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Title:

"Trip Computer & Recorder for Long-Haul Vehicles"

Project Supervisor: Mr. C. S. Knight

A dissertation submitted in partial fulfilment of the requirements of the University of Brighton and the University of Sussex for the degree of Master of Science in Digital Electronics.

Submitted by:

Panagiotis Kenterlis

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Abstract

The Motorola MPC555 is a powerful microcontroller with a large set of on-chip modules, which is targeted to the automotive industry for engine control, or other real-time control applications. This microcontroller was a candidate for use as an education tool by the Department of Engineering at the University of Brighton.

This report discusses the steps on researching, drawing the basic specifications and developing a digital trip computer with embedded trip data recorder facilities as a product. The actual aim of this project is to evaluate the specific microcontroller in a real application and also promote new ideas in product design in the automotive field. In addition, a number of different peripheral interfaces are being explored.

Both hardware and software designs are analysed in order to familiarise the reader with the technology and techniques used. Being considered as an educational tool, this report is largely shifted to the hardware part of the project, giving it more emphasis; however it is still significantly linked to the software tools used to produce the generated programs.

The report was written keeping in mind that the reader has some basic knowledge of microcontrollers and digital electronics. Wherever needed, topics are being discussed in much detail, while other parts are only briefly mentioned.

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Terms Used

ACK - Acknowledge

BDM – Background Debug Mode

CAN – Controller Area Network

CF Card – CompactFlash Card

CPU – Central Processing Unit

DPTRAM – Dual Ported TPU RAM

EBI – External Bus Interface

ECM – Engine Control Module. Also see ECU.

ECU – Engine Control Unit

EEPROM – Electrically Erasable and Programmable Read Only Memory

FPU – Floating-Point Unit

G1 Sensor – Camshaft Position Sensor

G1 Signal – Output Signal of the G1 Sensor

GPIO – General Purpose I/O

GUI – Graphics User Interface

ICE – In-Circuit Emulator

IDE – Integrated Development Environment

IMB – Inter-Module Bus

IRQ – Interrupt Request

ISR – Interrupt Service Routine

JTAG – Joint Testing Action Group

LBA – Logic Block Addressing

MCU – Micro-Controller Unit

MIOS1 – Modular Input Output System version 1

NACK – Negative Acknowledge

NMI – Non Maskable Interrupt

OCD – On-Chip Debugging

PSU – Power Supply Unit

PWM – Pulse Width Modulation

QADC – Queued Analogue to Digital Converter

QSMCM – Queued Serial Multi-Channel Module

QSPI – Queued Serial Peripheral Interface

RTC – Real Time Clock

SCI – Serial Communication Interface

SGPIO – SIU General Purpose I/O

SIU – System Interface Unit, see USIU

SPI – Serial Peripheral Interface

SRAM – Static Random Access Memory

TPU3 – Time Processor Unit version 3

UIMB - U-BUS TO IMB3 BUS INTERFACE

USIU – Unified System Interface Unit

VCC – Power Supply +5V (unless otherwise specified)

VDD – Power Supply +5V (unless otherwise specified)

VFD – Vacuum Fluorescent Display

VSS – Vehicle Speed Sensor

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I would also like to thank Mr. John Ellinas and Mr. Panagiotis Drosinopoulos, both professors during my undergraduate studies at the Technological Education Institute of Piraeus in Greece for their friendly support and encouragement during my internship at the Microprocessors laboratory of the same institute.

And of course, Mr. C. S. Knight my supervisor for this project, the report for which you are reading right now, for the interesting subject.

1. Introduction

Most medium to large sized companies support their own fleet of small cars, vans and trucks, to meet their transportation demands. Supervising activities of the fleet's drivers and minimizing usage costs is always an issue. In addition in the unfortunate case of an accident, large amounts of money need to be spent on fines, compensations and law suits.

A way of minimizing and avoiding such problems is to be able to record every use of the fleet's vehicles. A trip data recorder similar to flight data recorders found in airplanes, also called a 'black-box' by people of the media, is a way of monitoring the driver's and vehicle's road behaviour. Vehicle's engine and road travel parameters are recorded on a type of storage media hundreds or even thousands of times a second before and after a crash accident. These data can then be used to help in simulation to discover the actual events of the accident.

By implementing a trip computer, a series of information is available to the driver to allow better trip planning and evaluation. By recording all or some of these pieces of information on a storage media, they can be afterwards downloaded to a personal computer and examined to locate points in time where driver or vehicle fails to comply with company's fleet policy or plan more efficient routes and trip plans.

1.1. Aims of the Project

By taking up this project it was essential to create an innovative product. To achieve this goal some objectives were considered:

Firstly include functions that are of most interest to a Long-Haul vehicle driver. It is of great importance for the success of the product to be accepted by the end-user, the driver. If the driver is reluctant to use the device, then this attitude will have an impact to the adoption of the product in a wider range inside a company, which means more sales and technical support charges from the manufacturer's side.

Secondly, to help a company manage its fleet of vehicles more efficiently by allowing recording of the road behaviour of its drivers and log events such as loading/unloading, stopping for fuel/rest etc. These will eventually help the company plan more efficient routes for its transportation needs. For a company any investment, such as the installation of the trip computer to all the vehicles of its fleet, should return some profit in any way.

And last but not least, as a bonus function to make the device useful in the investigation of an accident. This will require from the trip computer to have some trip recorder capabilities, such as those found on flight recorders of airplanes.

1.2. Market Research

In the automotive industry some vehicle manufacturers offer their own solution in either or both fields of trip computers and trip data recorders. Most modern vehicles offer trip computer functionalities, however they offer basic pieces of information using a rudimentary user interface to the driver (Figure 1-1, URL [4], [11], [14]). Some other manufacturers, such as SCANIA (URL [25]), follow another path of providing a connection port to the vehicle's control unit, so that specially engineered software running on a PDA or portable PC can display and handle all trip and vehicle information. A typical low-cost limited-functionality trip computer for cars can be found at prices of $100, displaying only a minimum set of information with a primitive user interface compared to PC user interfaces (Figure 1-2, URL [33]).

Figure 1-1 Typical trip computer provided by the car manufacturer.

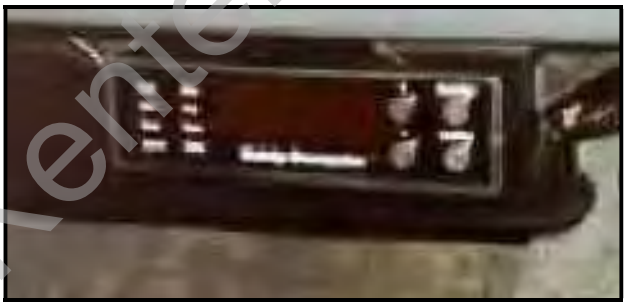


Figure 1-2 Typical low-cost/limited-functionality trip computer sold as a Do-It-Yourself kit.

In the field of trip data recording few are the manufacturers that offer such functions in their standard production-line vehicles. Vehicle data recorders are found primarily in F1 racer cars, where the parameters being recorded are out of proportions to the ones needed for a typical automotive car installation. Currently IEEE has formed a committee trying to draw a standard for automotive data recorders that will be adopted by the automotive industry. However a final standard proposal is not expected to be available for at least 1-1.5 years. In the market there are only a handful of companies that manufacture data recorders at very high prices, which is one of the reasons why they are not popular in cars being sold worldwide. In addition to that, legislation in force on most countries doesn't require or even promote the use of vehicle data recorders.

An academic project in digital data recorders for vehicles is currently in progress by undergraduate students S. Kapetanakis and L. Netsopoulos at the Technological Education Institute of Piraeus, Faculty of Technology Applications, Department of Electronic Computer Systems Engineering, in Greece. The team of students is developing an automotive data

recorder based on an 8bit microcontroller and although it acquires information from various sensors, the limited architecture of their design (small and slow memory) does not allow recording of many seconds before and after an accident has taken place. In addition a limited number of samples are acquired every second. Their research although it involves creating a very interesting piece of hardware it is limited in its design as it is targeted to the low-end of the automotive market where every penny added in the vehicle's price counts. Their work is remarkable in the sense it tries to deal with the actual problem by using low-complexity, low-cost and easy to find hardware.

Although another, more complex, implementation could arise from this project, the short time allocated and the complexity of such a venture strictly prohibits any more thoughts on accident data recorders for automotive purposes.

2. Project Specifications

After having researched on the current products available on the market and wanting to develop a product not similar to what is already available, a list of specifications was drawn.

The device to be built, a Trip Computer for long haul vehicles, will display a series of vehicle and trip information for use by the driver. In addition, some of this information will be stored on a non-volatile memory medium for later reviewing and processing at the company's headquarters, where useful conclusions can be extracted and help to better manage the company's fleet of vehicles.

The preliminary specifications outline published in the pre-course assignment for the MPE module included most of the items on the finalised specifications list that follows.

1. Average speed.
2. Current speed.
3. Present vehicle location (relative to total trip distance entered at start point).
4. Total elapsed trip time.
5. Battery voltage.
6. Fuel remaining.
7. Distance to empty fuel tank.
8. Total amount of fuel used since trip start.
9. Instantaneous fuel flow rate.
10. Refuel mark-up entry.
11. Elapsed time from last stop point.
12. Estimated time of arrival.
13. Time/Date.
14. Local time.
15. Alarm clock.
16. Engine RPM.
17. Odometer.
18. Outside temperature.
19. Cabin temperature.
20. Tiredness warning after x hours of continuous driving.
21. Driver access control using a digital key.
22. Trailer identification.

2.1. Functional System Diagram

The following basic diagram presents a generic overview of the connections and architecture of the system while more explanation is given on the following pages. Automotive sensors assigned as being either analogue or digital can be found in many forms by different manufacturers, however in most current vehicles they are found to have outputs as referenced below.

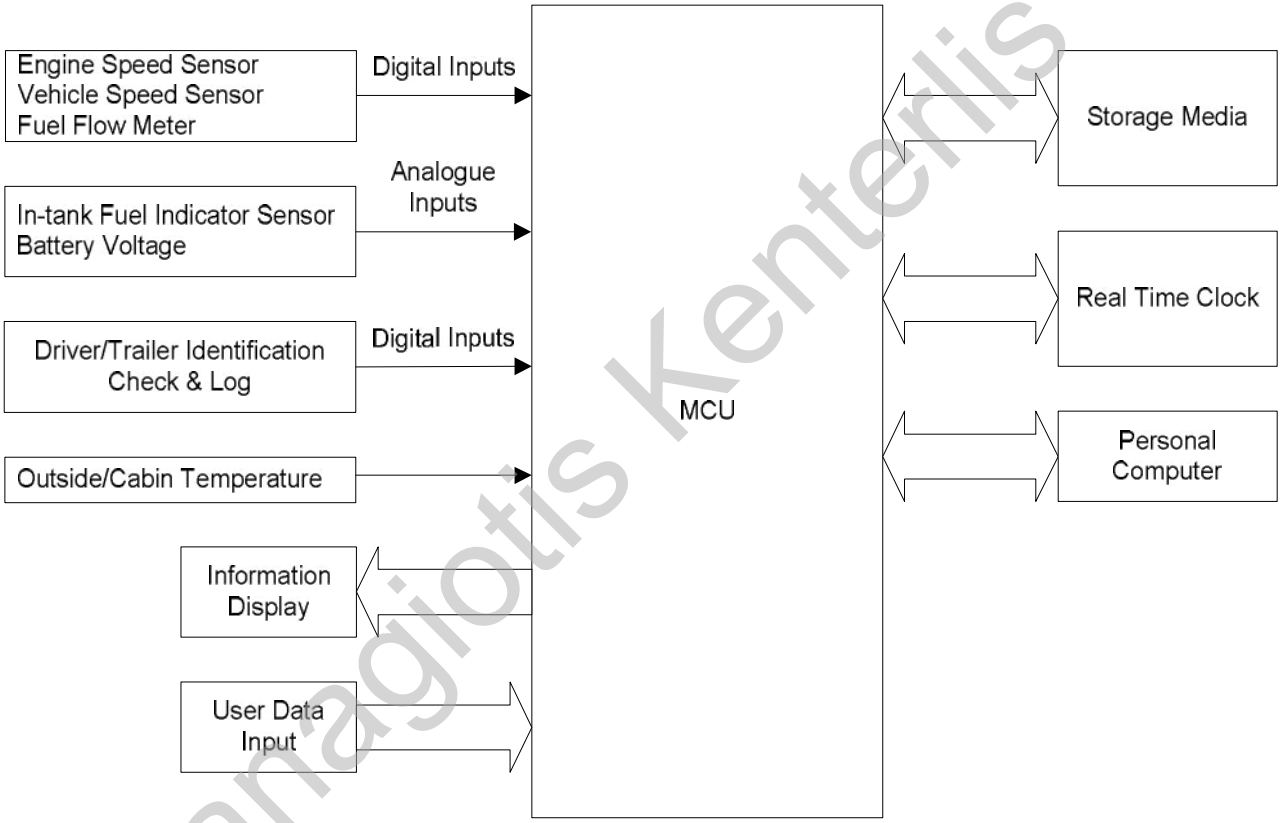


Figure 2-1 Generic System Outline

The entire project is based on a Micro-Controller Unit (MCU), which processes information and manages the peripheral modules, in order to deliver to the user the end-effect of a perfectly working system.

The engine's speed, vehicle's road speed and fuel consumption (flow meter) are digital inputs with the information carried in the frequency of the generated pulses (or otherwise stated the number of pulses within a time window of e.g. 1sec). For the analogue signals, some conversion is required by A/D converters before being fed to the MCU, so that the information carried by the voltage value can be extracted. The in-tank fuel sensor measures

the amount of fuel left in the fuel tank and the battery voltage input gives an indication of the vehicle's battery health.

Both cabin and outside temperature are measured by thermometer devices and the temperature readings are only used for display purposes, and not for control.

These ID devices are marked with a unique serial number used in conjunction to a database to identify the driver's name or trailer contents.

The external Real Time clock is used to hold current time and date, which can be presented on the display unit. It should also be able to provide a time reference of one second, which can be useful for various functions e.g. speed measurement.

A non-volatile storage media is used to store trip and vehicle data, which can be uploaded to a PC at the end of a trip for further process and statistical analysis. Information such as speed, attached trailers, distance covered, driver on wheel, amount of fuel used, etc are recorded on specific intervals or upon activation of an event.

A communications interface allows a PC with the proper software to connect to the trip computer while the vehicle is stopped and perform functions such as to download sensor configuration data and/or upload the data stored in the memory device. A high speed communications bus is desirable to minimize upload times when the amount of stored data is large.

2.2. Justification of Selections

After having drawn an initial project specifications outline, the technology behind every box needs to be defined. The following pages describe how decisions were made towards finding the right parts for the project.

2.2.1. Data Processing Hardware

In the automotive field of applications few processors are currently used. Most of them are high-speed 32bit processors or microcontrollers with embedded modules providing functions that fit in the automotive environment. Right from the start of this project the selection of the processor to be used had been pre-determined by the supervisor as an attempt to evaluate the microcontroller for use as an educational tool. The Motorola MPC555, a very powerful 32bit microcontroller oriented towards automotive applications and largely used for Engine Control Units (ECUs), was available by the University in a development board and was accompanied by all the necessary development tools.

Taking into account the number and functionality of modules available on the microcontroller, the specifications for the peripheral devices to follow were limited to fit the microcontroller and help make decisions easier.

2.2.2. Information Display Unit

The digital Trip Computer must provide very important information to the driver by means of a User Interface. Information needs to be displayed, selected and inputted to the trip computer. The driver can select from a pre-defined set of information and determine which functions should be activated and when. As a first step, information needs to be displayed in a form that is directly recognizable and utilizable. Text and graphics is the most important and commonly found form. Four display interfaces are most used for control applications: LED, LCD, VFD and CRT. The following pages contain analyzed information on each display type and through comparative thinking one of them will be selected as the best fit for the project.

Where text/numerical displays are discussed a 4 row x 20 characters standard display is considered, and for the graphics displays, a pixel matrix of 128x64 at minimum.

Table 2-1 Display Unit Weights Matrix											
		A	B	C	D	E	F	G	H	De-normalized	Normalized
Amount of Displayable Information	**A**	=	+	+	+	=	=	-	-	1	**9**
Discernible Display	**B**	-	=	+	+	+	+	-	-	1	**9**
Interface Type	**C**	-	-	=	-	-	-	-	-	-7	**1**
Interfacing Complexity	**D**	-	-	+	=	-	+	-	=	-2	**6**
Custom Information Type Display	**E**	=	-	+	+	=	+	-	+	2	**10**
Power Consumption	**F**	=	-	+	-	-	=	=	-	-4	**4**
Dimensions	**G**	+	+	+	+	+	=	=	+	6	**14**
Relative Cost per Amount of Information Displayable	**H**	+	+	+	=	-	+	-	=	2	**10**

Table 2-2 Display Unit Analyzed Weighted Selection Criteria			
Selection Criteria	**Description**	**Points**	**Weighted Points**
A. Amount of Displayable Information	Less than 10 Characters	1	**9**
	More than 10 Characters – Less than 80 Characters	2	**18**
	More than 80 Characters	3	**27**
B. Discernible Display	Only in Dark Environments	-1	**-9**
	Only in Bright Environments	-1	**-9**
	Special Lighting Circuit Required	1	**9**
	Irrespective of Environment Lighting	2	**18**
C. Interface Type:	Serial Interface	3	**3**
	Parallel Interface	2	**2**
	Proprietary Interface	-1	**-1**
D. Interfacing Complexity:	Requires External Logic	1	**6**
	Requires Special Connector	-1	**-6**
	Requires External Logic & Special Connector	-2	**-12**
	Requires No External Logic	2	**12**
E. Custom Information Type Display	Numbers Only	-1	**-10**
	Text Only	1	**10**
	Text Only + Custom Characters	2	**20**
	Graphics + Text	3	**30**
	Graphics + Text + Custom Characters	4	**40**
F. Power Consumption	Normal Power Supply (less than 1A)	2	**8**
	Normal Power Supply (more than 1A)	1	**4**
	Special Power Supply	-2	**-8**
G. Dimensions (relative to the dimensions of the information display area)	Small	2	**28**
	Medium	1	**14**
	Large	-1	**-14**
H. Relative Cost per Amount of Information Displayable	Low	2	**20**
	Average	1	**10**
	High	-1	**-10**

Some information on every type of displays is given below. Advantages and disadvantages given are considered from the writer's point of view.

7-Segment LED Displays

- ↑ Found in many sizes.
- ↑ High visibility in most lighting conditions.
- ↑ Relatively low cost in small displays.
- ↓ High power consumption.
- ↓ Driving circuits are complex when using multiplexing for large displays.
- ↓ Data conversion is required.
- ↓ Standard non-customisable display font.
- ↓ Aesthetic result is not always respectable from a user's point of view.

VFD (Vacuum Fluorescent Display)

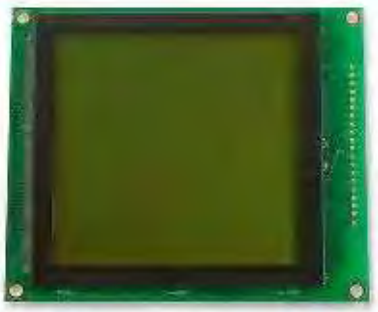
- ↑ Excellent visibility/brightness
- ↑ No need for backlight hardware.
- ↑ Available in wide range of colours.
- ↑ Available in graphics and text displays.
- ↑ Wide operating temperature range.
- ↑ Wide viewing angle.
- ↓ Medium cost relative to size.
- ↓ Higher cost than LCD modules.

LCD (Liquid Crystal Display)

Character LCD

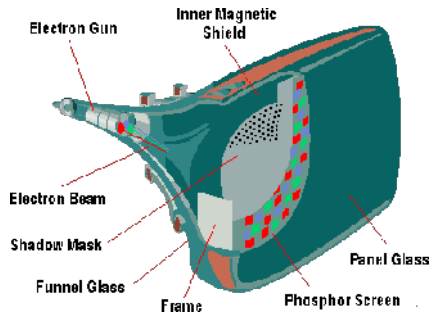
- ↑ Easy to interface.
- ↑ Relatively of low-medium cost according to text dimensions.
- ↑ Standard controller interface and programming.
- ↑ Assisted by backlight techniques for dark environments.
- ↓ Few customisable characters (up to 8).
- ↓ Standard character set.
- ↓ Limited row x column dimensions.
- ↓ Backlight hardware can draw much current or require special hardware.
- ↓ Limited viewing angle.

Graphic LCD



- ↑ Entire character set can be customized.
- ↑ Able to display bitmapped graphics to allow a friendlier user interface.
- ↑ Easy to interface to any microcontroller.
- ↑ Found in a variety of dimensions and pixel count.
- ↑ Also found in colour versions.
- ↑ Assisted by backlight techniques for dark environments.
- ↑ Found in pre-assembled module form.
- ↓ Programming is highly dependent on the controller used.
- ↓ Backlight hardware can draw much current or require special hardware.
- ↓ High cost relative to size.
- ↓ Limited viewing angle.

CRT (Cathode Ray Tube)



- ↑ All purpose (graphics, text, and moving picture).
- ↑ Found in colour and monochrome phosphor coating.
- ↓ Need special interfacing hardware.
- ↓ Require high voltages to operate (15-25KV).
- ↓ Bulky.
- ↓ Heavy.
- ↓ Relatively of low cost according to size, quality, resolution, display type (colour or monochrome) and interface technique.

Table 2-3 Display Unit Weighted Decision Matrix

Display Technology	A	B	C	D	E	F	G	H	Total Points
LED	9	-9	2	6	-10	8	14	-10	**10**
VFD (Text)	18	18	2	6	10	8	28	10	**100**
VFD (Graphics)	27	18	2	6	30	8	28	20	**139**
LCD (Text)	18	9	2	6	20	8	28	10	**101**
LCD (Graphics)	27	9	2	6	40	4	28	20	**136**
CRT	27	18	-1	-12	30	8	-14	20	**76**

2.2.3. User Data Input Unit

At some points in time the driver may need to input data or select different information screens. In PC environments this is usually done by using a keyboard and/or a mouse. However in control applications there is rarely the need for a full alphanumerical keyboard or even more unlikely a high-precision pointing device.

The most common input device is the matrix keyboard, which is easily manufactured to fit specifications and at low cost. Other options available, such as touch-screens, voice recognition, etc, not only require exotic driving circuits but also add software overhead and most importantly exceed cost for use and therefore are rejected.

2.2.4. Digital Identification Devices

For the project it is essential to identify different drivers and attached trailers using a medium that is cost effective, require little or no extra hardware, easy to use, reliable, small in dimensions and capable of operating in long distances from the main device, and at harsh environmental conditions.

To make a selection easier, a list of criteria to be considered was drawn and different weight of significance was assigned to each criterion.

Table 2-4 Digital Identification Device Weights Matrix

		A	B	C	D	E	F	G	H	I	J	K	De-normalized	Normalized
Unique ID	**A**	=	=	+	-	-	-	-	+	-	-	-	-5	**6**
Programmability	**B**	=	=	+	-	-	-	-	+	-	-	-	-5	**6**
Secure Communications	**C**	-	-	=	-	-	-	-	-	-	-	-	-10	**1**
Multiple Devices Support on Same Reader	**D**	+	+	+	=	+	=	+	+	=	=	-	5	**16**
Interfacing Complexity	**E**	+	+	+	-	=	-	+	=	-	-	=	0	**11**
Endurance at Harsh Environments	**F**	+	+	+	=	+	=	+	+	=	+	-	6	**17**
Dimensions	**G**	+	+	+	-	-	-	=	=	-	=	-	-2	**9**
Ease of Installation	**H**	-	-	+	-	=	-	=	=	=	-	-	-5	**6**
Maintenance	**I**	+	+	+	=	+	=	+	=	=	=	=	5	**16**
Cost of ID Device	**J**	+	+	+	=	+	-	=	+	=	=	=	4	**15**
Cost of Interfacing	**K**	+	+	+	+	=	+	+	+	=	=	=	7	**18**

Having weighed the significance of each criterion for the project, an analytical options table for each of them was built with points assigned to define the desired qualities from the device to be selected for use in the project.

Table 2-5 Digital Identification Device Analyzed Weighted Selection Criteria			
Selection Criteria	**Description**	**Points**	**Weighted Points**
A. Unique ID	No	1	**6**
	Yes	2	**12**
B. Programmability	No	1	**6**
	Some Programmable Features	2	**12**
	Yes	3	**18**
C. Secure Communications	No	1	**1**
	Some Security Features	2	**2**
	Yes	3	**3**
D. Multiple Device Support on Same Reader	No	-1	**-16**
	Yes	1	**16**
E. Interfacing Complexity	No Special Hardware Needed	2	**22**
	Special Connector Needed	1	**11**
	External Circuits Needed	-1	**-11**
	External Circuits + Connector Needed	-2	**-22**
F. Endurance at Harsh Environments	Sensitive Device	-2	**-34**
	Durable	2	**34**
G. Dimensions	Tiny	1	**9**
	Small	2	**18**
	Medium-Sized	-1	**-9**
	Bulky	-2	**-18**
H. Simplicity of Installation	Simple Placement	2	**12**
	Some Special Fitting Required	1	**6**
	Special Fitting Required	-2	**-12**
I. Maintenance	No Maintenance Required	2	**32**
	Periodical Service May Be Required	1	**16**
	Frequent Service Required	-2	**-32**
J. Cost of ID Device	Low	2	**30**
	Average	1	**15**
	High	-1	**-15**
K. Cost of Interfacing	Low	2	**36**
	Average	1	**18**
	High	-1	**-18**

A unique ID code although being a very attractive idea, it is not always present or applicable in actual products. In this case, it is necessary for the ID device to be programmable at least partly. By programming a device using a centralized control tool to assign unique serial numbers for own use, it is easy to create databases of categorized ID codes for drivers, trailers, containers etc.

For this project, increased security features are not required, since no security issues can be located, however should that is requested in the future, a device that allows secure information storage and exchange is always desirable as long as cost is not increased dramatically.

The ability to use the same device reader to access multiple ID keys at the same time is a highly important feature, since it can effectively reduce the number of readers needed and hence reduce cost. Connecting ID devices over a common medium is one way of achieving this goal.

Interface complexity should always be kept to a minimum level, to avoid introducing unstable behaviour and cost increase.

Endurance at harsh environments is another wanted feature, since the devices are likely to experience a wide range of climate changes and mechanical strain during a trip. Physical dimensions are important when the ID key needs to be carried by a driver or to be placed in the tractor, or trailers. Extremely small or large devices can be difficult to manipulate in all cases. Installation can become an issue if there is need to remove parts or otherwise physically alter the vehicle's or the trailers' structure. Simple installation is always desirable.

Maintenance can be brought to a minimum if the device's endurance is high and lifetime long. Maintenance increases cost of use and makes a product less appealing, should frequent service or replacement is needed. If maintenance is required while still on a trip, unwanted problems in use of the trip computer may arise.

As always cost of the ID devices and interfacing should be kept to a minimum. Costly products are seldom appealing.

Table 2-6 Digital Identification Devices

	RFID	SmartCard	iButton	Magnetic Strip Card	Barcode
Unique ID	Depending on Device	Depending on Card	Yes (64bit)	No	No
Programmability	Depending on Device	Yes	Depending on Device	Yes	No
Secure Communication	Depending on Device	Depending on Device	Depending on Device	Depending on Device	No
Reliable Communication	Depending on Distance - Error Checking	Error Checking	Error Checking	Error Checking	Error Checking
Multiple Device Support on Same Reader	Yes	No	Yes	No	No
Interfacing Complexity	Special Hardware Reader Required	Special Hardware Reader & Connector Required	2-Terminal Connector & Software Emulation of Interface by any microcontroller	Special Hardware Reader & Connector Required	Special Hardware Reader Required
Endurance at Harsh Environments	Yes	Average	Yes	No	No
Dimensions	Small/Average	Small/Average	Small	Average/Large	Average/Large
Simplicity of Installation	Transceiver and RF Antenna Fitting Required	Small Card Socket Installation	Simple Battery Holder or Two Terminal Probe	Reader Device Installation	Reader Device Installation
Maintenance	Periodical Service May Be Required	Periodical Service May Be Required	None - Little	Periodical Service May Be Required	Periodical Service May Be Required
Cost of ID Device	Low	Low	Low	Low	Low
Cost of Interfacing	High	Average	Low	High	High

The above introduced digital ID devices need to be weighted to select the best fit for the project.

Table 2-7 Digital Identification Device Weighted Decision Matrix												
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**Total Points**
RFID	12	12	2	16	-11	34	9	-12	16	30	-18	**90**
SmartCard	12	12	2	-16	-22	34	18	6	16	30	18	**110**
iButton	12	12	2	16	22	34	18	12	32	30	36	**226**
Magnetic Swipe Card	6	18	2	-16	-22	-34	-9	6	16	30	-18	**-21**
Barcode	6	6	1	-16	-11	-34	18	12	16	30	-18	**10**

Having used parts of the 1-Wire family range of products by Dallas Semiconductors as basic elements of my undergraduate project, accumulated knowledge can be considered an asset in developing the project in shorter time.

2.2.5. Temperature Sensors

A set of temperature sensors needs to be used to provide temperature readings of the driver's cabin (cockpit) and the outside environment. These readings will be printed on the display unit already selected in previous pages. To make sure the right temperature sensor is to be used, the selection procedure is performed with the use of decision matrices.

Table 2-8 Temperature Sensor Weights Matrix

Criteria		A	B	C	D	E	F	G	De-normalized	Normalized
Interface Type	**A**	=	+	-	-	=	-	-	-3	**1**
Temperature Range	**B**	-	=	=	+	-	-	-	-3	**1**
Temperature Resolution	**C**	+	=	=	=	-	-	-	-2	**2**
Accuracy	**D**	+	-	=	=	-	-	-	-3	**1**
Required Wiring	**E**	=	+	+	+	=	-	-	1	**5**
Cost of Sensor	**F**	+	+	+	+	+	=	=	5	**9**
Cost of Interfacing	**G**	+	+	+	+	+	=	=	5	**9**

Table 2-9 Temperature Sensor Analyzed Weighted Selection Criteria

Selection Criteria	Description	Points	Weighted Points
A. Interface Type	Analogue	1	**1**
	Digital – Parallel	-1	**-1**
	Digital – Serial (I^2C)	-1	**-1**
	Digital – Serial (SPI)	2	**2**
	Digital – Serial (1-Wire)	3	**3**
B. Temperature Range	$-40^oC \leftrightarrow +55^oC$	1	**1**
	$-55^oC \leftrightarrow +85^oC$	2	**2**
	$-55^oC \leftrightarrow +125^oC$	3	**3**
C. Temperature Resolution	1^oC	1	**2**
	0.5^oC	2	**4**
	0.25^oC	3	**6**
	0.125^oC	4	**8**
	0.0625^oC	5	**10**
D. Accuracy	$\pm 4^oC$	1	**1**
	$\pm 3^oC$	2	**2**
	$\pm 2^oC$	3	**3**
	$\pm 1^oC$	4	**4**
	$\pm 0.5^oC$	5	**5**
E. Required Wiring	2 – Wires	3	**15**
	3 – Wires	2	**10**
	4 – Wires	1	**5**
	More than 4 Wires	-1	**-5**
F. Cost of Sensor	Low Cost (<$1)	2	**18**
	Medium Cost – ($1< cost > $2)	1	**9**
	High Cost – (> $2)	-1	**-9**
G. Cost of Interfacing	Low	2	**18**
	Average	1	**9**
	High	-1	**-9**

Analogue sensors although very commonly used in many applications, in the case of automotive applications can become a source of problems because of high electrical noise levels created by the engine. Digital sensors can circumvent this problem by using an error detection technique. In addition the temperature reading from a digital sensor is always formatted as a value in units of a measurement system, most commonly degrees Celsius, and therefore no calculations or conversions are required from voltage levels to digital values.

The type of interface although it is important, it can always be emulated by a microcontroller with enough I/O pins. In the case of the microcontroller SPI and parallel interfaces are available in hardware, while I^2C and 1-Wire need to be emulated.

Using a temperature sensor that works in extreme temperatures allows a future upgrade to include temperature readings from various engine sections.

Although a high resolution in temperature readings is not required for this application, it is always considered a credit. Accuracy of temperature reading is always desired to be as good as possible, but without an increase in cost.

The number of wires is again related to electrical noise present as well as cost, cable length and installation complexity. The fewer the wires required to connect to the sensor, the better.

In the following description table, four of the most used temperature sensors are analysed.

Table 2-10 Temperature Sensors

	Thermistor	MAX6662	DS1820	LM75
A. Interface Type	Analogue	SPI	1-Wire	I^2C
B. Temperature Range	Depending on Device	-55°C to +150°C	-55°C to +125°C	-55°C to +125°C
C. Temperature Resolution	Depending on Device – Average	12-Bit + Sign, 0.0625°C Resolution	12-Bit + Sign, 0.0625°C Resolution	.5 °C
D. Accuracy	Depending on Device – Not Very Good	±1°C max to ±2.5 typ depending on temperature range	±1°C	±3°C
E. Required Wiring	2-3 Wires	7 Wires	3 Wires	8 Wires
F. Cost of Sensor	Depending on Device – Average/High	$1.37	$1.76	$0.90
G. Cost of Interfacing	Low	Low	Low	Low
Packaging	-	8/SOT23	TO-92	SOP-8
Manufacturer	-	Maxim/Dallas	Maxim/Dallas	National Semiconductors

Only one of the above temperature sensors is the most suitable for the project, and by creating the weighted decision matrix above the right part was found.

