Flexible Digital Display Technologies Using Open Source Hardware and Software for Automotive Applications

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Dedicated To:

My Father: John Mc Donnell

And

My Mother: Lish Mc Donnell

Declaration

I hereby certify that the material presented in this document is entirely my own work and has not been submitted previously as an exercise or degree at this or any other establishment of higher education. I the author alone have undertaken the work except where otherwise stated.

Signed: ________________________

Date: ________________

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Abstract

With the advances in electronics, digital dashboards are now becoming available for use in the automotive industry. The main difference between an analog dashboard and a digital dashboard configuration is that the later may easily be reconfigured.

To accommodate the influx of digital graphical displays in vehicles, manufacturers have started to run micro Real Time Operating Systems (RTOS) inside their vehicles. Two options are offered to manufacturers when choosing a RTOS for their project; commercial OSs or open source OSs. Commercial OS contain many overheads which include an upfront capital investment and licensing fee for each unit produced. While open source OS are royalty free and offer no such financial overheads. Any application software that is written by the manufacturer for a commercial OS, is seen as proprietary software, and hence is not accessible by other manufacturers. Whilst any software written and licensed for use with an open source OS would be accessible, therefore leading to reduction in manufacturing costs and time.

The main objective of this research was to develop a flexible digital display using open source hardware and software for use in automotive applications. The development of a digital dashboard using these technologies can allow for individual customisation and in addition facilitate a significant reduction in the design cycle time. The designed display controller incorporated an Analog Devices Blackfin development board onto which an open source OS was ported. Automotive information was read from a CAN network and was used to manipulate the data displayed on the digital dashboard.

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List of Abbreviations

ACK	Acknowledge
ANSI	American National Standards Institute
ARGB	Alpha Red Green Blue
bkg	Background
bpp	Bits Per Pixel
BRP	Baud Rate Prescaler
CAN	Controller Area Network
CANH	CAN High
CANL	CAN Low
CPU	Central Processing Unit
DLC	Data Length Code
DPLL	Digital Phase Lock Loop
FIFO	First In First Out
FTP	File Transfer Protocol
GIF	Graphics Interchange Format
HDD	Hard Disk Drive
Hz	Hertz
IC	Integrated Circuit
IDT	Interrupt Descriptor Table
IDTR	Interrupt Descriptor Table Register
IP	Internet Protocol
IPC	Inter Process Communication
ISR	Interrupt Service Routines
JPEG	Joint Photographic Experts Group
LCD	Liquid Crystal Display
LSB	Least Significant Bit
MB	Mega Bytes
MBR	Master Boot Record
MMU	Memory Management Unit
mph	Miles Per Hour
MSB	Most Significant Bit
NBR	Nominal Bit Rate

NBT	Nominal Bit Time
NRZ	Non Return to Zero
NTQ	Number of Time Quanta
OS	Operating System
PC	Personal Computer
PNG	Portable Network Graphics
PNM	Portable aNy Map
PPRAM	Pseudo Physical RAM
PS1	Phase Segment 1
PS2	Phase Segment 2
RAM	Random Access Memory
ROM	Read Only Memory
RPM	RPM Package Manager
rpm	Revolutions Per Minute
RTF	Rich Text Format
RTOS	Real Time Operating System
RTR	Remote Transmission Request
SCLK	System Clock
SDL	Simple Directmedia Layer
SJW	Synchronised Jump Width
SOF	Start-of-Frame
SPI	Serial Peripheral Interface
TCP	Transmission Control Protocol
TFT	Thin Film Transistor
TIFF	Tagged Image File Format
TQ	Time Quanta
TTF	True Type Font
UART	Universal Asynchronous Receiver/Transmitter
UDP	User Datagram Protocol
VESA	Video Electronics Standards Association
VM	Virtual Memory
XPM	X PixMap

1 Introduction

1.1 Introduction

In the automotive industry an analog/mechanical dashboard display is still the standard. This type of dashboard contains basic dials which usually include a speedometer, tachometer, temperature gauge, fuel gauge and warning lamps which may include low oil level, low fuel level, Engine Management, ABS etc. One of the limitations with this type of dash display is that the positioning of all instrumentation is fixed and cannot be reconfigured [1].

With the advances in electronics, digital dashboards are now becoming available for use in the automotive industry. The main difference between analog and digital dashboards is that the digital dashboard may easily be reconfigured. With a digital dashboard, information can be displayed either numerically or via a digital representation of an analog/mechanical dial. Hence, any dial can be removed if it is required to display a warning signal to the driver [2]. An example of this is the Night Vision Assist system used in the Mercedes S-Class. This system uses an infrared beam which goes beyond the reach of the head lights along with a special camera mounted in the rear view mirror which reads the infrared signals. The resulting image is displayed on the dashboard instead of the normal speedometer, which is reconfigured to be a bar graph at the bottom of the digital dashboard. This system is said to increase visibility by 125% while driving at night [3].

The Night View Assist system developed by Mercedes is just one example of the flexibility a digital dashboard has to offer. It could be used to display any information on the screen in real time. In a high-end sports car this type of dashboard could be used to display engine analysis and performance while in a family car it could display more safety-orientated information.

To accommodate the influx of digital graphical displays in vehicles, manufacturers began to utilise micro Real Time Operating Systems (RTOS) on the controlling microprocessor system. The microprocessors derive the vehicles data by linking to the CAN network.

Currently there are two options for manufacturers when choosing an RTOS for their project; a commercial OS or an open source OS. Commercial OSs contain many overheads which include an upfront capital investment and licensing fee for each unit produced [4]. While open source OSs are royalty free and offer reduced financial overheads.

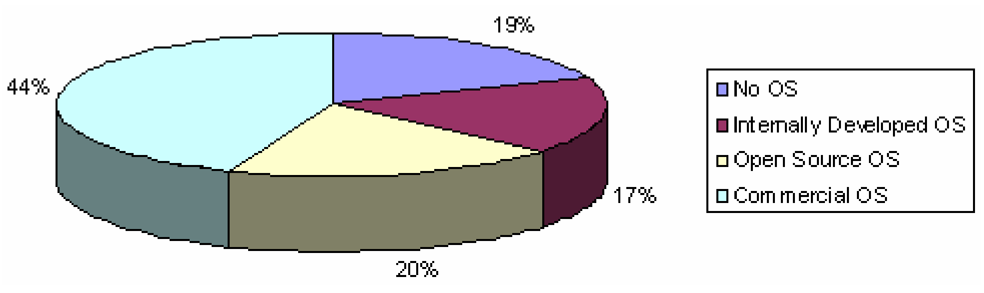


Fig. 1.1 Currently used OSs

In a recent survey undertaken by the website embedded.com, major global manufacturers were questioned on their use of RTOS in their embedded environments. The current trend is shown in Fig. 1.1. When questioned on future projects their responses were much different as can be seen in Fig. 1.2.

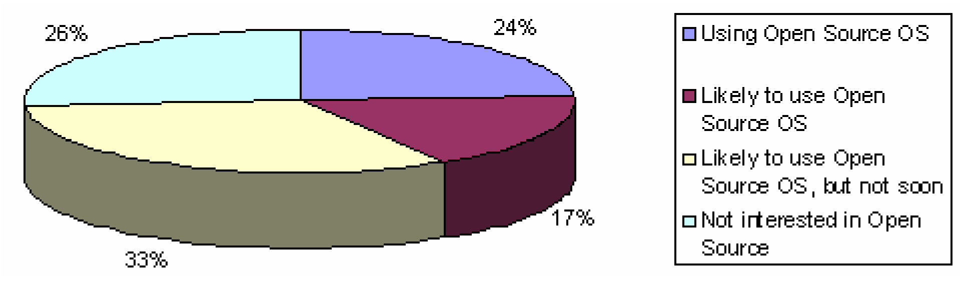


Fig. 1.2 Planned Future use of OS

Using the data in Fig. 1.1 and Fig. 1.2, it can be seen that the projected use of open source OSs will rise from 20% to 41%, with the potential to rise as high as 74%. The main reason cited for the move to open source is costs (savings) associated with it [5].

This research investigates the development of a flexible digital display using open source hardware and software for use in automotive applications. The development of a digital-dashboard using these technologies can allow for individual customisation and in addition facilitate a significant reduction in the design cycle time and costs.

1.2 Thesis Contributions

The material and information presented in this thesis has been compiled on the basis of:

(i) A comprehensive technical literature review of the current innovations in dashboard technology.

(ii) Design, configuration and implementation of a proposed digital display system using open source hardware and software.

(iii) Testing and conclusions.

The work presented in this thesis is laid out as follows:

Chapter 2 gives an overview of the most relevant information from all technical literature reviewed during the research stage of this study. This chapter also outlines the possible choices available during the design of the proposed system.

Chapter 3 provides an overview of the choices made and methods used to configure and design the proposed system. It also gives a complete explanation of the operation of the system with emphasis on the OS and application software.

Chapter 4 discusses how the final system was implemented and fully tested. This includes the development of a CAN process, video process and Inter Process Communications. The testing of the final system is also described in this chapter.

Chapter 5 outlines the conclusions made based on the research and testing. A discussion on further possibilities for research based on findings from this study is also provided.

2 Technical Literature Review

2.1 Introduction

The purpose of this chapter is to give an overview of the most relevant information from all technical literature reviewed during the research stage of this study. This chapter will also outline the possible choices available during the design of the proposed system. The information based on the literature review presented in this chapter is laid out as follows:

- Section 2.2 outlines the choices available when selecting a processor for this project. This section covers the pros and cons of the processors under selected headings. It also includes the selection process and the reasons for use of a particular processor.
- Section 2.3 provides the background information on the development host environment chosen for use in this project.
- Section 2.4 gives an overview of the operating system (OS) chosen for the process used in this project. It also details the bootloader that was used in conjunction with the OS.
- Section 2.6 discusses the possible options for Inter Process Communications and outlines each option and offers insight on the selection process.
- Section 2.7 gives an overview of the Controller Area Network protocol required for communication between the selected processor and external electronic control modules.
- Section 2.8 concludes the chapter with a brief summary.

2.2 Selection of a Processor

When selecting a processor for an automotive display application, key factors have to be taken into consideration. In an automotive environment the selected processor will have to endure very harsh conditions. The processor is required to perform at an optimal level to deal with the high computational needs of a graphical display along with the data transmission from the CAN network. It must also accommodate an appropriate operating system. The key considerations taken into account when selecting the processor are listed below:

- Automotive Conditions Compatibility
- Controller Area Network (CAN) support
- Graphical Display support
- Clock capabilities
- Memory

As the project was designed to use open source hardware and software, all of the scrutinised processors fully supported the use of an open source operating system. The development boards below contain suitable processors for the completion of this project and were evaluated using the key considerations above to determine the most suitable.

- Cogent CSB337 [6], [16], [17]
- Analog Devices ADSP-BF548 EZ Kit [7], [8]
- Atmel AT91SAM9263 [9], [10], [11]
- Cirrus EDB9315 [12], [13]

2.2.1 Automotive Conditions Specifications

Many conditions inside the automotive environment act as a hindrance to electronic components, one of which is the working temperature range [14]. Each board's temperature range was evaluated to ensure their durability in such an environment. The temperature range for Integrated Circuits (IC's) in the automotive setting is -40°C to 125°C [14]. Each board's specified temperature range was compared to the typical temperature found in an automotive environment to evaluate their use, as shown in Table 2.1.

Processor	Temperature Range (°C)
Cogent CSB337	0 to 70
Analog Devices ADSP-BF548	- 40 to + 85
Atmel AT91SAM9263	- 40 to + 85
Cirrus EDB9315	- 40 to + 85

Table 2.1 Ambient Operating Temperatures of Selected Processors

All of the boards' ambient operating temperatures are in the typical temperature range for an automotive setting, except for the Cogent CSB337. The Cogent CSB337 ambient operating temperature range is far less than the other three processors.

2.2.2 CAN Support

The CAN protocol is an automotive standard for vehicle communications, therefore, it was desirable to have an integrated CAN controller on the chosen development board. However if this was not possible, an SPI bus on the development board could be implemented for CAN communications [15]. This would lead to extra costs in designing and implementing a peripheral CAN controller, as well as having to implement a driver for the SPI CAN.

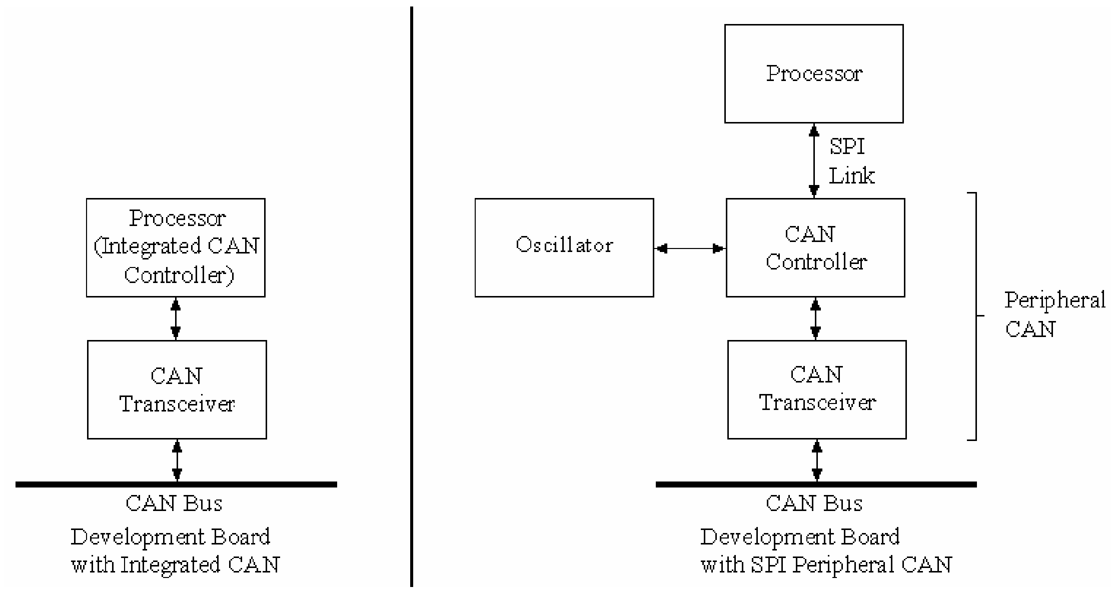

Processor (Integrated CAN Controller)
CAN Transceiver
CAN Bus
Development Board with Integrated CAN
Processor
SPI Link
Oscillator
CAN Controller
CAN Transceiver
Peripheral CAN
CAN Bus
Development Board with SPI Peripheral CAN

Fig. 2.1 Integrated Vs Peripheral CAN

As illustrated in Fig. 2.1, the use of peripheral CAN leads to an increase of components required. Also with a development board which supports an open source OS and has integrated CAN, it will be likely that the drivers for the integrated CAN will be contained in the kernel. When using the SPI port there will be no need for SPI-CAN drivers. The table below shows the CAN capabilities of the development boards under evaluation.

Processor	**Integrated CAN**	**Total Number of Rx/Tx Buffers**
Cogent CSB337	Yes	2Rx 2TX
Analog Devices ADSP-BF548	Yes	8 Rx 8 Tx 16 Configurable
Atmel AT91SAM9263	Yes	16 Configurable
Cirrus EDB9315	No	N/A

Table 2.2 CAN Capabilities of Selected Development Boards

With reference to Table 2.2, it can be seen that three of the four boards contain integrated CAN ports. The Cirrus EDB9315 does not contain an integrated CAN port but it does however have an SPI port, therefore CAN communications could still be a possibility. Comparing the three evaluation boards that do contain integrated CAN, it can be seen that the ADSP-BF548 (BF548) contains more CAN buffers than its rivals and hence makes its CAN handling abilities more powerful than the others.

2.2.3 Graphical Display Support

As this project was designed to display automotive data, it was essential that the chosen development board had the capabilities to support a graphical display. Also as it was designed to replace the standard dash configuration in a vehicle, the graphical display had to be quite powerful and needed to be able to accommodate in-depth images. An LCD screen was essential and as with CAN, an integrated screen was ideal as the appropriate drivers would probably be contained in the kernel.

Processor	**LCD Controller**	**Integrated LCD Screen**	**Resolution (bpp)**
Cogent CSB337	Yes	No	8
Analog Devices ADSP-BF548	Yes	Yes	24
Atmel AT91SAM9263	Yes	Yes	16 (without limitation)
Cirrus EDB9315	Yes	Yes	24

Table 2.3 Graphical Display Support of Selected Development Boards

As illustrated in Table 2.3, all of the boards under evaluation do have an integrated LCD controller, however the Cogent CSB337 does not have an integrated LCD screen. If the CSB337 was to be used, an external LCD screen would have to be included, therefore increasing the cost of the project. Comparing the other three development boards, it can be seen that the Atmel AT91SAM9263 supports 16bpp (bits per pixel) without limitations, it can supports 24bpp but this is at the cost of losing the Ethernet port. This leaves the BF548 and EDB9315 on par in their capabilities of display graphics.

2.2.4 Clock Capabilities

As this project will have an OS running on the development board's core along with application programmes running on top of the OS, it is desirable to have a processor with a relatively high clock frequency. As the OS used in the project is a Real Time OS (RTOS) and all application programmes will be run in real time, it is beneficial to have a high clock frequency. As in all cases, there are some tradeoffs in power consumption when using high frequency clocks, but a high bandwidth real time system is more important than power consumption for this application.

Processor	Max. CPU Clock Frequency (MHz)
Cogent CSB337	180
Analog Devices ADSP-BF548	533
Atmel AT91SAM9263	200
Cirrus EDB9315	200

Table 2.4 CPU Frequency of Selected Development Boards

Table 2.4 shows that the BF548 has considerably the highest clocking frequency of all the processors. The AT91SAM9263 and EDB9315 have the same processor clock frequency, with the CSB337 clock frequency being slightly lower. As speed is essential for the project, the BF548's processor is the most desirable of the four boards.

2.2.5 Memory

As an OS is required, it is vital that the development board has a sizeable amount of memory. This memory is needed due to the fact that a boot loader, OS, application code and a number of images will all be stored on the development board.

Processor	SDRAM (MB)	Flash (MB)	Memory Card Support	Hard Drive
Cogent CSB337	32	8	No	No
Analog Devices ADSP-BF548	64	32	Yes	Yes (40GB)
Atmel AT91SAM9263	64	256	Yes	No (does have HDD Port)
Cirrus EDB9315	64	32	No	No

Table 2.5 Available Memory of Selected Development Boards

As shown in Table 2.5, the Atmel AT91SAM9263 has a very large amount of flash memory when comparing it to any of the other development boards. It also supports a memory card (i.e. it has an SD memory card reader) and has a port to add a hard drive, however there is no HDD supplied. The BF548, while having less flash memory when comparing it to the AT91SAM9263, does however have a 40GB HDD supplied with its development board. The Cirrus EDB315 does have a substantial amount of integrated memory but does not offer any expansion on this, while the CDB337 has very little integrated memory. This leaves the BF548 and AT91SAM9263 equal, based on their size of memory.

2.2.6 Synopsis of Reviewed Processors

It was concluded from Table 2.6, that the Cogent CSB337 would not suffice for this project, as it did not contain the desired functionality needed. The BF548, AT91SAM9263 and EDB9315 are all sufficiently equipped for use in this project; however the BF548 was the processor of choice.

Processor	**Auto. Spec.**	**CAN Handling Abilities**	**Graphical Display**	**Clock Capability**	**Memory**
Cogent CSB337	Poor	Sufficient	Poor	Poor	Poor
Analog Devices ADSP-BF548	Sufficient	Excellent	Excellent	Excellent	Excellent
Atmel AT91SAM 9263	Sufficient	Sufficient	Sufficient	Poor/ Sufficient	Excellent
Cirrus EDB9315	Sufficient	Poor	Excellent	Poor/ Sufficient	Sufficient

Table 2.6 Synopsis of Reviewed Processors

This was due to the EDB9315 needing peripheral CAN to be added to the board and also its lower clock speed when comparing it to the BF548. Likewise, the AT91SAM9263 had lower clocking capabilities and graphical display resolution when compared to the BF548. As the BF548 had outstanding CAN handling abilities, along with very high screen resolution, a 533MHz processor and large amount of memory, including a 40GB hard drive, it was the obvious choice for use in this project. The next section will discuss the development host, which will be used to develop and compile the software to run on the BF548 processor.

2.3 Development Host

As the BF548 was selected as the processor of choice, it was recommended by Blackfin to use Cooperative Linux (coLinux) as the development host. Apart from coLinux, many other Linux operating systems could have been used, including Red Hat, Ubuntu, etc [18]. Along with the recommendation from the processor's manufacturer, it offered many other merits for its use as explained in the following sections.

2.3.1 coLinux

Cooperative Linux (coLinux) is the first open source method used for optimally running a Linux kernel natively alongside another OS, including Microsoft Windows, as shown in Fig. 2.2. CoLinux is a port of the Linux kernel which can freely run without the use of any virtualisation software, in a way which is much more optimal than using any virtualisation software [19].

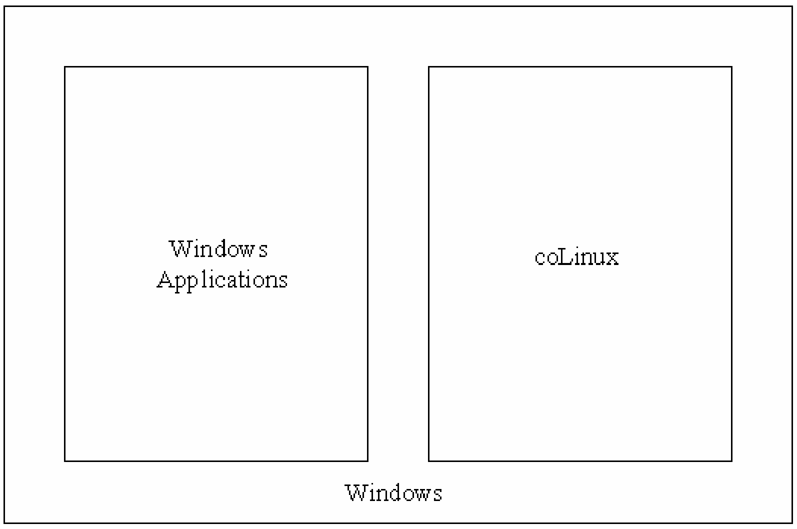


Fig. 2.2 coLinux running natively on Windows OS

Special driver software is used so that the coLinux kernel runs in a privileged mode on the host OS. Due to its operation in privileged mode, and by constantly switching between the host OS state and the coLinux kernel state, full control of the machine Memory Management Unit (MMU) is granted to coLinux in its own allocated address space. Therefore, coLinux acts in accordance to a native Linux kernel, while achieving almost the same performance and functionality that would be expected from a standalone Linux machine [18], [19].

2.3.1.1 Pseudo Physical RAM

As coLinux runs alongside Microsoft Windows, it does not work on the principle of the entire physical RAM being bestowed upon it during boot up, as is the case when Microsoft Windows boots. Instead coLinux is allocated a fixed set of physical pages and the translations needed to operate transparently in that set. This leads to coLinux considering the allocated pages to be the entire physical memory and this is known as Pseudo Physical RAM (PPRAM).

The PPRAM is allocated to coLinux using the standard function calls in each OS such that it is not mapped in any address space on the host. These allocated pages will always be resident and will only be freed once coLinux is closed. To map the allocated pages in coLinux virtual address space, page tables are used, therefore its address space resembles that of a regular kernel. The coLinux address space also has its own special fixmaps, such that the page tables themselves are mapped in order to provide the ability to translate from PPRAM addresses to physical addresses. Likewise, a special physical-to-PPRAM map is allocated and mapped to decrease the time needed for handling events which require physical addresses to be translated into PPRAM addresses. Due to bi-directional memory address mapping, negligible overhead is achieved in page faults and user space mapping operations [20], [18], [19].

2.3.1.2 Context Switching

When coLinux is running on a host OS, it only uses one of the host processes to provide a context for itself and its process. This one process, which is named as the coLinux-daemon, is known as a Super Process as it frequently calls the kernel driver to perform a context switch from the host OS to the coLinux kernel and back. This capability allows complete control of the CPU and MMU of the machine without affecting the host OS.

For the Intel 386 architecture a complete context switch requires the top directory table pointer register (CR3) to be changed. However, both the instruction pointer (EIP) and CR3 cannot easily be changed in the one instruction. Therefore, CR3 has to be mapped in both contexts for the change to be possible. Design limitations make it problematic to map the code at the same virtual address in both contexts. However both contexts can divide the kernel and the user space differently, such that one virtual address can contain a user mapped page in one OS and a kernel mapped page in the other. When context switching coLinux uses an intermediate address space, known as the “passage page” as shown in Fig. 2.3.

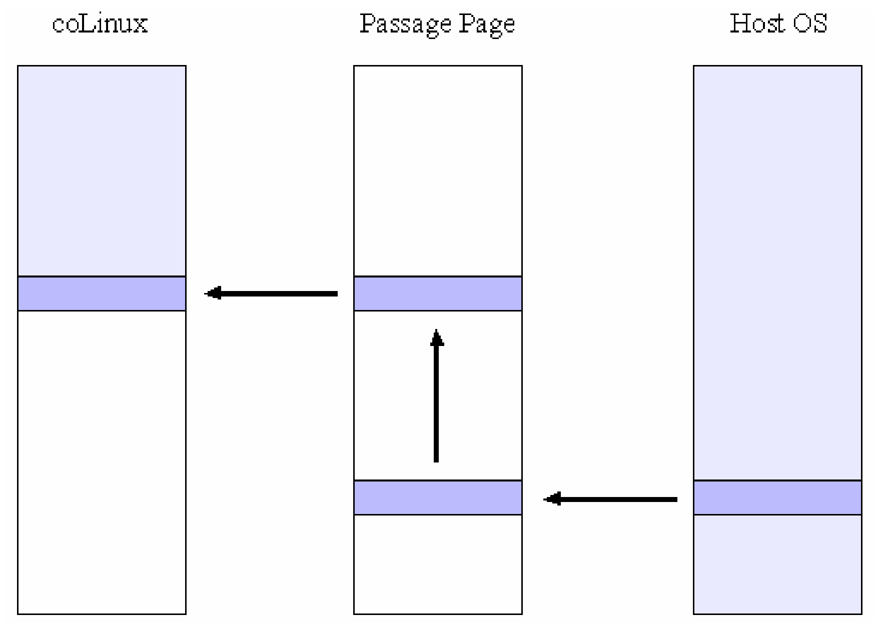


Fig. 2.3 Address Space Transition used in Context Switching

The "passage page" is defined by specially created page tables in both coLinux and the development host contexts. It maps the same code that is used for the switch at both of the virtual addresses that are involved. When a switch occurs, first CR3 is changed to point at the "passage page". EIP is then relocated to the other mapping of the passage code using a jump. Finally CR3 is changed to point to the top page directory of coLinux [20], [19].

2.3.1.3 Interrupt Handling

As a complete MMU context switch involves the Interrupt Descriptor Table Register (IDTR), coLinux sets an interrupt vector table to handle any hardware interrupts that occur while the system is in a running state. CoLinux will not act on these interrupts, but instead it will only forward the interrupts invocations to the host OS, with the host OS having to act on any interrupts for proper functionality. This enables the support of the coLinux-daemon itself.

The interrupt vectors for the internal processor exceptions and system call vectors are not edited such that coLinux handles its own page faults and other exceptions. However, the other interrupt vectors point to a special proxy Interrupt Service Routines (ISRs). If an ISR is invoked during coLinux time on the processor by an external hardware interrupt, a context switch is made to the host OS. On the host side, the address of the relevant ISR is determined by looking at its Interrupt Descriptor Table (IDT). With this an interrupt call stack is forged and a jump occurs to the address. The interrupt flag is disabled during the invocation of the ISR in coLinux and the handling of the interrupt on the host OS. The interrupt handling operation adds a minute latency in the interrupt handling of the host OS, but this is so small it can be neglected [20], [19].

2.3.1.4 Advantages of using coLinux

The main advantage of using coLinux, with regards to this project, is that it can run on Microsoft Windows, therefore only one machine is needed to run Microsoft Windows and a Linux development suite. This substantially reduces development costs by the use of only one PC as well as coLinux being open source [19]. As coLinux is the same as using a Linux box, all the toolchains needed for this project can be installed and implemented within coLinux with all application software being written and compiled in the same environment [18].

2.3.1.5 Disadvantages of using coLinux

As coLinux runs in tandem with Microsoft Windows this can also be one of its main disadvantages, due to the hardware abstraction layer being shared between both OSs. This abstraction layer does not have any hardware memory protection, as is the same between Microsoft Windows and coLinux and their device drivers. If coLinux violates Microsoft Windows address space, this will cause coLinux to crash along with Microsoft Windows and hence crash the machine [18].

There are also some security implications when using coLinux. If a malicious user gains root access to coLinux, then this user could potentially compromise the security of the Microsoft Windows machine. CoLinux is password protected so there is a degree of protection to combat this problem [18], [19].

To load or use coLinux, the user must have administrator rights to the host OS. However, coLinux can be started as a service, and so it is possible to start coLinux as a normal user, if the user has being granted the right to start the service [18], [19]. The next section will describe the OS and boot loader used in this project.

2.4 uClinux

uClinux (Micro (µ) Controller Linux) is an embedded port of the Linux Operating System. It was developed by Kenneth Albanowski and D. Jeff Dionne in January of 1998 and was first demonstrated on a Palm PDA. In February 1999, it was ported to its first microprocessors, the Motorola MCF5206 and MCF5307 ColdFire. Since then it has been ported to an array of microprocessors including Analog Devices Blackfin processors. As with all ports of Linux, uClinux is free software and licensed under the GNU Public License [21].

2.4.1 Differences between uClinux and Linux

As stated above, uClinux is a micro OS, which was ported from the Linux OS, and runs on microprocessors. As this operating system is designed for embedded systems, with small amounts of memory, therefore a lot of functionality had to be taken from the Linux OS. The main differences between both OSs will now be described [22].

2.4.1.1 No Memory Management Unit

The main difference between Linux and uClinux OSs is the absence of a memory management unit (MMU) in the latter. In Linux, memory management is achieved through the use of Virtual Memory (VM). However, uClinux was created for systems which do not support VM, and hence they can not implement memory management.

With VM, all processes run at the same address, albeit a virtual one, with the VM system being responsible for the physical memory that is mapped to these locations. The VM process sees its memory to be contiguous, despite the physical memory it occupies usually being scattered. Using VM, arbitrarily located memory can be mapped to anywhere in the processes address space, making it possible to add memory to an already running process. Without VM, each process has to be located at a place in memory where it can run, with this area of memory being contiguous. Generally, this memory can not be expanded as there may be other processes above and below it. Therefore, processes in uClinux cannot increase the size of its available memory during runtime [22], [23], [24].

2.4.1.2 Kernel Differences

As uClinux does not support VM, all standard executable formats used in Linux are unsupported; instead, a new format is used, the flat format. The flat format is a condensed executable format that stores only executable code and data, along with the relocations needed to load the executable into any location in memory.

The implementation of mmap, which is a function used when mapping between a process address space and a file, shared memory object or typed memory object, is also quite different. Though often transparent to the user, an understanding is needed to ensure it is not used inefficiently on an uClinux system. Unless the uClinux mmap can point directly to the file within the filesystem, thereby guaranteeing that it is sequential and contiguous, it must allocate memory and copy the data into the allocated memory. In uClinux only one filesystem, romfs, guarantees that files are stored contiguously, therefore this file system must be used. Only read-only mappings can be shared, which means a mapping must be read only to avoid the allocation of memory. The kernel must also consider the filesystem to be in ROM, i.e. nominally read-only area within the CPU’s address space. This is possible if the filesystem is present somewhere in RAM or ROM, however not if the filesystem is on a hard disk, as the contents are not directly addressable by the CPU. Device drivers also need to be edited when porting to uClinux, depending on the hardware the driver is used for [21], [22], [18], [25].

2.4.1.3 Memory Allocation (Kernel)

uClinux offers a choice of two kernel memory allocators, the standard Linux allocator and kmalloc2 (or page_alloc2 depending on the kernel version). The standard linux allocator is not desirable for applications running on uClinux as its uses a power-of-two allocation method. This method allocates memory to the next power of two, e.g. if a process required 33kB of memory, then it will be allocated 64kB of memory ($2^6 = 64$) as this is the next step up from 32 ($2^5 = 32$). Therefore, 31kB of memory is not used, hence leading to fragmented memory, as shown in Fig. 2.4.

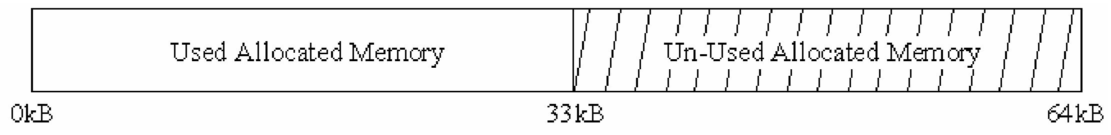


Fig. 2.4 Memory Allocation using Power-Of-Two Method

Using this allocation method on a PC is sufficient as memory is usually not a major factor, but as uClinux is used in embedded applications, this amount of memory wastage is unacceptable. For this reason, the memory allocator kmalloc2 was developed for uClinux.

In kmalloc2, the power-of-two memory allocation is used for allocations up to one page in size, where a page is 4kB. It then allocates memory to the nearest page. The previous example used 64kB, but with kmalloc2 only 36kB (9 pages) will be allocated, as shown in Fig. 2.5.

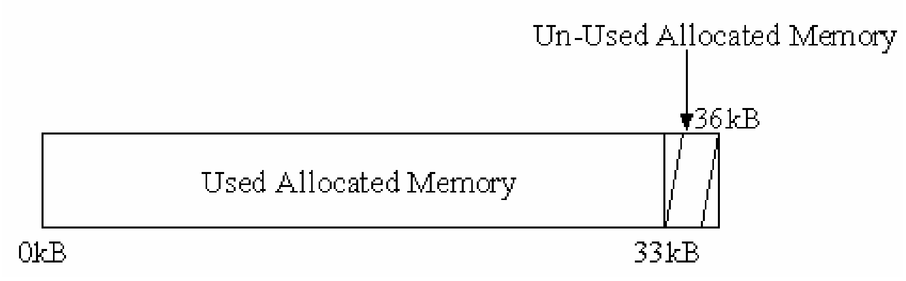


Fig. 2.5 Memory Allocation using Kmalloc2

Only 3kB of memory is now un-used when comparing it to the 33kB in the previous method. Kmalloc2 will also take steps to avoid fragmenting memory [21], [22], [18].

