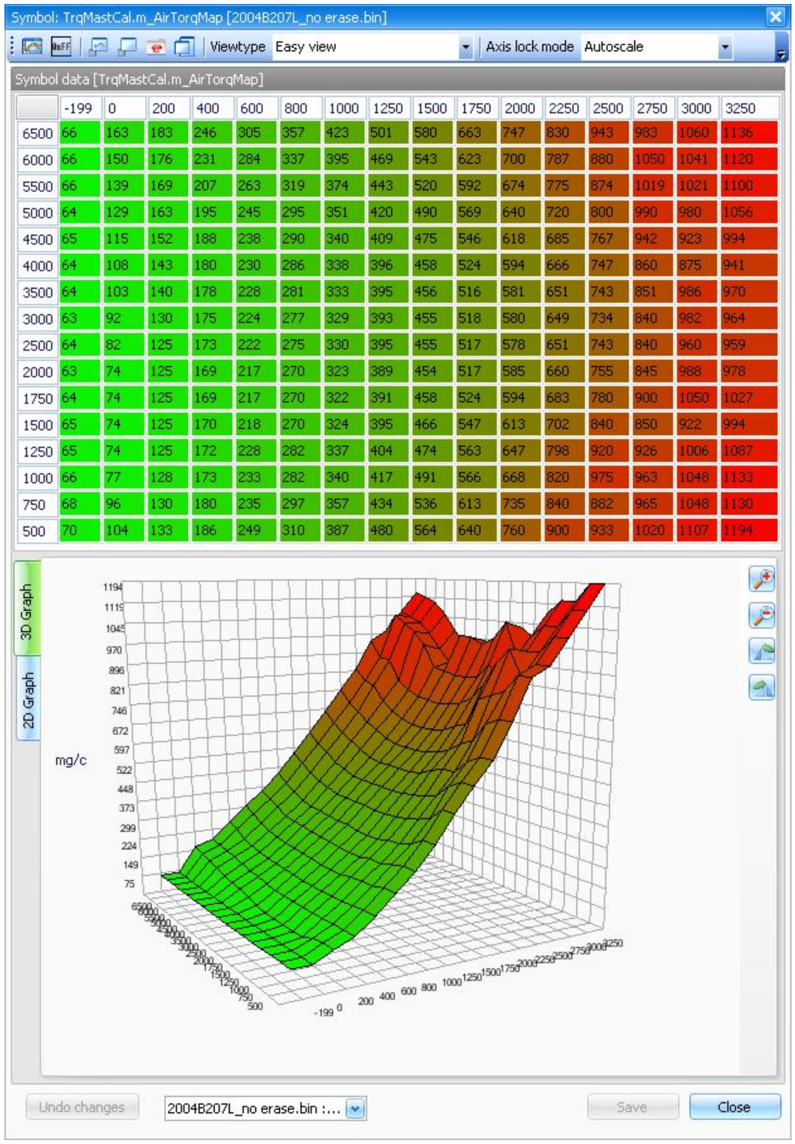
TORQUE LIMITERS

TrqLimCal.*



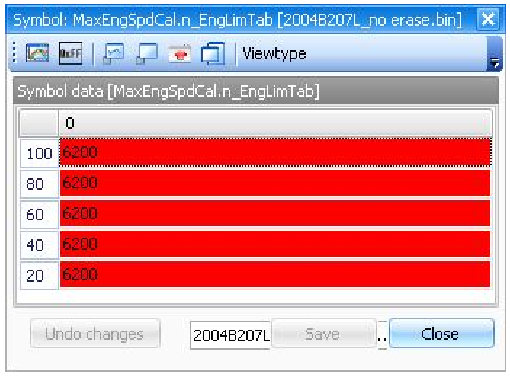
	75	100	125	160	180	240	300	360	420	480	540	600	660	720	780	840	900	1050
6500	-36,90	-27,90	-16,90	-2,90	19,00	38,00	58,00	81,00	99,00	118,00	138,00	156,00	174,00	192,00	210,00	228,00	242,00	270,00
6000	-33,90	-23,90	-12,90	5,00	24,00	43,00	66,00	89,00	108,00	129,00	149,00	167,00	188,00	206,00	223,00	240,00	255,00	275,00
5500	-29,90	-18,90	-7,90	12,00	30,00	52,00	73,00	95,00	117,00	138,00	156,00	178,00	196,00	213,00	226,00	242,00	256,00	280,00
5000	-21,90	-12,90	-1,90	18,00	34,00	58,00	82,00	103,00	125,00	147,00	165,00	186,00	207,00	225,00	246,00	255,00	260,00	285,00
4500	-18,90	-8,90	6,00	24,00	37,00	61,00	84,00	108,00	129,00	152,00	173,00	193,00	217,00	236,00	254,00	264,00	270,00	288,00
4000	-14,90	-4,90	10,00	29,00	40,00	64,00	85,00	109,00	136,00	158,00	181,00	202,00	223,00	242,00	260,00	272,00	281,00	294,00
3500	-12,90	-1,90	14,00	28,00	41,00	65,00	87,00	111,00	135,00	160,00	185,00	207,00	228,00	244,00	260,00	273,00	284,00	312,00
3000	-3,90	2,00	18,00	32,00	43,00	66,00	89,00	112,00	136,00	160,00	184,00	208,00	229,00	247,00	260,00	275,00	283,00	314,00
2500	-2,90	8,00	20,00	33,00	44,00	67,00	89,00	111,00	135,00	161,00	184,00	209,00	228,00	244,00	260,00	275,00	290,00	315,00
2000	1,00	9,00	20,00	34,00	47,00	68,00	92,00	113,00	138,00	159,00	185,00	205,00	225,00	239,00	258,00	274,00	286,00	310,00
1750	1,00	12,00	20,00	34,00	47,00	68,00	92,00	114,00	135,00	159,00	181,00	202,00	219,00	235,00	250,00	262,00	275,00	300,00
1500	1,00	10,00	20,00	34,00	46,00	68,00	92,00	112,00	134,00	155,00	172,00	197,00	211,00	231,00	245,00	250,00	255,00	268,00
1250	1,00	10,00	20,00	34,00	44,00	64,00	87,00	108,00	131,00	152,00	168,00	186,00	204,00	213,00	221,00	234,00	248,00	263,00
1000	-0,90	10,00	19,00	32,00	44,00	62,00	88,00	106,00	126,00	146,00	168,00	184,00	199,00	207,00	215,00	230,00	245,00	255,00
750	-4,90	1,00	18,00	32,00	40,00	62,00	81,00	101,00	122,00	135,00	151,00	171,00	189,00	196,00	212,00	225,00	230,00	245,00
500	-7,90	-2,90	17,00	30,00	38,00	57,00	77,00	95,00	106,00	125,00	140,00	165,00	180,00	190,00	205,00	215,00	225,00	235,00

AIRMASS TO TORQUE CALIBRATION MAP



	-199	0	200	400	600	800	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250
6500	66	163	183	246	305	357	423	501	580	663	747	830	943	983	1060	1136
6000	66	150	176	231	284	337	395	469	543	623	700	787	880	1050	1041	1120
5500	66	139	169	207	263	319	374	443	520	592	674	775	874	1019	1021	1100
5000	64	129	163	195	245	295	351	420	490	569	640	720	800	990	980	1056
4500	65	115	152	188	238	290	340	409	475	546	618	685	767	942	923	994
4000	64	108	143	180	230	286	338	396	458	524	594	666	747	860	875	941
3500	64	103	140	178	228	281	333	395	456	516	581	651	743	851	986	970
3000	63	92	130	175	224	277	329	393	455	518	580	649	734	840	982	964
2500	64	82	125	173	222	275	330	395	455	517	578	651	743	840	960	959
2000	63	74	125	169	217	270	323	389	454	517	585	660	755	845	988	978
1750	64	74	125	169	217	270	322	391	458	524	594	683	780	900	1050	1027
1500	65	74	125	170	218	270	324	395	466	547	613	702	840	850	922	994
1250	65	74	125	172	228	282	337	404	474	563	647	798	920	926	1006	1087
1000	66	77	128	173	233	282	340	417	491	566	668	820	975	963	1048	1133
750	68	96	130	180	235	297	357	434	536	613	735	840	882	965	1048	1130
500	70	104	133	186	249	310	387	480	564	640	760	900	933	1020	1107	1194

Maximum RPM depending on coolant temp:


Symbol: MaxEngSpdCal.n_EngLimTab [2004B207L_no erase.bin]
Viewtype
Symbol data [MaxEngSpdCal.n_EngLimTab]
0
100 6200
80 6200
60 6200
40 6200
20 6200
Undo changes
2004B207L
Save
Close

Footer information

Tuning the T8

Tuning with T8Suite

CAN BUS INTERFACE

Interfacing with the Trionic T8 unit through the CAN bus is possible.

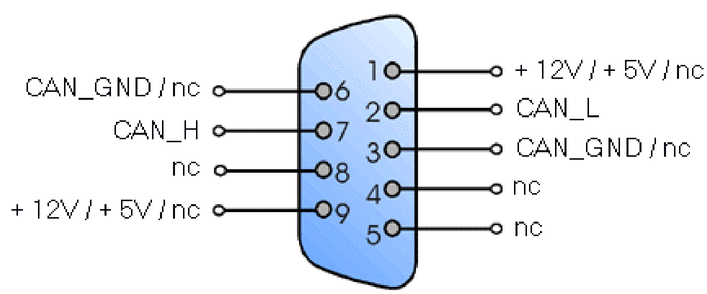
GENERAL INFORMATION

Chip used on Trionic side: Intel AN825257

Communication speed used: 615 kbit/s

The most frequently used interface for this is the lawicel CANUSB interface that can be found on www.canusb.com. This interface can convert CAN signals onto you USB port and vice versa. The interface has a USB port on one side – that connects to you computer – and an male RS232 (DB9) connector on the other side. This side connects to the CAN bus of the Trionic.

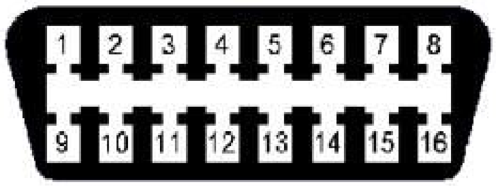
The lawicel interface has the following pinout on the DB9 connector.



CONNECTING TO CAN BUS WITH ECU ON YOUR DESK

OBDII SOCKET PINOUT

The OBDII port enables you to connect to the I bus directly.



Pinnumber	Description
1	
2	J1850 Bus+
3	
4	Chassis Ground
5	Signal Ground
6	**CAN High (J-2284)**
7	ISO 9141-2 K Line
8	
9	
10	J1850 Bus-
11	Airbag Controller (?)
12	ABS Controller (?)
14	**CAN Low (J-2284)**
15	ISO 9141-2 L Line
16	Battery Power

I-Bus There components are hooked up to the I-Bus (instrumentation bus):

SID	Saab Information Display
ACC	Automatic Climate Control
RADIO	Radion control unit
CDC	CD-Changer – in trunk
PSM	Power Seat Memory
STC	Soft Top Control – for carbios
Twice	Theft Warning Integrated Control Electronics
DICE	Dashboard Integrated Control Electronics

PBus These components are hooked up to the P-Bus (powertrain bus)

TC/ABS	Traction Control/ABS – in case of ABS only (without Traction Control) it is connected to MIU
Trionic 8	Motormanagement for petrol engines
VP44-PSG16	Motormanagement for diesel engines
TCM	Transmission Control System – in autmatic geared cars (petrol only)

SAAB P-BUS COMMUNICATION

P-bus on Trionic 8 vehicles is available from the OBDII socket in the car. It communicates with a bitrate of 500kb/s (high speed CAN), 11 bit frames. This bus will allow us to read from and write to the ECU. Currently, downloading flash and SRAM is supported as well as live data.

Downloading of the entire flash contents from the ECU takes about 25 minutes and results in a 1Mbyte binary file that can be opened in T8Suite.

The protocol complies largely with KWP2000.