Table 2-11 Temperature Sensor Weighted Decision Matrix

Temperature Sensor	A	B	C	D	E	F	G	Total Points
Thermistor	1	3	4	1	15	-9	18	**33**
MAX6662	2	3	10	2	-5	9	18	**39**
DS18B20	3	3	10	5	15	9	18	**63**
LM75	-1	3	4	2	-5	18	18	**39**

The DS18B20 having the same interface as the digital identification device selected in previous pages, can be characterized as an excellent selection, considering the fact that most software routines developed will be common and no extra hardware is required.

2.2.6. Real Time Clock

A Real Time Clock is a device that holds the current time and date in a set of counters clocked by a time reference signal, usually a square wave with a frequency of 1Hz. This reference square wave pulse is derived from an external crystal or other square wave signal source.

Dallas/Maxim is a huge manufacturer of RTC's and also provides samples of products, free of charge. All of the below mentioned RTC's were obtained as samples before deciding which to use.

Table 2-12 Real Time Clock Weights Matrix

		A	B	C	D	E	F	G	H	De-normalized	Normalized
Real Time Data Format	**A**	=	+	+	+	+	+	+	+	7	**14**
Interface Type	**B**	-	=	=	=	+	-	+	-	0	**7**
Interfacing Complexity	**C**	-	=	=	+	+	+	+	=	4	**11**
Backup Power Supply	**D**	-	=	-	=	+	-	=	-	-2	**5**
Interrupt Outputs	**E**	-	-	-	-	=	-	-	-	-6	**1**
Interrupt (1Hz)	**F**	-	+	-	+	+	=	+	-	2	**9**
CMOS RAM on-chip	**G**	-	-	-	=	+	-	=	-	-3	**4**
Cost	**H**	-	+	=	+	+	+	+	=	5	**12**

Table 2-13 Real Time Clock Analyzed Weighted Selection Criteria

Selection Criteria	Description	Points	Weighted Points
A. Real Time Data Format:	Binary	-1	**-14**
	Full format – hh:mm:ss dd/mm/yy	1	**14**
B. Interface Type:	Serial Interface – SPI	2	**14**
	Serial Interface – 1-Wire bus	1	**7**
	Serial Interface – I^2C/3-Wire	-1	**-7**
	Parallel Interface (De-multiplexed)	1	**14**
	Parallel Interface (Multiplexed)	-2	**-14**
C. Interfacing Complexity:	Requires External Logic	-1	**-11**
	Requires No External Logic	1	**11**
D. Backup Power Supply:	Backup Battery Input	1	**5**
	No Backup Power Supply	-1	**-5**
E. Interrupt Outputs:	No Interrupt Outputs	-2	**-2**
	One Interrupt Output	1	**1**
	Two Interrupt Outputs	2	**2**
F. Interrupt (1Hz):	Available	1	**9**
	Unavailable	-1	**-9**
G. CMOS RAM on-chip:	No RAM	-1	**-4**
	Less than 32bytes	1	**4**
	More than 32bytes – Less than or Equal to 96bytes	2	**8**
	More than 96bytes	3	**12**
H. Cost	Low Cost (<$2)	2	**24**
	Medium – ($2< cost > $4)	1	**12**
	High – (>$4)	-1	**-12**

Having the RTC counting in binary format can be a source of problems, since there is need to convert the amount of seconds counted into minutes, hours, days, months, etc allow for calendar corrections according to a reference day. Practically this would require a great deal of calculations to convert the number of seconds into meaningful and displayable time information. On the other hand counting in full format (as explained above) only requires for some registers to be read and possibly converting their contents into displayable information.

Interfaces available directly by the microcontroller are SPI and de-multiplexed data/address bus. Communications protocols such as 1-Wire and I^2C although not available in hardware; they can be emulated in software, with 1-Wire being already used for Digital Identification keys and Temperature Sensor devices.

Interfacing complexity is always an issue when having to create a prototype or build a finalized circuit board. If additional external circuitry is needed, then total cost increases.

Combining a backup power supply (a battery) with internal RAM, makes the RTC chip an ideal backup storage for important system data.

The number of interrupt outputs is important if every output can generate interrupt signals with different programmed time period or at a specific time/date. An interrupt signal generated every 1 second can be extremely useful for measurements, calculations or simply as a means of knowing when the contents of the RTC have changed.

Cost, as always, is an important factor when selecting parts for a project. The lowest the cost of parts used, the better.

Table 2-14 Real Time Clock Devices

	DS12C887	DS2417	DS1305	MAX6902
Real Time Data Format	Full Format	Binary	Full Format	Full Format
Interface Type	Muxed Data/Address Bus	1-Wire Bus	SPI	SPI
Backup Power Supply	Yes	No	Yes	Yes
Interrupt Outputs	1	1	2	0
Interrupt (1Hz)	Yes	Yes	Yes	No
CMOS RAM on-chip	113 Bytes	-	96 Bytes	31 Bytes
Cost	$4.80	$0.92	$1.84	$1.45
Manufacturer	Dallas/Maxim	Dallas/Maxim	Dallas/Maxim	Dallas/Maxim

Table 2-15 Real Time Clock Weighted Decision Matrix

Display Technology	A	B	C	D	E	F	G	H	Total Points
DS12C887	14	-14	-11	5	1	9	12	-12	**4**
DS2417	-14	7	11	-5	1	9	-4	24	**29**
DS1305	14	14	11	5	2	9	8	24	**87**
MAX6902	14	14	11	5	-2	-9	4	24	**61**

2.2.7. Storage Device

Some of the data acquired from the vehicle's sensors and digital ID devices need to be stored for later process at the company's headquarters. Due to the extended time of a trip the amount of data can be large, so memory devices with correspondingly large capacities are required. The storage device to be used needs to be non-volatile to retain data even after power disconnection or momentary loss. On the following pages some of the most popular memory devices on the market are analysed and through comparative thinking the most suitable for the project is selected.

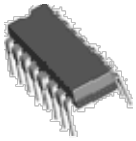
Table 2-16 Storage Media Weights Matrix

		A	B	C	D	E	F	De-normalized	Normalized
Capacity Range	**A**	=	-	-	+	-	-	-3	**3**
Interface Type	**B**	+	=	-	+	+	-	1	**7**
Interfacing Complexity	**C**	+	+	=	+	+	-	3	**9**
Access Mode	**D**	-	-	-	=	-	-	-5	**1**
Transfer Speed	**E**	+	-	-	+	=	-	-1	**5**
Cost/MB	**F**	+	+	+	+	+	=	5	**11**

Table 2-17 Storage Media Analyzed Weighted Selection Criteria

Selection Criteria	Description	Points	Weighted Points
A. Capacity Range:	Below 1MByte per unit	-2	**-6**
	Over 1MByte and less than 32MB	1	**3**
	Over 1Mbyte and up to 1GB	2	**6**
B. Interface Type:	Serial Interface	1	**7**
	Parallel Interface	2	**14**
C. Interfacing Complexity:	Requires External Logic	1	**9**
	Requires Special Connector	1	**9**
	Requires External Logic & Special Connector	-1	**-9**
	Requires No External Logic	2	**18**
D. Access Mode:	Byte Read – Byte Write	3	**3**
	Byte Read – Block Write	2	**2**
	Block Read – Block Write	1	**1**
E. Transfer Speed:	Slow (less than 100KB/sec)	-1	**-5**
	Medium (more than 100KB/sec – less than 1MB/sec)	1	**5**
	Fast (more than 1MB/sec)	2	**10**
F. Cost per MB	Low (less than 50p)	2	**22**
	Average (more than 50p -less than £1)	1	**11**
	High (more than £2)	-1	**-11**

E^{2}PROM & FLASH



Both these data storage technologies are available by many manufacturers, however due to packaging and pin count (because of individual byte read support) it is very difficult to market large capacity devices due to cost. The basics behind their technologies are used by the other devices analysed.

CompactFlash Card

The CompactFlash Card is a FLASH memory device that uses the same interface protocols and signals as ordinary ATA drives, that is hard disk drives. Its capacity ranges from a few hundred kilobytes to a few hundred megabytes. It implements three different interface protocols to allow interfacing for different application requirements. It is small in dimensions, fast, reliable and robust.

SmartMedia

The SmartMedia is a FLASH memory device that uses a proprietary parallel interface. It is small in dimensions, fast, reliable and robust. It can be easily interfaced and is used in many applications for data storage. Its parallel interface uses time multiplexing to reduce pin count, thus requires a multiplexed address/data bus from the processor.

Memory Stick

The Memory Stick is a FLASH memory device that uses a proprietary serial interface, thus allowing the use of less I/O pins. It is small in dimensions, fast, reliable and robust.

Table 2-18 Storage Media					
	E^2PROM	**FLASH**	**CompactFlash**	**Smart Media**	**Memory Stick**
Capacity Range	16kbit-4Mbit	256kbit-64Mbit	4-256MBytes	32-256MBytes	4-128MBytes
Interface	Parallel	Parallel	Proprietary Parallel - ATA	Proprietary Parallel	Proprietary Serial
Access Mode	Block Alterable Byte Access	Block Alterable Byte Access	Block Alterable Block Access	Block Alterable Block Access	Block Alterable Block Access
Write Times	Slow	Average	Fast	Fast	Fast
Cost	£27 (for 1Mbit)	£16-23 (for 8Mbit)	48p per MByte (for 32MB)	33p per MByte (for 32MB)	62p per MByte (for 32MB)
Other	Separate Programming Power Supply Required		Three Different Access Modes		

- Prices and capacity ranges as found on July-August 2002

Table 2-19 Storage Media Weighted Decision Matrix							
Storage Device	**A**	**B**	**C**	**D**	**E**	**F**	**Total Points**
E^2PROM	3	14	9	2	-5	-11	**12**
FLASH	3	14	9	2	5	-11	**12**
CompactFlash	6	14	18	1	10	22	**71**
SmartMedia	6	14	-9	1	10	22	**44**
Memory Stick	6	7	-9	1	10	11	**26**

The CompactFlash Card having collected the most points for its features is effectively characterized as the most suitable storage media for the project and will be analysed in more depth in the Hardware Design section o this report (Chapter 3.1.3.4, p. 3-50).

2.2.8. Communications Bus

Having nearly reached the budget limit for the project, an exotic solution in the decision for a high-speed communications bus for connection to a personal computer, could not be followed. Instead as a communication medium to a Personal Computer to download or upload data, one of the serial ports on the microcontroller was selected, running at the highest possible speed.

2.3. Finalised System Outline

Having selected the parts most suitable the project, a finalized system outline was drawn and is shown in Figure 2-2 below.

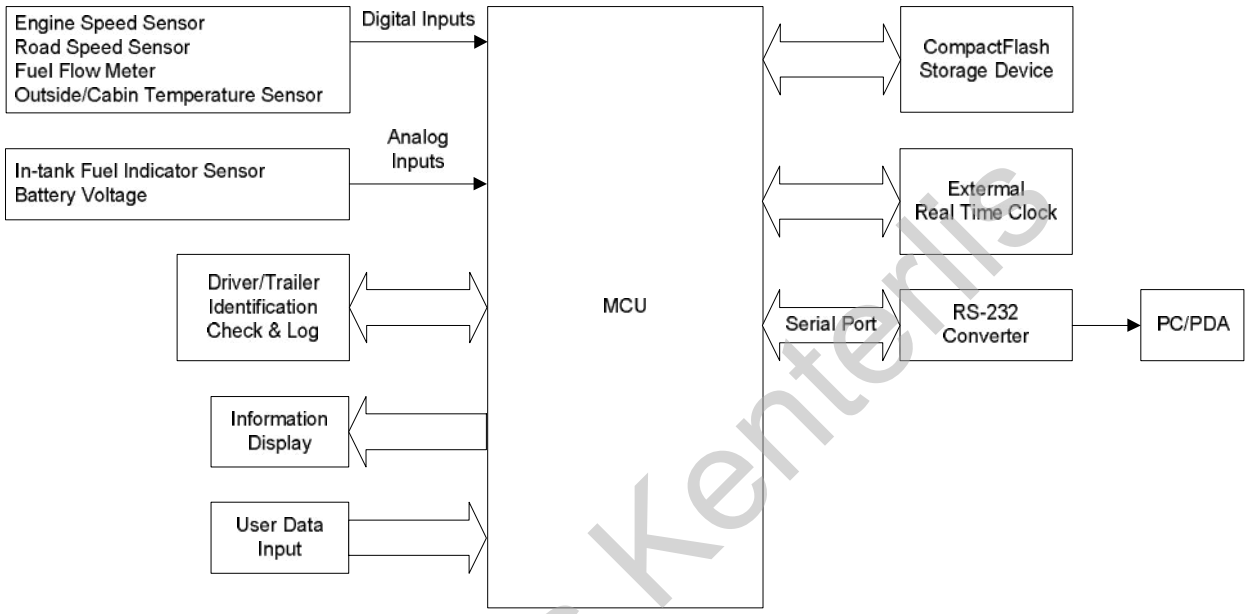


Figure 2-2 Finalized System Outline

3. Project Design

The project can be partitioned into two design areas, the Hardware Design and the Software Design. In this chapter both partitions will be presented and analysed as much as possible without reaching into much depth. For more in-depth information on modules and functions, please consult the datasheets that are found in the accompanying CD-ROM.

3.1. Hardware Design

3.1.1. Automotive Sensors

3.1.1.1. Engine Speed Sensor

The Engine Speed information is derived from the Camshaft Position Sensor (also called G1 Sensor). The G1 Sensor is of the pick-up coil type sensor, although many other types are also used by car manufacturers. This type of sensor consists of a permanent magnet, yoke, and coil. This sensor is mounted close to a toothed gear. This gear is connected to the camshaft, providing a 1:1 ratio of the actual engine speed. As each tooth moves by the sensor, an AC voltage pulse is induced in the coil. Each tooth produces a pulse. As the gear rotates faster more pulses are produced. The ECM determines the speed the gear is revolving based on the number of pulses. The number of pulses per second is the signal frequency.

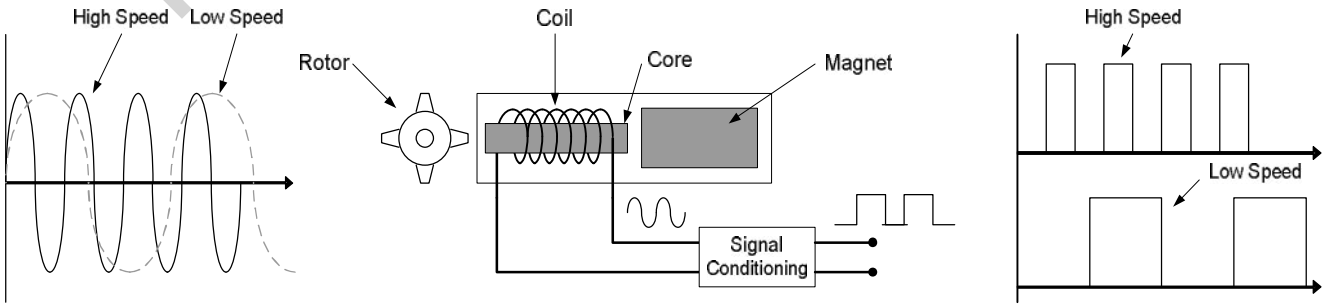


Figure 3-1 Pickup Coil Sensor

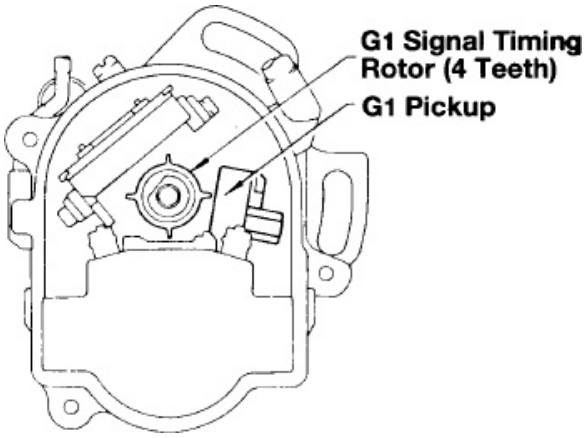


Figure 3-2 Engine Speed Sensor (G1 Sensor)

In the case of the G1 Sensor, by multiplying the number of pulses counted in a second with the number of seconds per minute, the engine's speed per minute is calculated. However a camshaft gear may have more than one tooth hence the number of pulses counted per engine revolution are a multiple of the number of teeth on the gear. Before doing any further calculations, division of the counted pulses by the number of teeth present is required to extract the number of engine revolutions.

The output of the G1 Sensor, after being conditioned to output clean square wave pulses, is fed to the microcontroller by using a TPU3 channel input as will be discussed later in this report.

3.1.1.2. Road Speed Sensor

The Road Speed Sensor (or Vehicle Speed Sensor, VSS) is typically of the same type as the Engine Speed Sensor, although many other types also exist. It is either located in the transaxle or the transmission of the vehicle. The vehicle's speed is again coded in the frequency of the output signal.

Knowing the number of pulses produced per wheel revolution, the number of pulses counted in one second and the perimeter (circumference) of the tire it is easy to calculate the vehicle's speed.

$$\text{Vehicle Speed} = \frac{\text{Counted Pulses in 1 Second}}{\text{Pulses Per Wheel Revolution}} \cdot \text{Tire Perimeter} \cdot 60\text{secs} \cdot 60\text{mins}$$

3.1.1.3. In-Tank Fuel Sensor

The In-Tank Fuel Sensor, also known as Fuel Tank Sending Unit, is as its name reveals located in the fuel tank of the car. It consists of a float, usually made of foam, connected to a thin, metal rod. The end of the rod is mounted on a potentiometer. In a fuel tank, the potentiometer consists of a strip of resistive material connected on one side to the ground. A wiper connected to the gauge slides along this strip of material, conducting the current from the gauge to the resistor.

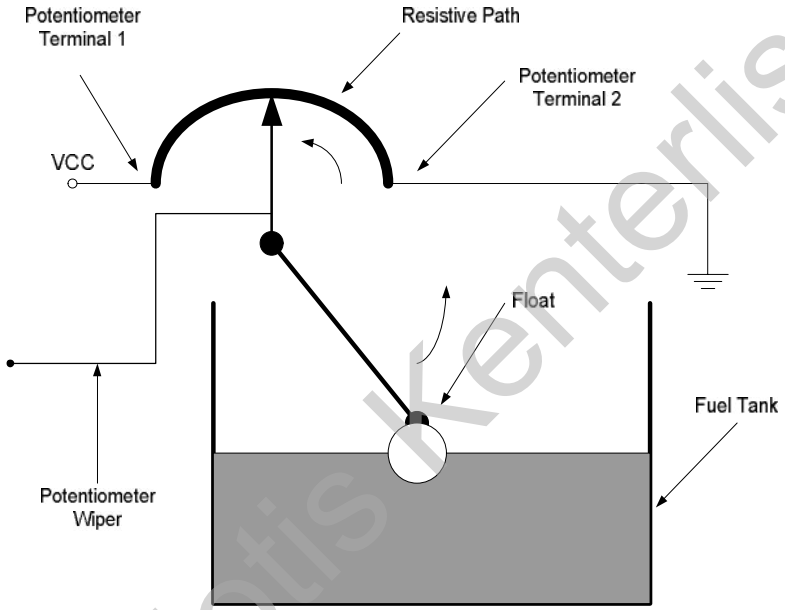


Figure 3-3 In-Tank Fuel Sensor

If the wiper is close to the grounded side of the strip, there is less resistive material in the path of the current, so the resistance is small and the voltage that is measured on the wiper terminal is small. If the wiper is at the other end of the strip, there is more resistive material in the current's path, so the resistance is large and the voltage that is measured on the wiper terminal is very close to V_{CC} (or equal to it, depending on potentiometer structure). By inference, the more fuel present inside the fuel tank the closer the voltage measured on the sensor's output (wiper).

For the project a linear behaviour of the float and the output of the sensor are assumed in relation to the amount of fuel in the tank. Simply by measuring the voltage on the sensor's output is enough to calculate the remaining fuel in a tank of a known capacity.

$$\text{Fuel in Tank} = \frac{\text{ADC Channel Conversion Result}}{2^{\text{ADC Bit Resolution}} - 1} \cdot \text{Fuel Tank Capacity}$$

3.1.1.4. Fuel Flow Meter

A flow meter is a device that produces a specific output when a specific amount of liquid or gas flows through it. For our purposes, a flow meter device for liquid fuel is assumed. There are many different technologies used to measure the quantity of fuel that flows through the gauge. The technology used is not a subject of this report.

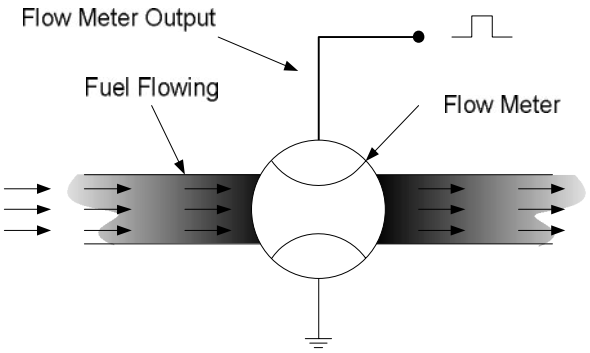


Figure 3-4 Fuel Flow Meter Operation

For the report a typical flow meter with digital output (TTL) is assumed, this means that for a given quantity of fuel having flowed through the meter, a pulse is generated on the output of the flow meter device.

By accumulating the number of pulses received from the flow meter during the course of time and multiplying with the amount of fuel flowing per pulse, the total fuel consumption of the vehicle is calculated. Again by using the flow meter's output pulses it is easy enough to calculate the fuel consumption of the vehicle per distance measuring unit.

$$\text{Total Fuel Consumption} = \left(\sum_{\text{Trip Start}}^{\text{Trip Finish}} \text{Flow Meter Pulses} \right) \cdot \text{Fuel Quantity Per Pulse}$$

Although fuel consumption can be calculated by measuring the amount of time that the injectors are on, the flow meter device is used instead, in order to simplify both hardware and software design for the project at this stage. Of course as expected there is an increase in cost, however by using a flow meter, the trip computer actually becomes independent of the vehicle's engine specifications and also prevents us from tampering with the ECU.

Had the fuel consumption information been acquired otherwise, much knowledge would be required of at least the amount of fuel sprayed by an injector within a specific amount of time and the number of injectors in the engine. In addition, a facility that allows counting the "ON" time of the injectors is required. This solution although it allows to keep cost down, it adds extra complexity to the project, which at this stage would not be possible to deal with, without proper equipment and facilities.

3.1.2. Microcontroller Presentation

Discussion on the hardware section of the project should fairly start with the heart of the project, the Motorola MPC555 microcontroller.

The MPC555 is a very powerful 32bit microcontroller based on the PowerPC core with on-chip floating point unit (FPU) targeted for the automotive industry. With a large amount of FLASH program memory of 448Kbytes in total, it can store large programs as well as large arrays of read-only data. It is equipped with 26Kbytes of internal SRAM, used for system variables and other storage requirements.

The Unified System Interface Unit (see USIU p. 3-30, Ref. [6]) of the MPC555 is responsible for controlling system start-up, system initialisation and operation, system protection, system interrupt handling, and the external system bus. Two serial asynchronous, one synchronous SPI and two CAN bus controllers constitute the microcontroller's communications facilities (see QMSCM p. 3-38 and TouCAN, Ref. [6]). The modular I/O system (MIOS1) consists of a library of flexible I/O and timer functions including I/O port, counters, input capture, output compare, pulse and period measurement, and PWM (see MIOS1 p. 3-39, Ref. [6]). Two Queued Analogue-to-Digital Conversion modules are available for interfacing analogue signals to the microcontroller (see QADC64 p. 3-36, Ref. [6]).

The strongest feature of the microcontroller however, is the Time Processor Unit, which is a programmable microcontroller itself, which deals with time related functions (see TPU3 p. 3-40, Ref. [6]). Having two TPU modules the MPC555 can control almost any function. 6Kbytes of Dual Ported RAM can be used for TPU related operations.

All these functionalities combined with an internal clock frequency of 40MHz maximum; make the MPC555 one of the most powerful microcontrollers available.

3.1.2.1. Use of Microcontroller Modules in the Project / Configuration

- ***USIU – Unified System Interface Unit***

The USIU, as already described, is a module that plays an important role in the operation of the MPC555. It controls and coordinates various critical system functions, which include the following:

- **System configuration and protection:** Controls the overall system configuration and provides various monitors and timers, including the bus monitor, software watchdog timer, periodic interrupt timer, PowerPC decrementer, time base, and real time clock.
- **Interrupt controller:** Handles interrupt requests according to hard-coded priority and masking. Both external and internal interrupt sources are supported.
- **System reset monitoring and generation:** Receives input from a number of reset sources and takes appropriate actions, depending on the source.
- **Clock synthesizer:** Generates the clock signals used by the SIU as well as the other modules and external devices.
- **Power management:** Various low-power modes are supported and configured for use by the system.
- **External bus interface (EBI) control:** Handles the transfer of information between the internal busses and the memory or peripherals in the external address space. Also allows external devices to become bus masters.
- **Memory controller:** Provides a programmable glueless interface to various types of external memory devices and peripherals. Four chip select pins are provided, with programmable timing attributes and activation address range.
- **Debug support:** Provides an interface which allows testing and debugging of programs by use of some external hardware and software running on a PC (see Testing & Debugging Methods p. 5-91).

Those functions used in the project are analysed in the following pages.

○ *Clock Synthesizer*

The CPU core, internal counter/timers and other facilities make use of clock signals that are produced by the microcontroller's internal circuits. System clocks can be configured to have any of three clock sources, the external quartz crystal (4MHz or 20MHz), the internal backup clock oscillator, and an external clock source connected to the EXTCLK pin. The external clock source should have a frequency of 4MHz or the same as the desired system frequency. These limitations exist due to the use of internal frequency division and multiplication circuits.

For the purposes of this project, only the clock oscillator using an external quartz crystal at 4MHz was used as a clock source (main clock oscillator). This clock drives the System Phase Lock Loop circuit, which acts as a programmable multiplier of 20 ($SPLL_{output} = SPLL_{input} \cdot [USIU.PLPRCR.B.MF + 1] \cdot 2$, where MF=9) generating an 80MHz clock, which is next fed to a prescaler circuit and divided by a programmable divider of 2 ($\text{USIU.SCCR.B.DFNL} = 0b000$). The output of the prescaler, after amplified, is fed to the CPU core as the main system clock (f_{CPU}).

The main clock after being fed to a programmable prescaler (Divide by 4, or by 16), and divided by 4 ($\text{USIU.SCCR.B.TBS} = 0b0$) and amplified, becomes the Time Base Clock, which is used to clock the Decrementer. The main clock also drives another programmable prescaler (Divide by 4, or by 256), which divides the clock signal by 256 ($\text{USIU.SCCR.B.RTDIV} = 0b1$) to generate a 15625Hz clock signal. This clock after amplification is fed to the internal RTC and the Periodic Interrupt Timer.

Clock programming explanatory diagram is displayed in Figure 3-5 below (Ref. [6]).

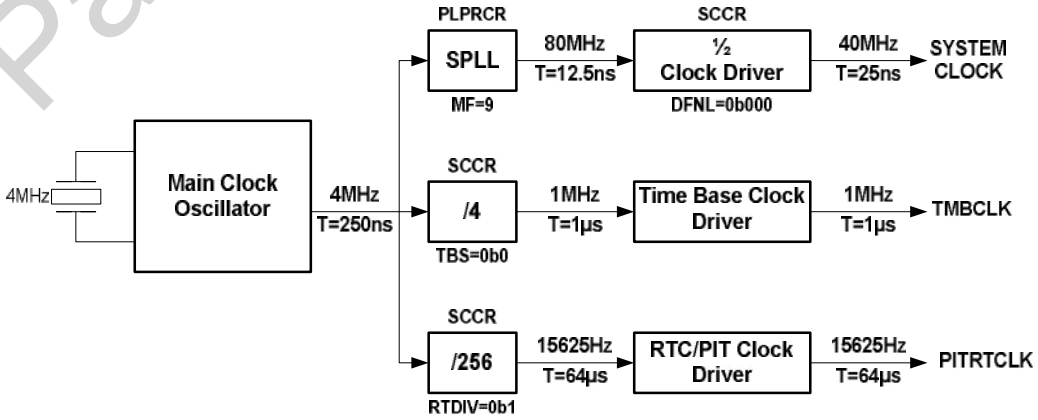


Figure 3-5 Clock Control

○ *Interrupt Configuration*

The Interrupt Controller (Ref. [2]) on the microcontroller has been configured for two external and three internal interrupt sources. Two more internal sources are configured but not enabled. Every source is assigned a priority that is hardware coded but can be altered by software to handle lower fixed priority sources first. External interrupt sources are hard-wired to specific $\overline{IRQ}$ pins of the microcontroller. $\overline{IRQ0}$ is a Non Maskable Interrupt (NMI) source hence it cannot be blocked from generating an interrupt. $\overline{IRQ0}$ should only be used by external hardware to indicate a catastrophic system fault. In total there are 8 external interrupt sources $\overline{IRQ0} - \overline{IRQ7}$ and 32 internal interrupt sources $LEVEL0 - LEVEL31$. Interrupt sources with a small index number have higher priority. Internal interrupt sources $LEVEL7 - LEVEL31$ are mapped to USIU interrupt request level seven ($LEVEL7$). The software must read the UIPEND register of the Inter-Module Bus (IMB) to determine the actual source of the interrupt. SIVEC is a 32-bit register holds an 8-bit code representing the unmasked interrupt source of the highest priority level.

Interrupt sources can be masked by clearing the corresponding bit on the System Interrupt Mask Register (SIMASK). After having serviced an external interrupt source, it is important to clear the interrupt flag bit in SIPEND, in order to clear the corresponding interrupt request latch if a logic '0' is no longer present on the pin. Clearing an interrupt request flag in SIPEND is done by writing logic '1' in the bit position of the interrupt source.

For the project, the interrupt sources and priorities shown in Table 3-1 were configured and used.

Table 3-1 Interrupt Sources and Priorities

Priority*[1]	Interrupt	Interrupt Source	Enabled
0	Level 0	Internal RTC	Yes
1*[2]	Level 1	TPU3_A	Yes
2	$\overline{IRQ1}$	External RTC $\overline{INT0}$	Yes
3	$\overline{IRQ2}$	External RTC $\overline{INT1}$	Yes
4	Level 2	SCI	Yes
5	Level 3	QSPI	No
6	Level 4	QADC	No

*[1] Highest priority has smallest value. Lowest Priority has largest value.

*[2] Level 1 although actually of lowest hardware priority, inside the ISR is handled before external interrupt sources.

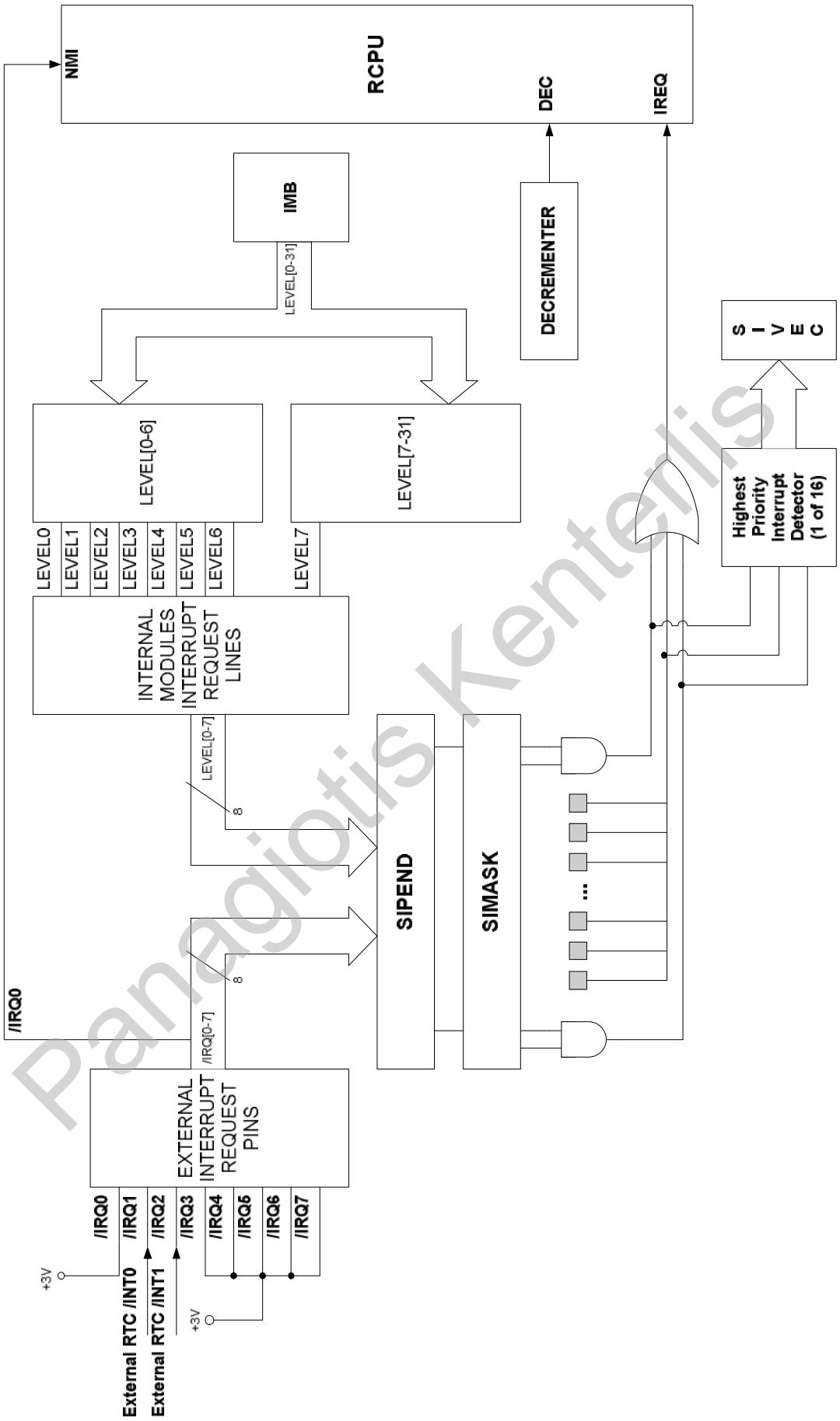


Figure 3-6 Interrupt Controller

○ *Internal Real Time Clock*

The internal RTC is a 32bit register/counter, accompanied by a 32bit Alarm register. The external crystal of the development board supplies a clock frequency of 4MHz, which is then divided internally by 256 (PITRTC Clock), and by 15625 by the internal RTC prescaler, which finally provides a clock frequency of 1Hz to the RTC counter.

$$\text{RTC Clock} = \frac{\dfrac{\text{External Crystal Frequency}}{\text{USIU.SCCR.B.RTDIV} = 1}}{\text{USIU.RTCSC.B.M} = 1} = \frac{\dfrac{4 \cdot 10^6\, Hz}{256}}{15625} = \frac{15625 Hz}{15625} = 1 Hz$$

A 32bit counter can count a total of 4,294,967,296 seconds, before overflowing and starting again from zero, which is enough to record time for a total of 136 years.