2.4.1.4 Memory Allocation (Application)

The major difference between both OSs in terms of application memory allocation is the lack of a dynamic stack in uClinux. The programmer must now be aware of stack requirements as the uClinux toolchains allocate 4kB, by default, for the stack, which is very small for modern applications. However, there are methods to increase the stack size.

Another substantial difference in uClinux is the lack of a dynamic heap, which allows an application to increase its process size. Dynamic heaps are traditionally implemented using sbrk/brk system calls, which increase/decrease the size of a process’s address space. Due to uClinux being unable to implement the functionality of brk and sbrk, it instead implements a global memory pool. When using a global memory pool, the programmer must be very cautious as a runaway process can use all of the system’s available memory. Its use offers some advantages, as only the amount of memory actually required is used, unlike in a pre allocated heap. This is extremely important for uClinux systems, as they generally run with little memory [21], [22], [18].

2.4.1.5 Applications and Processes

Another difference with uClinux is the lack of the fork() system call, uClinux does however offer the vfork() system call. The system calls fork() and vfork() allow a process to split into two processes, a parent and child. A process can split many times to create multiple children. When a process calls fork(), the child is a duplicate of the parent in every way, however it shares nothing with the parent and can operate independently, as can the parent. When using vfork(), the parent is suspended and cannot continue executing until the child exits or calls exec(), the system call used to start a new application. The child, directly after returning from vfork(), is running on the parent's stack and is using the parent's memory and data. This means the child can corrupt the data structures or the stack in the parent, resulting in failure [21], [22], [18].

2.4.2 Booting uClinux

As with every operating system, uClinux needs a bootloader to start the kernel from its location in memory. A boot loader is a small piece of software that executes on power up of a CPU. Linux uses software called lilo or grub, which resides on the master boot record (MBR) of the machines hard drive. After the PC BIOS performs various system initialisations, it will execute the boot loader in the MBR. The boot loader then passes system information to the kernel and then executes the kernel.

In an embedded system the role of a boot loader is more complicated as it does not contain a BIOS to perform initial system configuration. The low level initialisation of microprocessors, memory controllers, and other board specific hardware varies from board to board and CPU to CPU. These initialisations must be performed before a uClinux kernel image can be executed.

Depending on the application, the kernel may be stored in the processor's memory or the boot loader may have to download the kernel from a remote server. The boot loader which is used for booting uClinux on Blackfin processors is "Das U-Boot" [26], [27].

2.4.2.1 U-Boot

U-Boot is an open source, cross platform boot loader. It provides support for a large quantity of embedded development boards and a wide variety of CPUs including ARM, Coldfire, Blackfin, Microblaze and x86. U-Boot has its origins in the 8xxROM project, where it was called "PPCBoot". In 2002 the PPCBoot team retired the project which led directly to the creation of U-Boot.

U-Boot is a boot loader which is usually stored in the flash memory of an embedded system. It can load files from a variety peripherals including serial connections, Ethernet network connection, or flash memories. U-Boot can parse many types of filesystems on many different storage devices. It is executed upon power up or reset of a CPU and is used to load another application (in this case a uClinux kernel) [18], [26], [27]. The next section discusses the graphical libraries selected to create the final system display.

2.5 Graphics Libraries

There are two different graphical libraries supported by the BF548 uClinux kernel:

- DirectFB
- SDL

Both of these are open source libraries and can be used with C programming language to create graphical displays. The merits of both libraries will be explained in the following sections.

2.5.1 DirectFB

DirectFB (Direct FrameBuffer) is a thin layer library, which provides input device and handling abstraction, hardware graphics acceleration, integrated windowing system with support for translucent windows and multiple display layers on top of the Linux Framebuffer Device. DirectFB is a complete hardware abstraction layer with software fallbacks for any graphics operation that is not supported by the underlying hardware. It was designed for use in embedded systems and offers maximum hardware accelerated performance with minimum resource usage and overhead [28], [31], [33]. The DirectFB system diagram is shown in Fig. 2.6.

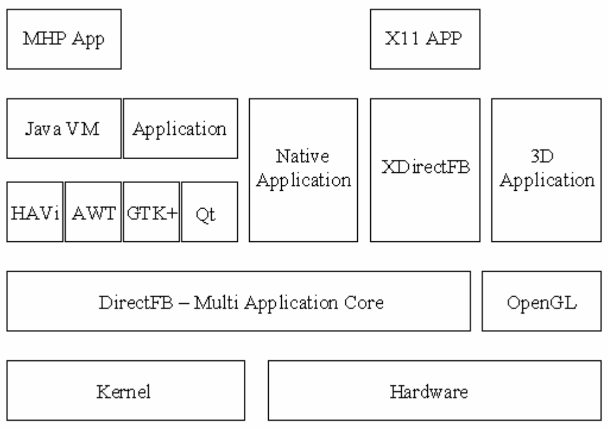


Fig. 2.6 DirectFB System Diagram

2.5.1.1 Access to Graphics Hardware by DirectFB

DirectFB relies on the existing kernel interface to access the graphics hardware and requires a working framebuffer to function. For some chipsets (including the BF548) there is a special framebuffer driver in the Linux kernel; however unsupported chipsets can use a VESA (Video Electronics Standards Association) framebuffer, although with some limitations. DirectFB uses the framebuffer device to perform the following tasks:

- Initialising the video mode
- Memory mapping of the development board’s framebuffer
- Changing the viewpoint of the framebuffer

If DirectFB supports the development board and the framebuffer driver for the chipset is present in the Linux kernel, it will use the framebuffer device in addition to the tasks mentioned above to perform the following tasks:

- Memory mapping of the development board's memory mapped I/O ports
- Disable the framebuffer driver's internal acceleration

To execute a specific graphics operation, the DirectFB chipset driver will access the memory mapped I/O ports of the graphics hardware to submit the command to the card's acceleration engine. The actual hardware acceleration is completed entirely in user space [29], [32], as shown in Fig. 2.7.

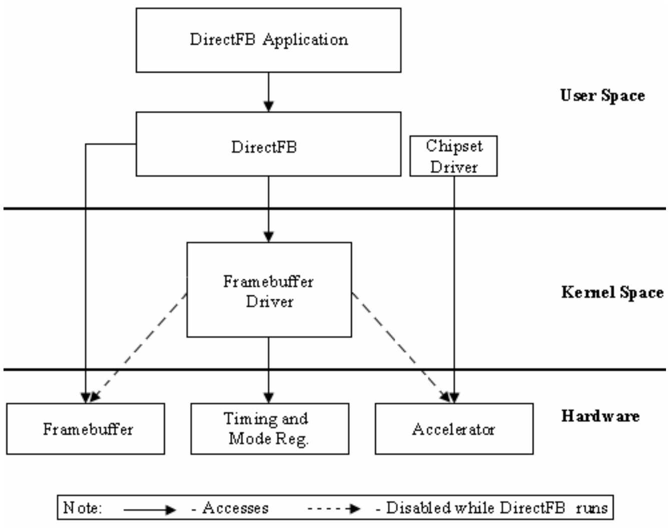


Fig. 2.7 DirectFB Access to the Framebuffer Device and the Graphics Hardware

2.5.1.2 DirectFB Features

DirectFB supports many different graphics operations, which can be done in hardware if supported by the chipset driver, or as a software fallback. The main features of DirectFB are as follows [30]:

- **Windowing System** - DirectFB has a fast windowing system which supports translucent windows. Windows using ARGB (Alpha Red Green Blue) Surfaces can be blended on a per pixel basis, with each window having its own global transparency.

- **Resource Management –** DirectFB has its own resource management for video memory, where display layers or input drivers can be locked for exclusive access. It provides abstraction for the different graphics targets.
- **Graphic Drivers** – DirectFB uses loadable driver modules for hardware acceleration. Many of the biggest driver card chipsets are supported including Matrox, ATI, NeoMagic, 3dfx and Intel. DirectFB will still run on unsupported chipsets, but there will be no acceleration support.
- **Input Drivers –** DirectFB supports many input devices including standard keyboards, serial and PS2 mice, joysticks, devices using the Linux input layer, touch screens and infra red controls. It is also possible to use an event buffer or query the hardware directly.
- **Image Loading** – DirectFB includes image providers, which allow for many image formats to be loaded directly into DirectFB surfaces. These image formats include JPEG, PNG and GIF among others.
- **Video Playback –** DirectFB also includes video providers, which allow for the rendering of many video formats. These video formats include mpeg1/2, AVI, Macromedia Flash, MOV and video4linux.
- **Font Rendering** – DirectFB supports anti-aliasing text drawings and includes font providers which allow for the loading of DirectFB bitmap fonts and TrueType fonts (TTF).

2.5.2 SDL

SDL (Simple Directmedia Layer) is a cross-platform multimedia library that has been used in commercial projects and video games. SDL works with a platform’s underlying multimedia capabilities to provide a consistent and open API across many OSs. It provides access to the computer’s multimedia capabilities where possible, and will attempt to compensate if the computer’s underlying support is missing in some areas. It is possible to use individual components of SDL separately, e.g. a game might use SDL for audio and another toolkit for graphics. The SDL library consists of several sub-APIs, which provide cross-platform support for video, audio, input handling, multithreading, OpenGL rendering contexts, and various other amenities [34], [35], [36]. The abstraction layers of Linux and Windows used in SDL are shown in Fig. 2.8.

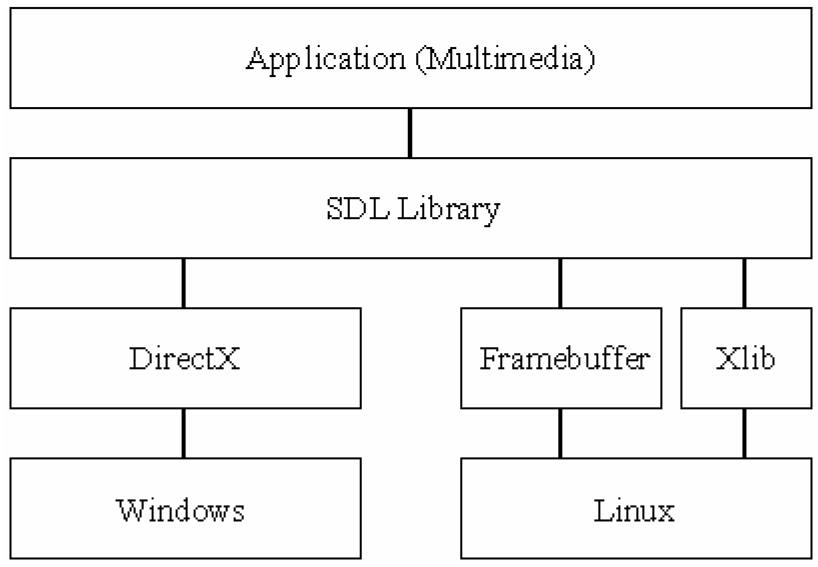


Fig. 2.8 Abstraction Layer of Windows and Linux SDL Platforms

2.5.2.1 SDL Libraries

SDL was deliberately designed to provide the bare bones of creating a graphical program. Therefore, the most basic library (SDL.h) does not contain all the desired functionality. Hence more libraries have been developed and these can be included in any project to add extra functionality [37], [38]. The main SDL libraries are:

- **SDL Image** – SDL Image (SDL_image.h) provides functionality such that many more image file types can be loaded, rather than the standard bitmap. The image files include PNM, XPM, GIF, JPEG, TIFF and PNG. It also adds support for alpha transparency.
- **SDL Mixer** – SDL Mixer (SDL_mixer.h) adds the functionality of a simple multi-channel audio mixer. It supports eight channels of sixteen bit stereo audio, plus a single channel of music. It can currently load Microsoft WAV files, Creative Labs VOC files and MP3 files.
- **SDL Net** – SDL Net (SDL_net.h) is a small networking library, with a sample chat client and server application. It offers a portable interface for TCP and UDP protocols.
- **SDL RTF** – SDL RTF (SDL_rtf.h) allows the display of simple Rich Text Format (RTF) files in SDL applications.

- **SDL TTF –** SDL TTF (SDL_ttf.h) is a True Type font rendering library. It offers powerful outline fonts and anti-aliasing such that high quality text can be obtained in applications.

2.5.2.2 SDL Features

Along with the libraries explained above, SDL also has built in functions that are used in the creation of graphical applications [38], [40]. These are as follows:

- **Event Based Inputs –** SDL provides inputs from the keyboard, mouse, joystick etc., using an event based model. As SDL is cross-platform, it has the same events for any OS.
- **Time and Timers** – SDL provides a reliable time and timer API that is both machine and OS independent. The SDL timer APIs allow for the creation of thousands of timers.
- **Threads –** SDL provides a thread API which acts as a simplified version of pthreads. These threads provide all the basic functionality desired from threads while masking the low level complicated details. These threads are supported on all OS that supports SDL and threads.
- **Graphics –** As well as the capability of working at a raw pixel level, SDL also supports OpenGL software which allows for hardware accelerated 2D and 3D graphics. SDL can also support the machines framebuffer.

Combining the aforementioned libraries with the features explained above can lead to very powerful graphical applications while using SDL. An example of an SDL application using these features and libraries is shown in Fig. 2.9.

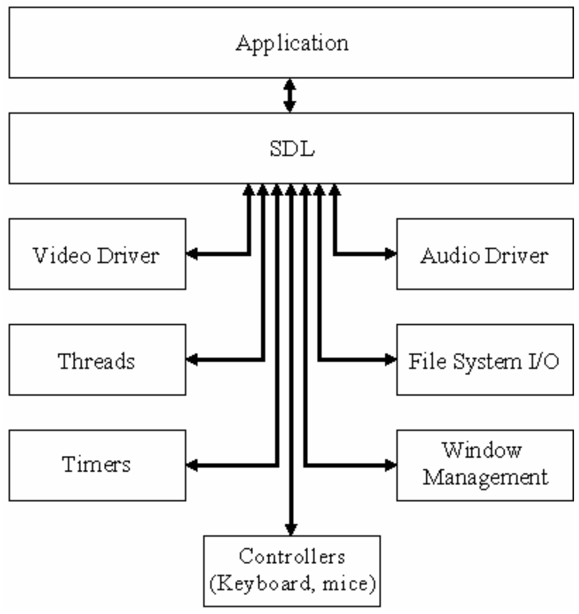


Fig. 2.9 SDL Application

2.5.3 Selecting the Graphical Library

As the display and manipulation of data in accordance with messages received from a CAN network was the priority and not the standard of graphics used, it was decided that the graphical display would only need to display 2D graphics. As 3D graphics would not be used, there would be no need for a hardware graphic accelerator.

As DirectFB uses a graphic accelerator and is mainly used in 3D applications, it was decided that this level of graphical display would exceed the requirements for the project [41]. SDL was chosen on the merits that it has been used in many commercial applications, as well as being natively written in C [34]. Also all of the required libraries were contained in the uClinux distribution that was selected as the OS for the BF548. If a graphic accelerator was needed later in the project, SDL supports OpenGL which could be used for this application, and SDL can also run on top of DirectFB [41]. For these reasons SDL was selected as the graphical library to be utilised. The next section will outline the options which can be implemented as the Inter Process Communications for this project.

2.6 Inter Process Communications

Inter Process Communications (IPC) are used in uClinux to transfer data between running processes on the kernel, as shown in Fig. 2.10. These IPCs also offer concurrency when transferring data such that no data is desecrated during data transfer. This is achieved by only allowing one process to use the IPC at a time, i.e. that one process will not try read data while another process is writing data [42].

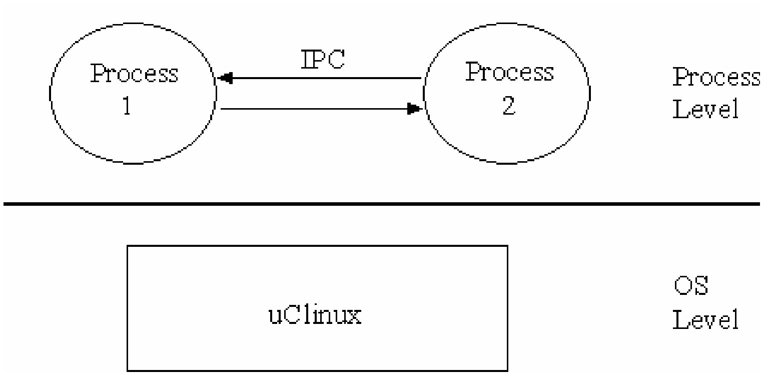


Fig. 2.10 IPC at process level

The four main IPCs used in Linux are [48], [53]:

- Semaphores
- Shared Memory
- Message Queues
- Named Pipes

2.6.1 Semaphores

Semaphores can be best described as counters used to control access to shared resources by multiple processes. Semaphores are used as a locking mechanism to prevent processes from accessing a shared resource at the same time, i.e. leading to concurrency.

A semaphore can be compared to a key to a locked room (shared resource), with a key keeper (uClinux) and many people who wish to gain access to the locked room (processes). As there is only one key (semaphore) for the room, once the key keeper has loaned the key to one of the people wishing to gain access to the room, every other person has to wait until the key has been returned to the key keeper. If many people want access to the key at the one time, the key keeper will give the key to the person with the highest priority, as shown in Fig. 2.11. Systems calls are used to create and manipulate semaphores; these are included in the standard Linux “System V IPC commands” [49].

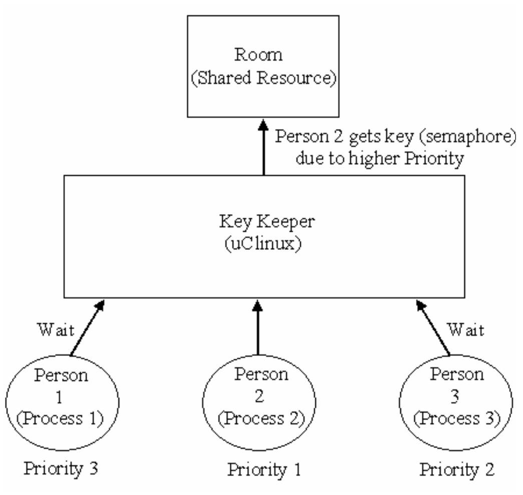


Fig. 2.11 Semaphore Metaphor

2.6.2 Shared Memory

Like semaphores, shared memory is another form of IPC provided by the “System V” release of Linux. Shared memory can be described as the mapping of a segment of memory that will be mapped and shared by more than one process. In shared memory, one process will create the segment, with any number of processes being able to read or write from it [50], as shown in Fig. 2.12.

Shared memory is the fastest method of IPC which could be used in the project, due to there being no intermediation. It can be employed to save on the amount of memory used by avoiding having two copies of shared pages in memory. If executable code is shared, then only one copy is needed in physical memory and those pages can be mapped into the address space of all other processes that are executing that code [43].

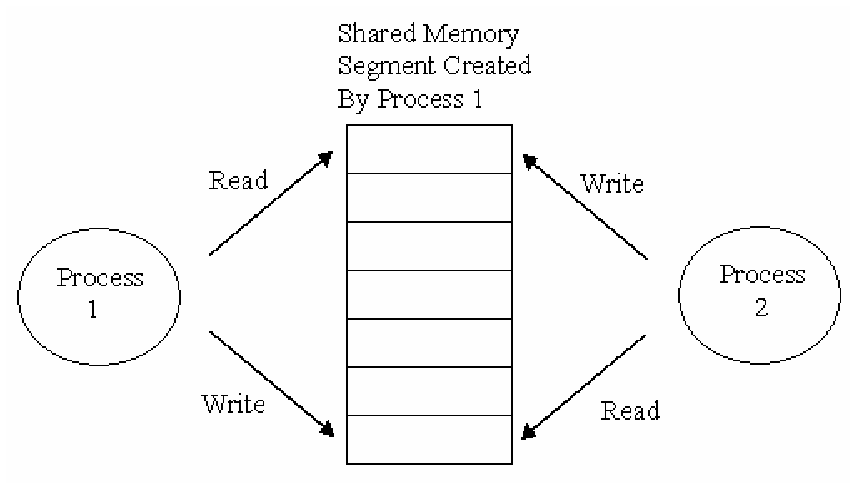


Fig. 2.12 Shared Memory

A major drawback when using shared memory is that it does not offer concurrency. To establish concurrency when using shared memory, a mechanism like semaphores would also have to be utilised in conjunction with it [54].

2.6.3 Message Queues

Message queues are best described as link lists within the kernel's address space. Messages are sent to a message queue by the sending process, and can then be received from the queue by one or many reading processes, in several different ways. Each message queue can be identified by its unique IPC identifier, which is assigned to the message queue upon creation [51].

Message queues offer the benefits of being able to buffer the sent messages until the receiver is ready to receive them, therefore a process can send a message and it will be saved until the receiver is ready for the message. As the messages are buffered, any process can read the sent messages from it as long as it knows the message queues IPC identifier [44]. A small message queue configuration is shown in Fig. 2.13.

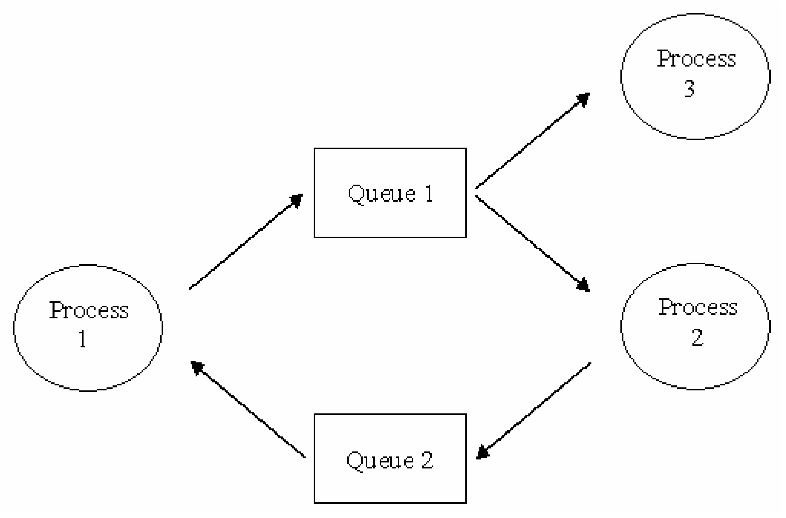


Fig. 2.13 Message Queue

As with semaphores and shared memory, message queues are also implemented using "System V IPC commands".

2.6.4 Named Pipes

A Named Pipe can be described as a FIFO (First In – First Out). A Named Pipe is an object which allows for communications between processes, i.e. it is like a file, which bytes of data can be written to and read from. When reading from a pipe, the receiving process receives the same data bytes that were written in and in the same order that they were written by the sending process [45], [57].

When using Named Pipes, the pipe can be set to two different operating modes; blocking and non-blocking. In blocking mode, the pipe will block after being opened for a read, it will only unblock when the pipe is opened for a write or vice versa. If a process writes data into the pipe, it will be blocked until another process reads that data, the pipe will now be blocked until the first process writes more information into the pipe. In non-blocking mode, the pipe can be continually written to without a read and vice versa. However, if a process is reading from the pipe the other process will not be let write to the pipe until the read is complete [52]. These operating modes are shown in Fig. 2.14. Unlike the previous three methods of IPCs, Named Pipes do not use the "System V IPC commands" [55].

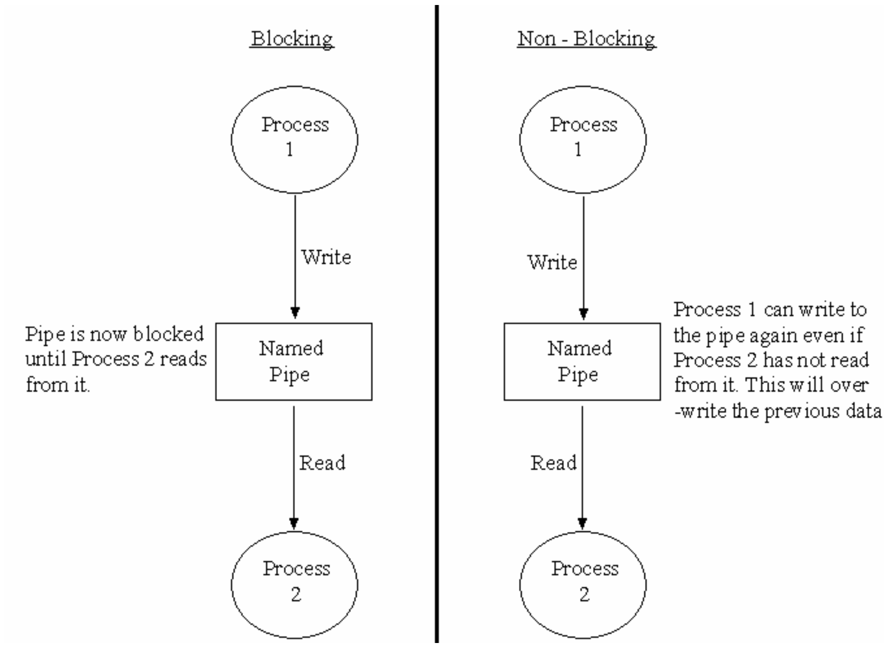

Blocking
Non - Blocking
Process 1
Write
Named Pipe
Pipe is now blocked until Process 2 reads from it.
Read
Process 2
Process 1
Write
Named Pipe
Process 1 can write to the pipe again even if Process 2 has not read from it. This will over -write the previous data
Read
Process 2

Fig. 2.14 Blocking Vs. Non-Blocking Named Pipes

2.6.5 Selecting an IPC

As stated earlier, semaphores, shared memory and message queues all require the “System V IPC commands” for creation and operation. To support the “System V IPC commands” the OS being used requires a Memory Management Unit (MMU), which uClinux does not contain. However, since the 2006 release of the uClinux kernel, these system calls have been integrated. These calls have been implemented in some projects and appear to function as desired [58].

As shared memory does not offer any concurrency as an IPC, without using another mechanism, it was not a viable option for this project. To enable concurrency when using shared memory, semaphores would have to be used, which offered no benefits as semaphores could have been used without shared memory [46].

Upon further research of semaphores and message queues, it was discovered that both can lead to deadlock and starvation between processes. Deadlock occurs when two or more processes are waiting for a resource which one of the other processes holds. These processes will wait forever, as none of the processes can make any progress and release its resources until the other releases a resource, which it will not until it receives a desired resource. Starvation occurs when a process is prevented from proceeding because of another process contains the resource it desires. It is different to deadlock as it is possible for the process to get the desired resource, but due to adversity in the timing of resource requests, it never receives the desired resource [47], [56].

As Named Pipes are a simpler mechanism for IPCs, and only use a file like system to read and write information, they can not lead to deadlock or starvation. Also using the blocking mode operation, it can be guaranteed that no information will be lost when communicating between two processes. With Named Pipes also being used as an IPC in uClinux since its creation, with the other methods only recently being supported in the kernel, it was decided that Named Pipes would be the best option for this particular project [45], [52]. The next section will discuss the external data network which will be used in this project, Controller Area Network.

2.7 Controller Area Network

The addition of electronic units in vehicles in the early ‘80s led to the need for real time communications within vehicles. The point-to-point wiring system was previously employed to connect all electronic units contained in the vehicles. With the addition of more electronic units, additional dedicated signal lines had to be added to the vehicle, which in turn increased the cost and decreased the reliability of each vehicle [60]. A point-to-point wiring system is shown in Fig. 2.15.

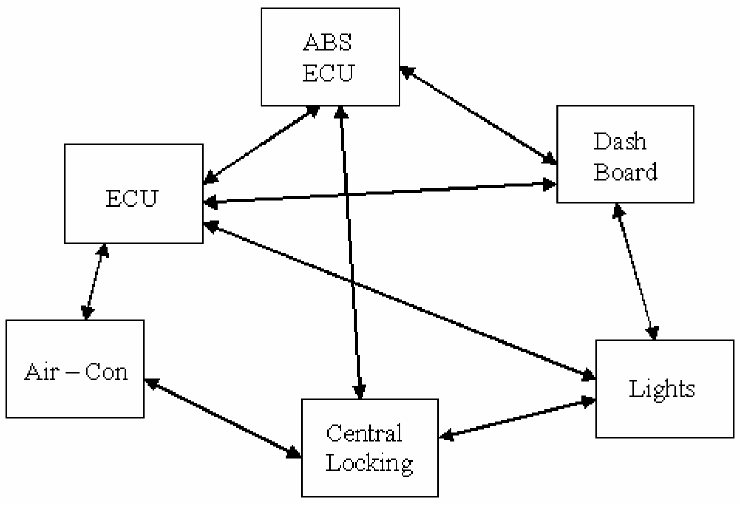


Fig. 2.15 Point-to-Point Wiring System

To fulfil the need for multiplexed communications, and replace point-to-point wiring, Controller Area Network (CAN) was developed in the 1980s by the “Robert Bosch GmbH” company. With CAN, point-to-point wiring was replaced by a single serial bus connecting all control systems and electronic devices using NRZ bit coding (Non Return to Zero) on the network [61], [63]. A typical CAN network is shown in Fig. 2.16.

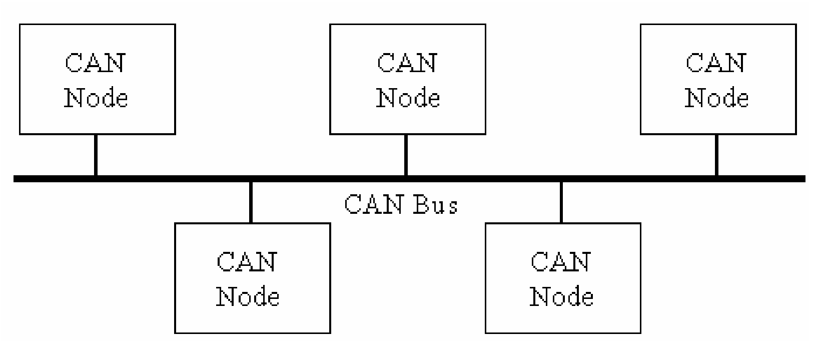


Fig. 2.16 CAN Network

2.7.1 CAN Bit Encoding

The CAN bus protocol uses NRZ bit encoding for data transmission. NRZ bit encoding uses logic 0 and logic 1 to represent the data. If two or more logic 1s occur in succession, the waveform does not return to logic 0 level until a logic 0 actually occurs, or vice versa. In the CAN protocol these two logical states are known as dominant (logic 0) and recessive (logic 1). ISO11898 defines a differential voltage, V_{DIFF}, to represent these two logic states [60], [65].

Typically, a twisted pair configuration is used for the CAN bus, which prevents electromagnetic interference from other electrical devices internal or external to the vehicle. One of the wires is labeled as CAN High (CANH), while the other is labeled CAN Low (CANL). The differential signal between the voltages carried in each wire defines the bus state [63], [64], as can be calculated using the following equation (2.1) and shown in Fig. 2.17.

$$V_{DIFF} = V_{CANH} - V_{CANL}$$

(2.1)

Where: V_{DIFF} is the Differential Voltage (V)

V_{CANH} and V_{CANL} are the CANH and CANL Voltages respectively (V)

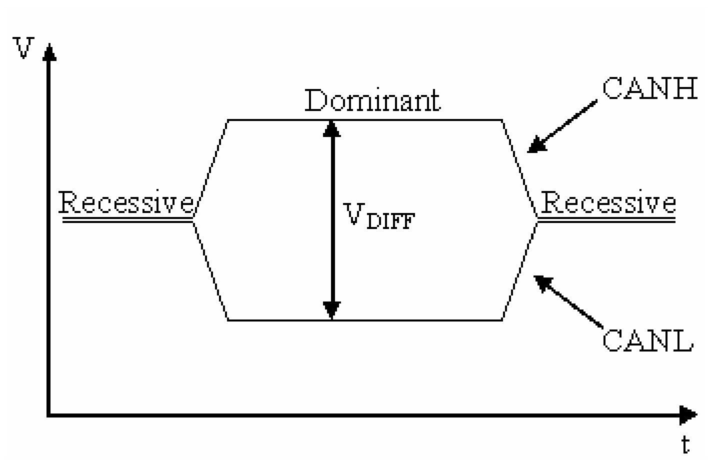


Fig. 2.17 Differential Bus Signalling

In the dominant state the differential voltage between CANH and CANL will be greater than a minimum threshold. Conversely, when in the recessive state the differential voltage is less than a minimum threshold. A dominant signal bit will always have precedence over a recessive bit, due to the fact that CAN uses a Wired-AND mechanism. Using this system, if any node transmits a dominant bit, the bus will be in the dominant state; the CAN network will stay in the dominant state until all nodes on the network transmit a recessive bit [61]. These threshold voltages adhere to the ISO11898 nominal bus levels as shown in Fig. 2.18.