SEED & KEY ALGORITHM

KWP2000 describes that certain functions in the ECU can be protected by a security algorithm: a seed and key calculation. If we want to gain access to memory read and write functions we need to get secured access to the ECU. For that we need to request a pseudo random number from the ECU, the seed. We have to do some mathematical calculations on this number and send the result back to the ECU, the key. If the seed and key values match, we will have gained security access to the ECU. So far i've found three levels of security access for which i don't yet know which allows for more functions than the others. The numeric level identifiers are 0x01, 0xFB and 0xFD.

To get access to level 0x01 we request a seed and calculate the key with this algorithm:

```
key = LOOKUPTABLE[seed];
key ^= 0x1D27;
```

To get access to level 0xFB we request a seed and calculate the key with this algorithm:

```
key = LOOKUPTABLE[seed];
key ^= 0x1D27;

key ^= 0x8749;
key += 0x06D3;
key ^= 0xCFDF;
```

To get access to level 0xFD we request a seed and calculate the key with this algorithm:

```
key = LOOKUPTABLE[seed];
key ^= 0x1D27;
key /= 3 ;
key ^= 0x8749;
key += 0ACF;
key ^= 0x81BF;
```

In all these functions LOOKUPTABLE is a 65536 integer long array with predefined values. You can find this list in the T8Suite sourcecode which is installed along with the application.

DATA ENCRYPTION

To be able to write to SRAM and FLASH we need to encrypt the data we send to the ECU. This encryption is relatively simple. The encryption is a rotating XOR mechanism:

XOR 0x39
XOR 0x68
XOR 0x77
XOR 0x6D
XOR 0x47
XOR 0x39

So, six XOR values, which are used one after the other. First byte goes XOR 0x39, second byte XOR 0x68 etc...

COMMON MISTAKES AND FAQ

GENERAL

This chapter will describe some frequently made mistakes in handling the Trionic.

IGNITION ADVANCE

When altering the ignition tables keep in mind that more than 35° advance from TDC is not good.

IGNITION RETARD

When altering the ignition tables keep in mind that more than 5° retarding from TDC is not good.

FAQ

Question: At what AFR should I try to keep the engine?

Answer: Try to keep the AFR between 10.8 and 12.5 at WOT.

Question: At what EGT should I try to keep the engine?

Answer: Try to keep the exhaust gas temperature below 950°C.

Question: What is the approximate ignition advance at wide open throttle?

Answer: Try to keep the ignition advance at approximately 10° BTDC

Question: How can I determine what the maximum boost request should be for my turbo?

Answer: Check that the boost request level fits somehow to compressor map:
http://www.squirrelpf.com/turbocalc/index.php

In addition you can read appendix IV.
Question: What is a good intake air temperature?

Answer: Upto 60°C is good enough. If temperatures rise above 60°C consider replacing your stock intercooler with an aluminum, cross-flow type. These are available from speedparts, Abbott, ETS and others.

TOOLS

T8SUITE

T8Suite has the following funtions:

- Checksum verification and correction
- Software ID adjustment
- Immobilizer code adjustment
- Extraction of symbol table
- Map visualisation
- Compare maps in binary to another binary
- Move maps from one binary to another

For usage of this tool please refer to its user manual.

IDA PRO

IDAPro stands for Interactive DisAssembler Professional. It enables the user to disassemble binary files to its original source code. IDAPro is commercial software, not freeware.

Example of how to use IDA Pro with a **Trionic 8** box.

Open binary/raw file
Set processor to Motorola series: 68330
Check the 'Create RAM section', start address 0xF00000, size 0xFFFF.
Go to address ROM:00000000 in 'IDA View-A' and hit D-key three times to get dc.l $FFFFEFFC
Go to the next address ROM:00000004 and hit D-key three times to get reset vector address (this varies from binary to binary)
You should get e.g. dc.l unk_5169A or something like that, double-click the unk_5169A text
Your now in the place where the code executation starts, press C to disassemble
Now, from the menu select Options -> General, go to Analysis tab and press 'Kernel options1' button
Check 'Make final analysis pass' and hit OK
Press 'Reanalyze program' button and wait a while (this really takes some time, a minute or so)

HEX EDITOR

Hexworkshop (or UltraEdit) is a tool that comes in handy often. It can be used to view, search and modify the raw binary file.

REFERENCES

WEBREFERENCES

- ECUproject initiative [www.ecuprojct.com Steve Hayes and friends]
- Xendus [www.xendus.se General Failure]
- SaabCentral [www.saabcentral.com]
- Motorola datasheet on MC68337
- Trionic Wiki pages [http://en.wikipedia.org/wiki/Trionic]
- T8Suite homepage [http://trionic.mobixs.eu]
- Townsendimports [www.townsendimports.com]
- BDM Software [http://www.xendus.se/bdm/bd32-122.zip]
- Ion sensing for knock detection [http://www.fs.isy.liu.se/~larer/Projects/main.html]
- Turbo compressor maps [http://www.automotivearticles.com/Turbo_Selection.shtml]
- Saab9000.com [http://www.saab9000.com]
- JKBPower forum [http://jkbpower.egetforum.se/forum/index.php]

APPENDIX I : SYMBOL LIST

This appendix will give a short description of the most important maps in Trionic 8. To give a list of all symbols would be kind of stupid because there are approximately X (!!!) symbols in a Trionic 8 binary.

Appendix II : Trionic 8 pinout

X pin connector

Pinnumber	Color	Description	Range	In/out
A2		+15 circuit (+12 volt)		
A3		+30 circuit (+12 volt)		
A5		P-bus (+)		
A6		P-bus (-)		
A19		+15 circuit (+12 volt)		
A20		+30 circuit (+12 volt)		
A47		Power ground		
A48		+12 volt from main relay		
A57		Power ground		
A60		Power ground		
A63		Power ground		
A64		+12 volt from main relay		

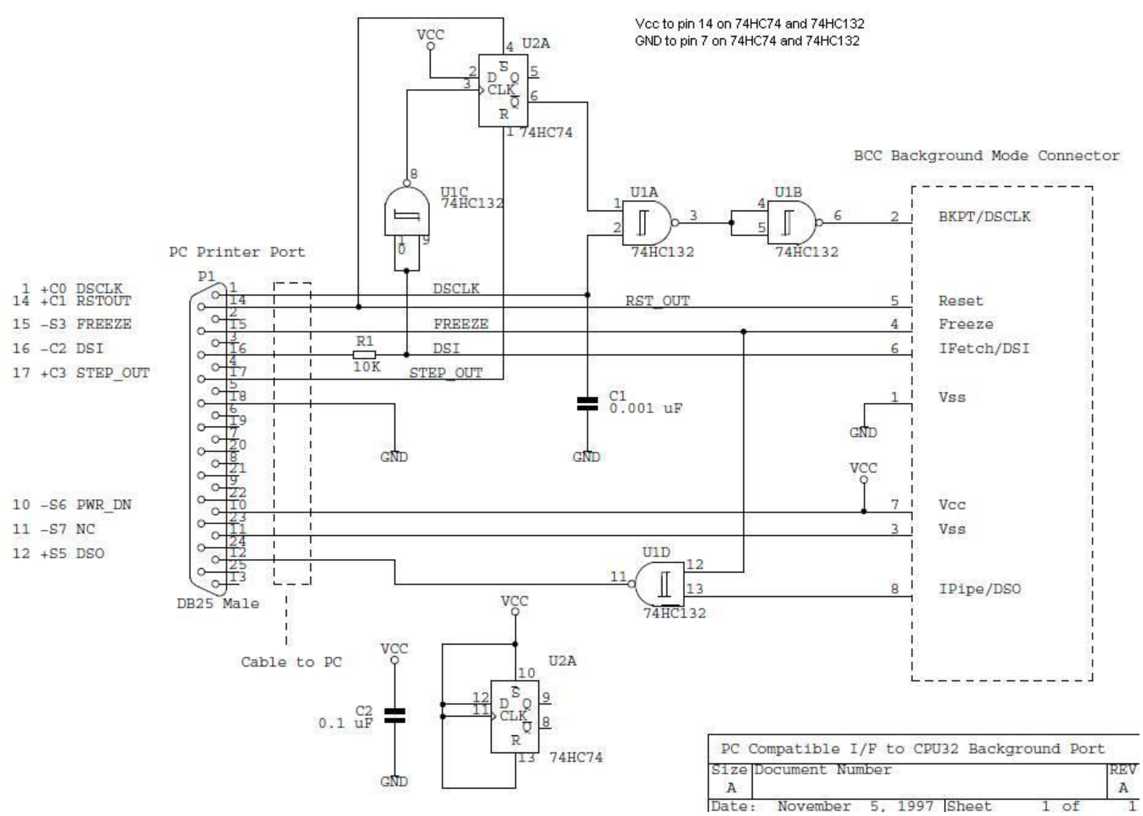
APPENDIX III : BDM TECHNICAL INFORMATION

GENERAL

BDM stands for Background Debug Mode. This refers to the mode the Motorola microcontroller is forced into when activating the BDM interface. This mode enables us to hold the processor in the program exection and read and write data from and to the memory inside the microcontroller and the memory connected to it. In this way we can download and program the flash contents which gives us access to the binaries we like so much! The BDM software you need can be downloaded from http://www.xendus.se/bdm/bd32-122.zip.

HOME BUILD 2 CHIPS DESIGN SCHEMA

An alternative to buying a BDM interface can be building one yourself. This chapter will hand you all information needed to buy the components needed and the schema to build the interface. The image below shows the shema for the 2 chip design. There is also a 5 chip design and a GAL based design but these are more difficult to build at home.



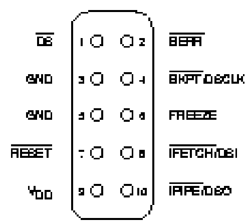
The table below shows the component list that you need to build the interface. Of course a soldering iron, PCB etc. are things that you also need.

Component	Amount	Description
74HC74	1	Dual JK Flip-Flop with Set and Reset
74HC132	1	Quad 2-input NAND Schmitt Trigger
Capacitor 0.1 uF	1	
Capacitor 0.001 uF	1	
Resistor 10 kΩ	1	
LPT cable + connector	1 meter	Smart is to get PCB type with normal LPT cable.
10 wire flatcable	20 cm	
10 pin female header for flatcable	1	

PINOUT

Pinnumber	Pin name	Description	Remark
1	DS	Data strobe from target MCU.Not used in current interface circuitry	
2	BERR	Bus error input to target. Allows development system to force bus error when target MCU accesses invalid memory	
3	VSS	Ground reference from target	
4	BKPT/DSCLK	Breakpoint input to target in normal mode;development serial clock in BDM.Must be held low on rising edge of reset to enable BDM	
5	VSS	Ground reference from target	
6	FREEZE	Freeze signal from target.High level indicates that target is in BDM	
7	RESET	Reset signal to/from target.Must be held low to force hardware reset	

8	IFETCH/DSI	Used to track instruction pipe in normal mode.Serial data input to target MCU in BDM	
9	VCC	+5V supply from target.BDM interface circuit draws power from this supply and also monitors 'target powered/not powered' status	
10	IPIPE/DSO	Tracks instruction pipe in normal mode.Serial data output from target MCU in BDM	



APPENDIX IV : TURBO COMPRESSOR MAPS

Each turbo has its own characteristics. These are determined by the size of the turbine housing, the size of the compressor wheel, the size of the turbine blades and many more parameters.