For the project, the internal RTC is only used to provide an interrupt signal every second, to record the elapsed trip time from a previous stop, as well as to support the tiredness warning alarm. The internal RTC can be configured to enable interrupt generation every second (USIU.RTCSC.B.SIE) and/or when the RTC counter matches the RTC Alarm register (USIU.RTCSC.B.ALE).

The RTC Alarm register is programmed every time a trip is started or resumed to hold the number of seconds for 3 hours ($3 hours \cdot 60 \min s \cdot 60 \sec onds = 10{,}800 \sec onds$), while the RTC counter itself is reset to 0 seconds. When the contents of the RTC counter match the contents of the RTC Alarm register, then an interrupt is generated with the alarm flag set (USIU.RTCSC.B.ALR).

When a second has elapsed the Once-per-Second flag is set (USIU.RTCSC.B.SEC) and an interrupt is requested if the interrupt condition has been enabled. Inside the interrupt service routine (ISR) of the internal RTC all measurements and related calculations are performed. If the source of the interrupt is an alarm match, then the tiredness warning alarm window is called.

The internal RTC can be stopped and resumed at any time by clearing/setting the USIU.RTCSC.B.RTE bit.

Internal RTC is assigned Interrupt Level 0, which has the highest priority from all other internal interrupts. The source code functions that handle the internal RTC are included in the **Routines.c** file.

○ *Decrementer*

The Decrementer is a 32bit timer/counter register configured by software to be clocked by a signal with a time period of 1μsec. As it name implies, the register decrements its contents at every clock pulse.

Inside the project the Decrementer is used to provide a basic time delay in multiples of a Decrementer clock period ($T_{TMBCLK} = 1\mu sec$). The delay function needs to initialise the Decrementer with the number of periods to wait, start the Decrementer and wait in a check loop until the contents have reached a terminating value (0).

However, since the Decrementer generates an exception when it underflows, an offset value is added to the number of periods to wait, and it is this number that is used as the terminating value. Termination of the check loop occurs when the Decrementer register's value is equal or less than the offset value. This is done in order to avoid the software overhead of executing the exception handling routine every time the delay function is used. However, if the software check snippet misses to identify that the requested number of periods has been counted and the Decrementer underflows (if because of an exception or interrupt being processed for too long) then the software check loop will not be aware of this condition and will continue to count down causing a very long delay (2^{32}–offset μseconds).

This problem can be eliminated by including as well as with a minimum check, a check on a global flag. If the Decrementer underflows, it will cause an exception, inside the service routine of which, the global flag is set and that will force the check loop to terminate when the exception service routine returns control to it. After that the Decrementer must be disabled to prevent it from causing unwanted exceptions.

Source code functions to control the Decrementer can be found in the **Routines.c** file.

○ *General Purpose I/O*

Pins primarily assigned for use as address, data and control bus can be configured for I/O functions by programming registers SGPIO Data Register 1 (SGPIODT1), SGPIO Data Register 2 (SGPIODT2) and SGPIO Control Register (SGPIOCR).

SGPIODT1 controls the I/O pins for the Data bus. SGPIODT2 controls I/O pins for the address and control bus. SGPIOCR controls the data direction of these I/O pins. For the external bus lines to be used as GPIO, the Single-Chip field (SC) on SIU Module Configuration Register (USIU.SIUMCR) must be configured accordingly.

- ***QADC – Queued ADC***

The MPC555 microcontroller embeds two QADC modules, for analogue signal interfacing of 16 inputs each. A total of 32 analogue inputs are controlled by the two modules, which can be increased to 82 channels by external multiplexing. The QADC module offers two queues of 32 entries each (Queue 1 & 2) used for conversion commands and 64 result registers, directly related with each other.

Every conversion command queue entry can control any of the 16 analogue input pins associated with the module and order the conversion of the voltage present on the pin defined by the command. The result of the conversion is stored in the conversion result word queue in three formats (right-justified unsigned, left-justified unsigned, left-justified signed).

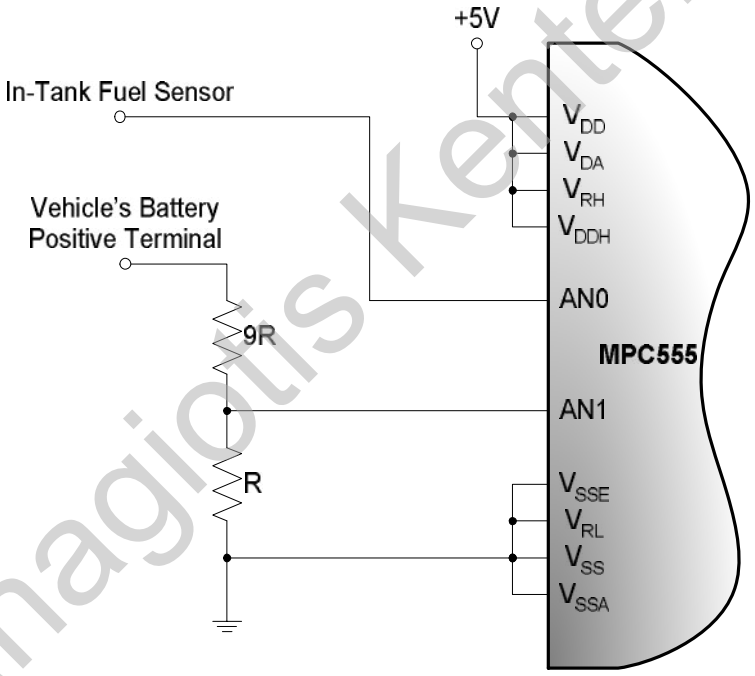


Figure 3-7 QADC_A Channel Connections

Both QADC modules have been configured to measure input voltages in the range of 0 to 5V by connecting voltage reference pins V_{RH} (Reference High) and V_{RL} (Reference Low) to V_{CC} (5V) and GND respectively (see Figure 3-7). Six power supply input pins are also connected for analogue power supply (V_{DDA} and V_{SSA}), external digital power supply (V_{DDH} and V_{SSE}) and internal digital power supply shared with other modules (V_{DD} and V_{SS}). The reason for using different analogue and digital supply pins is to reduce the amount of noise normally present in digital power supply pins. QADC conversion result has a 10bit resolution

and given an input signal with a voltage range 0-5V, then the voltage resolution is calculated as being equal to $\frac{V_{RH}-V_{RL}}{2^{10}-1}=\frac{5V-0V}{1024-1}=\frac{5V}{1023}\approx 4{,}89mV$.

For the project, QADC_A is used with two of its analogue inputs connected to the In-Tank Fuel Sensor (Channel Pin 0 – AN0) and the Battery Voltage divider (Channel Pin 1 – AN1). Both these inputs are conditioned to give a voltage value in the range of 0 to 5V. Queue 1, has been configured to operate in Periodic Timer Continuous Scan Mode with the maximum possible scan period of $QCLK\cdot 2^{17}$, where $QCLK$ has been configured by prescaling to have a period of $QCLK=40\cdot \text{IMB clock periods}=40\cdot 25ns=1{,}000ns=1\mu\text{sec}$, thus giving a scan period of $QCLK\cdot 2^{17}=1\mu\text{sec}\cdot 131{,}072\approx 131\text{ms}$. Two queue entries have been programmed to control these two channels. Both channels are read every 131ms and their conversion results are made available for use by the software. For software simplicity the data format used is right-justified unsigned giving result values in the range 0x000-0x3FF (0-1023_{10}).

After executing the conversion commands for the two used channels, the third queue entry containing an End of Queue command terminates Queue 1 and waits for the wait period to elapse before restarting queue execution.

The voltage divider for the Battery Voltage input (see Figure 3-7) is used to condition the voltage level and fit it in the range of 0-5V. To accommodate a real maximum voltage value of 50V, a 1/10 divider is needed to provide to the QADC channel pin a maximum voltage level of 5V. A potentiometer/trimmer is a practical way of achieving this, by setting the wiper at 1/10 of the resistor's value, e.g. for a 10KΩ trimmer, the wiper should be set at 1KΩ. One terminal of the trimmer is connected to the battery voltage power line, the other to the ground and the wiper to the QADC channel pin. The 1KΩ resistance value should be measured between the QADC pin and the ground. Any battery voltage applied will be divided by ten before being fed to the QADC for conversion. For example, by applying 42V as the battery voltage (new automotive battery standard value) gives 4,2V in the QADC pin. This value can then be multiplied in software by 10 to display the real value of the battery's voltage.

Source code function that configures the QADC_A module can be found in the **QADC_Functions.c** file.

- ***QSMCM – Queued Serial Multi-Channel Module***

The Queued Serial Multi-Channel Module of the microcontroller provides two asynchronous serial ports (SCI, Serial Communication Interface) and one QSPI (Queued Serial Peripheral Interface) port. Both SPI and the first SCI port are queued. This means that a set of information can be written to or read from the port, without requiring constant monitoring by software. The software will only have to transfer data when these are needed to be sent or are available to read. The amount of information to send or accept before re-involving the software is programmable.

For the project, all ports are used. The first SCI port is configured for operation at 115,200bps, 8 data bits, 1 stop bit and no parity bit. It is used to connect the trip computer to a personal computer and upload data stored on the CF Card, as well as download configuration information on the sensors used. Before connecting to the PC's serial port, the TTL voltage levels of the microcontroller's serial port need to be translated to RS-232 voltage levels. This voltage translation is performed by any RS-232 line driver/receiver.

The second SCI port is configured for operation at 19,200bps, 8 data bits, 1 stop bit and no parity bit. It is used to control the VFD module for printing information on the display. All commands and data are sent to the VFD and also some data can be read back from it.

The QSPI port is used to interface to the external RTC device at a speed of 500kbps (clock speed of 500 kHz). For the external RTC only one peripheral select pin is used (PCS0), out of the four available.

Although the queue facility could have been enabled for both the first SCI port and the QSPI port, this was not done, firstly to allow different time delays between data transfers to be inserted, and secondly, due to the need to verify whether a transfer has been successful or not, before sending more data. Instead, software flow control is implemented for both sending and receiving data from the communications module. Since most communication is performed outside the ISR, inside which most calculations take place, there is little or no CPU hogging because of executing wait loops to send or receive data.

Source code functions that control the SCI ports can be found in the **SerialPort.c** file. Source code functions for the QSPI port can be found in the **SPI_Functions.c** file.

- ***MIOS1 – Modular Input Output System***

Although the MIOS1 module offers many features (see datasheet), only the 16-bit Parallel Port I/O Sub-Module (MPIOSM) is used for the project. The I/O pins of the port are programmed individually to support external peripherals as control pins.

By writing to the MPIOSM Data Direction Register (MPIOSMDDR), the data direction for every can be individually assigned (Logic '1'=Output, Logic '0'=Input). By writing to or reading from the MPIOSM Data Register (MPIOSMDR) the logic state of the I/O pins can be altered or read.

I/O connections and data direction for every port pins are listed in Table 3-2.

Table 3-2 MIOS1 Parallel I/O Port Pin Connections

MIOS1 Pin	Data Direction	Pin Connection
PIN15	I/O	Cabin Temperature Sensor
PIN14	I/O	Outside Temperature Sensor
PIN13	I/O	Trailer ID network
PIN12	I/O	Driver's ID probe
PIN11	O	VFD Module Reset (/RESET)
PIN10	I	VFD Module Busy (MB)
PIN09	O	VFD Host Busy (HB)
PIN08	O	Buzzer Control
PIN07	O	Driver's ID probe LED
PIN06	-	Not Used
PIN05	-	Not Used
PIN04	-	Not Used
PIN03	O	CompactFlash /RESET
PIN02	O	CompactFlash /CS0
PIN01	O	CompactFlash /IOWR
PIN00	O	CompactFlash /IORD

I – Pin has been configured for Input function.
O – Pin has been configured for Output function.
Pin numbering uses Little-Endian Format.

An individual I/O pin can be manipulated by using logic masking techniques when reading from or writing to the data register. All functions used to control MIOS1 parallel I/O port are found in the **MIOS1_Functions.c** file.

- ***TPU3 – Time Processor Unit***

The Time Processor Unit version 3 (TPU3), is an intelligent programmable microcontroller designed for timing control. The MPC555 contains two independent TPU3 modules. The TPU3 module executes micro-instructions stored either in its own memory, which is completely invisible to the CPU, or from the Dual-Port Memory on the MPC555 chip. In the latter case, the TPU3 executes micro-instructions from RAM, which is no longer accessible by the CPU. The TPU3 in this case is said to be operating in Emulation mode. The TPU3 module has 16 channels, where every channel can be thought of as being similar to a task executed in a multitasking operating system. Every channel is assigned a function number and a priority level by the CPU software. An internal scheduler engine distributes processing time of the TPU3 execution engine to every channel according to its priority and status (enabled/disabled). I/O operations can be executed by the channel's selected function for the corresponding I/O pin. Connecting two or more channels is also possible by use of shared data space for inter-channel communication as long as the function executed by each channel permits it. The most important feature of the TPU3 is its requirement for minimum to zero CPU intervention in executing complex timing operations in real time by hardware.

The TPU3 module comes from Motorola with 16 pre-programmed functions in its microcode ROM. A full list of these functions is found in Table 3-3, however it is likely that some versions of the MPC555 may be shipped with other functions in the microcode ROM.

Table 3-3 TPU3 Microcode ROM Functions

Function Number	Function Nickname	Function Name
0xF	PTA	Programmable Time Accumulator
0xE	QOM	Queued Output Match
0xD	TSM	Table Stepper Motor
0xC	FQM	Frequency Measurement
0xB	UART	Universal Asynchronous Receiver/Transmitter
0xA	NITC	New Input Capture/Input Transition Counter
0x9	COMM	Multiphase Motor Commutation
0x8	HALLD	Hall Effect Decode
0x7	MCPWM	Multi-Channel Pulse Width Modulation
0x6	FQD	Fast Quadrature Decode
0x5	PPWA	Period/Pulse Width Accumulator
0x4	OC	Output Compare
0x3	PWM	Pulse Width Modulation
0x2	DIO	Discrete Input/Output
0x1	SPWM	Synchronized Pulse Width Modulation
0x0	SIOP	Serial Input/output Port

The TPU3 module was considered for use with the digital automotive sensors discussed previously (Engine Speed, Road Speed and Fuel Flow meter), whose information lies in the number of pulses generated by each of them.

Although for the purposes of the project, the Frequency Measurement (FQM) function (Ref. [4]) would seem most appropriate; this function actually operates in a time-window of specified duration. The reason for actually rejecting FQM is the fact that this time-window is very small, while the required measurement period is that of one second. Although it would be possible to use this function, in order to have correct values after a second has elapsed, the number of counted pulses for every time-window should be accumulated. At the end of every time-window an interrupt is generated and that could allow accumulating the pulses in a system variable. However the large number of interrupts per second, hogs the CPU, due to the need to save a number of registers to the stack every time the ISR is invoked and restoring them after the ISR has terminated.

Instead, the Input Transition Counter function was used (NITC) (Ref. [7]). This function allows the channel to act as a 16-bit pulse counter, which only generates an interrupt on counter overflow. Since it is not expected to have signals of frequency more than 65,535Hz (2^{16} Hz) as input to the TPU3 channels, it is unlikely that an interrupt will be invoked. However, should an input signal of frequency greater than 65,535Hz is applied to a channel and an interrupt is generated, inside the ISR the number of pulses already counted will be accumulated and used to sum the number of pulses in one second.

All channels used to interface to digital automotive sensors are configured to execute the NITC function, with a maximum number of pulses to count before generating an interrupt set to maximum (0xFFFF, 65535_{10}). The first TPU3 module (TPU3_A) was used for the project with three of its channels configured as explained above and as shown in Table 3-4 below.

Table 3-4 Use of TPU3_A Channels

Channel Number	Priority Level	Interrupt Enabled	Connected Sensor
0	Medium	Yes	Engine Speed Sensor (G signal)
1	High	Yes	Road Speed Sensor (VSS)
2	High	No	Fuel Flow Meter

The time base of one second is provided by the internal RTC as an interrupt every second.

The TPU3_A module, as already shown in Table 3-1 has been assigned with interrupt Level 1.

Source code functions to control the TPU3 modules and configure channels for the NITC function can be found in the **TPU3_Functions.c** file.

3.1.3. Peripheral Devices

In the following pages, the use and configuration of peripheral devices in the project is discussed.

3.1.3.1. Real Time Clock

The external Real Time Clock is connected to the microcontroller through the SPI port (see Figure 3-8). For the project development phase, the external RTC is connected to a temperature compensating crystal oscillator with an output frequency of 32.768 kHz and a 3.6V NiMH rechargeable battery. The crystal oscillator provides the reference frequency, which after a series of divisions inside the RTC chip, results to a frequency signal of 1Hz used for controlling the time registers on the RTC. The NiMH rechargeable battery is used to provide backup power supply for RTC functions and memory when the main power supply on V_{CC} pin has fallen below the voltage level of pin Vbat. Doing so, the RTC does not lose track of time or corrupt the contents of its memory when power is removed. For this reason, the RAM on the RTC is used as backup storage for various system variables and sensor configuration parameters.

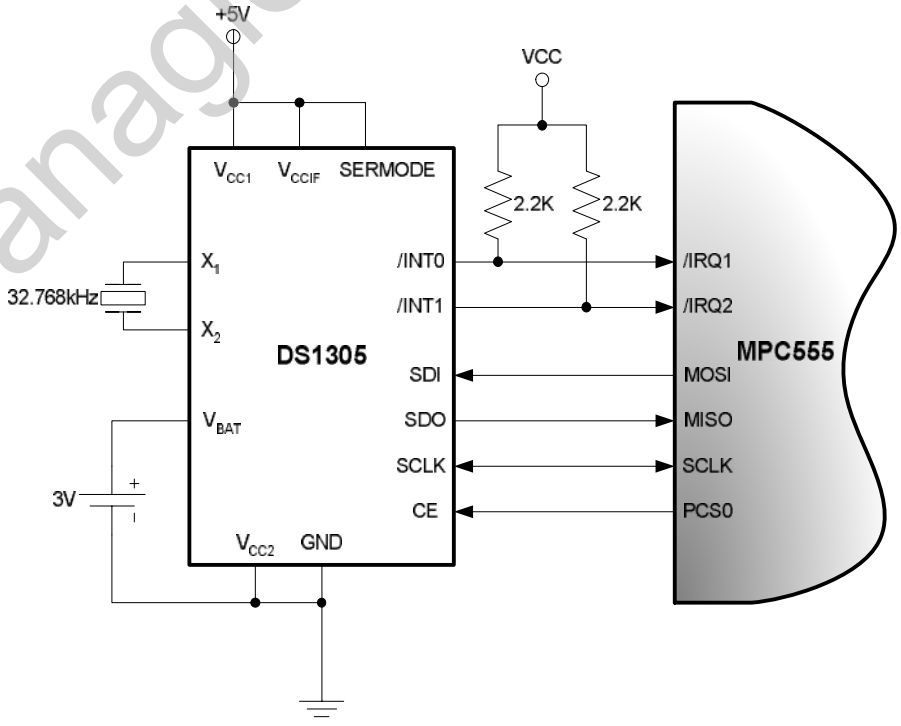


Figure 3-8 External RTC Connections

Please notice that only four I/O lines are required for SPI communication, SDI (Serial Data Input), SDO (Serial Data Output), SCLK (Serial Clock) and CE (Chip Enable). Unlike most devices the CE line is asserted when logic '1' is present. Two interrupt lines, $\overline{INT0}$ and $\overline{INT1}$, originating from the RTC are connected to $\overline{IRQ1}$ and $\overline{IRQ2}$ of the microcontroller, respectively. Output pin $\overline{INT0}/\overline{IRQ1}$ is controlled by Alarm0 facility on the RTC, which is programmed to generate a low pulse on the pin every second (1Hz). Output pin $\overline{INT1}/\overline{IRQ2}$ is controlled by Alarm1 facility on the RTC and is programmed and enabled by GUI routines to generate an interrupt when there is a match of the current time with the time value of the Alarm1 registers.

Every function that needs to carry a timestamp, such as saving data on the CF card, displaying time and date on the VFD, or displaying any other updated information on the VFD, is related to the ISR of the external RTC. This is either done directly, by executing the code inside the ISR, or indirectly, by setting a flag that will allow some code to be executed when the ISR has terminated.

The DS1305 external RTC has 32 register addresses assigned to RTC related registers and 96 bytes of RAM. These locations are accessed in different addresses for read and write operation.

Table 3-5 External RTC's Registers and Address Map

Address		Description
Read	Write	
0x00	0x80	Seconds Register
0x01	0x81	Minutes Register
0x02	0x82	Hours Register
0x03	0x83	Day Register
0x04	0x84	Date Register
0x05	0x85	Month Register
0x06	0x86	Year Register
0x07	0x87	Alarm0 Seconds Register
0x08	0x88	Alarm0 Minutes Register
0x09	0x89	Alarm0 Hours Register
0x0A	0x8A	Alarm0 Day Register
0x0B	0x8B	Alarm1 Seconds Register
0x0C	0x8C	Alarm1 Minutes Register
0x0D	0x8D	Alarm1 Hours Register
0x0E	0x8E	Alarm1 Day Register
0x0F	0x8F	Control Register
0x10	0x90	Status Register
0x11	0x91	Trickle Charger Register
0x12-0x1F	0x92-0x9F	Reserved
0x20-0x7F	0xA0-0xFF	96 Bytes RAM

The SPI port actually sends a 16bit word to the external RTC, comprising of one byte indicating the register to be accessed and one byte of data. Data is sent always with MSB first. When writing a byte, first the address of the register to write is sent and afterwards the data to write (Figure 3-9). When the device is accessed for read operation then the data byte has no meaning and its value is not important, however at the same clock ticks the data contained in the register accessed are read from the SDO line (Figure 3-10).

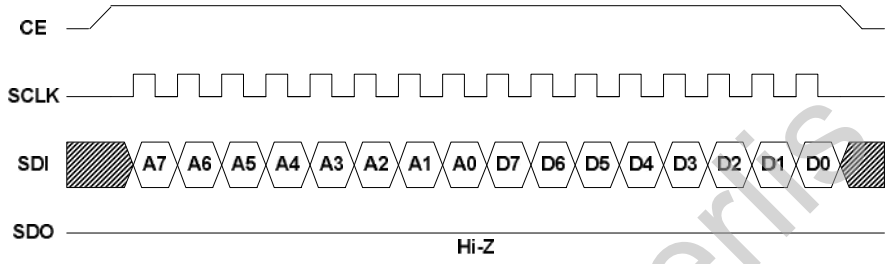


Figure 3-9 SPI Single-Byte Write

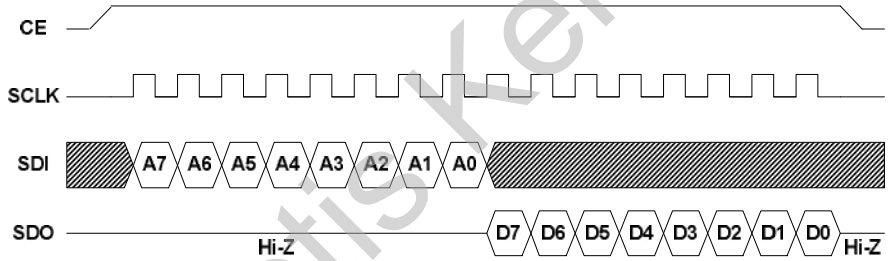


Figure 3-10 SPI Single-Byte Read

Source code functions to control the external RTC device can be found in the **ds1305.c** file. Source code functions to access the SPI port can be found in the **SPI_Functions.c** file.

3.1.3.2. Information Display Unit (VFD Module)

Having decided on the type of display to use and searching even more carefully at the available products and their prices, a specific VFD module was found that fitted the design specifications and unexpectedly offered more than what was initially considered.

The Itron GU126x64F-K610A3-01 is a 126x64 graphics display module. It has two serial ports, a synchronous (SPI) port and one CMOS full duplex asynchronous port, both of which are available for use on the microcontroller and can save on connection wiring and PCB space. A serial connection also allows for the display device to be placed away from the main device and closer to the driver's direct line of view. The module is powered by a transformer-less power supply unit (PSU), therefore there is no need for extra space, cost and wiring for a dedicated PSU. A standard 5V PSU capable of supplying 1.5-2A (7.5-10W) is enough to supply power to the entire trip computer's hardware circuits. The selected display module also comes with an on-board 8 line I/O port, which can be useful especially if the device is placed some distance away from the main device, for interfacing various circuits (see Data Entry Unit (Keyboard) - 3.1.3.3 - p.3-47).

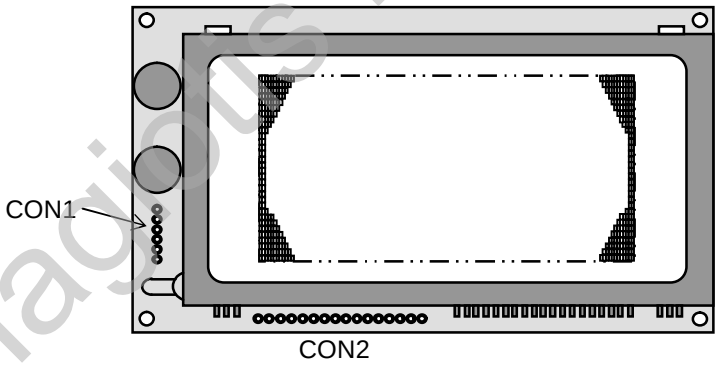


Figure 3-11 VFD Module Diagram

The asynchronous serial port and hardware flow control pins for it are found on the pins of Connector 1. The SPI port pins, other control pins such as Reset and the I/O port are found on the pins of Connector 2.

For the project, the asynchronous serial port connection to the microcontroller was selected, to allow fewer connections, control on the status of the VFD controller (see function of pins MB & HB) and less software overhead than the SPI functions. Connections to the microcontroller can be seen in Figure 3-12.

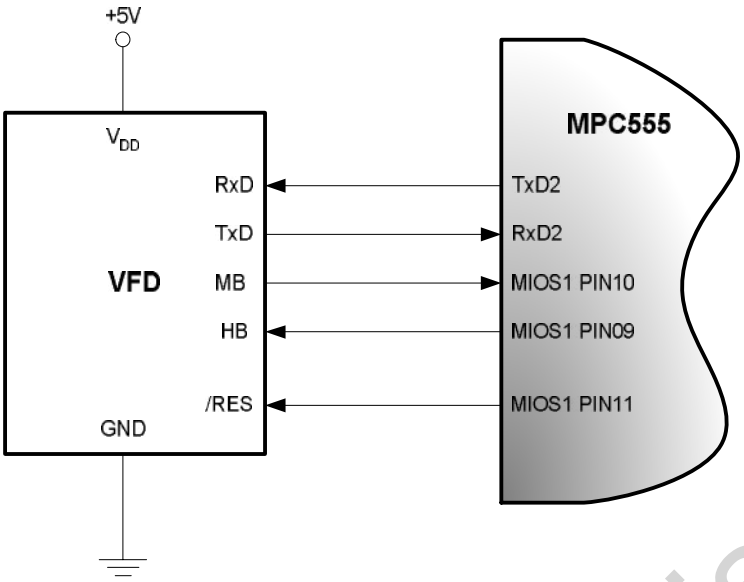


Figure 3-12 VFD Connections to the Microcontroller

The controller on the VFD module can execute various functions, such as print text in 4 different ASCII font sizes (5x5, 5x7, 10x14 and 20x28 pixels), display bitmapped graphics, set/clear display regions, set display brightness, power on/off the module and handle the on-module I/O port. All these functions were used to create a Graphics User Interface (GUI), for the driver to interact in a more friendly and productive manner with the trip computer.

Source code functions used to control the VFD module and the type of information displayed on it can be found in the **VFD_Functions.c** file.

3.1.3.3. Data Entry Unit (Keyboard)

The keyboard used for entering data, as well as navigation through the Graphics User Interface, follows the form of a standard 4x4 matrix keyboard, giving a total of 16 keys. Because of its form, identifying a key press requires well defined steps and techniques.

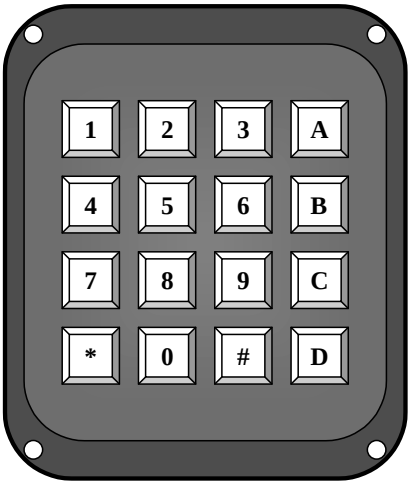


Figure 3-13 Keyboard Layout

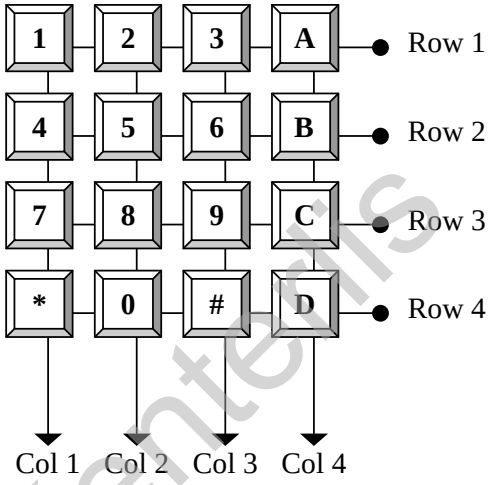


Figure 3-14 Matrix Layout

Reading the value of a pressed key is achieved by matrix scanning techniques. Since the keyboard uses a 4x4 matrix, it requires 8 I/O lines in total for scanning the state of the key-switches. These I/O lines are taken from the I/O port of the VFD module and are serially controlled by the microcontroller, although using the same concepts as if being connected to any parallel I/O port of the microcontroller. The I/O port on the VFD module can be programmed to have any pin configured as either Input or Output, by writing a logic '1' (Input) or logic '0' (Output) at the respective bit position.

The VFD module can be programmed to identify a change in the logic value of its input pins and send its I/O port value to the microcontroller through either of the serial interfaces available on it. Once this byte has been received by the microcontroller, an interrupt is generated, which in turn will activate the keyboard scanning function to identify the key pressed.

Since TTL and CMOS circuits assume the logic state of an input as logic '1' if floating, logic '0' is the dominate logic state. By writing a logic '0' at the pin controlling a row, and pressing any of the keys connected to that row, a circuit will close transferring the GND voltage (logic '0') to the column's line of the pressed key. Simply by moving a logic '0' value at the scan lines (rows) and reading the result on the return lines (columns) and by use of a look-up table, the value of the key that was pressed can be derived.

The electrical connections of the matrix keyboard with the I/O port of the VFD module are displayed on the following diagram.

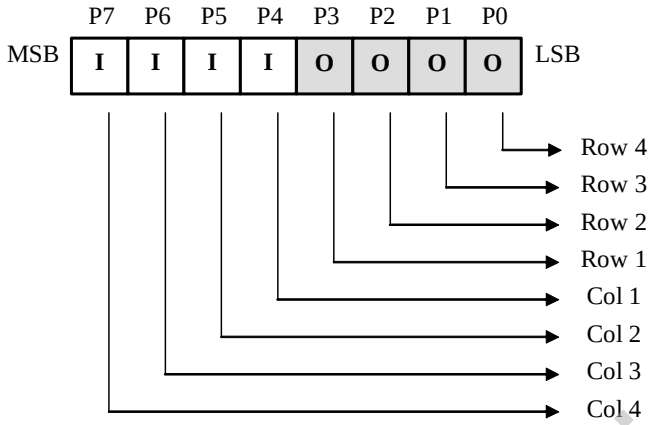


Figure 3-15 Keyboard I/O Connections

To scan the key matrix, the following Scan Patterns need to be outputted on the Scan Lines. The logic value '1' on the Column bits has no real meaning because it is not presented on the input pins, however it is used for compatibility purposes to the original program. It is worth noting that the moving '0' activates only the keys connected to it.