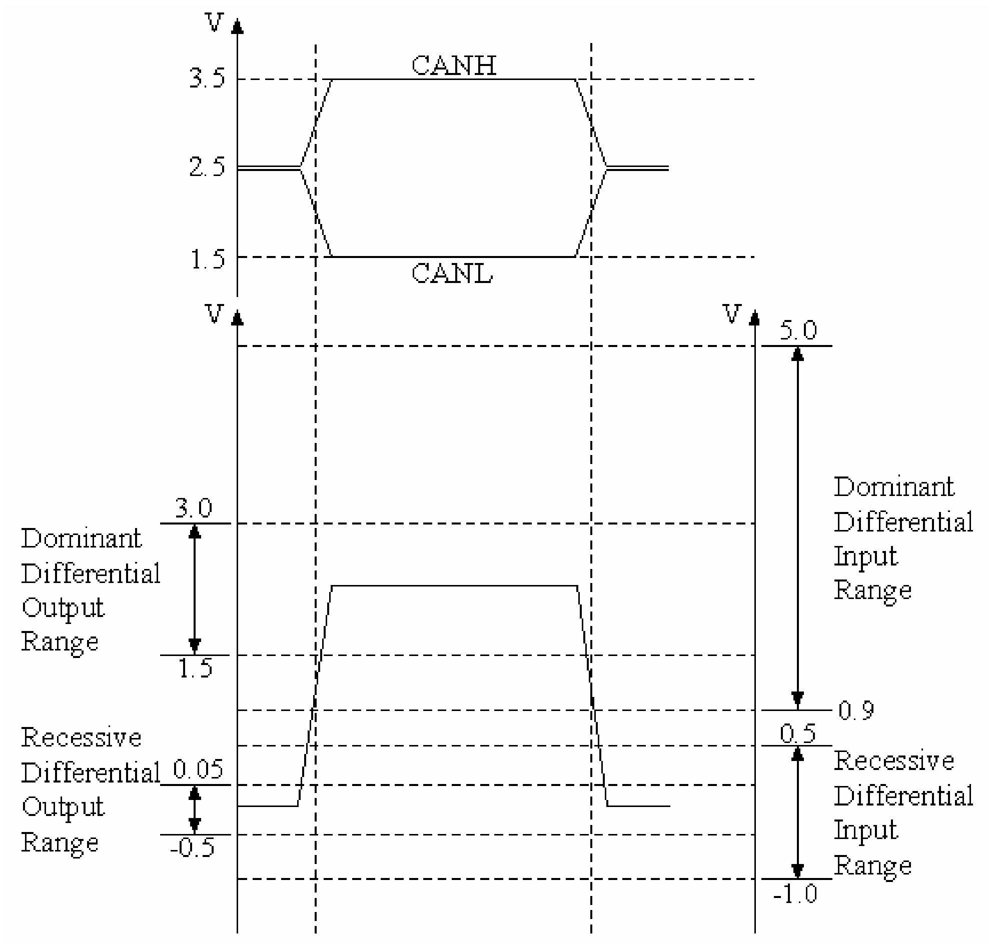

V
3.5
2.5
1.5
CANH
CANL
V
V
5.0
3.0
1.5
Dominant Differential Output Range
Recessive Differential Output Range
0.05
-0.5
Dominant Differential Input Range
0.9
0.5
Recessive Differential Input Range
-1.0

Fig. 2.18 ISO11898 Nominal Bus Levels

2.7.2 CAN Bit Rates and Timings

The bit time of a CAN message is divided into four segments; The Synchronisation Segment (Synch Seg.), Propagation Time Segment (Prop Seg.), Phase Buffer Segment 1 (Phase Seg. 1) and Phase Buffer Segment 2 (Phase Seg. 2) as shown in Fig. 2.19 and explained in Table 2.7 [68].

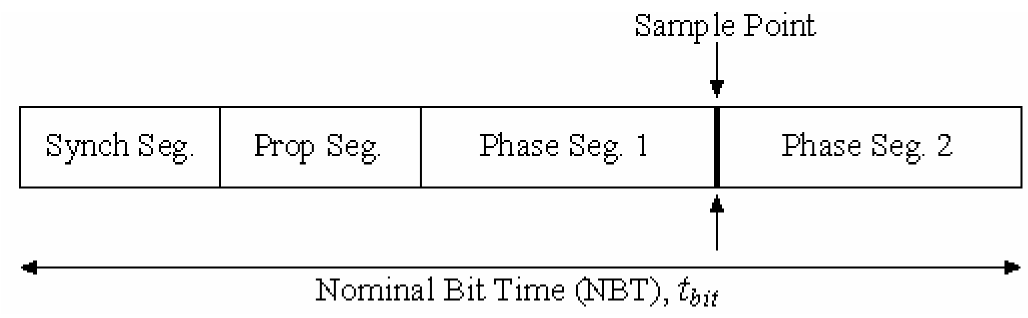


Fig. 2.19 CAN Message Layout

Name	Use	Time Period (TQ)
Sync. Seg	To synchronize the nodes on the bus. Bit edges are expected to occur within the Sync Seg.	1
Prop. Seg.	To compensate for physical delays between nodes.	Programmable : 1 - 8
Phase Seg.1 and 2	To compensate for edge phase errors on the bus. PS1 can be lengthened or PS2 can be shortened by resynchronisation	PS1- Programmable : 1 - 8 PS2- Programmable : 2 - 8

Table 2.7 Segments of a CAN Message

As illustrated in Fig. 2.19, the Nominal Bit Time (NBT), or t_{bit}, is made up of the four non-overlapping segments; therefore the NBT is the summation of the four segments [69].

$$t_{bit} = t_{SynchSeg} + \ t_{PropSeg} + \ t_{PS1} + \ t_{PS2} \tag{2.2}$$

Where: t_{bit} is the bit period (seconds),

$t_{SynchSeg}$ is the synchronisation segment period (seconds),

$t_{PropSeg}$ is the propagation segment period (seconds),

t_{PS1} and t_{PS2} are the periods (seconds) for phase segment 1 and 2 respectively.

Each of the four segments are made up of integer units called Time Quanta (TQ). The length of each Time Quantum is based on the oscillator period, with the base TQ equalling twice the oscillator period. The TQ length equals one TQ clock period (t_{BRPCLK}), which is programmable using the Prescaler named the Baud Rate Prescaler (BRP) [69], [68], as shown in the following equation (2.3).

$$TQ = 2 * BRP * T_{OSC} = \frac{2 * BRP}{F_{OSC}} \tag{2.3}$$

Where: TQ is the time quantum (seconds),
BRP is a user-configurable prescaler integer unit,
T_{OSC} is the period of the oscillator used within a node (seconds),
F_{OSC} is the frequency of the oscillator used within a node (Hertz).

The Nominal Bit Rate (NBR), which is the number of bits per second transmitted by an ideal transmitter with no resynchronisation, can now be calculated using the following equation (2.4).

$$NBR = f_{bit} = \frac{1}{t_{bit}} \tag{2.4}$$

Where: NBR is the nominal bit rate (seconds),
f_{bit} is the frequency of a bit (hertz),
t_{bit} is the bit period (seconds).

Developing Fig. 2.19 using the preceding equations, it can be seen that NBT can be broken down further into a number of TQ. The Synch Seg. is always equal to 1 TQ (Table 2.7) and the other three segments being the programmer's choice depending on the application and desired NBR, as shown in Fig. 2.20 [69].

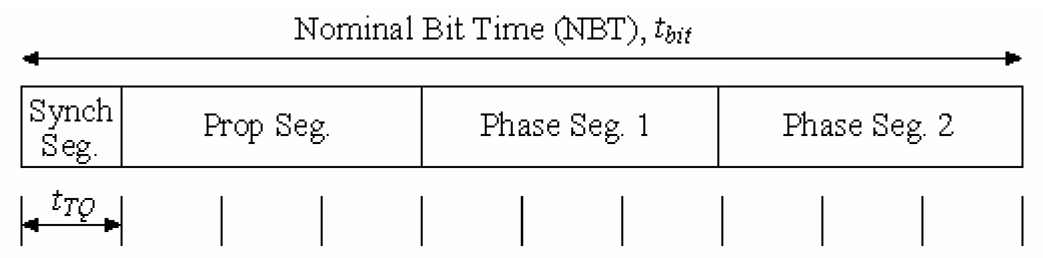


Fig. 2.20 CAN Message in TQ

2.7.3 Propagation Delay

As the CAN protocol is implemented to use a non destructive bit-wise arbitration scheme, it is affected by propagation delays. If two nodes transmit their messages at the same time, they must arbitrate for control of the bus, with the arbitration only being effective if both nodes can sample the bit at the same time. Extreme propagation delays will result in invalid arbitration. The propagation delay of a CAN system can be calculated as being a signal's round trip time on the physical bus, and is represented mathematically as shown in the following equation (2.5) and illustrated in Fig. 2.21.

$$t_{prop} = 2 * (t_{bus} + t_{cmp} + t_{drv}) \tag{2.5}$$

Where t_{prop} is the network propagation delay (seconds),
t_{bus} is the time duration of a signal's round-trip (seconds),
t_{cmp} is the input comparator delay (seconds),
t_{drv} is the delay of the output driver (seconds).

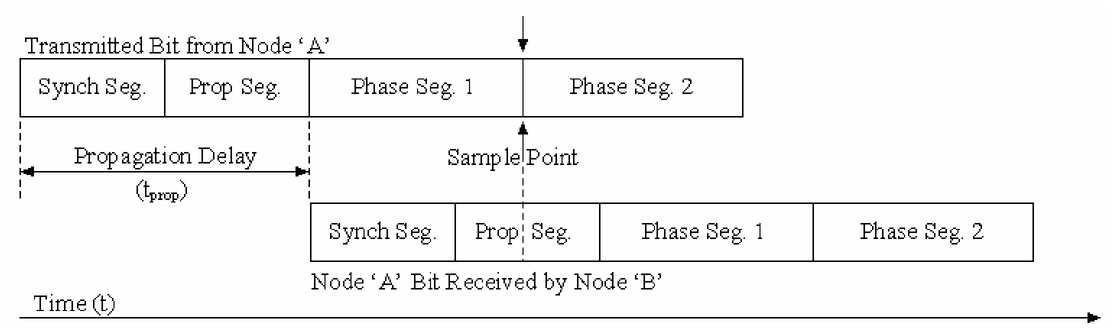


Fig. 2.21 Propagation Delay between Nodes

2.7.4 Synchronisation

In the CAN protocol, synchronisation occurs on the recessive to dominant edges and their purpose is to control the distance between edges and sample points. The Phase Buffer Segments (PS1 and PS2), along with the Synchronisation Jump Width (SJW) are used to compensate for the oscillator tolerances. Both PS1 and PS2 may be lengthened or shortened by synchronisation. There are two methods used for achieving and maintaining synchronisation; Hard Synchronisation and Resynchronisation [68].

2.7.4.1 Hard Synchronisation

Hard Synchronisation only occurs on the first logic 1 to logic 0 (recessive to dominant) edge during a bus idle condition. This represents a Start-of-Frame (SOF) condition. Hard Synchronisation forces the edge to lie within the Synchronisation Segment by causing the bit timing counter to reset to the Synchronisation Segment; hence, synchronising all receivers to the transmitter. Hard Synchronisation only occurs once during a message, and resynchronisation can not occur during the same bit time [68], [70].

2.7.4.2 Resynchronisation

Resynchronisation is implemented to maintain the synchronisation achieved by Hard Synchronisation. Due to oscillator drift between nodes, the receiving nodes can lose synchronisation if resynchronisation was not employed after Hard Synchronisation. Resynchronisation is achieved by implementing a Digital Phase Lock Loop (DPLL) function which compares the position of the expected edge (within the Sync Seg.) to the actual position of a recessive-to-dominant edge on the bus. The DPLL will then adjust the bit time as necessary. The SJW is used to compensate for any phase error by the defined amount in resynchronisation. It is a value programmed by the user, in a range of 1 to 4 TQ, by which the bit period can be lengthened or shortened [68], [70], as shown in Fig. 2.22.

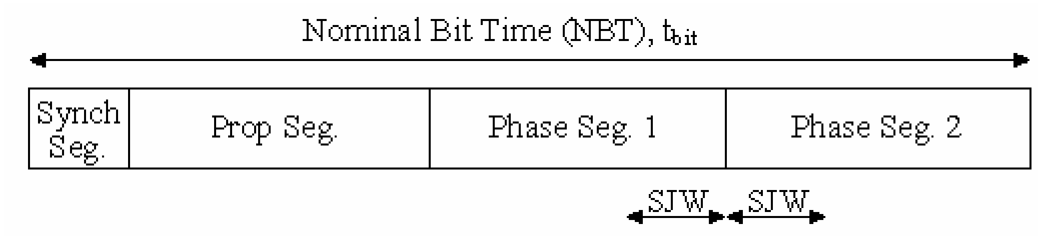


Fig. 2.22 SJW used in Resynchronisation

2.7.5 CAN Message Framing

The CAN protocol defines 4 different types of data frames:

(i) Data Frame
(ii) Remote Frame
(iii) Overload Frame
(iv) Error Frame

2.7.5.1 Data Frame

As the data frame is the most commonly employed frame type, it will be discussed in greater detail than the other three message frames. A Standard CAN data frame is shown in Fig. 2.23.

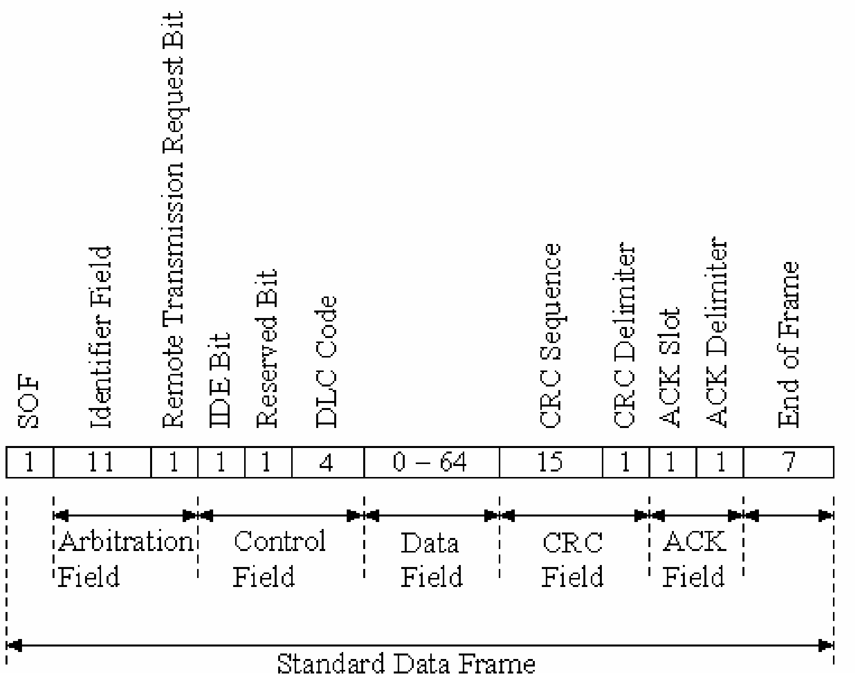


Fig. 2.23 Standard CAN Data Frame

As illustrated in Fig. 2.23, the Standard CAN data frame consists of many different fields; this is also true for the other three frame types. Each field is comprised of a number of bits. The composition of the data frame is as describe below [59], [62], [64], [66].

- **Start of Frame Field –** The SOF marks the beginning of the Data Frames and the Remote Frames. It consists of a single ‘dominant’ bit.
- **Arbitration Field –** The Arbitration Field consists of the Identifier Field and the Remote Transmission Request (RTR) Bit. The Identifier Field is 11bits in length, and transmitted in order of ID10 to ID0. The seven most significant bits (MSBs) (ID10 – ID4) must all not be ‘recessive’. For data frames, the RTR Bit must be ‘dominant’, and for a Remote Frame the RTR Bit has to be ‘recessive’.

- **Control Field –** The Control Field consists of 6 bits. 4 bits are used for the Data Length Code (DLC), which indicates the number of bytes in the Data Field, one bit is for the IDE, while the last bit is reserved for future expansion.
- **Data Field –** The Data Field contains the data to be transmitted within the data frame. It can contain 0 to 8 bytes, which are transferred MSB first.
- **CRC Field –** The CRC Field contains a cyclic redundancy check sequence, along with the CRC Delimiter which is set to be a single 'recessive' bit.
- **ACK Field –** The ACK (Acknowledge) Field consists of two bits, one for the ACK Slot and another for the ACK Delimiter. A transmitting node will send two 'recessive' bits, if a receiver receives the message correctly it will acknowledge this by sending a 'dominant' bit in the ACK Slot back to the transmitter.
- **End of Frame Field –** The End of Frame Field consists of a sequence of seven 'recessive' bits.

The data frame described above is the Standard CAN Data Frame as outlined in the CAN2.0A specifications. There has been a subsequent protocol release (CAN2.0B) which describes the Extended Data Frame. The main difference between both frames is that the Extended Data Frame has the capacity to support a twenty nine bit Identifier Field as opposed to the Standard eleven bits. Thus the extended frame format offers a greater ID range [62], [66].

2.7.5.2 Remote Frame

Remote Frames are used to request information between nodes. A node which desires information will transmit a Remote Frame on the CAN bus, on receiving the Remote Frame the node which contains the desired data will then transmitted it on the CAN bus. The Remote Frame's composition is nearly identical to that of the Data Frame with the only exceptions being that its RTR bit is 'recessive' along with its DLC being set to 0, to indicate no data is being transmitted [62], [67].

2.7.5.3 Overload Frame

The Overload Frame is comprised of an Overload Flag and an Error Delimiter. It is used for to tell the network that it is currently occupied and it is not ready to receive any further messages [61], [67].

2.7.5.4 Error Frame

An Error Frame consists of two fields; an Error Flag Field and an Error Delimiter Field. The content of the Error Flag Field is dependent on the error status of the node which has detected the error. The Error Delimiter consists of eight ‘recessive’ bits. If any node on the CAN bus detects a bus error, it will generate an Error Frame. Once the Error frame has been formed bus activity will return to normal and the node in which the error occurs will attempt to re-transmit any aborted messages [61], [67].

2.8 Summary

This chapter reviewed the literature needed to successfully design and implement the project. The main points covered in this chapter were:

- The selection of the processor to be used in this project, the Blackfin ADSP BF548 EZ-KIT
- The development host to be used to write and compile applications, boot loaders and kernels. In this case coLinux was selected as the development host.
- The OS to be used on the selected processor, in this case uClinux, along with the boot loader, U-Boot.
- The selection of SDL as the graphical library which will be used to generate the graphical display.
- The method of Inter Process Communication to be used in the project.
- The operation and implementation of the CAN protocol.

The next chapter will discuss the configuration of the development host and environment as discussed in this section.

3 System Configuration and Design

3.1 Introduction

This chapter details the configuration and design of the complete system. All choices made and methods used were based on the findings from the literature review. To explain the system's configuration and design process undertaken for this study the chapter is divided into the following sections:

- Section 3.2 illustrates the configured system. It introduces all of the individual components needed. These components will be explained in further detail in the following sections.
- Section 3.3 outlines the configuration of the development host, coLinux. This section describes the steps needed to install and configure coLinux, such that it can be used to develop and compile U-boot, the uClinux kernel and any application code for the BF548.
- Section 3.4 describes the compilation and porting of the boot loader, U-Boot and also details the saving of U-Boot to flash memory.
- Section 3.5 covers the compiling and porting of the evaluation boards OS, uClinux. The configuration of the uClinux kernel is also covered and describes the inclusion and exclusion of functionality in the kernel.
- Section 3.6 outlines the configuration and modification of the CAN drivers, as well as testing of sample code. It describes the problems encountered and solutions faced while designing the CAN software on the BF548.
- Section 3.7 details the design principles for the graphical display used in the project. It covers the design principles and development of basic SDL code, along with the testing of this code.
- Section 3.8 outlines the method used for Inter Process Communications in the project. It details the initial development and testing of the Named Pipes.
- Section 3.9 provides a summary of information presented in this chapter.

3.2 System Configuration Overview

This chapter describes the configuration of the development host (PC) and evaluation board (BF548). A complete overview of the system is shown in Fig. 3.1. Each section of the diagram will be explained in more detail in the following sections.

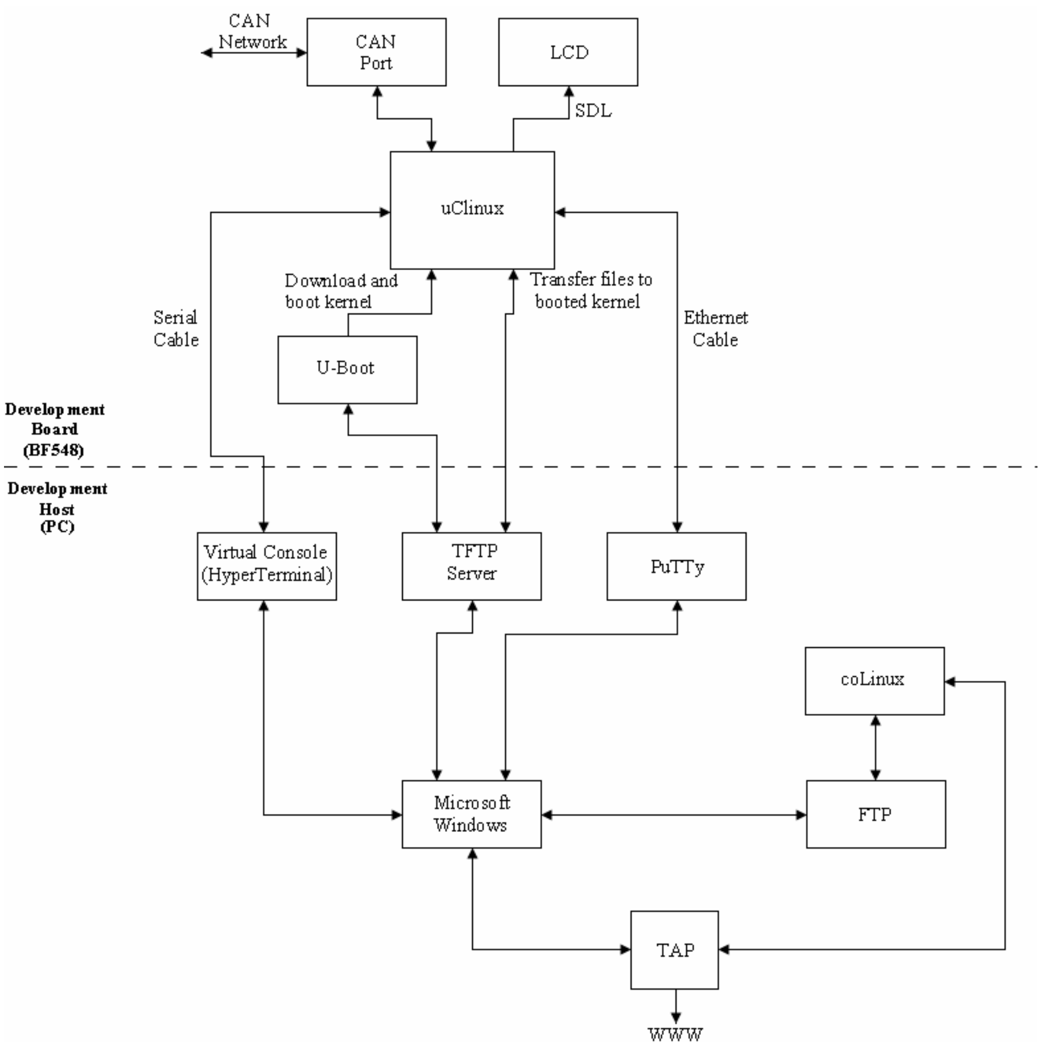


Fig. 3.1 System Configuration Overview

3.3 coLinux

When developing software for a uClinux based project, a Linux development host is required. This development host is used to compile the boot loader (U-Boot), the board's OS (uClinux) and any applications that are run on the BF548. coLinux was chosen as the development host for the project, as it can operate on top of a Windows

OS, and hence a full Linux box was not needed. The installation and configuring of coLinux will be explained in the next section.

3.3.1 Installing coLinux

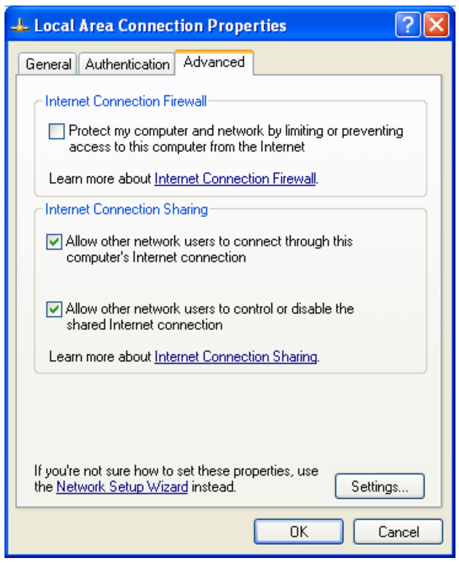
The Debian version of coLinux was used in the project. The Debian installer file was downloaded from the Blackfin website [71]. When the installer file was run on the Windows machine, it set up a one gigabyte (1GB) partition that was then used for all coLinux files. When the installation was complete, the partition contained all of the standard directories associated with any Linux machine. Finally a batch file was written to create a Windows shortcut for coLinux.

3.3.2 Configuring coLinux

coLinux had to be configured such that the Windows partition and the coLinux partition could communicate with each other. This was achieved by configuring a network connection such that coLinux could use the Windows Ethernet network connection for downloading new packages, and also for transferring files between both operating systems.

3.3.2.1 Configuring the Network

During the installation of coLinux, a TAP interface was automatically created in the network connections folder of Windows. It is this interface that is used to connect both the coLinux and the Windows OSs to the Ethernet. To allow connections, the Windows Ethernet connection had to be shared as shown in Fig. 3.2 [72].


Local Area Connection Properties

General | Authentication | Advanced

Internet Connection Firewall

☐ Protect my computer and network by limiting or preventing access to this computer from the Internet

Learn more about Internet Connection Firewall.

Internet Connection Sharing

☑ Allow other network users to connect through this computer's Internet connection

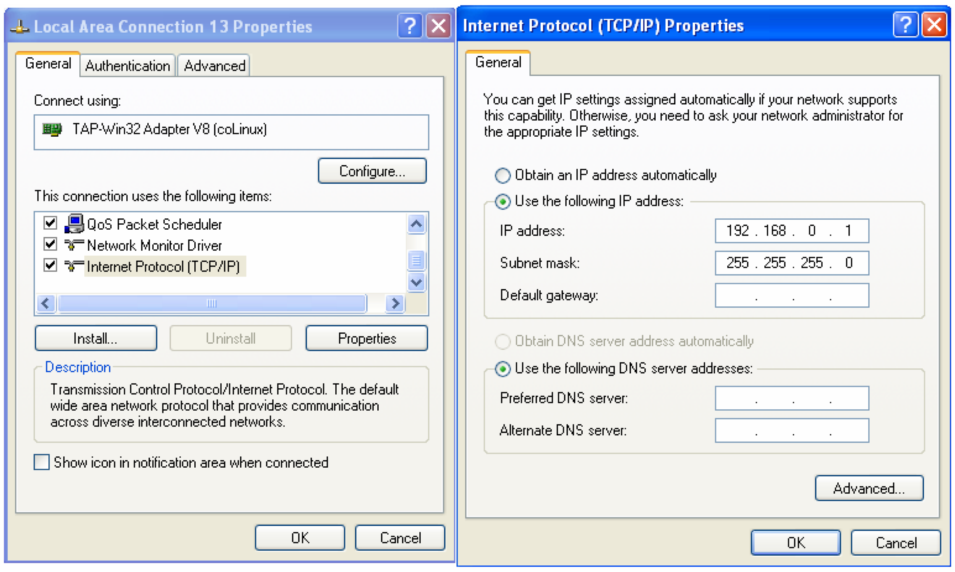
☑ Allow other network users to control or disable the shared Internet connection

Learn more about Internet Connection Sharing.

If you're not sure how to set these properties, use the Network Setup Wizard instead.

Fig. 3.2 Sharing Ethernet Connection

This TAP interface was configured to have an IP address of 192.168.0.1 and a subnet mask of 255.255.255.0 as shown in Fig. 3.3.


Local Area Connection 13 Properties

General | Authentication | Advanced

Connect using:

TAP-Win32 Adapter V8 (coLinux)

This connection uses the following items:

☑ QoS Packet Scheduler
☑ Network Monitor Driver
☑ Internet Protocol (TCP/IP)

Description

Transmission Control Protocol/Internet Protocol. The default wide area network protocol that provides communication across diverse interconnected networks.

☐ Show icon in notification area when connected

Internet Protocol (TCP/IP) Properties

General

You can get IP settings assigned automatically if your network supports this capability. Otherwise, you need to ask your network administrator for the appropriate IP settings.

○ Obtain an IP address automatically
[✓ Use the following IP address:]

IP address:	192 . 168 . 0 . 1
Subnet mask:	255 . 255 . 255 . 0
Default gateway:	. . .

○ Obtain DNS server address automatically
[✓ Use the following DNS server addresses:]

Preferred DNS server:	. . .
Alternate DNS server:	. . .

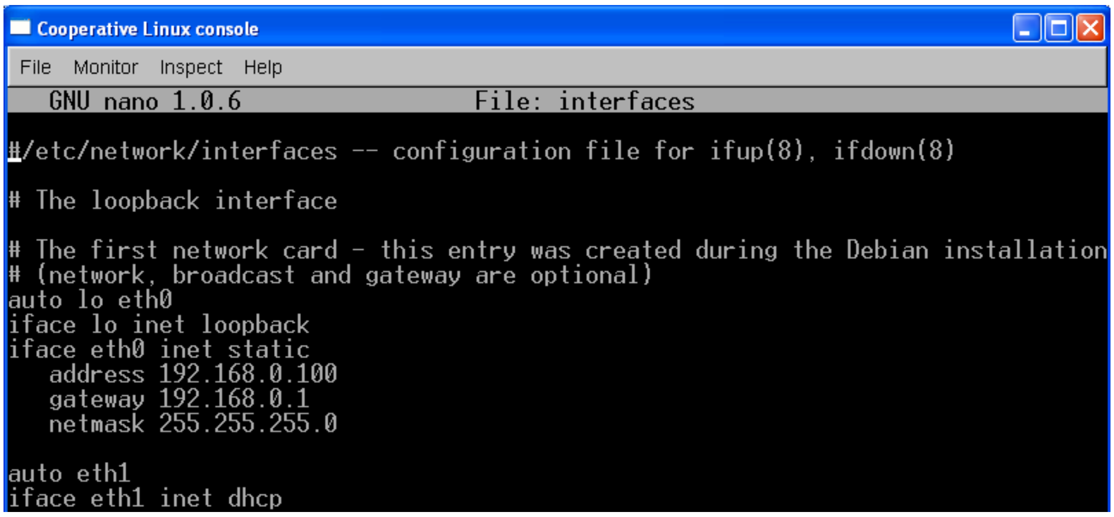
Fig. 3.3 Configuring the coLinux TAP Interface

The Windows side of the network configuration was now complete. To configure the network on coLinux the resolv.conf and interfaces files had to be edited to include the IP address, subnet mask, gateway IP and the name server [73]. The interfaces file was edited to contain the information shown in Table 3.1 and edited interfaces file is shown in Fig. 3.4.

.

Name	Address
IP Address	192.168.0.100
Gateway IP	192.168.0.1
Subnet Mask	255.255.255.0

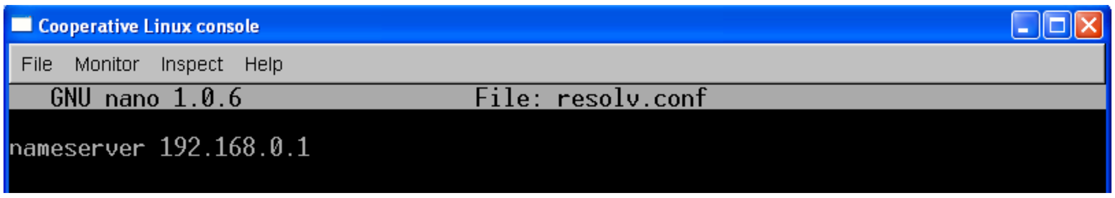
Table 3.1 coLinux Network Configurations



```
  GNU nano 1.0.6                    File: interfaces

#/etc/network/interfaces -- configuration file for ifup(8), ifdown(8)

# The loopback interface

# The first network card - this entry was created during the Debian installation
# (network, broadcast and gateway are optional)
auto lo eth0
iface lo inet loopback
iface eth0 inet static
   address 192.168.0.100
   gateway 192.168.0.1
   netmask 255.255.255.0

auto eth1
iface eth1 inet dhcp
```

Fig. 3.4 Edited coLinux Interfaces File

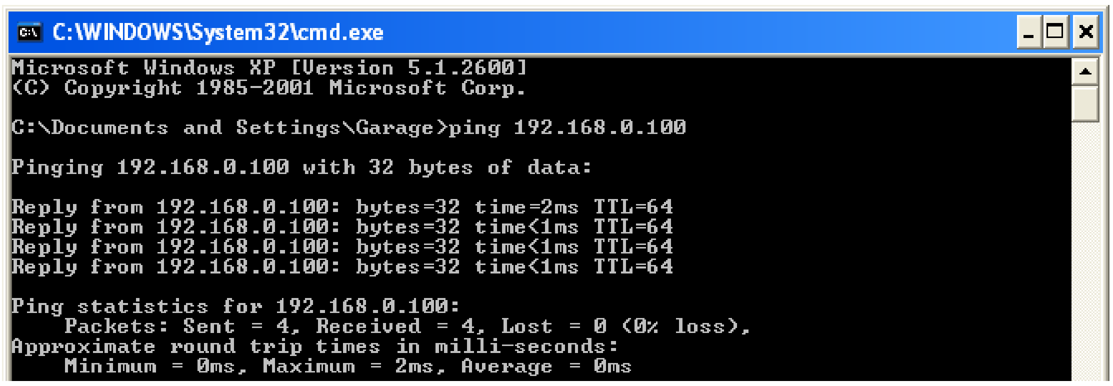
When editing the resolv.conf file, the IP address set for the TAP interface is set as the name server as shown in Fig. 3.5.



```
  GNU nano 1.0.6                    File: resolv.conf

nameserver 192.168.0.1
```

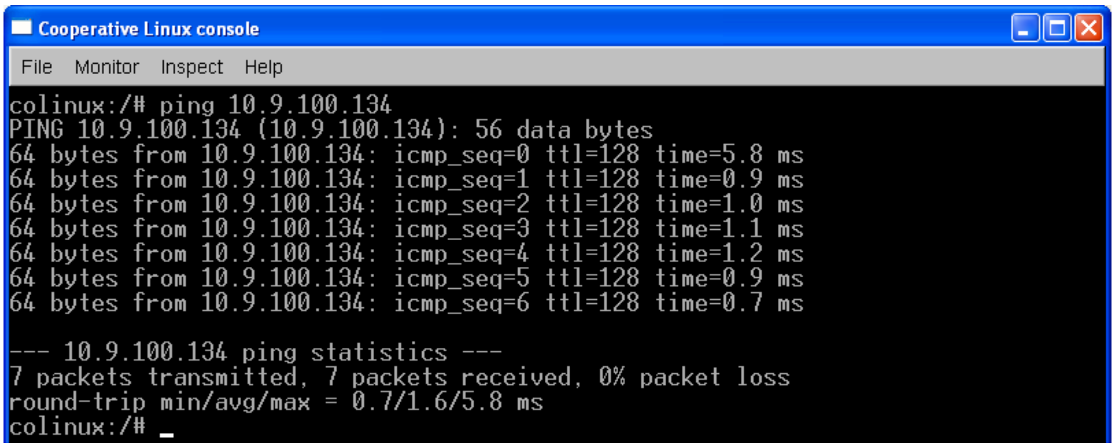
Fig. 3.5 Edited coLinux Resolv.conf File

coLinux was now configured to connect to the Ethernet. To test these connections ping was used as shown in Fig. 3.6 and Fig. 3.7.



```
Microsoft Windows XP [Version 5.1.2600]
(C) Copyright 1985-2001 Microsoft Corp.

C:\Documents and Settings\Garage>ping 192.168.0.100

Pinging 192.168.0.100 with 32 bytes of data:

Reply from 192.168.0.100: bytes=32 time=2ms TTL=64
Reply from 192.168.0.100: bytes=32 time<1ms TTL=64
Reply from 192.168.0.100: bytes=32 time<1ms TTL=64
Reply from 192.168.0.100: bytes=32 time<1ms TTL=64

Ping statistics for 192.168.0.100:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 2ms, Average = 0ms
```

Fig. 3.6 Pinging coLinux from Windows



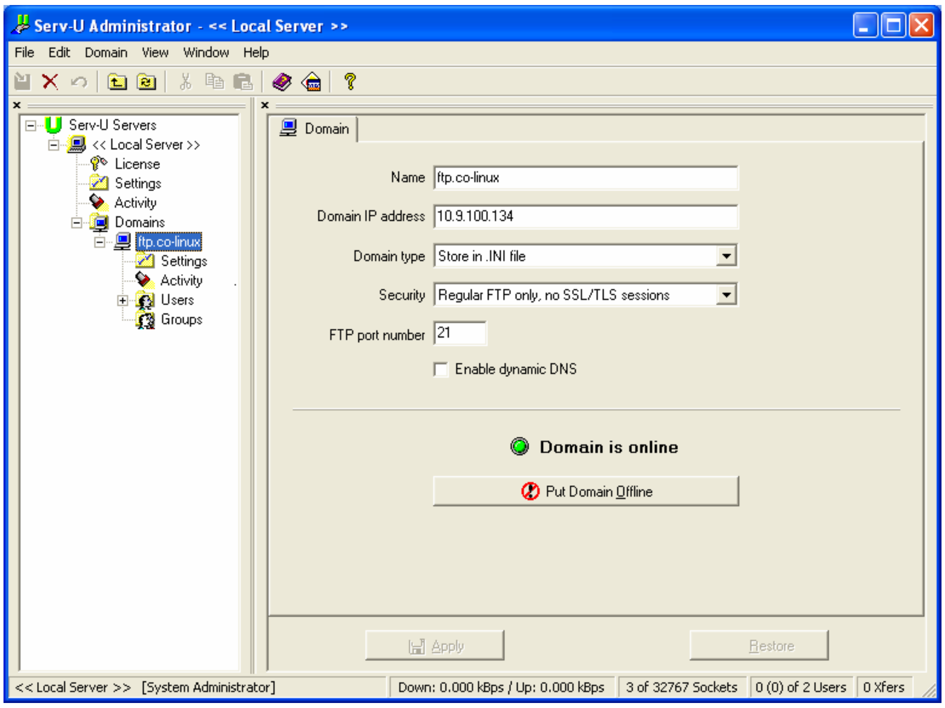
```
colinux:/# ping 10.9.100.134
PING 10.9.100.134 (10.9.100.134): 56 data bytes
64 bytes from 10.9.100.134: icmp_seq=0 ttl=128 time=5.8 ms
64 bytes from 10.9.100.134: icmp_seq=1 ttl=128 time=0.9 ms
64 bytes from 10.9.100.134: icmp_seq=2 ttl=128 time=1.0 ms
64 bytes from 10.9.100.134: icmp_seq=3 ttl=128 time=1.1 ms
64 bytes from 10.9.100.134: icmp_seq=4 ttl=128 time=1.2 ms
64 bytes from 10.9.100.134: icmp_seq=5 ttl=128 time=0.9 ms
64 bytes from 10.9.100.134: icmp_seq=6 ttl=128 time=0.7 ms

--- 10.9.100.134 ping statistics ---
7 packets transmitted, 7 packets received, 0% packet loss
round-trip min/avg/max = 0.7/1.6/5.8 ms
colinux:/# _
```

Fig. 3.7 Pinging Windows from coLinux

Finally communications between coLinux and the World Wide Web were verified by using the "*apt-get update*" command. This command connects to the Web and updates any coLinux packages that are not the latest revision. The web addresses which are used for the updates were configured during the installation of coLinux. When the command was run, each package currently installed in coLinux was checked and updated if a newer version was available; hence proving that coLinux connected to the web. With coLinux and Windows communicating, a method was needed to transfer files between both OSs. This was accomplished using an FTP (File Transfer Protocol) server.