The most important identification of a turbocharger is by its compressor map. This is a graphical representation of its efficiency. In SAAB Trionic 5 cars there are 2 commonly used turbo chargers: the Garrett T25 for B204E, B204S, B204L, B234E and B234L engines and the Mistubishi TD04-HL-15G/T (6cm2) for the B234R engines.

http://www.automotivearticles.com/Turbo_Selection.shtml

Terms to know:

- Compressor and turbine wheels. The turbine wheel is the vaned wheel that is in the exhaust gases from the engine. It is propelled by the exhaust gases themselves. The turbine wheel is connected to the compressor wheel by an axle. So, the compressor wheel will spin together with the turbine wheel. The compressor wheel also is vaned and these vanes compress the air and force it into the intercooler.
- Wheel "trim". Trim is an area ratio used to describe both turbine and compressor wheels. Trim is calculated using the inducer and exducer diameters. As trim is increased, the wheel can support more air/gas flow.
- Compressor and turbine housing A/R. A/R describes a geometric property of all compressor and turbine housings. Increasing compressor A/R optimizes the performance for low boost applications. Changing turbine A/R has many effects. By going to a larger turbine A/R, the turbo comes up on boost at a higher engine speed, the flow capacity of the turbine is increased and less flow is wastegated, there is less engine backpressure, and engine volumetric efficiency is increased resulting in more overall power.
- Clipping. When an angle is machined on the turbine wheel exducer (outlet side), the wheel is said to be 'clipped'. Clipping causes a minor increase in the wheel's flow capability, however, it dramatically lowers the turbo efficiency. This reduction causes the turbo to come up on boost at a later engine speed (increased turbo lag). High performance applications should never use a clipped turbine wheel. All Garrett GT turbos use modern unclipped wheels.
- CFM = Cubit feet per minute.
- Lbs/minute = pounds (weight) per minute.
- M3/s = cubic meters per second.
- Corrected Airflow. Represents the corrected mass flow rate of air, taking into account air density (ambient temperature and pressure)
  Example:

Air Temperature (Air Temp) - 60°F
Barometric Pressure (Baro) - 14.7 psi
Engine air consumption (Actual Flow) = 50 lb/min

$$\text{Corrected Flow} = \frac{\text{Actual Flow}\ \sqrt{([\text{Air Temp}+460]/545)}}{\text{Baro}/13.95}$$

$$\text{Corrected Flow} = \frac{50*\sqrt{([60+460]/545)}}{14.7/13.95} = 46.3\ \text{lb/min}$$

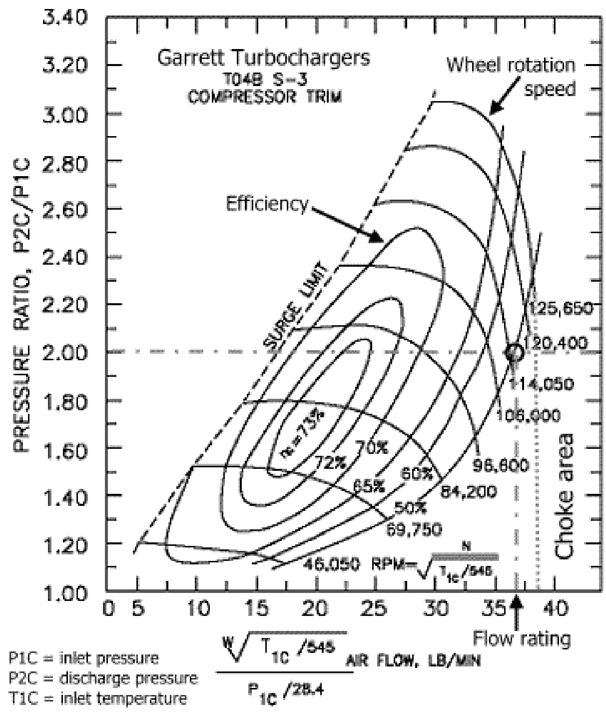
- Pressure Ratio
  Ratio of absolute outlet pressure divided by absolute inlet pressure
  Example:
  Intake manifold pressure (Boost) = 12 psi
  Pressure drop, intercooler ($\Delta P_{Intercooler}$) = 2 psi
  Pressure drop, air filter ($\Delta P_{Air\ Filter}$) = 0.5 psi
  Atmosphere (Atmos) = 14.7 psi at sea level

$$PR = \frac{\text{Boost} + \Delta P_{Intercooler} + \text{Atmos}}{\text{Atmos} - \Delta P_{Air\ Filter}}$$

$$PR = \frac{12+2+14.7}{14.7-.5} = 2.02$$

HOW TO READ COMPRESSOR MAPS

A 2-dimensional pressure map looks like this.



Turbo compressor map

The **curved lines** indicate the rotation speed (rpm) of the compressor wheel. In the sample map above these values are 45050, 69750, 84200 up to 125650 rpm. This is how fast a turbine wheel spins!!

The **elliptical circle** means the compressor's efficiency area. It's marked by the percent sign.

The **horizontal axis** is the amount of air before turbo, (1 m3/s = 2118.88 cfm, 10 lb/min = 144.718 cfm).

The **vertical axis** is the pressure ratio, the ratio of air pressure leaving to the turbo to air pressure entering the turbo.

Pressure Ratio=The pressure at compressor exducer vs the pressure at compressor inducer.

In another word, the ratio of the pressure of the air after compression vs the pressure before compression. As you can see, the pressure ratio depends on the ambient pressure. For example, at sea level, a turbo boosts 14.7psi. Ambien pressure is 14.7psi. That's 2 pressure ratio (PR) on the compressor map. Take that turbo to a higher elevation, the ambient pressure is less than 14.7psi. If the turbo still boosts 14.7psi, the pressure ratio would be higher. Now on the compressor map, you will see by moving up along a vertical line (to pump out the same cfm) and turbo efficiency has decreased as the elevation increases (PR increases). Simply put, turbos lose performance and become less efficient as elevation gets higher.

CHOKE AREA

The area to the right of the outer most elliptical circle is the least efficient area, the **choke area**. It means when the compressor reaches certain rpm, the air moved by the compressor wheel in the diffuser area of the compressor housing is moving at or past the speed of sound. When the air speed reach sounic speed, the amount of air flow increase is very small as compressor wheel rpm increases. In plain words, the compressor has reached its limit. You can try to pump more psi, have the wheel spin faster, but very little more air is pumped out the turbo compressor. You can see now, the compressor housing will need to properly match the compressor wheel. If you simply stuff a big wheel inside a small compressor housing, the diffuse area will be very small. This causes the air inside the housing to move at higher speed. That's why some of the so-called T28s which use a bigger compressor wheel inside the stock compressor housing does not produce good hp.

COMPRESSOR MAXIMUM FLOW

The max flow of a compressor is shown on the compressor map. On the map, look for the intersection of maximum compressor wheel speed (rpm) and the least compressor efficiency curve. Find that intersection. The horizontal coordinate is the max flow.
The area to the right of maximum flow is the 'choke area'.
The vertical coordinate is the pressure ratio at which the compressor reaches that maximum flow. From this boost level, as the boost increases, very little air flow is increased. For example, if a compressor reaches its maximum flow at 2 PR or 1 atm pressure or 14.7psi, higher boost does not pump more air into the motor. But higher boost may be needed to increase the manifold pressure for the motor to flow more air. A 5 liter motor with this turbo needs 15psi of manifold pressure to flow a certain CFM. A 3 liter motor with the same turbo will need much higher manifold pressure to flow the same amount of air although that turbo's compressor does not flow more air past 14.7psi.

COMPRESSOR MAXIMUM PRESSURE

On the map, find the top-most point on the graph. The vertical coordinate is the max pressure ratio. For example, 2.8 pressure ratio at sea level is 1.8 times the atmospheric pressure, 1.8x14.7psi=26.46 psi. Compressor max pressure is limited by compressor wheel speed. It's physically impossible to boost higher than this maximum pressure for one particular turbo. Plus the pressure drop in the intercooler system, the actual maximum boost reading from a boost gauge that's plugged into the intake manifolds maybe a few psi lower than this maximum pressure.

WHAT THE COMPRESSOR MAP READS

Most manufactures rate their turbos at 1 bar (15 psi). That's 2 pressure ratio. On the map, draw a horizontal line from 2PR. When the line intersects the right-most elliptical circle, the corresponding number on the x-axis is the maximum cfm the turbo can flow at 1 bar.
Use the TD04-15G's map for example, where the 2 PR line hits the right-most efficiency curve, it reads 428cfm as its flow rate at 15psi.

COMPARING COMPRESSOR MAPS

Well, compressor maps are really 3-dimensional maps. Any compressor map looks a hill/peak in 3 dimensions. Our compressor maps look like if you look at the hill directly from above vertically.The eclliptical lines of elevations are the efficiency curves. Since in theory, we can always boost more and decrease turbo efficiency to get more cfm, lets set the same Pressure Ratio and compare turbos at the same efficiency curves.

As a rule of thumb, a large turbo will be better at making a lot of pressure but will spool slower than a small turbo. A small turbo will build boost fast but is less capable to make big boost pressure.

Understanding information within the compressor map

1. The oblong ovals on the chart or "islands" as they are called represent the efficiency of the turbo in that range. As you can see on this map, the most efficient operation (73%) is in the very center of the chart. This is general characteristic of most turbochargers. Without getting into the thermodynamics of adiabatic heat-pumps, we'll just say that efficiency is a measure of how much excess heat the turbo puts into the compressed air coming out of the outlet. So intuitively, more efficient is better.

2. Wheel rotational speed is simply the rpm at which the compressor wheel is spinning.

3. The choke point, which is usually not indicated on flow maps, is the maximum flow rating the turbo is capable of regardless of pressure or efficiency.

4. Beyond the surge limit on the left of the plot, compressor surge occurs. In laymen's terms, this phenomenon is caused by a back pressure wave entering the exit of the compressor housing and disrupting flow through the compressor wheel. Surge will kill turbos and is to be avoided at all costs.

Surge Limit

To the left of the surge limit line on the flow map is the *surge area* where compressor operation can be unstable. Typically, surge occurs after the throttle plate is closed while the turbocharger is spinning rapidly and the by-pass valve does not release the sudden increase in pressure due to the backed-up air. During surge, the back-pressure build-up at the discharge opening of the compressor reduces the air flow. If the air flow falls below a certain point, the compressor wheel (the impeller) will loose its "grip" on the air. Consequently, the air in the compressor stops being propelled forward by the impeller and is simply spinning around with the wheel, which is still being rotated by the exhaust gas passing through the turbine section. When this happens, the pressure build-up at the discharge opening forces air back through the impeller causing a reversal of air flow through the compressor. As the back pressure eventually decreases, the impeller again begins to function properly and air flows out of the compressor in the correct direction. This sudden air-flow reversal in the compressor can occur several times and may be heard as a repetitive "Whew Whew whew" noise if the surge is mild (such as when the by-pass valve is set a little too tight) to a loud banging noise when surge is severe. Surge should be prevented at all costs because it not only slows the turbocharger wheels so that they must be spooled back up again but because it can be very damaging to the bushings or bearings and seals in the center section.

SELECTING A DIFFERENT TURBO CHARGER

CALCULATING YOUR ENGINE'S FLOW REQUIREMENTS

Now that you can read and understand a compressor flow map, its time to figure out how to match a turbo to your engine, this involves selecting the proper compressor and turbine wheels along with the right combination of housing A/R. A mismatched turbo could not only result is extreme lag, but also wasted potential as a turbo can easily outflow an engine. I.e. bigger is not always better.

The only real calculation that needs to be done is to determine how much air you engine is actually flowing. This depends on a number of things including the RPM, absolute temperature (Rankin, equal to 460 + Fahrenheit temp), absolute manifold pressure (psi, equal to boost pressure plus atmospheric pressure), and lastly the engine volumetric flow or EVF in cfm.

First to calculate EVF use the following equation:

$$EVF = \left(\frac{engineCID}{1728}\right) * \left(\frac{RPM}{2}\right)$$

engineCID = Engine displacement in cubic inches.

Next we'll use EVF to calculate the amount of air in lb/min the engine is flowing under boost and at temperature using this equation:

$$N = \frac{P * EVF * 29}{10.73 * T}$$

Where N is the airflow in lb/min, P is the absolute pressure in psi, and T is the absolute ambient temperature in Rankin.

