Faculty of Engineering – University of Porto

Software for a Gasoline Internal Combustion Engine

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Dissertation / Project of
Integrated Master in Electronic and Computer Engineering
Major Automation

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June, 2010

Resumo

Os motores de combustão interna continuam a ser o mecanismo mais comum e fiável para fazer movimentar os meios de tansportes actualmente. A facilidade com os reabastecimentos e consequentemente a autonomia que isso proporciona, tornam a sua extinção um cenário ainda distante. As alternativas actuais tal como os veículos movidos a motores eléctricos deparam-se precisamente com o aspecto da autonomia como ponto de fulcral desvantagem, apesar de serem cada vez mais uma alternativa levada a sério e alvo de investigação de ponta.

Apesar da sua posição dominante, a efficiencia e rendimento de um motor de combustão interna está longe do ideal, sendo que nesse aspecto a alternativa motores eléctricos superam largamente.

O caminho a seguir para tornar o uso de motores de combustão interna menos penoso para o meio ambiente, ou seja diminuir o consumo de combustiveis fosseis e diminuir as emissões de gases nocivos, enquanto não chegamos a uma solução alternativa definitiva, será avançar cada vez mais na evolução dos sistemas de controlo electrónicos. Estes sistemas procuram aumentar a efficiencia e fiabilidade do motor e consequentemente diminuir os efeitos nocivos do uso do mesmo.

O documento seguinte descreve o projecto de criação de software para uma unidade de controlo electrónico de um motor de 4 cilindros a gasolina normalmente aspirado.

Algumas considerações gerais e introdutórias relativas à teoria de funcionamento de um motor de combustão interna são apresentadas, assim como o funcionamento de todos os componentes associados a este projecto.

A industria automóvel e os seus departamentos de desenvolvimento estão entre as industrias de ponta na área de investigação e desenvolvimento de novas descobertas de tecnologias e suas aplicações. Algumas ferramentas usadas na industria são apresentadas.

Abstract

Internal combustion engines are still the most common and reliable source of power to move vehicles. The easiness of re fuelling and its inherent autonomy makes it hard to find a replacement. The alternatives, for now, as the electric vehicles which is becoming a more and more serious point of investigation still finds barriers in autonomy vs. performance which the internal combustion engine doesn't have.

Nevertheless, the efficiency of the internal combustion engine is still far from great when compared with electric motor for example.

The way to try to make the use of internal combustion engines less harmful to the environment until a definitive and concrete solution is achieved to completely replace this type engine is to advance more and more on the engine management systems. These systems intend to increase efficiency at its maximum and reduce fossils fuel consumptions to its minimum.

The following document describes the project of creating software for an Electronic Control Unit to provide Engine Management to a 4 cylinder normally aspirated gasoline internal combustion engine.

General overviews about theory of operation of a spark ignition (SI) engine are described as well as the function of main components relevant for this project.

The automotive industry and its developments departments are among the high-end in the research and demands for new technologies and breakthroughs. Several tools to help in development of control software for the automotive industry are presented.

This project tries to give an insight on the basic foundations of creating software for the automotive industry and its requirements.

Acknowledgments

I would like to take this space to thank the several people who, in one way or another, helped me reach here, the final stage of my academic life.

I like to thank to my supervisor, Prof Dr. Armando Araújo, for the help and time to answer my questions, and giving valuable inputs on the way to follow to reach this point.

I thank to people from Vocis Driveline Controls the possibility of this internship, accepting me here and allow me to learn and grow in so many ways.

A special word to my company supervisor Rob J. Barnes, without whom I wouldn't be here, the enormous amount of time dedicated to help and tutoring me was invaluable.

I would like to thank to all my family to make possible the fact I am graduating in the degree I want, and the fact they helped me bare the time abroad.

Last, but not least, I would like to thank to all my friends the support, the patience and the jokes with all those days and nights of work and fun, luckily for me it would be too long to name it all, but you know who you are.

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Abbreviations and Symbols

ADC	Analogue to Digital Converter
A/F	Air Fuel Ratio
CT	Coolant Temperature
BDC	Bottom Dead Centre
ECU	Electronic Control Unit
EMS	Engine Management System
ETPU	Enhanced Timer Processor Unit
GDI	Gasoline Direct Injection
IAT	Inlet Air Temperature
ICE	Internal Combustion Engine
IGBT	Insulated Gate Bipolar Transistor
MAF	Mass Air Flow
MIRA	Motor Industry Research Association
O2	Oxygen Sensor
SI	Spark Ignition
TDC	Top Dead Centre
TPS	Throttle Position Sensor
VVT	Variable Valve Timing

Chapter 1

Introduction

This chapter presents the project and its goals, the company where it was developed and a generic overview about the studied subjects. At the end of this chapter an overview of the report is presented.

1.1 Project Context

This project took place at Vocis Driveline Controls [1] in order to fulfil the requirements to obtain the degree of Masters in Electronics and computer Engineer at Faculty of Engineering – University of Porto. The exchange occurred by Erasmus Placement program.

The following description summarizes the motivation of the company and the main proposed goals for the final application.

Vocis have designed an engine management electronic control unit (ECU), based on the Freescale 'Black Oak' MPC555 [2] and Freescale 'Copperhead' MPC5554 [3] microprocessors, for a 12 cylinders, spark ignited, internal combustion engine (ICE). This ECU is designated 'EMS-12'. Vocis have the need to generate a first engine control application for the ECU, and have chosen a 4 cylinder, spark ignited, Volkswagen Golf as the target for this purpose. To assist in generating the control software, Vocis have also created a bench testing rig, consisting of most of the sensors and actuators present on the target engine. Summarizing the target application should be capable of:

- Interpretation and failure checking of analogue and digital inputs.
- Synchronization of a Time Processor Unit (TPU) with an internal combustion engine using crankshaft and camshaft position sensors.
- Control of fuel injectors to inject fuel at a desired crankshaft angle for a specified time period.

- Control of ‘wasted spark’ ignition coils to fire cylinders at specified angles.
- Closed loop fuelling control using an exhaust gas oxygen sensor.
- Control of an electronic throttle unit.

The main areas of study and application can be described by:

- Knowledge and understanding of microprocessor based systems for study and identification of the MPC555/MPC5554 architecture.
- Implementation of a custom Time Processor Unit ,TPU/eTPU, software for the processors.
- Synthesis and proposal of a low level ‘C’ code program for the processors.
- Application of the ETAS ASCET-SD programming and modelling language, and the generation of fixed point ‘C’ code.
- Application of the Vector CANape tool, and the Controller Area Network (CAN) vehicle network system.
- Integration of all developed subsystems in the design of a complete control system for the 4 cylinder, spark ignited, ICE.

1.2 The Company

Vocis was formed in September 2006 by five highly-experienced automotive engineers with a proven track-record of project delivery in the field of transmission and driveline systems for all types of passenger cars and trucks. The aim was to provide an alternative source of expertise for vehicle OEM and tier one company to tap into.

Shortly after formation, Vocis were approached by GrazianoTransmissioni, part of the Oerlikon group [4]. Negotiations were concluded such that a majority shareholding is owned by OerlikonGraziano Drive Systems, but Vocis is able to work with anyone in the marketplace.

Within five months of formation, Vocis created a demonstrator vehicle (based on a wet-clutch dual clutch transmission) to showcase their control system expertise. Vocis designed their own controller hardware capable of running sophisticated control methods. Vocis developed a complete suite of dual clutch transmission control software (Driving Strategy, Shift Sequencing, Clutch Control, Synchronizer Control, Engine Interface and Diagnostics) from scratch. Vocis have continued development of control methods since the first demonstrations in March 2007, taking on board comments from those who have driven the car.

In addition to its own demonstrator car, Vocis has delivered a number of projects for external clients.

Vocis Driveline Controls clients are some of the best-known OEM and tier one organizations in the automotive industry - Vocis work for them ranges from:

- Production-intent programmes for controllers and/or software.
- Designs for transmissions and driveline mechanical and hydraulic systems.
- Specification of electronic hardware and system components.
- Concept studies for future transmissions and drivelines.
- Specification of software for safety-critical driveline systems.

For test purposes the company holds a workshop in MIRA proving ground. MIRA stands for Motor Industry Research Association, and it is a place where several companies that make engineering products and development for the automotive industry gather to use hidh-end facilities with all the requirements to the industry.

MIRA also has its own projects as a company and can make consultant or outsourcing projects for other companies (like using wind tunnels available on site).[5] This project took place in these facilities. The workshop is equipped with all the necessary tools and equipment to help on any kind of work in a car. It's here where the company makes the tests with/to all their projects. The proving ground is a big complex with several different tracks for different tests. The confidentiality is taken very seriously as cameras of any kind (including cell phones) are not allowed in the proving ground. This proving ground is test base for several of the most known manufactures in the world.

1.3 An overview on the studied subjects

1.3.1 Internal combustion Engines

Internal combustion engines (ICE) are so deeply rooted in our everyday lives, that many doesn't even wonder or care what's under the hood of their car, what makes people and goods, move all over the world.

This centenary invention, knew an imaginable growth and popularity that its research and development which lead to better and more efficient engines is now seen as normal.

The list of innovations and performance improvements it's so wide, that won't be detailed in this document. Although their peripherals may have changed, the materials used being improved, and the management systems become more and more accurate, the four strokes internal combustion engine functional description remains the same.

In Figure 1.1, it is visible an internal engine cut with all the main components for the function of the engine.

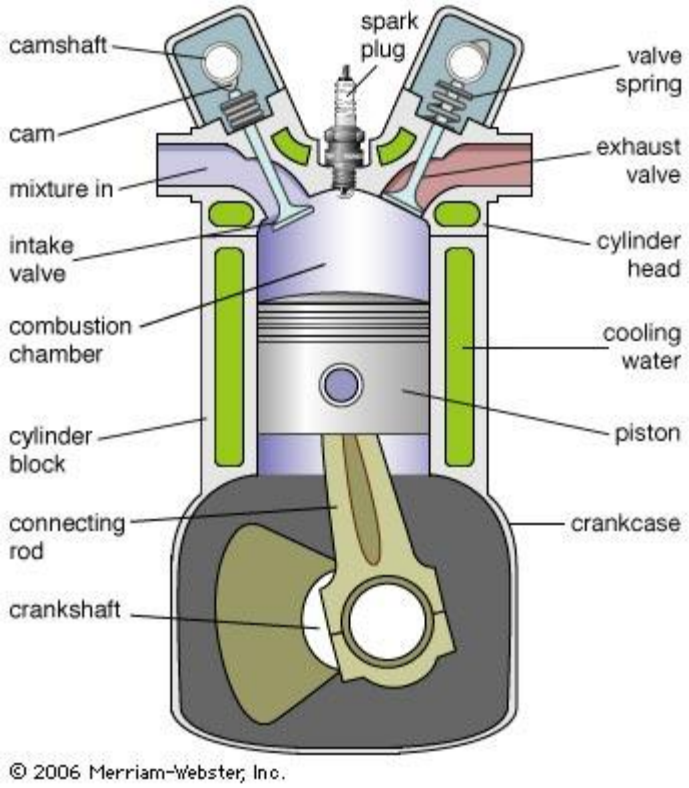


Figure 1.1 - Engine cut view

It is named four strokes after Otto [6] named the four stages of a petrol engine. It was accepted that in order to produce power from the engine and therefore make the engine useful this four strokes happens in every cylinder of the car. They are named:

- Admission.
- Compression.
- Explosion (or Power)
- Exhaust.

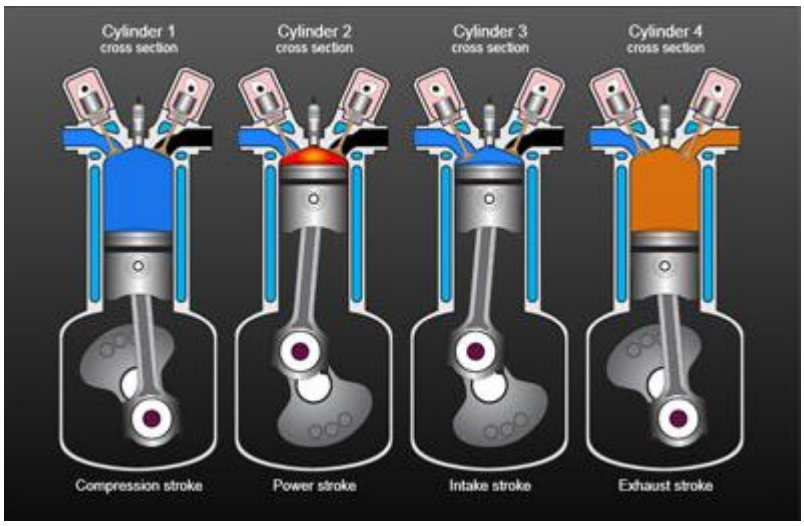


Figure 1.2 - Four Stroke cycle [7]

In Figure 1.2, it is visible the four strokes in an engine cycle, and what happens in each one of them.

The meaning of each one of the steps is easily concluded by the names they have. In admission stage the intake valve open for that cylinder chamber, the air fuel mixture is inserted (via electronic injection or carburetor into the intake manifold or directly in the cylinder) and then the intake valve is closed.

On compression, the piston is moving upwards to top dead centre (TDC), with both cylinder valves closed. This reduces the volume of the cylinder chamber and the air fuel mixture becomes compressed.

The explosion stage is where the mixture is ignited (via the spark plugs) and forces the piston to go down. There are a lot of parameters that influence, directly or indirectly, the method for calculating timing and give the spark. There are systems with multi sparks and techniques for changing the timing goes from purely mechanical distributors to complex microprocessor computations, that makes thousands of calculations, to give spark advance. It's in this stage, of engine cycle, that torque is generated by the force pushing the piston down.

On the last stage, of engine cycle, the exhaust valves open and the gases from the combustion are expelled into the exhaust manifold.

In this stage the piston is going up (the second time in a complete engine cycle) and pushes the combustion gases out.

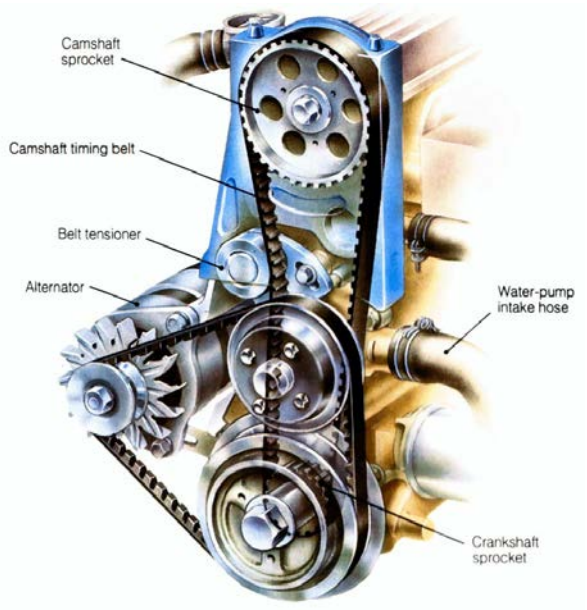


Figure 1.3 - Time belt and alternator belt

Figure 1.3, shows the typical format of a time belt connection, this connects the crankshaft to the camshaft, with some tensioners to adjust tension (may get loose with

aging), In the figure it is also visible the alternator belt. This belt provides rotating power to the alternator, which generates power to charge car batteries.

Each engine has its own timing, that corresponds to the moment of opening and closing of each valve (for each cylinder) and that's why the timing belt is so important. If a piston is on TDC with any of the valves open this could bend the valve and completely destroy the engine.

The valves are opened by "bumps" in the camshaft, which is connected to the crankshaft

Cam shaft, sits on top of the engine and controls the opening and closing of the valves, it has a rotating movement synchronized with crankshaft.

Figure 1.4 - Camshaft

The crankshaft is one of the main components of an engine. It receives the linear motion of the pistons (vertically up and down) and creates a rotational movement which is the output from the engine to transmission and wheels.

Figure 1.5 – Crankshaft [8]

Cam and crankshaft are connected by the time belt, some manufactures started to create systems with dual camshafts that opens the intake and the exhaust valves separately, and this allows larger range of control.

There are systems to change the timing of the valves with some manufactures choosing different techniques (Toyota BWM Nissan, Honda). At high engine speeds, an engine requires large amounts of air

Pressure to meet environmental goals and fuel efficiency standards is forcing car manufacturers to turn to variable valve timing (VVT) as a solution. Most simple VVT systems advance or retard the timing of the intake or exhaust valves. Others (like Honda's VTEC) switch between two sets of cam lobes at a certain engine RPM. Furthermore Honda's i-VTEC can alter intake valve timing continuously [9].

The torque and power are passed to the outside of the engine by the crankshaft (which is solider with the pistons). In a standard car this shaft is the input to the transmission and gearbox systems that will put power into the wheels; the clutch that the normal everyday driver actuates by pressing a pedal isn't more than the connection between these two systems.

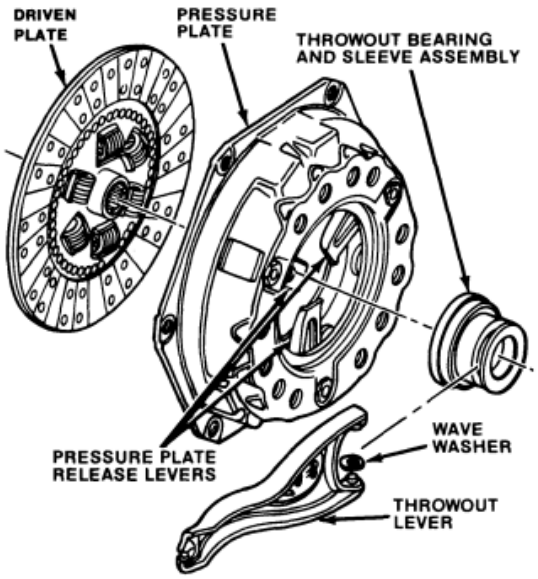


Figure 1.6 - Clutch Diagram

Figure 1.6 presents a schematic of the main components of a clutch The most common type of clutch is a disc (or several), made from similar material as brake pads, and with a frictional force that attaches the gearbox to the crankshaft. Some springs and release bearings allow the smooth connection or interruption of this system as shown in Figure 1.6.

Since early days in engine building and control, the aim to make cars more efficient and powerful was a need and a passion. The amount of progress achieved in engine management systems (EMS), is mind blowing. So, the aim of this part is to provide the reader a description of what's involved in EMS, how and why the evolutions took place and to present a standard approach to the techniques able to make an EMS.

Putting it in simple words, a management system will consist in something that controls (therefore manages) the system in question. In this case the first things that were controlled, in a regular petrol engine, were injection and ignition systems [13].

As explained before the engine always had these two systems, in order to be able to function correctly, but independently they were targets of enormous changes along the decades from purely mechanical to full electronic.

1.3.2 FUEL management system

Air/fuel ratio (A/F) control, or the amount of injected fuel into the cylinder chamber, was, for many years, made by the purely mechanical system known as the carburettor [8]

This device externally blends air and fuel and inserts the mixture into the intake manifold. Figure 1.7 presents the diagram and main components of a traditional carburetor. It is possible to see the process of mixing air and fuel. The circuit of fuel and some adjusts are possible in a carburetor system.

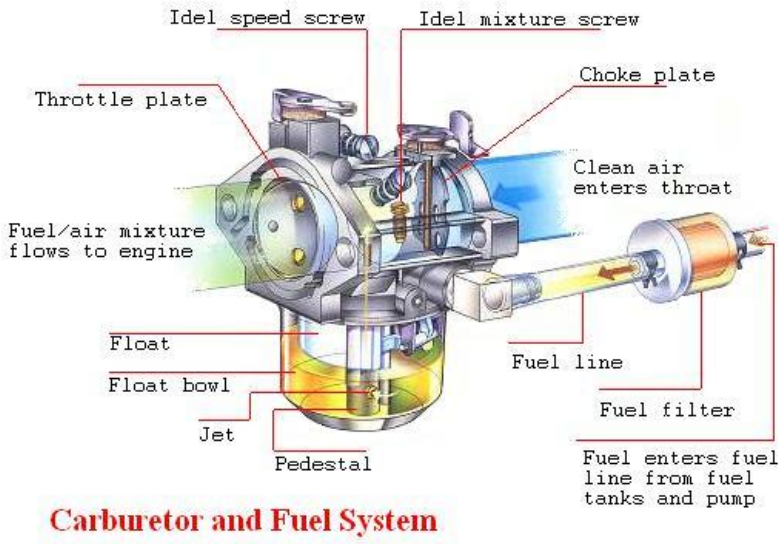


Figure 1.7 - Typical carburetor

This device proved to be reliable and lasted many years as the predominant mechanism for this job. The ability to manually tuning it by mechanical means still attracts many enthusiasts that use them on old cars. The carburetor was refined over the years, but reached a point where emission control and fuel cuts demands were too strict for it. Its performance being limited leaded to the search for new alternative systems for air/fuel mixture control.

With electronics breakthroughs and the constant demanding from the automotive industry to present better, more reliable and efficient products electronic injection systems appeared naturally.

There are several configurations possible in injection systems, the most common used is called single point injection. This system consists in a single injector that controls the amount of fuel into intake manifold. Then the opening of the intake valves make the admission of fuel into combustion chamber.

Another system is the multi-point injection. This time there are several injectors or (normally one per cylinder) and their individual control allows injection of fuel into the intake of each cylinder separately.

These two systems may be configured then in groups, where several injectors work simultaneously, this happens normally in engines with high number of cylinders.

The latest innovation for multi-point injection is the gasoline direct injection (GDI), where the injector is placed inside the combustion chamber. This wide the range of control possible in these systems, since the configuration, timing and amount of fuel can be much more efficient if localized close the spark system.