3.3.2.2 Configuring the FTP server

The FTP server used in the project was Serv-U. This server was downloaded and configured such that a folder called FTP Documents was created on the Windows OS. This folder was the used to send and receive files from coLinux. As the folder was situated on the Windows OS, the Domain IP of the server had to be set to the IP address of the Windows OS, 10.9.100.134. The configured server is shown in Fig. 3.8.



Name: ftp.co-linux
Domain IP address: 10.9.100.134
Domain type: Store in .INI file
Security: Regular FTP only, no SSL/TLS sessions
FTP port number: 21
Enable dynamic DNS

<< Local Server >> [System Administrator] | Down: 0.000 kBps / Up: 0.000 kBps | 3 of 32767 Sockets | 0 (0) of 2 Users | 0 Xfers

Fig. 3.8 Configured FTP Server

To send and receive files from coLinux, the command *"ftp 10.9.100.134"* is used to log on to the server. The user is asked to enter a username and password, once these are entered properly, the user can receive files from the folder in the Windows environment using the *"get filename"* command. To send files from coLinux to Windows the *"put filename"* command is used. With the FTP server functioning correctly, full communications were established between coLinux and Windows. Next the Blackfin toolchains had to be installed in coLinux.

3.3.2.3 Installing the Blackfin Toolchains

The Blackfin toolchains contain all the necessary library files and cross compilers needed to compile code that is to be run on a Blackfin BF548 board, including U-Boot, uClinux and any application programmes. There are two toolchains which need to be installed, blackfin-uclinux and blackfin-linux-uclibc. Both of these toolchains were downloaded from the Blackfin website [74]. The rpm (RPM Package Manager) versions of the toolchains were downloaded to coLinux and were installed using the *"alien –i filename"* command [18].

With the toolchains installed in coLinux, the path had to be edited such that it includes the Blackfin toolchains. The path is used while compiling any code, to point to the appropriate cross compiler, i.e. if compiling a uClinux kernel, without editing the path to include the appropriate cross compilers, an error will be received. To edit the path the following command is used;

"export PATH=$PATH:/opt/uClinux/bfin-uclinux/bin:/opt/uClinux/bfin-linux-uclibc/bin"

With the path edited to include the Blackfin toolchains, coLinux can now be used to compile programmes to run on the BF548. As a boot loader is needed to boot the uClinux kernel on the board, U-Boot had to be compiled first.

3.4 U-Boot

U-Boot is the boot loader used when running uClinux on a Blackfin platform. Its job is to point the CPU to the starting address of the OS, in this case a uClinux Kernel. To accomplish this, the latest version of U-Boot was compiled and then saved into flash memory such that it will run every time the BF548 board is powered up. When compiling and porting U-Boot to the BF548, the steps given by Blackfin were closely followed [18].

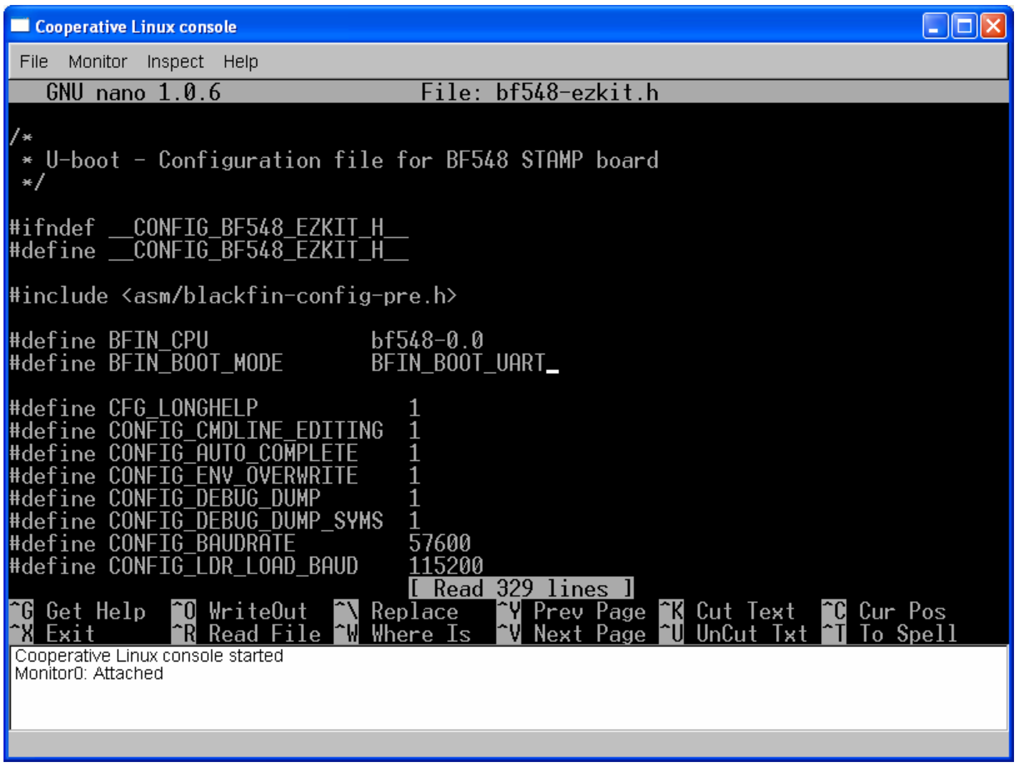
3.4.1 Compiling U-Boot

To compile U-Boot the Blackfin toolchains must be installed in the development host, coLinux, as stated earlier. The latest version of U-Boot was downloaded and uncompressed using the command, *"tar jxf U-Boot-1.1.6-2008R1.tar.bz2".* This command will unpack U-Boot and put it into a directory with the same name, i.e. the directory U-Boot-1.1.6-2008R1 will be created in coLinux. With the source code installed in coLinux, U-Boot was then compiled.

3.4.1.1 Compiling U-Boot for Loading over the UART

As the compiled version of U-Boot was to be loaded to the BF548 using the UART, this had to be set in the header file for the device. To accomplish this, the Blackfin boot mode must be set to Blackfin boot UART in the BF548-ezkit header file, as shown below [18]. This edited header file is shown in Fig. 3.9.

```
#define      BFIN_BOOT_MODE           BFIN_BOOT_UART
```

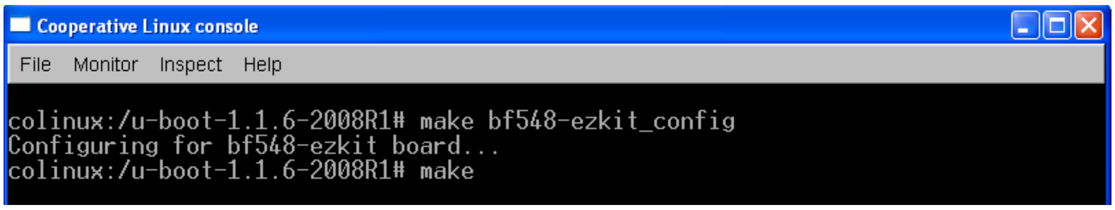


```
  GNU nano 1.0.6                    File: bf548-ezkit.h

/*
 * U-boot - Configuration file for BF548 STAMP board
 */

#ifndef __CONFIG_BF548_EZKIT_H__
#define __CONFIG_BF548_EZKIT_H__

#include <asm/blackfin-config-pre.h>

#define BFIN_CPU                bf548-0.0
#define BFIN_BOOT_MODE          BFIN_BOOT_UART_

#define CFG_LONGHELP               1
#define CONFIG_CMDLINE_EDITING     1
#define CONFIG_AUTO_COMPLETE       1
#define CONFIG_ENV_OVERWRITE       1
#define CONFIG_DEBUG_DUMP          1
#define CONFIG_DEBUG_DUMP_SYMS     1
#define CONFIG_BAUDRATE            57600
#define CONFIG_LDR_LOAD_BAUD       115200
                               [ Read 329 lines ]
^G Get Help  ^O WriteOut  ^\ Replace   ^Y Prev Page ^K Cut Text  ^C Cur Pos
^X Exit      ^R Read File ^W Where Is  ^V Next Page ^U UnCut Txt ^T To Spell
```

```
Cooperative Linux console started
Monitor0: Attached
```

Fig. 3.9 Setting Boot Mode to UART

After setting the boot mode to UART in the header file, the edited configuration file had to be compiled for the changes to take affect. The command *"make bf548-ezkit_config"* was used to compile the configuration file, as shown in Fig. 3.10.



```
colinux:/u-boot-1.1.6-2008R1# make bf548-ezkit_config
Configuring for bf548-ezkit board...
colinux:/u-boot-1.1.6-2008R1# make
```

Fig. 3.10 Configuring and Compiling U-Boot

Once U-Boot has compiled successfully the following files are created in the U-Boot directory, as shown in Table 3.2.

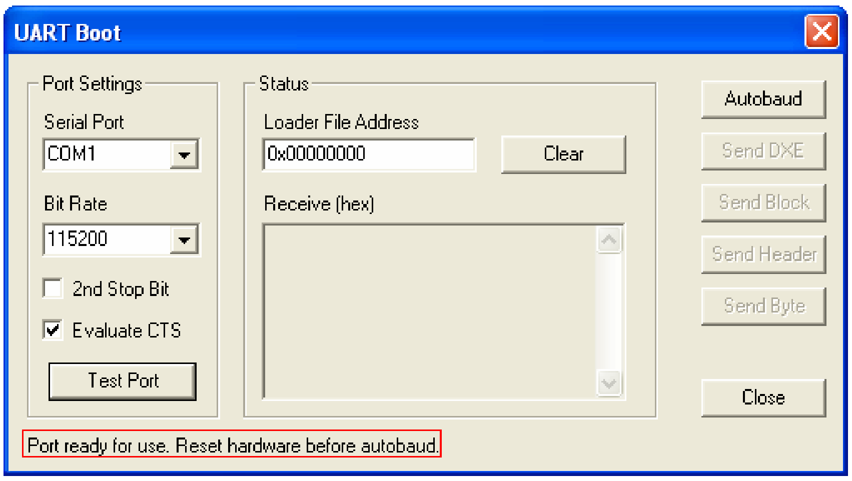
File	Description
u-boot	Compiled ELF image
u-boot.bin	u-boot converted to a raw binary
u-boot.hex	u-boot.bin converted to Intel Hex format
u-boot.srec	u-boot.bin converted to Motorola S-records format
u-boot.ldr	u-boot converted to Blackfin Loader format
u-boot.ldr.hex	u-boot.ldr converted to Intel Hex format
u-boot.ldr.srec	u-boot.ldr converted to Motorola S-records format

Table 3.2 Created Files from U-Boot Compilation

U-Boot was loaded on the BF548 using a UART loader (LdrViewer), and the file required was “u-boot-ldr”.

3.4.2 Loading U-Boot onto the BF548

LdrViewer was used to load U-Boot, through the UART to the BF548 evaluation board. This was achieved by connecting an RS232 cable from COM1 on the development machine to the BF548 board and setting switch 1 on the BF548 to 7 (UART boot). The U-Boot file (u-boot-ldr) was then opened and both the baud rate and com port were set in LdrViewer. The port was then tested using the “test port” button as shown in Fig. 3.11.


UART Boot

Port Settings

Serial Port: COM1

Bit Rate: 115200

☐ 2nd Stop Bit

☑ Evaluate CTS

Status

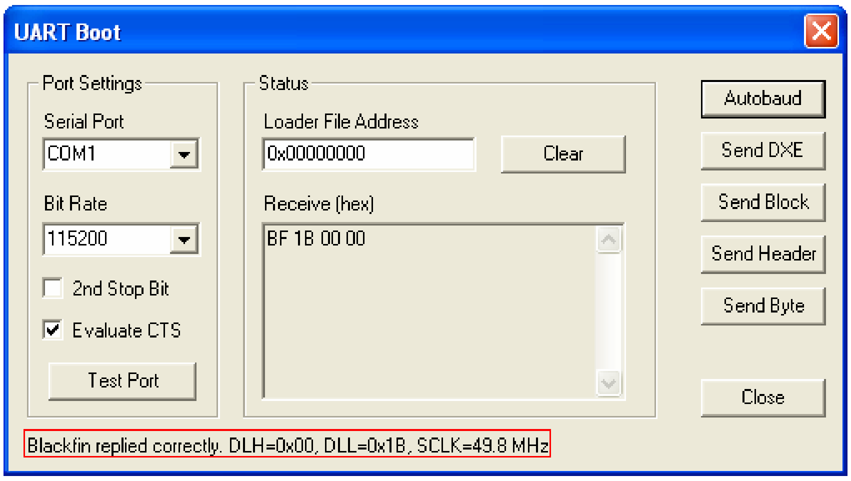
Loader File Address: 0x00000000

Receive (hex)

Port ready for use. Reset hardware before autobaud.

Fig. 3.11 Configuring LdrViewer

When testing the port, if the message highlighted in Fig. 3.11 is received then the LdrViewer can successfully talk to the port. The “Autobaud” button was then used to test the connections between LdrViewer and the BF548 as shown in Fig. 3.12.



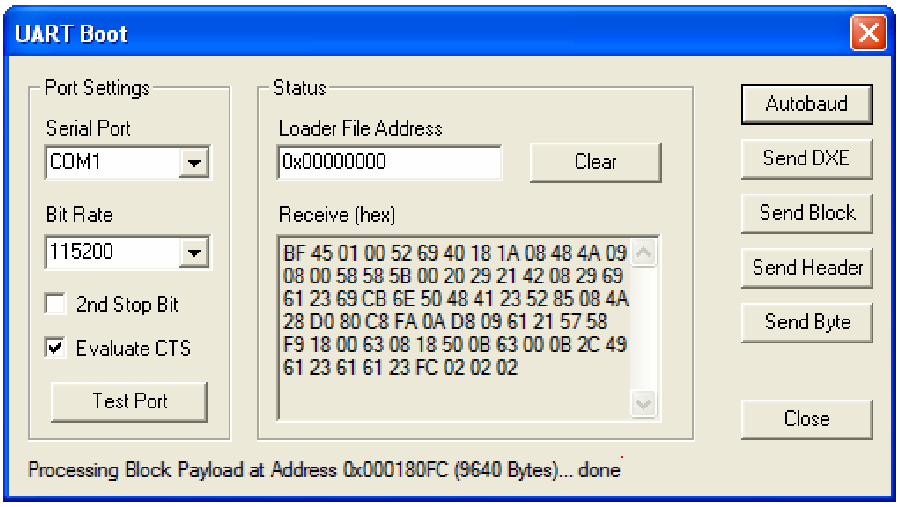
Serial Port: COM1
Bit Rate: 115200
☐ 2nd Stop Bit
☑ Evaluate CTS
Loader File Address: 0x00000000
Receive (hex):

```
BF 1B 00 00
```

Blackfin replied correctly. DLH=0x00, DLL=0x1B, SCLK=49.8 MHz

Fig. 3.12 Testing Communications between LdrViewer and BF548

If the message highlighted in Fig. 3.12 is received after running the “Autobaud”, the BF548 is ready to receive the U-Boot file over the UART. This was achieved by pressing the “Send DXE” button. When the U-Boot file had been successfully sent, the feedback from the target was displayed in LdrViewer as shown in Fig. 3.13.



Serial Port: COM1
Bit Rate: 115200
☐ 2nd Stop Bit
☑ Evaluate CTS
Loader File Address: 0x00000000
Receive (hex):

```
BF 45 01 00 52 69 40 18 1A 08 48 4A 09
08 00 58 58 5B 00 20 29 21 42 08 29 69
61 23 69 CB 6E 50 48 41 23 52 85 08 4A
28 D0 80 C8 FA 0A D8 09 61 21 57 58
F9 18 00 63 08 18 50 0B 63 00 0B 2C 49
61 23 61 61 23 FC 02 02 02
```

Processing Block Payload at Address 0x000180FC (9640 Bytes)... done

Fig. 3.13 U-Boot Transferred Successfully

3.4.3 Saving U-Boot to Flash

When storing U-Boot into the flash memory, it was written into the serial flash on the BF548. However when booting from flash, the boot mode will be set SPI boot. This meant that U-Boot had to be recompiled, this time setting the boot mode to be SPI. To accomplish this, the BF548 U-Boot header had to be edited as shown below. With the following line replacing the previous boot mode, U-Boot was recompiled and ported to the BF548 as explained above.

```
#define   BFIN_BOOT_MODE      BFIN_BOOT_SPI_MASTER
```

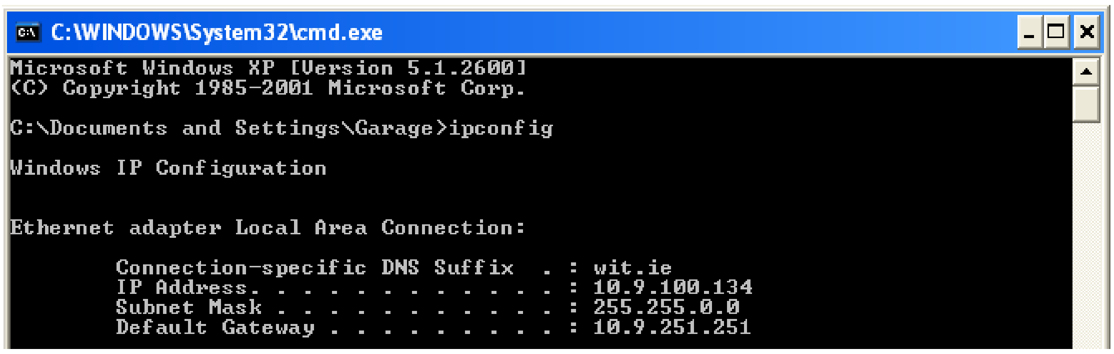
This new version of U-Boot was then written into the serial flash, giving the BF548 the capabilities to boot from flash. When writing to the flash the following command was entered into the virtual console (HyperTerminal) when connected to the board [18].

```
eeprom write 0x1000000 0 $(filesize)
```

The command above writes U-Boot into the serial flash of the board at address 0x1000000. When using the command the variable filesize will be replaced by the actual size of the U-Boot file. The boot mode switch (switch 1) was then set to 3 (SPI boot mode) and the board was reset. Now and every time the board is reset, U-Boot will run automatically from the serial flash.

3.4.4 Configuring the Network Settings in U-Boot

U-Boot is used to boot the uClinux kernel, which for this project was stored on the development host. U-Boot will have to be able to connect to Ethernet so that it can port the uClinux kernel from the development host. To configure the network settings on the BF548, the network settings of the development host had to be established. These settings were established using the command “ipconfig” in DOS, Fig. 3.14.



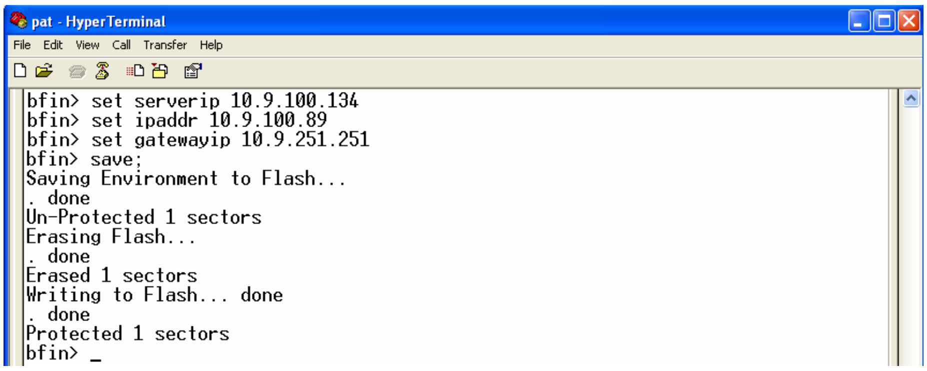
```
Microsoft Windows XP [Version 5.1.2600]
(C) Copyright 1985-2001 Microsoft Corp.

C:\Documents and Settings\Garage>ipconfig

Windows IP Configuration


Ethernet adapter Local Area Connection:

        Connection-specific DNS Suffix  . : wit.ie
        IP Address. . . . . . . . . . . . : 10.9.100.134
        Subnet Mask . . . . . . . . . . . : 255.255.0.0
        Default Gateway . . . . . . . . . : 10.9.251.251
```

Fig. 3.14 Network Configuration of Development Host

From Fig. 3.14 it can be seen that the development host’s IP address is 10.9.100.134. As the development host is used as a server for the board to port the uClinux kernel from, this address was used for the server IP. The default gateway, 10.9.251.251, was used by the board to connect to the network; hence this will be used for the gateway IP. Lastly the board itself must be given an IP address, as the address 10.9.100.89 was not being used on the network; this was assigned to the board. These settings were applied to the board by entering the following commands in U-Boot.

```
set serverip 10.9.100.134
set ipaddr 10.9.100.89
set gatewayip 10.9.251.251
```

These settings were then saved by writing their values into the U-Boot that is stored in flash using the command *“save;”* as can be seen in Fig. 3.15.



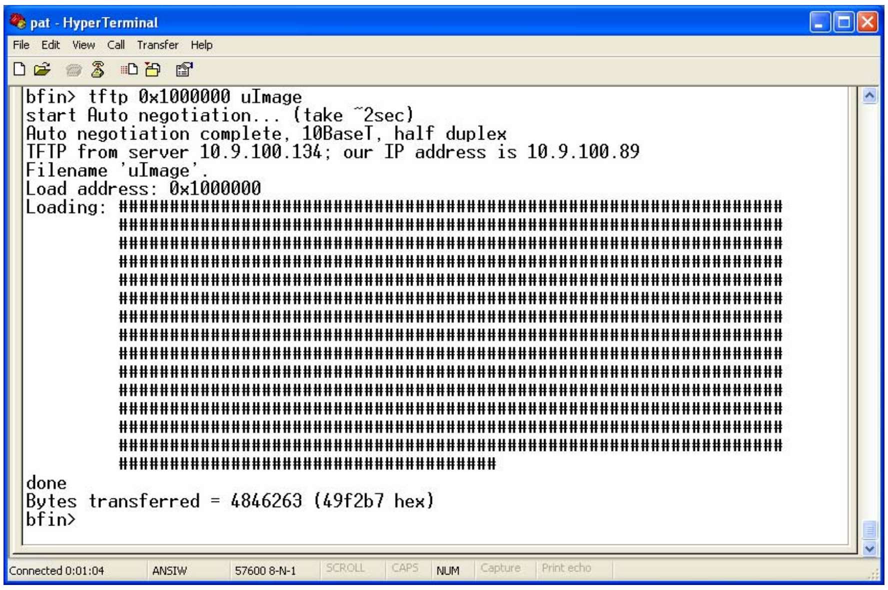
```
bfin> set serverip 10.9.100.134
bfin> set ipaddr 10.9.100.89
bfin> set gatewayip 10.9.251.251
bfin> save;
Saving Environment to Flash...
. done
Un-Protected 1 sectors
Erasing Flash...
. done
Erased 1 sectors
Writing to Flash... done
. done
Protected 1 sectors
bfin> _
```

Fig. 3.15 Configuring the Network in U-Boot

Now every time the BF548 is booted, these network configurations will be used, so that U-Boot will be able to connect to the network.

3.4.5 Testing U-Boot

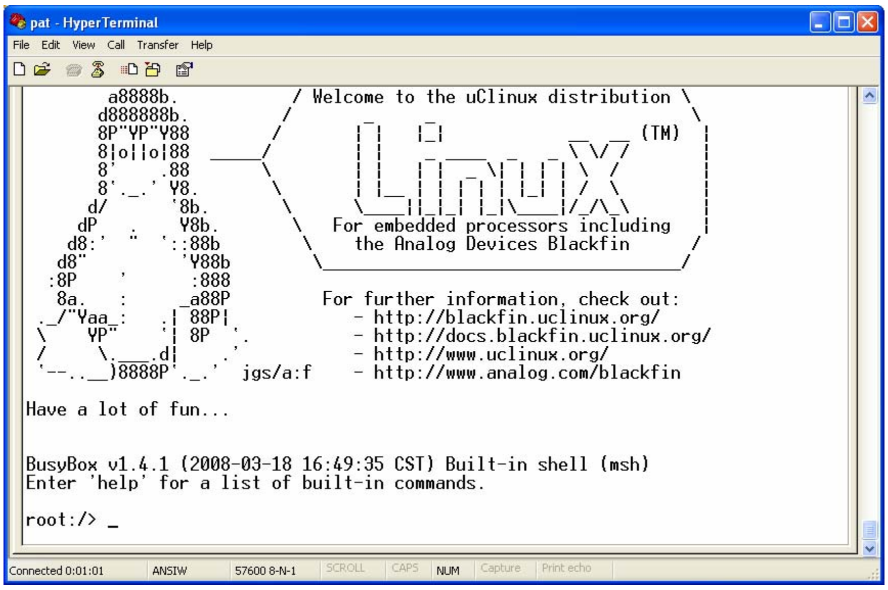
To test U-Boot a pre-compiled version of a uClinux kernel (uImage) was downloaded from the Blackfin website [76]. This uImage was then stored on the development host so that U-Boot would be able to access it through the network. To port the uImage to the board, the *"tftp 0x1000000 uImage"* command was used in U-Boot, where tftp is the command used to transfer the file using ftp, 0x1000000 is the starting address in RAM where the file is to be placed and uImage is the actual kernel. When the command was entered, the following was displayed on the virtual console (Fig. 3.16).



```
bfin> tftp 0x1000000 uImage
start Auto negotiation... (take ~2sec)
Auto negotiation complete, 10BaseT, half duplex
TFTP from server 10.9.100.134; our IP address is 10.9.100.89
Filename 'uImage'.
Load address: 0x1000000
Loading: #################################################################
         #################################################################
         #################################################################
         #################################################################
         #################################################################
         #################################################################
         #################################################################
         #################################################################
         #################################################################
         #################################################################
         #################################################################
         #################################################################
         #################################################################
         #################################################################
         #####################################
done
Bytes transferred = 4846263 (49f2b7 hex)
bfin>
```

Fig. 3.16 Downloading the uImage

When the uImage is downloaded, it can be then booted using the command *"bootm"*. Fig. 3.17 shows that the uClinux kernel has booted successfully and therefore proves U-Boot is functioning correctly using the pre-compiled kernel. However, this pre-compiled kernel does not have the desired functionality required for the project; hence a new kernel has to be configured compiled using coLinux.



```
        a8888b.           / Welcome to the uClinux distribution \
       d888888b.         /       _     _                          \
       8P"YP"Y88        /       | |   |_|              __  __ (TM)  |
       8|o||o|88  _____/        | |    _ ____  _   _  \ \/ /        |
       8'    .88       \        | |   | |  _ \| | | |  \  /         |
       8`._.' Y8.       \       | |__ | | | | | |_| |  /  \         |
      d/      `8b.       \      \____||_|_| |_|\____|/_/\_\         |
     dP   .    Y8b.       \   For embedded processors including     |
    d8:'  "  `::88b        \    the Analog Devices Blackfin        /
   d8"         'Y88b        \_____________________________________/
  :8P    '      :888
   8a.   :     _a88P          For further information, check out:
 ._/"Yaa_:   .| 88P|             - http://blackfin.uclinux.org/
 \    YP"    `| 8P  `.           - http://docs.blackfin.uclinux.org/
 /     \.___.d|    .'            - http://www.uclinux.org/
 `--..__)8888P`._.'  jgs/a:f     - http://www.analog.com/blackfin

Have a lot of fun...


BusyBox v1.4.1 (2008-03-18 16:49:35 CST) Built-in shell (msh)
Enter 'help' for a list of built-in commands.

root:/> _
```

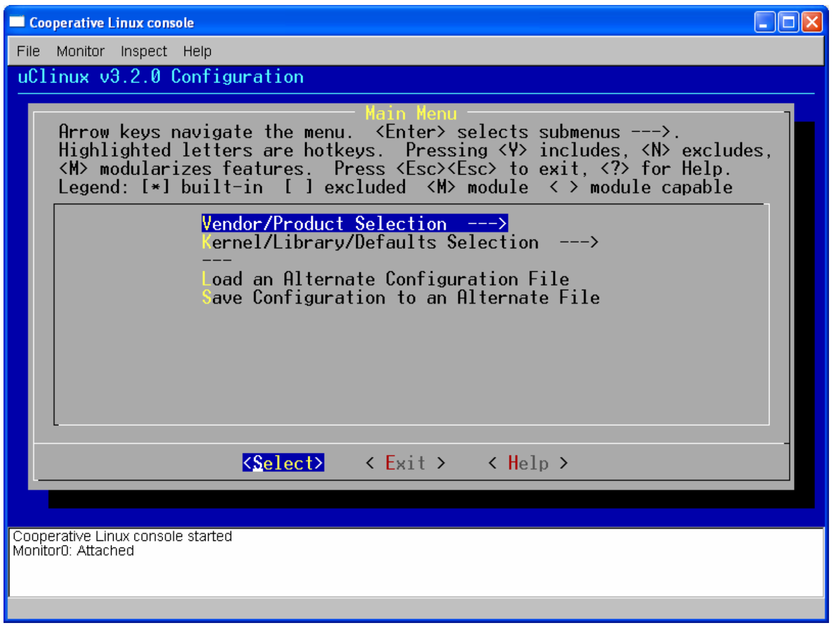
Fig. 3.17 Booted Kernel

3.5 The uClinux Kernel

As the uClinux kernel contains a lot of different functionality, some of which was required and some which was not, an optimum kernel had to be configured and complied for use in this project.

3.5.1 Configuring and Compiling the uClinux Kernel

The latest version of uClinux for the BF548 was downloaded from the Blackfin website [76]. This source code was unpacked in coLinux using the *"tar"* command as explained earlier. To configure the uClinux kernel to be compiled, the *"make menuconfig"* command was used in coLinux whilst inside the uClinux directory. This command runs a menu script; this menu script is then used to configure the uClinux kernel, as shown in Fig. 3.18.