Finally, multiply N by the volumetric efficiency of your engine (VE). This compensates for the fact that upon every cycle of the engine, not all of the old air/fuel mix in the cylinders is forced out the exhaust. Thus there is a difference between the actual airflow through and engine and the predicted airflow. This discrepancy is equated to a VE. There is literally thousands of hours worth of online reading about volumetric efficiencies for just about every production engine. To get the most accurate results from this step I would suggest researching your engine and coming up with the most realistic VE possible as this does have a significant affect on engine flow. If you are just messing around with compressor flow maps and need a value for VE just to experiment with, 85% efficiency is a nice conservative number for most modified turbocharged cars at high rpm (6500-7500). Keep in mind though that on a forced induction setup VE can easily exceed 100% so again it will be very beneficial to research ***your*** engine.

For our SAAB engines these number apply.

EVF / RPM	2.0L engine (122 cubic inch)	2.3L engine (140 cubic inch)
1000 rpm	35.3	40.6
2000 rpm	70.6	81.2
3000 rpm	105.9	121.8
4000 rpm	141.3	162.4
5000 rpm	176.6	203.1
6000 rpm	211.9	243.7
7000 rpm	247.2	284.3

Since the amount of air to be flowed by the turbo is largest when RPM is at its top we will take the worst case scenario and get EVF @ 7000 RPM. We have to make an assumption on the abient temperature which we will set at 20°C. This is 68° Fahrenheit which is (460 + 68) = 528 Rankin.

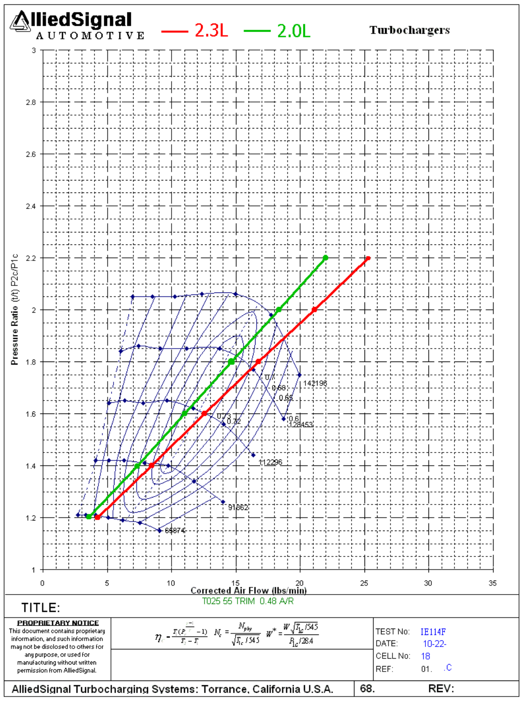
Now we can calculate the airflow of the engine in lb/min for any given boostlevel.

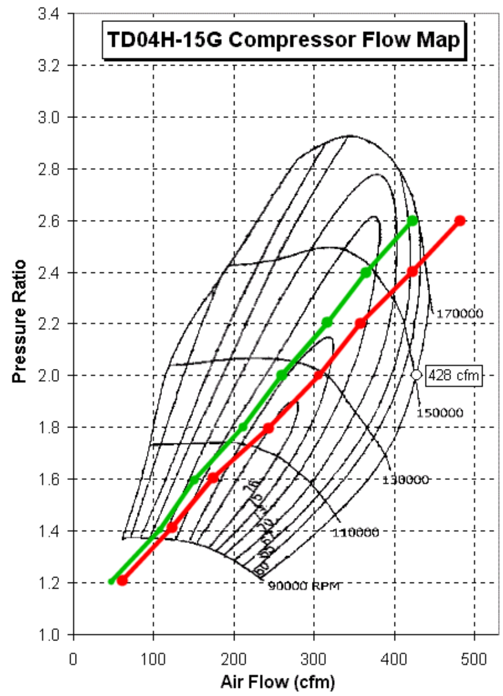
If we want to draw a line into the compressor map for our engines needs we need to calculate the needed airflow for several boost levels.

Airflow / boostpressure	2.0L lb/min	2.0L cfm	2.3L lb/min	2.3L cfm
0.2 bar (2.9 psi)	3.7	53.1	4.2	61
0.4 bar (5.8 psi)	7.3	106.1	8.4	122
0.6 bar (8.7 psi)	11	159.2	12.6	183
0.8 bar (11.6 psi)	14.7	212.2	16.9	244
1.0 bar (14.5 psi)	18.3	265.3	21.1	305

1.2 bar (17.4 psi)	22	318.3	25.3	366
1.4 bar (20.3 psi)	25.7	371.4	29.5	427
1.6 bar (23.2 psi)	29.3	424.4	33.8	488

This all results in 2 simple lines in the compressor map which indicate the maximum flow required from the turbo by our engine.





Now we can clearly see where out engine leaves the compressor map and thus the limit for the combination of the two (engine and turbo) lies.

We also see that – even for the 2.3 liter engine – the TD04 can sustain a much higher boost pressure at higher rpms than the T25 can. Even at 1.4 bar boost (pressure ratio = 2.4) the TD04 is within its limits and would flow approximately 420 cfm. Would we have done the same with the T25 turbo we would most certainly be in the choke area and the turbo would be unable to get us the airflow that we required.

Determining the Best Wheel Trim-Housing A/R Combination

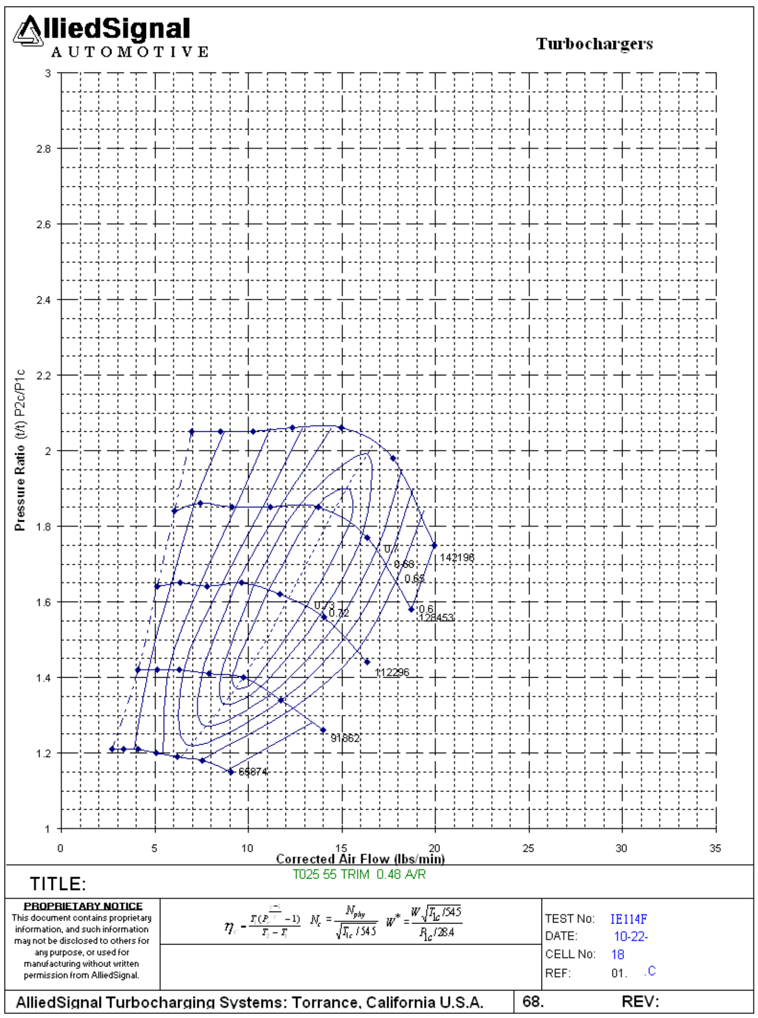
With the flow rate you have just calculated, you can look at compressor maps of different turbo chargers to see which ones give you the air flow you need at the pressures and efficiencies that you want to run.

When selecting a turbo, it is important to do the above calculations for a number of different RPM's and boost pressures because you will not always be at redline under full boost while driving you car. Checking the turbo performance at various engine speeds and pressures will give the overall picture of how well the turbo is sized to your vehicle.

Matching a flow map to your engine flow requirements will allow you to pick the compressor wheel trim for your application. However before you can go out and purchase that new turbo, you still have to settle on an exhaust wheel and turbine A/R. The real determining factor in this selection is maintaining compressor wheel speed. Remember the wheel RPM lines on the flow map? Well a properly sized exhaust wheel/housing combination will keep the compressor wheel operating within the maximum and minimum wheel speeds on the map as often as possible. Since different "hot side" combinations can affect your turbo's performance, (i.e. a little more lag in return for more top end, or quicker spool up at the cost of overall power) the best thing to do is to contact a turbo manufacturer or distributor (www.extremeturbo.com, www.forcedpeformance.com, www.turbochargers.com) and they will be able to tell you the exact effects you can expect from all of the various hot side combos available for your turbo model.

GARRETT T25 SPECIFICATIONS

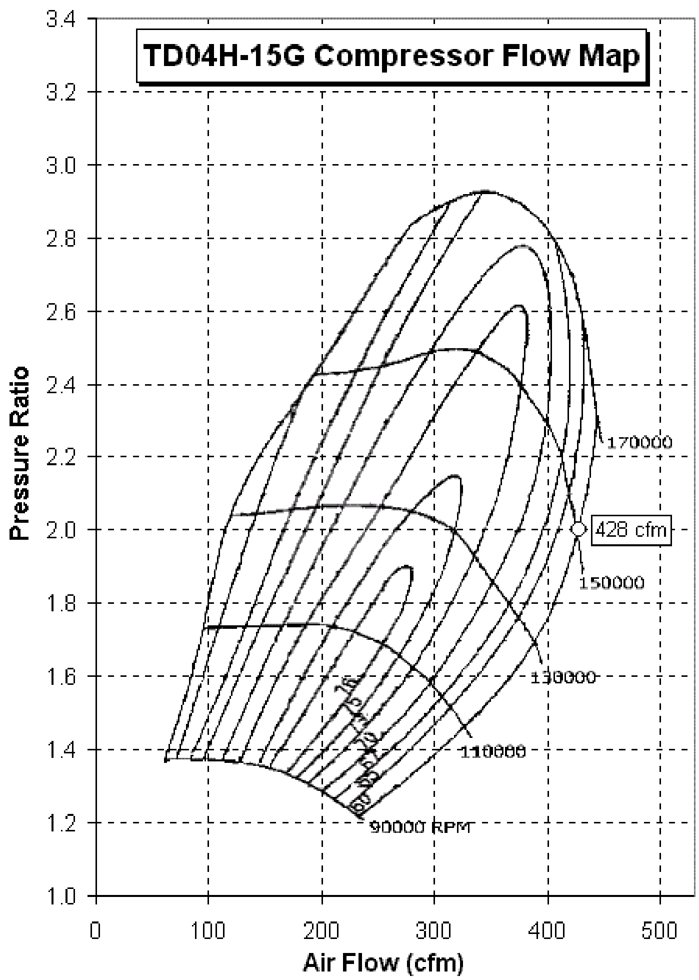
Weight: 7,5kg
Compressor diameter: 60mm
Turbine diameter: 65mm and 59mm
Bearing span: 37,8mm
Moment of inertia: 5,4x10-5 kg/m2
Oil flow: 1,7L/min / SAE30 / 90C / 2,75bar
Compressor wheel: 54mm 55 trim, A/R 48
Turbine wheel: 53.8mm 61 trim, A/R 49



As you can see the T25 (trim 55) can flow 18 lbs of air per minute @ pressure ratio = 2 and efficiency will be ~65%. This 18 lbs/minute converts to about 260 cfm. The maximum efficiency zone (73%) reaches upto pressure ratio 1.9. This would be ~0.9 bar overpressure.

In terms of usage the T25 can take us upto ~1.1 bar boost pressure and bring upto 250 bhp.