Table 3-6 Keyboard Row Scan Pattern Codes

Scan Line	C4	C3	C2	C1	R1	R2	R3	R4	Scan Code (Hex)
	P7	P6	P5	P4	P3	P2	P1	P0	
1st Row	1	1	1	1	**0**	1	1	1	**0xF7**
2nd Row	1	1	1	1	1	**0**	1	1	**0xFB**
3rd Row	1	1	1	1	1	1	**0**	1	**0xFD**
4th Row	1	1	1	1	1	1	1	**0**	**0xFE**

After reading the contents of the keyboard's I/O port, using a bit mask of 0xF0 and AND-ing the values, in order to mask the scan pattern code nibble. If a bit '0' is found in any of the return line bit positions, then the key-switch in that row has been pressed. If no logic '0' is found in any return lines, then no key-switch has been pressed.

Table 3-7 Keyboard Column Scan Return Codes

Return Line	C4	C3	C2	C1	R1	R2	R3	R4	Return Code (Hex)
	P7	P6	P5	P4	P3	P2	P1	P0	
Idle	1	1	1	1	0	0	0	0	**0xF0**
1st Column	1	1	1	**0**	0	0	0	0	**0xE0**
2nd Column	1	1	**0**	1	0	0	0	0	**0xD0**
3rd Column	1	**0**	1	1	0	0	0	0	**0xB0**
4th Column	**0**	1	1	1	0	0	0	0	**0x70**

The information given be the previous two arrays, are combined using a look-up table technique, with which we it is possible to decode the coordinates of the pressed key into any desired coding system.

For the project, and in order to make programming and debugging easier, the direct conversion to the ASCII code of the legend on the pressed key was selected.

Table 3-8 Pressed Key Lookup Table				
Scan Lines	**Return Lines**			
	1st Column	**2nd Column**	**3rd Column**	**4th Column**
1st Row	**1**	**2**	**3**	**A**
2nd Row	**4**	**5**	**6**	**B**
3rd Row	**7**	**8**	**9**	**C**
4th Row	*****	**0**	**#**	**D**

Keys '*' (Asterisk) and '#' (Hash) are used for confirming (ENTER) or aborting (CANCEL) operations of the Graphics User Interface.

Keys '1', '2' and '3' are used for selecting one of the three categories of information available "Vehicle Information", "Trip Information" and "Clock/Calendar", respectively.

Keys 'A' to 'D' are used to select sub-functions or information sub-pages of the currently selected information category (see above).

Key '5' is used to configure the brightness of the display from 25% to 100% in increments of 25%.

Keys '7' and '9' are used for "DECREASE/YES OPTION" and "INCREASE/NO OPTION" respectively, according to the type of selection to be made.

Key '0' is used to switch on and off the display when it is required by the driver.

The above keyboard related arrays and the key scan function are included in the **keyboard.c** file.

3.1.3.4. Storage Device (CompactFlash Card)

The CompactFlash card is a small, removable, storage and I/O card. Originally invented by SanDisk Corporation, the specifications are now determined by the CompactFlash Association (CFA) (http://www.compactflash.org), a non-profit corporation that promotes the adoption of CompactFlash. CompactFlash cards are a widely available solution for systems requiring a compact, solid state mass storage system. CompactFlash can be used in such applications as portable and desktop computers, digital cameras, handheld data collection scanners, personal digital assistants (PDAs), Pocket PCs, handy terminals, personal communicators, audio recorders, monitoring devices, set-top boxes, and networking equipment.

CompactFlash is essentially a small form factor card version of PCMCIA's PC Card ATA (AT Attachment) specification and includes a True IDE (Integrated Drive Electronics) mode which is compatible with the ATA/ATAPI-4 specification. There are 3 distinct interface modes that a CompactFlash card can use:

- PC Card Memory Mode (uses $\overline{WE}$, $\overline{OE}$ to access memory locations)
- PC Card I/O Mode (uses $\overline{\text{IOWR}}$, $\overline{\text{IORD}}$ to access I/O locations)
- True IDE Mode (uses $\overline{\text{IOWR}}$, $\overline{\text{IORD}}$ to access I/O locations)

The CompactFlash card is essentially a solid state ATA disk drive. To control an ATA disk drive, one writes to the task file registers. The values put into these task file registers control the drive (the ANSI T13 committee defines these registers and the commands used to control all ATA/IDE drives — see http://www.t13.org) (Ref. [3]). These task file registers can be mapped into either memory or I/O address space.

Wanting to avoid the use of an external PCMCIA controller or glue logic to a CompactFlash card, the True IDE mode was selected during the project design phase. The main disadvantage is that hot insertion and removal (while the device is still working) will not be possible because of the probable disruption of signals on the system bus; however the CF Card according to the specifications, is meant to be constantly mounted on the trip computer, and only removed for replacement.

The main reason that the True IDE mode is easier to use, is because only $\overline{\text{CE1}}$ needs to be asserted, in order to perform a 16 bit read or write to the data register. To perform a 16 bit

read or write operation in PC Card mode, both $\overline{CE1}$ and $\overline{CE2}$ must be asserted simultaneously which generally requires some custom glue logic.

Table 3-9 AT Task Files (True IDE mode)					
/CE2	**/CE1**	**Addr.**	**Read (-IORD = L)**	**Write (-IOWR = L)**	**LBA Mode**
1	0	0h	Data Register (16 bit)	Data Register (16 bit)	
1	0	1h	Error Register	Feature Register	
1	0	2h	Sector Count Register	Sector Count Register	
1	0	3h	Sector Number Register	Sector Number Register	Lower Byte
1	0	4h	Cylinder Low Register	Cylinder Low Register	Low Middle Byte
1	0	5h	Cylinder High Register	Cylinder High Register	Upper Middle Byte
1	0	6h	Drive Head Register	Drive Head Register	Upper Nibble Byte
1	0	7h	Status Register	Command Register	
0	1	6h	Alt. Status Register	Device Control Register	
0	1	7h	Drive Address Register	Reserved	

Using the microcontroller's external memory controller (external address, data and control bus) to interface the CF Card would violate the CF Card's timing. To avoid this problem, the same data and address lines were used as General Purpose I/O lines. Data lines D0-15 (Big-Endian) are connected to the CF Card's D15-0 (Little-Endian) and address lines D28-30 of the microcontroller (Big-Endian) are connected to the CF Card's A2-0 (Little-Endian). MIOS1 16bit I/O port pins are used for connection to the CF Card's control pins. For detailed connections see Table 3-10. Access to the CF Card is done by emulating the address, data and control bus with the General Purpose I/O lines.

Table 3-10 CompactFlash Connections to the microcontroller				
MCU	**ATA**		**CompactFlash**	
Power GND	40	Power GND	1	Power GND
D12 – SGPIOD12	11	D3	2	D3
D11 – SGPIOD11	9	D4	3	D4
D10 – SGPIOD10	7	D5	4	D5
D9 – SGPIOD9	5	D6	5	D6
D8 – SGPIOD8	3	D7	6	D7
MIOS1 PIN2	38	/CS0	7	/CE1
Not Connected			8	A10
Power GND			9	/ATA SEL
Not Connected			10	A9
			11	A8
			12	A7
Power VCC			13	Power V_{CC}
Not Connected			14	A6
			15	A5
			16	A4
			17	A3
A28 – SGPIO28	36	A2	18	A2
A29 – SGPIO29	33	A1	19	A1
A30 – SGPIOA30	35	A0	20	A0
D15 – SGPIOD15	17	D0	21	D0
D14 – SGPIOD14	15	D1	22	D1
D13 – SGPIOD13	13	D2	23	D2
Not Connected	32	/IOCS16	24	/IOCS16
Not Connected			25	/CD1
			26	/CD2
D_4 – SGPIOD4	10	D11	27	D11
D_3 – SGPIOD3	12	D12	28	D12
D2 – SGPIOD2	14	D13	29	D13
D1 – SGPIOD1	16	D14	30	D14
D0 – SGPIOD0	18	D15	31	D15
Power Vcc	38	/CS1	32	/CE2
Not Connected			33	/VS1
MIOS1 PIN0	25	/IORD	34	/IORD
MIOS1 PIN1	23	/IOWR	35	/IOWR
Power Vcc			36	/WE
	31	INTRQ	37	INTRQ
Power VCC			38	Power VCC
Power GND			39	/CSEL
Not Connected			40	/VS2
MIOS1 PIN3	1	/RESET	41	/RESET
Not Connected	27	IORDY	42	IORDY
Not Connected			43	/INPACK
Power VCC			44	/REG
Not Connected	39	/DASP	45	/DASP
	34	/PDIAG	46	/PDIAG
D7 – SGPIOD7	4	D8	47	D8
D6 – SGPIOD6	6	D9	48	D9
D5 – SGPIOD5	8	D10	49	D10
Power GND			50	Power GND

3.1.3.5. Digital Identification Devices

To provide the means of identifying different drivers and trailers, the iButton devices manufactured by Dallas/Maxim were selected and more specifically DS1990A.

This is a read-only memory circuit, containing a unique serial number of 64bits. The uniqueness of the serial number is guaranteed by the manufacturer by use of laser recording the number on the memory circuit.

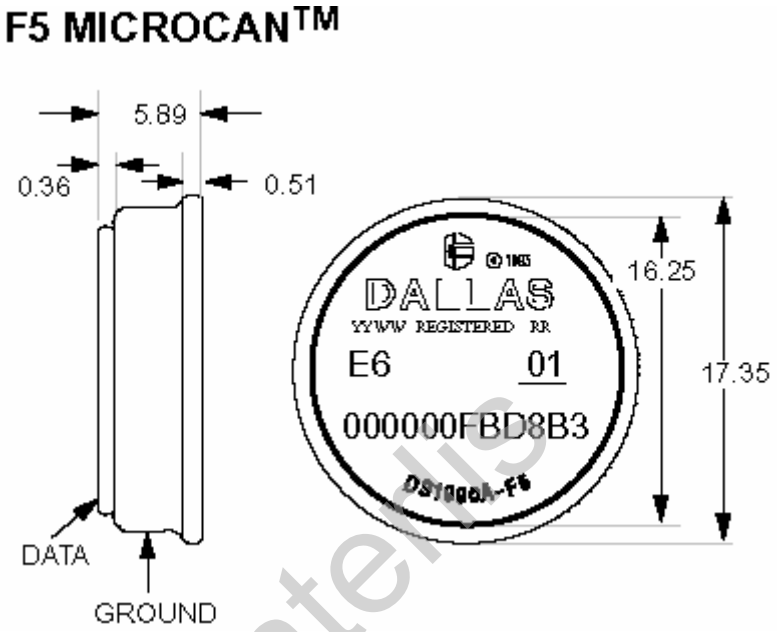


Figure 3-16 iButton Container Dimensions

It is distributed in a F5 MICROCAN container, with dimensions shown on the above figure. It has two connection terminals to the reader circuit marked as DATA and GROUND. It is noteworthy that a power supply terminal is absent. Power supply and data transfer are two issues handled by a proprietary bus (designed by Dallas Semiconductors), named MicroLan and is administrated by the 1-Wire protocol. This bus allows supplying a device with positive voltage and transferring data both over a single wire, while a grounding wire is also required. The DATA terminal can be connected to a microcontroller's open collector I/O pin like shown in the following diagram. The pull up resistor is required to supply the device with current.

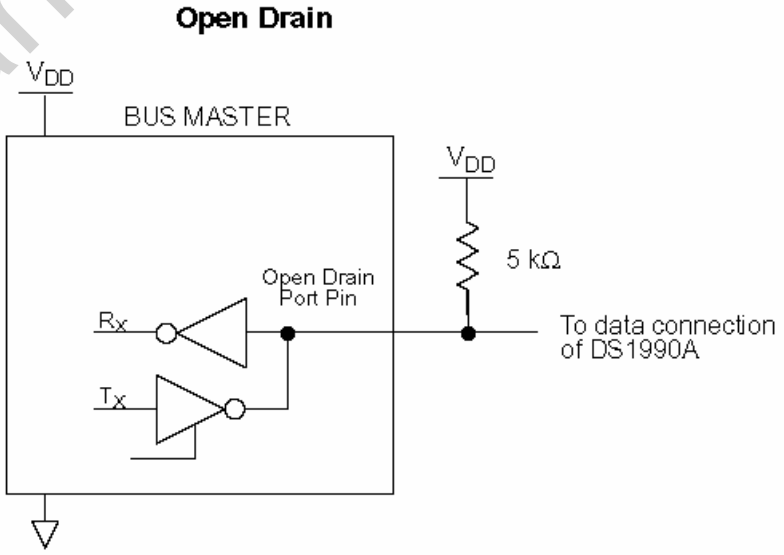


Figure 3-17 iButton connection to a microcontroller

Reading data of the device can only be successful if appropriate timings and rules that the 1-Wire protocol defines are followed. The data to be read from the specific part (DS1990A) are sectioned in 8bits being dedicated for definition of device family that the part belongs to (value 0x01 for DS1990A), 48bits containing the unique serial number and 8 more bits containing the CRC (Cyclic Redundancy Check) value of the previous 56bits. By using a CRC algorithm, the recognition of the family code and the serial number is not corrupted by read errors. The CRC byte is calculated by the CRC polynomial $x^8 + x^5 + x^4 + 1$. To confirm the integrity of transferred data, it is required from the microcontroller's side to calculate the CRC polynomial on the data read from the iButton and compare the result with the read CRC byte. If these two values match then data transfer was error-free.

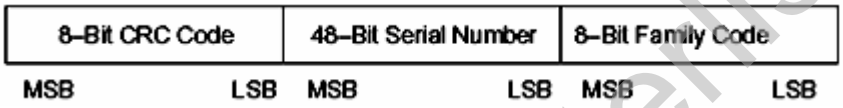


Figure 3-18 iButton ROM Code

The metallic container of the device protects the IC from dust, mechanical strain and humidity. It operates in a wide range of environment temperatures (-40^{o}C to +85^{o}C). In addition, the device container permits reading the device by use of a two-terminal socket, without the need of special hardware reader.

An iButton mounted on a key ring can be used to identify the driver of the vehicle, while many can be used to identify the connected trailer.

- ***Connection to the Microcontroller***

The iButton device is connected to the microcontroller using one I/O pin of the MIOS1 Digital I/O port. Different pins are assigned for the buses to operate, the driver's ID bus (MIOS1 PIN12) and the trailers' ID bus (MIOS1 PIN13).

- ***Communication Initialisation***

After connecting the iButton to the 1-Wire bus, it will draw current from the DATA terminal. The iButton then generates a presence pulse in the form of logic '0' (low voltage). The first action that the bus master (microcontroller) must take is to execute a Master Reset Pulse

which is effectively done by pulling the DATA line to ground. After that the iButton responds with another presence pulse.

After executing this procedure the iButton can be accessed. If only one 1-Wire device is connected on the bus, then in order to access it is first needed to read its ROM code. If more devices than one are connected on the bus, then before doing anything else, the ROM code of every device must be identified. For doing so a search algorithm must be followed, which will allow to read the ROM code of one device while the rest remain “silent” on the bus. If this procedure is not followed then all devices will try to respond to a command issued by the bus master and the data read will be corrupted.

- ***Reading the iButton***

The 1-Wire protocol defines three different bus access slots: the Logic ‘1’ Write slot, the Logic ‘0’ Write slot and the Bit Read slot. Every one of them is strictly defined by a set of time spaces, within which the logic level of the DATA line must change state, in order to correctly signal the above mentioned slots. With the termination of the initialisation slot, the DS1990A enters idle state waiting for a command. After the transmission of a command has been completed, the device executes it and returns the results to the bus master. Complete read of the ROM code of a device is performed in less than 5ms, if standard timings are followed.

Detection, identification and reading of the device are operations performed by functions included in the **OneWire.c** file. The multi-drop device search and CRC calculation are modified functions of the code offered freely by the manufacturer company.

- ***iButton Overview***

Altogether the reasons for selecting the specific range of products are:

- Unique 64bit serial number
- Communications error detection capability
- Use of two wires for basic communications
- Simple communications protocols
- Direct connection to the microcontroller
- High endurance to harsh environments
- Low cost - Minimum to zero maintenance cost

3.1.3.6. Temperature Sensing Devices

For the purpose of displaying the cabin and outside temperature, two temperature sensor devices are used. These are the DS1820 device by Dallas/Maxim. This part is found in two variants, the DS18B20 and the DS18S20. The DS18B20 variant provides programmable temperature conversion resolution from 9bits (0.5°C) to 12bits (0.0625°C) and maximum conversion time of 93.75ms in 9bit mode and 750ms in 12bit mode. The DS18S20 variant provides a fixed temperature conversion resolution of 9bits (0.5°C) and maximum conversion time of 750ms. Both these variants are supported by the microcontroller's software, however, for the project the DS18B20 variant was used and will be analysed henceforth.

DS18B20 uses the same communications interface as the digital identification key DS1990A discussed in previous pages. In fact, DS18B20 is accessed the same way as DS1990A with the addition of an array of nine byte registers, which are read successively. This array is called the Scratchpad memory. In the first two registers of the Scratchpad, the temperature conversion result is stored after a conversion has finished. In the third and fourth registers, two values T_H and T_L are stored which are used to trigger an alarm condition when the converted temperature is outside the range these two values define $T_L < Temperature \leq T_H$. For the project's purposes, since there is no need for controlling other hardware, the values are set to the highest and lowest measurable temperature values respectively, in order to prevent the thermometer from entering the alarm condition. In the fifth register of the Scratchpad memory, a configuration byte is stored. This byte code defines the thermometer resolution of the DS18B20 device in bits. The DS18B20 device is also equipped with a small EEPROM memory, which is used to save the configuration register and the two trigger registers. Special commands are used to read from and write to the Scratchpad memory, as well as store changed trigger register and configuration register in the EEPROM. The ninth register of the Scratchpad memory contains the CRC8 value of the previous eight registers.

Since there is no real need for high precision in temperature measurements, the DS18B20 device is configured for 9bit (0.5°C) resolution. Every time the device's scratchpad is read, a check is made for its Configuration byte. If it doesn't match the 9bit Resolution code, then the device is re-programmed. This will happen only the first time a new sensor is connected, so, replacing a defective part is an easy procedure and doesn't require any other procedures to be followed. In the case of a DS18S20 device, such operations are not performed. The

DS18B20 variant can perform a conversion at least 7.5 times faster than the DS18S20, allowing more time to be spent for other system operations.

Before acquiring thermometer information, a Conversion Start command must be sent to the sensor, after this has been uniquely selected. Since two sensors are used, every sensor must receive this command. After both sensors have been put to Conversion mode, the microcontroller has to wait for the required amount of time for the conversion to finish. Since the software must support both variants, a check is made to identify the type of the attached variants and the conversion delay is adjusted to fit the slowest device. If both devices are DS18B20 variants, then the conversion wait time is set to 100ms, while if at least one of the devices is a DS18S20 variant then the wait time is set to 750ms (see variant specifications). Once the temperature conversion result has been read and processed as required, it can be displayed on the VFD.

In order to avoid programming of the trip computer to uniquely identify a specific temperature sensor on a common 1-Wire bus as being used as outside/cabin temperature sensor, which would require special configuration of the trip computer, two different 1-Wire buses are used. Each bus connects directly to only one sensor, so selecting and sending commands to a device is very easy. Since the only requirement to create a stand-alone 1-Wire bus is dedicating an I/O pin this solution doesn't increase product cost. The temperature sensor for the outside environment is connected on PIN15 of MIOS1, while the cabin temperature on PIN14. A connection diagram of temperature sensors to the microcontroller can be seen in Figure 3-19.

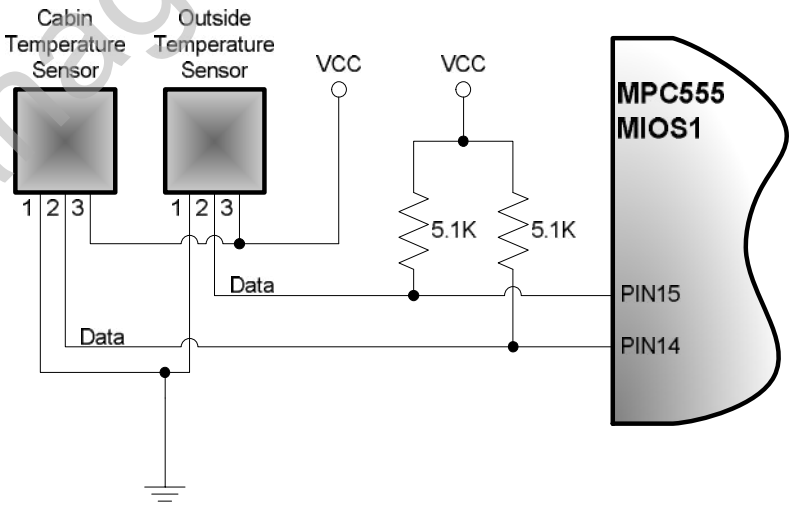


Figure 3-19 Temperature Sensor Connections to the Microcontroller

Source code functions controlling both variants of DS1820 temperature sensor device can be found in the **ds1820.c** file.

3.1.3.7. Other Circuits

- ***Buzzer Control***

To increase the usability of the User Interface, an audio warning capability was added. The purpose for doing so, was to warn the driver for errors created, completion of a process, selection of a GUI function and warnings such as activation of the alarm clock and the tiredness warning alarm.

The circuit used is very simple since it uses only a PNP transistor and a current limiting resistor of 1KΩ. Depending on the h_{fe} of the transistor and the current it sinks, a resistor of different value may need to be connected. Control of the buzzer is achieved by connecting the base of the transistor (through the resistor) to an I/O port pin of the microcontroller (MIOS1 PIN8). In order to activate the buzzer, a logic value of '0' must be written on the I/O pin. Respectively logic '1' on the I/O pin will deactivate the buzzer.

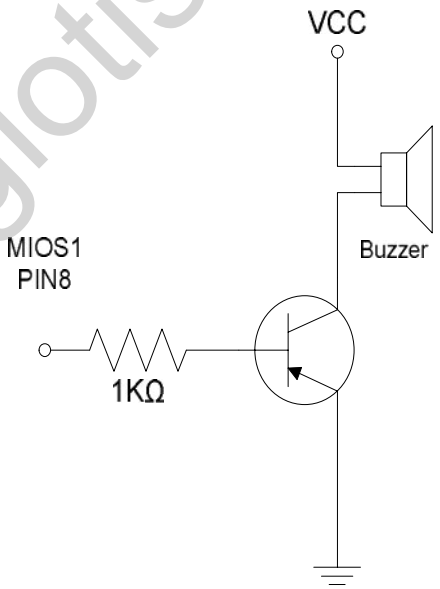


Figure 3-20 Buzzer Control

Functions controlling the buzzer device can be found in the **Routines.c** source file.

3.2. Software Design

3.2.1. Development Tools Used

- ***Metrowerks CodeWarrior 6.0***

To develop the resident software on the microcontroller, the Metrowerks CodeWarrior v6.0 Integrated Development Environment (IDE) was used. This is a software development suite including a C/C++ compiler, Assembler and Emulator/Debugger facilities for Embedded Systems based on Motorola's PowerPC core microcontrollers, such as the MPC555.

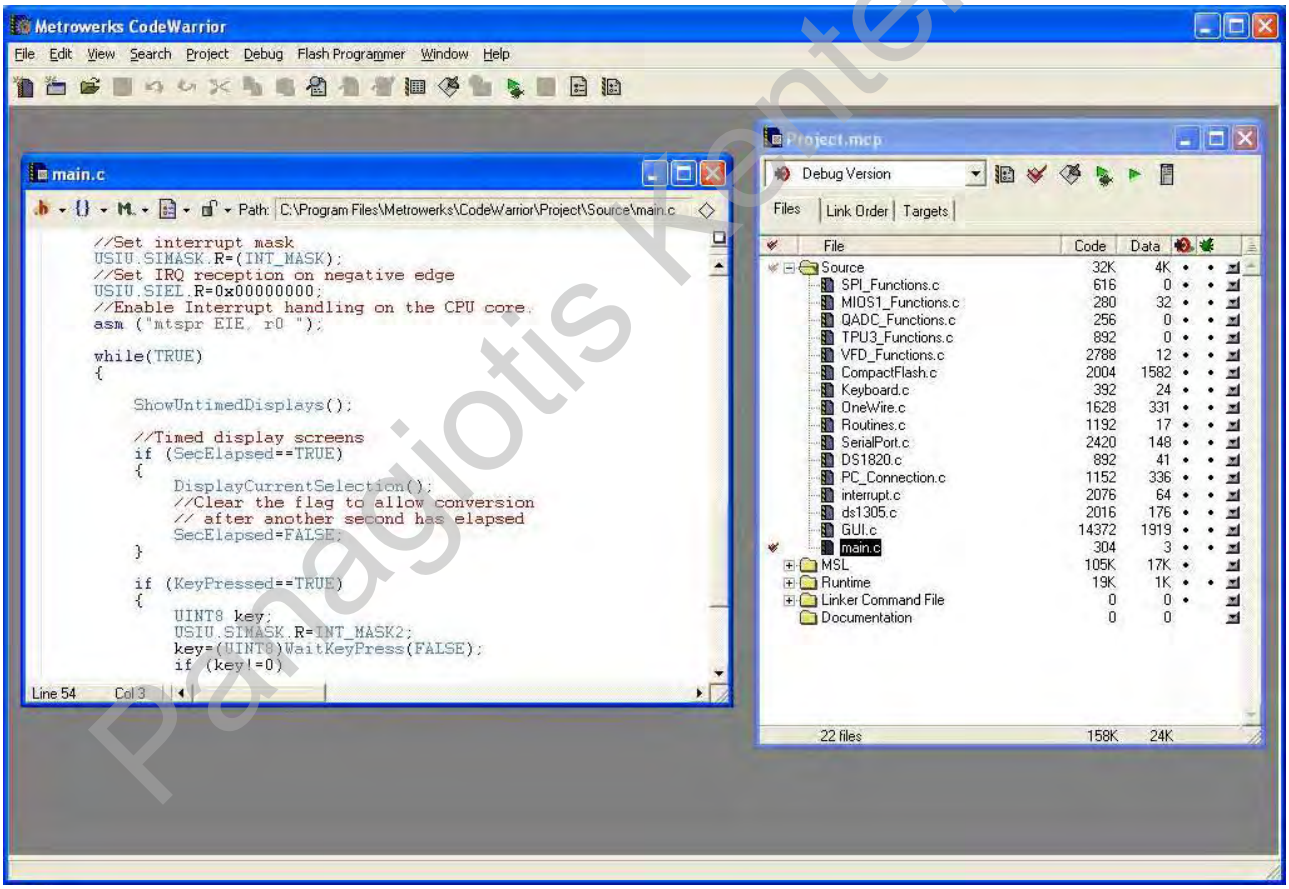


Figure 3-21 Metrowerks CodeWarrior IDE Main Interface

- ***Microsoft Visual Basic 6.0***

The Microsoft Visual Basic development system is a tool for creating software solutions for Windows (Figure 3-22). Being a visual tool, it allows building a user interface with a few mouse movements and linking code with objects, events and processes. Visual Basic was used to build the PC software which controls the trip computer device. Since Visual Basic is a standard programming Windows tool and no special configuration was performed, presenting it is not within the scope of this report, so no discussion on using Visual Basic will follow.

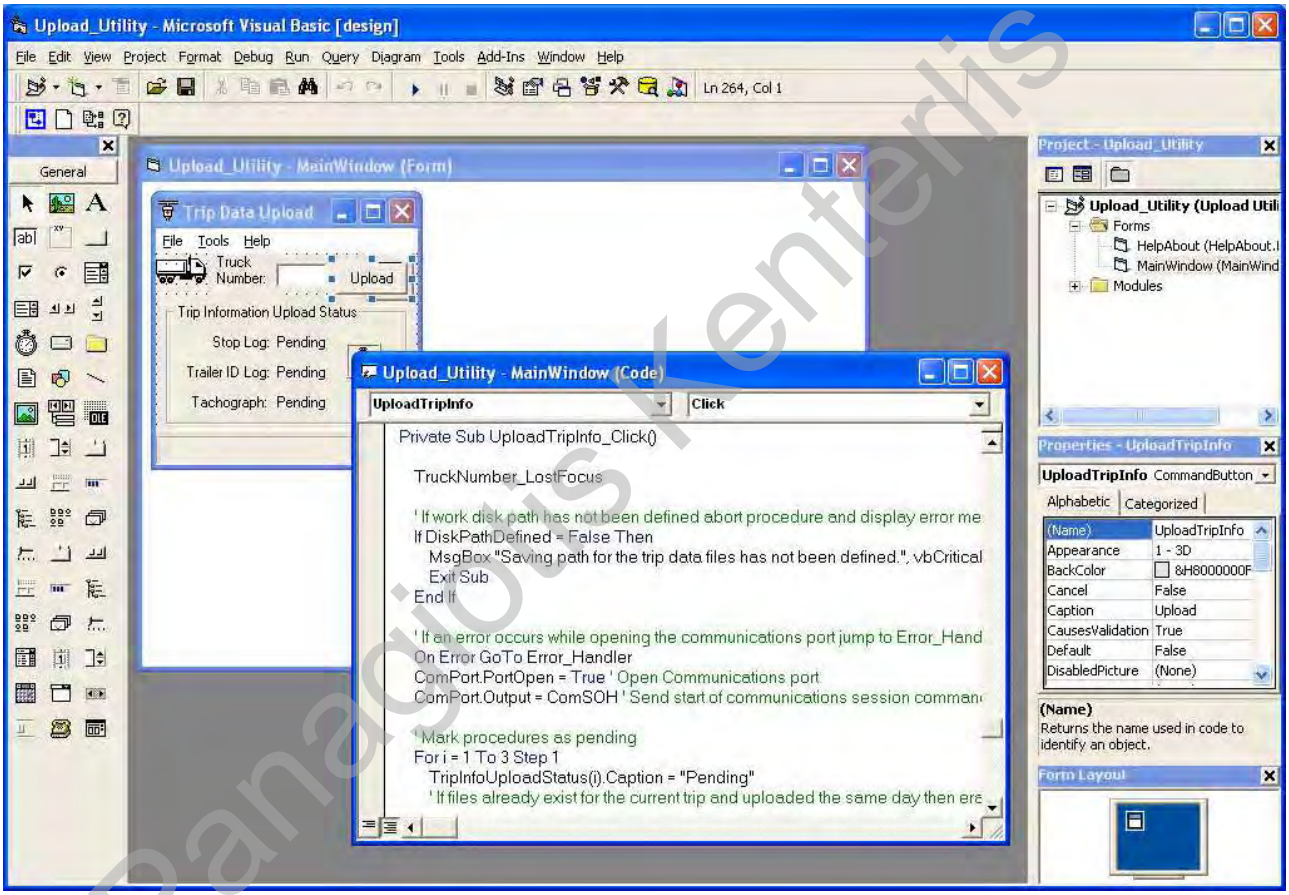


Figure 3-22 Microsoft Visual Basic 6.0 Programming Environment

3.2.1.1. Metrowerks CodeWarrior Registration Issues

Before starting to use the IDE, there is need to register the software with the manufacturing company. This is done in steps.

Firstly the Product Registration utility that comes installed at the same program folder as the executable files, needs to be executed. Once this is done the following window will appear with all fields blank.

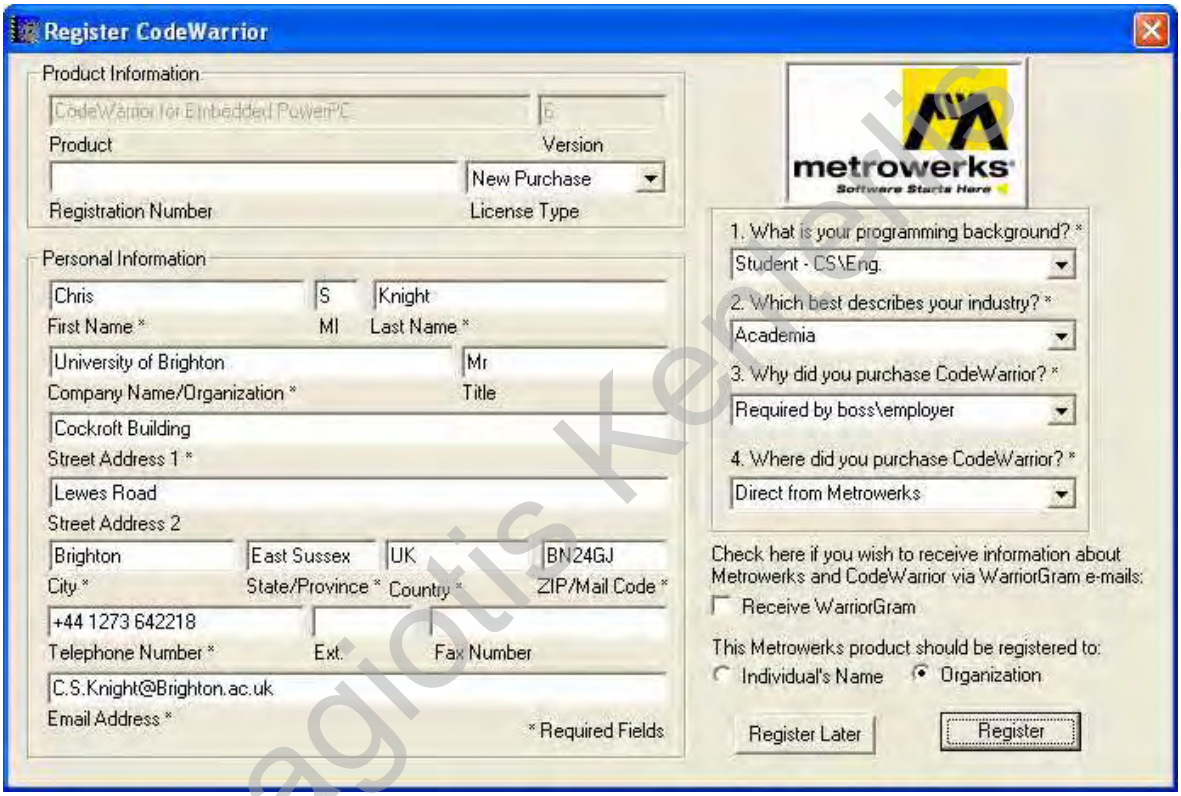


Figure 3-23 Metrowerks CodeWarrior Registration Utility

After providing all the required information (name, university, contact email, etc) and pressing the “Register” button, a file is created with the name MWRegistration.txt, that contains all the above information, plus some information linked to the machine that the software will be used, such as volume ID of the hard disk drive. This file should then be sent by electronic mail to license@metrowerks.com to register the product. In reply, another file will be sent after a short period of confirmation (could be a few days actually).