A parameter object of attention in the control strategies is the idle speed of the car. This is inherent to the fuel system since the mixture and the amount of fuel to keep the car running smoothly and with very low fluctuation on speed, provides economy and comfort for the drivers.

There are several studies on the area, in [18][19][20] some possible strategies are presented that can be used. In [18] a PID scheme is discussed to control target speed as shown in Figure 1.8.

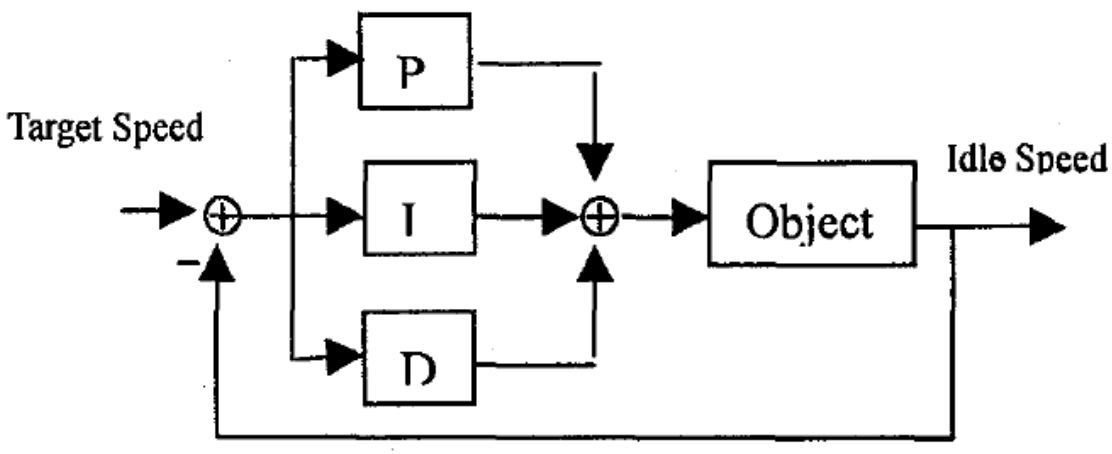


Figure 1.8 – PID block diagram for idle speed control

1.3.3 Ignition management system

Ignition systems are responsible for delivering a spark in order to ignite the mixture inside a compressed volume, the cylinder. Making combustion of A/F mixture forces it to expand and increase its volume; this will push the piston down and produce torque.

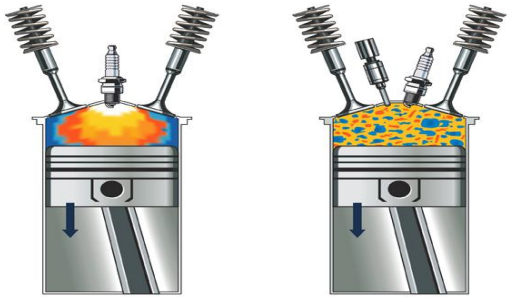


Figure 1.9 - Ignition on combustion chamber

Again, as the fuel system, ignition started to be almost purely mechanical so the first systems consisted on the so called distributor, Figure 1.10 .

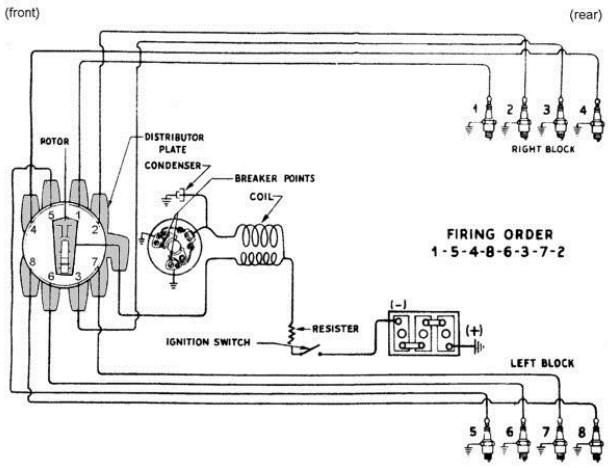


Figure 1.10 - Distributor Schematic

This system consists of a rotor (rotates with camshaft), provided with shaped contacts and a mechanical circuit breaker that opens and closes an electrical circuit with an autotransformer, known as the ignition coil. Current in the ignition coil is provided by a battery and this current is interrupted, at calculated angular positions, to give the spark. These calculations are purely mechanical.

The corrections consist in moving the spark time relatively to TDC. With engine rpm increasing and the combustion time being almost the same, it's easily understanded that the

spark needs to occur early (in degrees scale means more degrees before TDC) in order the combustion occurs at an optimal time to push the piston down.

In purely mechanical systems this is accomplished with centrifugal mechanisms that adjust the contacts with shaft speed. Vacuum mechanisms are used to change timing with load, which in this case can be seen as function of the amount of air (or pressure) in the intake manifold, the spark will be closer to TDC with a load increase.

The ignition system knew a lot of progresses during time. The exact time to provide a mixture with a spark is crucial to the best performance, efficiency and durability of an engine.

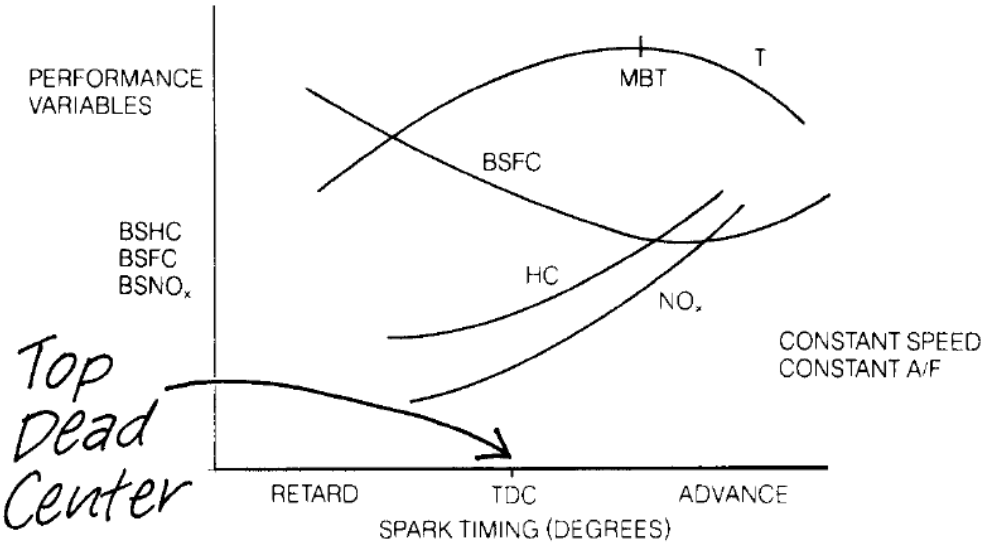


Figure 1.11 - Emissions and efficiency variation with spark timing

A spark must be given while the piston is going up, so the time mixture takes to ignite and explode occurs when the piston is just starting to go down. This produces the maximum power and torque. In Figure 1.11, its visible the emissions and torque variations with spark advance or retard. It's possible to see that the increase of the advance its good for output power but bad for the emission, until a certain point. So manufacturers find a trade-off between these two points.

The time is normally referred as an angular position, since the timing is linked to the crankshaft position (therefore the piston position) so it's normal to hear and read that the spark is given alpha degrees before top dead centre (TDC). Notice that the term advance means the spark will be given earlier. The term advance refers to the angle before TDC where the spark should occur; if the angle advances the spark is given further away (earlier) from TDC.

A consequence of over advancing the spark is the appearance of knock in the respective cylinder.

If the spark is given so early that the explosion occurs while the piston is going upwards Knock appear. This may cause severe damage to the engine and it's highly unwanted by

control systems. The sensor that detects knock is normally a type of microphone which detects vibrations on the engine. The control systems then creates a range of window angles (of crankshaft) where monitors the vibrations, this normally is set to work around the spark angles, because vibrations will be noticed always after the explosion.

The control system then advances the spark angle until knock is detected, when reaches knocking point the spark is retarded a big step and then advanced again until knocking point again, this allows the engine operate in maximum torque (maximum optimal advance) and prevent severe damages to the engine. Excessive compression is other possible factor to generate knock [13].

The naturally development of the ignition system has eliminated ALL mechanical parts of the system. Gaps and time aging of contacts cause several problems in ignition system as inaccurate timing and misfires. So, the new systems can miss the distributor if they can read correctly the cam and crankshaft position, knowing at each time what is the piston position.

The first systems started to remove the mechanical contacts by transistors electronically controlled; this reduces maintenance and timing inaccuracy and better ignition of rich mixtures (during engine start).

After, the distributor was removed, and the ignition systems are called DIS (distributorless ignition system). There are several types of DIS systems; the one present on the test car is an EDIS with coil packs. EDIS.

Other type of ignition system is the CDI (Capacitor Discharge Ignition). This system works with the discharge of an external capacitor into the coil primary winding when required. The rate of discharge is much higher than in inductive systems which will cause a quicker variation on the voltage of the secondary winding. This leads to more powerful sparks, CDI systems can operate either with or without distributor.

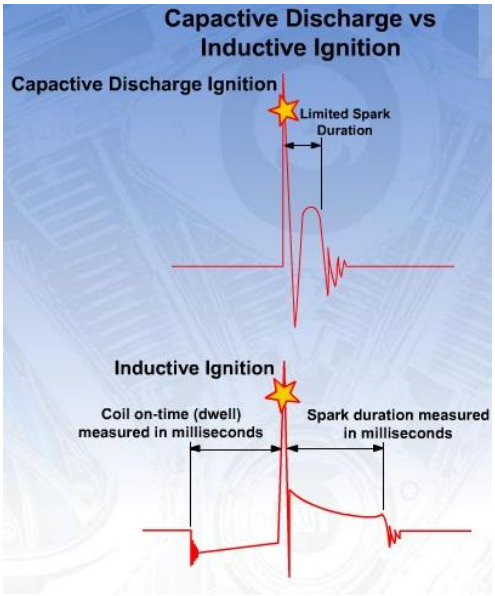


Figure 1.12 - DCI vs. EDIS ignition system

1.3.4 Electronic control unit, ECU

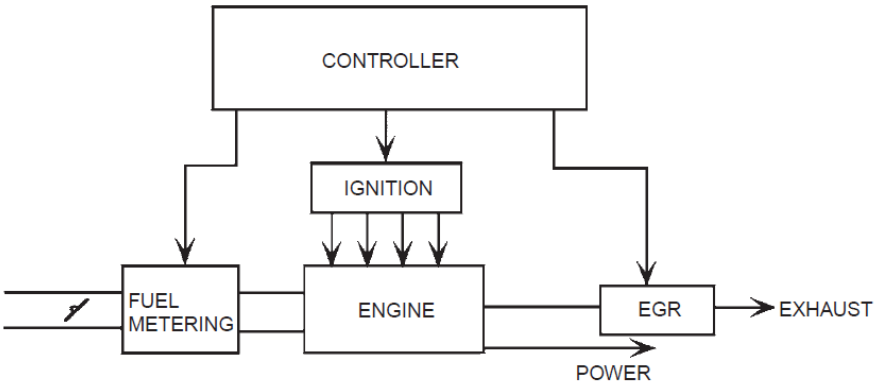


Figure 1.13 - Major ECU components [13]

Engine control, in the vast majority of engines, means regulating fuel and air intake, as well as spark timing, to achieve desired performance in the form of torque or power output.

Until the late 1960s, control of the engine output torque and RPMs was accomplished through some combination of mechanical, pneumatic, or hydraulic systems [13]. Then, in the 1970s, electronic control systems were introduced. [13]

Due to the growing need of more efficient and powerful cars the need of a system capable to handle every system in one and to be able to deal with greater and greater information was a major concern. Since all the information is directly linked and dependent for different subsystems, it's natural that a central "brain" is maintained to supervise and control car behaviour.

The most basic systems can control only the ignition or the electronic fuel injection.

There are a lot of do it yourself kits with new ignition systems to replace the distributor and some control module to make it work; this can be seen as a very basic ECU system.

On the current time things are a lot different, the amount of information and computational data are indescribable.

Nowadays there are several EMS, almost all proprietary of the manufacturers which spend an enormous amount of money in research and development. So, it's understandable that information about these systems is almost inexistent. Nevertheless it's always more productive and accurate if development is done together with the engine manufacturer and the project management defining the goals of each EMS.

Many specialized companies have solutions with tens of years of development, and in many cases they just need to make software and calibration changes until they meet the new requirements. The most known company doing this type of products is perhaps BOSCH automotive, which was pioneer in many software and hardware design for the whole range of

electronics presented in the car, since sensors, actuators network configurations, communication protocols and so on [14].

Their systems have proven record with the automotive industry and it's not strange that many of the cars nowadays in the street have a BOSCH ECU.

Some other companies present fairly competitive solutions, like Siemens, just to give an example, and some manufactures have their own department to produce ECUs.

As an alternative to huge prices and the lack of customizations possible in proprietary ECUs, some cheaper, basic and modifiable solutions started to appear in the market. Some systems may not be considered ECU, as they are just part of engine management system, but they insert electronic controlled components, such as electronic injection and ignition.

A solution of a full ECU, with a low price and completely tuneable is provided by MegaSquirt project.[15]. This project, created by former Automotive Engineers, delivers a budget solution for an ECU. The software is available online, and there are a lot of discussion, tips and instructions on how to set-up, modify and test this system. This is particularly to people with fairly old cars that don't have an ECU. Reminding that changing the specs of your car can be illegal, and therefore forbidden, depending on country legislation about the matter; this is used for recreational purposes mainly [15].

1.4 Structure of Report

The first chapter tries to give an overview about the main goals and subjects studied along this project. The company is presented and the functional description of the SI engine is described. Major groups of the ECU are related within some historical evolution.

On Chapter 2 is intended to specify and give a detailed insight on the materials used and created for the conclusion of the project, the test rig, and the car where the tests took place are described as well as the changes made to those systems.

Chapter 3 presents the software tools used to create and monitor all the software of the project, some general guidelines of their use and how they can be useful to the project.

The microprocessor, its capabilities and the reasons why it's so widely used in the automotive industry are presented on Chapter 4. Some explanation on how the main functions related to the project are set up and their functional description are presented.

Chapter 5 shows the algorithms created for this project, control techniques used in each module, and how it is implemented with the software tools described in Chapter 3.

Chapters 6 and 7 tries to give a fair resume on the tests and results achieved showing the software working and the main goals achieved.

An overview about the work achieved and some insights on what should be the next steps to continue and improve the product are given in the Conclusions and Future Work sections

With this first chapter it is expected to present a first overview and some introduction to internal combustion engines, the control methods and components possible, and its evolution along time.

The report now follows with the description of the main components used during this project

Chapter 2

Hardware and Set Up

This chapter presents and describes the hardware tools used during the development of this project. Test tools used as well as the car where the project was implemented are also presented.

2.1 Engine Management System, EMS-12

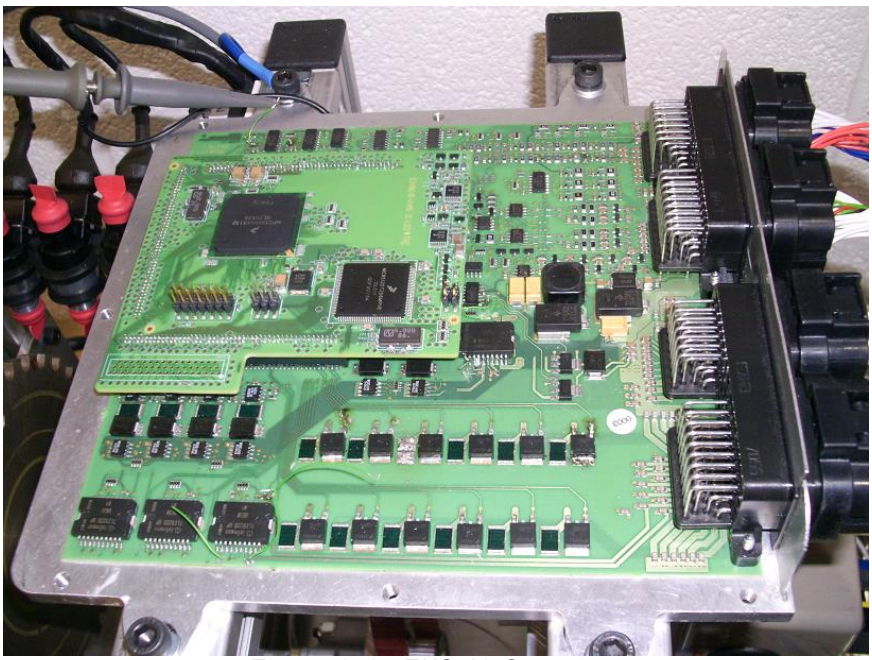


Figure 2.1 - EMS-12 Overview

The EMS-12 board got its name for being the Engine Management System for control an engine up to 12 cylinders. This board was designed on the early days of the company, and this project serves as proof of its capability, not to its full extent, but as a concept.

The board has all data acquisition and signal condition circuits necessary for almost every automotive sensor used on Engine Management Systems:

There are 12 IGBT transistors used for spark plugs ignition coils driving.

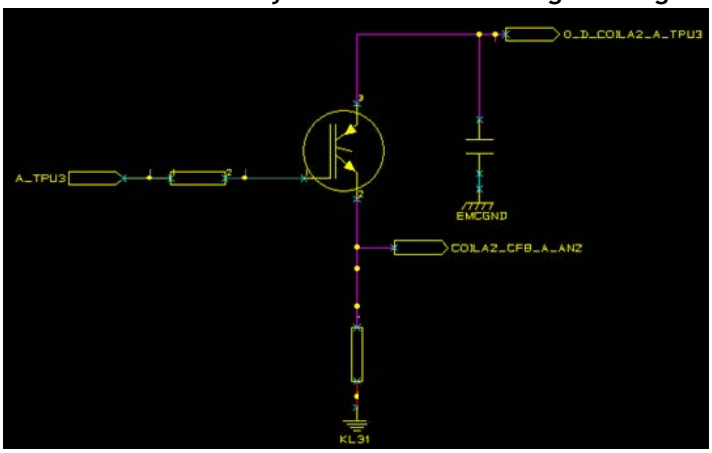
The coil pack is connected directly into the board through the signal as shown in the 

Figure 2.2.

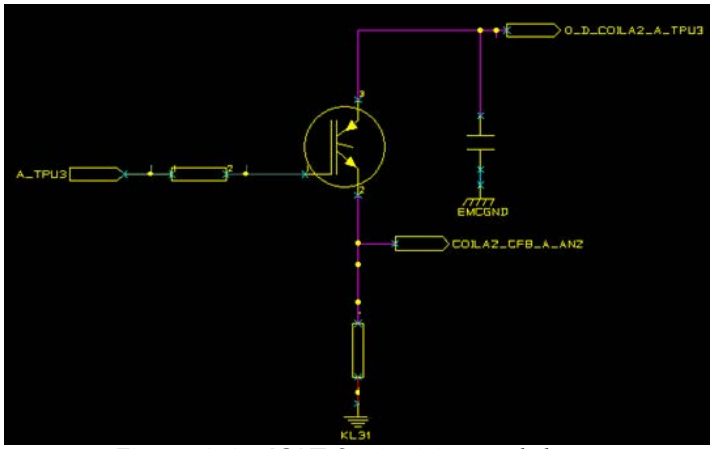


Figure 2.2 - IGBT for ignition coil drive

The board has every speed input signal conditioned, the ability to choose between variable reluctance (VR), and Hall-Effect (HE), sensor types for either CAM or CRANK positioning or speed sensing.

Figure 2.3 SHOWS CIRCUIT acquisition FOR CAM input from an HE sensor.

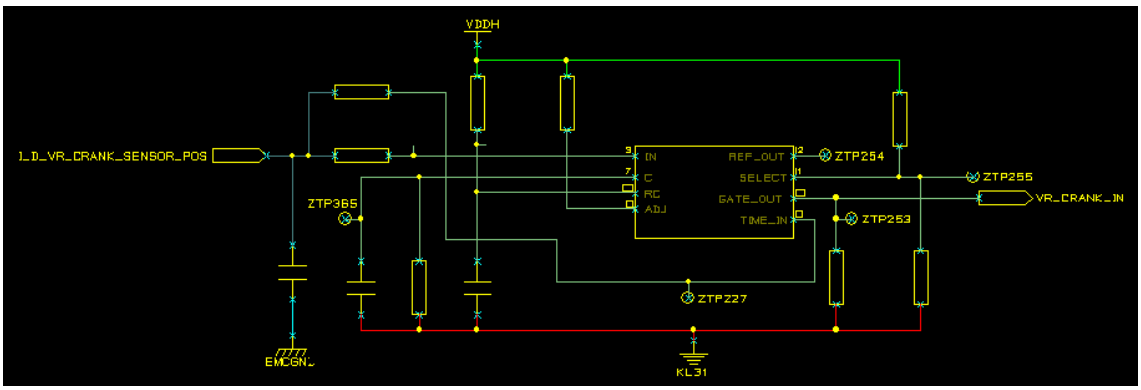


Figure 2.4 shows CIRCUIT acquisition FOR a variable reluctance sensor signal for CRANK signal (used in the test-rig).