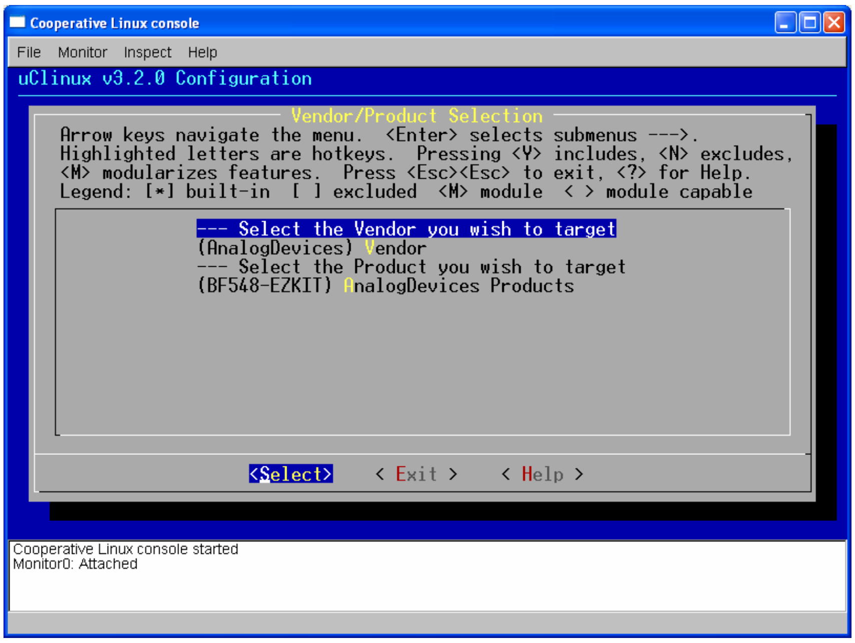


```
uClinux v3.2.0 Configuration
                                 Main Menu
  Arrow keys navigate the menu.  <Enter> selects submenus --->.
  Highlighted letters are hotkeys.  Pressing <Y> includes, <N> excludes,
  <M> modularizes features.  Press <Esc><Esc> to exit, <?> for Help.
  Legend: [*] built-in  [ ] excluded  <M> module  < > module capable

              Vendor/Product Selection  --->
              Kernel/Library/Defaults Selection  --->
              ---
              Load an Alternate Configuration File
              Save Configuration to an Alternate File

                   <Select>    < Exit >    < Help >
```

```
Cooperative Linux console started
Monitor0: Attached
```

Fig. 3.18 Main Menu for Configuring the uClinux Kernel

As can be seen in Fig. 3.18, the main menu offers four options, Vendor/ Product and Kernel/ Library selections, and the option to load or save configurations files. The first option is used to set which vendor of board being used, i.e. Analog Devices, and which product, i.e. BF548. As the uClinux kernel can be compiled for many different types of processors, it is essential to select the correct vendor and product to ensure operation. The selection used in this project is shown in Fig. 3.19.

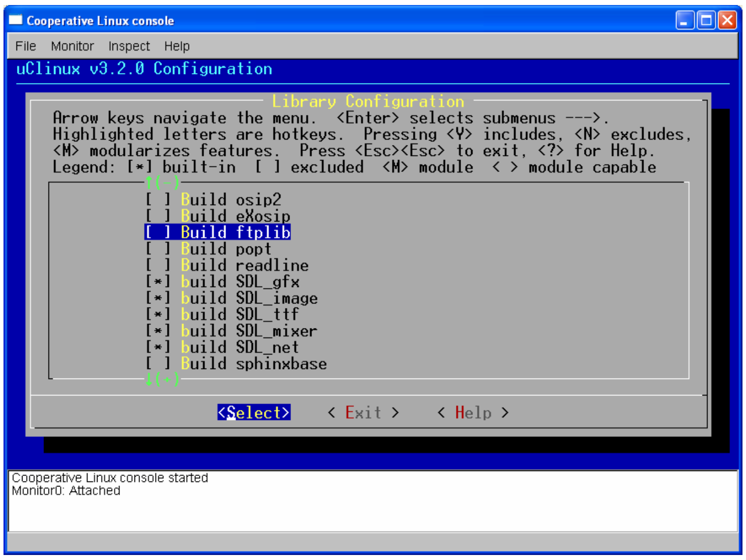


```
uClinux v3.2.0 Configuration
                          Vendor/Product Selection
  Arrow keys navigate the menu.  <Enter> selects submenus --->.
  Highlighted letters are hotkeys.  Pressing <Y> includes, <N> excludes,
  <M> modularizes features.  Press <Esc><Esc> to exit, <?> for Help.
  Legend: [*] built-in  [ ] excluded  <M> module  < > module capable

              --- Select the Vendor you wish to target
              (AnalogDevices) Vendor
              --- Select the Product you wish to target
              (BF548-EZKIT) AnalogDevices Products

                   <Select>    < Exit >    < Help >
```

```
Cooperative Linux console started
Monitor0: Attached
```

Fig. 3.19 Selecting Vendor and Product

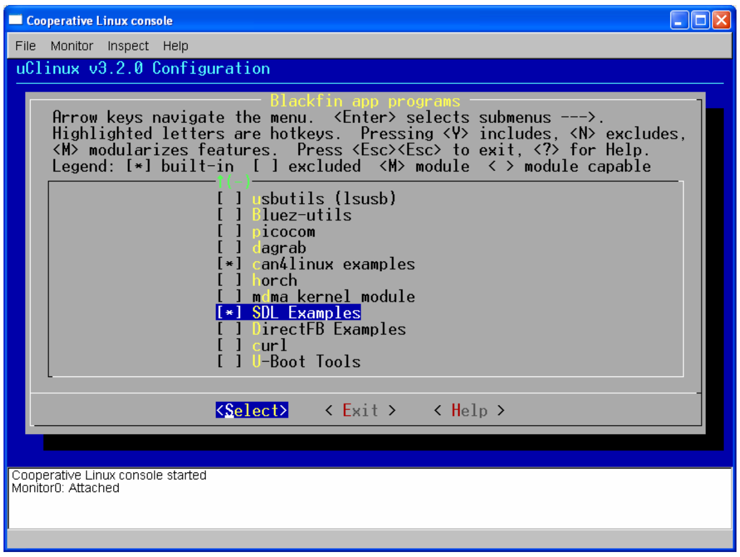
The second option offered on the main screen is used to configure the libraries and functionality included in the uClinux kernel. Inside this option, the choice to reconfigure the current kernel configuration is offered. If the user chooses to reconfigure the current kernel configuration, many pages of options will be displayed. Using these options the user can select the desired functionality in the kernel.



```
uClinux v3.2.0 Configuration
                      Library Configuration
  Arrow keys navigate the menu.  <Enter> selects submenus --->.
  Highlighted letters are hotkeys.  Pressing <Y> includes, <N> excludes,
  <M> modularizes features.  Press <Esc><Esc> to exit, <?> for Help.
  Legend: [*] built-in  [ ] excluded  <M> module  < > module capable
            ↑(-)
            [ ] Build osip2
            [ ] Build eXosip
            [ ] Build ftplib
            [ ] Build popt
            [ ] Build readline
            [*] build SDL_gfx
            [*] build SDL_image
            [*] build SDL_ttf
            [*] build SDL_mixer
            [*] build SDL_net
            [ ] Build sphinxbase
            ↓(+)

              <Select>    < Exit >    < Help >

Cooperative Linux console started
Monitor0: Attached
```

Fig. 3.20 Including SDL Library Files

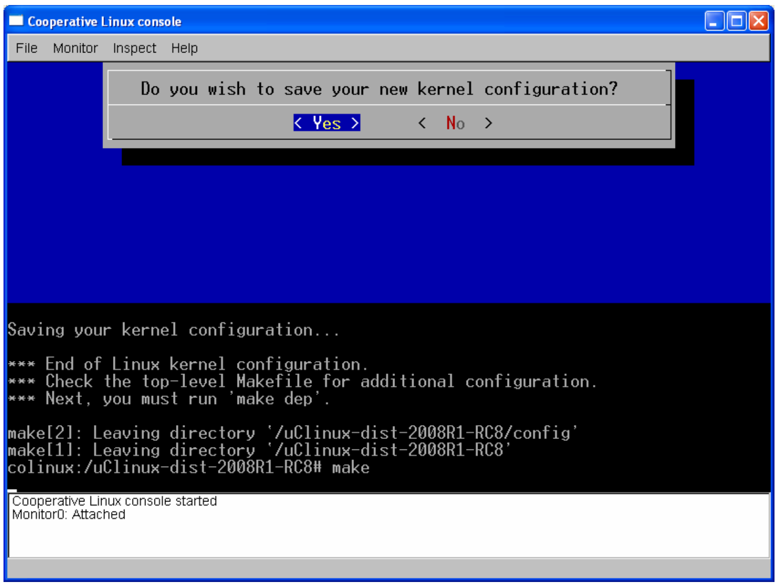
As explained in the literature review, SDL and CAN were required for the final system in this project. It was, therefore, important that all of the available SDL and CAN functionality were included in the new kernel as shown in Fig. 3.20 and Fig. 3.21.



```
uClinux v3.2.0 Configuration
                      Blackfin app programs
  Arrow keys navigate the menu.  <Enter> selects submenus --->.
  Highlighted letters are hotkeys.  Pressing <Y> includes, <N> excludes,
  <M> modularizes features.  Press <Esc><Esc> to exit, <?> for Help.
  Legend: [*] built-in  [ ] excluded  <M> module  < > module capable
                   ↑(-)
                   [ ] usbutils (lsusb)
                   [ ] Bluez-utils
                   [ ] picocom
                   [ ] dagrab
                   [*] can4linux examples
                   [ ] horch
                   [ ] mdma kernel module
                   [*] SDL Examples
                   [ ] DirectFB Examples
                   [ ] curl
                   [ ] U-Boot Tools

              <Select>    < Exit >    < Help >

Cooperative Linux console started
Monitor0: Attached
```

Fig. 3.21 Including SDL and CAN Examples

After including all desired functionality, the new configuration was then saved and the *"make"* command is used to compile the new uClinux kernel as shown in Fig. 3.22.



```
Do you wish to save your new kernel configuration?

Saving your kernel configuration...

*** End of Linux kernel configuration.
*** Check the top-level Makefile for additional configuration.
*** Next, you must run 'make dep'.

make[2]: Leaving directory '/uClinux-dist-2008R1-RC8/config'
make[1]: Leaving directory '/uClinux-dist-2008R1-RC8'
colinux:/uClinux-dist-2008R1-RC8# make
```

```
Cooperative Linux console started
Monitor0: Attached
```

Fig. 3.22 Compiling New Kernel

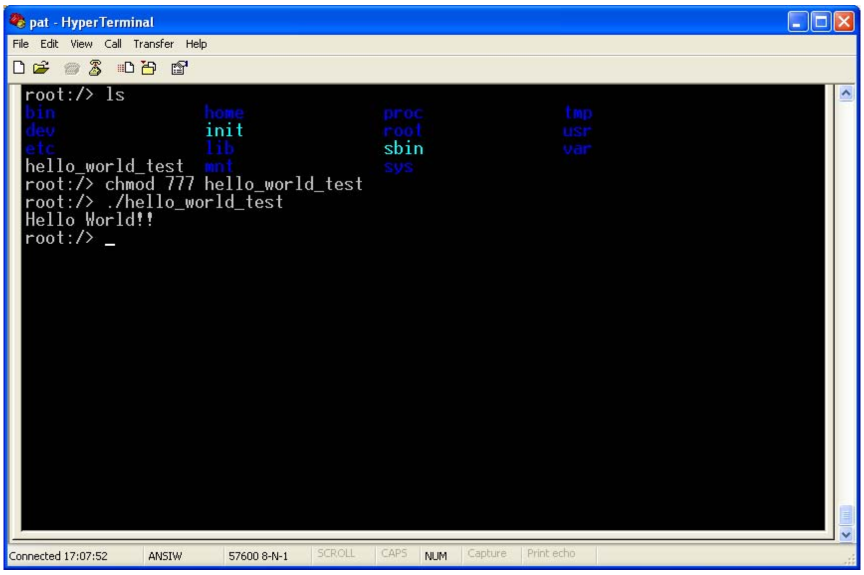
Once the kernel has compiled successfully, a new directory is created inside the uClinux directory. The new directory was named "images" and contained the newly compiled uClinux kernel (uImage). This uImage was then ported to the board and booted using U-Boot as before. With the new uClinux kernel running on the BF548 board a simple "hello world" program was used to test the new kernel's functionality.

3.5.2 Testing the new uClinux Kernel

The code for the "hello world" program was written in 'C'. This program was compiled and ported to the BF548. After porting the program to the board, its permissions had to be changed, such that the OS has permission to execute the file. To achieve this, the command *"chmod 777 hello_world_test"* is used. The chmod (change mode) command is used to change the access permissions of the file, 777 is a numerical way of settings all users' access rights to read, write and execute. The hello_world_test is the name of the compiled file.

After changing the access rights of the file, it was then run using the "*./hello_world_test*" command. When the program was run, its displayed "Hello

World!!” on the virtual console and hence proved that the new kernel was functioning properly, as seen in Fig. 3.23. After successfully testing the new uClinux kernel on the board, other programmes were then developed to run on the BF548 to check full functionality.



```
root:/> ls
bin                 home                proc                tmp
dev                 init                root                usr
etc                 lib                 sbin                var
hello_world_test    mnt                 sys
root:/> chmod 777 hello_world_test
root:/> ./hello_world_test
Hello World!!
root:/> _
```

Fig. 3.23 Running Hello World Test Program

3.6 CAN Functionality

The design and operation of the CAN program for this project, included editing the drivers in the kernel for the successful operation on the board. This is explained in the next sections.

3.6.1 Initial CAN Setup

The BF548 contains two CAN ports (CAN0 and CAN1); which are used to connect the board to an external CAN network. To access these ports, their drivers were included in the compiled uClinux kernel. As stated earlier, the BF548 board was the latest generation of Blackfin boards and therefore all of its functionality had not been fully tested. This became apparent when the CAN drivers failed to initialise the CAN ports. This lead to the CAN driver files being edited. It transpired that the kconfig file did not include the BF548 which lead to there been no CAN drivers included in this processor’s kernel. Investigating the kconfig file, it was noticed that the file contained three different Blackfin model numbers, none of which were the BF548 as shown below.

```
depends on CAN4LINUX && EMBEDDED && (BF534 || BF536 ||
BF537)
```

This observation was then passed back to Blackfin and it was discovered that the BF548 CAN driver was not actually included in the new kernel. Blackfin suggested making the following edits to the kconfig file of the CAN driver [58].

```
depends on CAN4LINUX && EMBEDDED && (BF534 || BF536 ||
BF537 || BF548)
```

After this change was made the driver was now available in the BF548 configuration file as shown below.

```
Character devices --->
    CAN, the car bus and industrial fieldbus  --->
     [*] can4linux support, the car bus and industrial fieldbus
     <M>   Analog Devices BlackFin CAN Controller
```

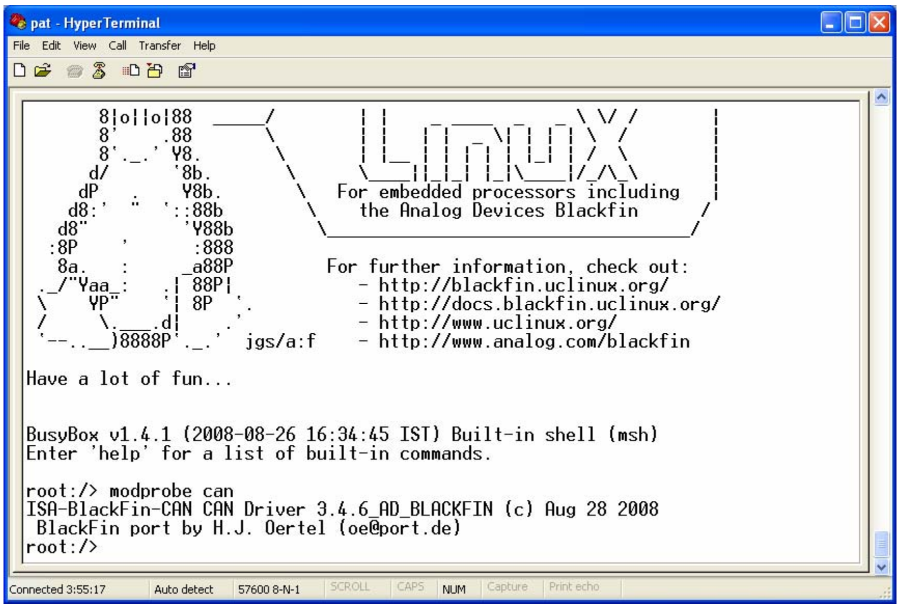
Note: The <M> means the driver will be a module in the kernel

With the "Analog Devices BlackFin CAN Controller" driver selected, the kernel was recompiled. During this compilation different errors were encountered. These errors were associated with one of the Blackfin CAN C programs (core.c). After investigating the program file it was noticed that the section for the BF548 looked incomplete and the missing values were consistent with the errors received. These results were passed to a moderator of the Blackfin website, who implemented the required changes such that the driver would work for the BF548.

3.6.1.1 Activating the CAN Driver

As the CAN driver is a module driver, it has to be loaded into the kernel. To do this the kernel must first be fully booted, and then the command "*modprobe can*" is used. Where "modprobe" is a program used to add and remove modules from the uClinux

Kernel [18]. After entering the command the CAN driver was activated and the confirmation of this was shown on the virtual console, Fig. 3.24. With this the CAN on the BF548 was ready for initial testing.

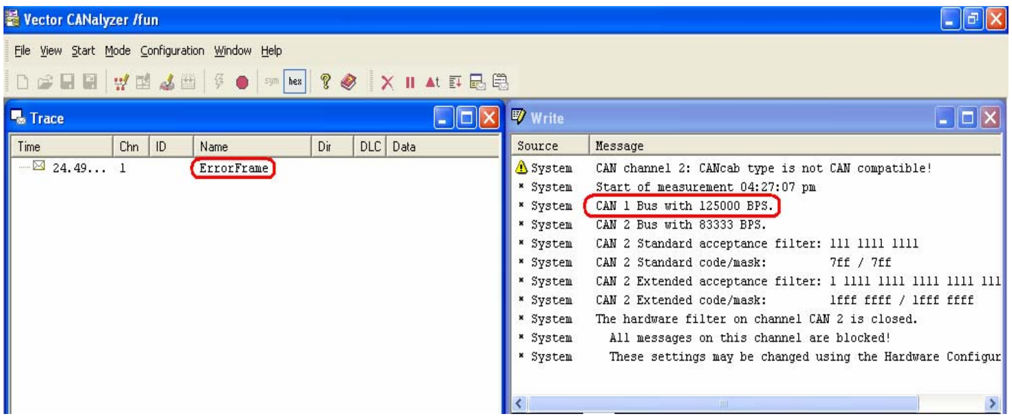


```
       8|o||o|88  _____/         | |    _ ____  _   _ \ \/ /      |
       8'    .88       \         | |   | |  _ \| | | | \  /       |
       8`._.' Y8.       \        | |___| | | | | |_| | /  \       |
      d/      `8b.       \       \_____|_|_| |_|\____|/_/\_\      |
     dP   .    Y8b.       \   For embedded processors including    |
    d8:'  "  `::88b        \    the Analog Devices Blackfin       /
   d8"         'Y88b        \___________________________________/
  :8P    '      :888
   8a.    :     _a88P        For further information, check out:
 ._/"Yaa_:   .| 88P|            - http://blackfin.uclinux.org/
 \    YP"    `| 8P  `.          - http://docs.blackfin.uclinux.org/
 /     \.___.d|    .'           - http://www.uclinux.org/
 `--..__)8888P`._.'  jgs/a:f    - http://www.analog.com/blackfin

Have a lot of fun...


BusyBox v1.4.1 (2008-08-26 16:34:45 IST) Built-in shell (msh)
Enter 'help' for a list of built-in commands.

root:/> modprobe can
ISA-BlackFin-CAN CAN Driver 3.4.6_AD_BLACKFIN (c) Aug 28 2008
 BlackFin port by H.J. Oertel (oe@port.de)
root:/>
```

Fig. 3.24 Activating the CAN driver

3.6.2 Initial Testing

CAN sample code, with a baud rate of 125kbps, was provided in the uClinux kernel and was used to test the CAN communications between the BF548 and a mikroElektronica EasyPIC 4 board. On initial testing it was found that no communication was achieved between both devices. CANalyzer, the automotive industries standard tool for CAN network development and analysis, was used to monitor the traffic on the CAN bus. It was first connected to the EasyPIC 4 board at the specified baud rate (125kbps) and communications without errors was achieved. When CANalyzer was connected to the BF548 at the specified baud rate, error messages were detected on the CAN bus, Fig. 3.25.



```
Vector CANalyzer /fun
File  View  Start  Mode  Configuration  Window  Help

Trace
Time      Chn  ID  Name        Dir  DLC  Data
24.49...  1        ErrorFrame

Write
Source   Message
System   CAN channel 2: CANcab type is not CAN compatible!
System   Start of measurement 04:27:07 pm
System   CAN 1 Bus with 125000 BPS.
System   CAN 2 Bus with 83333 BPS.
System   CAN 2 Standard acceptance filter: 111 1111 1111
System   CAN 2 Standard code/mask:         7ff / 7ff
System   CAN 2 Extended acceptance filter: 1 1111 1111 1111 1111 111
System   CAN 2 Extended code/mask:         1fff ffff / 1fff ffff
System   The hardware filter on channel CAN 2 is closed.
System     All messages on this channel are blocked!
System     These settings may be changed using the Hardware Configur
```

Fig. 3.25 Error Frames at 125kbaud

It was believed that these errors were due to the baud rate setting on the BF548 being incorrect.

3.6.2.1 Baud Rate Error

The bus between the BF548 and CANalyzer was probed using an oscilloscope to look at the signal voltage and frequency, as seen in Fig. 3.26.

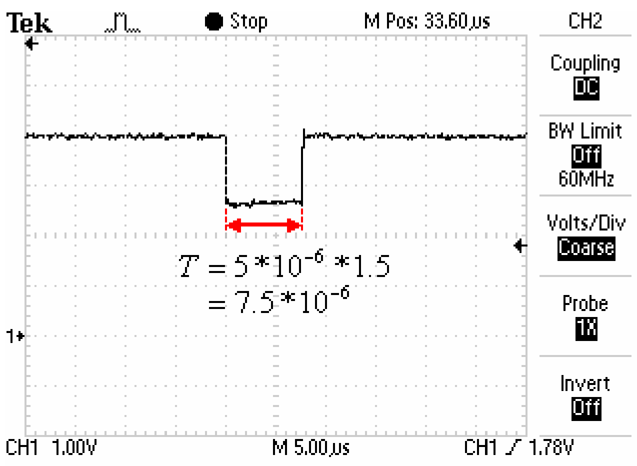


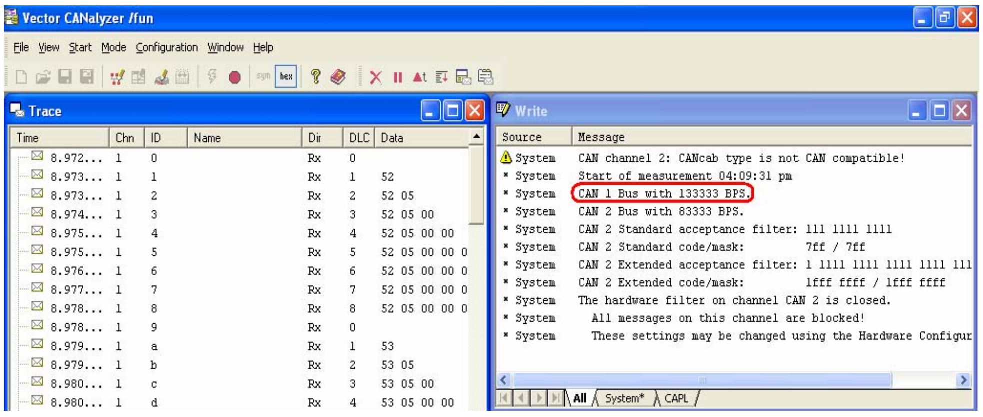
Fig. 3.26 CAN signal from BF548

With the value of the time period of the CAN signal determined to be approximately 7.5µs, the value of frequency was then calculated.

$$f = \frac{1}{T} = \frac{1}{7.5*10^{-6}} = 133.33Kbps$$

(3.1)

Setting the baud rate on CANalyzer to the calculated frequency, 133kbps, allowed communications without errors between the two devices, Fig. 3.27.



```
Time        Chn  ID   Name   Dir  DLC  Data
8.972...    1    0           Rx   0
8.973...    1    1           Rx   1    52
8.973...    1    2           Rx   2    52 05
8.974...    1    3           Rx   3    52 05 00
8.975...    1    4           Rx   4    52 05 00 00
8.975...    1    5           Rx   5    52 05 00 00 0
8.976...    1    6           Rx   6    52 05 00 00 0
8.977...    1    7           Rx   7    52 05 00 00 0
8.978...    1    8           Rx   8    52 05 00 00 0
8.978...    1    9           Rx   0
8.979...    1    a           Rx   1    53
8.979...    1    b           Rx   2    53 05
8.980...    1    c           Rx   3    53 05 00
8.980...    1    d           Rx   4    53 05 00 00
```

```
Source    Message
System    CAN channel 2: CANcab type is not CAN compatible!
System    Start of measurement 04:09:31 pm
System    CAN 1 Bus with 133333 BPS.
System    CAN 2 Bus with 83333 BPS.
System    CAN 2 Standard acceptance filter: 111 1111 1111
System    CAN 2 Standard code/mask:         7ff / 7ff
System    CAN 2 Extended acceptance filter: 1 1111 1111 1111 1111 111
System    CAN 2 Extended code/mask:         1fff ffff / 1fff ffff
System    The hardware filter on channel CAN 2 is closed.
System      All messages on this channel are blocked!
System      These settings may be changed using the Hardware Configur
```

Fig. 3.27 CAN RX at 133kbps

3.6.2.2 CAN Header Files

With the baud rate established to around 133kbps and not the desired 125kbps, the CAN header files for the BF548 were checked to ensure that the CAN variables were set to the correct values. The section of code which configured the CAN for 125kbps was found at line 480 of the header file.

```
#if CAN_SYSCLK == 125
{----- lines cut -----}
#define CAN_BRP_125K            49
#define CAN_TSEG_125K           0x002f
```

From the code above it can be seen that the BRP (Baud Rate Prescaler) is set to 49, also it can be seen that the value for TSEG is set to 0x002f. This hex number breaks down as follows,

	TSEG2	TSEG1
TSEG = 0x 0 0	2	F

The hex number above, shows that the value of TSEG2 is 0x2 (2_{10}) and the value of TSEG1 is 0xF (15_{10}). With these two values and the value of the propagation segment, which was set in the header file, the value of the NTQ (Number of Time Quanta) was established.

$$\begin{aligned} NTQ &= prop\_seg + TSEG1 + TSEG2 \\ &= \quad 3 \quad + \quad 15 \quad + \quad 2 \\ &= 20 \end{aligned} \tag{3.2}$$

Using the information ascertained from above and a system clock (SCLK) of 125MHz, as stated in product documentation, the baud rate was found as follows.

$$\begin{aligned} Baud\ \ Rate &= \frac{SCLK}{((BRP+1)*NTQ)} \\ Baud\ Rate &= \frac{125*10^6}{(50*20)} \\ Baud\ Rate &= 125kbps \end{aligned} \tag{3.3}$$

From above, the settings in the CAN configuration file should warrant the desired baud rate. Also from the header file, the values of the BRP and NTQ are known to be correct. From this information, it can be seen that the only variable not confirmed, and would cause the baud rate to be incorrect, is the system clock. Therefore the system clock must not be operating at 125MHz.

3.6.2.3 Editing the System Clock

Once it was discovered that SCLK was not running at the desired speed and after researching the Blackfin site yielded no answers, a post was placed on the Blackfin website [58]. From the replies received, it was discovered that the clock might have not been set correctly in the kernel. The easiest fix for this was to edit the system clock on boot up such that each time the kernel boots it sets all its clocks to 125Mhz, this in turn will set the correct baud rate. To do this, changes had to be made to the kernel configuration file. The system clock is determined using the following equation (3.4), [18].

$$SCLK = \frac{\left(\left(\frac{CLKIN}{2^{CLKIN\_HALF}}\right) * VCO\_MULT\right)}{SCLK\_DIV} \tag{3.4}$$

$$SCLK = \frac{\left(\left(\frac{25*10^{6}}{2^{0}}\right) * 20\right)}{4}$$

$$SCLK = \frac{500*10^{6}}{4} = 125*10^{6}$$

$$SCLK = 125MHz$$

Where:	CLKIN - The clock input frequency
	CLKIN_HALF - Cut input frequency in half
	VCO_MULT - Clock input multiplier
	CCLK_DIV - Core clock divider
	SCLK_DIV - System clock divider

Note: CLKIN_HALF can only be 1 or 0.

Once the changes were made in the kernel configuration file, it was recompiled and downloaded to the BF548. When the new kernel was booted, it froze. The kernel was recompiled, downloaded and booted once more yielding the same result but eliminating compilation errors. On researching this new issue it was discovered that the kernel version (2008R1) used contained a bug which caused the kernel to freeze while re-programming the clocks on boot-up.

This left two possible options;

(i) Upgrade to the latest kernel release

(ii) Edit the system clock in the current kernel

Careful deliberation resulted in the use of the second option, with a major factor being all previous development in the project to this time had worked with the current version of the kernel, and the newer kernel might involve newer problems.

There were two possible options in which to achieve the desired CAN baud rate;

(i) Change the clock in U-Boot and recompile it, so that it sets the system clock to 125MHz.

(ii) Edit the kernel's CAN header files so that it could take the current system clock and manipulate it to get the desired 125kbps baud rate.

It was decided that the second option would be the best, as all previous development had been working fine in the current kernel, and changing the system clock in U-Boot might lead to other problems. This option offered the benefits of a deeper understanding of CAN in uClinux.

To edit the CAN header files, the actual system clock frequency was required. This was established by checking the parameters in U-Boot. These parameters were stored in the BF548 U-Boot header file and were used in the following equation (3.5) to calculate the actual system clock.

$$SCLK = \frac{\left(\left(\frac{CLKIN}{2^{CLKIN\_HALF}}\right) * VCO\_MULT\right)}{SCLK\_DIV} \tag{3.5}$$

$$SCLK = \frac{\left(\left(\frac{25*10^6}{2^0}\right)*21\right)}{4}$$

$$SCLK = \frac{525*10^6}{4} = 131.25*10^6$$

$$SCLK = 131.25MHz$$

With the correct value of the system clock, equation 3.3 can now be used to find the value of the CAN baud rate.

$$
\begin{aligned}
Baudrate &= \frac{SCLK}{((BRP+1)*NTQ)} \\
&= \frac{131.25*10^6}{((49+1)*(3+15+2))} \\
&= \frac{131.25*10^6}{50*20} \\
&= 131.25kbps
\end{aligned}
\tag{3.6}
$$

From above it can be seen that CAN was actually running at 131.25kbps instead the desired 125kbps. With the value of the system clock at 131.25MHz and the desired CAN baud rate of 125kbps. Using these values, and using the initial value of BRP (49), as set in the CAN header file, then the value for NTQ can be established.

$$
\begin{aligned}
125*10^3 &= \frac{131.25*10^6}{((49+1)*NTQ)} \\
\Rightarrow 125*10^3 &= \frac{131.25*10^6}{(50*NTQ)} \\
&\Rightarrow NTQ*50 = 1050 \\
&\Rightarrow NTQ = 21
\end{aligned}
\tag{3.7}
$$

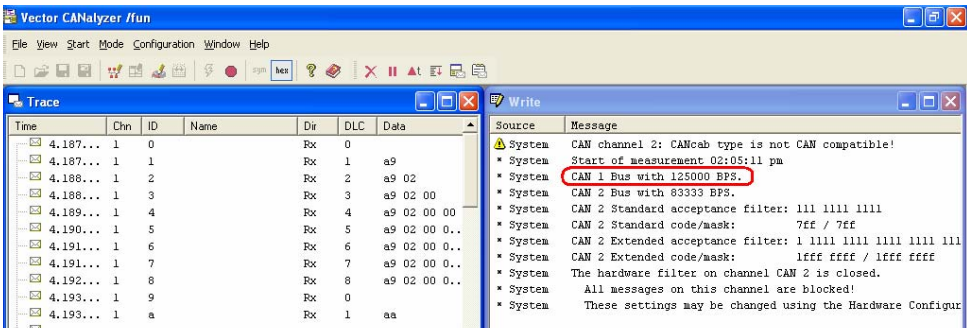
The desired NTQ was accomplished by setting TSEG1 = 15 and TSEG2 = 3 such that.

$$
\begin{aligned}
NTQ &= 3 + 15 + 3 \\
21 &= 3 + 15 + 3 \\
21 &= 21
\end{aligned}
\tag{3.8}
$$

The value of TSEG_125K in the CAN header file was then set to 0x003F, instead of 0x002F as shown below.

```
#if CAN_SYSCLK == 125
{----- lines cut -----}

#define CAN_BRP_125K          49
#define CAN_TSEG_125K         0x003f
```

The kernel was recompiled with the new edited header files and downloaded to the evaluation board resulting in the CAN network running at the desired 125kbps. Fig. 3.28 shows the output from the BF548 CAN port when connected to CANalyzer



```
Time        Chn  ID   Name   Dir  DLC  Data
4.187...    1    0           Rx   0
4.187...    1    1           Rx   1    a9
4.188...    1    2           Rx   2    a9 02
4.188...    1    3           Rx   3    a9 02 00
4.189...    1    4           Rx   4    a9 02 00 00
4.190...    1    5           Rx   5    a9 02 00 0..
4.191...    1    6           Rx   6    a9 02 00 0..
4.191...    1    7           Rx   7    a9 02 00 0..
4.192...    1    8           Rx   8    a9 02 00 0..
4.193...    1    9           Rx   0
4.193...    1    a           Rx   1    aa
```

```
Source   Message
System   CAN channel 2: CANcab type is not CAN compatible!
System   Start of measurement 02:05:11 pm
System   CAN 1 Bus with 125000 BPS.
System   CAN 2 Bus with 83333 BPS.
System   CAN 2 Standard acceptance filter: 111 1111 1111
System   CAN 2 Standard code/mask:         7ff / 7ff
System   CAN 2 Extended acceptance filter: 1 1111 1111 1111 1111 111
System   CAN 2 Extended code/mask:         1fff ffff / 1fff ffff
System   The hardware filter on channel CAN 2 is closed.
System     All messages on this channel are blocked!
System     These settings may be changed using the Hardware Configur
```

Fig. 3.28 CAN RX from BF548 at 125kbps

3.6.3 Testing CAN on the BF548

To test CAN on the BF548, the sample code inside the uClinux kernel was used. This sample code contained two programmes;

(i) can_send – This program is used to send CAN messages from the BF548 and has many different options for sending CAN messages.