Once this file has been received, its contents should be copied to the clipboard and then pasted to replace the contents of the license.dat file found in the top directory of the installation path.

Once this is done, the full features of the software are available to use.

3.2.1.2. Using the Metrowerks CodeWarrior IDE

The programming environment of CodeWarrior is simple and resembles those of other Windows based programming languages.

A software upgrade to version 6.03 was available at the time the development phase was starting, which provided some stationery for the AXIOM development boards, however these were not specific to the board used and some configuration settings needed to be edited (Chapter 3.2.1.3, p. 3-66).

Developed programs are handled in projects. Every project is associated with some source files. To create a new project, select File>New and the window in Figure 3-24 will appear. In this window, firstly the EPPC Stationery Wizard needs to be selected, which helps us configure the project by asking simple questions and requiring selection from a number of options. Afterwards the name and work path of the project needs to be entered.

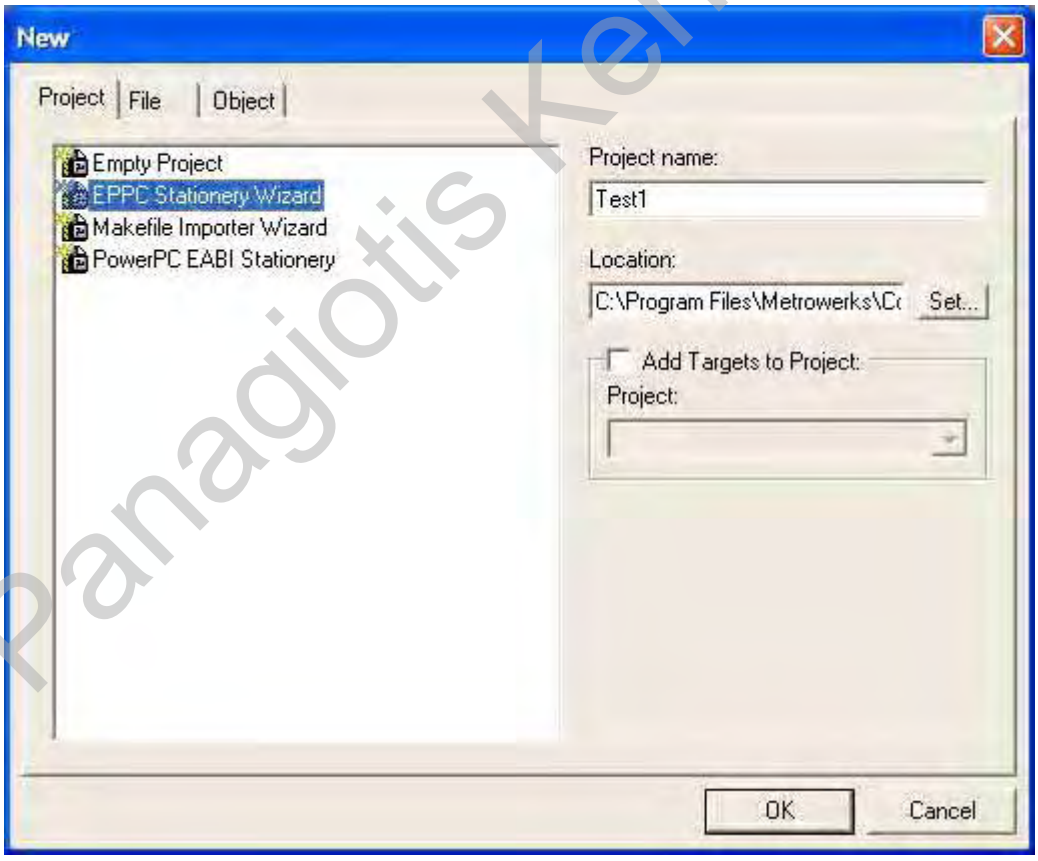


Figure 3-24 Project Creation #1

The wizard will start asking questions concerning the project to set up. The microcontroller development board used is manufactured by AXIOM and the processor is the PowerPC 555.

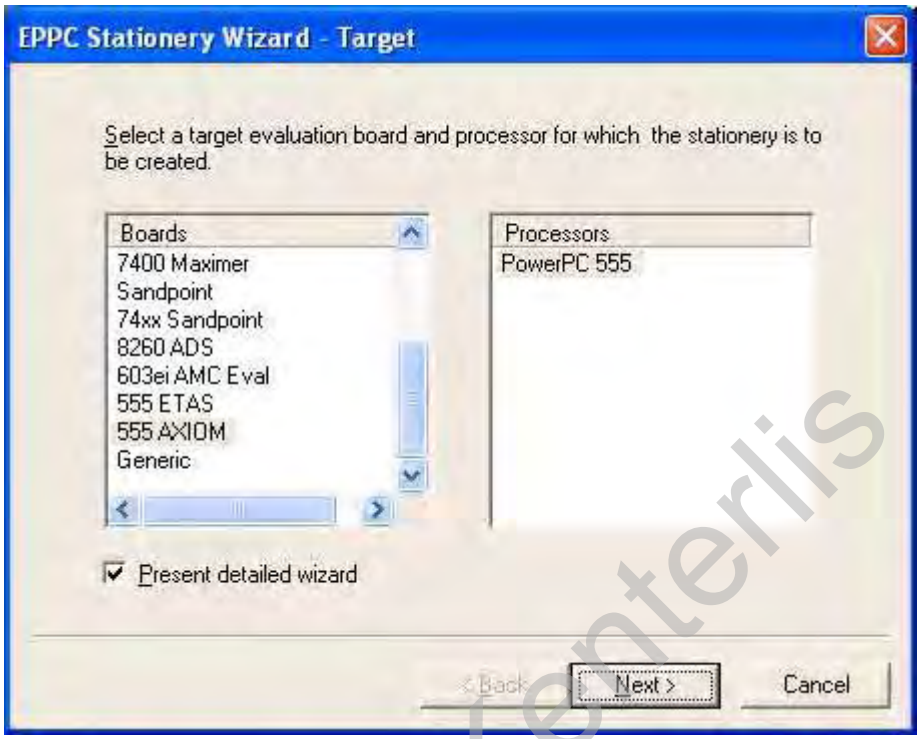


Figure 3-25 Project Creation #2

The programming language is set up on the next window (Figure 3-26). For the purposes of the project, the C compiler is used.

Figure 3-26 Project Creation #3

One important feature of the microcontroller is the on-chip FPU, which should be enabled next (Figure 3-27) in order to speed up calculations that operate on floating point numbers.

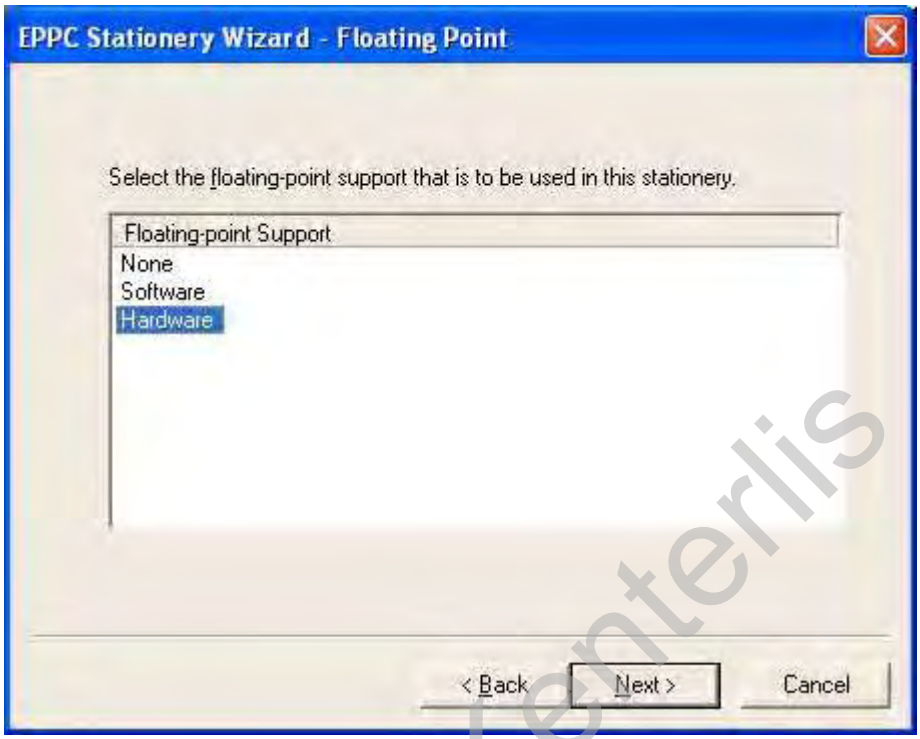


Figure 3-27 Project Creation #4

The external hardware debugger interface should be selected next (Figure 3-28) to be used when debugging the software (see Chapter 5-Testing & Debugging, p. 5-91).

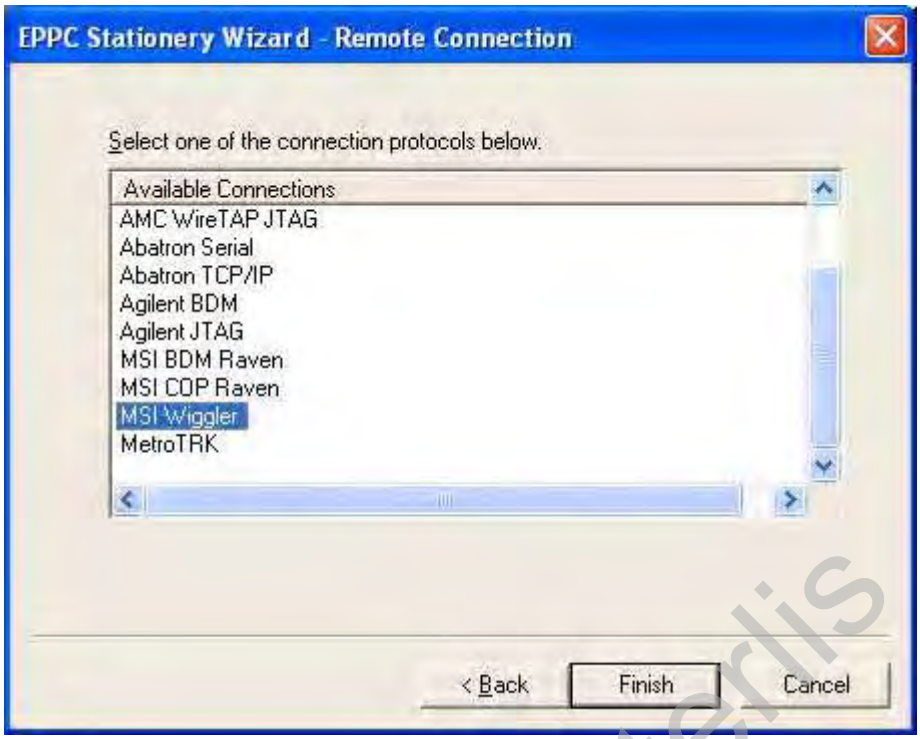


Figure 3-28 Project Creation #5

Pressing the Finish button, the wizard starts creating a sample project configured as selected previously. After this process has ended, the project manager window appears with some source files divided in groups.

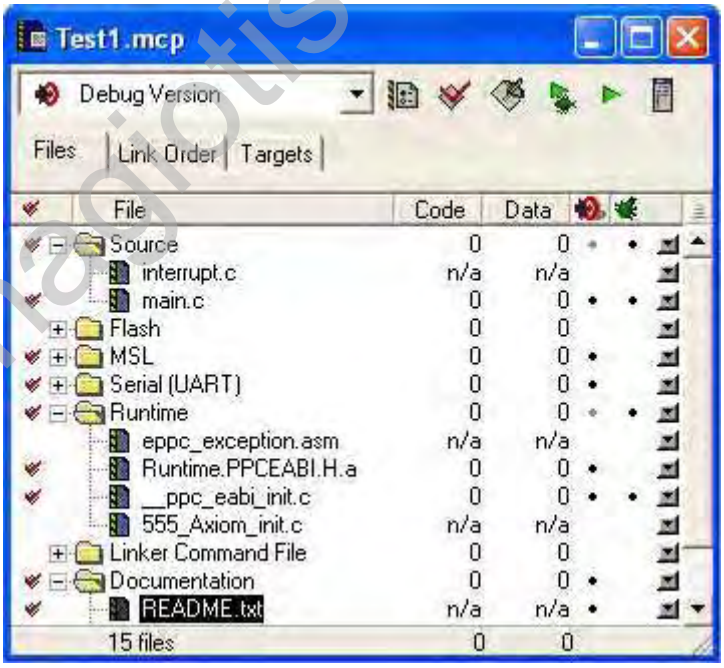


Figure 3-29 Project Manager Window

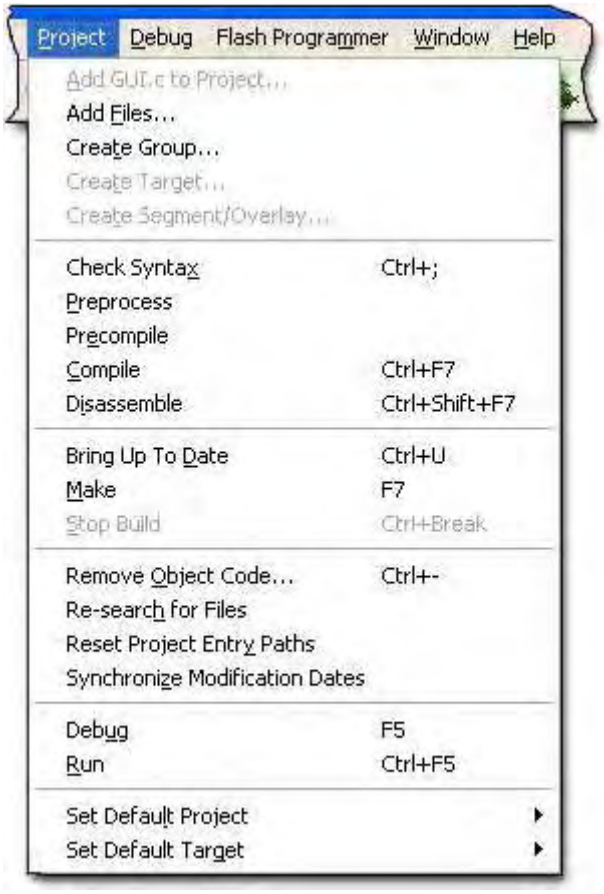


Figure 3-30 Project Menu

Source code files can be shared by many projects, to increase code reusability.

From the Project menu (Figure 3-30), it is easy to identify some functions available to the user.

Adding files to a project, creating a group of files, compiling the project, disassembling and debugging (see Chapter 5-Testing & Debugging, p. 5-91) the generated code, are the most frequently used functions.

3.2.1.3. Configuring the Metrowerks CodeWarrior IDE

The IDE allows the user to have multiple build targets for the same code being developed. Each build target in a CodeWarrior project has its own settings. These settings control a variety of features such as compiler options, linker output, error and warning messages, and remote debugging options (Ref. [9]).

By using the stationery provided, three target versions are available, Debug, ROM and Auto-FLASH.

For the project's purposes, only the first two were used and will be analysed in more detail next. The currently active target can be changed from the drop down menu in the project management window.

Figure 3-31 Target Selection

Current target settings can be changed from Edit>"Target's Name" Settings as shown in Figure 3-32 below.

Figure 3-32 Target Settings

- ***Debug Version***

The Debug version of the firmware code originates at address 0x003FA000, which is the start address of the internal SRAM memory. The stack pointer is set to 0x00400000 and decrements when data is pushed. Data is also stored at the same region as the code and the stack (0x003FA000-0x00400000). Using the Debug target, the Metrowerks CodeWarrior IDE can download compiled code to the microcontroller's RAM memory and execute it like an In-Circuit Emulator (ICE) (see Testing & Debugging p. 5-91). For the Debug Version target settings see Figure 3-33 below.

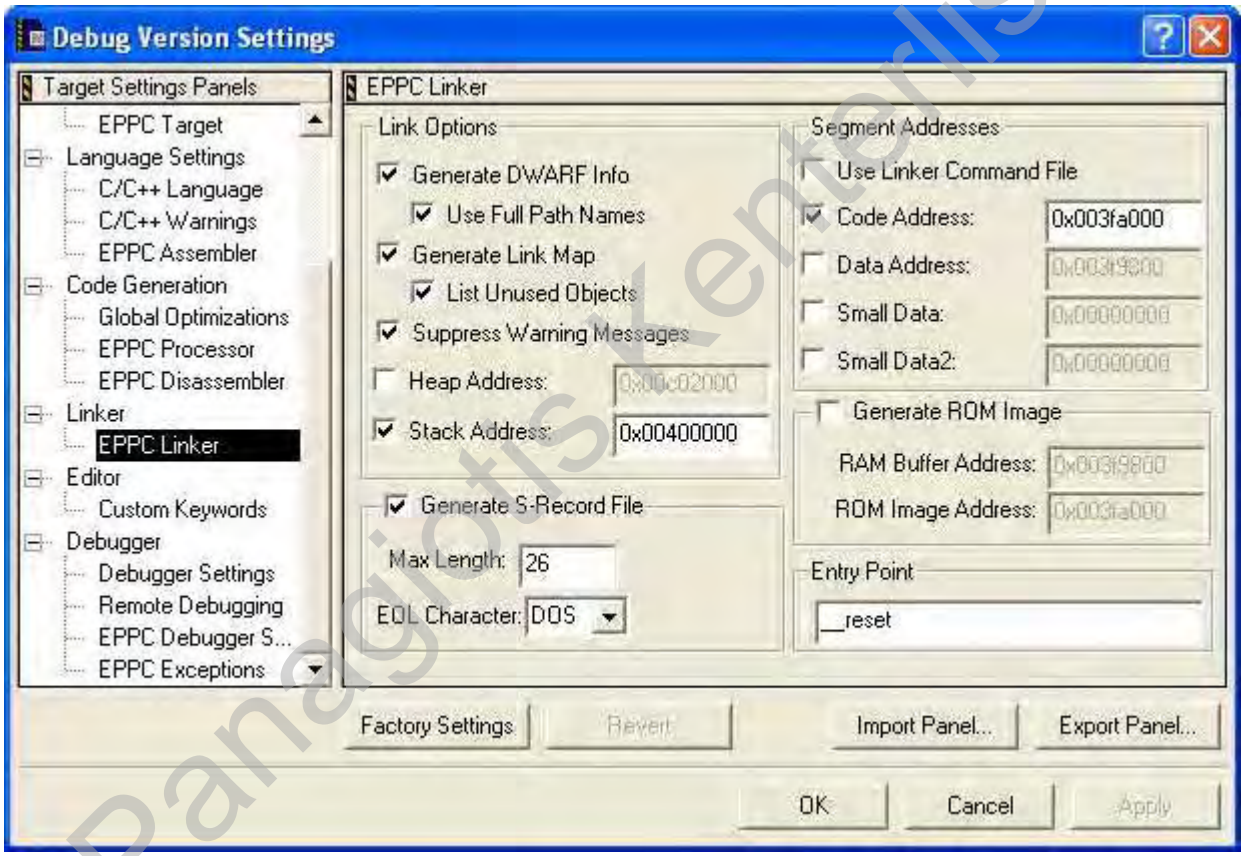


Figure 3-33 Debug Version Settings

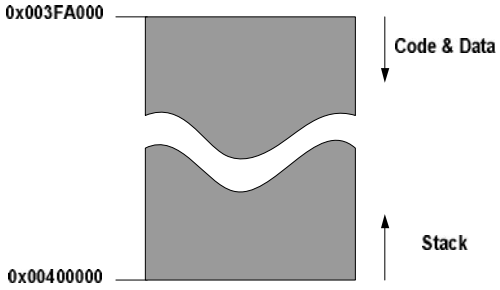


Figure 3-34 Debug Target Memory Map

Figure 3-35 IDE Preferences Menu

In order to use the Metrowerks CodeWarrior IDE as a debugger tool, the external debugging hardware interface needs to be connected and configured. This is done by selecting the menu Edit>Preferences as shown in Figure 3-35.

On the window that opens (Figure 3-36), the MSI Wiggler, which was available for the project together with the Axiom development board, needs to be selected and the configuration file for target setup should point to the configuration script file 555_AXIOM_flash_init.cfg (Appendix 2), which is included in the source files directory.

The rest of settings mainly involve how the IDE is displayed and are of no interest to this project. One should configure the IDE according to his/her own preference.

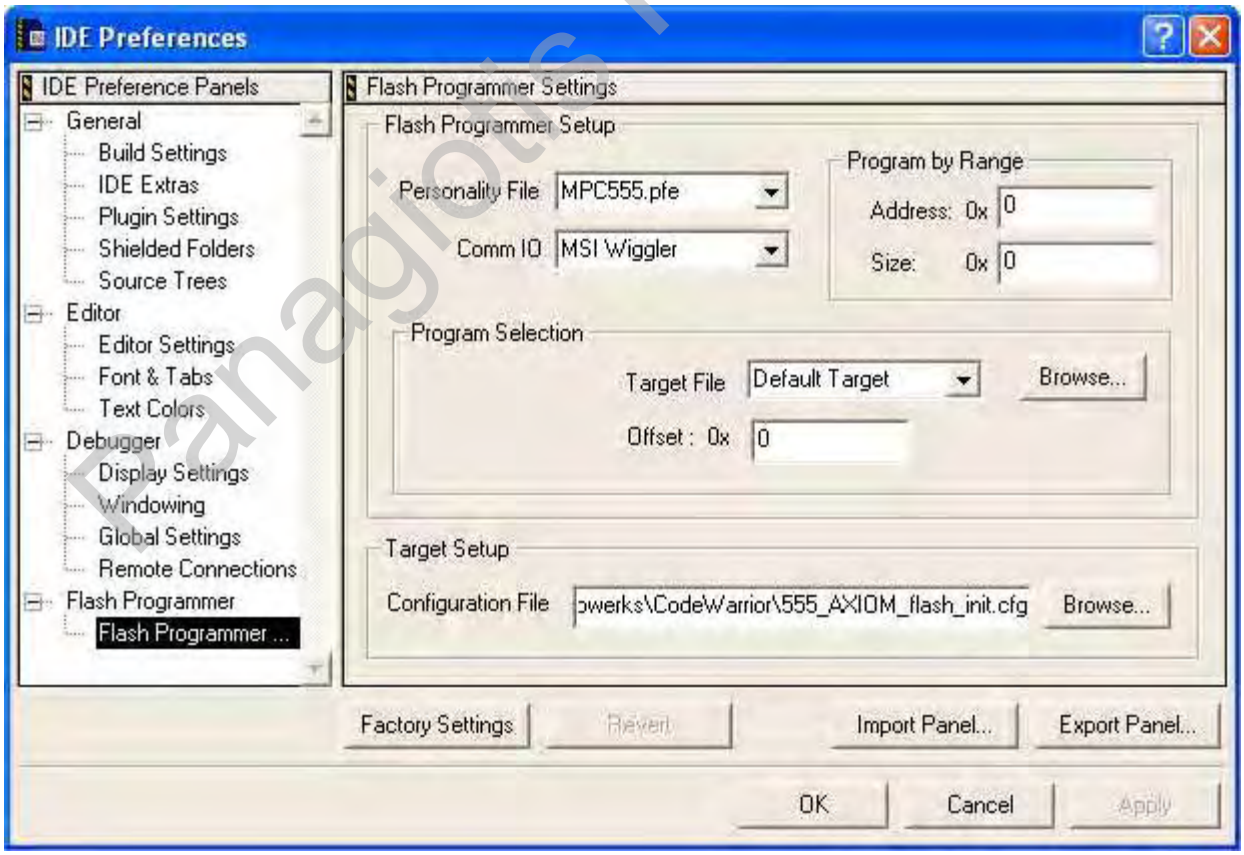


Figure 3-36 IDE Preferences

- ***ROM Version***

The ROM version compiles a ROM image of both code and data according to the settings provided for the target. These settings are contained in the 555_Axiom_ROM.lcf file (Appendix 1) included in the source files directory.

The ROM image originates at address 0x00010000, which is the start address of the internal FLASH memory available for use, since the previous 64Kbytes are used by the monitor program provided by the development board's manufacturer.

The memory region (0x00010000- 0x0006FFFF) is used to store an image of both code and data. On execution of the code in this region the contents of the data segment are copied from the FLASH to the SRAM. The target start address for the data segment is that of the SRAM memory (0x003FA000-0x003FFFFF).

The stack pointer is set to the end of the Dual Ported TPU RAM (DPTRAM), at address 0x00303800 and decrements when data is pushed. The entire 6Kbytes region of the DPTRAM (0x00302000-0x003037FF) is assigned for use by the stack.

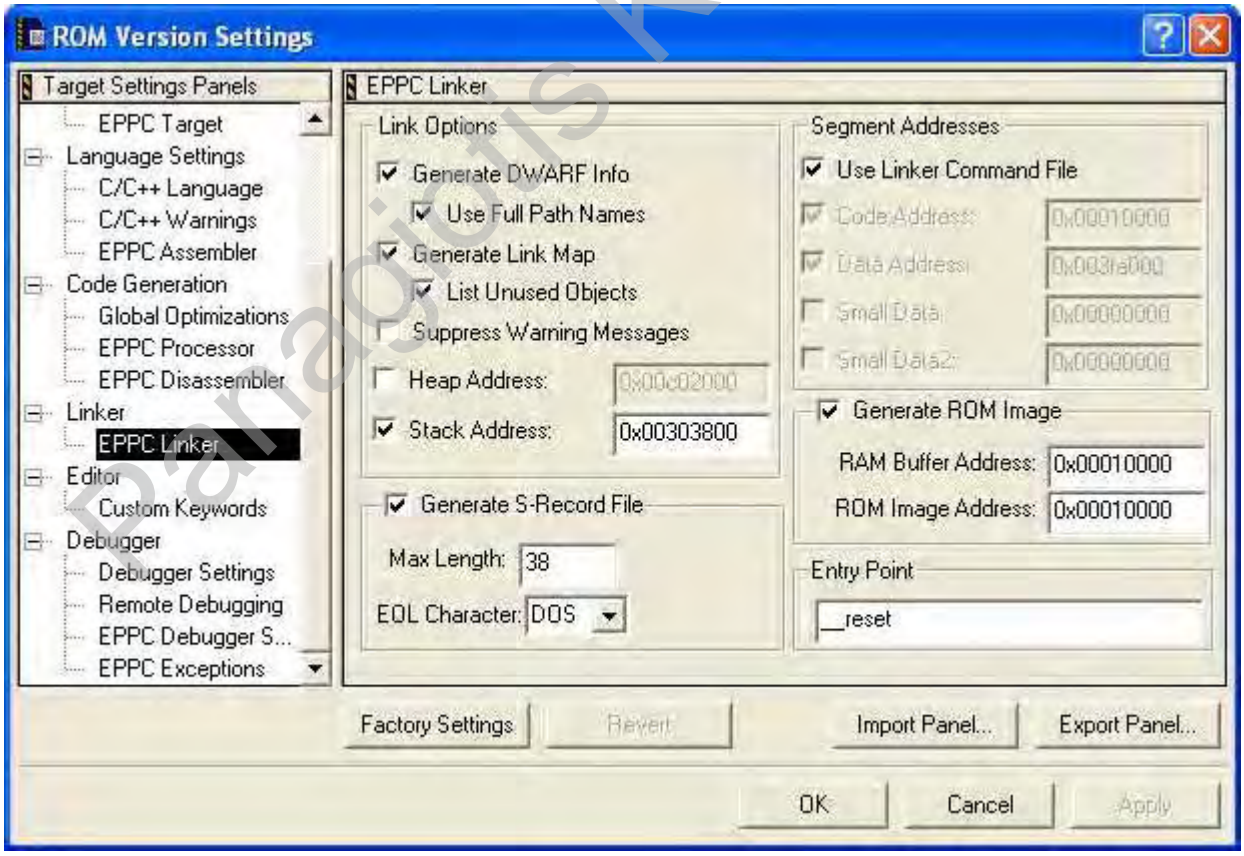


Figure 3-37 ROM Version Settings

The memory map for the ROM target is shown in Figure 3-38.

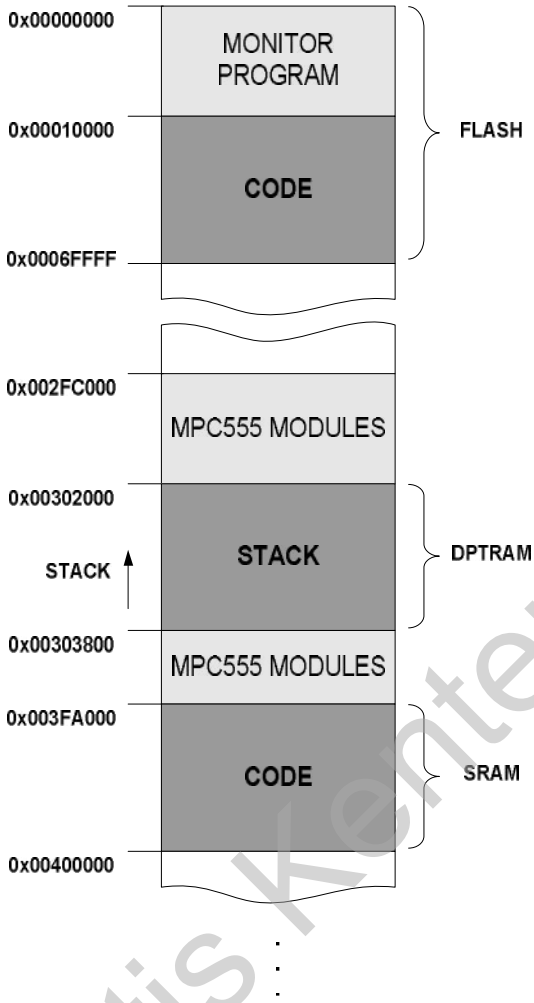


Figure 3-38 ROM Target Memory Map

- ***Auto-Flash***

This target uses the ROM image created in ROM target. It utilizes RAM memory as buffer to execute a FLASH burning program, download the ROM image and burn in to FLASH by using the debugger hardware (MSI Wiggler) and software (Metrowerks CodeWarrior). Since the development board already contained a monitor program that allowed programming of the FLASH memory, this target was not employed.

For all targets discussed the rest of settings can be configured to produce faster/smaller code, to allow easier debugging, configure the behaviour of the compiler, etc, and they are not analysed because some experimentation may be needed to produce compiled code of desired attributes.

3.2.2. Microcontroller Firmware Code Explanation

Building a real-time system can be a very tedious and complex job. Careful thought is required when writing functions that are time-critical, and priority needs to be assigned to them. In order to prevent some functions from hogging the CPU and losing timing of some events which could prove catastrophic, all functions that may introduce delays and dead-times in code execution have been removed from ISRs. The ISRs set flags that are used after termination to initiate processes when the processor hasn't received and interrupt request. That way, all GUI related functions are executed outside ISRs, inside which only time critical processes and calculations are performed. In addition, by designing the software in this manner, the processor is more efficiently dedicated to executing real code, instead of delay loops, and system performance is increased. GUI functions have been assigned a low priority over the data acquisition and process functions that are executed inside ISRs (Figure 3-39).