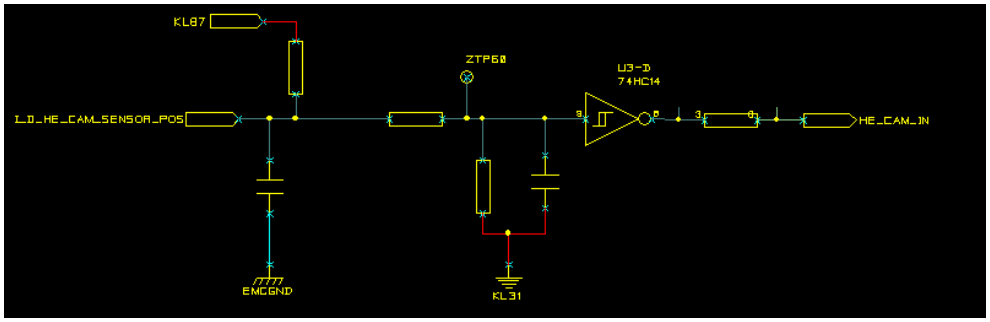


Figure 2.3 - HE sensor signal conditioning

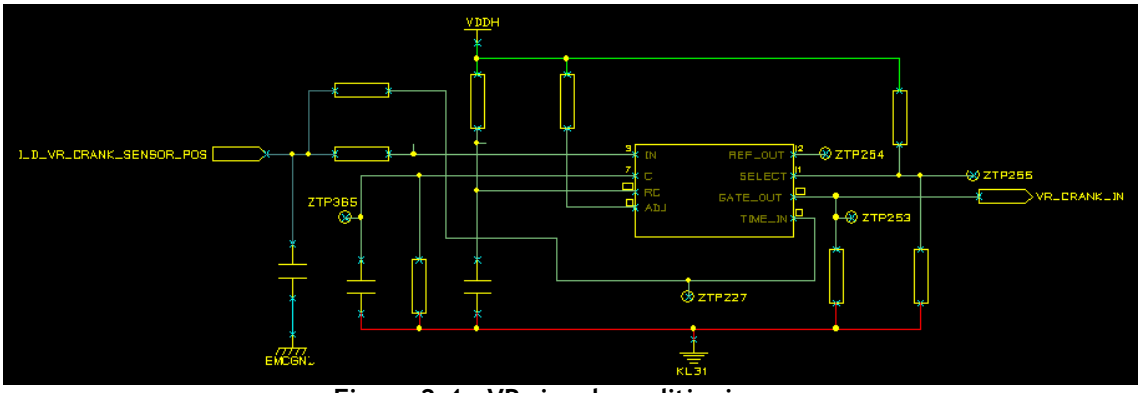


Figure 2.4 - VR signal conditioning

Main relays and fuel pump relay are monitored and controlled; these relays are normally low side drives.

There are three injector drives each one with four channels (one cylinder per channel gives up to 12 cylinders) and an H-bridge PWM output for controlling DC motor (used in this project for controlling the idle speed motor of throttle body).

The base board as the ability to interchange with different top boards which contains the microprocessors. Top board (called MPC5556 because of the used microprocessor) also includes a monitor processor, running a watchdog, that checks for correct working of the main processor and has the ability to shut the board down in case of a serious flaw.

Analogue inputs have pull-up/down resistors. Initially both for each channel are fitted, and the user needs to remove the correct one for their application and sensor used, although many times this can be solved by the software.

There are two classes of analogue inputs, slow and fast ones. These are determined by the analogue to digital converters (ADC) frequency.

Fast ones are related with safety critical measurements, for example, throttle position sensor, TPS, must be connected to a fast analogue input while the coolant temperature, CT, is connected to a slow one. It is easily understood that is necessary to monitor TPS much quicker than the temperature, the CT sensor has a considerable time constant (the engine's temperature doesn't have the ability to change drastically in few milliseconds) while TPS needs to be measured as fast as possible, in order to get the correct reading and provide fast actuation to prevent damages.

2.2 Wiring Connections

A new wire harness was built from scratch in order to provide the interchangeability between original controller from the car and the EMS-12. The wires coming out from the original ECU were interrupted and numbered, after a connector with 80 pins supported all the original wires. The similar was made to the other part of the wires, this time with a female connector. This way a point of disruption is created in the wires from sensors and actuators to the original controller.

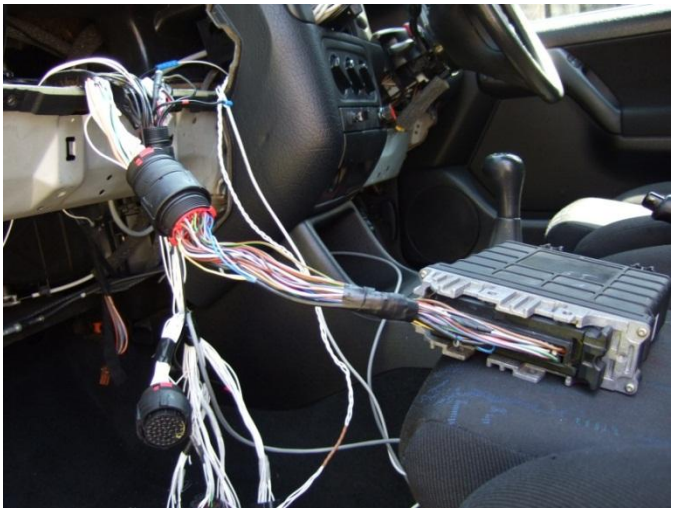


Figure 2.5 - Wire Harness with original controller

The next step consisted in producing the new harness to connect the EMS-12. On one end the connector is identically to the original ECU, allowing interchanging with all the wires existent in the car. On the other end of the harness all the wires had to match to the specific point in the EMS-12 and therefore match the right application (speed inputs must be connected to the speed inputs pins). The next figures demonstrate the relation between the existent ECU pins and the match in the EMS-12; notice that not all connections are used, since EMS-12 doesn't work with ABS system for example. A list of the new connector created is also shown, this connector was created mainly because the use of the new ignition system, which is non-existent on the original ECU, and with free space it was useful to connect the new lambda wideband sensor (O2) and some ground connections.

Some terms appear as simple KL15 KL30 KL87 or KL31, these terms refer to relays connection on the relay box and are widely used within the automotive industry, although some manufacturers may change the designation, in this case these terms should read as in Table2.1:

Table2.1— KL Designation.

Name	Designation
KL30	12V Battery direct connection
KL87	12V main relay feed (from relay box)
KL15	12V igniton switch
KL31	Ground connection (Battery)

ECU Pin No.	New connecto r Pin No.	Wire colour	Approx. Wire Size	Conected to ? On vehicle	EMS-12 Pin No.	Designation
1	1	Brown	1	Ground - Lambda sensor (White/Red pin1), Multiplug (Red pin17), Coil (pin1)	B1-18	ground
2	2	Grey	0,75	Injector Cyl.1	A1-3	Injector 4ms @iddle
7	4	Green/Red	0,5	Coil (pin2)	x	NA
8	3	Black/Red	0,5	Ign. ON 11.4v	A2-24	Low Side Drive Main Relay
9	5	(Black 3 Core) - Black	0,5	Knock Sensor (pin3)		ground
10	6	Purple/White	0,5	Ign. OFF 9.7v		NA
11	7	Blue/White	0,5	Ign. OFF 11.4v		KL15
12	8	Blue	0,5	Coolant temp sensor (pin3)	B1-25	CT Reading Sense
14	9	Red/Green	0,5	MAF Sensor (pin1)	B1-24	MAF Reading Sense 10V
16	10	Brown/Blue	0,5	Flywheel speed (Pin3)	A2-10	Flywheel Ground
17	11	(Grey 3 Core) - White	0,5	Lambda Sensor (pin4)	B2-17	Reading Sense
18	12	Grey/Yellow	0,5	TPS (pin3)	B2-19	Iddle Switch 12V (Not Fitted)
19	13	Green/Black	0,5	Ign. OFF 9.7v		10v when cranking
20	14	Brown	0,75	Lambda Sensor (Pin2)	Splice to B1-27	Sensor Supply
21	15	(Grey 3 Core) - Black	0,5	NOT CONNECTED Cut off at Lambda sensor connector		
23	16	Black/Yellow	1	MAF Sensor (pin3)	B1-27	MAIN RELAY 87
25	17	White	0,75	TPS (pin2)	A2-19	TPS MOTOR
26	18	Brown/Grey	0,5	MAF Sensor (pin2)	A2-8	Ground
28	19	Red/Grey	0,5	TPS (pin8)	x	Full Open Switch
29	20	Brown/Blue	0,5	Inlet air temp sensor	B2-2	Analogue Ground
30	21	Black	0,75	TPS (pin1)	A2-13	TPS MOTOR
31	22	Yellow Blue	0,5	Ign. ON 12.2v	A2-5	Fuel Pump relay Drive
32	23	Red/Green	0,5	NOT CONNECTED Main fuse box under drivers dash - Relay 167 (pin1)		NA
33	24	Green/Yellow	0,5	Purge valve (inner wing)		KL15
34	25	(Black 3 Core) - Blue	0,5	Knock Sensor (pin2)		NA
35	26	Brown/Blue	0,75	Distributor sensor (pin1), TPS (pin7), Coolant temp sensor (pin1)	A1-24	Ground
36	27	(Black 3 Core) - Grey	0,5	Knock Sensor (pin1)		NA
37	28	White/Yellow	0,5	Inlet air temp sensor	B2-16	Inlet Temp Sense
38	29	Black/White	0,5	Ign. On 12.2v, Reverse switch on T/M (Black/Red pin1), Speed sensor on T/M (Black pin1), Air Inlet temp sensor (White/yellow), Emmissions valve (inner wing, Black/White)	X	KL15
40	30	Red/Blue	0,5	TPS (pin5)	B2-18	4.2 Throttle and 0.8v Full Throttle
41	31	Red/White	0,5	TPS (pin4)	B2-20	TPS Sensor Supply
42	32	(Grey 3 Core) - Yellow	0,5	Lambda Sensor (pin3)	B1-19	Ground
43	33	Grey/White	0,5	ABS Module		ABS ??
44	34	Green/White	0,5	Distributor sensor (pin2)	A1-29	CAM sensor
45	35	Red/Black	0,5	Distributor sensor (pin3)	Splice to B1-27	Cam Sensor Supply
46	36	Grey/Green	0,75	Injector Cyl.2	A1-12	Injector 4ms @iddle
47	37	Grey/Red	0,75	Injector Cyl.3	A1-19	Injector 4ms @iddle
48	38	Grey/Blue	0,75	Injector Cyl.4	A1-13	Injector 4ms @iddle
67	39	Green/Black	0,5	Flywheel speed (Pin2)	A1-30	Flywheel Sensor
68	40	Red/Yellow	0,5	Flywheel speed (Pin1)	Splice to B1-27	Flywheel Supply

Figure 2.6 - Wiring connections table

NEW CONNECTOR 18PIN		EMS-12
Pin No.		Pin No.
1	Crank Sensor (-)	A1.31
2	Crank Sensor(+)	A1.22
3	Coil 12v	Splice to B1-27
4	Coil 1-4	A1.33
5	Coil 3-2	A1-17
6	KL30	B1-26
7	KL15	B1-29
8	Batt Ground	B1-17

Figure 2.7 - List of connection of new connector created with 18 pins

2.2 Test Rig

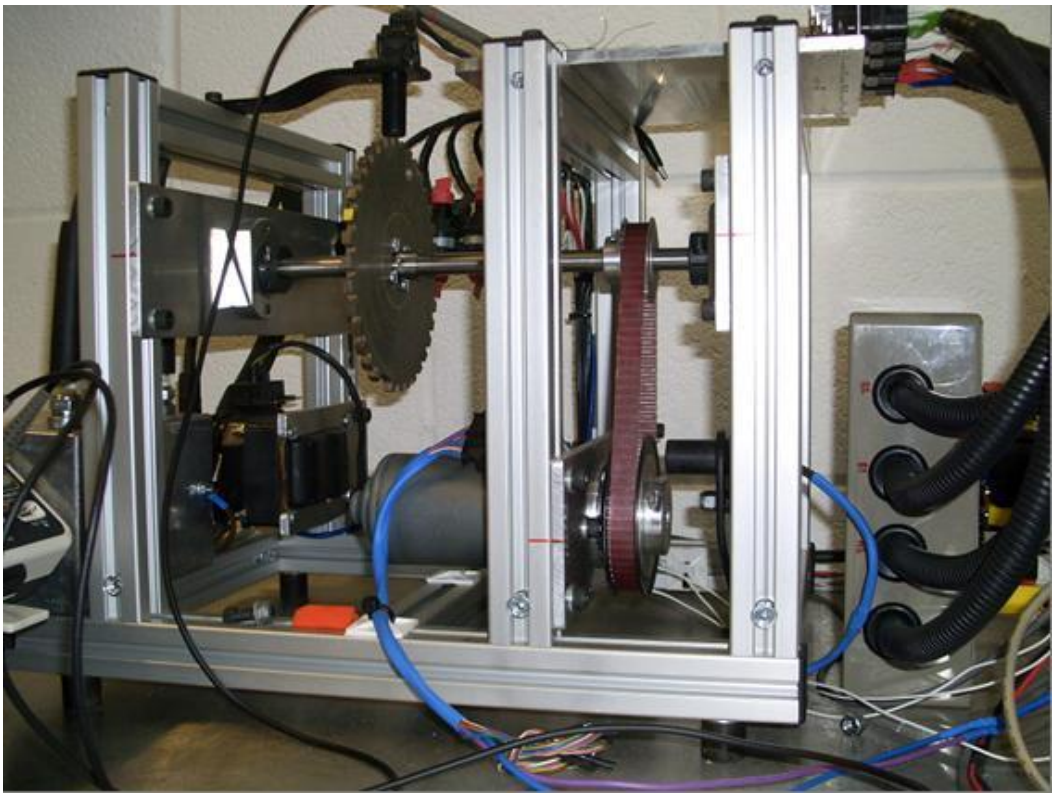


Figure 2.8 - Test Rig Overview

Figure 2.8 shows one of the most valuable pieces of hardware to the development of this project, the test rig. It was provided by the company since the very beginning of the project.

This test rig replicates a flywheel (that spins with engine's crankshaft), a time belt, and a camshaft and includes four spark plugs and four injectors. The flywheel and crankshaft are connected through a time belt again replicating the real car (Crankshaft has twice the frequency than Camshaft).

This allows that a great part of the structural software be tested in a safe environment. Absence of other engine parts, real fuel, oil or compression makes that every software error can be spotted without harming any valuable part of the real engine.

The test rig uses two speed sensors; these read the flywheel position and the camshaft pipe (the position indicator). These sensors are magnetic; the flywheel one is a VR sensor that generates a voltage and frequency across its terminals proportional to the magnetic field created in front of it. The voltage and the frequency across the terminals of a VR sensor will be directly proportional to the speed of the flywheel.

Due to toothed configuration of the flywheel the sensor will have discontinuities in its magnetic field, and this will create a discontinuity in the waveform as shown in Figure 2.10.

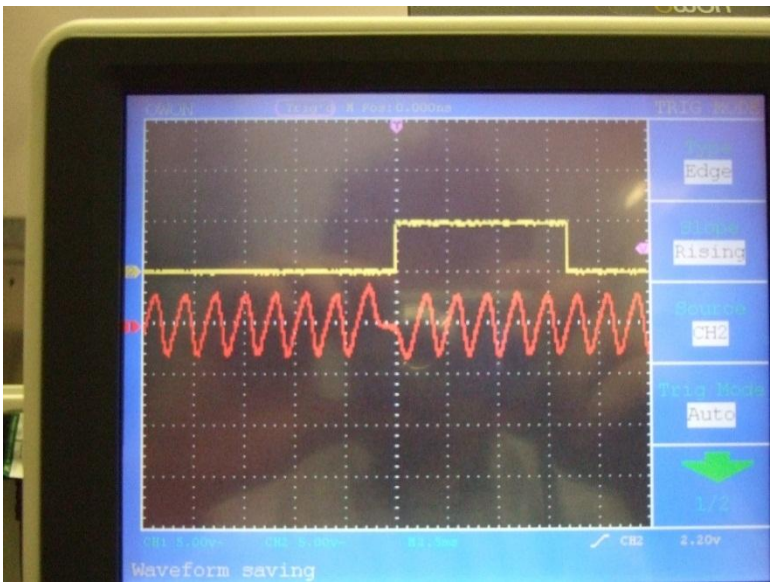


Figure 2.9 - Crank signal from VR sensor (red) and Cam signal (yellow)

The signal is then processed through on board hardware that shapes a square wave with same frequency of the sine wave but 0-5v so it can be acquired by the microprocessor; this is visible in the Figure 2.10.

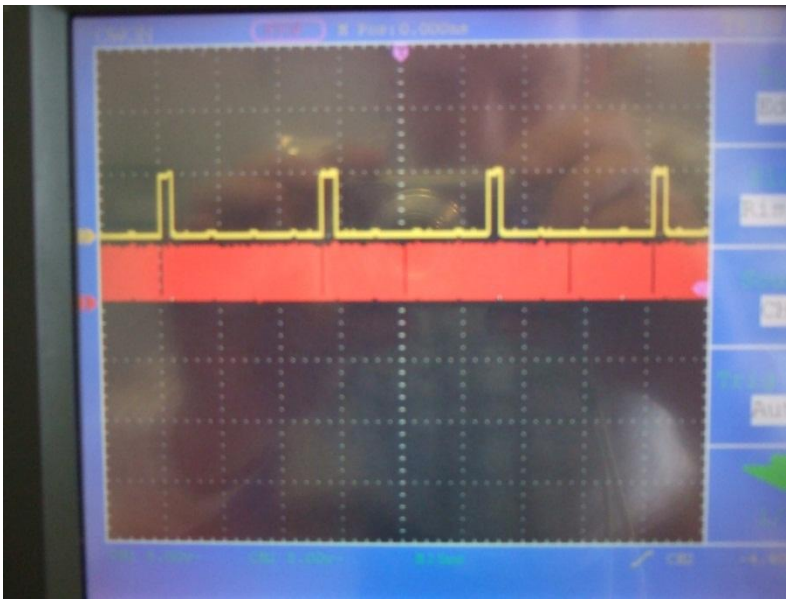


Figure 2.10 - Crank Signal (red) and Cam signal (yellow)

This type of sensor must use a shielded cable and the threshold voltages that determine the 0 and 5V of the output has to be defined, otherwise large variations with speed (and even with synchronization reads) may occur. The conditioning signal is applied with comparators that generates a square wave on the output with 0-5V. The VR sensor send an analogue signal and at lower speeds the voltage may be low therefore more sensitive to noise coming from other electric parts, that's why its important to use shielded cable and try to route the wires away from noise sources (such as wires for the spark plugs). The camshaft and crankshaft are connected through the time-belt. By the functional description of a four cylinder engine, where the piston reaches TDC twice every cycle (every four strokes) it's understandable that crankshaft rotates twice for each camshaft revolution. That's why an engine works in 720º cycles; each 360º corresponds to a crankshaft revolution and its reset by the camshaft. The software by "seeing" the camshaft knows if a piston is going up to compress the mixture or if it's going up to make the exhaust of the burned fuel.

This is important for synchronization of injectors and spark events. The sensor used on this shaft is a HE sensor. This sensor produces an impulse every time the metal part crosses the sensor.

This type of sensors is widely used in a very large range of industries.

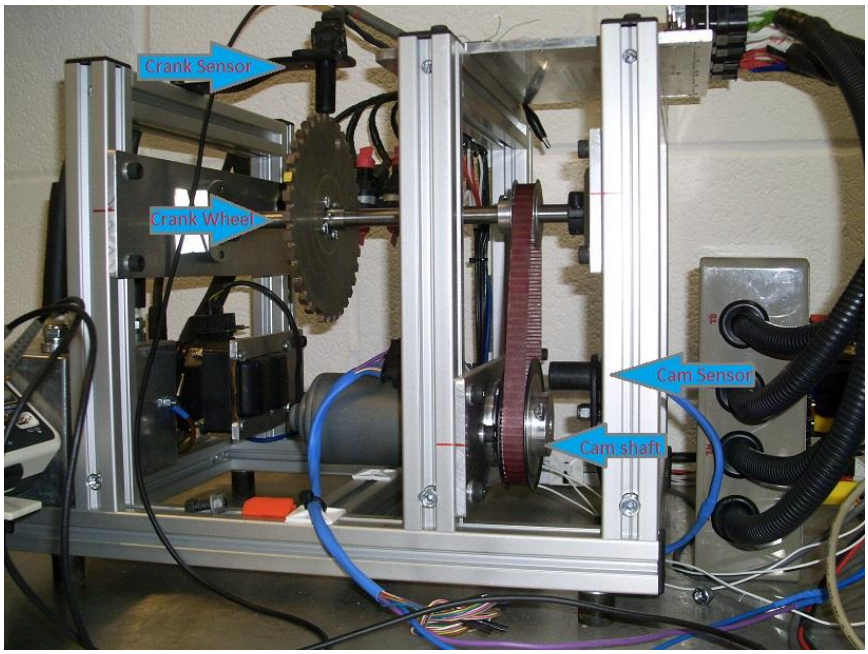


Figure 2.11 - Sensors Positions

The other parts of the rig are the actuators or outputs that generate the required movement, such as injectors and the coils for the ignition and spark plugs.

The motor that provides the movement of the parts to the test-rig and allows simulating the rotation of a crankshaft is a standard DC motor OEM (no specifications indicator). The speed is variable with the applied voltage across the terminals, and the torque required by the rig is negligible since the components on test-rig produces low amount of load. The motor speed in with the power supply maximum voltage (15V) is capable of producing circa 8000rpm which is enough for the tests taken. The rig is provided with an EDIS spark system which uses a wasted spark setup with two coils for 4cylinders Each coil is "fired" twice in each revolution, and every time it fires, provides a spark for two cylinders at the same time. This happens in cylinder 1-4, for one coil, and 2-3 for the other coil. In Figure 2.12**Error! Reference source not found.**, it is visible the event of 2 spark events before the cam lobe is detected, and two gaps in the crank reading (VR in this case) indicating that the crankshaft spins twice for every revolution of the camshaft.