MITISUBISHI TD04-15G SPECIFICATIONS

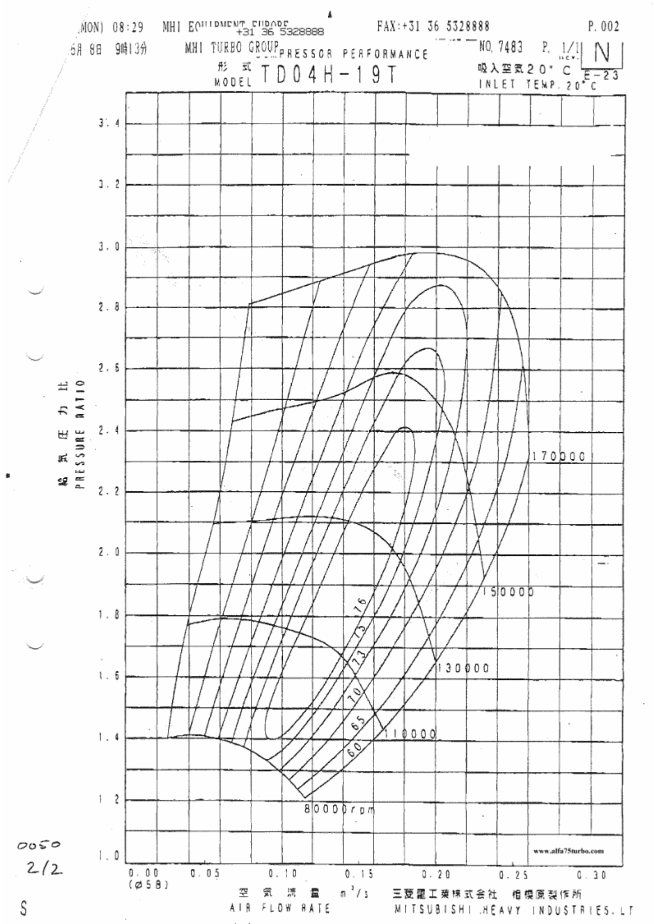


The TD04-15G from the 9000 Aero can flow more air than the "little" T25. Looking at the map we can see that the TD04-15G can flow ~428 cfm @ pressure ratio 2 and efficiency of 60%.

Also, the maximum efficiency zone (76% vs 73% for the T25) reaches upto 1.9 pressure ratio with would be ~0.9 bar.

In terms of usage the TD04 can take us upto ~1.4 bar boost pressure. The TD04 can bring upto ~330bhp.

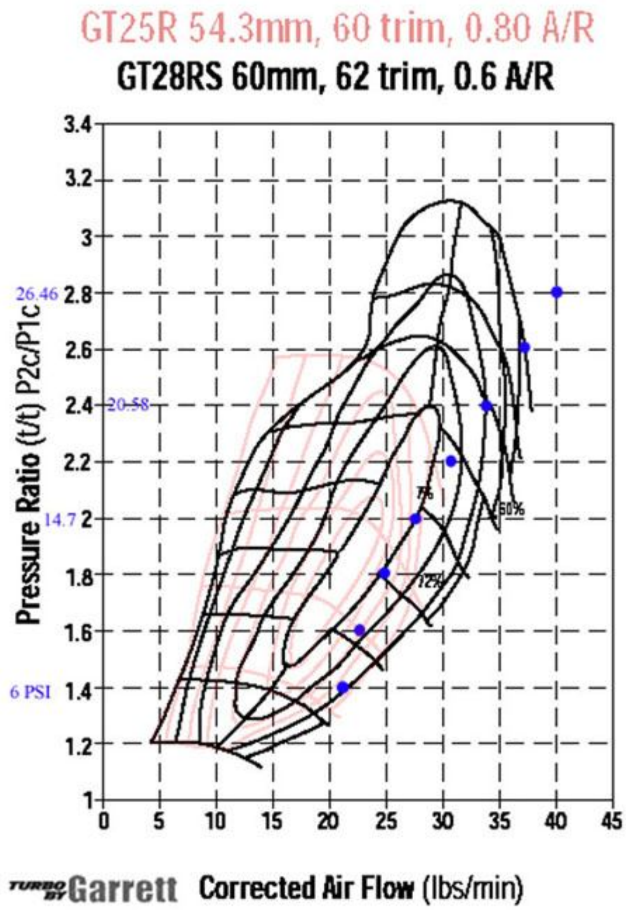
MITSUBISHI TD04-19T SPECIFICATIONS



This TD04-19T compressor map has the air flow axis noted in m3/s. 1 m3 per second means 2118 cfm. So this turbo can flow approximately 0.26 m3/s = 550 cfm @ pressure ratio 2.3.

At the standard ratio of 2 it still flows 510 cfm which is more than a GT28RS. The TD04-19T can bring upto ~380 bhp.

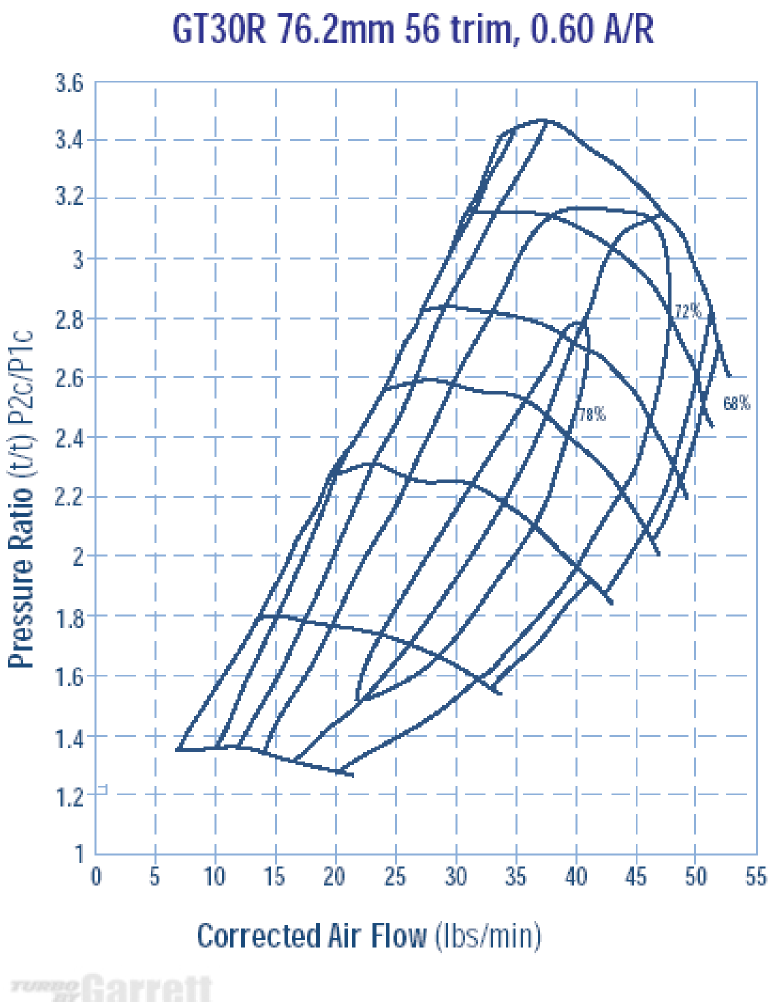
GARRETT GT28RS (GT2860R) SPECIFICATIONS



The GT28RS is frequently used in modified cars. It can flow much more air than the TD04 and the T25. If we look at the compressor map for the GT28RS (black lines) we see that this turbo is capable of flowing ~33 lbs/minute which is ~477 cfm at pressure ratio 2. The maximum efficiency runs much higher than that. Upto 1.4 bar boost pressure this turbo will run at 75% efficiency.

In terms of usage the GT28RS can run nicely upto 1.6 bar at an air flowrate of ~37 lbs/min = 535 cfm. This is much more than the TD04-15G of course. The GT28RS can bring upto ~350 bhp.

GARRETT GT30R SPECIFICATIONS



The GT30R (GT3071) is given for reference reasons only. It can flow even more air than the GT28RS. If we look at the compressor map we see that this turbo is capable of flowing ~45 lbs/minute which is ~650 cfm at pressure ratio 2. The maximum efficiency runs upto 1.8 bar boost pressure. In terms of usage the GT30R can run nicely upto 1.8 bar at an air flowrate of ~52 lbs/min = 750 cfm. Even within the maximum efficiency zone this turbo will flow 40 lbs/minute which is more than the GT28RS will flow even at maximum.

The GT30R can bring upto ~500 bhp.

CONCLUSION

Comparing the two compressor maps for TD04 and T25 we can clearly see that the TD04 can flow more air at a higher pressure ratio and with a higher efficiency. Given the fact that the turbine blades are larger than in the T25, spoolup will be a bit slower, but high end power will be much better.

Upgrading your turbo will affect more than meets the eye. The VE map in the Trionic would probably need adjustments because the hardware in the airflow has been changed. This means the volumetric efficiency also changes and thus the correction table needs changing too.

Also, when boost values rise, the intercoolers capacity for air flow comes into play. You must make sure that the intercooler is not so restrictive that upgrading the turbo will result in a burst intercooler. A high capacity cross flow intercooler would be a good option here.

And last but not least, upgrading the turbo charger means – that is the goal here – more air flow to the cylinders and thus more oxygen to burn. If we upgrade the turbo we need to consider the injectors too. If the injectors can't flow the amount of fuel needed to burn the amount of oxygen pushed into the cylinders we would have gained nothing.

APPENDIX V: UPGRADE STAGES 1-7

If you want to go beyond the standard stages I – III there's more to alter than just the "silly" stuff like ECU, exhaust and catalyst. This chapter will describe what steps are needed for stages 1 upto 7.

STAGE I

The target amount of power for stage I is about 235 bhp for FPT versions (T25 turbo) and 260 bhp for Aero models (TD04-15 turbo)

Component	Stock	Stage I minimum requirement
ECU	200/225 bhp	Stage I
Exhaust	2"	2"
Intake	---	---
Catalyst	---	---
Injectors	345 cc/min	345 cc/min
Fuel lines	---	---
Turbo	T25/TD04-15	T25/TD04-15
Exhaust manifold	---	---
Intercooler	---	---
Clutch	450 Nm	450 Nm
Camshafts	---	---
Fuel pump	---	---
Wastegate	---	---
Mapsensor	2.5 bar	2.5 bar
Air delivery pipe	---	---
Cylinder head	---	---

STAGE II

The target amount of power for stage II is about 250 bhp for T25 models and 270 bhp for TD04 models.

Component	Stock	Stage II minimum requirement
ECU	200/225 bhp	Stage II
Exhaust	2"	3" cat-back
Intake	---	---
Catalyst	---	---
Injectors	345 cc/min	345 cc/min
Fuel lines	---	---
Turbo	T25/TD04-15	T25/TD04-15
Exhaust manifold	---	---
Intercooler	---	---
Clutch	450 Nm	450 Nm
Camshafts	---	---
Fuel pump	---	---
Wastegate	---	---
Mapsensor	2.5 bar	2.5 bar
Air delivery pipe	---	---
Cylinder head	---	---

Stage III

The target amount of power for stage III is about 270 bhp for T25 models and 280 bhp for TD-04 models.

Component	Stock	Stage III minimum requirement
ECU	200/225 bhp	Stage III
Exhaust	2”	3” turbo back
Intake	---	Open/sport air filter
Catalyst	---	Sport (3”) catalyst
Injectors	345 cc/min	345 cc/min
Fuel lines	---	---
Turbo	T25/TD04-15	T25/TD04-15
Exhaust manifold	---	---
Intercooler	---	---
Clutch	450 Nm	450 Nm
Camshafts	---	---
Fuel pump	---	---
Wastegate	---	---
Mapsensor	2.5 bar	2.5 bar
Air delivery pipe	---	---
Cylinder head	---	---

STAGE IV

The target amount of power for stage IV is about 300 bhp. From stage 4 there's no longer a difference between FPT and Aero models because the T25 turbo cannot reach a stage IV level and has to be replaced from this stage on.