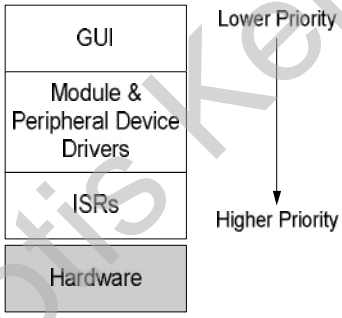
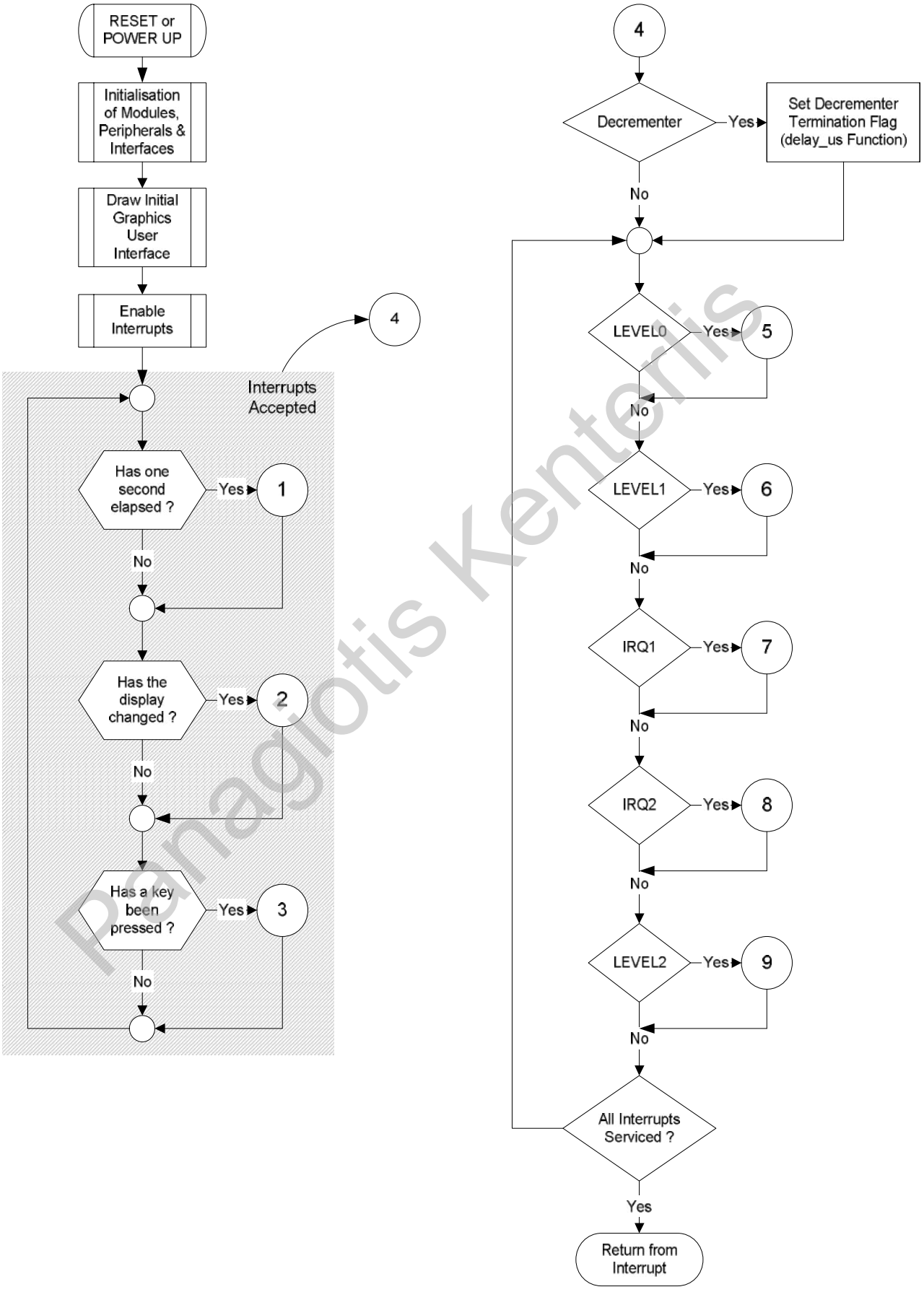


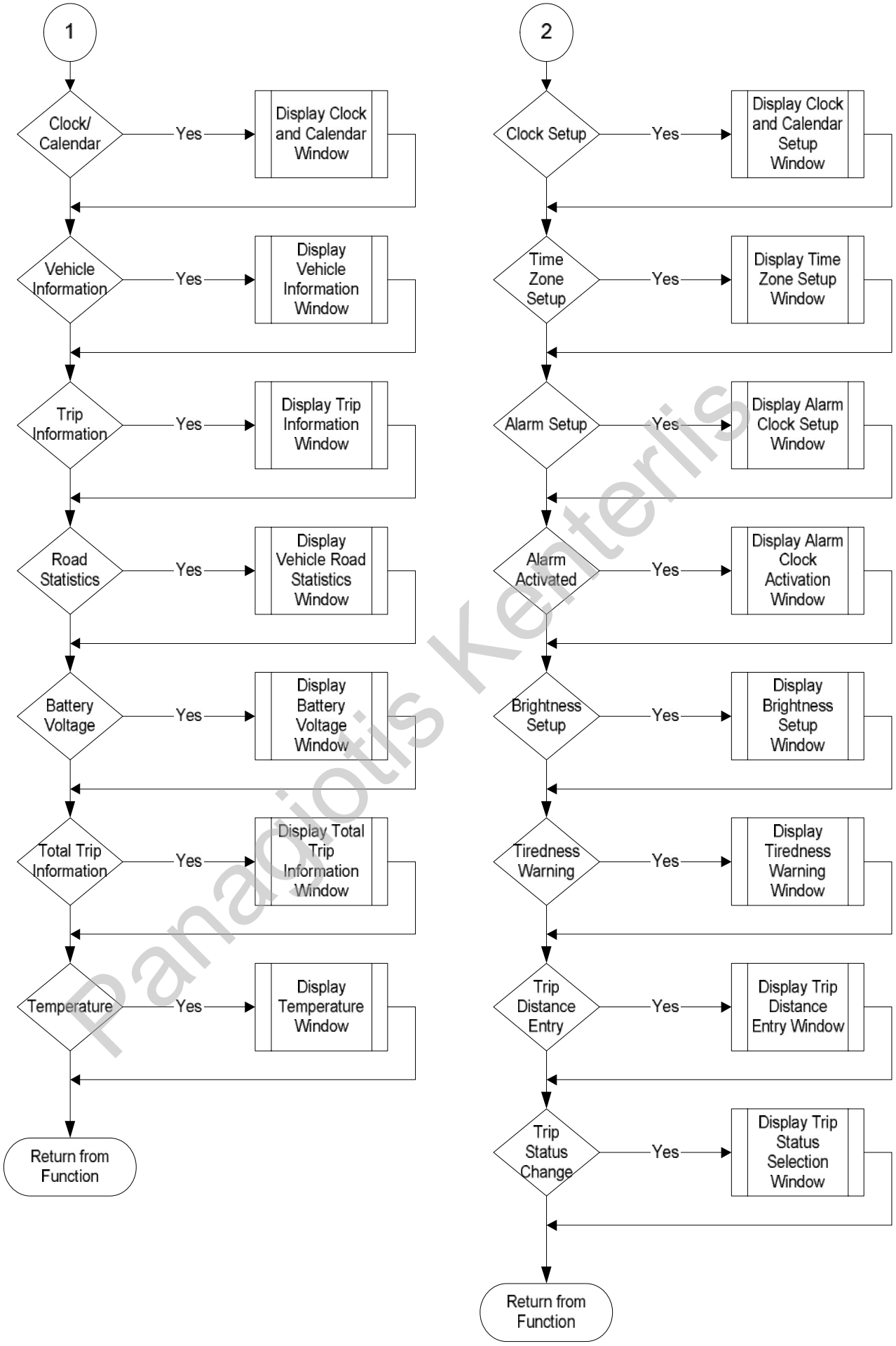
Figure 3-39 CPU Code Execution Priority

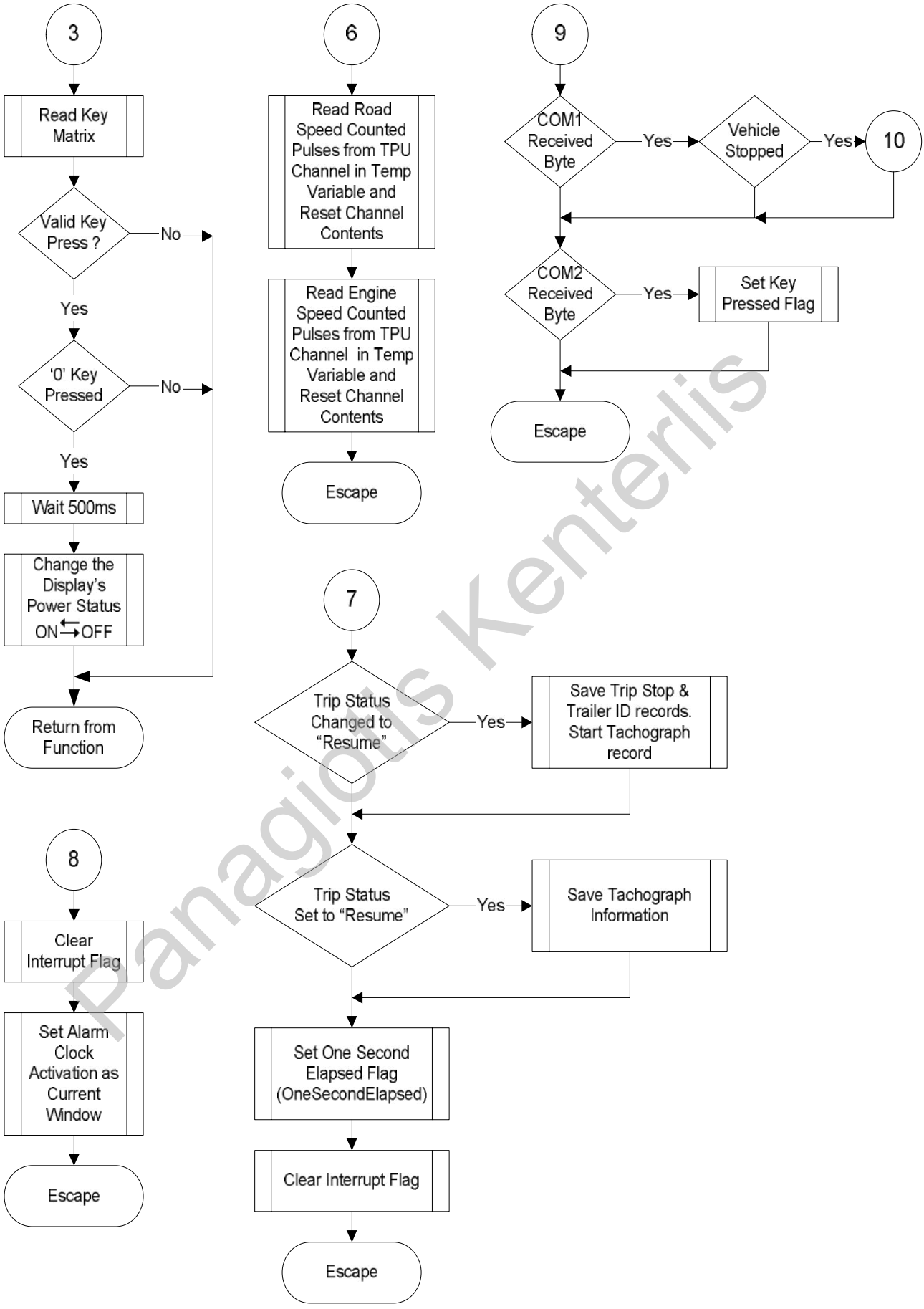
All initialisations of modules, peripherals and interfaces are performed during the boot up sequence, which is executed only once at system power up. Many check conditions have been included in the source code to allow better debugging and prevent some functions from putting the system to an invalid state, should an error or undefined condition appear. The default measuring units used for acquiring measurement data, calculating and storing results are kilometres and litres. These were used because of my own familiarity with these units. However, by driver's selection, different measuring units can be displayed.

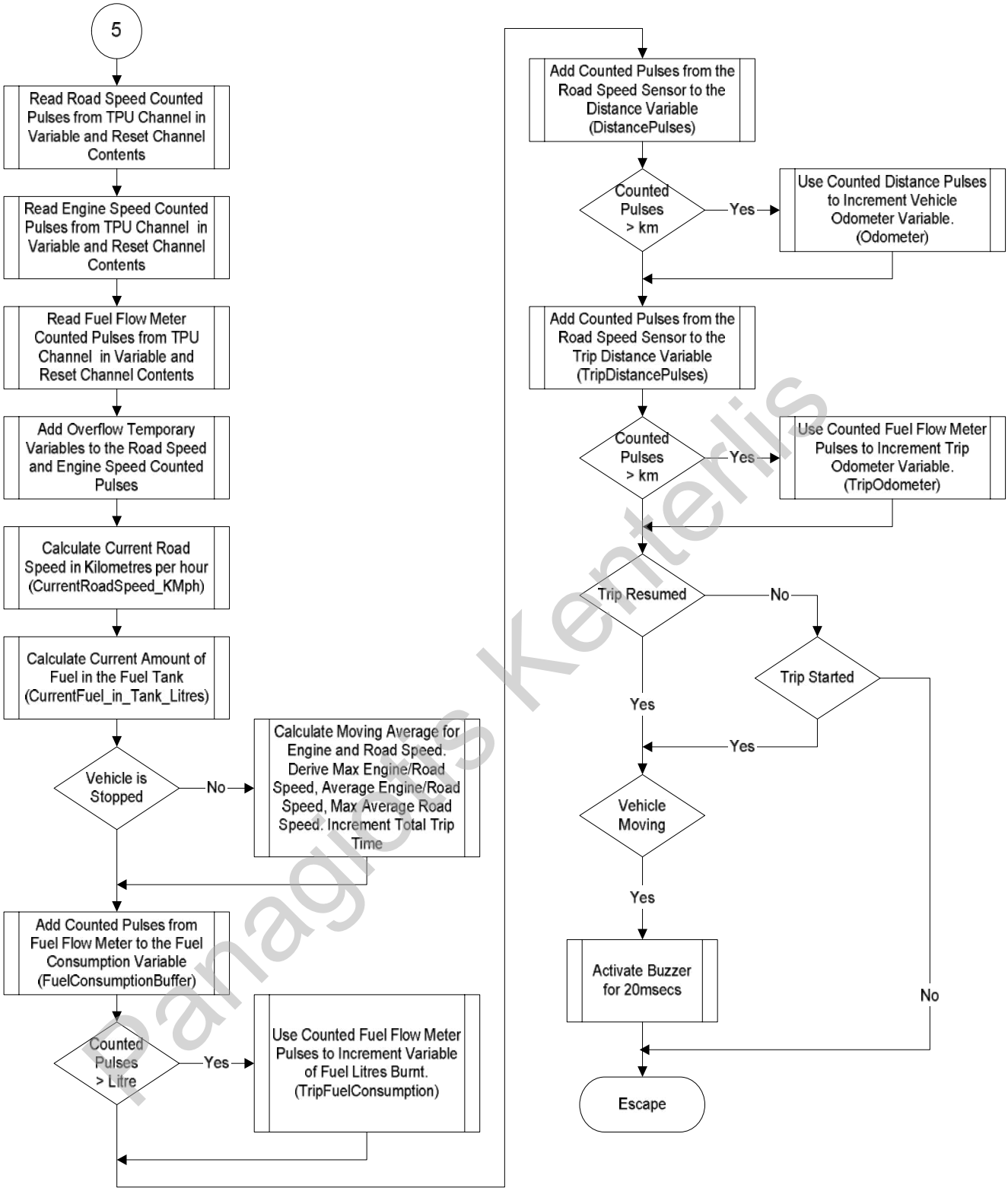
In the following pages some flowcharts for the basic functions performed by the microcontroller's firmware are also provided. Due to the extreme volume and complexity of the source code it is not possible to deliver all flowcharts before deadline. For more information on the actual operation of the firmware it is advisable to read the source files, which are heavily and well commented.

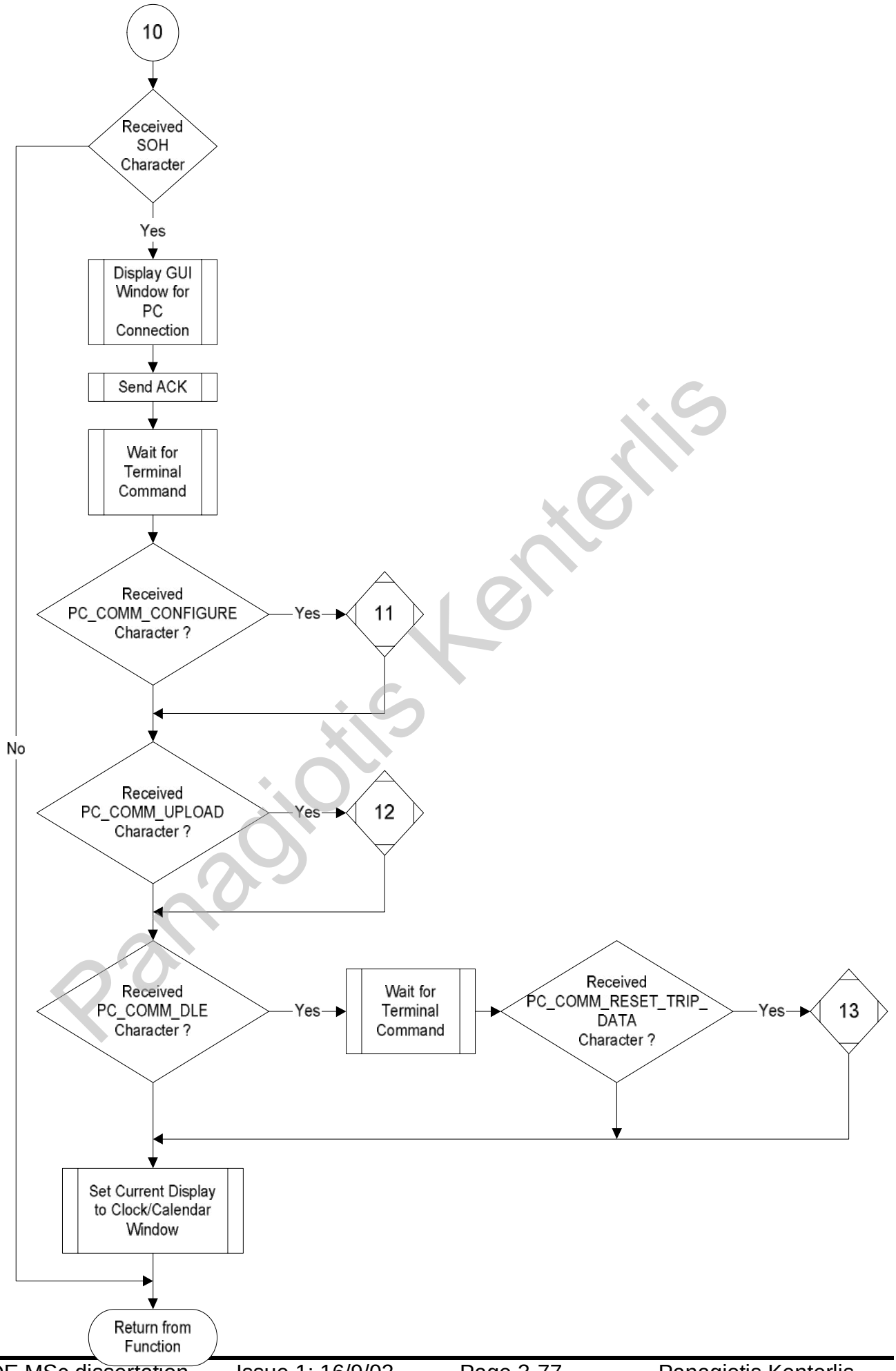
- ***General Flowcharts***

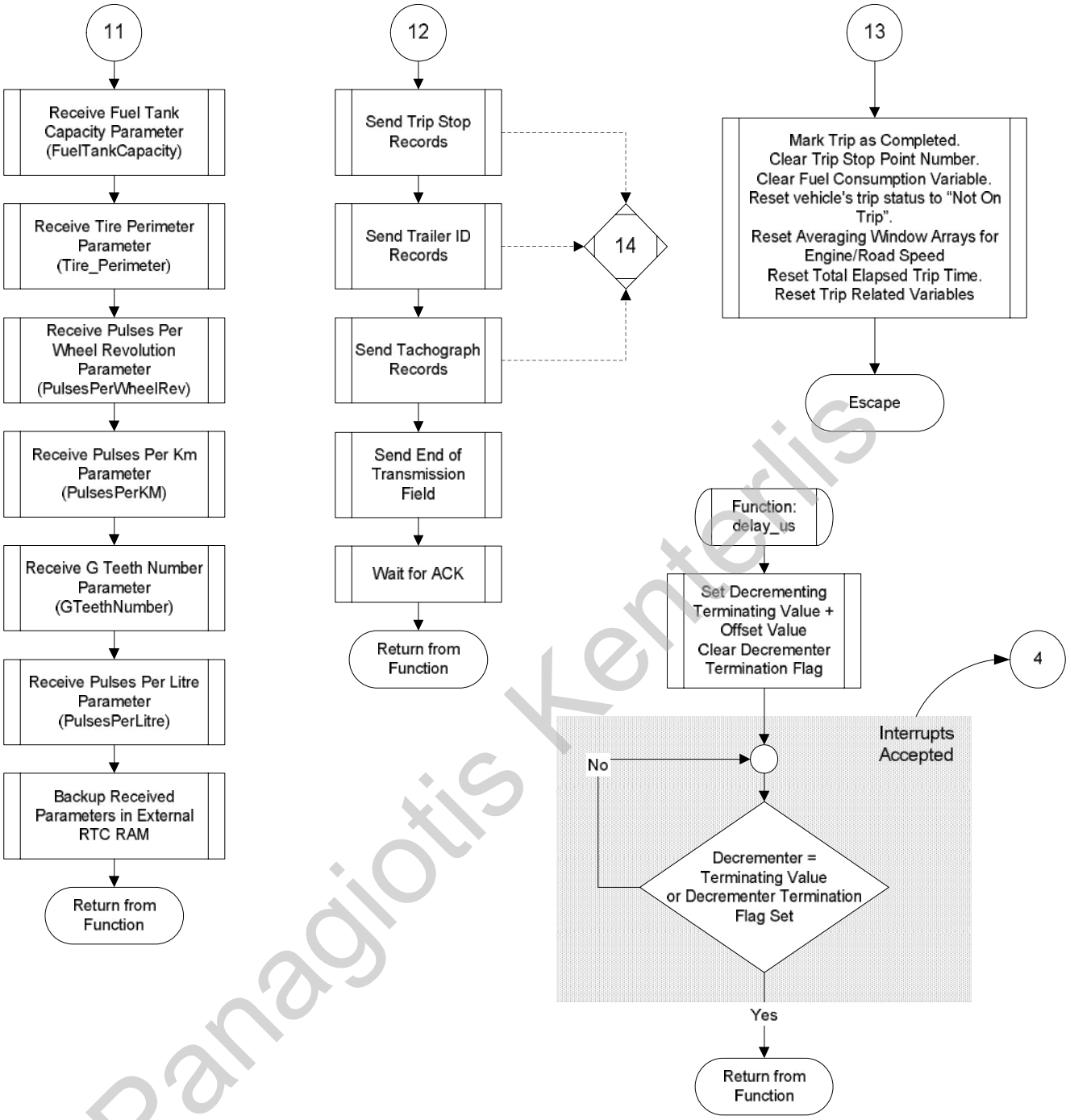


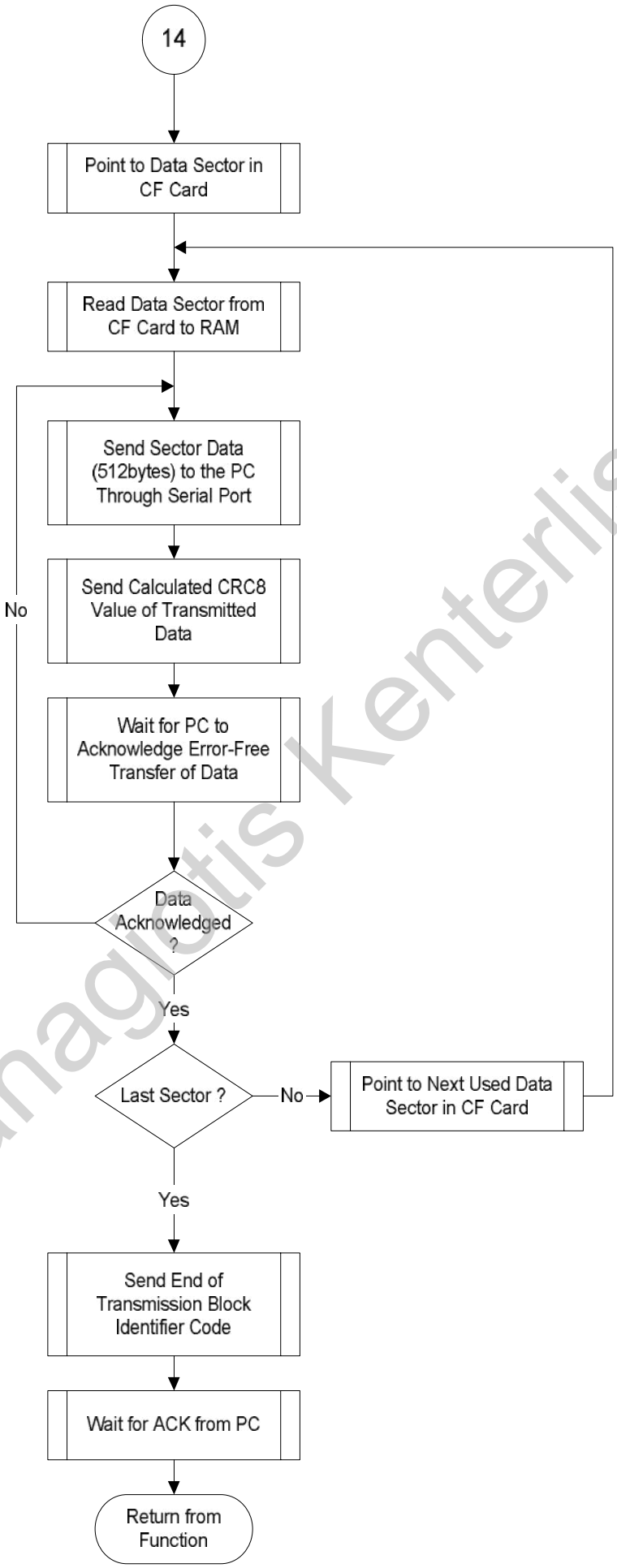












3.2.2.1. Trip Data Storage

Trip data is stored in the CompactFlash memory device in records. The formats of these records are analysed below.

The Trip Stop record holds information about the time and date the trip was resumed (every field takes 8bits), the amount of fuel inside the fuel tank when the vehicle stopped (16bits), the amount of fuel (16bits) and the value of the trip odometer value (16bits), as well as the identity of the driver (64bits) at the time the trip was resumed. The Trip Stop Number field is an 8bit number that serially marks the trip route. All records saved in the CF card carry this field to link them together.

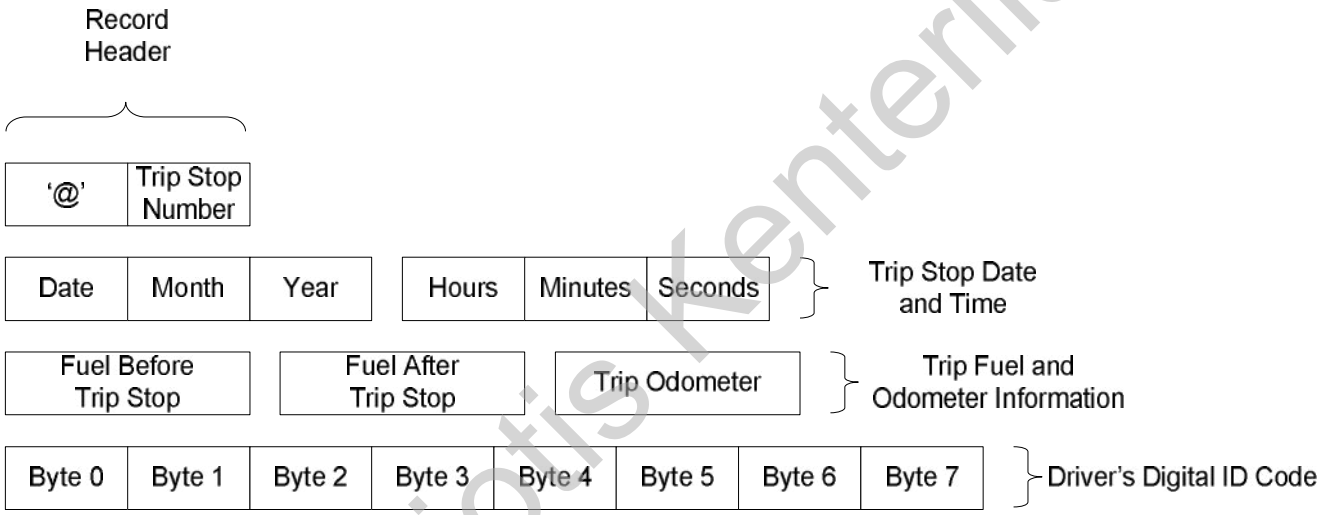


Figure 3-40 Trip Stop Record

For the maximum number of 256 trip stop points, and with every Trip Stop record carrying 22bytes of information, the maximum number of sectors on the CF Card that needs to be allocated for these records is:

$$\text{Number Of Sectors} = \frac{256 \cdot 22bytes}{512bytes/Sector} = \frac{5632bytes}{512bytes/Sector} = 11Sectors$$

The Trailer ID record holds the ID codes of the attached trailers. A maximum of 8 trailer I_D codes is held per record. The header includes a Start-of-Record character ('@'), the Trip Stop number and the number of discovered ID codes. The ID codes discovered follow next. The record ends with an End-of-Record character ('#'), which has been added to keep the record size to an even number of bytes.

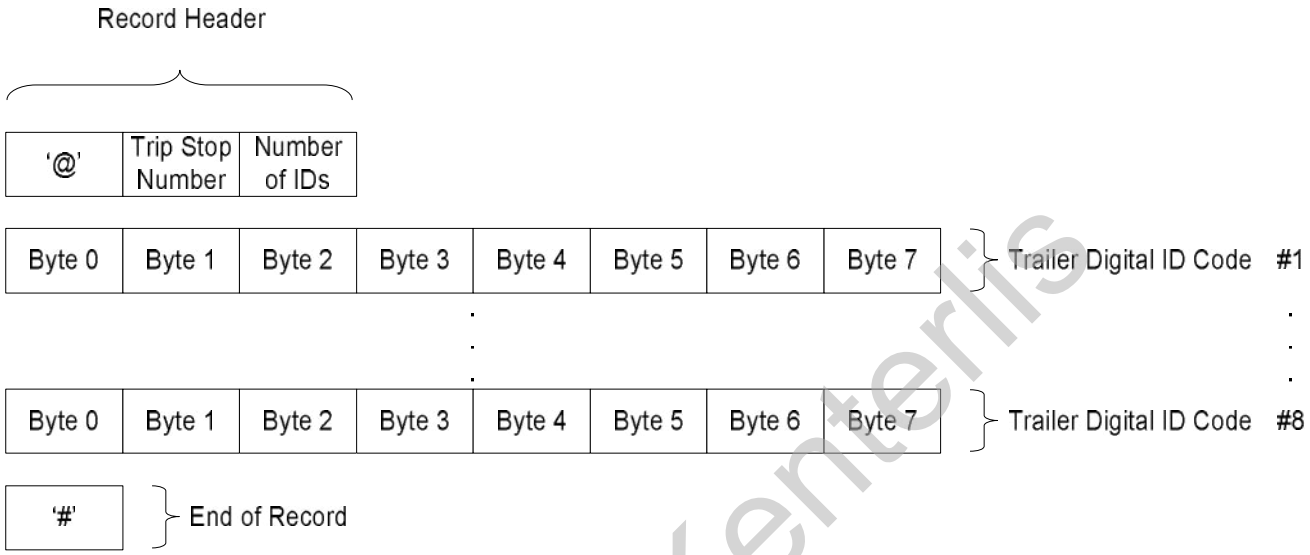


Figure 3-41 Trailer ID Record

For the maximum number of trip stop points and the maximum number of discovered ID codes, a total of $\text{Number Of Sector} = \frac{256 records \cdot 68 bytes}{512 bytes/Sector} = \frac{17408 bytes}{512 bytes/Sector} = 34\ Sectors$ needs to be assigned on the CF Card.

The Tachograph record holds the vehicle's road speed divided by 100 (16bits of data stored in the integer form of e.g. 57.500km/h is saved as value 575), which is recorded for every second of actual trip time.

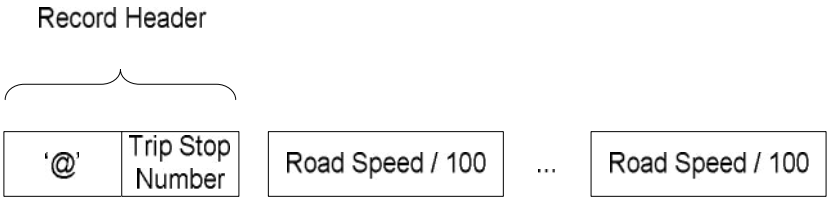


Figure 3-42 Tachograph Record

In order to avoid reducing the CF Card's lifetime by saving data every second, road speed data is kept inside a buffer of 8 elements in depth (16bits per element) and flushed to the CF

Card when full, that is, every 8 seconds. Changing the depth of this buffer will prolong the CF Card's life.

During the initialisation phase of the firmware execution, the total number of sectors available on the CF Card is discovered and used as the maximum sector value for storing Tachograph Data. The number of sectors allocated to storing Tachograph information defines the amount of total recorded trip time. To allow future upgrades to both software and hardware, the Tachograph records are saved last on the CF Card.

The memory map of the CF Card is displayed in Figure 3-43 below.