The yellow trace represents the signal of the cam lobe appearing (one complete engine revolution), and the red channel, indicates the trigger for the spark events of one cylinder. As this is a wasted spark system there are two spark events on one cylinder for each revolution

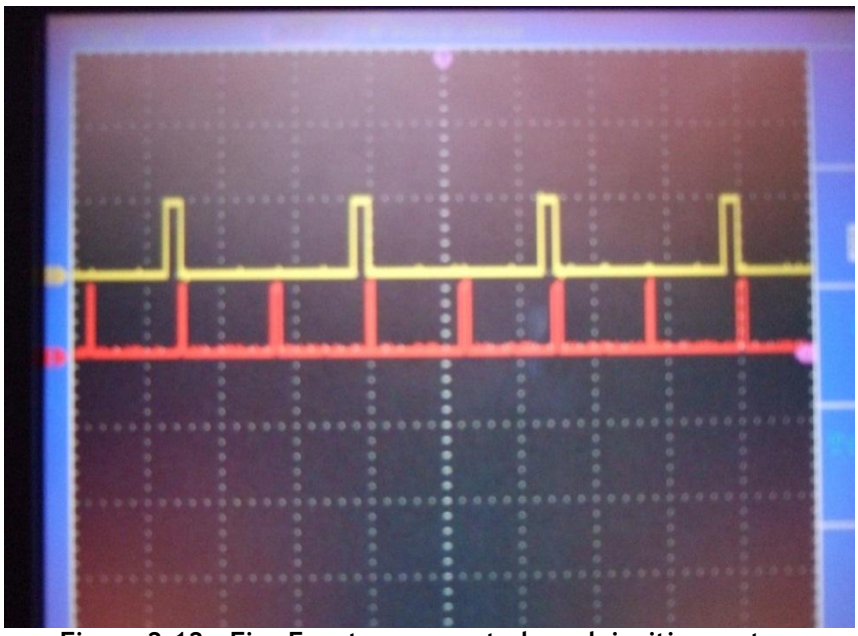


Figure 2.12 - Fire Events on a wasted spark ignition system

Note that when cylinder one is in compression cylinder four is in exhaust, so the spark on cylinder one will ignite A/F mixture while spark on cylinder four will do nothing. The idea is the same for cylinders two and three.

Again having this system on the test rig proved to be very helpful because allowed a huge amount of troubleshooting and bug checking, the ability to actually see the sparks, their intensity without igniting any fuel or create explosions is a very helpful iteration on development.

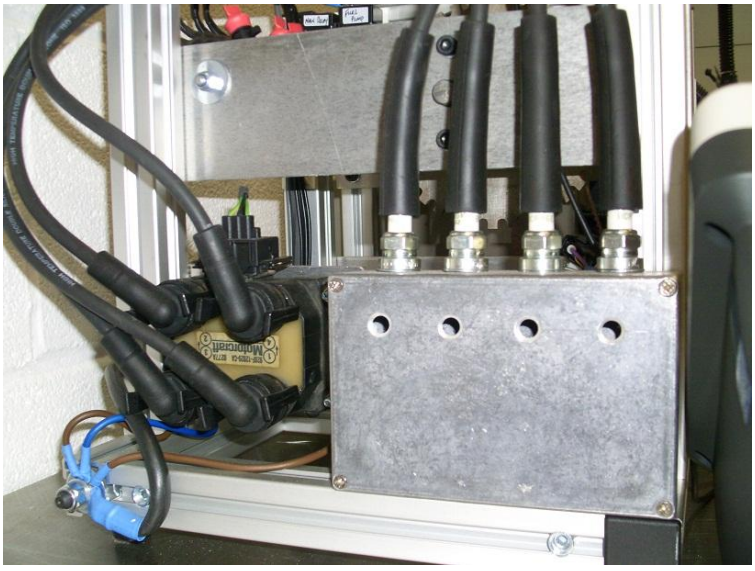


Figure 2.13 - Test Rig Ignition system

The rig has four injectors similar to the ones in the car; the injectors are electro-magnet valves. It helps for the project to put the figure all together and check the microprocessor outputs with the real parts connected. It serves as a debug tool as the injectors shall only be

actuated when synchronization is achieved, so it serves as signal of lost synchronization. In Figure 2.14 it's visible the pulses to injector drives, one can see that there is one impulse for each cam pipe that appears, again its shown that CAM signal is required to know what stage the correspondent cylinder is in. Without CAM signal the controller wouldn't know if that position was the explosion or intake (both times piston is going down).The power supply for the injectors is simulated by the fuel pump relay, which is non-existent in the test-rig. In order to make the connection of all parts to and from the microprocessor there is a connection box that replicates all the EMS-12 board numbered and a Control Area Network, CAN, connection lead.

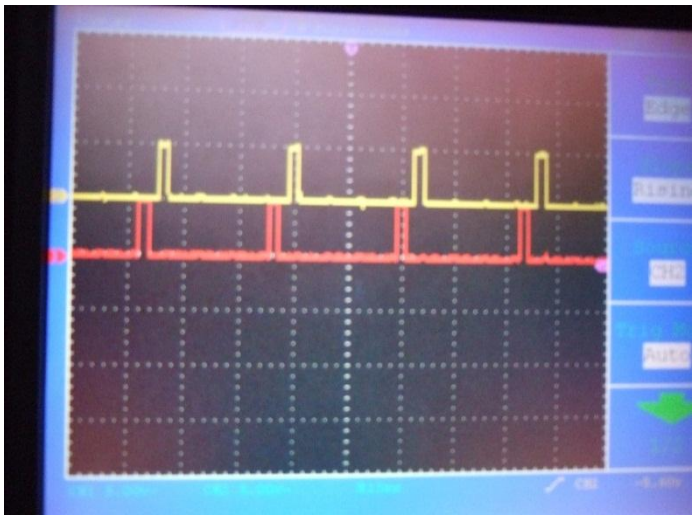


Figure 2.14 - Fuel Trigger (red) and Cam signal (yellow)

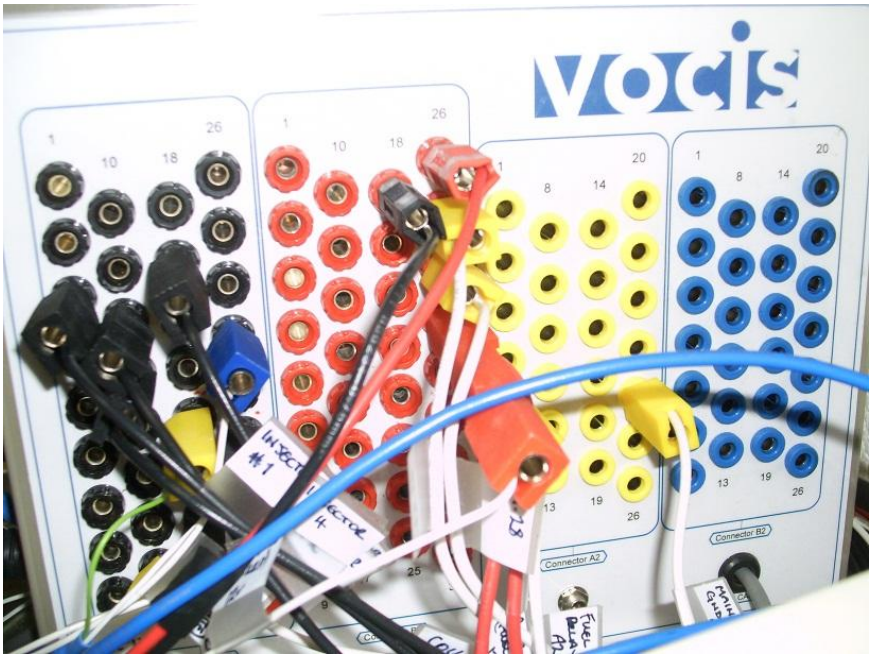


Figure 2.15 - Test Rig Connection Box

The first process was to write a piece of software that could read the sensors and indicate FULL_SYNC as position status, this would indicate that the microprocessor is reading the sensors correctly and the functions set-ups are correct. This process proved to be largely time consuming.

The EMS12 base board was designed on the early days of the company and wasn't object of new revisions creating some implications with the new MPC5566 top boards. So, the company has documentation in order to make correspondence tables between MPC555 and 5566.

2.3 Test Car

Figure 2.16 - Test Car

For this project the company acquired a Volkswagen Golf GTI 2.0 with a petrol engine, Figure 2.16.

Everything used is stock besides the ignition system. The car has an electronic multi point injection system with four injectors (one for each cylinder) injecting fuel once at every engine revolution.

Throttle body system with a DC motor to idle speed control. The throttle body has a position sensor (TPS) which is a variable resistance that changes with throttle position. There is the idle switch; this is an on/off contact that changes when the throttle passes by a certain point. There is a full open switch that indicates the maximum position of throttle is achieved.

A/F control uses a Mass Air Flow sensor, (MAF). MAF sensor is "Hot-wire" type. This type of sensor uses an in-built heater that creates a current flow through a thin wire. With the passage of air this wire will cool down, changing the current across its terminals.

Coolant temperature sensor, CT and Air Inlet Temperature, AIT, are thermistors, their function is relatively straightforward, they work as a potentiometer, or a voltage divider,

from a voltage reference from microcontroller (5V), by changing their electrical resistance with temperature the voltage drop across its terminals will vary, and a temperature dependent on voltage may be extracted. VR/HF speed/position sensors of the type used in the test rig, these are magnetic sensors that works by sensing electromagnetic forces across the sensor, the magnetic field originates a current flow in the sensor.

2.4 Set up

The test car used has a two litre (2.0) gasoline engine, normally aspirated (no turbo charged), four cylinder and 8 valves,

Figure 2.17.

Figure 2.17 - Engine Overview

By the time this project started the car engine was sitting out of the car to be serviced with a new time belt, new alternator belt, and general services in order to provide reliability for the upcoming tests.

The distributor was maintained so the change between the original controller and the one in development can be easily made. A new wasted spark two coil packs was mounted with new spark plug leads, this way we can change between either controllers in short time, Figure 2.18.

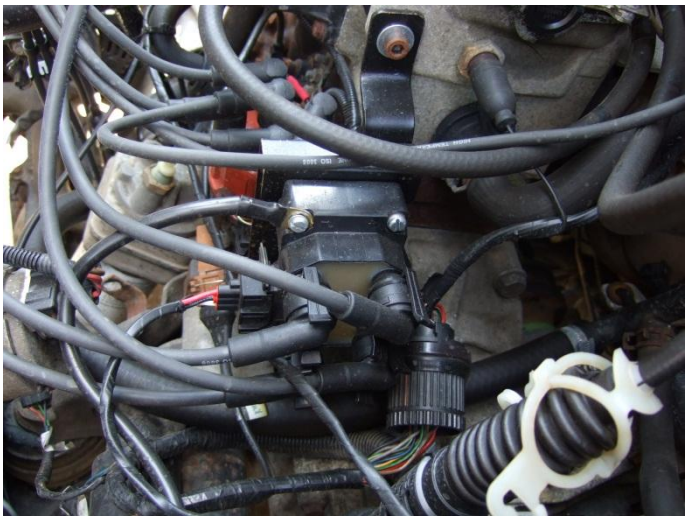


Figure 2.18 - Coil Pack added with distributor in background

The only difference for the test rig, is the use of the flywheel sensor as crank signal, this is mounted on a 60-2 (50 physical teeth and 2 missing teeth) configuration and uses a HE sensor type. The flywheel is mounted inside the engine case and it has a Hall Effect sensor as position/speed measurement. First it was being used an external crank wheel with a VR sensor, this toothed wheel is a 36-1 configuration but after some tests and problems identified the decision was to use the Volkswagen standard flywheel (mounted inside engine case) which proved reliable. The software is easily interchanged between the two configurations (36-1 or 60-2).

The process to start the car tests begun with the task to assemble the engine back into the car, and make all the old connections so the car run as normal state, this was very helpful because after this process we can conclude that any problems that could appear has to do only with the new hardware/software introduced.

After this verification was completed, the new task was to identify every wire from the old controller, this turns into a complicated task since many wires in a car electrical scheme are common or ends up somewhere connected to ground (as the car chassis for instance).

A new harness was created that allows the interchange between the old and new controller by just plug in/out as the wires were kept by the same order, Figure 2.5.

A multimeter and an oscilloscope were used to identify some of sensors signals and check continuity for new connections. This was a tedious job that required a lot of attention, since problems occurring from bad wirings are common but their source incredibly hard to identify after everything is in place.

Several new wires had to be added, for the new ignition system, for example, so a separate wire harness was created to keep the interchange ability between the two systems.

This new harness now contains some power feeds direct from car's battery ground connections and the connections for the new O2 sensor lately bought. Figure 2.19, shows the main specifications of the wideband 02 controller, this controller allows the output of a linear

0-5V output signal configurable, so the user can change the transfer function to allow different performances or to fool the ECU (making the Original controller think it's running lean leading to an increase of fuel injected and more performance).

The wideband sensors allow linear output, a straight line indicates the relation between the A/F ratio and the voltage output. The wideband sensor has the possibility of reading all the range of the A/F mixture (this sensor reads from 9.0 to 20).

This controller has the possibility of connection to a narrowband sensor. This type of output is highly nonlinear, and the controller just has the possibility to know if the mixture is reach or lean.

Figure 2.19 - O2 Sensor and main specifications

As we didn't have sensor's datasheets it was hard to know what throttle position matches a certain voltage. So tests were made in order to map sensors transfer functions. Scope and multimeter helped to extract valuable data. This was done for TPS, MAF and all other sensors.

To map CT and AIT, an external thermometer was used with the help of boiling and freezing water. This proved to be accurate enough for this experience.

Figure 2.20 shows the signal of the crank sensor at a start attempt. We can see engine speed versus time. The little "jumps" corresponds to compression of the cylinders that makes the starting motor slow down. When the engine finally starts speed immediately rises. This was one of the first tests made, that's why the crank time to the car start takes so long. The cranking speed is around 200-300rpm and it increases to 800rpm (engine firing and running).

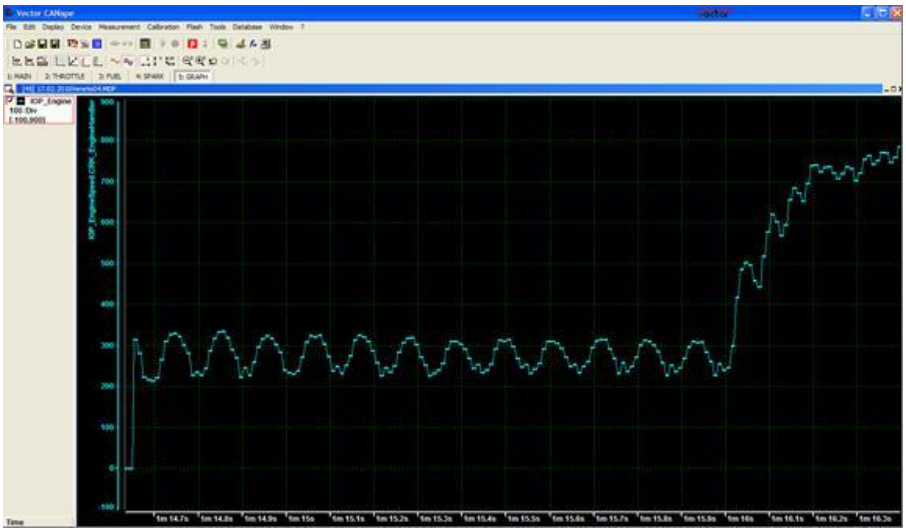


Figure 2.20 Crank Attempt

In this chapter the main hardware components are presented. The assembly and functional description are described, showing how the hardware is used, and the scope figures pretend to give some views on what the expected output should be.

The new wiring and engine assembly are described in this chapter, which is always a source of problems for troubleshooting in the future.

It is possible to view that the test rig, the car and the wiring are fitted and completed.

Following, the document presents the tools that served as support to create software for the above hardware.

Chapter 3

Software Development Tools

This chapter describes the tools used for debugging and creation of software in order to realize the project. Many of the programs listed here are widely common within the automotive industry. Some other tools are suited for the same purpose, but these ones were available and fit the purpose.

3.1 Lauterbach Debugger

An important tool provided for the first problems trace in software was the Lauterbach debugger.

With this debugger the user had the ability to check and change in real time the values of configuration registers on the microprocessor, and therefore do a quick debug of what may be wrong on software. On the first software versions that were built this was particularly useful as configuration errors cause the microprocessor to enter in restart mode, and it is impossible to detect problems without running step by step and analysing the important memory segments for flaws.

Some configurations of port bits and function assignments can be viewed by this debugger

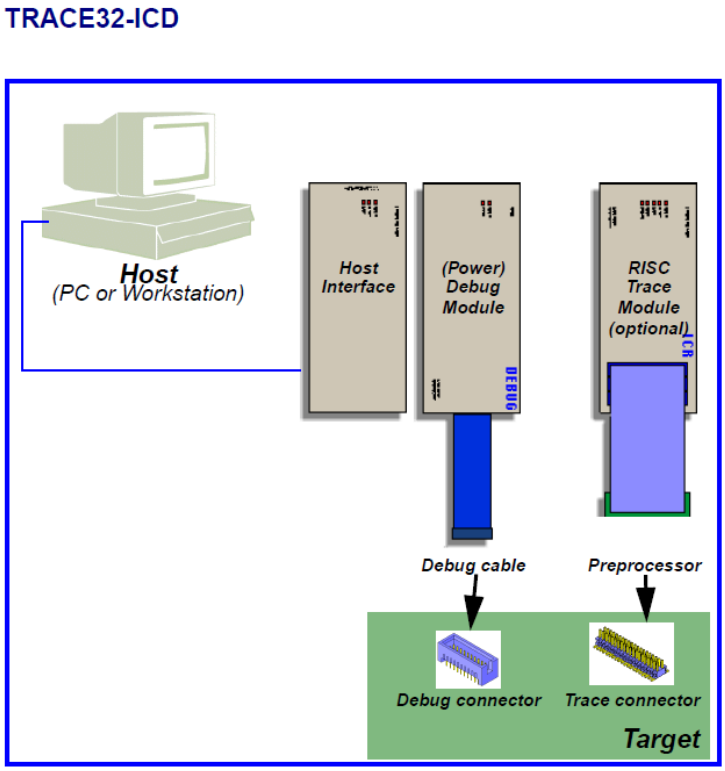


Figure 3.1 - Lauterbach

3.2 ETAS ASCET

ASCET is a family of software developed by ETAS (ETAS makes tools for automotive engineering)[8].

Vocis uses ASCET-MD (for Modelling & Design), ASCET-SCM for source and version control, and ASCET-SE (Software Engineering) which is the tool to auto-generate the code and help the engineer through the implementation (memory layout, data types, configuration of the compiler).

Most of software can be written directly in C code or another language, but, in most cases, in software created by the company it is written in block diagram. So, most of the code would consist in logical assignments and/or calculations. This is a block type language very similar to MATLAB/Simulink.

ASCET is not limited to writing code in block diagrams; in fact, it does everything that is needed to have complete ECU (Engine Control Unit) software. It is possible to build state machines, where this type of implementations suits better the application, for example for discrete events such as switching buttons or other.

A real example would be the buttons to select what kind of traction mode you need (Normal, winter, Sport, Track). ASCET also includes an experimental environment where code can be tested in real time. That is what we would call a Software-in-the-Loop system.

The biggest feature of ASCET is the auto generation of the code. When writing software for some automotive project, we have a lot of standards to respect. Those standards have been established because of safety critical aspect of everything that is done on a car. Any problem could cause a lot of trouble; some could even lead to the death of the driver. Anyone can understand the importance of reliable software while doing 70 mph on the highway. Those standards are called MISRA:C or MISRA:C++, and MISRA stands for Motor Industry Software Reliability Association [16].They have been established in 1998 and updated in 2004 by a committee composed of leading actors in the automotive industry.

When generating code with ASCET, you don't have to worry about all those standards as they are automatically implemented and checked, and the programmer will know that the standards are being respected.

One last important thing about ASCET is that when code is built, it provides an a2l file. This file is the database of every variable, every constant, every signal present in the software, with its address in memory and type of data. It is very important because it is thanks to this file that we can easily communicate with the unit.

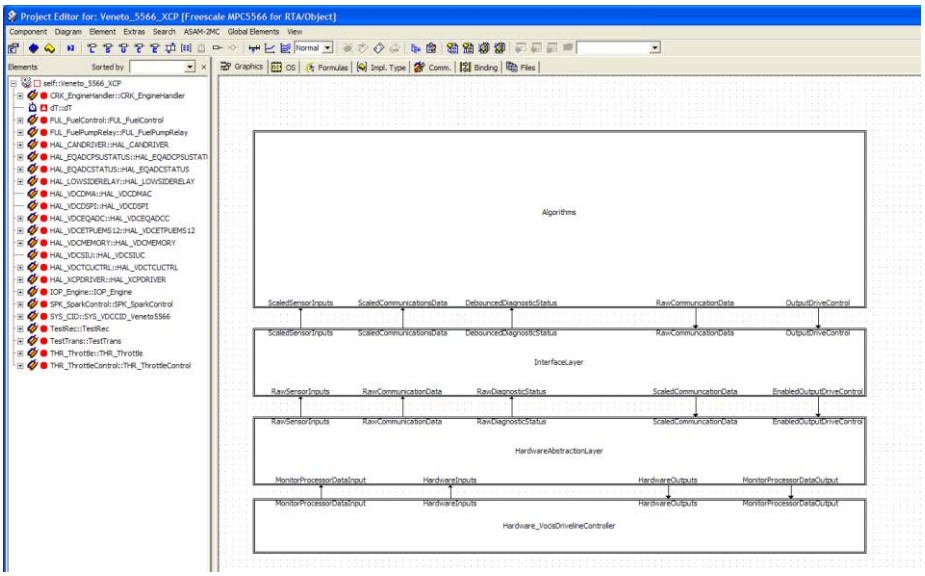


Figure 3.2 - Ascet project layers Figure 3.3 - Lauterbach

Figure 3.2 shows the architecture of every project and software created; there are 4 layers of software where the modules should be created and implemented. Used Vocis software is inserted on the first and second lowest layers, and represents the communications and raw data received through the sensor inputs and passed to digital values with the ADCs converters.