(ii) receive – A program which is used to listen for CAN messages on the network. If a CAN message is received, it is displayed in the virtual console.

Each of the above programmes were tested individually and their results are explained below.

3.6.3.1 Testing the can_send program

To test the can_send program, the BF548 was connected to CANalyzer. Both CANalyzer and the BF548 baud rates were set to 125kbps. The can_send program offers many options to send CAN messages, including bursts of 10 or 20 messages, but for initial testing, single messages were sent using the command line. This method was chosen so that the user knows exactly what messages are sent and hence confirming the operation of can_send. The command used to send CAN messages is shown in Fig. 3.29.

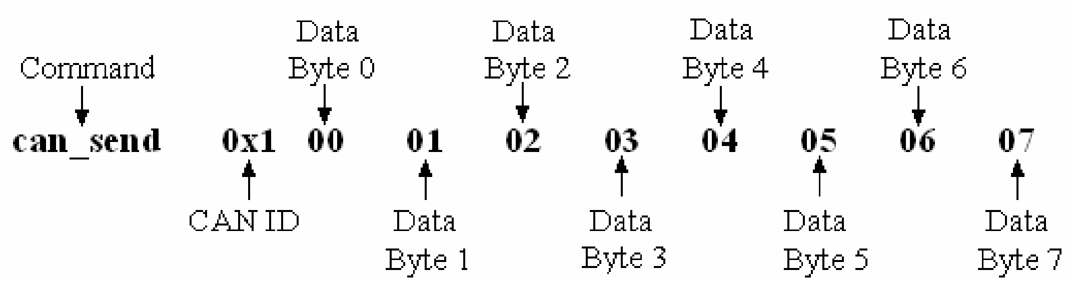
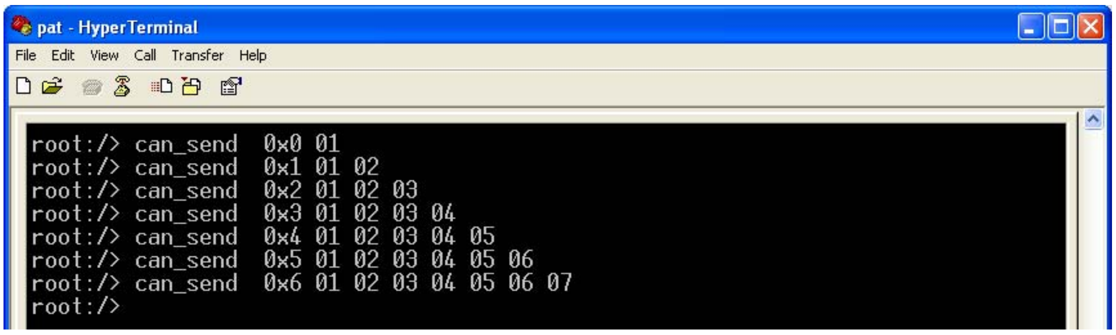


Fig. 3.29 can_send Command

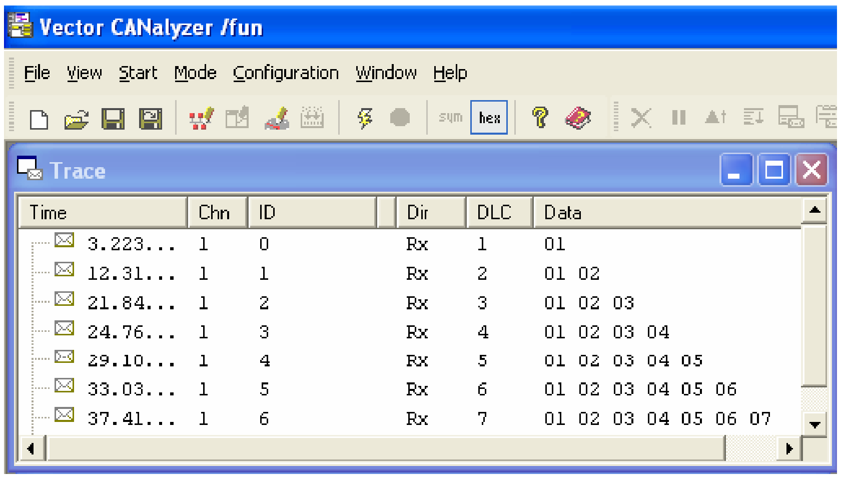
To test can_send, seven different CAN messages were sent from the BF548 using the command line as shown in Fig. 3.30.



```
root:/> can_send  0x0 01
root:/> can_send  0x1 01 02
root:/> can_send  0x2 01 02 03
root:/> can_send  0x3 01 02 03 04
root:/> can_send  0x4 01 02 03 04 05
root:/> can_send  0x5 01 02 03 04 05 06
root:/> can_send  0x6 01 02 03 04 05 06 07
root:/>
```

Fig. 3.30 Sending CAN messages using can_send

While sending the messages shown above, the following data was received by the CANalyzer, Fig. 3.31.



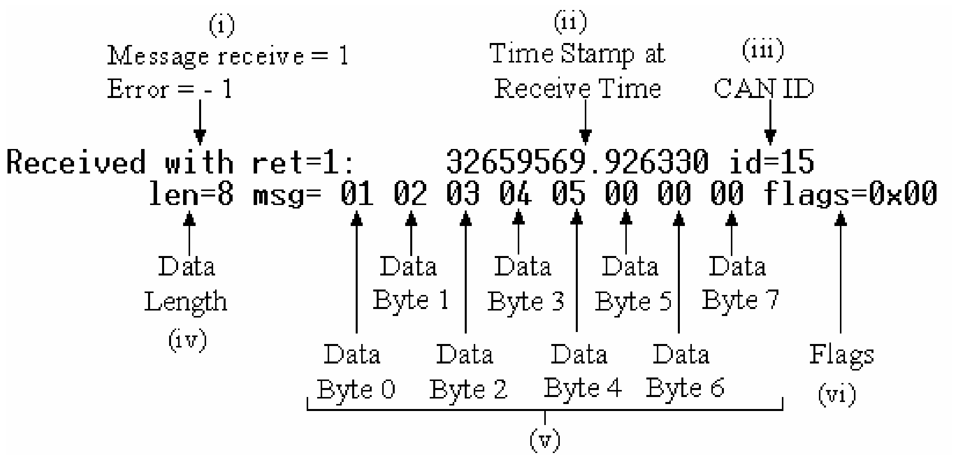
Time	Chn	ID	Dir	DLC	Data
3.223...	1	0	Rx	1	01
12.31...	1	1	Rx	2	01 02
21.84...	1	2	Rx	3	01 02 03
24.76...	1	3	Rx	4	01 02 03 04
29.10...	1	4	Rx	5	01 02 03 04 05
33.03...	1	5	Rx	6	01 02 03 04 05 06
37.41...	1	6	Rx	7	01 02 03 04 05 06 07

Fig. 3.31 Messages received on CANalyzer

Fig. 3.31 shows that all CAN messages that were sent from the BF548 were transmitted on the bus and received by CANalyzer correctly. The testing of the can_send program was complete, and was proved that the CAN communication was working successfully.

3.6.3.2 Testing the receive program

To test the receive program, both the BF548 and CANalyzer were connected and set to 125kbps. The receive program was then run on the BF548, whilst messages were transmitted on the CAN network using CANalyzer. The receive program monitored the CAN network and if any CAN messages were received, these were displayed on the virtual console. An example of a typical display is shown in Fig. 3.32.

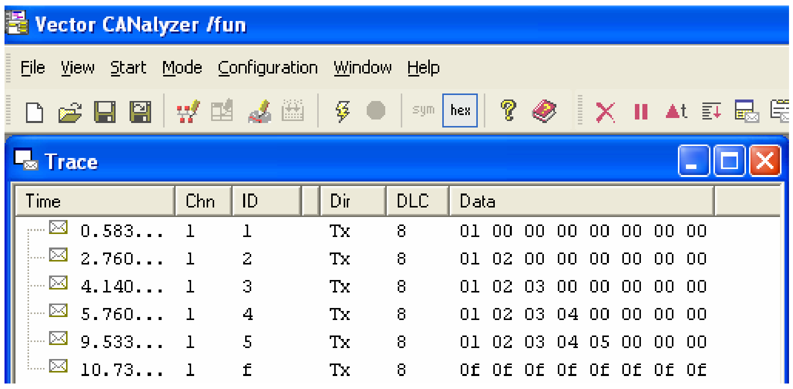


```
Received with ret=1:     32659569.926330 id=15
        len=8 msg= 01 02 03 04 05 00 00 00 flags=0x00
```

Fig. 3.32 Example of Received Message

The received messages comprises of six different parts;

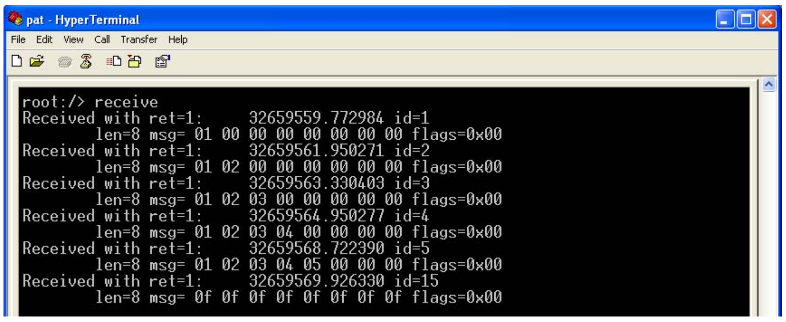
(i)	Received with ret	– Used to signal if a message has been received. If a message is received with no errors this will equal 1, if there is errors it will equal -1
(ii)	Receive time	– Displays the board's time stamp when the message was received
(iii)	CAN ID	– Displays the CAN ID. The CAN ID for this program was displayed in decimal
(iv)	Data Length	– Displays the data length of the CAN message
(v)	Data Bytes	– Display the data contained in the CAN message, this was displayed in hex
(vi)	Flags	– Displays flags associated with the CAN message



Time	Chn	ID	Dir	DLC	Data
0.583...	1	1	Tx	8	01 00 00 00 00 00 00 00
2.760...	1	2	Tx	8	01 02 00 00 00 00 00 00
4.140...	1	3	Tx	8	01 02 03 00 00 00 00 00
5.760...	1	4	Tx	8	01 02 03 04 00 00 00 00
9.533...	1	5	Tx	8	01 02 03 04 05 00 00 00
10.73...	1	f	Tx	8	0f 0f 0f 0f 0f 0f 0f 0f

Fig. 3.33 Messages used to Test the Receive Program

To test the receive program, messages were sent using CANalyzer, as shown in Fig. 3.33, these were received by the BF548 and displayed on the virtual console, Fig. 3.34.



```
root:/> receive
Received with ret=1:     32659559.772984 id=1
        len=8 msg= 01 00 00 00 00 00 00 00 flags=0x00
Received with ret=1:     32659561.950271 id=2
        len=8 msg= 01 02 00 00 00 00 00 00 flags=0x00
Received with ret=1:     32659563.330403 id=3
        len=8 msg= 01 02 03 00 00 00 00 00 flags=0x00
Received with ret=1:     32659564.950277 id=4
        len=8 msg= 01 02 03 04 00 00 00 00 flags=0x00
Received with ret=1:     32659568.722390 id=5
        len=8 msg= 01 02 03 04 05 00 00 00 flags=0x00
Received with ret=1:     32659569.926330 id=15
        len=8 msg= 0f 0f 0f 0f 0f 0f 0f 0f flags=0x00
```

Fig. 3.34 Messages Received using receive program

All the messages sent using CANalyzer were received, with no errors, on the BF548. With testing complete, an edited version of the receive program was used later in this project. This edited program uses the data received in the CAN messages to change the information displayed on the BF548's LCD Panel (Implementation and Testing chapter).

3.7 Simple Directmedia Layer

Initial testing of the Simple Directmedia Layer (SDL) was performed using the SDL software provided in the uClinux kernel.

3.7.1 Graphical Representations

The objective of this project was to create a flexible digital display, therefore it was decided that two different forms of graphical representations would be used to display information.

(i) A digital representation of a standard instrument display configuration. This configuration contained two dials, a speedometer (speed) and a tachometer (rpm).

(ii) A digital bar chart. This would display the speed in the form of a bar chart along with any error messages that were ascertained from the CAN network.

During early development and testing of both SDL programs, a random number generator was used to change both the speed and rpm. Both programmes were written and tested individually. Later in the project, both programmes were combined with the data from the CAN network being used to dictate the variables currently dictated by the random number generator (see Implementation and Testing section).

3.7.2 Digital Representation of a Standard Dash Configuration

The Digital Dash configuration was based on the analog dials used in the majority of cars presently. This configuration contained both a speed dial and an rpm dial.

3.7.2.1 Graphics Creation

The two dials were created using a graphics editor. However some considerations had to be assessed before creating the graphics for the dash configuration. After researching the available options, key decisions were made with the design layout such that:

(i) An image file would be created for each increment in speed or rpm for each dial. This decision was made due to the heavy computational needs of SDL to rotate an image. To overcome the amount of memory required to store all the images, each image was stored as a PNG (Portable Network Graphics) file, which offers very good compression ratios when compared to other standard image file types.

(ii) The speed dial would also be in a separate file to that of the rpm dial such that one of each would be called by SDL, thus reducing the memory used to store the files. If both dials were in the same image, then multiple versions of the fixed speed with different rpm would be required and vice versa.

Once these decisions were made, the dials were then created. Each incremental image of a dial was achieved by rotating the needle by one degree in the image editing software. The following diagram is the image used to represent the speed at 0 mph, Fig. 3.35.

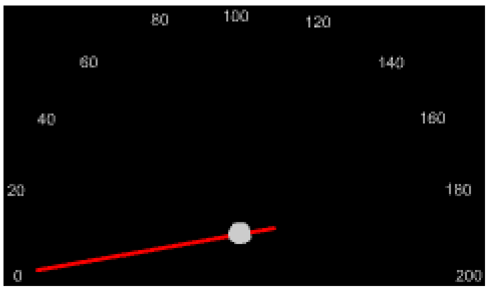


Fig. 3.35 Speed dial at 0 mph

The rpm dials were created such that they would be slightly smaller in size and also using a different background colour. This was merely for variation on the screen. The following diagram is the image used to represent rpm at 0 rpm, Fig. 3.36.

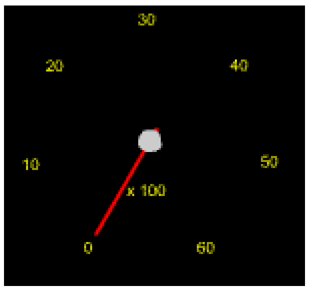


Fig. 3.36 rpm dial at 0 rpm

The SDL code called one image of each dial. Fig. 3.37 shows the display for a speed of 0 mph and rpm of 0 rpm.

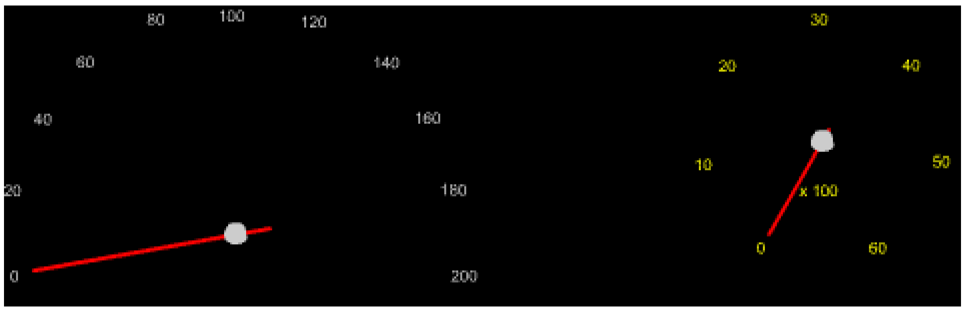


Fig. 3.37 End users display

3.7.2.2 Initial SDL Code (Analog Dials)

Initial SDL code was very basic and only included one dial, the speed dial at first. This program used a for loop to go from 0mph to 5mph. The speed was set using a variable in the for loop i.e. if the variable “i” is equal to zero then the speed displayed on the screen was 0 mph. A flow chart for the program is shown in Fig. 3.38.

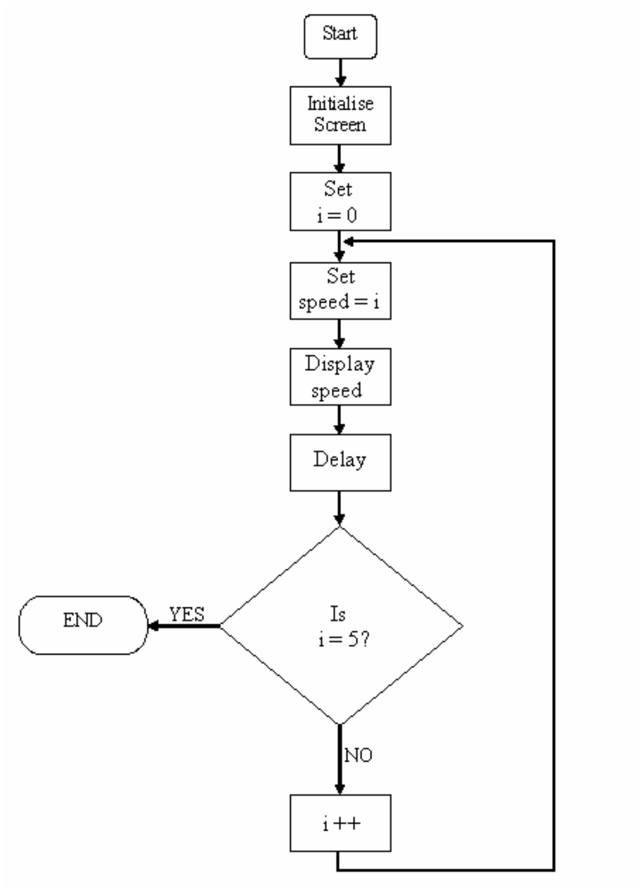


Fig. 3.38 Flow Chart of Basic SDL Dial program

To implement the flow chart above, the following code was used.

```
for (i=0;i<=5;i++)
{
     sprintf(mph, "%d.png", i);
     message1 = IMG_Load( mph );
     apply_surface( 0, 0, message1, screen );
     if( SDL_Flip( screen ) == -1 )
            {
            return 1;
            }
     SDL_delay(del);
     SDL_FreeSurface( message1 );
}
```

The variable *message1* is initialised as an SDL surface, the desired image is then loaded into a variable. The 2nd line of the code places the string x.png into the variable *mph*, where *x* is equal to the value of *i*, e.g. if i = 3, then 3.png is stored in the variable. It is the variable *mph* which is then used to load the desired image. This image is then applied to the screen surface, where the variable *screen* is an SDL surface which is set to the dimensions of the actual screen on the BF548 evaluation board. The two zeros in the "apply_surface" function, represent where the image is applied, pixel 0 horizontally and pixel 0 vertically i.e. the top left hand corner of the screen. The "SDL_Flip" function displays the image in memory onto the evaluation board's screen. If this returns "-1" then the code will exit. A delay was introduced when displaying each image, such that the images do not change so abruptly that the human eye can not distinguish each step of the needle. Lastly the surface is freed to facilitate the loading of the next image into the variable *message1*.

3.7.2.3 Using a Random Number Generator to Vary the Speed

As the speed will not vary linearly in reality, it was necessary to test the code using a random number generator. The two major differences needed in the code when using a random number generator are:

(i) As a random number generator will not vary linearly in a given direction, the code requires the capability to both increase and decrease the speed displayed relative to the previous number generated.

(ii) The code will have to increment/decrement the speed on the screen so that the dial doesn't just jump, for example, from 25mph to 12mph, hence the code will have to include some form of stepping mechanism.

To overcome the issues explained above an "if else" statement was used to distinguish the direction of the speed and is shown below.

```
mph_value = rand() % 140;
if(mph_value < last_mph)
                {
```

```
               last_mph = last_mph - 1;
               }
else if (mph_value > last_mph)
               {
               last_mph = last_mph + 1;
               }
sprintf(mph, "%d.png", last_mph);
```

The value of *mph_value* is set by the random number generator, where %140 sets 140 as its maximum value. The value of *last_mph* is initially set to zero. On the first iteration of the loop, *mph_value* will always be greater than *last_mph*, so the speed will increase, in steps of 1mph, until the value of *last_mph* equals that of *mph_value*. When this occurs a new value will be generated for *mph_value* and depending on whether it is greater or smaller than *last_mph*, the speed will either increase or decrease.

After fully testing the code used to display the speed dial, the same code was implemented for the rpm dial. With both programmes running as desired independently, the next step was to integrate both programmes into one.

3.7.2.4 Integrated Dial Code

As SDL is a sequential language, the code needs to run such that each dial will rotate concurrently rather than the speed dial running to completion, then the rpm dial running. As seen in Fig. 3.39 the code still runs sequentially, however each needle will only rotate one increment and then the next needle will rotate one increment, and so on. When one needle has run to completion and the dial displays the desired information, the other needle will then run constantly until it has completed. When both dials display the information received from the random number generator, new values for the speed and the rpm are then generated. Due to the delay between each needle rotation being so diminutive, the human eye can not distinguish when one needle is rotating and the other isn't. This visually leads to concurrency in both the dials. To achieve this, a "do – while" loop was used.

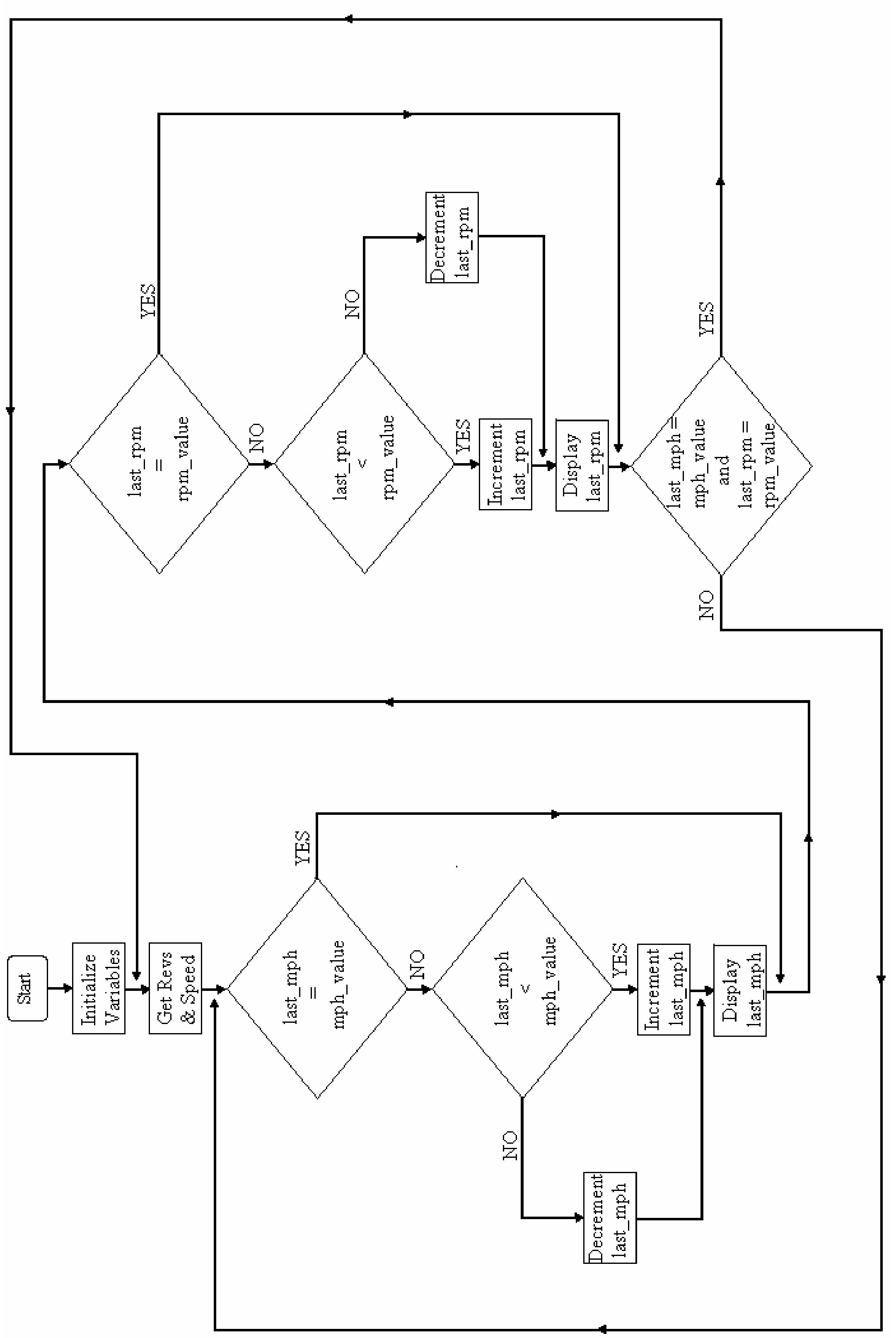


Fig. 3.39 Flow Chart for Integrated Dial Code

```
do{
        if(rpm_finished != 1)
        {
         // Display rpm

         if(last_rpm == rpm_value)
               {
               rpm_finished = 1;
               }
         }

         if(mph_finished != 1)
         {
          // Display mph

         if(last_mph == mph_value)
               {
               mph_finished = 1;
               }
         }

  }
while((rpm_finished != 1) || (mph_finished != 1));
```

The code uses two variables; *mph_finished* and *rpm_finished*, both of which are initialised to zero. These variables were used to flag when the corresponding needle had run to completion, i.e. when the mph dial displays the desired speed, *mph_finished* is then set to 1. To accomplish this an "if" statement was used such that, if the variable *last_mph* was equal to the variable *mph_value*, set by the random number generator, then *mph_finished* is set. When this occurs the rpm needle will now rotate to completion and hence set *rpm_finished* to 1. The ending expression for the "do-while" states that when *rpm_finished* is set, OR (||) *mph_finished* is set then exit the loop. A truth table for a logical OR is shown below, where A and B are inputs and X is the output.

A	**B**	**X**
0	0	0
0	1	1
1	0	1
1	1	1

Table 3.3 Logical OR Truth Table

The truth table above shows that only when both A and B are false, will X also be false. This is the same principle in the code, only when *rpm_finished* is false and *mph_finished* is false, will the ending expression be false and hence the code will exit the “do-while” loop. In the code the ending expression states “rpm_finished != 1”, this statement is always true (1) until the rpm needle has reached the desired rpm. When the needle has run to completion it will then set *rpm_finished* to 1 and hence make the rpm side of the ending expression false (0). When the mph needle has run to completion it will do the same and set the ending expression to be false thus exit the “do-while” loop.

The dials code was now successfully running as desired using the random number generator. This code was later used with CAN messages, so that the CAN message varied the speed and rpm on the dials rather than the random number generator. This will be discussed later in this document (Implementation and Testing chapter).

3.7.3 Digital Bar Chart Representation

The digital bar chart contained both a bar chart that represented the speed and also an error message area, which would display any faults transmitted on the CAN network. The idea being, if there were no faults requiring the user’s attention then the dials display would be used. However, if a fault was introduced then the screen would drop its dials configuration (speed and rpm), and display just the speed using the bar chart configuration with its error message area clearly displaying the fault. In this section all testing was preformed using the bar chart and later in this document, testing will be performed on the dials and bar chart combined (Implementation and Testing chapter).

3.7.3.1 Graphics Creation

The approach used to create the bar chart in SDL was slightly different than that used for the dials. The bar chart configuration required a background bar chart with tiny coloured bars placed on top to represent the speed. An advantage of this approach is it required a very small amount of memory to save the images as the coloured bars are minute. By displaying the bar chart in this fashion it proved that there are many different ways to program the display. The bar chart design used for the project can be seen in Fig. 3.40.

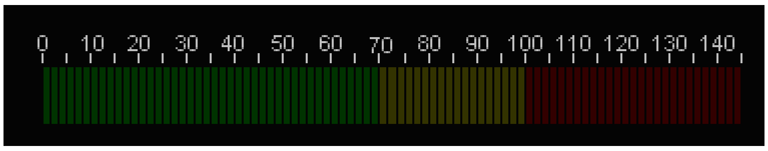


Fig. 3.40 Bar Chart

It was decided that as the speed increased the bars on the display would change colour such that;

(i) Any speed less than 70 mph was displayed in green (Fig. 3.41)

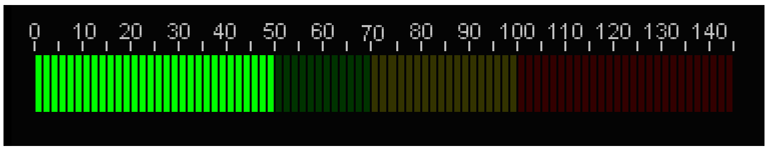


Fig. 3.41 Speed below 70mph

(ii) Any speed less than 100 mph but greater than 70 mph was displayed in yellow (Fig. 3.42)

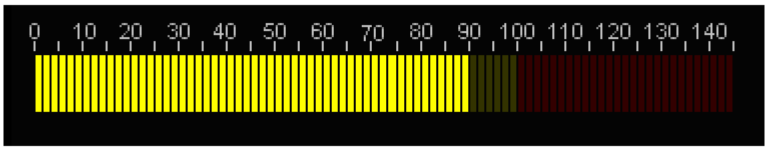


Fig. 3.42 Speed greater than 70mph and below 100mph

(iii) Any speed over 100 mph was displayed in red (Fig. 3.43)

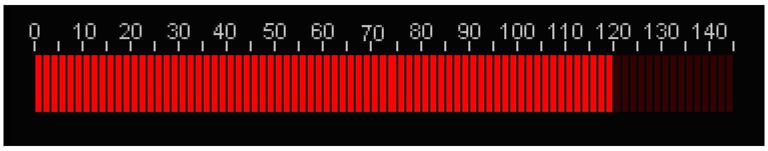


Fig. 3.43 Speed greater than 100mph

To fill the bar chart the same coloured bar is placed multiple times over the background, therefore instead of creating an image for each speed as in the dials code, only one red, one green and one yellow bar was required. When displaying error messages it was decided to place the error message in the same image as the background bar chart such that, if an error was to be displayed it would be part of the background. Three different errors were created for testing purposes and an example of one is shown in Fig. 3.44.

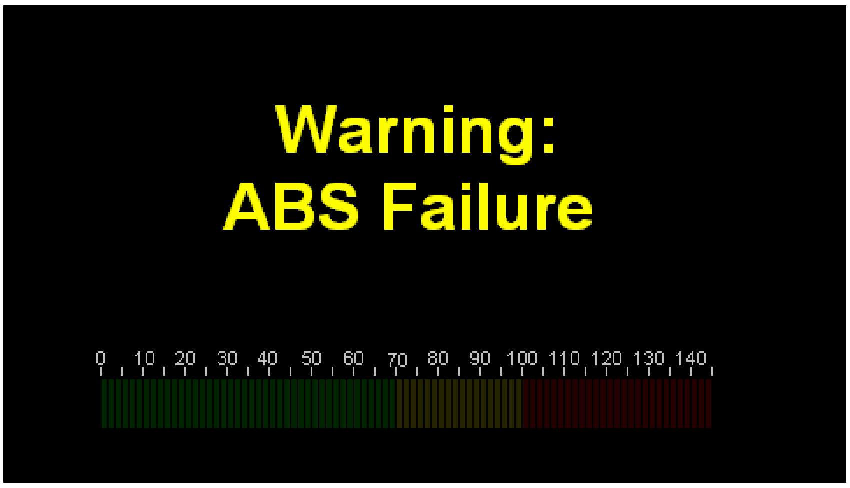


Fig. 3.44 Bar Chart with Error Message

3.7.3.2 Initial SDL Code (Bar Chart)

Initial code written for the bar chart design, was used to prove that using one image as a background and imposing another image on top to represent the speed was possible. The implemented code was as follows.

```
message = IMG_Load( "green.PNG" );
background = IMG_Load( "basic_dial_black.PNG" );

    //Apply the background to the screen
apply_surface( 0, 0, background, screen );
    //Apply the message to the screen
apply_surface( 50, 122, message, screen );
apply_surface( 54, 122, message, screen );
apply_surface( 58, 122, message, screen );
apply_surface( 62, 122, message, screen );
```

The program code above loads two images, the bar chart (“background”) and the green coloured bar (“message”). The background is placed at location 0, 0 of the screen (top left hand corner) and then the green bar is placed in 4 different locations, each of which are 4 pixel apart horizontally. This 4 pixels shift represents the distance between each bar in the bar chart, as shown in Fig. 3.45.

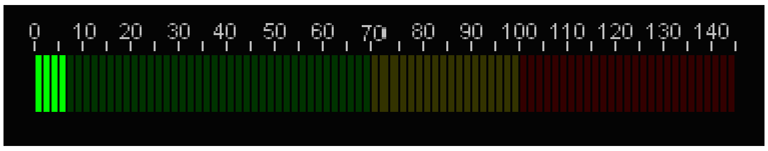


Fig. 3.45 Output from Initial Code

The code implementation and testing above proved that it was possible to layer images on top of other images in SDL.

3.7.3.3 Basic Bar Chart Code

Initial development and testing of the bar chart used a “for” loop to vary the speed. The “for” loop was used to vary the required number of bars to be displayed rather than each mph increment i.e. due to the scale on the bar graph, each bar represents 1.6mph. During initial testing the bar chart background with no error messages was used, these will be introduced later in this section. The objective of the basic code was to increment the speed from 0 bars to 5 bars, i.e. 8mph. A flow chart for the program is shown in Fig. 3.46.

When writing the program code it was decided that each time the speed was updated and displayed on the bar chart, the background would also be reloaded. This was to accommodate later error message development i.e. when errors are introduced, the code will check for errors between increments/decrements of the speed. If an error occurs, the background representing that particular error message would then be displayed. No delay was introduced when reloading the background; therefore the human eye could not observe this. Similarly when the speed is incrementing/decrementing each bar is refreshed on the screen but again due to the refresh rate the human eye can not identify this. A flowchart of the program code is shown in Fig. 3.46.