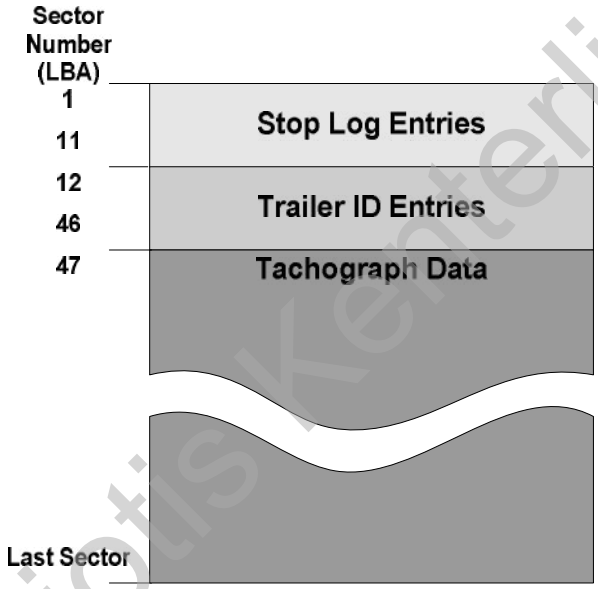


Figure 3-43 CompactFlash Information Storage Map

The 4Mbytes version of the CF Card that was used for the project has a total of 7872 sectors in LBA mode, which amounts to $7872 Sectors \cdot 512 bytes/Sector = 4{,}030{,}464 bytes$. With the memory map already displayed above, a total of $7872 - 47 = 7825$ Sectors are available for Tachograph information to be stored. This capacity is enough for storing information for $\frac{7825 Sectors \cdot 512 bytes/Sector}{2 bytes/second} = \frac{4{,}006{,}400 \text{bytes}}{2 bytes/second} = 2{,}003{,}200 \text{ seconds}$, which is equal to 23 days of continuous driving (results to be verified by the reader).

By using a CF Card of larger capacity, Tachograph information can be stored over a much longer period of time and by altering the firmware it is possible to increase the number of identified trailers and use this facility for tracking contents of trailers.

3.2.3. PC Software Code Explanation

The software utilities developed for the PC in Microsoft Visual Basic 6.0 for the Windows platform are used to communicate with the trip computer through a serial port (by default set to COM1, although it can be changed by the user) and control transfers of data to and from the trip computer device. By implementing the analysed communications protocol these programs can be easily ported to any operating system or programming language.

Short explanation and flowcharts for the most important functions executed by the software on the PC are provided in the following pages. To obtain a more clear knowledge on the actual code executed you are requested to read the well commented source code.

- ***Configuration Download Utility***

This utility is used for downloading configuration data for the automotive sensors connected to the trip computer (Figure 3-44). Sensor parameters are given in clear text form and can be saved to and/or stored in files. If required, the default communications port can be changed to another COM port of the system where the utility is installed. Configurable parameters are:

- Tire Perimeter (in metres) (32bits).
- Fuel Tank Capacity (in litres) (16bits).
- Pulses per Wheel Revolution (from Road Speed Sensor) (16bits).
- Pulses per Kilometre (from Road Speed Sensor) (32bits).
- Pulses per Engine Revolution (from Engine Speed Sensor) (16bits).
- Pulses per Litre (from Fuel Flow Meter) (32bits).

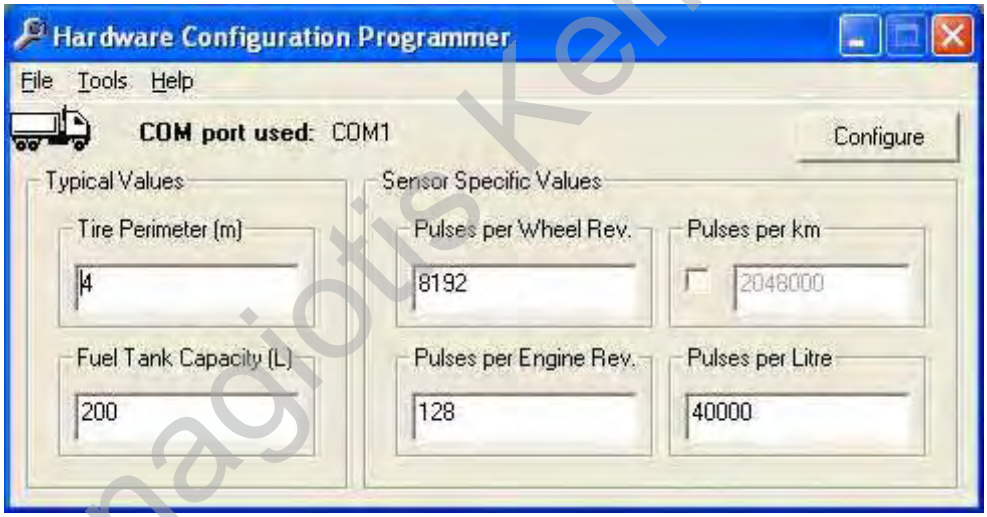
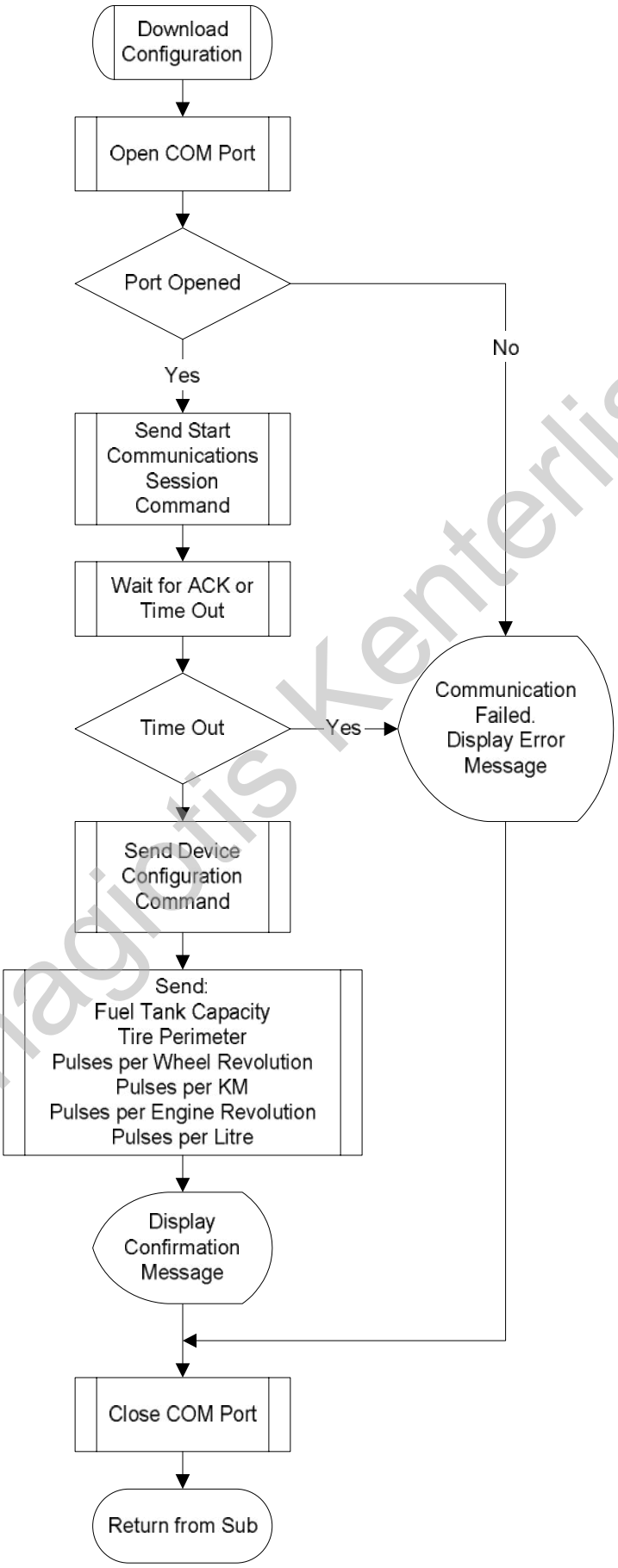


Figure 3-44 Hardware Configuration Utility

In the case that a sensor is replaced with one of different specifications, only the specific information for its configuration needs to be changed. These parameters are stored in the RAM of the external RTC on the trip computer and are used in calculations to produce accurate results. The utility simply sends a Start of Communication Session command and expects an acknowledgement (ACK) from the device, after that it sends the Device Configuration command and the parameters. When every parameter has been sent, acknowledgment from the device is expected to proceed with the next one.

○ *General Flowchart*



- ***Trip Data Upload Utility***

This utility is used for uploading vehicle and trip information stored on the CompactFlash and saving them in files (Figure 3-45). Only sectors that carry information are uploaded to the PC through the serial port. Data uploaded are stored in three different files (Trip Stop Log, Trailer ID log, Tachograph information). To start the upload process the utility sends the Start of Communication Session command and expects and acknowledgement from the device, after that it sends the Upload Trip Data command to the trip computer. The trip computer responds with the data in one sector (512bytes) plus the calculated CRC8 value of the data sent. The PC monitors the serial port and every byte received is added to a temporary buffer. Once 513bytes have been received, the PC recalculates the CRC8 value of the received data and compares it to the received CRC8 value. If these values match, then the transmission didn't contain errors and the received data are appended to the currently pointed file. The PC sends an ACK (Acknowledge) command to indicate that the sector was received correctly and that the next sector should be sent. If the CRC8 values did not match the received data are discarded and a NACK (Negative Acknowledge) command is sent to the trip computer to indicate a transmission fault and request retransmission of the entire sector. The PC also monitors the buffer for the appearance of special transmission terminating commands. These commands indicate that a set of records has been uploaded and that the PC should save the next data to be transmitted to the appropriate file (End of Transmission Block), and that the entire upload procedure has finished and that the PC should not wait for any more data to be received (End of Transmission).

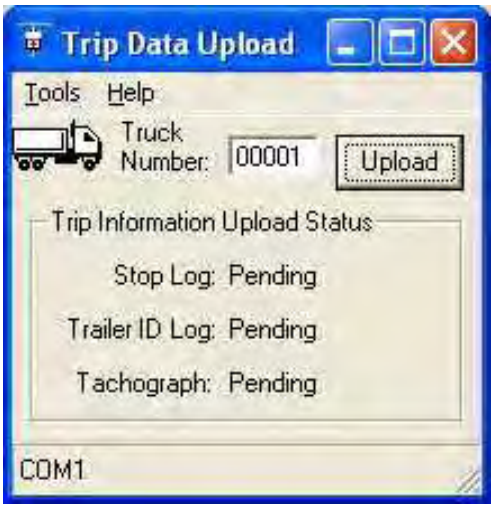
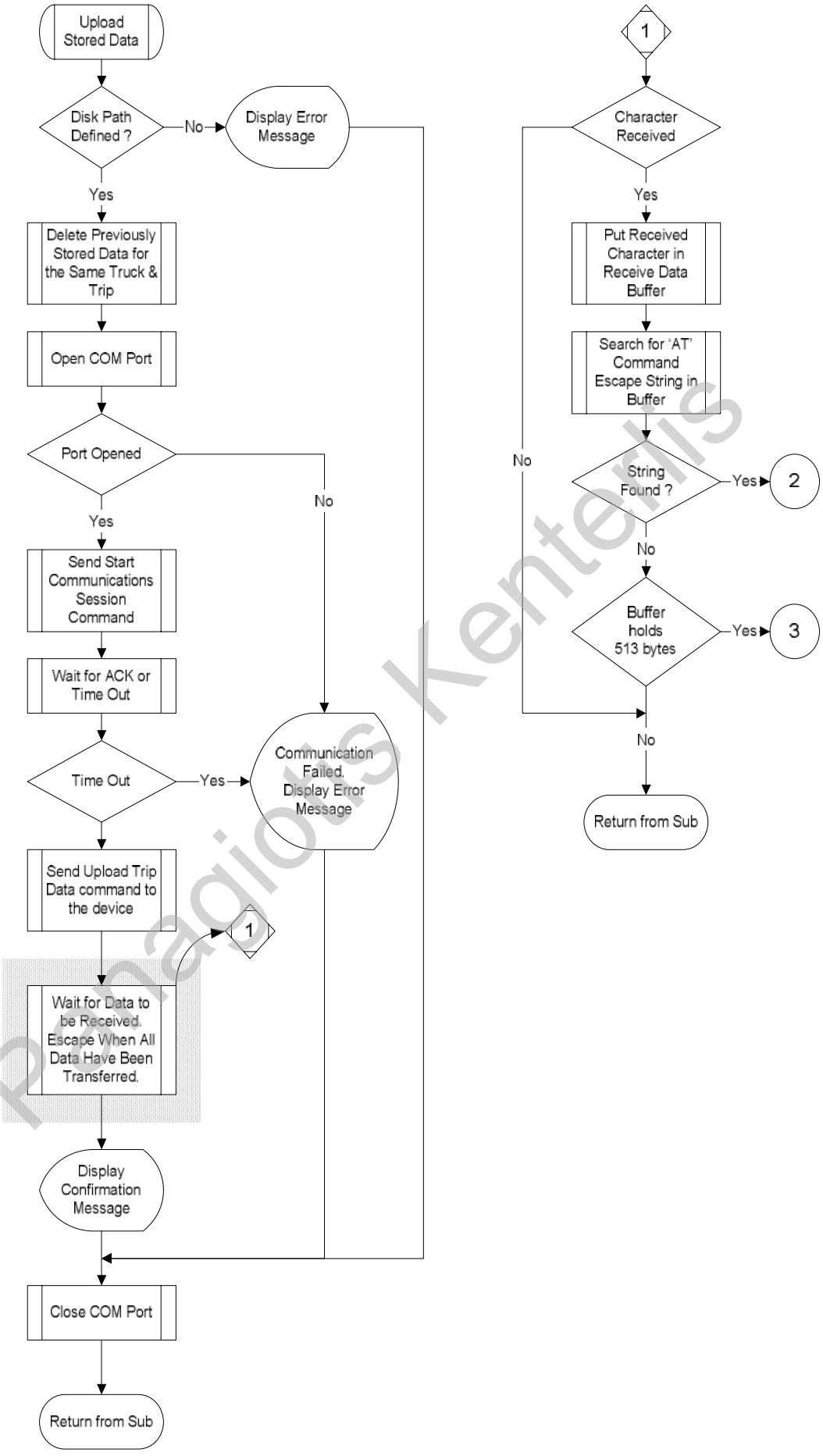
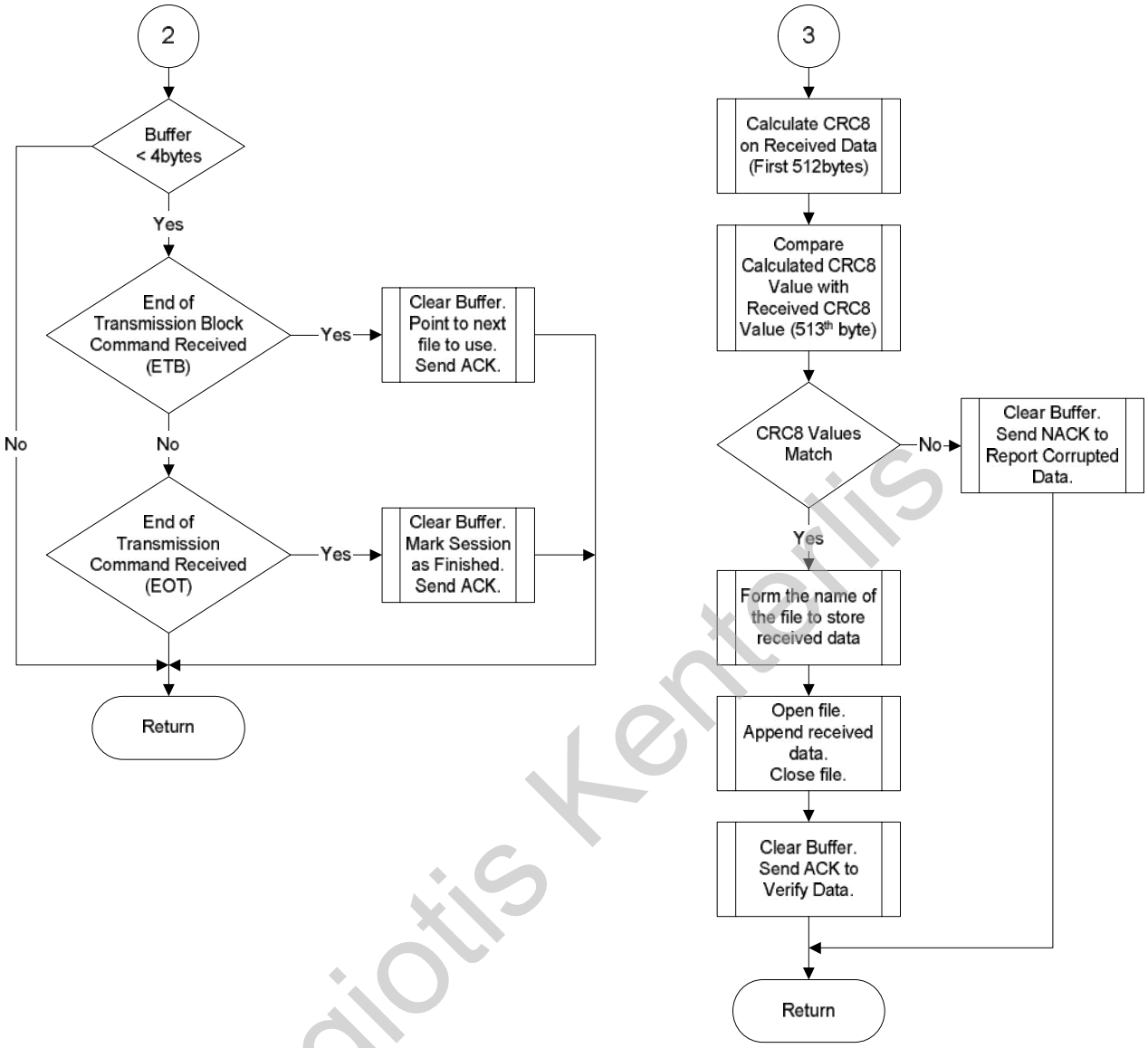


Figure 3-45 Trip Data Upload Utility

○ *General Flowcharts*





4. Building the Project

4.1. Practical Building Considerations

While in the development phase of the project, some problems needed to be resolved. The most important of them are given in the text that follows. Both hardware and software sections are mentioned.

4.1.1. Hardware

Developing the hardware part was somewhat tricky mainly because of the development board used for the microcontroller (Axiom PB-0555). This board (Figure 4-1) provides almost all the pins of the microcontroller in 4 headers of 4x17 pins each. Trying to establish a fixed connection of the developed hardware with the development board required some manufacturing tricks, since no standard connectors are available for such a pin layout. The main concern was to avoid using a soldering iron on the board itself that could incur possible damage.

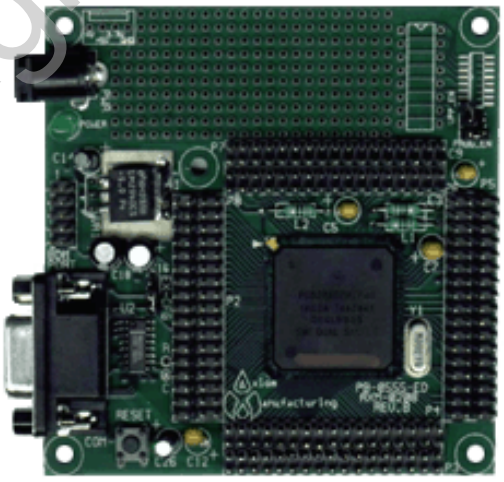


Figure 4-1 Photograph of the MPC555 Development Board

This obstacle was overcome by using single row pin connectors and arranging them on a spotted matrix board, so that all of the microcontroller's pins would become available on the

copper side of the matrix board. After that, the matrix board was used to form a motherboard with connectors for all other developed peripheral boards (Figure 4-2).

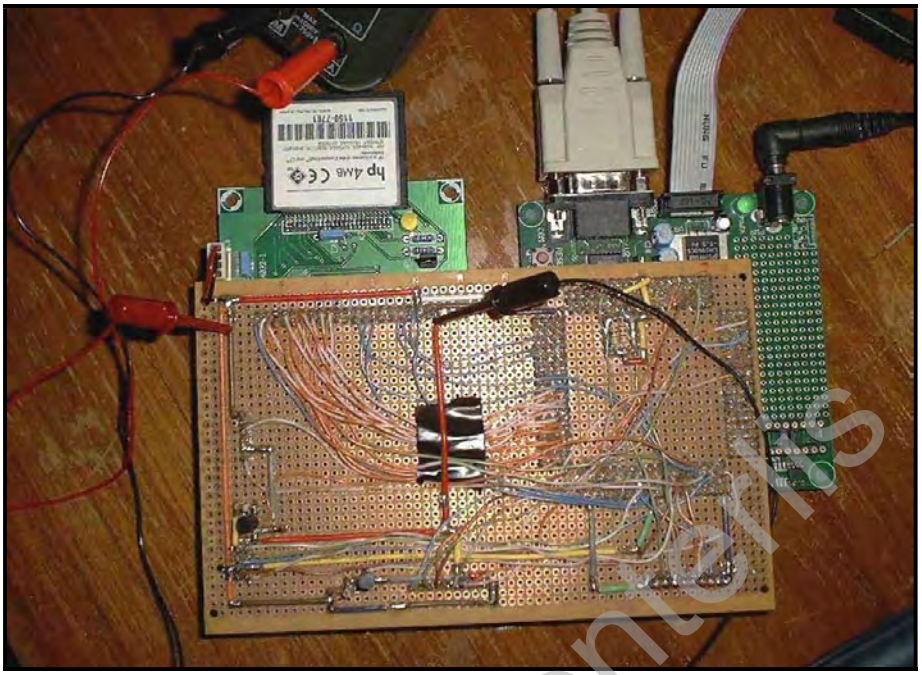


Figure 4-2 Development Board with Connected Motherboard

4.1.2. Software

The main problems encountered with the software part of the project was obtaining the license for the Metrowerks CodeWarrior and configuring the target settings for the microcontroller development board used, since no stationery was available for it. Having no external memory on the development board, all software development needed to be done in internal memory. For the Debug version the limited memory size for code development (26Kbytes SRAM) and the fact that at this mode processing of interrupts could not be performed was a problem. For the ROM version although code size was not an issue (448Kbytes FLASH available) and interrupts could be processed, however, actual debugging could not be performed and a very time-consuming FLASH program download procedure had to be performed every time the code changed. In addition programming the FLASH memory was limited to a maximum of 100 cycles so care had to be taken not to wear out the FLASH memory cells. A mixture of both target versions was used; Debug when specific routines needed to be tested and ROM when interrupts had to be processed to view system response.

5. Testing & Debugging

The device developed was fully tested in laboratory conditions with all connections to automotive sensors being emulated by standard testing methods and equipment. Field tests could not be performed because of the requirements for such a case, i.e. the trip computer would have to be installed on a truck and tested in a real trip scenario.

While developing the project, at all times there was need to test changes in the programs and the operation of modules.

For this purpose the following tools were used:

- A fixed frequency crystal oscillator running at 32.768 kHz.
- A pulse generator.
- A digital Multimeter.
- The microcontroller's serial port in connection to the PC.
- The display module, for displaying test information.
- And largely the Metrowerks CodeWarrior 6.03 Integrated Development Environment, used as a debugger-emulator.

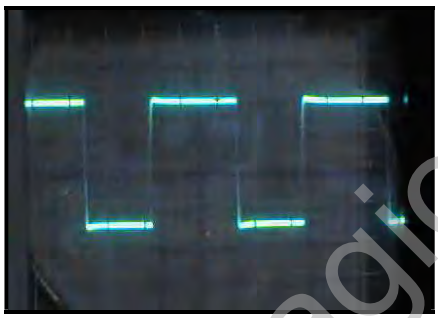


Figure 5-1 Oscilloscope view of square wave signal

Both the crystal oscillator and the pulse generator were used to provide square wave pulses to the TPU3 inputs of the microcontroller in order to emulate the automotive sensors for road speed, engine speed and fuel flow.

Figure 5-2 Multimeter used to test voltage level of I/O pin

The digital Multimeter was used to measure voltage levels on various test points while developing system circuits. Being the first testing device to be involved while still starting on the project, it was first used to verify the logic value of I/O pins of the MIOS1 module, when the control functions for that module were developed. Also used to check circuit boards for short-circuits and electrical continuity of connection wiring.

The microcontroller's serial port connected to the serial port of a PC running terminal emulation software proved to be a very helpful debugging tool. Printing information on the terminal window such as test values, contents of registers, breakpoint execution flag text, measurement readings and time signaling, were all functions that were performed to help eradicate bugs and improve the design of both software and hardware.

In Figure 5-3, frequency/pulse counting results of the TPU channels for Road Speed and Engine Speed sensors are displayed with a display frequency of once per second, as code was executed inside the ISR of the internal RTC.

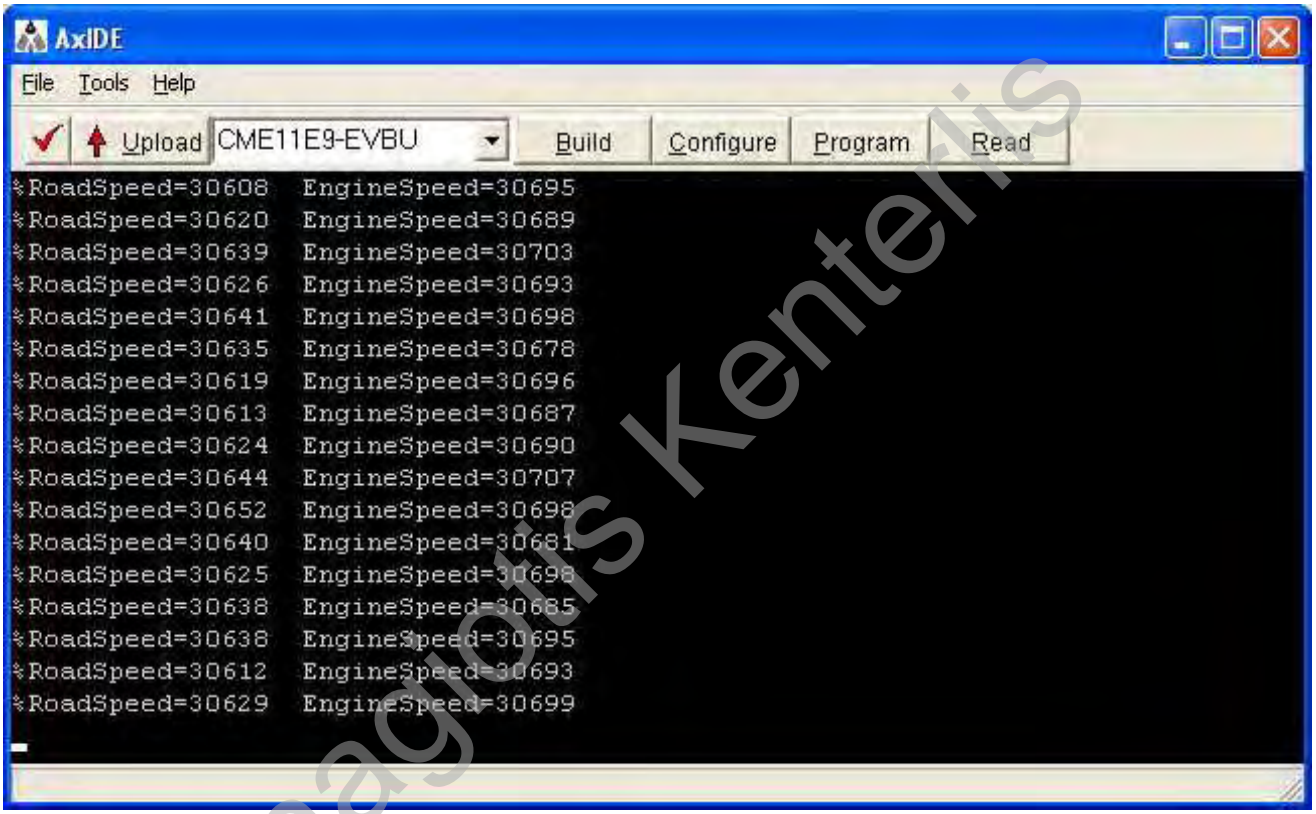


Figure 5-3 PC Terminal Debugging

The Metrowerks CodeWarrior IDE was the most important of all development, testing and debugging tools. With the use of a device connected on the parallel port (MSI Wiggler), CodeWarrior was able to communicate with the microcontroller and its BDM port (Background Debug Mode) (Ref. [6] & [10]). The Wiggler is effectively, at a minimum, a parallel port to JTAG (Joint Testing Action Group) serial interface converter. The BDM port, which is based on the JTAG interface, allows for instructions and data to be downloaded to the microcontroller even at execution time, accessing and modifying memory and processor resources, single stepping, processor reset and status control (running or halted). It essentially allows the user to download a program in RAM and execute it by using a software-hardware control scheme, with the microcontroller itself acting like an In-Circuit Emulator (ICE). The entire scheme is called On-Chip Debugging (OCD) by Motorola and it is used in many of its products.

In the screenshot of Figure 5-4, Metrowerks CodeWarrior is displayed while debugging the application software by using the opened windows to display processor registers and memory locations, as well as code that is executed both in C language and assembly. Instructions can be executed step-by-step in both C and Assembly, while the result of every instruction can be monitored by looking at the relating processor/system information window.

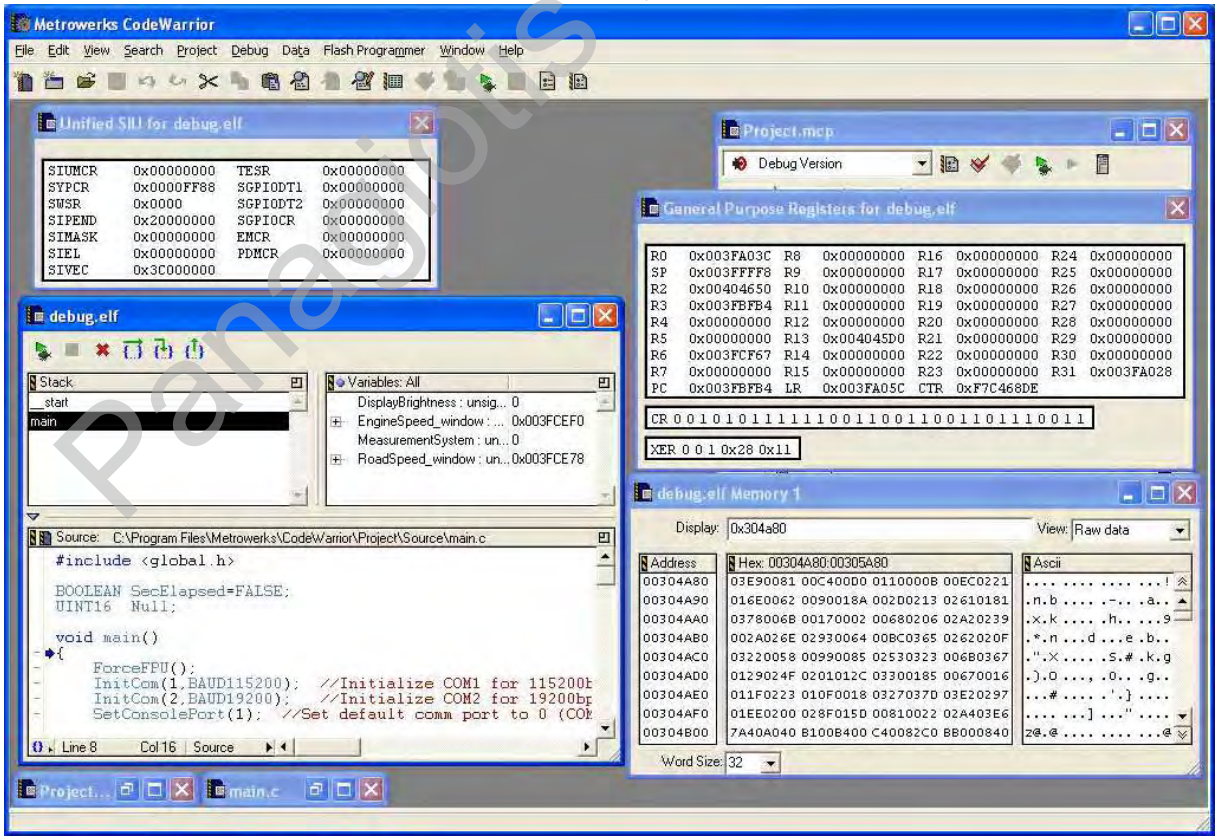


Figure 5-4 Debugging of the application software using BDM/OCD inside Metrowerks CodeWarrior

In Figure 5-5 the full set of General Purpose Registers of the PowerPC architecture followed by the MPC555 is displayed and changes can be monitored while executing the application code. Like a true debugging tool, the user can also alter the contents of any register whenever this is needed.