The software created for this project consists mainly on the “interface layer” and “algorithms layer”. The algorithms are the highest level layer and that’s where the control methods and computational work is done.

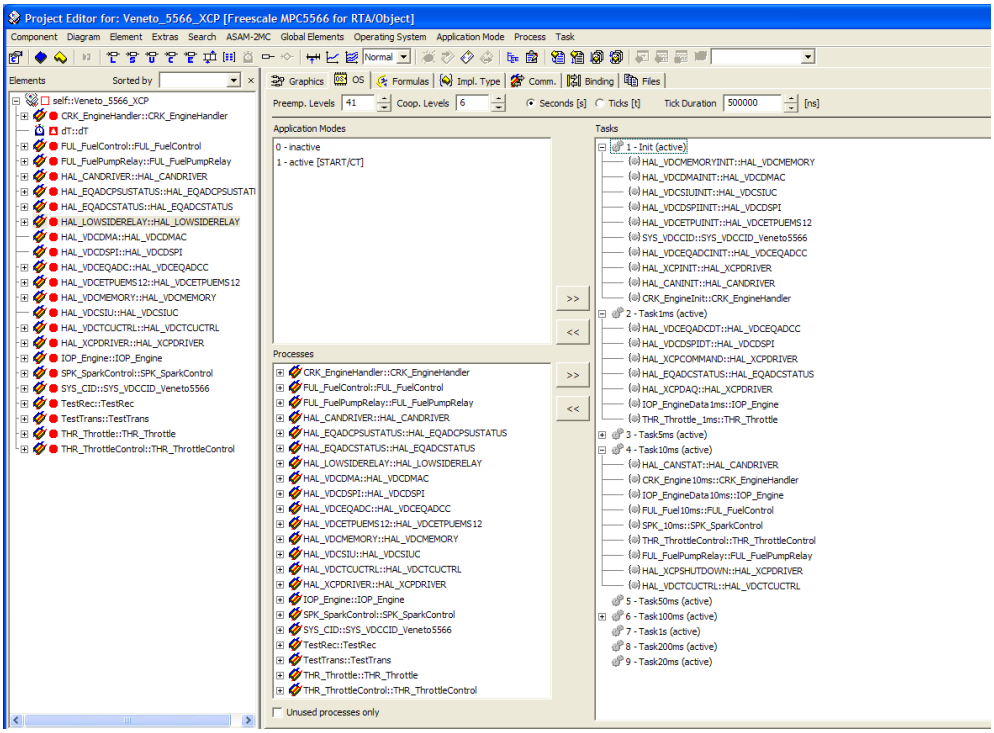


Figure 3.4 - Ascet overview of project components and OS process

3.3 VECTOR CANape

CANape is a software developed by Vector Informatik [6] a company created by three of the people who create CAN protocol back at Bosch. When developing an ECU, or any other type of controller, it is essential to be able to communicate with the unit. Even when the controller is placed in the car, it has to communicate with other controllers, send messages to the instrument board or with the on-board diagnostics computer. Together with the CAN protocol, the XCP (CAN extended Calibration Protocol) is used to access all the calibration data of the ECU. With this protocol, one can have access to every signal that is used in the software.

Basically, that is what the software CANape is doing. The signals to monitor are specified in a list, then CANape is looking up this signal on the database to know at which address in memory it needs to look, and then display the data to the user in a graphic or numeric form.

It’s a complete calibration and diagnostics tool.

On next figure it is visible a standard configuration page of what can be done with Vector CANape. From the left hand side, it is visible the raw data read by the microprocessor, with

the centre correspondence to physical variables, after being calculated through transfer functions within the software. On the right side there is some status variables with strings which are called enumerations, this allows to pass numerical codes to words easily identifiable by the user for instance one can read CRK_ENGPOSSEEK which states that engine position is unknown to the microprocessor instead of the status code “0”.

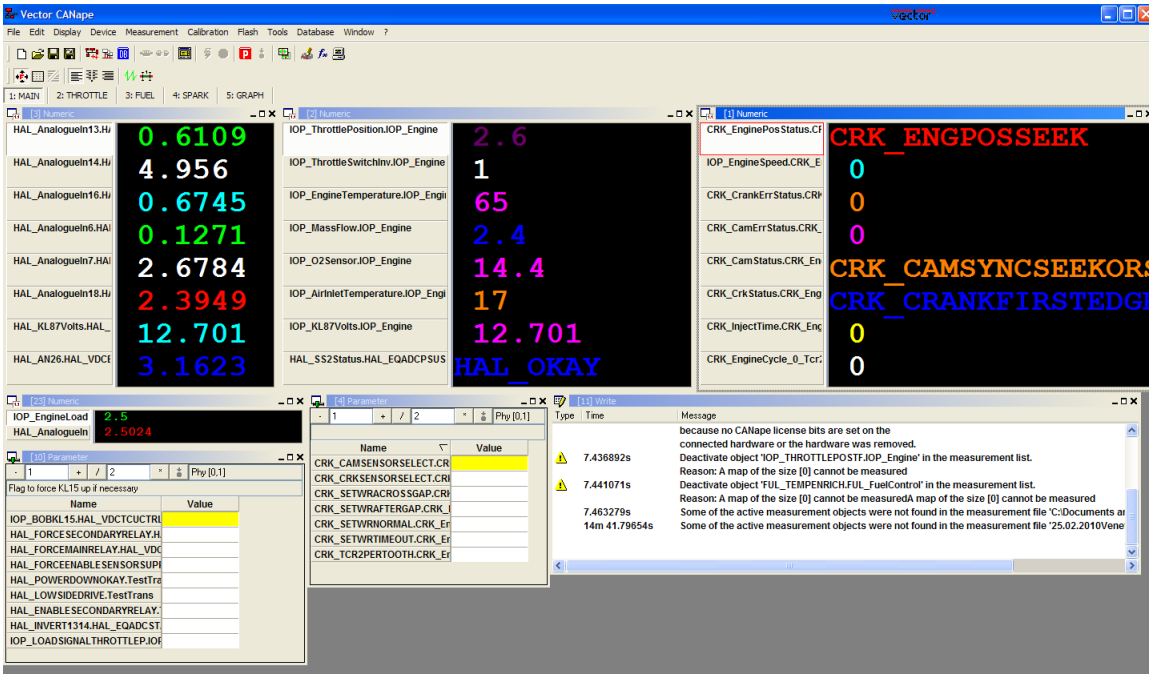


Figure 3.5 - CANape set up to understand what is happening

With these tools, it is possible to generate virtually almost any application and consequently make the debugging and calibration of an automotive application. These are high-end software tools for code generation and calibration of software for the industry.

Next the microprocessor which serves as target for the applications created on the previous tools is presented. Also the group of functions specifically created for the automotive industry are described.

Chapter 4

Microprocessor and Automotive Function Set

This chapter contains information related to microprocessors used on automotive industry and their main characteristic. A brief description on some available functions for basics commands in engine control is presented.

4.1 Microprocessor

Freescale semiconductors are a benchmark for the automotive industry, their microprocessors are widely used in every branch of the industry and their reliability makes the very demanding business sector trustworthy. The microprocessor which on the actual days is a true brain for the car used within this project is the MPC5556 [2].

Freescale provides some function sets of preconfigured functions for use in automotive industry (other sets are available for brushless DC motors for example). The various application notes provided by freescale were a precious help in understanding the function set, and how to use it for this application.

4.2 ETPU Engine

The MPC5566 has several cores that deal with specific computational work, the main host is what keeps everything alive, but for this type of application the most important core is the enhanced Time Processor Unit (eTPU). Freescale provides a C-array compiled code that is copied into the main host processor. Each function has a number that identifies it and the channel assigned to each function will have the correspondent function number.

As described below, from the MPC566, these are the key features of an eTPU.

- Execute programs independently from the host core
- Detect and precisely record the timing of input events
- Generate complex output waveforms
- Enhances the CPU with time processing without requiring real-time host processing

The host core setup and service times for each input and output event are greatly minimized. The eTPU improves the performance of the device by providing high-resolution timing:

- eTPU dedicated channels include two match and two capture registers (TPUs had one).
- eTPU engines are optimized to service channel hardware
- Fast instruction execution rate of the eTPU engine reduces service time

Because responding to hardware service requests is primarily done by the eTPU engine, the host is free to handle higher level operations.

The eTPU is a real-time microprocessor subsystem. Therefore, it runs micro engine code from instruction memory to handle specific events and accesses data memory (SDM) for parameters, work data, and application state information. Events can originate from I/O channels (due to pin transitions and/or time base matches), device core requests, or inter-channel requests. Events that call for local eTPU processing activate the micro engine by issuing a service request. The service request microcode can send an interrupt to the device core, but cannot directly interrupt the core using I/O channel events.

Each channel has a function that consists of a set of micro engine routines, called threads that service eTPU requests which define the channel's behaviour. Function routines, which reside in the SCM, are also used to configure the channel. A function can be assigned to several channels, but a channel can only processes one function at a given moment. The eTPU can change the function assigned to a channel if the channel is reconfigured by the device core.

The device core configures the function to channel assignments. The following eTPU hardware supplies resource sharing features that support concurrency:

- A hardware scheduler dispatches the service request micro engine routines based on a set of priorities defined by the device's core. Each channel has its own unique priority assignment that primarily depends on CPU assignment. The channel's number is an inherent property also used to determine priority.

- A service request routine cannot be interrupted by another service request until it ends, that is, until an end instruction is executed. This sequence of uninterrupted instruction execution is called a thread. The core can terminate the thread by writing 1 to the FEND bit in the ETPU_ECR register.
- Channel-specific contexts (registers and flags) are automatically switched between the end of a thread and the beginning of the next one.
- SDM arbitration, a dual-parameter coherency controller, and semaphores can be used to ensure coherent access to eTPU data shared by both eTPU engines and the device core.

4.3 eTPU Position (CRANK and CAM) functions

The position of a piston in an internal combustion engine is determined as an angular position relative to Top Dead Centre (TDC). All the calculation regarding engine control to a specific cylinder are made knowing its angular position. A piston moves in a linear straight line, so it may cause some confusion the fact its position being measured in degrees.

This happens because the only way to know the actual position of a piston is to read the movement of the crankshaft, which presents rotational movement therefore angular variations, the crankshaft has a solid connection with the piston therefore have a direct correspondence with the linear movement of a piston.

Each engine has a specific construction value, which relates the TDC of the cylinder number 1 to a specific angular position of the crankshaft. This position will match another well-known and specific position of the camshaft.

The microprocessor, and the automotive function set available from freescale, has two functions that work together in order to acquire and maintain a read in engine position at all time. CRANK function is responsible to read every tooth from the rotational crank flywheel, and the CAM function detects and stores the angular position where the CAM pipe appears.

CRANK function starts detecting the teeth and when a gap is recognized, it changes the position of motor to HALF_SYNC, this means that crank position is known, engine control can be made without major danger, but it is not advised since one can’t know if the engine is in its first or second 360º turn.

Once CAM function detects camshaft position and informs CRANK function of its position, the engine position changes to FULL_SYNC, from this moment on, the complete position and cycle of every piston is known. For example, cylinder 1 is at explosion and escape at TDC, and only with full synchronism between the two functions one can tell which time is which.

Both functions belong to the available function set at freescale, and their result can be accessed by the function fs_etpu_eng_pos_get_engine_position_status().

In any moment if the synchronization is lost by any reason the status changes and the software should be constantly reading this function to act accordingly if sync is lost.

This function (CRANK) supports two different crankshaft wheels, 36-1 or 60-2 which indicates that the toothed wheel will have 35 or 58 physical teeth and one or two missing; there are special layouts of some manufacturers that allow different control techniques for re synchronization and other extra things that may be required.

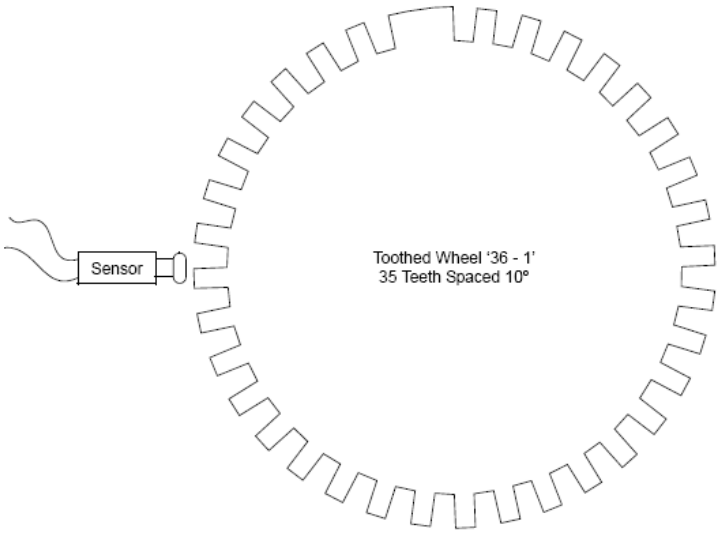
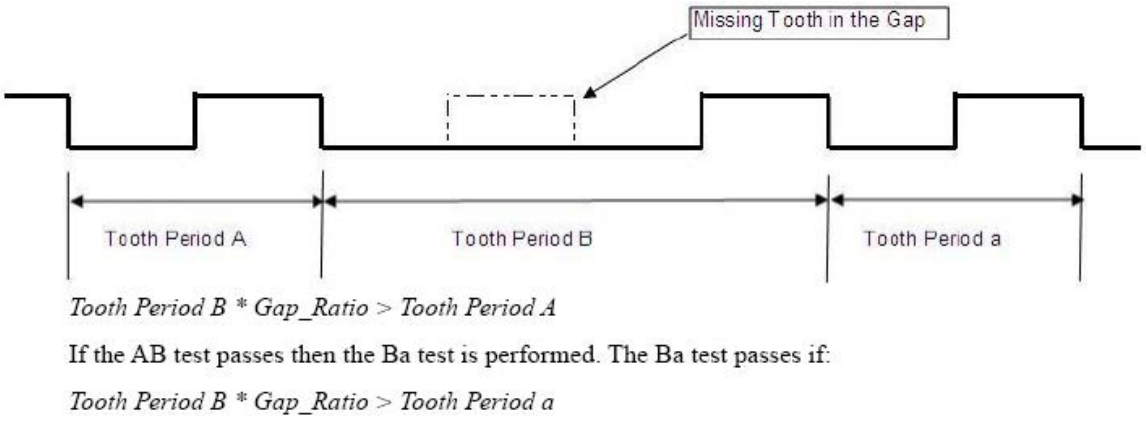


Figure 4.1 - CRANK position wheel 36-1 configuration

The function has the ability to make gap tests in order to verify the position and synchronization. There are a lot of initialization parameters to be careful with. This function dictates the good behaviour of every other function used in this project. The function uses previous tooth period and defined ratios to assure the gap has been found. These ratios are very important and it was one of the initial problems to solve between the test rig and the car.

On cranking, the engine speed changes every quarter of a revolution due to cylinder compression. So, starting motor slows down and this can create problems if the compression corresponds to the gap. To bypass these problems ratios must be specified. Ratios allow the software to distinguish from gaps between normal teeth, the gap and the first teeth and tooth after the gap. They are used together with previous periods of detecting teeth, and guarantees correct behaviour in accelerations and decelerations.



*Tooth Period B * Gap_Ratio > Tooth Period A*

If the AB test passes then the Ba test is performed. The Ba test passes if:

*Tooth Period B * Gap_Ratio > Tooth Period a*

Figure 4.2 - Gap test

4.4 ETPU FUEL function

The application describes this as follows. The FUEL eTPU function generates one or more fuel injection pulses and thus controls the amount of fuel in the intake manifold. Fuel injection pulses start at a calculated engine cycle angle (0–720 degrees) based on a specified end angle and the amount of fuel required. Multiple additional injection pulses are allowed.

Injection time for the last engine cycle (per cylinder) as well as the total injection time over all cylinders is stored. The eTPU synchronization functions, CAM and CRANK, provide angular information to the FUEL function.

Figure 4.2shows the behaviour of the fuel function and the main parameters used to the execution of an event for fuel injection into the intake manifold. This is the simpler form of an injection pulse, and this is the form used through the application created.

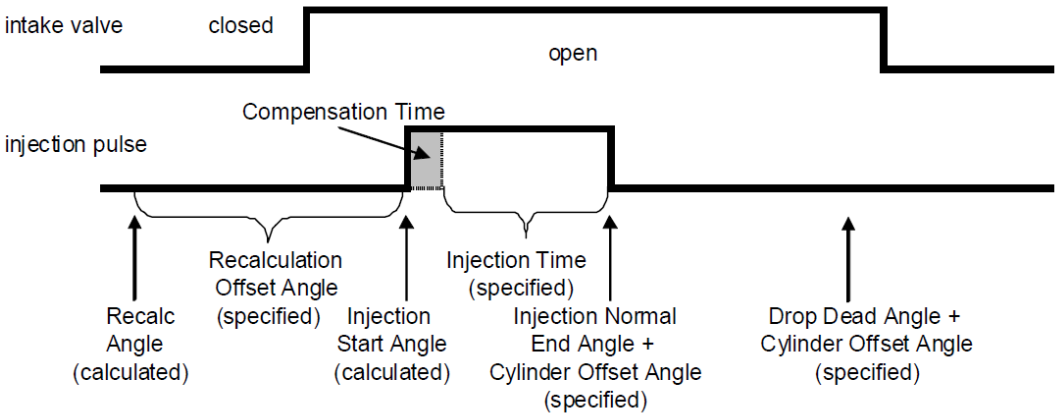


Figure 4.2- Time diagram of a simple injection pulse

It's possible to create more complex events for fuel injection. These methods are used in complex control systems for direct injection and air/fuel mixture stratification processes.

The FUEL function guarantees that no fuel is injected after the drop dead angle, which corresponds to the angular position of closing the intake valves specified for that cylinder, even if it's requested more fuel. So while this angle is not met, the user can configure and change injection times for different types of requests, for example for fuel economy and efficiency. Figure 4.3 shows a direct injection event, with one pulse serving the wet wall stage and multi pulses cause mixture stratification. Stratification occurs when the gasoline and air are not completely mixed. This means that there are layers of air and layers of fuel. This allows a better fuel efficiency since allows the combustion and explosion in poorer mixtures producing the same torque. Some systems even work to create geometry favourable to combustion inside the cylinder chamber. The opening of intake valves and the direct fuel injection works so the air flow creates space so the fuel sits closer to spark in order to make the ignition and combustion easier.

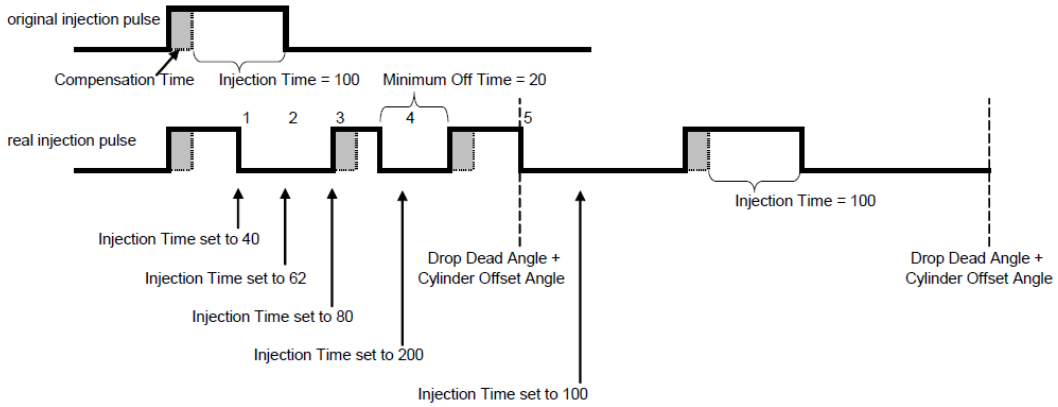


Figure 4.3 - Complex fuel injection pulse

The eTPU channels assigned with this function are linked to the CRANK function by the CRANK_LINK parameter; this allows the channels to be disabled in case an engine stall occurs.

This is important for safety reasons. This function is time based opposite to the Spark function which is angle based.

There is the possibility to change in real time the specification of each fuel event, but many of the parameters are for initialization only and they must be correctly specified such as cylinders offset angles and crank channel for position recognition.

4.5 ETPU SPARK function

The eTPU SPARK function initializes and controls the generation of spark pulses synchronized to specific angular positions of a rotating engine, thus controlling ignition timing of the engine. The function outputs one or more spark pulses during each complete engine cycle without CPU intervention. The properties of these pulses are programmable, and update functions allows for the pulse properties to be changed during runtime.

The SPARK function supports the generation of either one or two main spark pulses per 720° engine cycle, as well as optional multi spark pulse generation.

Minimum and maximum dwell time enforcement, selectable output polarity, and asynchronous updates are also provided. Dwell is effectively the time that the circuit remains closed charging the coils.

The most important and easy to understand parameters of this function are explained on the following figure. The min and max dwell times, guarantees that the coil charging times are never smaller or greater than these values. They serve as absolute maximum values.

The Recalculation offset angle is a derived parameter, this is because this function works in angle based, so it has to calculate the angle when start charging the coil to give an event at a specified angle, it has to use engine speed for this, and every event requires that the start angle is derived accordingly to the engine speed and end angle.

The control software has no control on the position where the coils charge starts, it only specifies the dwell time and spark angle, the eTPU SPARK function is responsible to every engine cycle determine the exact position of start angle in order to guarantee the parameters specified.