Component	Stock	Stage IV minimum requirement
ECU	200/225 bhp	Stage IV
Exhaust	2"	3" turbo back
Intake	---	Open/sport air filter
Catalyst	---	Sport (3") catalyst
Injectors	345 cc/min	413 cc/min
Fuel lines	---	---
Turbo	T25/TD04-15	TD04-15
Exhaust manifold	---	---
Intercooler	---	---
Clutch	450 Nm	Sports clutch (600 Nm)
Camshafts	---	---
Fuel pump	---	---
Wastegate	---	Reinforced model (Forge)
Mapsensor	2.5 bar	3 bar
Air delivery pipe	---	---
Cylinder head	---	---

STAGE V

The target amount of power for stage V is about 350 bhp

Component	Stock	Stage V minimum requirement
ECU	200/225 bhp	Stage V
Exhaust	2"	3" turbo back
Intake	---	Open/sport air filter
Catalyst	---	Sport (3") catalyst
Injectors	345 cc/min	413 cc/min
Fuel lines	---	---
Turbo	T25/TD04	TD04-18T/19T
Exhaust manifold	---	---
Intercooler	---	Cross flow, high capacity
Clutch	450 Nm	Sports clutch (600 Nm)
Camshafts	---	---
Fuel pump	---	---
Wastegate	---	Reinforced model (Forge)
Mapsensor	2.5 bar	3 bar
Air delivery pipe	---	---
Cylinder head	---	---

Stage VI

The target amount of power for stage VI is about 400 bhp

Component	Stock	Stage VI minimum requirement
ECU	200/225 bhp	Stage VI
Exhaust	2”	3” turbo back
Intake	---	Open/sport air filter
Catalyst	---	Sport (3”) catalyst
Injectors	345 cc/min	630 cc/min
Fuel lines	---	---
Turbo	T25/TD04	Garrett GTBB30
Exhaust manifold	---	---
Intercooler	---	Cross flow, high capacity
Clutch	450 Nm	Sports clutch (600 Nm)
Camshafts	---	Upgraded model for better engine breathing
Fuel pump	---	Walbro 255 or Bosch 044
Wastegate	---	Reinforced model (Forge)
Mapsensor	2.5 bar	3 bar
Air delivery pipe	---	---
Cylinder head	---	---

STAGE VII

The target amount of power for stage VII is about 500 bhp

Component	Stock	Stage VII minimum requirement
ECU	200/225 bhp	Stage VII
Exhaust	2"	3" turbo back
Intake	---	Open/sport air filter
Catalyst	---	Sport (3") catalyst
Injectors	345 cc/min	750 cc/min
Fuel lines	---	Upgraded piping and rail
Turbo	T25/TD04	Garrett GT30R
Exhaust manifold	---	Tubular model with all mandrels of same length
Intercooler	---	Cross flow, high capacity
Clutch	450 Nm	Sports clutch (700 Nm)
Camshafts	---	Upgraded model for better engine breathing
Fuel pump	---	Walbro 255 or Bosch 044
Wastegate	---	Reinforced model (Forge)
Mapsensor	2.5 bar	3 bar
Air delivery pipe	---	Upgraded model (Abbott)
Cylinder head	---	Custom ported

APPENDIX VI: CHECK ENGINE LIGHT (CEL)

APPENDIX VII: KNOCK AND MISFIRE DETECTION

Trionic detects knocking and misfires by means of the ionization current that flows between the spark plug gaps. This appendix will explain how this works.

http://www.fs.isy.liu.se/~larer/Projects/main.html

IONIZATION CURRENT GENERATION

In an ideal combustion reaction, hydrocarbon molecules react with oxygen and generate only carbon dioxide and water, e.g. isooctane gives

$$C_8H_{18} + \frac{25}{2}O_2 \longrightarrow 8CO_2 + 9H_2O.$$

In the combustion there are also other reactions present, that include ions, which go through several steps before they are completed.

$$\begin{aligned} CH - O &\longrightarrow CHO^+ + e^- \\ CHO^+ + H_2O &\longrightarrow H_3O^+ + CO \\ \\ CH + C_2H_2 &\longrightarrow C_3H_3^+ + e^-. \end{aligned}$$

These ions, and several others, are generated by the chemical reactions in the flame front. Additional ions are created when the temperature increases as the pressure rises.

The processes creating the ionization current are complex and are also varying from engine cycle to engine cycle. *Image 25* shows ten (10) consecutive cycles of the cylinder pressure and the ionization current operating at constant speed and load.

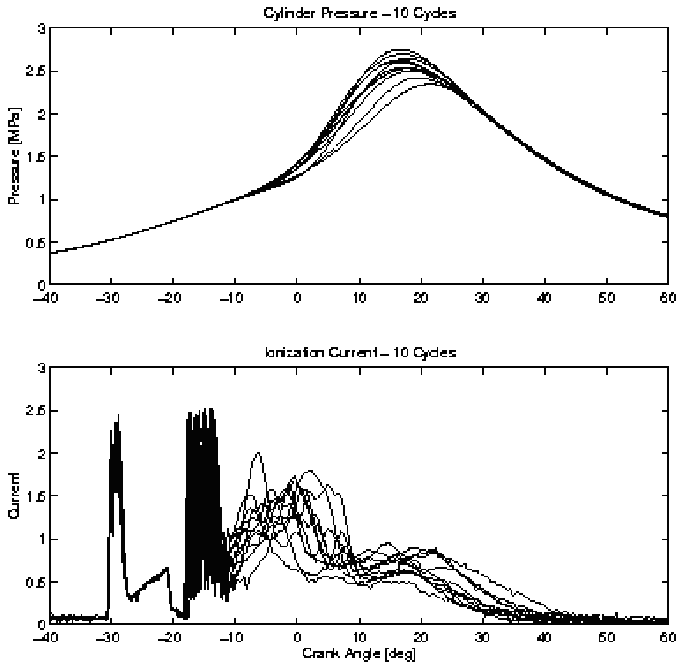


IMAGE 2: CYCLE TO CYCLE VARIATIONS IN THE COMBUSTION

As can be seen, the cycle-by-cycle variations are significant, which is a given problem in interpreting these signals.

IONIZATION CURRENT SENSING

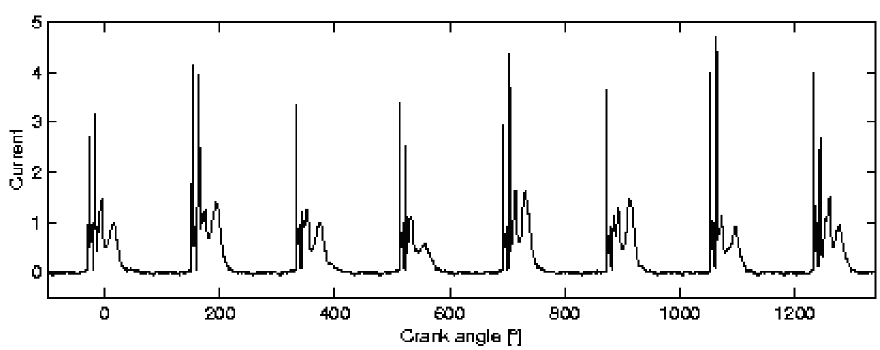


IMAGE 3: IONIZATION CURRENT IN ONE CYLINDER

Knock is a pressure oscillation in the cylinder with a frequency determined by the geometry of the combustion chamber. The oscillation is present in the current measurement and can be extracted mainly by using a band pass filter in a well chosen time window of the current signal. Knocking can destroy the engine. When there is a misfire, then there are no resulting ions and hence no current which is easily detected. Misfires can and will destroy the catalyst.

Ionization current interpretation can be used for both purposes, knock detection and misfire detection.

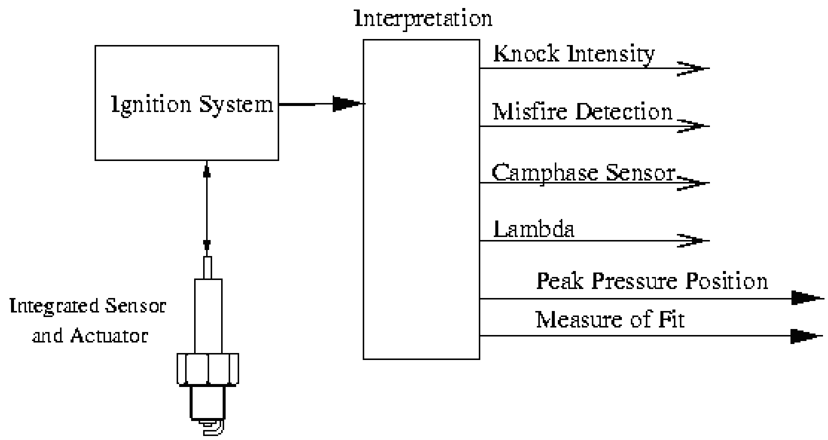


IMAGE 4: POSSIBLE SENSOR INFORMATION FROM IONIZATION CURRENT

Detection

To detect the ions, a DC bias is applied to the spark plug, generating an electrical field. The electrical field makes the ions move and generates an ion current. A schematic illustration is shown in *Image 28 (a)*. The current is measured at the low-voltage side of the ignition coil, and does not require protection from the high-voltage pulses in the ignition, *Image 28 (b)*.

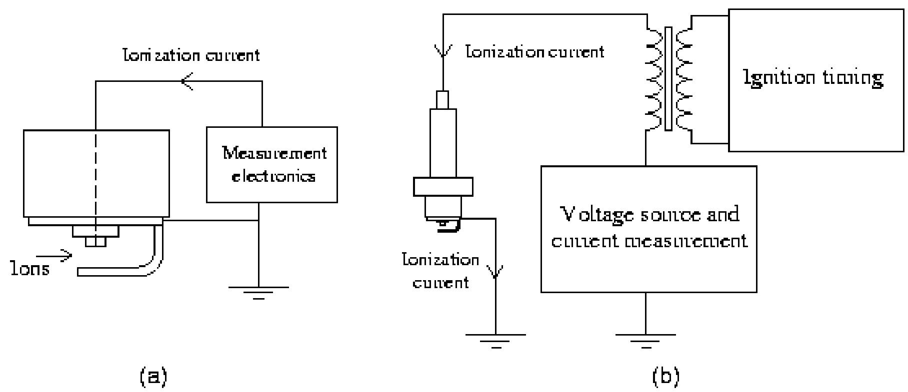


IMAGE 5: MEASURING THE IONIZATION CURRENT

Measurement of the ionization current. (a) The spark plug-gap is used as a probe. (b) Measurement on the low voltage side of the ignition coil.

The ionization current is an interesting engine parameter to study. It is a direct measure of the combustion result that contains a lot of information about the combustion, and several challenges remain in the interpretation of it. Some of the parameters that affect the ionization current are: temperature, air/fuel ratio, time since combustion, exhaust gas recycling (EGR), fuel composition, engine load, and several others.

Ionization Current Terminology

The ionization current typically has three phases: a phase related to ignition, a phase related to ions from the flame development and propagation, and a phase related to pressure and temperature development. In *Image 29*, the three phases of the ionization current are displayed. Each of these phases has varying characteristics and they also mix together in complicated ways. In the ignition phase, the ionization current is large, with reversed polarity. Due to the high current in the ignition the measured signal shown in the figure is limited. What can be seen in the image too is the ringing phenomenon in the coil after the ignition.

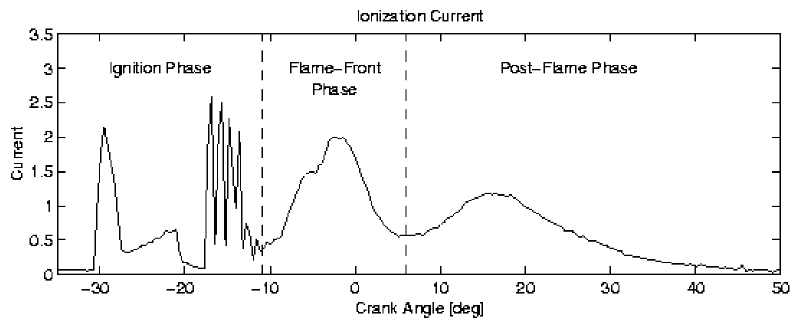


IMAGE 6: IONIZATION CURRENT PHASES: IGNITION, FLAME FRONT, AND POST FLAME

In the flame-front phase, the high level of ions associated with the chemical reactions in the flame produces one or more characteristic peaks. The ions generated by the flame have different recombination rates. Some ions recombine very quickly to more-stable molecules, while others have longer residual times. The result is a high peak which after some time decays as the ions recombine.