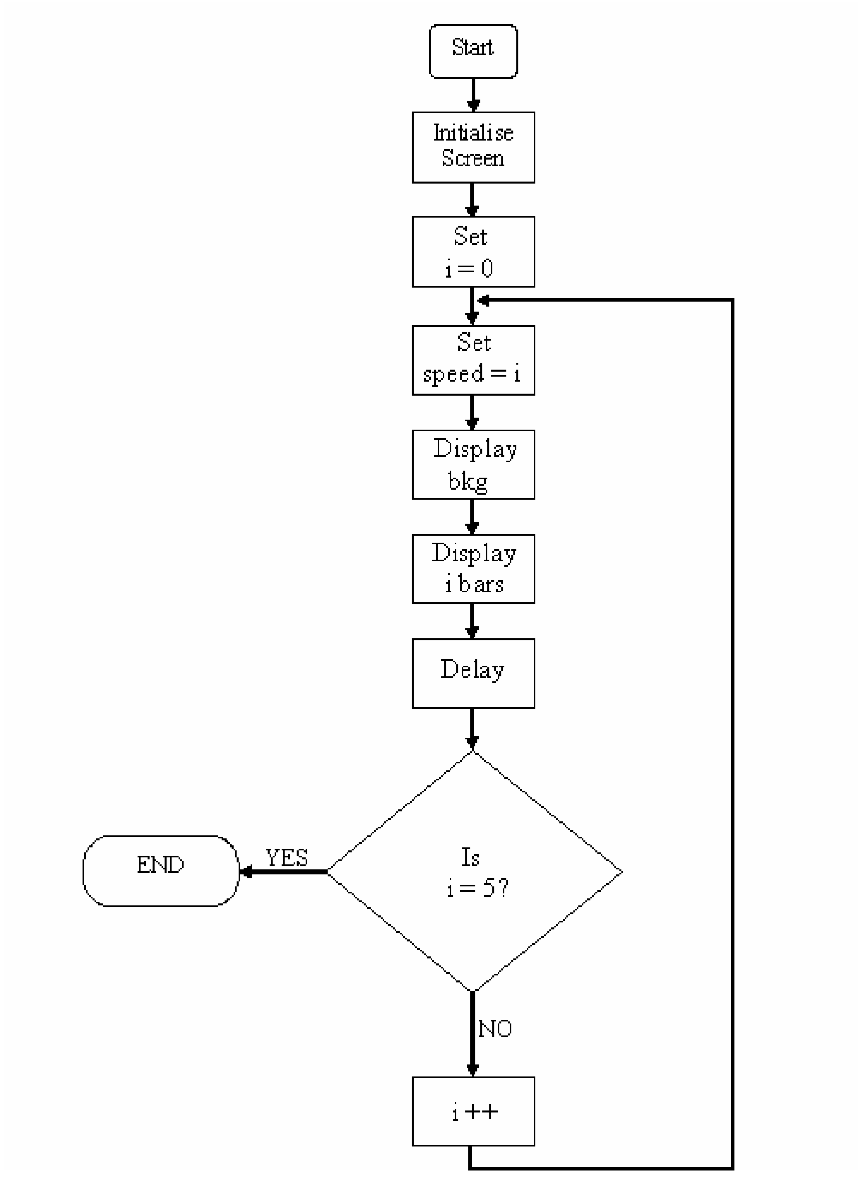


Fig. 3.46 Basic Bar Chart Flow Chart

The code used to implement the flow chart in Fig. 3.46 is shown below.

```
for (s=0;s<=5;s++)
    {
    background = IMG_Load( “bground.PNG” );
    message1 = IMG_Load( "green.PNG" );
    apply_surface( 0, 0, background, screen );
    for (k=0;k<=s;k++)
    {
```

```
    apply_surface( j, 212, message1, screen );
    j=j+4;
    }
    if( SDL_Flip( screen ) == -1 )
    {
        return 1;
    }
    SDL_Delay( del );
    SDL_FreeSurface( message1 );
    SDL_FreeSurface( background );
    j = 56;
    }
```

The code above contains two “for” loops. The first “for” loop was used to generate the speed, and the second “for” loop was used to display the desired speed. The code uses the variable *k* to count from 0 to the value of the variable *s*, which holds the value of the desired speed. The value stored in *k* is the number of bars required to represent the speed. Inside the loop the variable *j* is used to distinguish where each bar is to be placed on the screen. *j* is initialised to 56, which is the starting point of the bar chart, and each time a new bar is placed onto the screen, 4 is added to *j* such that the next bar will be placed 4 pixels to the right of the last. This loop will then run until the value in *k* is equal to that in *s*. When this occurs the code displays the desired speed and then delays so that the eye can see the change in speed.

3.7.3.4 Changing the Bar Colour with Speed

As mentioned earlier the bar chart design required different ranges of speeds to be displayed with different coloured bars. To accomplish this, the change over values in speed and bars was required. This information is represented in Table 3.4.

Bar Colour	Green	Yellow	Red
Speed (mph)	0 - 70	70 - 100	100 – 145
No. of Bars	0 - 41	42 - 59	59 – 88

Table 3.4 Change Over Values of Coloured Bars

With the information above, “if” statements were used in the code so that the colour of the bars used to display the speed, changed for different ranges of speed. These statements are shown below:

```
if ((s>=0) && (s<42))
                       {
                       //use green bars
                       }
else if ((s>=42) && (s<60))
                       {
                       //use yellow bars
                       }
else if ((s>=60) && (s<88))
                       {
                       //use red bars
                       }
```

The only additional change now needed to the basic code was to load the appropriate coloured bar, i.e. change the image to be loaded (e.g. yellow.PNG or red.PNG) in the following line of code:

```
message1 = IMG_Load( "green.PNG" );
```

3.7.3.5 Decrementing the Speed

With the speed bars incrementing and changing bar colour as desired, the code would be required to decrement the speed also. This was achieved by editing the basic code previously discussed in this document to add the decrementing functionality. The changes made to the code are shown below.

```
for (s=5;s>=0;s--)
      {
      background = IMG_Load( bground );
      message1 = IMG_Load( "green.PNG" );
```

```
apply_surface( 0, 0, background, screen );
for (m=1;m<s;m++)
{
apply_surface( j, 212, message1, screen );
j=j+4;
}
```

The code above sets the initial speed to 5 and decrements to zero; it is the first "for" loop, based on the variable *s*, which sets the speed. The second "for" loop, based on the variable *m*, sets how many coloured bars are used to display the speed. Comparing this loop to that used for incrementing the speed there is a slight change. The variable *m* "for" loop sets the number of bars to be displayed; therefore if the loop used for incrementing was the same as that for decrementing, then the actual speed displayed would be two bars off the actual speed. To eliminate this problem, *m* was set equal to 1 rather than zero, and the loop was set to terminate when *m* is equal to *s*.

3.7.3.6 Using a Random Number Generator to Vary the Speed

As speed does not vary linearly in a vehicle, it was necessary to test the code using a random number generator. When using a random number generator the code must be capable of increasing and decreasing the speed accordingly. This was accomplished as shown in the flow chart in Fig. 3.47.

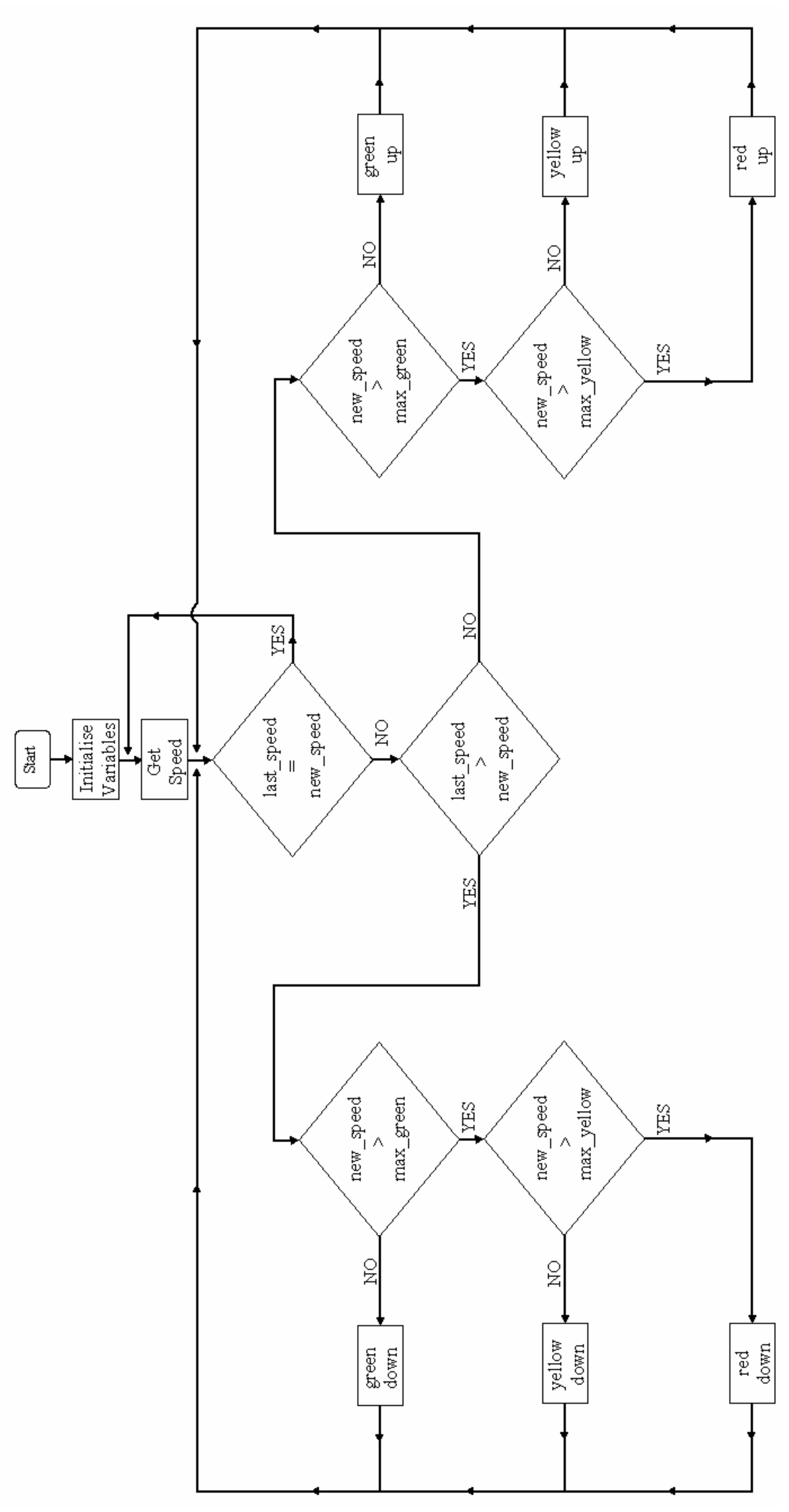


Fig. 3.47 Flow Chart for Bar Chart Representation of Speed

The flow chart illustrates that several conditions must be met before choosing which function to run in the code. To accomplish this “if” statements were used and are shown below:

```
if ((i>=0) && (i<42) && (t>i))
                       {
                       green_up;
                       }
              else if ((i>=0) && (i<42) && (t<i))
                       {
                       green_down;
                       }
              else if ((i>=42) && (i<60) && (t>i))
                       {
                       yellow_up;
                       }
              else if ((i>=42) && (i<60) && (t<i))
                       {
                       yellow_down;
                       }
              else if ((i>=60) && (i<88) && (t>i))
                      {
                       red_up;
                       }
               else if ((i>=60) && (i<88) && (t<i))
                       {
                       red_down;
                       }
```

In the code the variable *i* represents the value *last_speed* and the variable *t* represents the value *new_speed*.

```
else if ((i>=42) && (i<60) && (t>i))
```

The line of code above states, that if the last speed is greater than or equal to 42 (minimum value for the bar colour to be yellow) and less than 60 (maximum value for the bar colour to be yellow), and if the new speed is greater than the last speed, then use the function ‘yellow_up’. It can be seen in the last condition, if the new speed is greater than the last speed displayed, then the number of bars must be incremented to display the new speed. Also with the values falling inside the yellow range, the function executed will be the ‘yellow_up’ function.

The “for” loop now had an added stipulation requiring it to perform the loop until the correct speed is reached. The “for” loop below is taken from the ‘yellow_up’ function, but each function has their own appropriate “for” loop.

```
for (s=i;((s<60)&&(s<t));s++)
```

The “for” loops inside the functions, use the variables set by the random number generator. When the program enters a function, in this case ‘yellow_up’, it first sets the variable *s* to the value of the last speed, this value of *s* can be anything from 42 to 60 as the program is inside this particular function. Next the “for” loop checks that the last speed is less than 60 (max. yellow value) and less than the new speed. To accomplish this, a logical AND was used, for which a truth table is shown in Table 3.5, where A and B are inputs and X is the output.

A	**B**	**X**
0	0	0
0	1	0
1	0	0
1	1	1

Table 3.5 Logical AND Truth Table

Using this in the “for” loop inside the condition, when the value of the variable *s* increases above the maximum value of the yellow bars (60) then the first stipulation (s<60) becomes false and hence the program exits this conditional statement. Also if the value of the variable *s* is not less than the value of variable *t*, i.e. last speed is equal to the new speed, then the code will also exit the function. Looking at the flow chart in Fig. 3.47 it can be seen that if the value of last speed (variable *s*) is greater than the maximum value for the yellow bars then the code will enter the ‘red_up’ function. Once the value of last speed (variable *s*) is equal to that of the new speed (variable *t*), then the random number generator will generate a new speed.

3.7.3.7 Displaying Error Messages with the Bar Chart

With the bar chart displaying the speed as desired from the random number generator, the last functional requirement to be met for the bar chart was to display error messages on the screen. Using the random number generator to generate the speed, it was decided to prompt the user to select the error message at the start of the program. This decision was made due to only a small number of error message screens being created for testing purposes. The code to select the error messages is shown below.

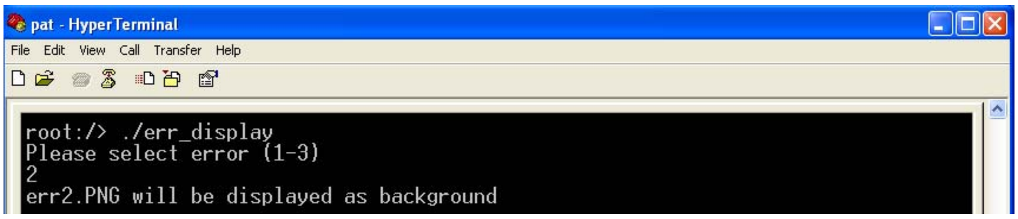
```
printf("Please select error (1-3)\n");
scanf("%d", &err);
sprintf(bground, "err%d.PNG", err);
printf("%s    will    be    displayed    as    background\n",
bground);
```

The program code above prompts the user to select an error message between 1 and 3. The value entered by the user is then initialised to an integer. This integer sets the number of the error file, i.e. if the user enters the number 2, then the string err2.PNG will be saved in the variable *bground*. A table of the error messages is shown in Table 3.6.

Filename	Description
err1.PNG	Basic Bar Chart with no errors
err2.PNG	Back left tyre pressure low
err3.PNG	ABS Failure

Table 3.6 Bar Chart Error Screens

When executing the code, the following was displayed on the virtual console.



```
root:/> ./err_display
Please select error (1-3)
2
err2.PNG will be displayed as background
```

Fig. 3.48 Users Prompt for Selecting Errors

From Fig. 3.48, the error selected was error 2; this in turn was displayed on the BF548's screen, as shown in Fig. 3.49.

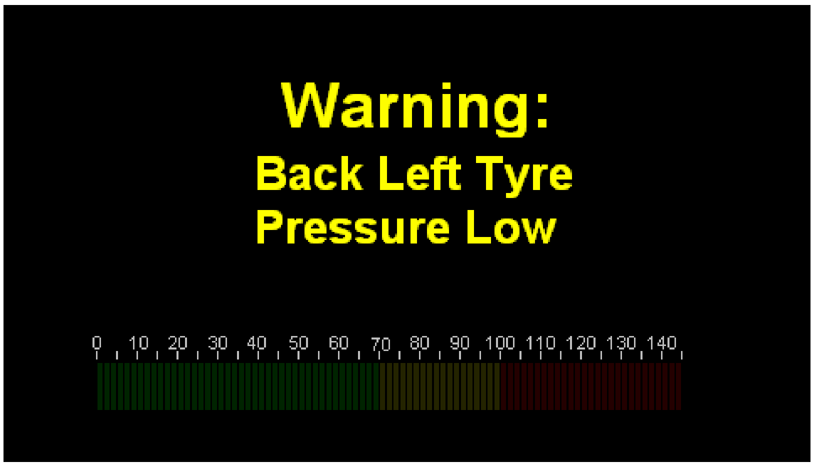


Fig. 3.49 Background set as Error 2

The bar chart code was now producing the desired functionality using the random number generator. This program code was then used with CAN messages, such that the CAN message would vary the speed on the bar chart rather than the random number generator and the CAN ID would set the error message to be displayed. This is discussed later in this document (Implementation and Testing chapter).

3.8 Inter Process Communications

The Inter Process Communications (IPC) used in this project is called Named Pipes, which allows for communications between running processes in the uClinux kernel, namely, the CAN and the SDL processes. When using pipes, one has to be able to write to a pipe and read from the same pipe. This involves writing two different pieces of code as explained below.

3.8.1 Writing to a Pipe

As Named Pipes was used in the project the first thing that had to be accomplished was to name and create the actual pipe used.

3.8.1.1 Naming and Creating a Pipe

The name of the pipe is created by using a “#define” in C code. The name of the pipe being used for the initial test was “RECFIFO”; receive FIFO (First In First Out). To name the pipe, the following line of code was used:

```
#define RFIFO_FILE "RECFIFO"
```

The line above sets the name of RFIFO_FILE to be “RECFIFO”; this was then used to create the Named Pipe, to name the actual pipe. To create the pipe the following line of code was used:

```
mknod(RFIFO_FILE, S_IFIFO | 0666, 0);
```

To create a Named Pipe the mknod() function must be used. When using the mknod(), three arguments have to be passed to the function; the first argument is the desired name of the Named Pipe. As RFIFO_FILE is defined as the desired name for this pipe, it is passed as the first argument. The second argument is the creation mode, in the example above the second argument is “S_IFIFO | 0666”, this line tells the mknod() function to create a Named Pipe (S_IFIFO) and sets the access permissions. In this case the access permission is 0666 which sets all users permissions to read and write. The last argument passed is a device number, as this is not used in Named Pipes it is set to zero [52].

3.8.1.2 Writing to the Created Pipe

When writing to a pipe, data is required to be put into the pipe. Later in the project this data was taken from the CAN network, but in the interim a simple string was used. To create the string the following line of code was used.

```
char mes[] = "Hello World\n";
```

The line of code above sets up a string called *mes* containing “Hello World”. To write the string to the pipe it first has to be opened.

```
fp = open(RFIFO_FILE, O_WRONLY);
```

The line above opens the pipe, RFIFO_FILE, and sets it to write only (O_WRONLY). A third argument can be added to the code above, known as the non-blocking option (O_NONBLOCK). This option allows the pipe to be opened for another write even if the current data has not been read. This option was not desired in this case and was not enabled in the code [52]. With the pipe open, it can be written to by using the following:

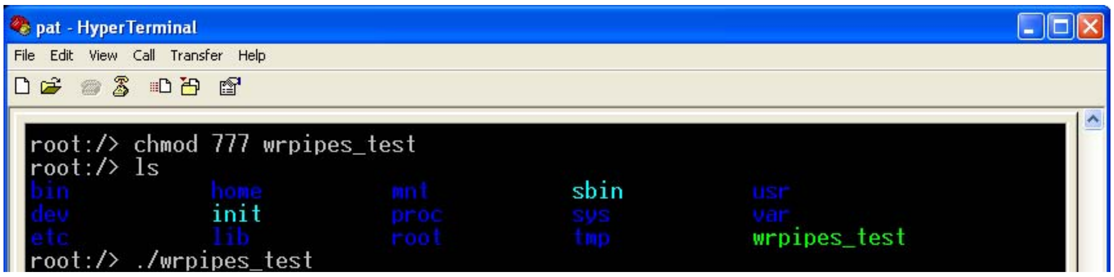
```
write(fp, mes, 12);
```

The write function above takes three arguments; firstly the file that the write function is to write to, in this case this is fp, which is the opened pipe. The second argument is the buffer the function has to write from; in this case the buffer will be the string *mes*. The last argument is the number of bytes of data to be written from the buffer, in this case 12. Lastly the pipe must be closed; this accomplished using the following:

```
close(fp);
```

Since the non blocking option was not enabled, this pipe can not be opened again until the data has been read from the pipe. This was desired for the project as it prevents any data being lost.

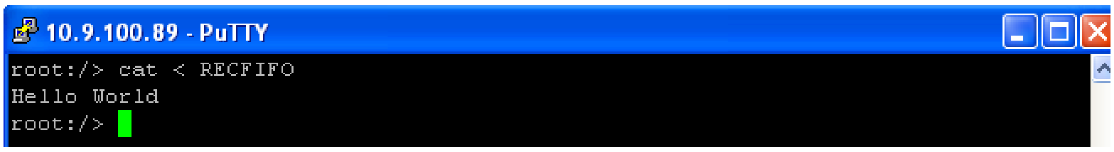
Once the program was ported to the BF548, its access rights were changed to make the program executable. The contents of the directory were then listed to show the write program was on the evaluation board (wrpipes_test). The program was then run as shown in Fig. 3.50.



```
root:/> chmod 777 wrpipes_test
root:/> ls
bin            home           mnt            sbin           usr
dev            init           proc           sys            var
etc            lib            root           tmp            wrpipes_test
root:/> ./wrpipes_test
```

Fig. 3.50 Running Write to Pipes code on BF548

When the program was executed, it created a pipe and wrote the string into it. The program waited until the pipe was read from, and then exited. As of yet no code had been written to read form the pipe. Instead the "cat" command was used to display the contents of a file; in this case the Named Pipe (RECFIFO). To display the contents of the Named Pipe the command "*cat < RECFIFO*" was used. The command was run on PuTTY to display the contents of the pipe, as the write pipes program was still running on the virtual console. The following was shown on the PuTTY screen, Fig. 3.51.



```
root:/> cat < RECFIFO
Hello World
root:/>
```

Fig. 3.51 Displaying the Contents of the Named Pipe

From Fig. 3.51, it can be seen that the pipe contained the string "Hello World", which was written to the pipe by the write to pipes program (wrpipes_test). This test proved that the write to pipes program was working correctly. Next code had to be written to read from a Named Pipe.

3.8.2 Reading from a Pipe

Reading from a Named Pipe is less difficult than writing to a Named Pipe, but both follow the same methodologies with the exception of a few minor steps. When reading from a Named Pipe the pipes name has to be defined in the code as explained earlier.

No Named Pipe has to be created when reading, however, the Named Pipe must be reopened. To open a Named Pipe for reading the following code is used.

```
fp1 = open(RFIFO_FILE, O_RDONLY);
```

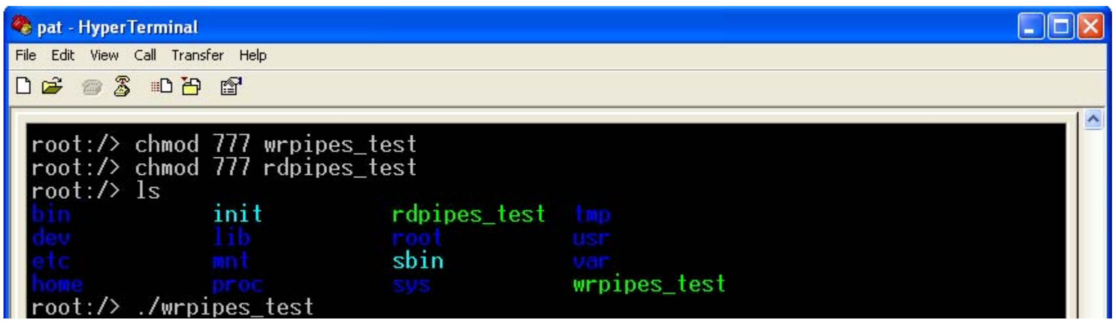
This Named Pipe was now set to be read only (O_RDONLY) when opening and again it can be seen that the non blocking option was not set, therefore the Named Pipe will be in blocking mode. With the Named Pipe open, the program can now read the file. This is accomplished using the following:

```
read(fp1, readbuf1, 12);
```

The line of code above read 12 bytes of data from the open pipe, *fp1*, and then placed the data in the buffer *readbuf1*, which was initialised as an array of 12 characters. After reading from the pipe, the pipe was again closed using the close function. Lastly, the contents of *readbuf1* were displayed to the user using:

```
printf("%s",readbuf1);
```

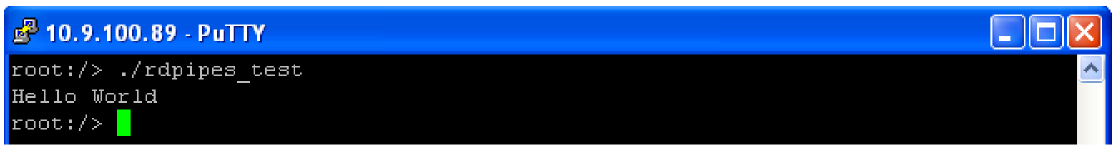
The code was compiled and ported, along with the write program (wrpipes_test) to the BF548 and the access permission of both programmes were changed. The contents of the directory were listed to show that both programmes were in the directory. The write program (wrpipes_test) was then executed using the virtual console as shown in Fig. 3.52.



```
root:/> chmod 777 wrpipes_test
root:/> chmod 777 rdpipes_test
root:/> ls
bin             init            rdpipes_test    tmp
dev             lib             root            usr
etc             mnt             sbin            var
home            proc            sys             wrpipes_test
root:/> ./wrpipes_test
```

Fig. 3.52 Running Write program in conjunction with Read program

At the same time, the read program (rdpipes_test) was run on PuTTY, the results of which are shown in Fig. 3.53.



```
root:/> ./rdpipes_test
Hello World
root:/>
```

Fig. 3.53 Read from Pipes

Fig. 3.53 shows that the read program (rdpipes_test) functioned properly and the string that was written into the pipe using the write program (wrpipes_test) was successfully read from the pipe. These methodologies were applied to the CAN and display programmes as discussed later in this document (Implementation and Testing chapter).

3.8.3 Disadvantages of Named Pipes

The main disadvantage of using Named Pipes is that integers can not be sent successfully through the pipe, instead the ASCII equivalent of the integers are sent. To send integers using a Named Pipe, the integers had to be converted into a string. This was not an issue in the example programs above as the only data sent were strings. To overcome this issue some extra lines of code had to be added to both the read and write programs.

3.8.3.1 Editing the Write Program to allow the Transmission of Integers

To send an integer using a Named Pipe, it must first be converted into a string and then sent through the pipe. To do this, the "sprintf" function was used.

```
int x;
char y[3];
sprintf(y, "%d", x);
```

The code initialises *x* as an integer and *y* as an array of 3 characters (string). The "sprintf" function, prints the integer value stored in *x* into the string *y*, i.e. if *x* was equal to 10, then 10 would be stored in the form of a string in *y*. Therefore *y* will contain 10 in string format. This format can now be sent using a Named Pipe.

3.8.4 Editing the Read Program to allow the Manipulation of Integers

The read program does not need to be edited to receive the integers in the string format. However the read program will only be able to display the integer in its string format. The string format of an integer was not the desired format; therefore the read program had to change the string version of the integer to an actual integer. This is accomplished using following line of code.

```
t = atoi(y);
```

The variable *t* is initialised to be an integer. The line of code above uses the "atoi" function to convert the string contained in *y* into an integer and then places into the variable *t*.

3.8.5 Testing the Transmission and Reception of Integers

To test the transmission and reception of integers using Named Pipes, the example code used in sections 3.8.1 and 3.8.2 were edited.

3.8.5.1 Editing the Write Program

The write program (wrpipes_test) was edited such that the user was prompted to enter an integer between 0 and 100. This integer was then converted into a string and written into the Named Pipe, RECFIFO, as shown below.

```
printf("Please enter a number between 0 and 100.\n");
scanf("%d", &i);
sprintf(mes, "%d", i);
fp = open(RFIFO_FILE, O_WRONLY);
write(fp, mes, 3);
```

```
close(fp);
```

The integer inputted by the user was stored in the variable *i*, which is then converted into a string and written into the Named Pipe.

3.8.5.2 Editing the Read Program

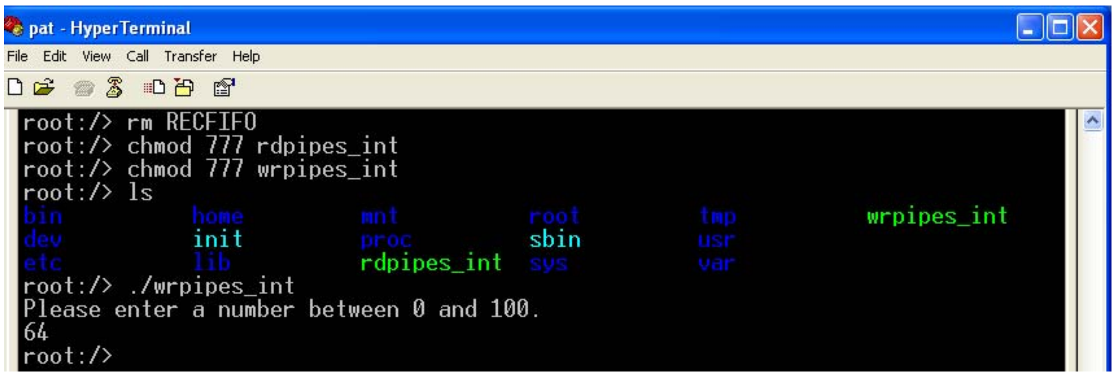
The read program (rdpipes_test) was also edited; such that the number the user entered in the write program would be displayed on the virtual console. This was achieved using the following:

```
fp1 = open(RFIFO_FILE, O_RDONLY);
read(fp1, readbuf1, 3);
close(fp1);
j = atoi(readbuf1);
printf("String: %s\n",readbuf1);
printf("Integer: %d\n",j);
```

This code reads the string from the Named Pipe, RECFIFO, and then stores it in the variable *readbuf1*. The contents of *readbuf1* is then converted into an integer and stored in the variable *j*. The string, *readbuf1*, and the integer, *j*, were both displayed on the virtual console to show the user that they were the same.

3.8.5.3 Running the Test Programmes

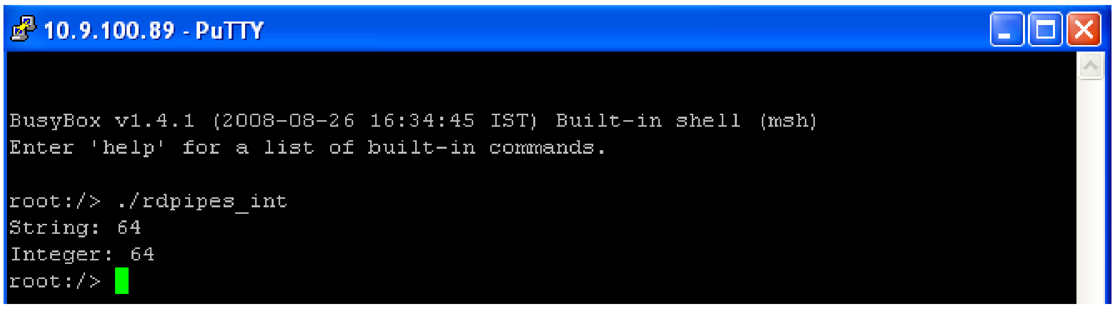
After editing the write and read programmes both were run on the BF548 evaluation board. The write program (wrpipes_int) was executed on the virtual console as shown below, Fig. 3.54.



```
root:/> rm RECFIFO
root:/> chmod 777 rdpipes_int
root:/> chmod 777 wrpipes_int
root:/> ls
bin           home          mnt           root          tmp           wrpipes_int
dev           init          proc          sbin          usr
etc           lib           rdpipes_int   sys           var
root:/> ./wrpipes_int
Please enter a number between 0 and 100.
64
root:/>
```

Fig. 3.54 User Prompt to enter Integer

As the write program was running on the virtual console, the read program (rdpipes_int) was running on PuTTY as shown, Fig. 3.55.



```
BusyBox v1.4.1 (2008-08-26 16:34:45 IST) Built-in shell (msh)
Enter 'help' for a list of built-in commands.

root:/> ./rdpipes_int
String: 64
Integer: 64
root:/>
```

Fig. 3.55 Output from Read Program

From Fig. 3.55, the number the user had entered in the write program i.e. 64, has been successfully sent through the pipe and converted back into an integer.

3.9 Summary

In this chapter the system design was taken from the problem definition and requirements, to a final system design. This chapter reviewed the methods used and choices made when configuring and designing the proposed system. The main points covered in this chapter were:

- The configuration of the development host, coLinux, which was used to compile all code that ran on the BF548.
- The compilation and porting of both U-Boot and uClinux to the evaluation board.

- The changes made to the CAN driver for proper execution on the BF548, along with the testing of the CAN sample code.
- The design of the display programmes in SDL, including the testing of the both the Analog Display and the Bar Chart configurations.
- The design methods used for Named Pipes as the IPC for the system, which included testing of basic Named Pipes programs.

The next chapter will discuss the implementation and testing of the final system using the design processes discussed in this chapter.

4 System Implementation and Testing

4.1 Introduction

This chapter outlines and explains all methods used during the system implementation and testing stage of this study. The chapter is divided into the following sections:

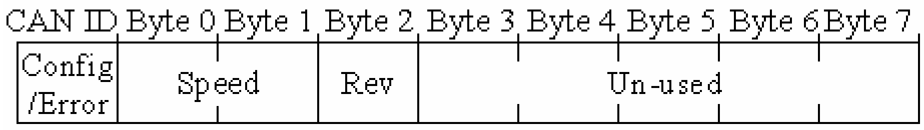
- Section 4.2 outlines the methods used when implementing the CAN process for the final system. This will include the manipulation of received data from the CAN network and the addition of Named Pipes to the CAN code.
- Section 4.3 describes the methodologies applied when implementing the SDL process in the final system. This included the integration of both SDL programs explained earlier. Also IPC were added to the SDL code to allow communications between the display and CAN processes
- Section 4.4 details the results found while testing the final system, and comments on these results.
- Section 4.5 shows the results found from stress testing the final system, and comments on these results.
- Section 4.6 provides a summary of information presented in this chapter.

4.2 CAN Implementation

The sample code supplied with the uClinux kernel was used to receive data from a CAN network. This code was edited such that the desired parts of the message would be parsed from the CAN message and, using Named Pipes, be sent to the SDL code. This sent data would then be manipulated and displayed on the BF548's LCD screen.