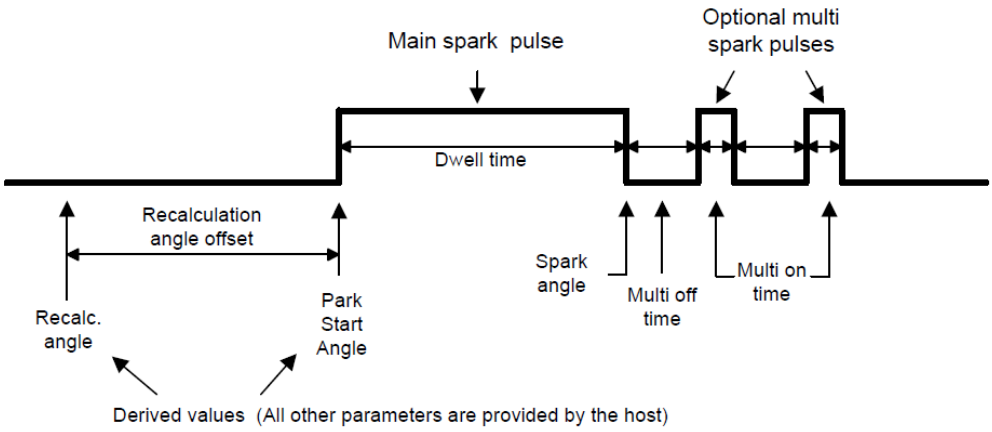


Figure 4.4- Spark Event

The link with CRANK link provides the information about acceleration and deceleration by means of a counter set to a high frequency and records counts per tooth, the changes in this variable indicates if the speed increases or decreases.

With this chapter it's expected to give an overview on the freescale 32bit microprocessors used on the automotive industry.

The automotive function set, allows the user to quickly set-up the base of the functions to control an internal combustion engine.

After the comprehension of the previous chapters as the base for the understanding the subject in study, the hardware and the tools available, the control algorithms implemented are presented and some strategies followed described.

Chapter 5

Implementation

The process of software creation is dealt in this chapter. Some cautions in create software for safety critical applications are explained. All the algorithms created specifically for this application are described.

5.1 Software Requirements

The first software for the controller was written in C-code and served to test operation of eTPU functions. Most part of initial steps consisted in understanding and being able to correctly operate the eTPU function set from freescale for automotive applications.

Vocis created a large part of the initial software needed to use on this project: configuration of microcontroller base registers, input/output ports, ADC sampling and conversion rates and values where configured from previous projects and are property of Vocis, Ltd.

ASCET stores all data (such as algorithms names, values, parameters etc) as a database. This allows the export and import of previous models into new projects and the user can reuse some models from previous projects. For example is the hardware is the same, the user can use the configuration models and the can communication setup and start creating control algorithms for a new project.

The company owns a MKS server to keep records and history version of all software created inside it. For security and confidentiality reasons students can't access to this server, so it's impossible to change any of the software created by employees, but every module needed was provided in an offline environment.

The EMS-12 was design to use a top board with the MPC555 microprocessor, but with the migration to the MPC5566, some problems arise. Main connections had to be kept in place but

some ports and channels are interchanged with this microprocessor. For that an excel file containing corresponding channels from the 555 to the 5566 was provided. With this it was possible to start configuring the channels needed to correctly configure the MPC5566.

From the initial configuration some changes had to be done in the SIU configuration. This part of microprocessor is responsible for defining the task for every pin. The Lauterbach debugger was a precious help on this matter since we can see bits value at register levels, so it's easy to spot errors and miss configurations.

In order for the company to comply with standards for software creation for automotive industry, many rules were to be learnt by persistent failures. For an inexperienced software writer many of the rules seem dull and meaningless, but as the same inexperienced software developer may learn they were very useful in the future.

As described the software is written in modules, so it can be easily understood and complex programs easily read. There is an imposition that every variable created within a module has a three letters prefix stating the module where it was created. For example IOP_EngineLoad, is created on the module IOP and although is used in many parts of the software this indicates that if anyone wants to see anything related to this variable should go to that block.

There are several types of data in a program; the most common in this software are variables and parameters. Another important rule is the naming of these two different types of data. Every variable has the prefix and then is written as a normal word or set of words together (IOP_EngineLoad), while the parameters are compulsory written in capital letters like THR_THROTTLEIGAIN. This is very important in large and complex programs, since in the development chain there are people writing software and other people doing the calibration (controller gains, maps, transfer functions) so to avoid mistakes a code name is used so anyone can easily identify what type of data is dealing with.

Other thing is the implementation definition. ASCET works with physical values, and all the values represented are physical measures (for example time, temperature and so on). In order to have enough resolution normally an implementation is created where the writer gives the order to ASCET to use values greater than the physical ones so the computational work is done with more resolution. Is another mandatory rule for developed software that every single variable, parameter and table is implemented with meaningful values and acceptable resolution. In many cases the compiler accepts and warns that the resolution will be changed to fin in variable range, this should be carefully looked by the software writer and according modifications should be made.

There are a lot of rules to comply the listed above are just a small idea of the kind of things that may seem pointless but are very useful in safety critical applications

Figure 5.1 shows a formula editing that will be used to give resolution to the InjectTimeRatio variable. This allows the time of the last injection be presented in

milliseconds with microsecond resolution. CPU frequency is 16MHz so you need to multiply by 16000 to have milliseconds. On background it is visible some other formulas used within the project.

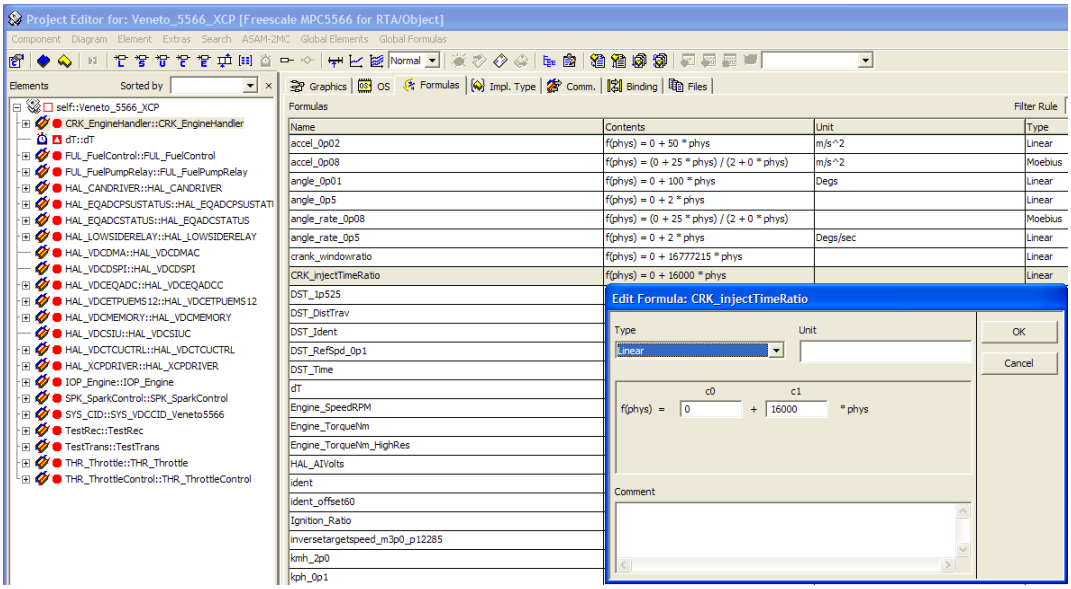


Figure 5.1 – Formula edit in ASCET

5.2 Fuel Pump Module

The fuel pump is responsible for providing fuel rail pressure so when the injectors open fuel is injected into intake manifold. The fuel pump should not be ON permanently for obvious reasons, such as overheating, battery consumptions, and safety reasons with fuel pressure.

The fuel pump is started when the conditions for fuel request are met. For example if the crank speed is different from 0, the fuel pump starts.

When the fuel pump stops being requested, for example the engine stops, it waits 2seconds until switch off.

This allows that for a really quick stop in fuel demanding the fuel pump is not off, the state diagram of the fuel pump is described in Figure 5.2.

Figure 5.3 represents the module created in ASCET to make this control. If engine speed is greater than 0 or if the engine position status is different than POSITION_SEEK (which has the code 0) then the fuel is ON.

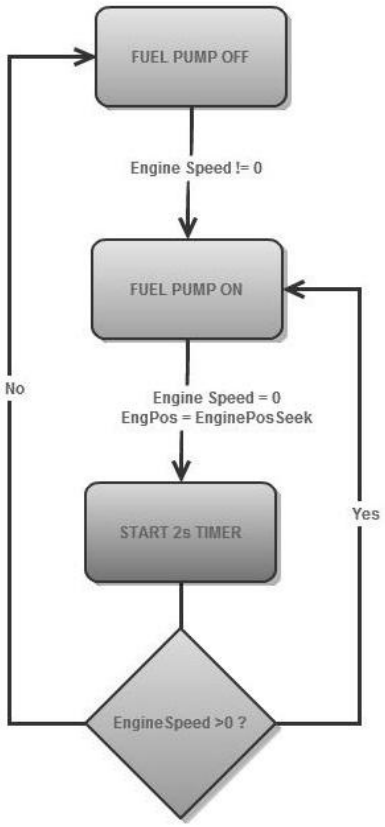


Figure 5.2 - Fuel Pump State Diagram Figure

The message FUL_FuelPump is the output and is a logical variable. Whenever FUL_PumpRelayTime is greater than 0, the fuel is ON.

If those two conditions are not verified, the timer will be decremented until 0; otherwise it keeps being fed with a static value which will maintain the pump ON.

The output will drive the fuel pump relay in the relay box of the car; this relay is a low side drive. Notice the sequence calls, the output is the last task done in this process (you can see on bottom of the left hand pane the processes names) and this process is added to the 10ms task in the microprocessor's operating system.

Notice the variable names and parameters follow the rules imposed inside the company for software writing, all variables as a prefix that corresponds to the module they belong to and the parameters (that can be changed in real time by CANape) are always capital letters

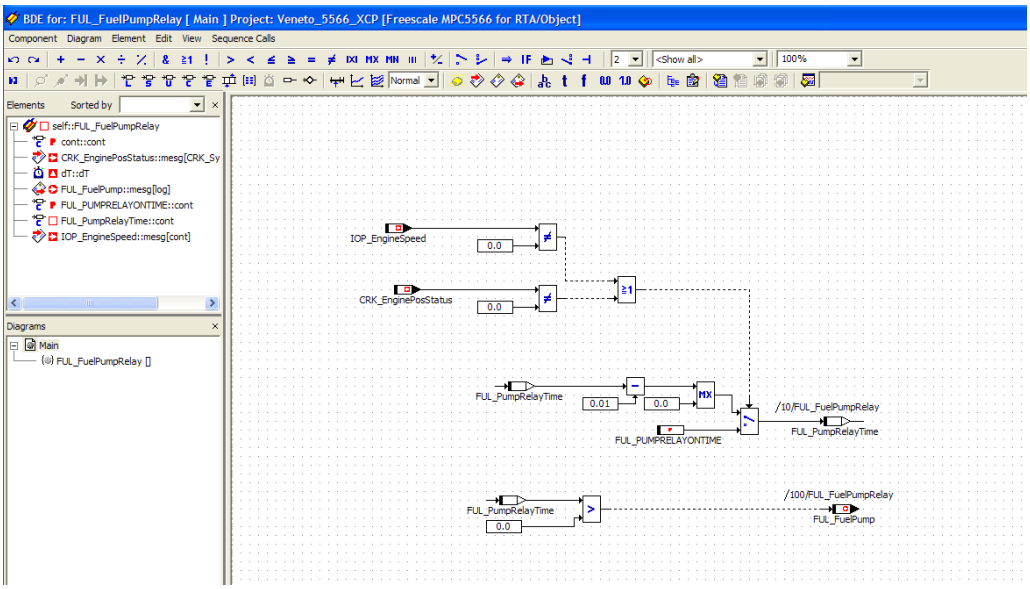


Figure 5.3 - Fuel Pump Relay Control

5.3 IOP Module

IOP module represents the input output processing module. In this module raw data is acquired in terms of voltage and the data treatment takes place in order to give a meaning to those values. The software in ASCET and within the company (and generally in the automotive industry) is processed in physical values. For example, a variable resistance measuring the coolant temperature gives an output of 0-5V but in the software that has to correspond to -45 to 130 degrees.

In this module values from analogue to digital converters (ADC) are treated and passed to meaningful physical values. So, software from this point on makes more sense and it's easy to follow.

Analogue inputs received from ADCs modules (which turn the voltage into digital values) passes through a specific transfer function so the output is a physical variable.

For example Analogueinput13 turns into Throttle Position percentage due to the transfer function created. As explained before this represents physical meanings, in which case is throttle percentage. The implementation gives a resolution of 0.01%. The example of this transfer function is shown on Figure 5.4. All analogue variables are processed similarly.

The voltage values between are calculated through linear interpolation, this is the easiest way and most understandable one of calculation intermediate points.

Figure 5.4 – Throttle position sensor transfer function

Figure 5.5 shows the block diagram created in ASCET to deal with the several analogue inputs. The functional description is very similar for each and every one of the different inputs, this kind of diagram is similar to the SIMULINK of Matlab with some basics differences, an experienced user in Matlab would take few time to adapt into ASCET.

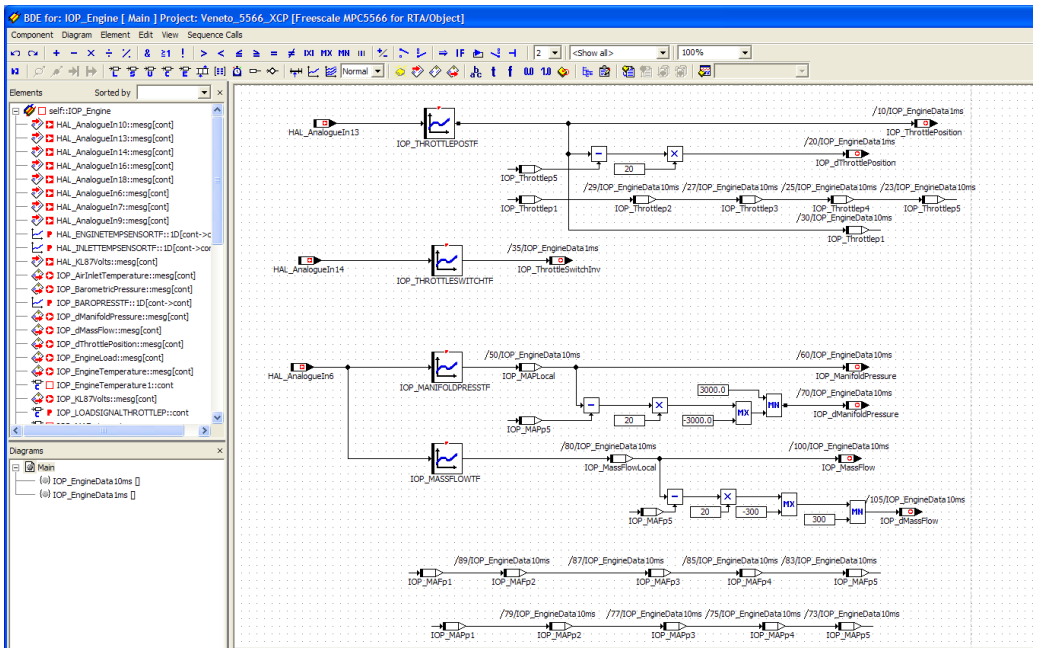


Figure 5.5 - IOP Software

An important variable created here is IOP_EngineLoad. In the created software this variable can be linked either to MAF (Mass air flow) or ThrottlePosition. This is one of the most difficult parameters to calculate experimentally, and the choice was to keep the variable connected only to MAF reading as it proved to give good results and become easier to understand.

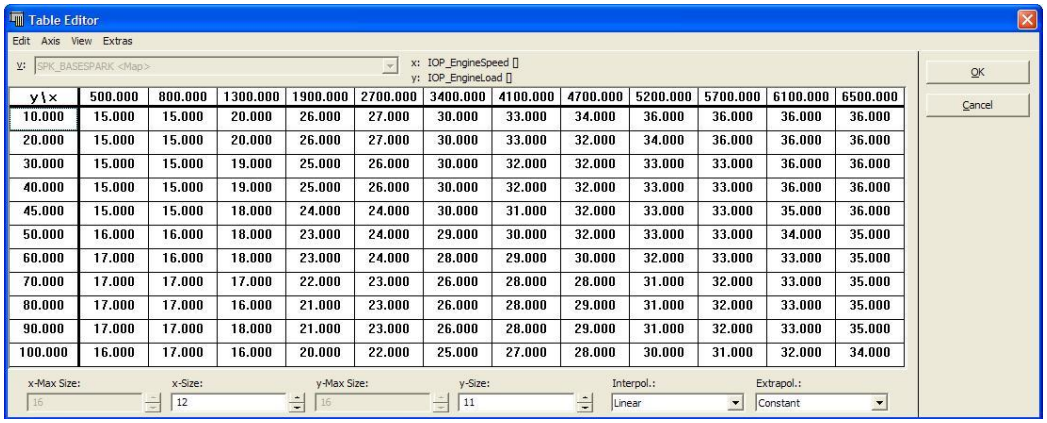
In a commercial application or a high-end ECU, this variable will be calculated through a numerous parameters such as TPS, RPM, MAF, MAP, and more altogether.

This parameter is crucial to fuel and spark mapping and for create smooth engine responses to any load and speed regimes. Also if complex calculus is done, the fuel and emissions efficiency can be improved.

5.4 SPK Module

In this module the correct angles to fire the sparks are calculated and passed to the eTPU functions every 10ms.

A Spark control module like this is expected to determine at every engine regime, the optimal spark angle for each cylinder. As this system consists on a wasted spark ignition system the calculations are for a pair of cylinder. The sparks are calculated through maps (like look up tables). The software uses the input parameters to extract and read the specific map cell correspondent to the engine regime at each revolution.



y \ x	500.000	800.000	1300.000	1900.000	2700.000	3400.000	4100.000	4700.000	5200.000	5700.000	6100.000	6500.000
10.000	15.000	15.000	20.000	26.000	27.000	30.000	33.000	34.000	36.000	36.000	36.000	36.000
20.000	15.000	15.000	20.000	26.000	27.000	30.000	33.000	32.000	34.000	36.000	36.000	36.000
30.000	15.000	15.000	19.000	25.000	26.000	30.000	32.000	32.000	33.000	33.000	36.000	36.000
40.000	15.000	15.000	19.000	25.000	26.000	30.000	32.000	32.000	33.000	33.000	36.000	36.000
45.000	15.000	15.000	18.000	24.000	24.000	30.000	31.000	32.000	33.000	33.000	35.000	36.000
50.000	16.000	16.000	18.000	23.000	24.000	29.000	30.000	32.000	33.000	33.000	34.000	35.000
60.000	17.000	16.000	18.000	23.000	24.000	28.000	29.000	30.000	32.000	33.000	33.000	35.000
70.000	17.000	17.000	17.000	22.000	23.000	26.000	28.000	28.000	31.000	32.000	33.000	35.000
80.000	17.000	17.000	16.000	21.000	23.000	26.000	28.000	29.000	31.000	32.000	33.000	35.000
90.000	17.000	17.000	18.000	21.000	23.000	26.000	28.000	29.000	31.000	32.000	33.000	35.000
100.000	16.000	17.000	16.000	20.000	22.000	25.000	27.000	28.000	30.000	31.000	32.000	34.000

Figure 5.6 - Spark Base Map

The SPK_BASESPK 2D table, Figure 5.6, contains the base of the spark advance map calculated with EngineSpeed vs. EngineLoad, these variables contain the engine speed (rpm) and the load, which is the variable explained in the previous section as being the mass air flow given a SPK_BaseAdvance value. This value corresponds to the amount of degrees the spark should be advanced or retarded from the base map. For example if the base map says that for a speed of 200rpm and a load of 50% the spark should be given at 10degrees before top dead centre (TDC), the advance map may calculate 10degrees of advance which will mean that the spark is given 20degrees before TDC. There is a temperature advance correction as shown in Figure 5.8. This values are added together to generate the total advance spark angle. Notice the max and min boundaries are parameters that can be changed in real time; this is a very important feature that helps saving a lot of time in compile and download of new software into the controller. The functional chart is described in Figure 5.7

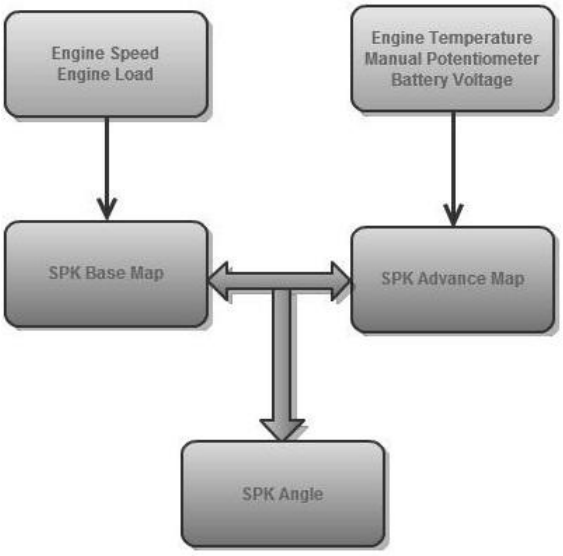


Figure 5.7 - SPK Angle Calculation

The eTPU function doesn't work in advance angles, it receives and generates an event at a specific angle (between 0 and 720 degrees) so the advance angle is a feed into the spark angle calculation. This block ensures that the angles where the firing event will occur is the top dead centre (TDC) of each cylinder) minus the total advance calculated before.