In the post-flame phase the most stable ions remain, generating a signal that follows the cylinder pressure due to its effect on the temperature and molecule concentration. Ions are created by the combination of the measurement voltage and the high temperature of the burned gases, since the temperature follows the pressure during the compression and expansion of the burned gases, when the flame propagates outwards and the combustion completes. The ionization current thus depends on the pressure.

Spark Advance and Cylinder Pressure

The spark advance is used to position pressure development in the cylinder such that the combustion produces maximum work. Under normal driving conditions the mixture is ignited around 15 – 30° in crank angle before the piston has reached top dead center (TDC), and the pressure peak comes around 20 degrees after TDC. In the graph below three different pressure traces, resulting from three different spark timings, are shown. Earlier spark advance normally gives higher maximum pressures and maximum temperatures that appear at earlier crank angles.

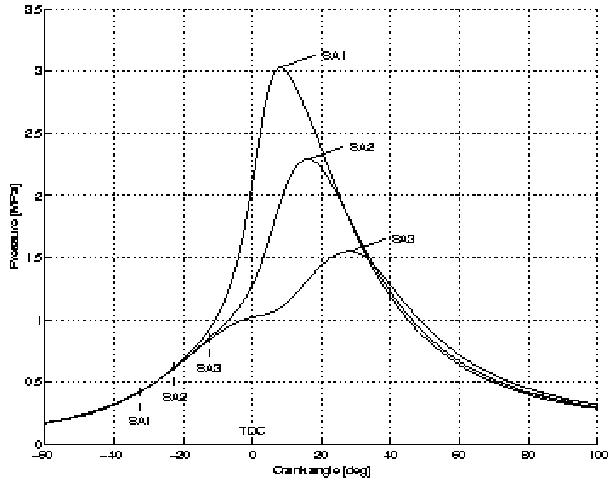


IMAGE 7: CYLINDER PRESSURE VS. IGNITION TIMING

Three different pressure traces resulting from three different spark advances. The different spark advances are; **SA1**: spark advance 32.5° before top dead center (TDC), **SA2**: 22.5° before TDC, **SA3**: 12.5° before TDC. The optimal spark advance is close to **SA2**.

The optimal spark advance for maximum output torque is close to **SA2** for the operating point in the figure, and the resulting peak pressure position lies around 17° after TDC. With too early ignition timing the pressure rise starts too early and counteracts the piston movement. This can be seen for the pressure trace with spark advance **SA1** where the pressure rise starts already at -20° due to the combustion. There are also losses due to heat and crevice flow from the gas to the combustion chamber walls, and with an earlier spark advance the loss mechanisms start earlier reducing the work produced by the gas. Higher pressures give higher temperatures which also decrease the difference in internal energy between the reactants and products in the combustion, thus resulting in lower energy-conversion ratios. The heat loss mechanisms and the lower conversion ratio can be seen in *Image 30*, at crank angles over 30°, where the pressure trace from the **SA1** spark advance is lower than the others.

Too late ignition gives a pressure increase that comes too late so that work is lost during the expansion phase. In *Image 30*, the pressure increase for spark advance **SA3** starts as late as at TDC. But work is also gained due to the later start of the effects mentioned above, which also can be seen in the figure. The pressure trace from the spark advance, **SA3**, is higher than the others at crank angles over 30°. However, this gain in produced work can not compensate for the losses early in the expansion phase.

PEAK PRESSURE CONCEPT

Thus, optimal spark advance positions the pressure trace in a way that compromise between the effects mentioned above. To define the position of the in-cylinder pressure relative to TDC, the peak pressure position (PPP) is used, *Image 31*. The PPP is the position in crank angle where the in-cylinder pressure takes its maximal value. There also exist other ways of describing the positioning of the combustion relative to crank angle, e.g. based on the mass fraction burned curve.

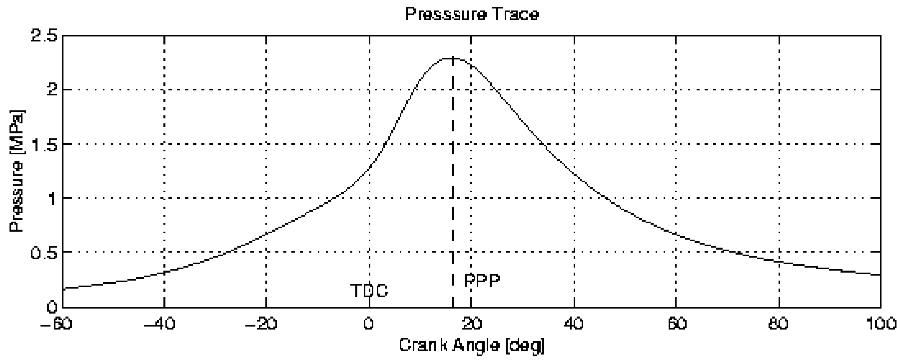


IMAGE 8: PEAK PRESSURE POSITION

ENGINE-TUNING FOR EFFICIENCY

To be able to get the maximum torque from the engine at a given loadpoint we have to investigate the torque development in different settings. In *Image 32*, mean values, over 200 cycles, of the PPP are plotted together with the mean value of the produced torque at four different operating points covering a large part of the road load operating range for the engine. Two of the operating points have an engine speed of 1500 rpm with different throttle angles, and for the two other operating points the engine speed is doubled to 3000 rpm. The PPP for maximum output torque in the figure lies around 15˚ATDC (after TDC) for all these operating points, , even though the spark advance differs a lot.

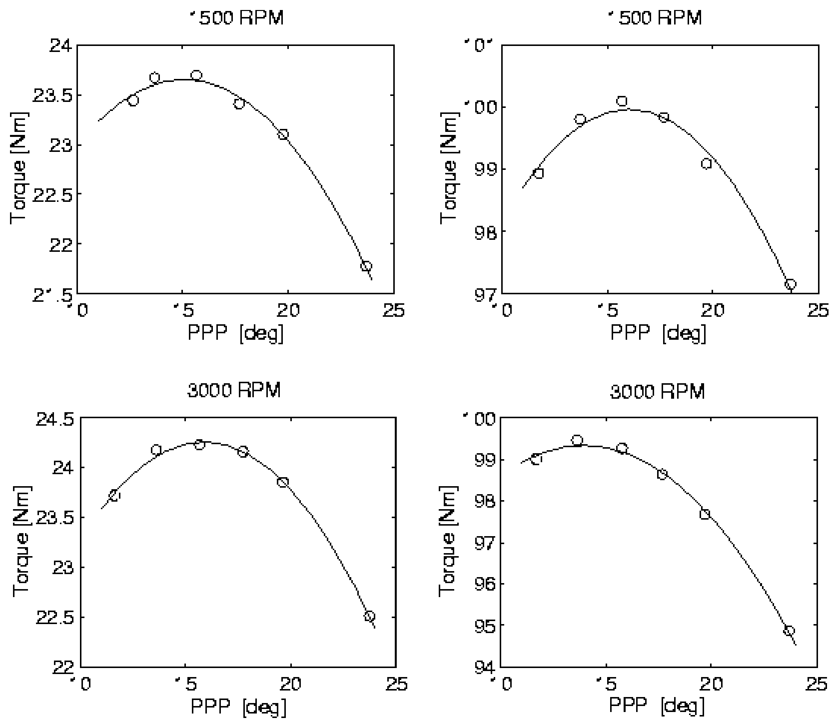


IMAGE 9: PPP VS. TORQUE IN DIFFERENT SETTINGS

Note that the load and speed are changed over large intervals, and that the PPP for maximum output torque at the different operating points does not differ much. The PPP versus torque curve is flat around the position for the maximum. Therfore a spark schedule that maintains a constant PPP at 15˚ is close to optimum. Considering only the work produced, this motivates that an optimal spark schedule maintains almost the same position for the peak pressure. However, the optimal PPP changes slightly with the operating points. The efficiency can thus be improved a little bit further by mapping the optimal PPP for each operating point, and provide these values as reference signal to the spark timing controller. The peak pressure positioning principle can also be used for meeting emission standards.

Appendix VIII: Sensors and actuators

This appendix will list details about the sensors and actuators used in a T8 car.

General

Sensors are devices used to gather information. In a Trionic 8 car a lot of sensors are used to determine what actions to take inside the ECU. These sensors are all analogue, which means they output a signal that has to be converted to digital numbers for the ECU to be able to understand them. Actuators on the other hand are devices that enable the ECU to interact with the processes in the car. Actuators are driven (or activated) by the Trionic be it directly or indirectly.

Sensors

Actuators

APPENDIX XVI: INTERCOOLER CALCULATION

DESCRIPTION

This appendix will explain how to do calculations on intercooler flow capacity. A larger than stock intercooler is needed of you plan to go over 300 bhp with a Trionic 5 engine.

An intercooler is a heat exchanger. That means there are two or more fluids or gases that don't physically touch each other but a transfer heat or energy takes place between them. At wide open throttle and full boost the hot compressed air coming from a turbocharger is probably between 250 and 350 °F depending on the particular turbo, boost pressure, outside air temperature, etc.. We want to cool it down, which reduces its volume so we can pack more air molecules into the cylinders and reduce the engine's likelihood of detonation.

How does an intercooler work? Hot air from the turbo flows through tubes inside the intercooler. The turbo air transfers heat to the tubes, warming the tubes and cooling the turbo air. Outside air (or water in a watercooler intercooler) passes over the tubes and between fins that are attached to the tubes. Heat is transferred from the hot tubes and fins to the cool outside air. This heats the outside air while cooling the tubes. This is how the turbo air is cooled down. Heat goes from the turbo air to the tubes to the outside air.

There are some useful equations which will help us understand the factors involved in transfering heat. After we look at these equations and see what's important and what's not, we can talk about what all this means.

EQUATION 1

The first equation describes the overall heat transfer that occurs.
Q = U x A x DTlm

Q is the amount of energy that is transferred.
U is called the heat transfer coefficient. It is a measure of how well the exchanger transfers heat. The bigger the number, the better the transfer.
A is the heat transfer area, or the surface area of the intercooler tubes and fins that is exposed to the outside air.
DTlm is called the log mean temperature difference. It is an indication of the "driving force", or the overall average difference in temperature between the hot and cold fluids. The equation for this is:

$$DTlm = \frac{(DT1-DT2) * F}{\ln(DT1/DT2)}$$

where **DT1** = turbo air temperature in - outside air temperature out
DT2 = turbo air temperature out - outside air temperature in
F = a correction factor, see below

Note:

The outside air that passes through the fins on the passenger side of the intercooler comes out hotter than the air passing through the fins on the drivers side of the intercooler. If you captured the air passing through all the fins and mixed it up, the temperature of this mix is the "outside air temperature out".