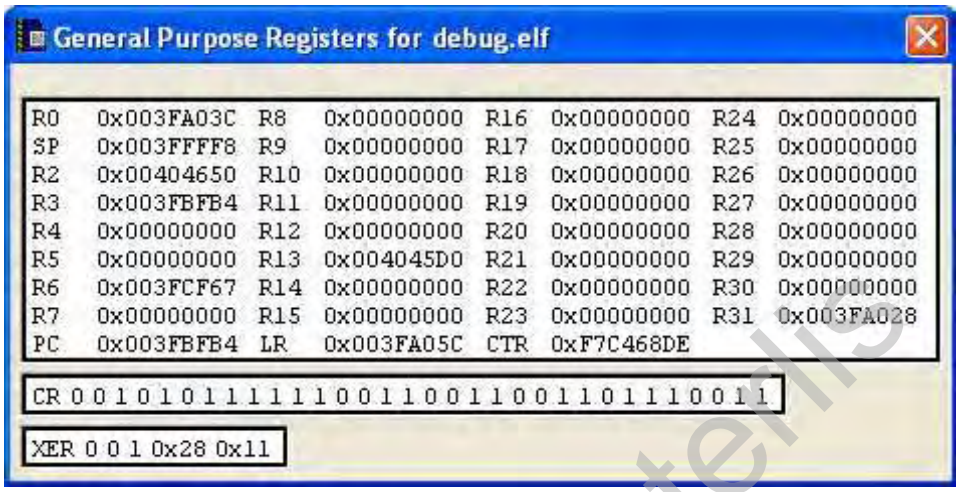


Figure 5-5 General Purpose Registers of the Microcontroller in BDM while executing the application.

Other available facilities are Memory Dump, Special Function Register windows, displaying memory contents as any type of data (binary, hexadecimal, long integer, floating point number, text, arrays, etc).

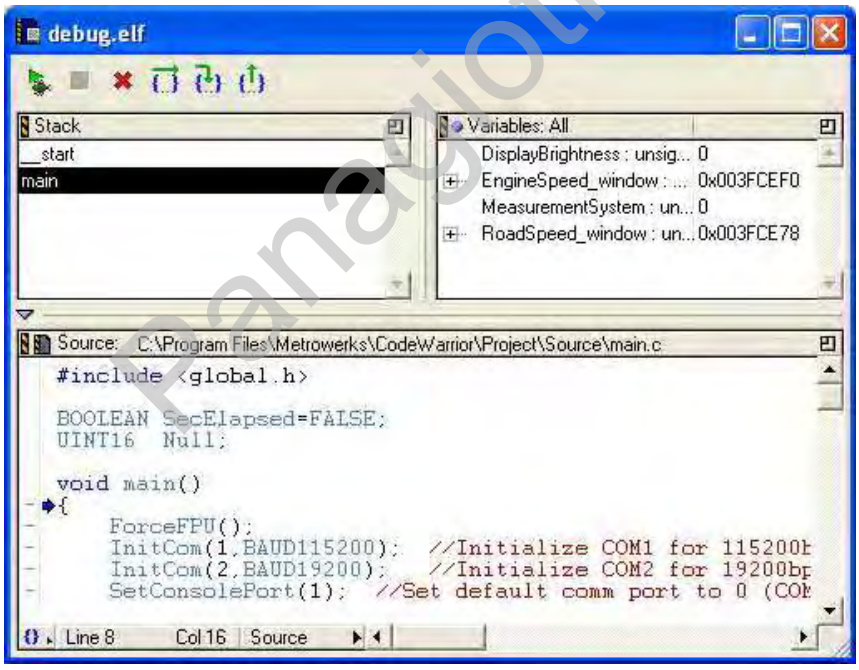


Figure 5-6 Source Code Execution Window

The Source Code Execution window displays the source code to be executed. The user can execute the code step-by-step, insert breakpoints, start and stop execution, enter functions or simply execute them and change execution flow. The program being executed can be displayed as C/C++ and/or assembly code.

The values of local and global variables are also displayed and can be altered.

The Stack pane allows viewing of local variables and temporary variables used in stacked functions.

One of the methods used to test and debug the CF Card storage functions and the serial upload functions of the trip computer was to save an entire sector of data (512 bytes) with incrementing values from 0 to 255 and then display them on the computer's screen. The same test was also executed in Metrowerks CodeWarrior and results displayed as data elements of an array. Once the data had been uploaded to the PC and saved to a file, they were displayed by using a Hex-Editor (in this case the Norton Commander Editor). In Figure 5-7 and Figure 5-8 the contents of one sector filled with test data are displayed in both Hexadecimal and ASCII.

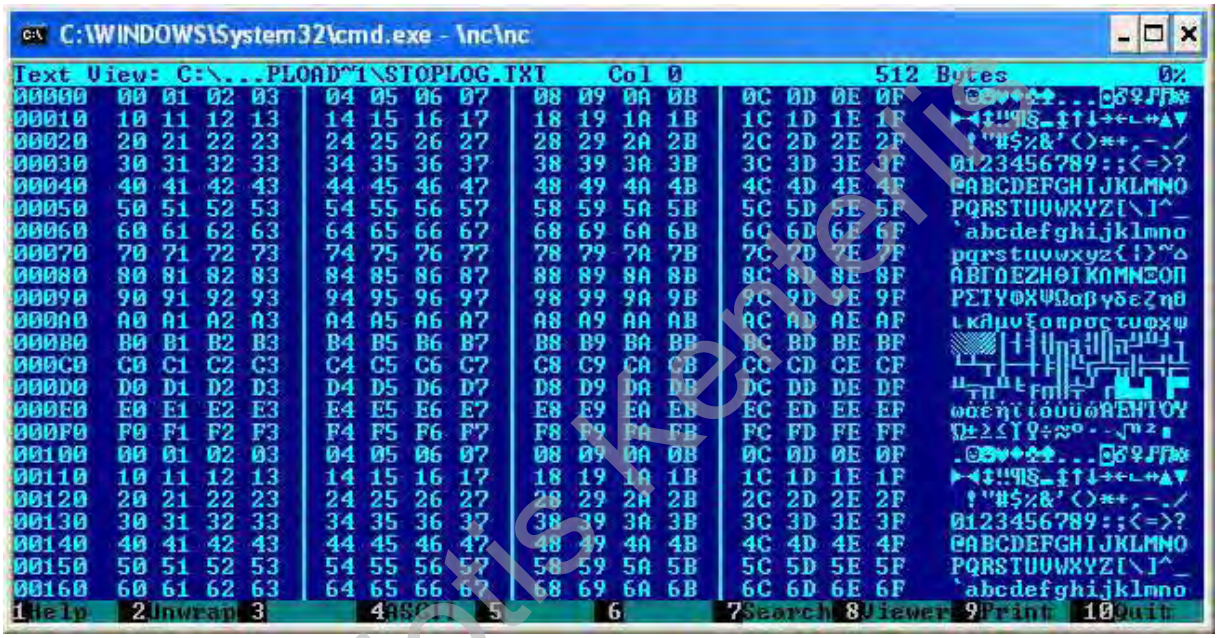


Figure 5-7 Sector Contents as uploaded to the PC (1/2)

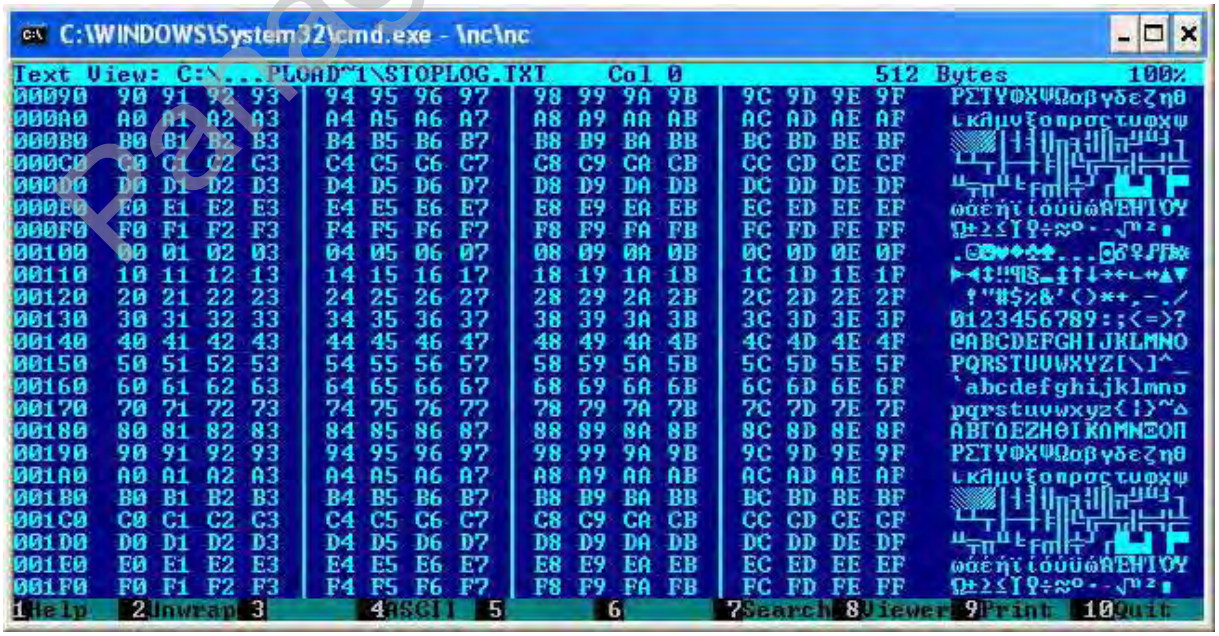


Figure 5-8 Sector Contents as uploaded to the PC (2/2)

5.1. Electromagnetic Compatibility Issues

With the automotive environment being extremely rich in electrical noise, due to spark plugs and solenoids on the engine, there is need for immunization of the device. To achieve this, the trip computer circuit boards have to be placed in a steel enclosure and ferrite beads mounted to all wires in and out. The microcontroller is equipped with a watchdog timer on-chip, which should be enabled to eradicate rampant processor behaviour. In addition, the power supply to the device needs to feature a large capacitor to compensate for instantaneous power loss when turning on the ignition, as well as transient voltage suppressor diodes to filter out high frequency voltage spikes.

6. Project Results

Upon completion of the project all specifications drawn at the beginning and reviewed during the course of development have been met, along with a few more not originally included. This was made possible by performing a well-planned, methodical programming and module usage, as well as exploiting a number of features found being hidden in the microcontroller's datasheets. The designed hardware device is capable of performing the following functions:

1. Current speed shown in two measurement systems (km/h and m/h).
2. Road Speed statistics such as maximum road speed, average road speed, and maximum average road speed.
3. Present vehicle location (relative to distance from next stop) by displaying a trip odometer and distance to next stop and to final destination.
4. Total elapsed time since start of trip (drive time).
5. Elapsed trip time since last stop (drive time).
6. Vehicle's Battery Voltage.
7. Fuel remaining in the fuel tank in two measurement systems (litres and gallons).
8. Distance to empty fuel tank in two measurement systems (km and miles).
9. Total amount of fuel used since trip start in two measurement systems (litres and gallons).
10. Instantaneous fuel flow rate in two measurement systems with four variations (km/litre, miles/litre, km/gallon and miles/gallon).
11. Estimated time till arrival to the next stop point.
12. Estimated time of arrival to the next stop point.
13. Time of day displayed on-screen (Home Time/Date).
14. Date displayed on-screen (Home Time/Date).
15. Local time, calculated by entering a time difference from Home Time.
16. Alarm clock that can be set by the driver to sound at specific time of day.
17. Engine speed in 1000x RPM.
18. Engine Speed statistics (maximum engine speed and average engine speed).
19. Vehicle's independent digital odometer.
20. Trip independent digital odometer.
21. Outside/Cabin temperature acquired by a digital thermometer device.

22. Tiredness warning after 3 hours of continuous driving (according to EU traffic laws).
23. Driver's ID logging using a digital key.
24. Trailer identification and logging using digitally coded devices.

The memory device (CF card) is used to store the following set of information:

1. Time and date of trip resume after leaving a stop point.
2. Trip odometer value displayed at trip resume point.
3. Fuel gauge indication before vehicle stopping and after vehicle continuing trip from a stop point (refuel mark-up).
4. Driver's digital ID code to allow tracking a driver change over the trip duration.
5. A log of all trailer digital ID codes at every stop point, to allow tracking of trailers being transported.
6. Arrays of tachograph information (road speed) starting at every resume trip point and stopping at every trip stop point. Values are acquired every second and saved on the memory device every 8 seconds or when a sector buffer is full or another event e.g. signal from a G sensor indicating an accident has occurred (should that be implemented in future product upgrades).

Having implemented part 6 of the above list, the Trip Computer device can be used as a simplistic trip data recorder in the undesirable event of an accident, as evidence of the vehicle's road speed seconds or minutes before the accident. Such functionality makes the installation of the trip computer on a vehicle fleet even more useful to companies, since it could be used in a court of law to relieve both driver and company from legal accusations and financial claims.

As indicated in the finalised specifications list, all information saved in the CF Card are uploaded to a personal computer using software utilities specifically designed for that purpose. After the information has been saved on the PC, a software program, which was not developed as part of the project due to limited time at hand, can be used to process the data files and visualize the information for inspection and statistical or other analysis.

By implementing all of the above, the project can be characterized as successfully having met with the targets that had been designated, in order to develop a product unique and functional in its whole.

7. Future Upgrades and Development

Like any other product, the trip computer can be deployed to include even more features and thus exploit more of the microcontroller's true capabilities, which exceed the ones currently used for this project.

Future plans on the software side of the project should certainly include building an Integrated PC Software Suite, which was not developed as part of the project and will assume the management of entire fleets of vehicles and automate various procedures.

Future hardware upgrades could also include some ideas originally suggested, however during the selection phase were eliminated either because of cost, complexity or time margins:

- Implementing a high speed communications bus such as the Universal Serial Bus (USB) will minimize data upload times, especially when collecting data after a very long trip, with the amount of stored information being proportionately high.

- Incorporating a GPS receiver would allow recording the exact position of the vehicle at every time. By doing so, it is possible during the data process phase, to verify that the driver has followed the route suggested by the company. Also to make the product even more appealing, it would be interesting and useful, if by connecting to a PC or PDA to display vehicle's current position on digital maps relatively to the drawn route.

- A wireless communications channel, such as GSM/DCS, could allow transferring data from the device to the company's computers during the trip, even when abroad. This can prove to be very useful to a company that wishes to be aware of the location of its vehicles at regular intervals.

- By using more sensor inputs and connecting to the Engine Control Unit of the vehicle, it will be possible to provide more information on the vehicle's status. Following this, the trip computer could eventually replace the entire vehicle's analogue instruments dashboard.

8. Conclusions

Having finished this project, I feel more confident about my abilities in handling projects of such magnitude in real life. Managing such a project, although difficult at some points and damaging to my bank account, it proved to be a very interesting and invaluable experience. Much knowledge was gained from the logical reflections occurring at every moment, as many aspects of the problems being faced with needed to be considered in order to decide on the best likely solution.

During both research and development periods, I had the opportunity to study on real-time embedded systems and expand my knowledge in microcontroller and microprocessor systems design, which is my main field of interest.

Never having a driving license before or being interested in cars in any way, studying in the field of automotive applications provided some background information on the technology of engines, mechanical, electrical and electronic systems found on cars. Although this hasn't dispelled my fears of becoming a driver, it will at least assist me in understanding better what is happening underneath the metallic hood or plastic covers, and in the future may point me in design more products for the automotive market.

In conclusion, as expected, this project proved to be the most exciting and most educative part of the MSc course.

9. Project Management

9.1. How Was the Project Planned?

The Baseline Time Schedule for the project was designed for a development period of 11weeks using a worst case scenario. This scenario assumed that every task would take up the entire day allocated to it, without dealing with other tasks. At the time the project was being planned little knowledge was present on the difficulty level in using the development tools, which were therefore considered to be not extremely productive. In addition the author's abilities to deal with 32bit advanced microcontrollers and complex real-time software were assumed to be basic at that point. Uncertainty in the selection of module inter-connection protocols until the related components were available, also contributed in the decision to follow a scenario of such a wide time spread.

However, the initially drawn baseline plan proved to be inconsistent with reality. While working with the development tools, although initially a myriad of problems had to be solved, seeking for advices on the internet from a forum specifically for these tools helped gradually solve problems at a short time, and proved highly productive. Dealing with many tasks at the same period of time also allowed to accumulate knowledge much faster and thus helped to get a clearer picture of the project at an early time. It was thus discovered that the author was underestimated for his abilities in dealing with such a complex project. Additionally by cutting corners and underwriting the financial burden of purchasing the most essential components, saved much time in obtaining the components and allowed to start development of the related project sections earlier. The end result of these actions was for the development phase of the project to actually last 7weeks, which is 4weeks earlier than originally planned.

This march of events was greeted with a smile of contentment since it allowed more time to be spent preparing this assignment, as well as the project's presentation and report.

9.2. Problems and Achievements

Some ideas that emerged during the research period, like incorporating a GPS receiver and a high speed communications bus had to be abandoned after careful consideration of cost levels, time available for project completion and possible impact on the product if removed. More specifically the cost was prohibiting in both cases and only if removed (GPS) or replaced with lower cost versions (communications bus) the project could be kept inside budget and deadlines.

While still discussing with the project supervisor on the available funds for the project, it became clear that there might be some problems in obtaining some of the expensive parts. That led the author to purchase the display module using own funds. The module was delivered 5 weeks earlier than originally planned, had it been obtained through the university.

In addition to the above, many components and parts were purchased by the author to allow for faster delivery times, than if ordered through the university. As proven later by the extremely slow delivery rate of components that had been ordered through the university, this decision was very wise and saved lots of development time, although it surely cost more. However during development stages where specifications have not been absolutely finalised, time is of more essence, while actually finding the most cost-effective supplier for the same parts to be used can be a matter to resolve prior the manufacturing stage. It is always necessary to keep in mind that large deviations from the drawn budget should not become common practice.

The above mentioned steps helped finish the project earlier than originally planned, thus allowing more time for testing and debugging to develop a stable and full-featured product. More available time also allowed finishing all writing works earlier or at least provided more time to produce a better result.

At the start of the development period of the project a number of connectors were required to build a main adapter board that would allow connection of the peripheral boards to the microcontroller's development board. Although having been reassured that the supplier would be able to deliver these within a few days, in reality it took more than 6 weeks just to receive the wrong type of connectors. Having nearly finished with the hardware development and urgently needing these connectors, switching suppliers seemed the only solution to obtain the parts required. The second supplier having compatible connectors at the same price managed to deliver the parts one day after the order was placed. This allowed finishing the project within 2-3 days (See Gantt Chart in the Appendix).

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A. Appendix

Appendix 1 Contents of 555_Axiom_ROM.lcf File

```
_flash_source = 0x00010000; // **NOTE: MUST match RAM buffer address
                                                    // setting in linker preference panel


MEMORY {
        ram : org = 0x003FA000, len=0x6000
        rom : org = 0x00010000 // desired ROM address (boot address for 555)
}

/* We use FORCEFILES so that the linker will not deadstrip the file reset.s. The function
        reset would be deadstripped since it is not ever called by anything */

FORCEACTIVE { gInterruptVectorTable, __reset }

SECTIONS {

                .reset(TEXT) BIND(0x10000) ALIGN(0x100) : {} >rom
                .init (TEXT)  ALIGN(0x100):   {} >rom

        GROUP BIND(0x10000): {

                .text (TEXT)   ALIGN(0x2000): {}
                .rodata (CONST) : {
                        *(.rdata)
                        *(.rodata)
                }
                .ctors : {}
                .dtors : {}
                extab : {}
                extabindex : {}
        } > rom         // for ROM images, this can be 'rom' if you want to execute in ROM
                                // or 'code' if you want to execute in RAM
        GROUP : {
                .data : {}
                .sdata : {}
                .sbss : {}
                .sdata2 : {}
                .sbss2 : {}
                .bss : {}
                .PPC.EMB.sdata0 : {}
                .PPC.EMB.sbss0 : {}
        } > ram

        // The dummy section is just a placeholder.  The linker automatically
        // generates an address for it in the ROM image, which tells us
        // where the end of the ROM image is.

        .dummy ALIGN(64): {}

        _flash_dest = _f_reset;                         // true flash address starts w/.init section
```

```
        _flash_size = _f_dummy_rom - _flash_dest;

        // The .fcopy section contains a small piece of code that copies the
        // ROM image to flash.  We don't copy the .fcopy section itself to flash
        // because it could erase the flash if it were accidentally executed
        // at a later time.
        //
        // Bind it to the address it will occupy in the RAM buffer so we can
        // execute it directly from the RAM buffer.

        .fcopy BIND(_flash_source + _flash_size) ALIGN(64) : {
                *(.fcopy)
        }

        .fcopy_data : {}

        // The internal flash algorithms provided by Motorola are
        // packaged in a binary file.  The linker includes the contents
        // in the .BINARY section.
        .BINARY : {}
}
```

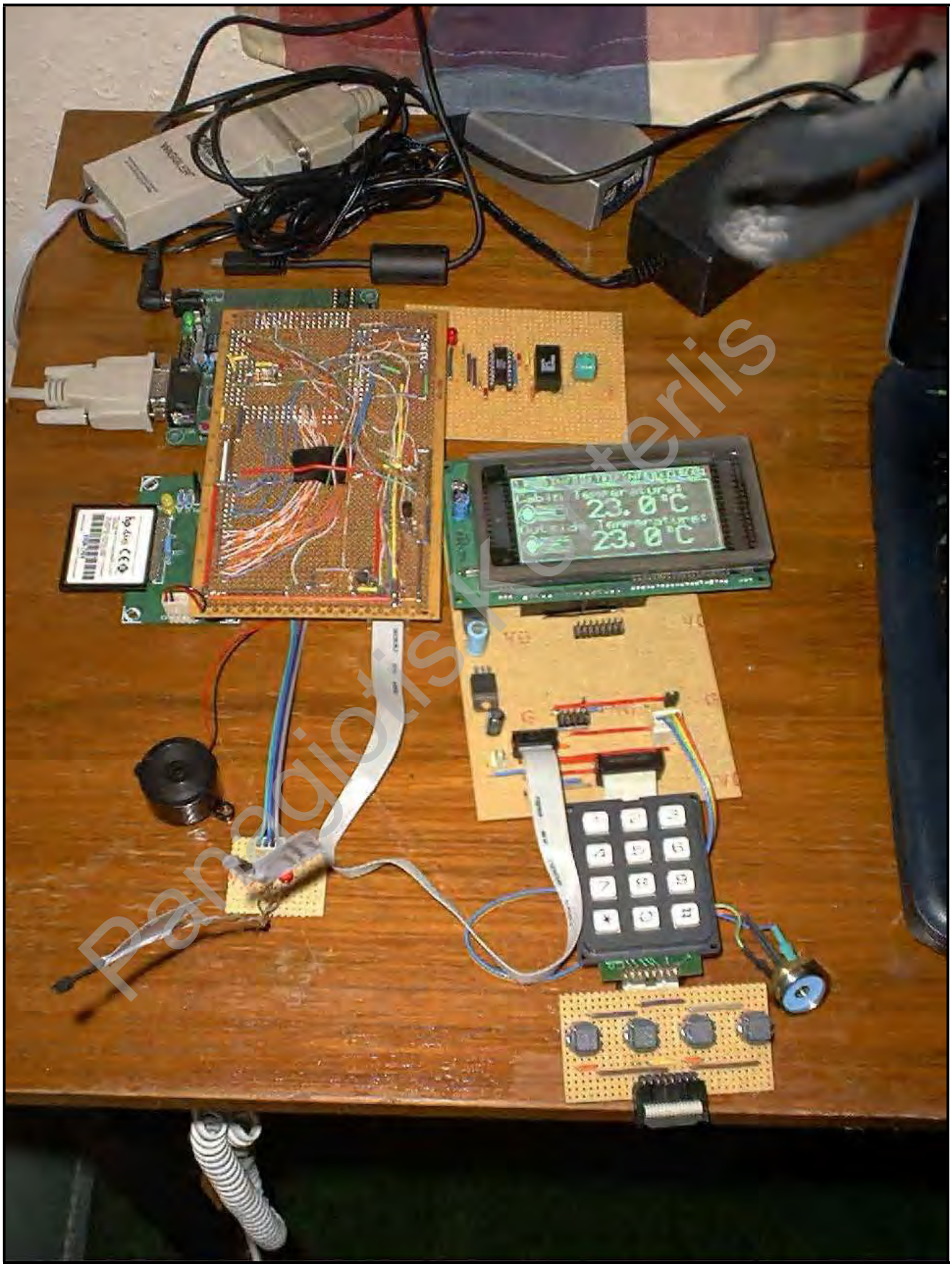
Appendix 2 Contents of 555_AXIOM_flash_init.cfg File

```
writereg MSR 0x00003002 ; MSR
writespr 27 0x3002 ; SRR1
writespr 560 0x0000 ; BBCMCR
writemem.l 0x002fc384 0x55ccaa33 ; PLPRCRK: open key

;Problem on CME-555 board: SIUMCR set the IRQ0 (NMI) to a SPGOC0
writemem.l      0x002FC000   0x00000000

;(disable) watch dog / SYPCR=0xFF88
;writemem.l     0x002FC004   0xFFFFFF88
writemem.l      0x002FC004   0x0000FF88

;Enable internal flash (CMF A at 0x0-0x3FFFF, CMF B at 0x40000-0x6FFFF)
writereg        IMMR         0xFFF00800   ;set FLEN bit in IMMR register (overwrites RCW
register, FLEN flag)
writemem.l      0x002FC800   0x85000000   ;CMFMCR A
writemem.l      0x002FC808   0x00000022   ;CMFCTL A
writemem.l      0x002FC840   0x85000000   ;CMFMCR B
writemem.l      0x002FC848   0x00000022   ;CMFCTL B

;CS0: Disabled
writemem.l      0x002FC100   0x00A00002   ;BR0:
writemem.l      0x002FC104   0xFFF80012   ;OR0:

;CS1: Disabled
writemem.l      0x002FC108   0x00C00002 ;;
writemem.l      0x002FC10C   0xFFF80012 ;;

;CS2: Disabled
writemem.l      0x002FC110   0x00C00002
writemem.l      0x002FC114   0xFFF80012
```

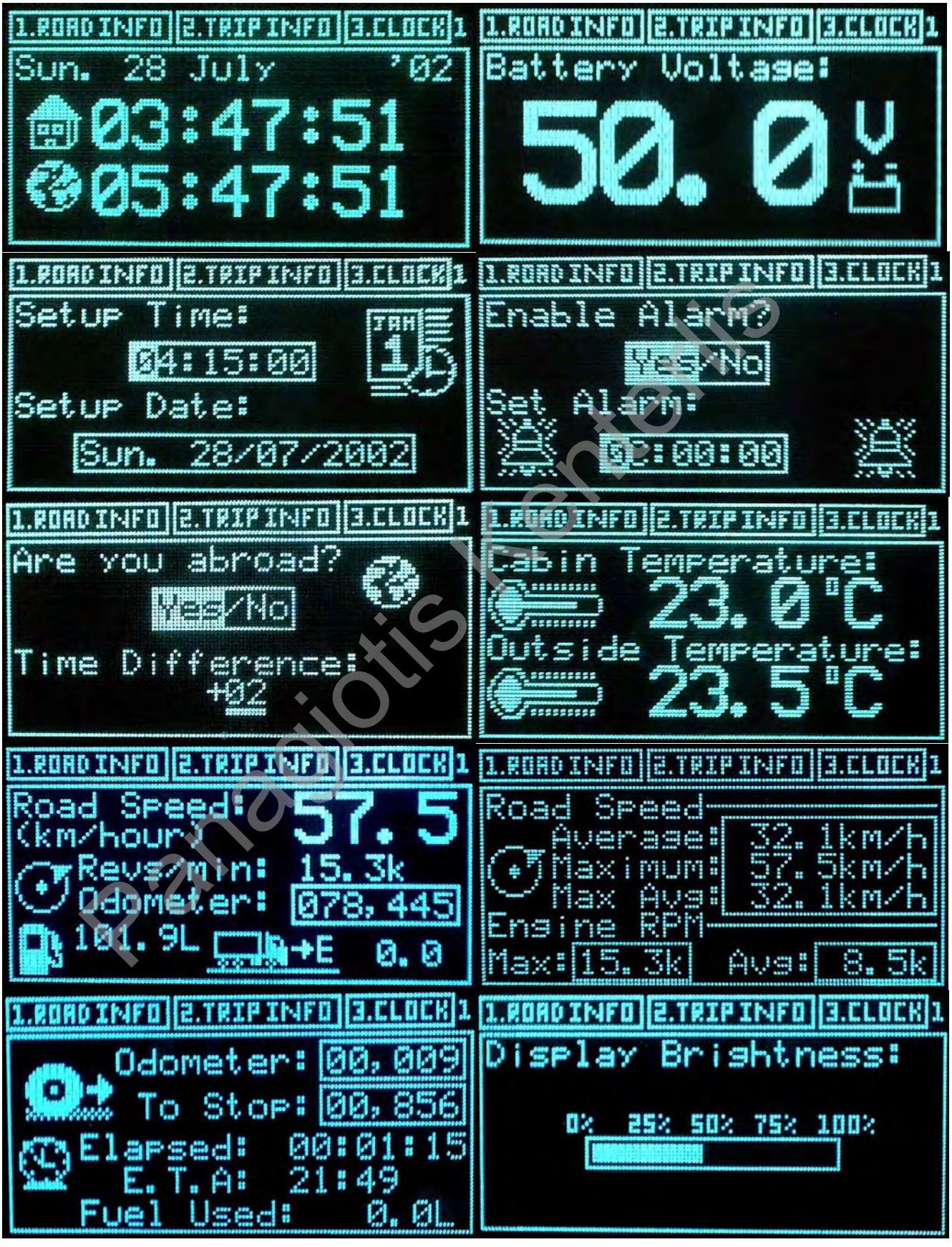
```
;CS3: Disabled
writemem.l      0x002FC118   0x00D00002
writemem.l      0x002FC11C  0xFFF80012


;set PLPRCR to have 40 MHz (required by GMD driver for flashing)
writemem.l      0x002FC284   0x00900000


writemem.l 0x002fc140 0x00000000 ; DMBR ;Dual Mapping off
writemem.l 0x002fc144 0x00000000 ; DMOR
writemem.w 0x00300000 0x0000 ; DPTMCR
writemem.w 0x00300004 0xffa0 ; RAMBAR
writemem.w 0x00305014 0x0000 ; PORTQS
writemem.w 0x00305016 0x0000 ; PQSPAR/DDRQS
writemem.w 0x00306100 0x0000 ; MPIOSMDR
writemem.w 0x00306102 0x0000 ; MPIOSMDDR
writemem.w 0x00306800 0x0000 ; MIOS1TPCR
writemem.l 0x00380000 0x00000000 ; SRAMMCR
writemem.l 0x002fc024 0x00000000 ; SGPIODT1
writemem.l 0x002fc028 0x00000000 ; SGPIODT2
writemem.l 0x002fc02c 0x00000000 ; SGPIOCR
writemem.l 0x002fc030 0x00000000 ; EMCR
writemem.l 0x00307f80 0x00000000 ; UMCR

#-----------------------------------------------------------------
# The debugger sets the DER register based on the EPPC Exceptions
# preference panel after running this initialization file, this
# this value will be overwritten.  We only put it in here because
# the flash programmer uses this file also.
#-----------------------------------------------------------------
writereg        DER             0x73e67c0f
```

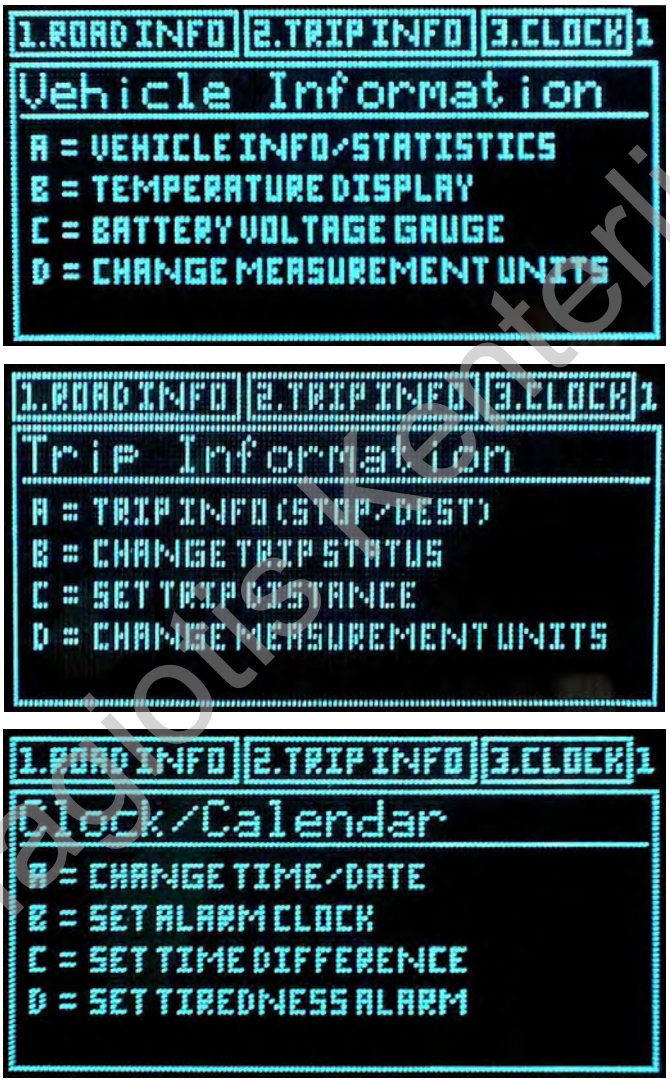
Appendix 3 Photo of Hardware during Development Period

Appendix 4 Photo of Developed Hardware



Appendix 5 GUI Screenshots





Appendix 6 Gantt chart

Appendix 7 Manuals and Documents not in Electronic Form