As the SPK function allows the change of the dwell time, which is the time the coils are charged, a parameter was created to be possible to change it in real time to understand the differences. This is important to connect to battery voltage as it is necessary to charge the coils longer if the battery voltage is lower.

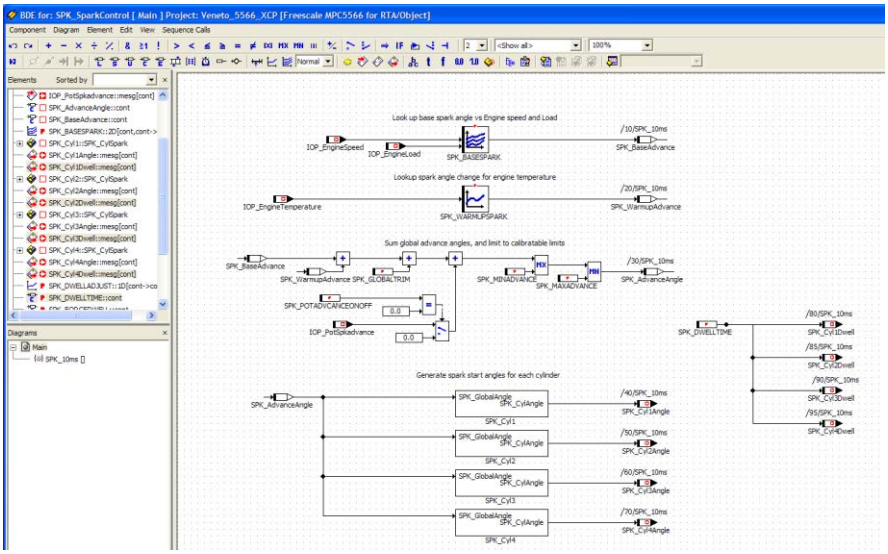


Figure 5.8 - SPK Spark software control

The values are passed to the C-function module to update the values into the eTPU as its shown in the next figure, SPARK1_SPARK4 and SPARK2_SPARK3 are the corresponding eTPU channels for cylinders pairs, the code guarantees that cylinder 1 receives an angle lower than cylinder 4.

```
        /* Spark Dwell & Cyl Angles updates */

  if (SPK_Cyl1Angle> SPK_Cyl4Angle)
   {
   fs_etpu_spark_set_end_angles( SPARK1_SPARK_4,SPK_Cyl4Angle,SPK_Cyl1Angle);
   }
else
   {
   fs_etpu_spark_set_end_angles( SPARK1_SPARK_4,SPK_Cyl1Angle,SPK_Cyl4Angle);
   }

if (SPK_Cyl3Angle> SPK_Cyl2Angle)
   {
   fs_etpu_spark_set_end_angles( SPARK3_SPARK_2,SPK_Cyl2Angle,SPK_Cyl3Angle);
   }
else
   {
   fs_etpu_spark_set_end_angles( SPARK3_SPARK_2,SPK_Cyl3Angle,SPK_Cyl2Angle);
    }
```

Figure 5.9 - Spark angles load into SPARK function

5.5 Throttle

This module was created to control the idle speed by moving the throttle blade. The throttle body has a small DC motor that has the availability to open slightly the air blade allowing air into the intake manifold and therefore control the engine speed. This motor is controlled by an H-Bridge included in the EMS12 board, the microprocessor has to define the PWM frequency and H-bridge direction and then update the duty cycle wanted to keep the blade at a certain point.

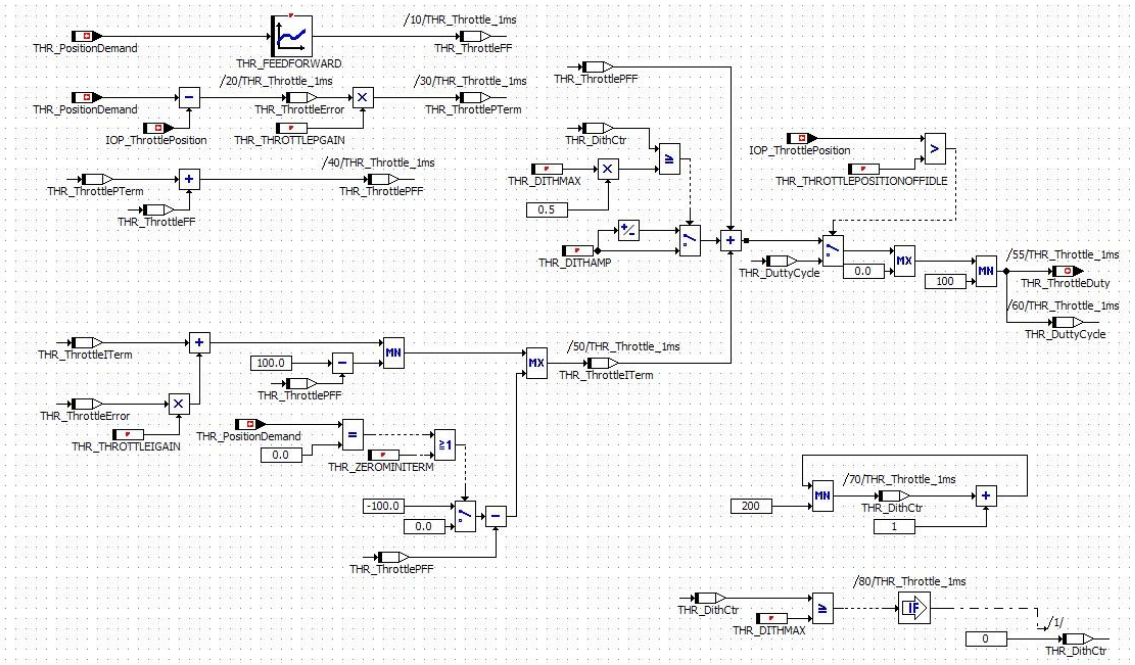


Figure 5.10 - Throttle Duty Cycle control

The strategy consists in the creation of two loop or stages PI controllers running at different speeds.

The inner loop is responsible for providing position control, and its output is the direct duty cycle for the H-Bridge, the error for this PI controller is then the difference between the actual position measured and the position that we want the throttle.

By the following figure we can see that a feed forward stage was added to the PI controller. This allows a certain amount of prediction as the feeedforward indicates what the duty cycle should be for that request. This is calibrated by experimental data and test and error tries.

One of the differences you may spot from the diagram to the traditionally PI schematics is the inclusion of some “funny blocks” in the controller. These blocks create a Dither Filter, very used in dynamic of moving objects; their main goal is to even when the throttle is stopped this filter makes it vibrate at a certain frequency. This allow that rapid position demands can occur with less overshoot, if a mechanical part is stopped you need to create a force just to opposite to its inertia to put it in motion, this filter tries to reduce that amount so when you apply a force is just to position the blade not overshooting position which may be dangerous in vehicle operation.

On Figure 5.11its visible the creation of the modulated wave, THR_DithCtr will be incremented until reaches THR_DITHMAX (again this is full capital letters indicating that is a parameter) and then reset. The counter increments one unit every 1ms so with the parameter we can easily change the frequency of the modulated wave

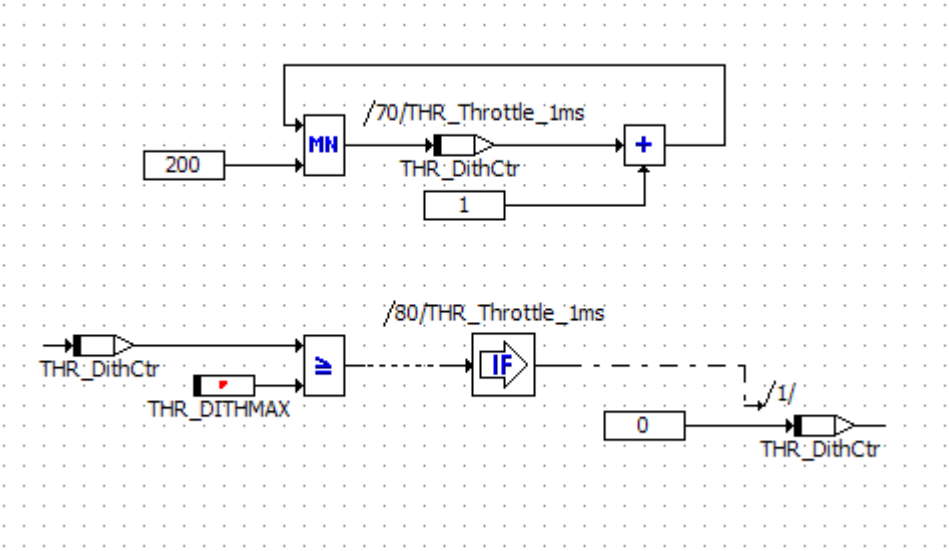


Figure 5.11 – Dither filter

This block, after some parameters tuning proved to be very accurate and the inclusion of the anti-windup blocks helped to the rapid response of the controller.

On the first tests made only this block was implemented in the car and it allowed us to hold the throttle at a specified position without having to press the foot against the pedal

This block is linked to the process which is included in 1ms task, so the update for the PWM will occur every 1ms.

The outer loop for this controller consists on a speed based PI controller, this stage is responsible for maintain a speed reference as idle speed demand, and create position demand for the inner loop. The error for this will be the difference between the speed demand and the engine speed measured. Once again a feed forward stage was included to provide some kind of prediction on what is the best position for a certain speed demand. The following figure demonstrate the outer loop created, its visible the P term I term and FEEDFORWARD term being added together, the output limited is a requirement for software writing and ASCET and there is a possibility to turn this off for test purposes. The I term is cramped with anti-windup terms that states that at any time its value is greater than the inverse of the P term.

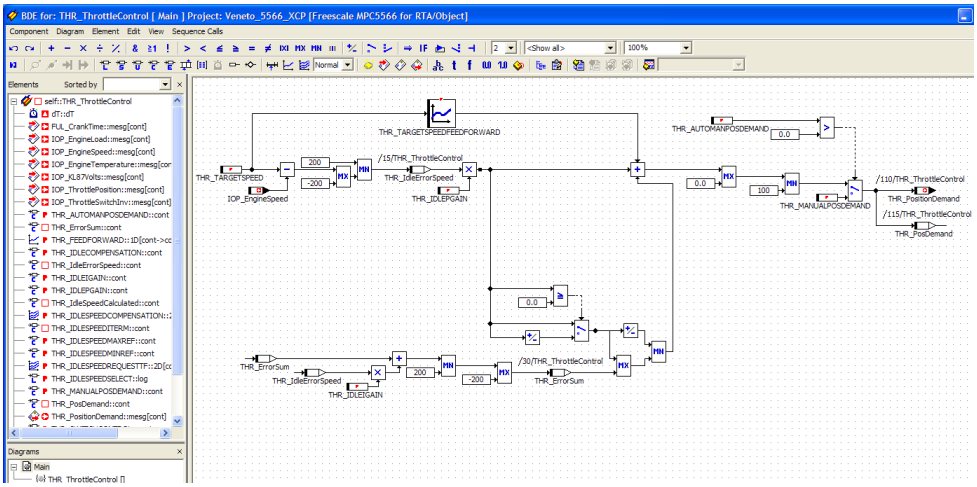


Figure 5.12 - Throttle control for idle speed

5.6 Fuel Control

This module was subject to most attention and time consuming one. In the beginning there were only the blocks to determine the pulse with without any type of variability or changes. With the software evolution and system comprehension more control techniques were sequentially added until the fuel map become fully automated with base maps and enrichment strategies.

The values of timings and fuel amount where sets on empirics knowledge and experimentations. The MegaSquirt [15] website presents some default values for injectors of the same car. These values may serve as base for start testing.

The amount of fuel injected is proportional to the time the injector is opened and the flow rate of the injector itself. So in one cylinder the fuel comsumption can be simplified to:

$$Fuel_{consumption} = T_{inject} * FlowRate_{injector} \quad (1)$$

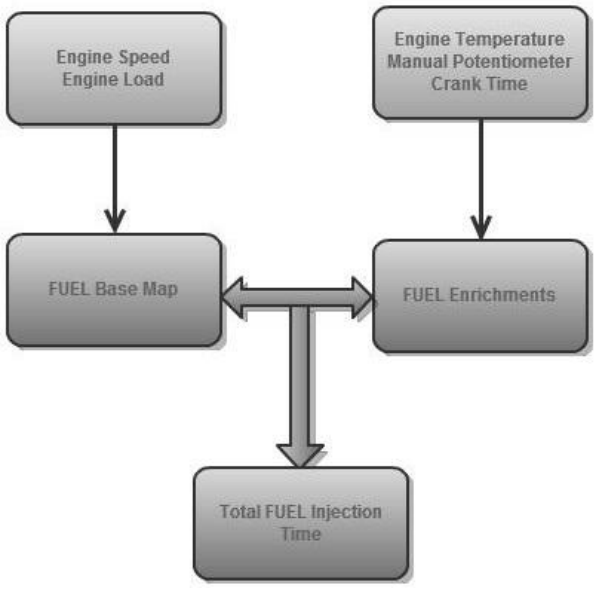


Figure 5.13 - FUEL Total Time Calculation

To explain this module is better to divide it in parts. There is the base map, the enrichments calculations and the O2 control. Monitoring all this there is the shutdown controllers and some overrun fuel cut off.

The base fuel map was created mapping the Engine Speed against engine load. This is usually common in all applications; the difference sits in how to calculate the engine load variable. Next to the engine base map, it's multiplied the FUL_GammaEnrich which is a percentage variable that's multiplied to the base fuel map; this variable contains the sum of the FUL_AccelEnrich ,FUL_AfterStartEnrich and FUL_TempEnrich. These enrichments are

correspondent to acceleration, after cranking and temperature enrichment. After this we have an addition of fuel that refers as FUL_CrankEnrich, this is the cranking enrichments (when the car is starting with help of the start motor) and is added in milliseconds that's the reason why is not contained in gamma enrichments.

Next figure shows the complete code created to calculate fuel injected from base map plus enrichments. Notice that is possible to turn the enrichments off (less the CrankEnrich) using the parameter FUL_ENRICHMENTSONOFF.

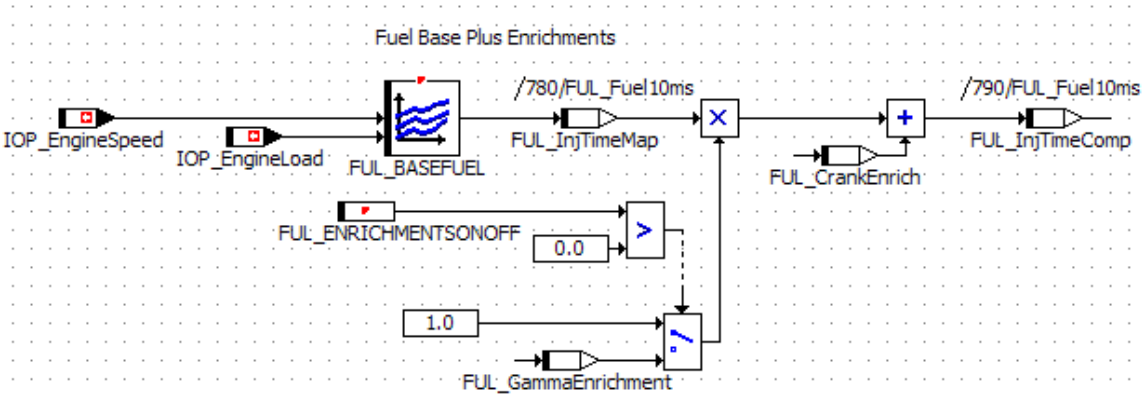
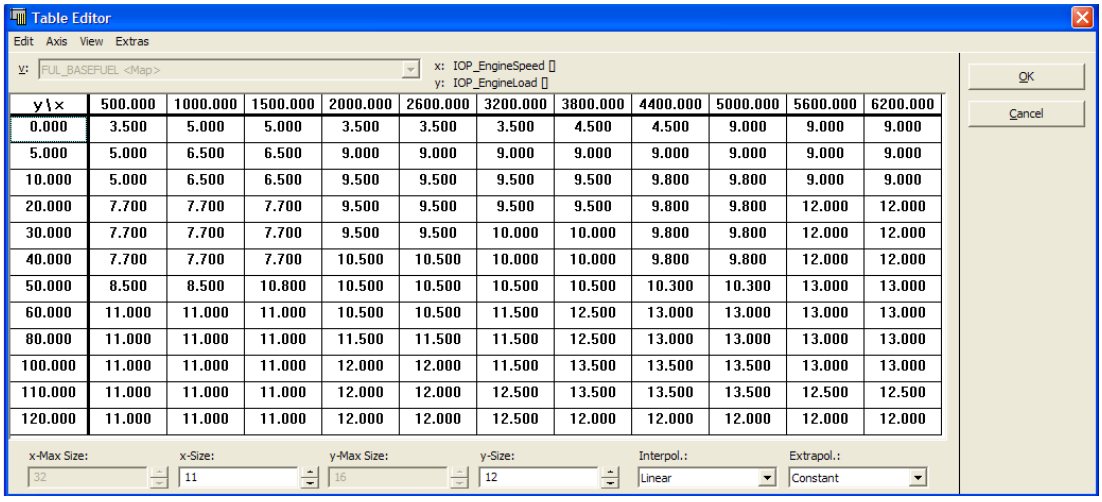


Figure 5.14 - Fuel Pulse width calculation



y\x	500.000	1000.000	1500.000	2000.000	2600.000	3200.000	3800.000	4400.000	5000.000	5600.000	6200.000
0.000	3.500	5.000	5.000	3.500	3.500	3.500	4.500	4.500	9.000	9.000	9.000
5.000	5.000	6.500	6.500	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000
10.000	5.000	6.500	6.500	9.500	9.500	9.500	9.500	9.800	9.800	9.000	9.000
20.000	7.700	7.700	7.700	9.500	9.500	9.500	9.500	9.800	9.800	12.000	12.000
30.000	7.700	7.700	7.700	9.500	9.500	10.000	10.000	9.800	9.800	12.000	12.000
40.000	7.700	7.700	7.700	10.500	10.500	10.000	10.000	9.800	9.800	12.000	12.000
50.000	8.500	8.500	10.800	10.500	10.500	10.500	10.500	10.300	10.300	13.000	13.000
60.000	11.000	11.000	11.000	10.500	10.500	11.500	12.500	13.000	13.000	13.000	13.000
80.000	11.000	11.000	11.000	11.500	11.500	11.500	12.500	13.000	13.000	13.000	13.000
100.000	11.000	11.000	11.000	12.000	12.000	11.500	13.500	13.500	13.500	13.000	13.000
110.000	11.000	11.000	11.000	12.000	12.000	12.500	13.500	13.500	13.500	12.500	12.500
120.000	11.000	11.000	11.000	12.000	12.000	12.500	12.000	12.000	12.000	12.000	12.000

Figure 5.15 - Fuel base map

On the following figure is showed the blocks created to make the enrichments, one extra thing is the enrichments created by IOP_PotGamaEnrich this was a late addition and basically a potentiometer was inserted into the car's central console so the driver can add or remove fuel for test purposes, this is clamped to more or less 50% fuel at any time, and a gain is optional to reduce that amount.

The variable FUL_TimeSinceCrank was also created and is a timer that starts to count every time that engine speed is different from zero. In order to turn the crank enrichments

off, the speed is compared to a parameter defined Crank speed and once it's over the crank enrichment is zero

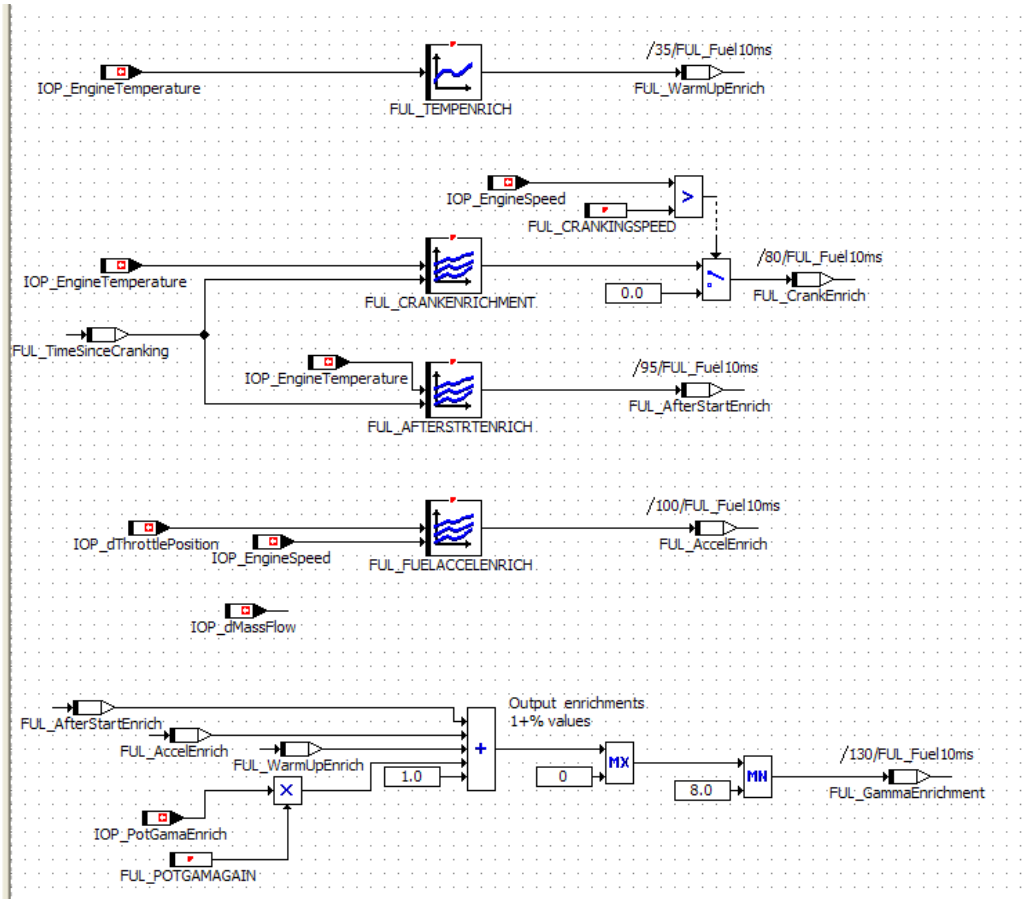


Figure 5.16 - Fuel

The are some extra rules created for fuel module, one thing that is normally done, is to do an open loop fuel injection (when using closed loop with lambda sensor) when the car is accelerating and requires more fuel, this normally makes the car actuate outside the recommended AFR region so having the sensor close loop would stop this to happen.