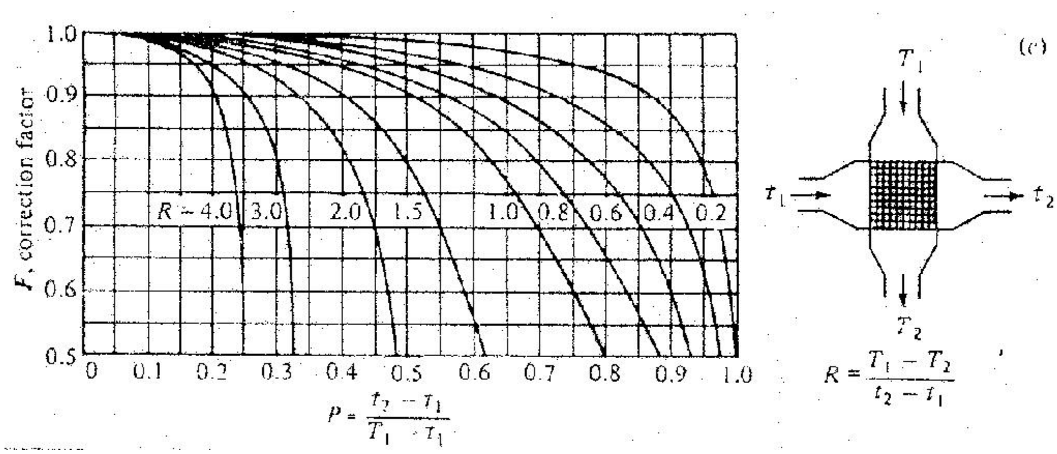
F is a correction factor that accounts for the fact that the cooling air coming out of the back of the intercooler is cooler on one side than the other.

To calculate this correction factor, calculate "P" and "R":

$$P = \frac{\text{turbo air temp out - turbo air temp in}}{\text{outside air temp in - turbo air temp in}}$$

$$R = \frac{\text{outside air temp in - outside air temp out}}{\text{turbo air temp out - turbo air temp in}}$$

Find P and R on "Fchart.jpg" (below) and read F off the left hand side.



This overall heat transfer equation shows us how to get better intercooler performance. To get colder air out of the intercooler we need to transfer more heat, or make Q bigger in other words. To make Q bigger we have to make U, A, or DTlm bigger, so that when you multiply them all together you get a bigger number. More on that later.

Equation 2

We also have an equation for checking the amount of heat lost or gained by the gas (or fluid) on one side of the heat exchanger (ie, just the turbo air or just the outside air):

Q = m x Cp x DT

Q is the energy transferred. It will have the exact same value as the Q in the first equation. If 5000 BTU are transferred from turbo air to outside air, then Q = 5000 for this equation AND the first equation.

m is the mass flowrate (lbs/minute) of fluid, in this case either turbo air or outside air depending on which side you're looking at.

Cp is the heat capacity of the air. This is a measure of the amount of energy that the fluid will absorb

for every degree of temperature that it goes up. It is about 0.25 for air and 1.0 for water. Air doesn't do a great job of absorbing heat. If you put 10 BTU into a pound of air the temperature of it goes up about 40 degrees. If you put 10 BTU into a pound of water, the temperature only goes up about 10 degrees! Water is a great energy absorber. That's why we use water for radiators instead of some other fluid.
DT is the difference in temperature between the inlet and outlet. If the air is 200 deg going in and 125 deg coming out, then DT = 200 - 125 = 75. Again, on the cooling air side the outlet temperature is the average "mix" temperature.

If you know 3 of the 4 main variables on one side of the exchanger (the amount of heat transferred, the inlet and outlet temperatures, and the fluidís flow rate) then this equation is used to figure out the 4th. For example, if you know the amount of heat transferred, the inlet temperature, and the flow rate you can calculate the outlet temperature. Since you canít measure everything, this equation is used to figure out what you donít know.

Caveat:
These equations are all for steady state heat transfer, which we probably don't really see too much under the conditions that we are most interested in – turbocharged engines! Cruising on the highway you would definitely see steady state.

So, now that we've got these equations, what do they **REALLY** tell us?

1. Heat transfer goes really well when there is a large temperature difference, or driving force, between the two gases. This is shown in equation 1 as a large DTlm. It doesn't go as well when there is a small temperature difference between the two gases (small DTlm). The closer you get the intercooler outlet temperature to the outside air temperature the smaller DTlm gets, which makes the heat transfer tougher.

2. The difference between the intercooler outlet temperature and the outside air temperature is called the approach. If it is 100 degrees outside and your intercooler cools the air going into the intake manifold down to 140 degrees, then you have an approach of 40 degrees (140 - 100 = 40). To get a better (smaller) approach you have to have more area or a better U, but there is a problem with diminishing returns. Lets rearrange the first equation to Q/DTlm = U x A. Every time DTlm goes down (get a better temperature approach) then Q goes up (transfer more heat, get a colder outlet temperature), and dividing Q by DTlm gets bigger a lot faster than U x A does. The upshot of that is we have a situation of diminishing returns; for every degree of a better approach you need more and more U x A to get there. Start with a 30 deg approach and go to 20 and you have to improve U x A by some amount, to go from 20 to 10 you need to increase U x A by an even bigger amount.

3. I would consider an approach of 20 degrees to be pretty good. In industrial heat exchangers it starts to get uneconomical to do better somewhere around there, the exchanger starts to get too big to justify the added expense. The one time I checked my car (stock turbo, stock IC, ported heads, bigger cam) I had an approach of about 60 deg. The only practical way of making the DTlm bigger on an existing intercooler is to only drive on cold days; if you buy a better intercooler you naturally get a better DTlm.

4. You can transfer more heat (and have cooler outlet temps) with more heat transfer area. That means buying a new intercooler with more tubes, more fins, longer tubes, or all three. This is what most aftermarket intercoolers strive for. Big front mounts, intercooler and a half, etc... are all increasing the area.

   A practical consideration is the fin count. The area of the fins is included in the heat transfer area; more fins means more area. If you try to pack too many fins into the intercooler the heat transfer area does go up, which is good, but the cooling air flow over the fins goes down, which is bad. Looking at the 2nd equation, Q = m * Cp * DT, when the fin count is too high then the air flow ("m") drops. For a given Q that you are trying to reach then you have to have a bigger DT, which means you have to heat up that air more. Then THAT affects the DTlm in the first equation, making it smaller, and lowering the overall heat transfer. So there is an optimum to be found. Starting off with bare tubes you add fins and the heat transfer goes up because you're increasing the area, and you keep adding fins until the it starts to choke off the cooling air flow and heat transfer starts going back down. At that point you have to add more tubes or make them longer to get more heat transfer out of the increased area.

5. Make U go up. You can increase the U by adding or improving "turbulators" inside the tubes. These are fins inside the tubes which cause the air to swirl inside the tube and makes it transfer its heat to the tube more efficiently. Our intercoolers have these, but I understand that more efficient designs are now available. One of the best ways to increase the U is to clean the tubes out! Oil film (from a bad turbo seal or from the stock valve cover breather) inside the tubes acts as an insulator or thermal barrier. It keeps heat from moving from the air to the tube wall. This is expressed in our equation as a lower U. Lower U means lower Qs which mean hotter turbo air temperatures coming out of the intercooler.

6. Air-to-water. If we use water as the cooling medium instead of outside air, we can see a big improvement for several reasons: Water can absorb more energy with a lower temperature rise. This improves our DTlm, makes it bigger, which makes Q go up and outlet temps go down. A well designed water cooled exchanger also has a much bigger U, which also helps Q go up. And since both DTlm and U went up, you can make the area A smaller which makes it easier to fit the intercooler in the engine compartment. Of course, there are some practical drawbacks. The need for a water circulation system is one. A big one is cooling the water down after it is heated (which means another radiator). This leads to another problem: You heat the water, and cool it down with outside air like the Syclone/Typhoon. You can't get it as cool as the outside air, but maybe you can get it within 20 degrees of it. Now you are cooling the turbo air with water that is 20 hotter than the outside air, and you can only get within 15 degrees of that temperature so coming out of the intercooler you have turbo air that is 35 degrees hotter than outside! (turbo air is 15 deg over water temp which is 20 deg over outside temp). You could have easily done that with an air to air intercooler! But... if you put ice water in your holding tank and circulate that... Then maybe the air temp coming out of the intercooler is 15 deg above that or 45 to 50 deg. Hang on! But after the water warms up, you're back to the hot air again. So, great for racing, not as good for the street.

7. Lower the inlet temperature. The less hard the turbo has to work to compress the air then the lower the temperature the air coming out of the turbo is. This actually hurts the DTlm, but still if it's cooler going in it will be cooler coming out. You can work the turbo less hard by running less boost, by improving the pressure drop between the air filter and the turbo, or by having a more efficient compressor wheel. You can also reduce the pressure drop in the intercooler,

which allows you to run the same amount of boost in the intake manifold while having a lower turbo discharge pressure. More on this later. If you can drop the turbo outlet pressure by 2 psi, or raise the turbo inlet pressure by 1 psi, that will drop the turbo discharge temperature about 16 degrees (depending on the compression efficiency and boost level). If the turbo air is going into the intercooler 16 degrees colder then it may come out only 10 degrees colder than before, but that is still better than what it was.

PRESSURE DROP

Another aspect of intercoolers to be considered is pressure drop. The pressure read by a boost gauge is the pressure in the intake manifold. It is not the same as the pressure that the turbocharger itself puts out. To get a fluid, such as air, to flow there must be a difference in pressure from one end to the other. Consider a straw that is sitting on the table. It doesn't having anything moving through it until you pick it up, stick it in your mouth, and change the pressure at one end (either by blowing or sucking). In the same way the turbo outlet pressure is higher than the intake manifold pressure, and will always be higher than the intake pressure, because there must be a pressure difference for the air to move.

The difference in pressure required for a given amount of air to move from turbo to intake manifold is an indication of the hydraulic restriction of the intercooler, the up pipe, and the throttle body. Let's say you are trying to move 255 gram/sec of air through a stock intercooler, up pipe, and throttle body and there is a 4 psi difference that is pushing it along. If your boost gauge reads 15 psi, that means the turbo is actually putting up 19 psi. Now we increase the amount of air travelling though to 450 gram/sec of air. At 15 psi boost in the intake manifold the turbo now has to put up 23 psi, because the pressure drop required to get the higher air flow is now 8 psi instead of the 4 that we had before. More flow with the same equipment means higher pressure drop. So we put on a new front mount intercooler. It has a lower pressure drop, pressure drop is now 4 psi, so the turbo is putting up 19 psi again. Now we add the larger throttle body and the pressure drop is now 3 psi. Then we add the 3" up pipe, and it drops to 2.5 psi. Now to make 15 psi boost the turbo only has to put up 17.5 psi. The difference in turbo outlet temperature between 23 psi and 17.5 psi is about 40 deg (assuming a constant efficiency)! So you can see how just by reducing the pressure drop we can lower the temperatures while still running the same amount of boost.

Pressure drop is important because the higher the turbo charging pressure is, the higher the temperature of the turbo air. When we drop the turbo charging pressure we also drop the temperature of the air coming out of the turbo. When we do that we also drop the intercooler outlet temperature, although not as much, but every little bit helps. This lower pressure drop is part of the benefit offered by new, bigger front mount intercoolers; by bigger up pipes; and by bigger throttle bodies. You can also make the turbo work less hard by improving the inlet side to it. K&N air filters, these all reduce the pressure drop in the turbo inlet system which makes the compressor work less to produce the same boost which will reduce the turbo charge temperature.

APPENDIX XVII: ACRONYMS

ENGINE MANAGEMENT SPECIFICS

Acronym	Description
ABS	Antilock Braking System
AMM	Air Mass Meter
BDM	Background Debug Mode
CANBUS	Controller Area Network (Car Area Network)
CPS	Crankshaft Position Sensor
DI	Direct Ignition
DICE	Dashboard Integrated Control Electronics
ECM	Engine Control Module
ECU	Engine Control Unit
EDU	Electonic Display Unit
FPR	Fuel Pressure Regulator
FPT	Full Pressure Turbo
HOT	High Output Turbo
IAT	Intake Air Temperature
LPT	Light Pressure Turbo / Line Printer Terminal
MAF	Mass Air Flow
MAP	Manifold Absolute Pressure
OBD	On Board Diagnostics
RAM	Random Access Memory
ROM	Read Only Memory
RPM	Revolutions Per Minute
SFI	Synchronous Flash Interface (Production test interface)
SID	System Information Display
TPS	Throtte Position Sensor

TWICE	Theft Warning Integrated Central Electronics
VSS	Vehicle Security System
WOT	Wide Open Throttle