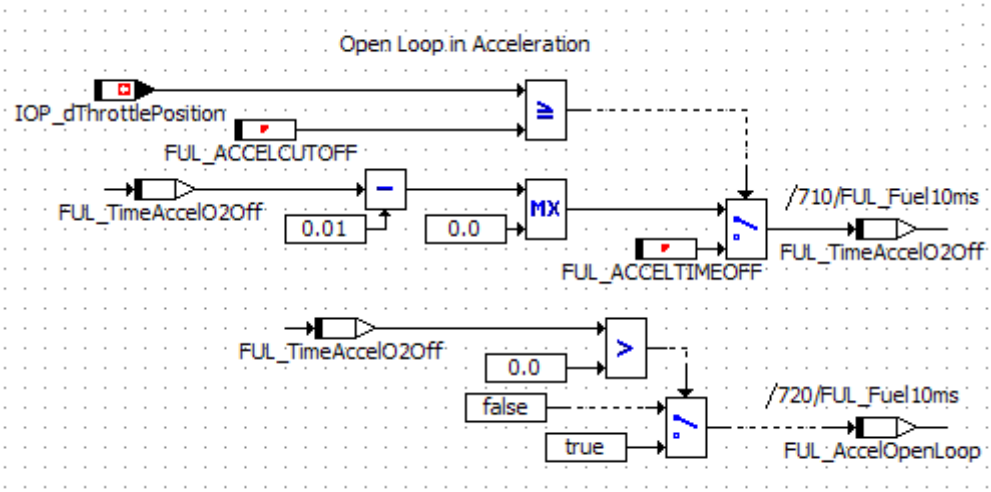


Figure 5.17 - Open Loop fuel rules

Another rule is the fuel cut off with overrun. Over run is achieved when the driver isn't pressing the pedal but the car is still with high rpm, in this case the fuel map will continue to order injection of fuel when is no need, so an over run cut off is implemented in order to stop the fuel injection.

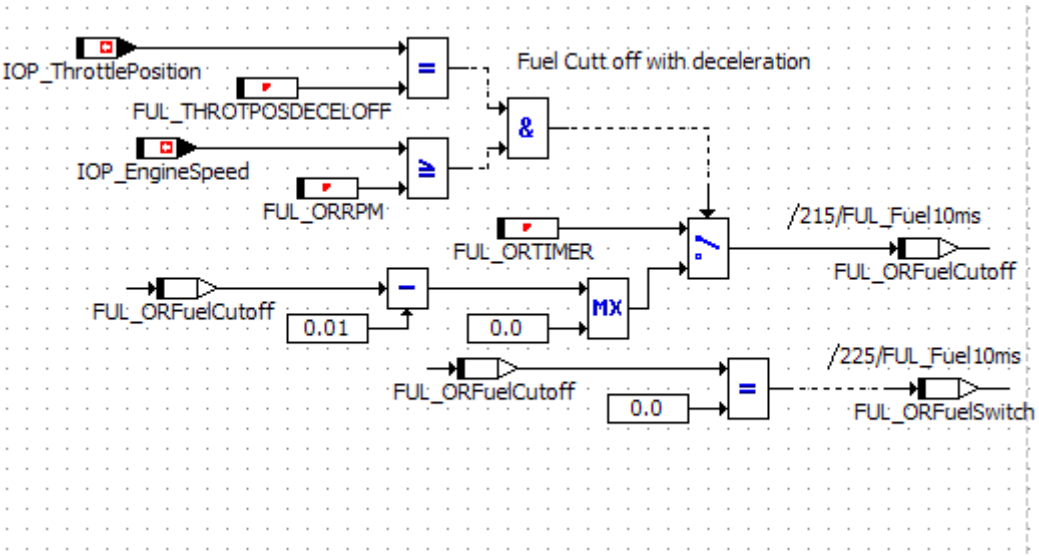


Figure 5.18 - Fuel Overrun

All this rules come together to calculate the final injection time passed to the eTPU function. One can see on next figure that the rules explained before turn the total injection time in zero.

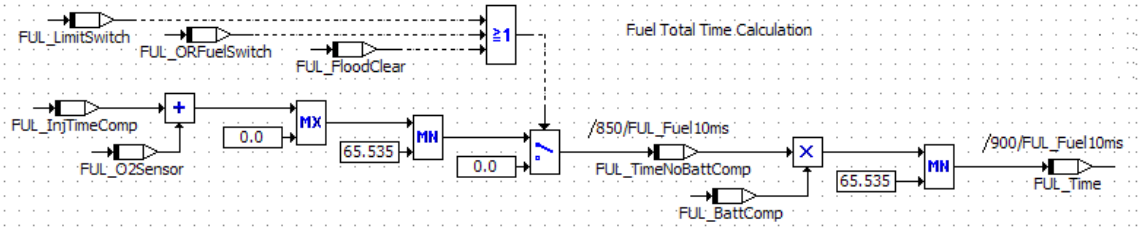


Figure 5.19 - Fuel time output

One last fuel rule created was the rev limiter, this piece of code limits the rpm by cutting fuel after a user defined rpm limit, and there's an hysteresis window created so the fuel will be re activated after the rpm drop the speed defined.

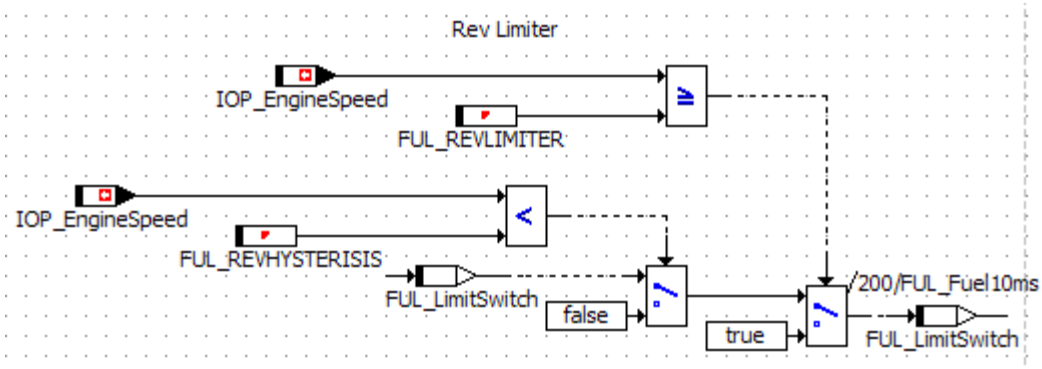


Figure 5.20 - Fuel limiting rpm

With the amount of tests made with fuel eventually the exhaust and spark plugs gets with too much fuel, so a part of software was created to clean it ordering the engine to fire sparks and getting air into the exhaust by shutting the fuel off. This was called FUL_FloodClear and as it is presented on next figure, if the engine speed if lower than 550rpm and the driver is with is foot on the pedal over 70% then it will created a condition to put the injection time to 0 and cut the fuel.

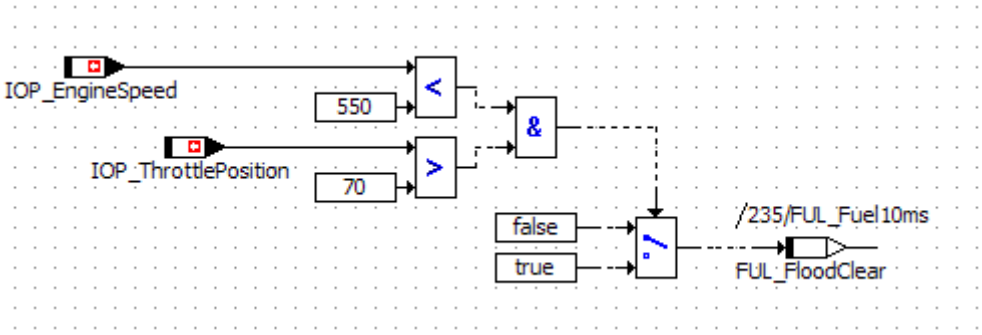


Figure 5.21 - Fuel flood clear

A techedge 2J1 wideband lambda sensor was acquired to make a closed loop fuel control process. The wideband lambda sensor allows the user to read all the scale of the AFR while a narrow band sensor usually just indicates if the mixture is rich or lean.

The close loop is used to try to maintain the mixture at 14.7 which represents lambda 1.

Chapter 6

Tests and Results

Tests

"The 0 errors 0 warning the compiler gives don't mean the software is right. It is right only when it does what you want."

Along the project, as stated in previous chapters the software created was constantly validated by tests either in the real car or on the test rig. All the rules for create software that company uses were followed so the safety of the application is maintained. The company is certified for writing software for the automotive industry, this states the quality level and the commitment they put into their applications. It proves reliability and this is often demanded by company's clients.

The tests made include the validation of software by the ASCET compiler, the implementation errors and warnings must be corrected as it's not allowed to download software with any type of fault into the controller.

The correct behaviour of the software was checked and verified on the test rig when possible and after checked on the real car. On the early stages the results were considerably different on two systems mainly due to wiring faults.

The most time consuming and that can frustrate anyone doing such a job is to write software, test it on the rig and not working on the car, this many times conducts to nearly despaired states. It is very recommended that people take their time to make up the wiring and wire "guessing" as this proved to be very painful in future stages.

The car tests consisted mainly in idle the car on the car park, this was done to prove all the functions were working accordingly to expected, the synchronism wasn't lost and the firing events were occurring at correct times, some problems with floating grounds and misfires where found during this process. The wire used to bring the signal from the VR sensor

to the EMS-12 was unshielded and their proximity to the spark plug leads (where high current flows) the sensor signal was simply suppressed by the noise created. This was solved by using the HE sensor in the engine flywheel which has a much higher signal to noise rejection allowing the correct reading from the controller.

After this being achieved, the fuel maps started to be the focus of the tests. First the start enrichments were the problem since every morning with the cold car the car struggled a lot to start the first time. Some experiments dictated the amount of enrichment in order the car started fairly quick, once this was accomplished, it was time for a few runs around the compound to check load variations and fuel injection, first attempts conducted to very wobbling rides around the car park, but with the CANape help and changing in real time the fuel amount it got smoother.

Finally the car went into the track for more demanding tests, and for more fuel mapping, after a while the tuning was allowing good performance in almost every region of the map (Load vs. rpm) and it achieved a top speed of nearly 200 Km/h on track.

Results

A small video was created to show the test rig working. In this video it's possible to hear the injectors working and sparks are visible in the spark box of the test rig. As the project ended prematurely it wasn't possible to book the track for video footage with the car running with EMS-12 controller, but the principles are the same as the test rig. To view the video please visit http://www.flickr.com/photos/whynot_uk/4668762704/ .

The list of results presented tries to prove the project works and does what is supposed to. Many oscillograms and figures could be added but these ones are intended to resume the project in a fair way.

The prohibition on cameras usage within MIRA's proving ground makes the process more difficult.

The results obtained where very satisfactory and proved all the implementation and software. The test rig oscilloscope reading showed the correct behaviour of every parameter important for the project.

With Figure 6.1, it is possible to see the variables of synchronism and shows that the software is working, reading and presenting all the values needed to know the position and speed of the engine.

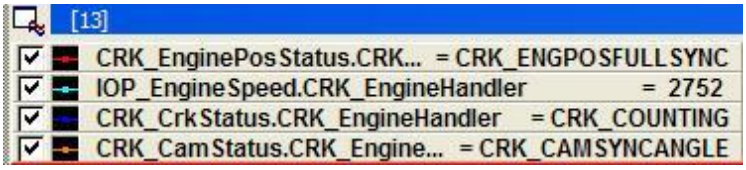


Figure 6.1 - Engine Position Status

With the following figure, it is possible to see the variation of the fuel injection time coming for the base fuel map (without enrichments or corrections) with the engine load. With help of CANape software, it is easily visible that the software is changing the amount of fuel accordingly to the load at every moment; this allows understanding and debugging this part of software showing that the engine load is being read and calculated and it's correctly linked to the fuel map.

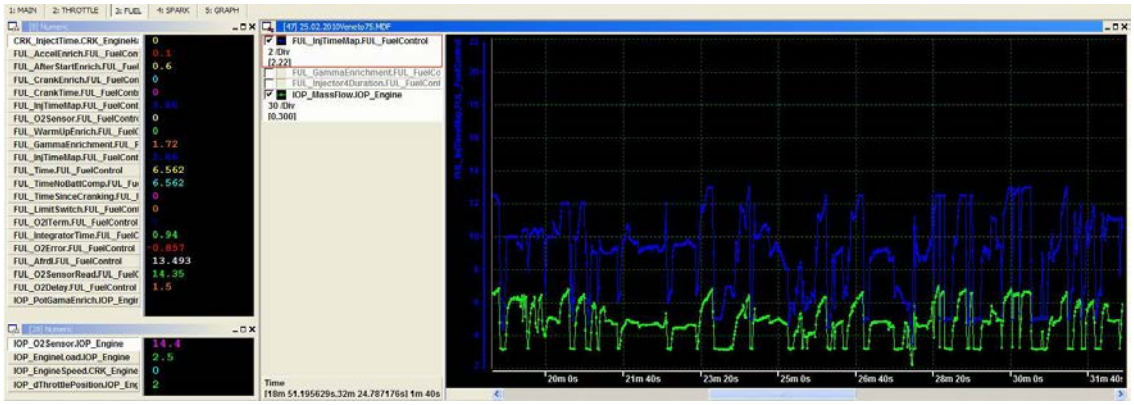


Figure 6.2 – Fuel injection variable with load

The next figure intends to show the configuration in CANape where it's visible the spark angles, one can see that cylinders 1&3 and 2&4 have the same absolute angle. This is because the system used is wasted spark, so each cylinder receives two sparks in each engine cycle. To make the debug easily, the variable speed and load are also visible in the same page.

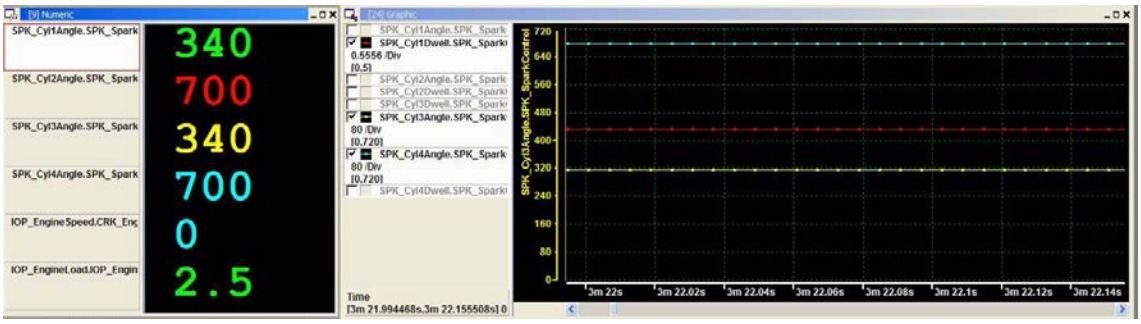


Figure 6.3 – Spark Angles in CANape

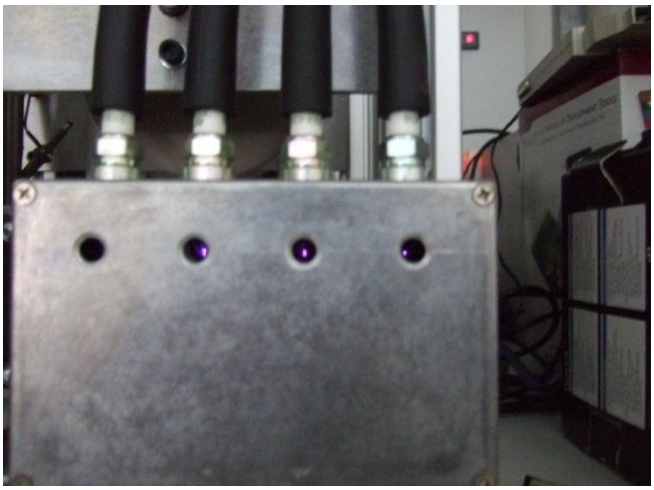


Figure 6.4 - Visible Sparks in Test Rig

With Figure 6.5, it's visible the control of the fuel map by the O2 sensor feedback, in the pink line its visible the reading from the O2 sensor and the white line is the injection time of the injectors. The PI controller is not calibrated, but one can see that when the pink line rises, meaning a lean (lack of fuel or too much air) mixture, the amount of fuel (yellow line) increases.

This tries to follow a reference of an A/F equal to 14.7 which is the stoichiometry for gasoline engines.

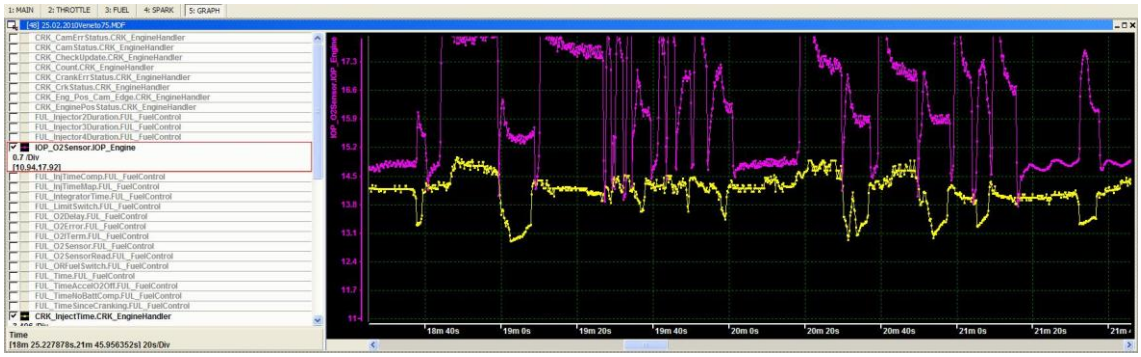


Figure 6.5 – Fuel O2 Sensor and Fuel Inject Time

Conclusions

As referred along this document, the product presented doesn't have the time of development of the systems on the market; at this point it doesn't constitute a valid alternative. But instead, it shows that has the potential to become a very valid and serious product in this sector. The hardware is very high standard and as good as any other system, and the software needs more and more development to reach the actual standards.

Analysing the actual state of the project, one can say that the main goals were achieved, many other things could have been done as stated in previous section, but due to the early ending of the project it is fair to consider that the project is more than satisfactory.

Initially the idea was to spend 8 months developing an ECU so it would be a competitive product among the rivals, but with company's business strategy and negotiation it has been decided that this product establishes the basis for the build of an ECU and the algorithms and high level software should be left to possible clients of this product.

The subjects presented in this project were of particular interest and some previous knowledge of the electronics and mechanical automotive was present, completed with the class Automotive Electronics at faculty.

This project tests a wide range of knowledge simultaneously, many areas of the degree are tested, such as electronic knowledge in measuring connecting, and acquisition signals from sensor. Soldering and PCB design interpretation were part of the project. The microprocessor coding and functioning are an extent to the subjects learnt in faculty.

The company is pleased with the actual status of the product, and they already studied some modifications to do on the board if they release a new version of it.

In my perspective I couldn't ask for a more motivating final project to finish my studies, I've always loved the automotive industry so for me this is quite an achievement to be able to work with such experienced people in the business. The company's atmosphere is very friendly, mainly because it is a small company where everybody knows each other and great inter help spirit and atmosphere is installed. Also the company is provided with very capable engineers who are used to work in several high-end domains within the automotive industry.

Future Work

As stated on the early chapters of the document, the possibilities are almost endless, and nowadays the amount of work and complexity of an ECU is extremely high. In this document was presented the low level configuration and early stages of software development for create an ECU that works.

For the immediate, next work would be to insert a wideband O2 sensor, which probably would require the change of the complete exhaust system since the actual one is much damaged. With this it would be possible to tune the car for stoicometric mixture, which would conduct to better performance and lower emissions for the car.

The use of knock sensor would be something to look into very soon as well since the maximum advance of the spark timing produces more power and torque from the engine. And constant knock of the engine may produce irreparable damages to it.

It was discussed to include a full electronic throttle body system into the car, this part is stock in many cars and belongs to the drive by wire parts. With this part a better idle speed control and a torque demand with the throttle pedal could be achieved.

Nowadays the level of computer calculations is so demanding that the workforce is distributed among several small ECU, for example the abs systems, ESP and differential control (when car is provided with electronic active differentials) have their own dedicated control modules. Ultimately the main ECU can control these separate modules and provide a safety check and act in emergency scenarios.

This type of car only has abs system of the listed above and it could be one next step to taking into account

The tuning of fuel and spark maps can go indefinitely, and several set-ups for different applications can be created, for example the ECU may have the possibility to change between sport and economic configurations that totally change the fuel and spark maps.

As described before the EMS12 is prepared for an engine with up to 12cylinders and this project used just a part of its capabilities, so one of future works could be the creation of

generalized software for different type of engines. The configurations set-ups can be easily interchanged in boot definitions.

These are just a few ideas on where to go next, since there are a lot that can be achieved, and the current status of the project is a good starting point for the application of the any of the future projects.

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