4.2.1 CAN Message Breakdown

The first step was to design the CAN message strategy to be used in conjunction with the SDL code. After some research it was discovered that there were no set standards or practices concerning CAN message data and the displaying of information. From this research it was discovered that automotive manufacturers use different bytes of the CAN message data to represent the speed, i.e. one manufacturer might use byte 4 and 5, while another might use byte 1 and 2. With no standard to adhere too, the selection of which bytes to use was completely the programmer's choice. The data bytes chosen for this project are shown in Fig. 4.1.



CAN ID	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7
Config /Error	Speed		Rev	Un-used				

Fig. 4.1 Breakdown of CAN message

The CAN ID was used to configure the screen layout e.g. to display either the digital dash or the bar chart configuration. The CAN ID would also set the error screen to be displayed if the bar chart configuration was chosen. Both bytes 0 and 1 were used to represent the speed and byte 2 was used to represent the rpm.

4.2.2 CAN Sample Code

The CAN sample code (receive) provided in the uClinux kernel was used for CAN communications between the BF548 and the CAN network. This code was already fully tested as explained earlier (CAN design section). A flow diagram for the receive program is shown in Fig. 4.2.

The receive program extracts both the CAN ID and the data length from the CAN message. Using the data length, the program executes a "for" loop to obtain each data byte from the received CAN message. When the variable *i* is equal to the data length, all the data bytes have been extracted from the message and the code will then await the next message.

Due to the layout of the code, it allows for easy extraction of the desired data for this project. As the CAN ID is stored in its own variable, this variable can be used to write the CAN ID into a Named Pipe. Likewise due to each data byte being stored in individual variables, e.g. data byte 0 from the first received CAN Message will be stored in the variable rx[0].data[0], this allows for the insertion of individual data bytes into a Named Pipes with relative ease.

Using the information gained above, the CAN receive sample code was then edited to add Named Pipes, so as to allow for Inter Process Communications (IPCs) between the CAN program and the SDL program.

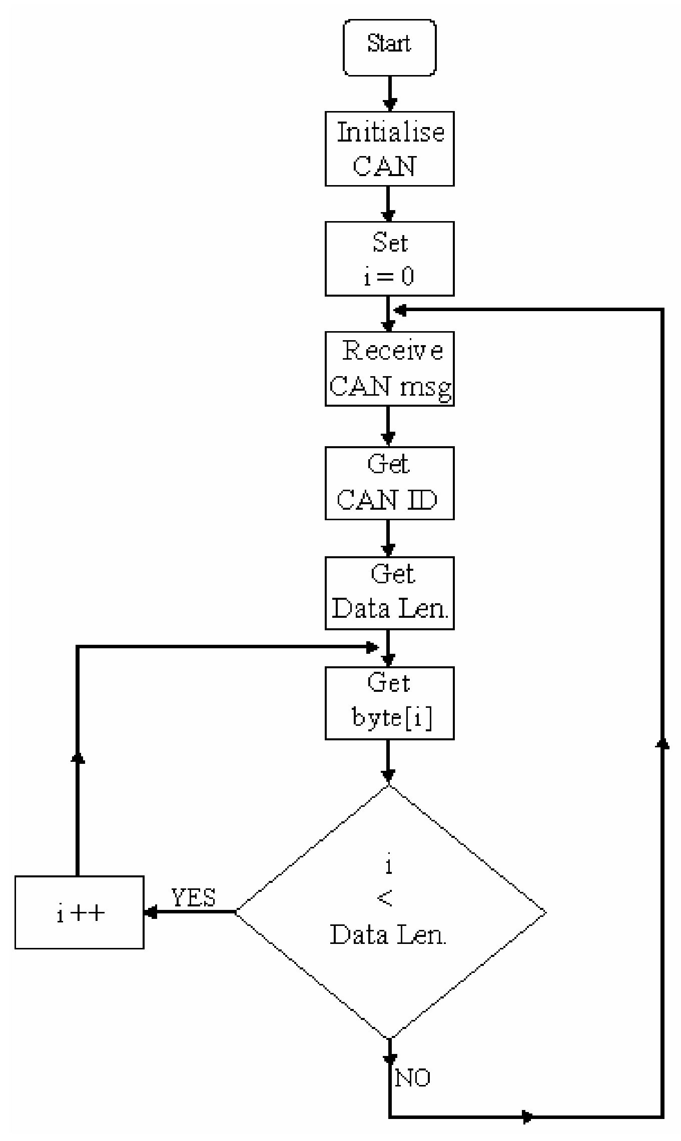


Fig. 4.2 Receive Flow Chart

4.2.3 Editing the Sample Code

The CAN receive sample code had to be edited such that the values of the CAN ID, of both byte 0 and 1 (speed) and byte 2 (rpm) be put into three different pipes IDFIFO, SPEEDFIFO and RPMFIFO respectively. To accomplish this, the same methodology used when developing the write to pipes program (wrpipes_test) was applied. A flow chart for the edited receive program is shown in Fig. 4.3.

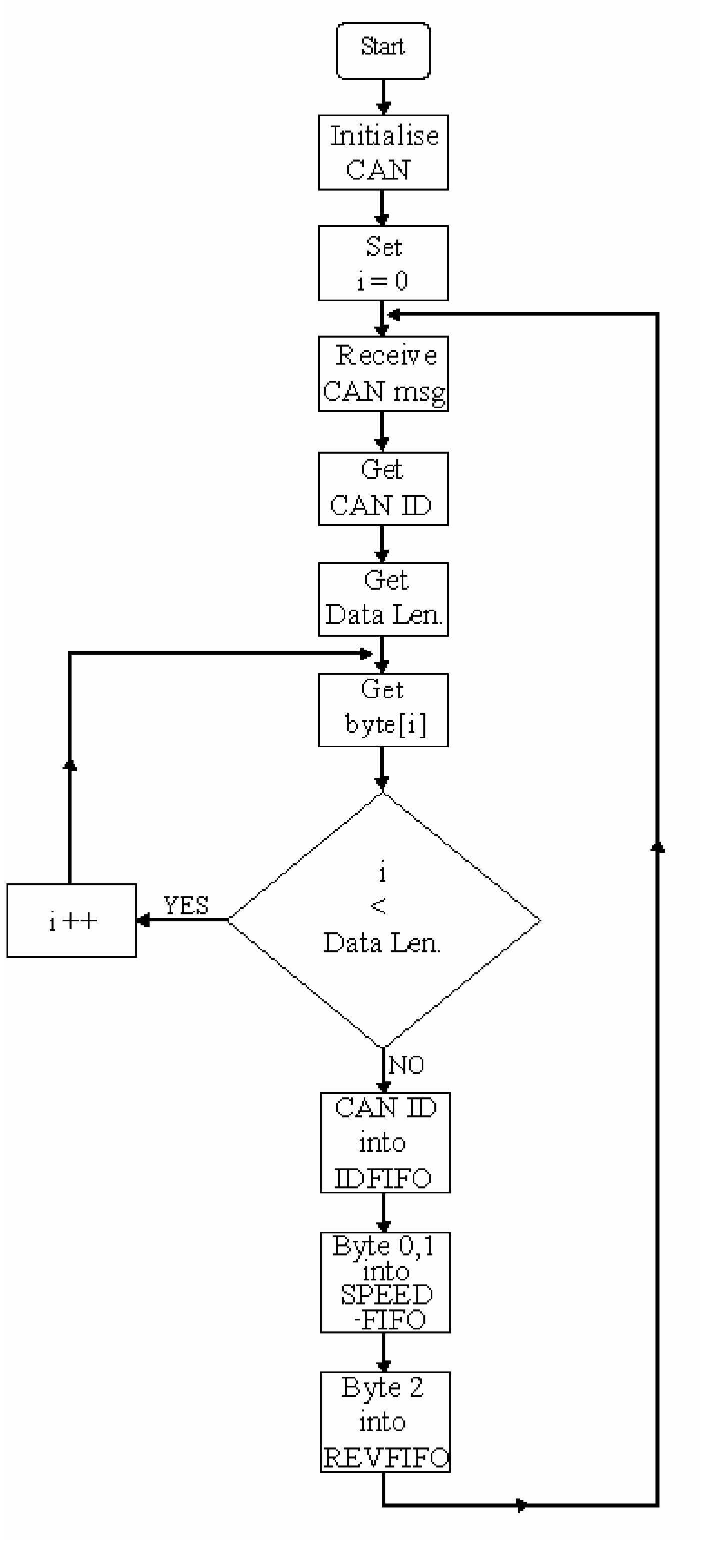


Fig. 4.3 Receive with Named Pipes Flow Chart

4.2.3.1 Creating the Named Pipes

To add Named Pipes to the receive code; firstly the three pipes must be defined.

```
#define SPEEDFIFO_FILE "SPEEDFIFO"
#define IDFIFO_FILE "IDFIFO"
#define RPMFIFO_FILE "RPMFIFO"
```

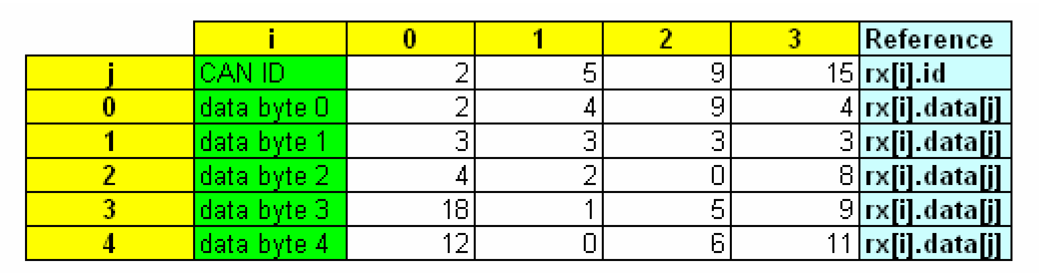
The Named Pipes are then created using the mknod() function as explained earlier (see IPC section).

```
mknod(SPEEDFIFO_FILE, S_IFIFO|0666, 0);
mknod(IDFIFO_FILE, S_IFIFO|0666, 0);
mknod(RPMFIFO_FILE, S_IFIFO|0666, 0);
```

With the Named Pipes created, the variables used to populate these must be developed.

4.2.3.2 Populating the Variables used when Writing to the Named Pipes

The receive code required two "for" loops to obtain the CAN messages. The first "for" loop is used to monitor the number of CAN messages received from the network, while, the second monitored the data sent in each message. Both "for" loops are also used to populate a 2D array. The first "for" loop uses the variable *i* as one coordinate of the array. The variable *i* stores the number of messages received. The second "for" loop uses *j* to count the data bytes from 0 to the data length for each message, for each increment the value of the equivalent data byte is stored in the array location rx[i].data[j]. An example of a 2D array is shown in Table 4.1. Looking at the table, it can be seen that the value of data byte stored in rx[2].data[1] is 3, where 2 is the value of *i* and 1 is the value of *j*.



	i	0	1	2	3	Reference
j	CAN ID	2	5	9	15	rx[i].id
0	data byte 0	2	4	9	4	rx[i].data[j]
1	data byte 1	3	3	3	3	rx[i].data[j]
2	data byte 2	4	2	0	8	rx[i].data[j]
3	data byte 3	18	1	5	9	rx[i].data[j]
4	data byte 4	12	0	6	11	rx[i].data[j]

Table 4.1 2D Array used in Receive Program

4.2.3.3 Populating the Variable used for the CAN ID

The CAN ID array location was then used to populate the variable for the CAN ID; this was accomplished using the code below.

```
sprintf(id, "%d", rx[i].id);
```

The line of code above, copies the value from the array location, rx[i].id, into the string *id*. The *i* variable in the array rx[i].id distinguishes which CAN message the ID is taken from, e.g. if the CAN message was the first received message then its ID would be stored in rx[0].id. The CAN ID variable is now populated and ready to write to the Named Pipe. Next the speed and the rpm variables must also be populated.

4.2.3.4 Populating the Speed Variable

As mentioned earlier, the speed may be varied using two data bytes, data byte 0 and data byte 1, as shown in Fig. 4.1. Therefore, a decision had to be made whether to send each data byte through its own pipe, or to send both data bytes through one pipe. As the SDL program will have to manipulate both data bytes mutually to display the speed, it was decided that both would be sent using one pipe. Prior to writing the speed value to the pipe, both bytes were combined to represent a single decimal value.

Due to the fact that both data bytes are in hex format, the decimal equivalent of each data byte was obtained, and then added to give an overall decimal value. When obtaining the decimal equivalent, the value of data byte 1 was seen as the least significant bit (LSB) while the value of data byte 0 was seen as the most significant bit (MSB). The following lines of code were used to accomplish this.

```
byte0 = ("%d", rx[i].data[0]);
byte1 = ("%d", rx[i].data[1]);
```

The code above, sets the value of byte 0 and byte 1 to be the decimal equivalent of the hex numbers stored in the 2D array, rx[i].data[0] and rx[i].data[1] respectively. With the decimal equivalent of each byte, the following line of code was used to establish their combined value.

```
speed = byte0*pow(16,2) + byte1;
```

With the equivalent value calculated it is then stored in the variable, *mes*, which is initialised as a string. This is accomplished using the line of code shown below.

```
sprintf(mes, "%d", speed);
```

With the CAN ID and speed variables populated, the rpm variable is the last to be populated.

4.2.3.5 Populating the rpm Variable

As the rpm value is only one data byte of the CAN message, less manipulation is required in comparison to the speed value. Firstly, the decimal value of data byte 2 had to be obtained. This was achieved using the following line of code.

```
byte2 = ("%d", rx[i].data[2]);
```

With the value of data byte 2 obtained, the rpm variable was populated by using the following line of code.

```
sprintf(rpm, "%d", byte2);
```

4.2.3.6 Writing the Populated Variables to their Named Pipes

Once all three variables had been populated, they were copied to their equivalent Named Pipes. This was accomplished using the same methodologies as explained earlier (IPC section). The code used to write the CAN ID to the pipes is shown below.

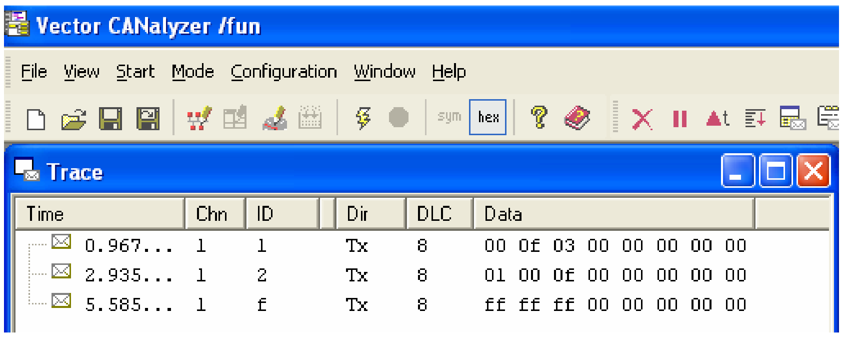
```
fp1 = open(IDFIFO_FILE, O_WRONLY);
write(fp2, id, 10);
close(fp2);
printf("id = %s\n", id);
```

The code above is similar to that utilised in the IPC section. The only difference being that after each variable is written to it's pipe it is then displayed to the user, using a "printf"; this was used for testing purposes, as will be described later in the testing section.

4.2.4 Testing the CAN with Named Pipes Code

To test the CAN code (receive_pipes), the read pipes program (rdpipes_test) was edited such that it would open the three Named Pipes, IDFIFO, SPEEDFIFO and RPMFIFO and display the information contained in them to the user.

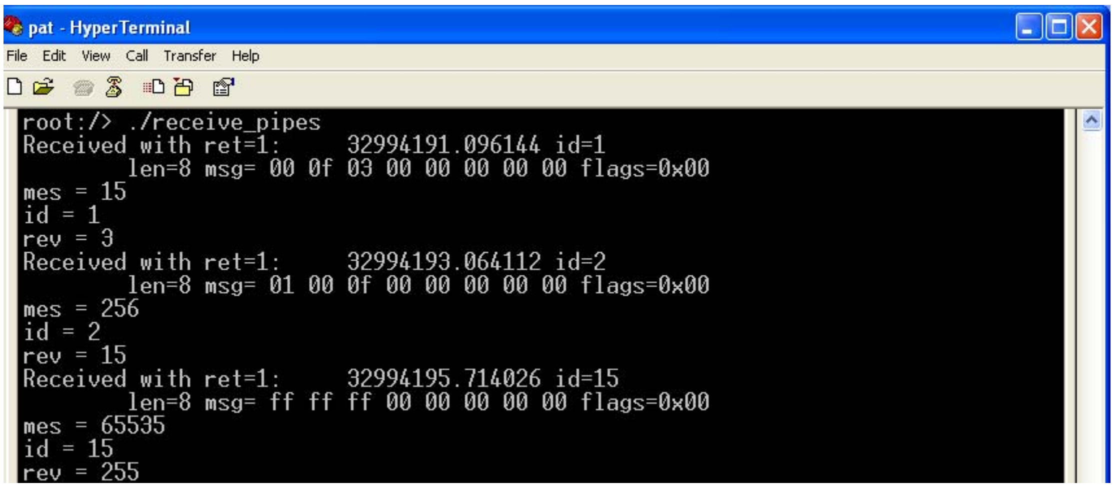
CANalyzer was used to transmit CAN messages to the BF548, while the receive program (receive_pipes) ran in the virtual console, and the read pipes program (rdpipes_can) ran in PuTTY. The messages transmitted using CANalyzer are shown in Fig. 4.4.



Time	Chn	ID	Dir	DLC	Data
0.967...	1	1	Tx	8	00 0f 03 00 00 00 00 00
2.935...	1	2	Tx	8	01 00 0f 00 00 00 00 00
5.585...	1	f	Tx	8	ff ff ff 00 00 00 00 00

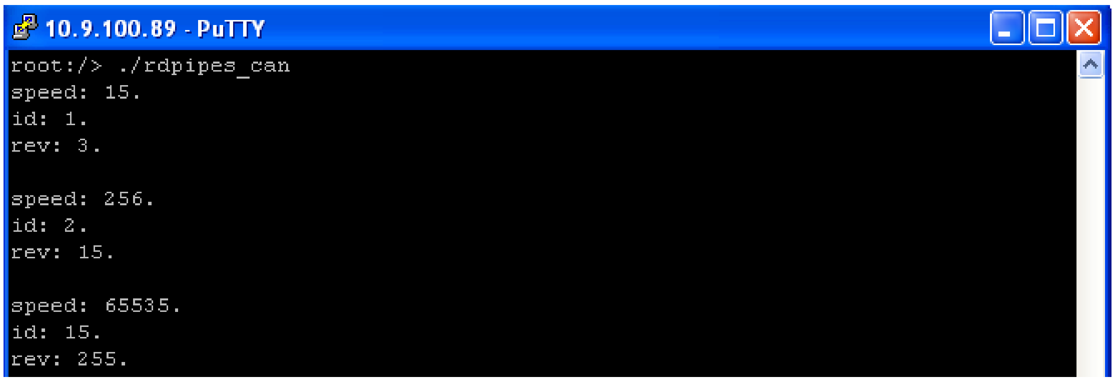
Fig. 4.4 Test Messages sent using CANalyzer

These messages were then received by the receive program (receive_pipes). Fig. 4.5 displays the values of the variables copied to the Named Pipes. These values were then checked against the values received in the read pipes program (rdpipes_can) to prove that the communications were successful.



```
root:/> ./receive_pipes
Received with ret=1:     32994191.096144 id=1
        len=8 msg= 00 0f 03 00 00 00 00 00 flags=0x00
mes = 15
id = 1
rev = 3
Received with ret=1:     32994193.064112 id=2
        len=8 msg= 01 00 0f 00 00 00 00 00 flags=0x00
mes = 256
id = 2
rev = 15
Received with ret=1:     32994195.714026 id=15
        len=8 msg= ff ff ff 00 00 00 00 00 flags=0x00
mes = 65535
id = 15
rev = 255
```

Fig. 4.5 Messages received and Wrote into Named Pipes



```
root:/> ./rdpipes_can
speed: 15.
id: 1.
rev: 3.

speed: 256.
id: 2.
rev: 15.

speed: 65535.
id: 15.
rev: 255.
```

Fig. 4.6 Read Pipes Program Displays Sent Data

Comparing the values copied to the Named Pipes (Fig. 4.5) to those read from the Named Pipes (Fig. 4.6) it can be seen that the IPC was successful. Therefore, all of the values sent using CANalyzer had been received by the receive program (receive_pipes), and then been successfully transmitted using Named Pipes to another process (rdpipes_test). This confirms that the CAN code with Named Pipes executed as desired. Next, the SDL program required editing such that it could read values from the Named Pipes and display the desired information.

4.3 SDL Implementation

To implement SDL, both the digital dash and bar chart code were merged. The CAN ID was then used to select the display configuration, with the speed and rpm data affecting the displayed speed and rpm on the LCD screen.

4.3.1 Merging the Digital Dash and Bar Chart Code

As stated earlier, it was decided that the CAN ID would be used to change the configuration of display. If the CAN ID was equal to zero, then the digital dash configuration would be displayed. If the CAN ID was not equal to zero, then the bar chart configuration would be displayed, with the error messages being dependent on the actual value of the CAN ID. A flow chart of the selection process is shown in Fig. 4.7.

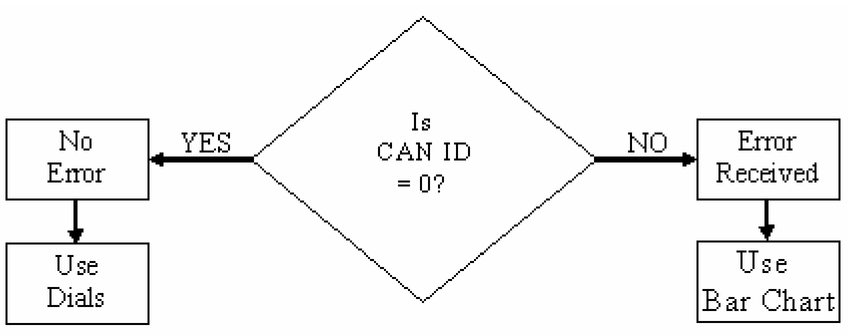


Fig. 4.7 CAN ID used to select Display Configuration

To implement the flow chart shown above in the SDL code an “if” statement was used as shown below.

```
if(id == 0)
     {
     // Use Dials
     }
else if(id != 0)
     {
      // Use bar chart
     }
```

The code shown simply states that if the value of the CAN ID is equal to 0, then use the dial configuration, otherwise if the value of the CAN ID is not equal to 0, use the bar chart configuration. To test the merged code, the SDL had to be able to communicate with the CAN network, through the Named Pipes IDFIFO, SPEEDFIFO and RPMFIFO.

4.3.2 Opening and Reading Named Pipes in SDL

To open and read from the three Named Pipes in SDL, the same methodology as used in the original read program (rdpipes_test) was implemented. Firstly the Named Pipes were defined in the SDL code, these definitions had to be exactly the same as those defined in the CAN code. After defining the Named Pipes, the code will then open each pipe in turn and read their contents. The CAN ID code is shown below.

```
fp1 = open(IDFIFO_FILE, O_RDONLY);
read(fp1, readbuf1, 10);
close(fp1);
```

The section of code opens a Named Pipe and sets its permissions to be read only before reading its contents. The read values are stored it in the variable *readbuf*. The Named Pipe is then closed.

The SDL code now had the ability to read from the Named Pipes, containing the desired data from the CAN network. This data must then be manipulated by the SDL code prior to displaying it on the LCD screen.

4.3.3 Manipulating the Received Data

The data from each pipe had to be manipulated in some way before it was represented on the display. The CAN ID was used to select the configuration, and/or the error message displayed. Bytes 0 and 1 of the CAN message data were used to vary the speed displayed and byte 2 was used to vary the rpm displayed. A broad outline of the system is shown in Fig. 4.8.

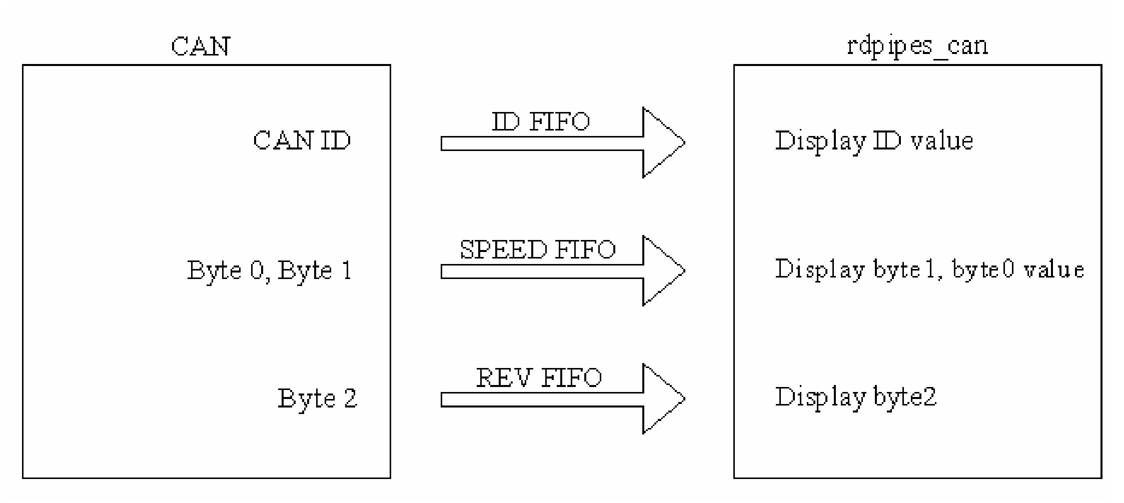


Fig. 4.8 Communications between both Processes

The data in each pipe was in string format, which must be converted into an integer prior to manipulation. Also, depending on the data's application, further manipulation may be needed. The error, speed and rpm manipulation will be explained in the following sections.

4.3.3.1 Manipulating the CAN ID

The CAN ID was used to select the display configuration, and the error message displayed, if one is received. The configuration displayed, e.g. dash or bar chart, was selected from the value of the CAN ID as stated earlier. To select which configuration was displayed, the value of the CAN ID must be converted to an integer. This is accomplished using the following line of code.

```
id = atoi(readbuf1);
```

As the CAN ID was also used to select the error message displayed for the bar chart configuration, its manipulation was not complete. Each error message was saved as a different background in the form errX.PNG, where the value of X is a decimal number. The value of the CAN ID is then used to set the decimal number X. For example, if the CAN ID was 4 then the displayed background would be the file err4.PNG. To accomplish this, the following line of code is used.

```
sprintf(bground, "err%d.PNG", id);
```

The code prints the string errX.PNG, where the value of X is set by the CAN ID, into the variable *bground*. The variable *bground* was then used to display the background inside the bar chart function. This was achieved using the following lines of code.

```
background = IMG_Load( bground );
apply_surface( 0, 0, background, screen );
```

This method will not affect the digital dash configuration if the CAN ID is equal to zero, as the digital dash does not use a background; it prints a new dial for each increment of a dial. Hence the variable *bground* is only ever used in the bar chart configuration. Lastly the value of the CAN ID is printed to the screen for testing purposes, as will be explained later.

4.3.3.2 Manipulating the Speed Data

The speed was displayed in two different forms; a dial form and a bar chart form, each of which has their own scale. Therefore each display required a different method to set the appropriate scale.

4.3.3.2.1 Setting the Scale for each Configuration

As the speed displayed on either configuration must be the same at all times, the scale used in one configuration had to be consistent with the other. This was achieved by choosing a denominator to divide the data received into each speed increment for one configuration; this denominator was then used in every other calculation. This led to full consistency in speed when changing from one configuration to the next.

The denominator chosen for the bar chart configuration was such that for every 30 increments/decrements of the speed value read from the Named Pipe, one bar would be added to/subtracted from the current speed. For example, if the data sent through the SPEEDFIFO pipe was 0, the bar chart would display 0 mph, when the data in

SPEEDFIFO increased to 30 (0x1E) then 1 bar (1.67 mph) would be displayed on the bar chart.

With the denominator chosen for the bar chart, the value for the dial had to be calculated using the chosen denominator. As 6 bars represent 10mph on the bar chart, each bar represents 1.67mph. Each step of the dial represents 1mph, therefore the dial will vary more than the bar chart and hence the dials denominator will be different to that of the bars. To calculate the dial denominator the following equation (4.1) was used.

$$\textit{Speed Dial Denominator} = \frac{30}{1.67} = 18 \tag{4.1}$$

These denominator values were then tested to prove their viability. It was decided that the maximum speed to be displayed would be 145mph. Using this as an example, it can be shown that both denominators equate to a consistent speed for each configuration. The values of byte 0 and 1 of the CAN message were calculated for the maximum speed, 145mph, which is the equivalent of 87 bars, using the following equation.

$$\textit{Bar Chart Denominator * Max. Num. of Bars = Max. Speed CAN message} \tag{4.2}$$

$$30 \quad * \quad 87 \quad = \quad 2610$$

Therefore, to display the maximum speed byte 0 and 1 would have to be equal or greater than 2610 (0x0A32). Using this value with the speed dial denominator, the speed to be displayed on the dials was calculated as shown.

$$\textit{Speed Displayed} = \frac{\textit{Max. Speed CAN Message}}{\textit{Speed Dial Divisor}} \tag{4.3}$$

$$\textit{Speed Displayed} = \frac{2610}{18}$$

$$\textit{Speed Displayed} = 145$$

As can be seen from above, the displayed speed is consistent for both the bar chart and dial configuration. These values were then used in the code to the display the speed.

4.3.3.2.2 Manipulating the Speed Data for use with the Bar Chart

When manipulating the speed data received for use on the bar chart, the value of denominator was set to 30 and was implemented by the use of the following lines of code.

```
z = atoi(readbuf2);
t = ceil(z/30);
```

The variable *z* contains the integer value read from the Named Pipe. The variable *t* contains the value, in bars, of the received speed. The function ceil outputs smallest integral value not less than the input, e.g. the ceil of 2.8 is equal to 3, basically it rounds the input to the nearest whole number. The value of the variable *t* is then used to vary the speed on the bar chart.

Due to the CAN messages being simulated for the testing of the project, a fail safe was also introduced to the code. The reason for this fail safe was due to the fact that when testing the system, the tester can simulate a speed message up to 65535 (0xFFFF). Therefore, the maximum speed would far extend the maximum displayable value on the screen and hence cause system errors. To eradicate this problem the following code was used. The code sets *t* equal to 87 (maximum speed in bars) if the received data exceeds the maximum value.

```
if (t > 87)
    {
    t = 87;
    }
```

4.3.3.2.3 Manipulating the Speed data for use with the Speed Dial

When manipulating the speed data received, the value of denominator was set to 18 as explained earlier. To accomplish this, the following line of code was used.

```
mph_value = ceil(z/18);
```

In the code above, the variable *mph_value* is the value, in mph, of the received speed. This value is calculated using the ceil function, as explained earlier. The value of *mph_value* is then used to vary the speed. A fail safe was also used for the speed dial, this fail safe is accomplished using the similar code as above. Lastly the value of the value of the speed is printed to the virtual console for testing purposes. To implement this, the line of code below was used.

```
printf("mph_value = %d\n",mph_value);
```

4.3.3.2.4 Variable Consistency when changing between Configurations

If the speed dial has operated from the start and is now displaying a speed of 80mph, then the variable *last_mph*, which is used in varying the speed for the dial, will be equal to 80. However, the variable *i*, which is used in varying the speed for the bar chart, will be equal to zero, as it has never operated. Thus if an error was introduced, causing the bar chart to be displayed, the bar chart would show an initial speed of 0mph rather than the current speed which is 80mph. To overcome this problem the following line of code was added, such that it will run every time the speed dial has updated, i.e. *last_mph* equals *mph_value*.

```
i = ((last_mph*18)/30);
```

This sets the variable *i* equal to the value of the variable *last_mph* multiplied by 18, all of which is then divided by 30. This will set *i* to the corresponding value, in bars, of the current speed in mph. Using 80mph as an example it can be seen that the value of *i* is now correct.

$$i = \frac{80*18}{30} = 48$$

(4.4)

The resultant value of *i* is 48 bars and as each bar is equal to 1.67mph, the value of *i* in mph can be found as follows.

$$i\ (mph) = 48 * 1.67 = 80mph$$

(4.5)

Also when the bar chart was running, the following line of code was added, such that it will run every time the bar chart has updated speed, i.e. *i* equals *t*. With the addition of the code below, the two speed variables were now consistent no matter which display was used.

```
last_mph = ((i*30)/18);
```

4.3.3.3 Manipulating the rpm data

As the rpm data is only one byte of the CAN message its manipulation was not as complex as that used for the speed data. Also the rpm data was only ever used while using the dial configuration; therefore only one scale is required. When manipulating the rpm data, it first had to be converted to an integer using the same line of code as before.

```
rpm_value = atoi(readbuf3);
```

This sets the variable *rpm_value* to the integer value of the string contained in *readbuf3*. As rpm dial changes in increments of 20rpm, the received data had to be manipulated to match these increments. This was accomplished using the line of code below.

```
rpm_value = rpm_value * 20;
```

This code sets the value contained in *rpm_value* to be twenty times its original. This value is then used to display the desired revs on the rpm dial. Lastly the value of the rpm is printed to the virtual console for testing purposes using following line of code below.

```
printf("rpm_value = %d\n\n",rpm_value);
```

4.3.3.3.5 Variable Consistency when changing between Configurations

When the bar chart configuration is running on the screen, the rpm data is not used as it is not displayed. This leads to the variable *last_rpm*, which stores the value of the last rpm displayed and is used in displaying the next rpm, not being set to the latest value of the rpm data. If the dash configuration was then displayed it would lead to the initial value of the rpm displayed being inconsistent with the actual value. To overcome this problem the following line of code was added, which is executed when the bar chart code has run to completion for each new message.

```
last_rpm = rpm_value;
```

The sole purpose of the line above is to keep the variable *last_rpm* up to date with the actual value of rpm data received when the dial configuration is not in use. If the dial configuration is being used, then this line will neither run, nor be required, due to the fact that rpm data will be used, and hence the variable will be up to date.

4.4 Testing the Final System

In adding the Named Pipes to both the CAN and SDL programs, these two processes could now communicate with each other. Also, with the data received in the SDL code being manipulated as desired, the system was now complete and is shown in Fig. 4.9. When testing the final system, CANalyzer was used to simulate the CAN messages transmitted from the CAN nodes on the network.

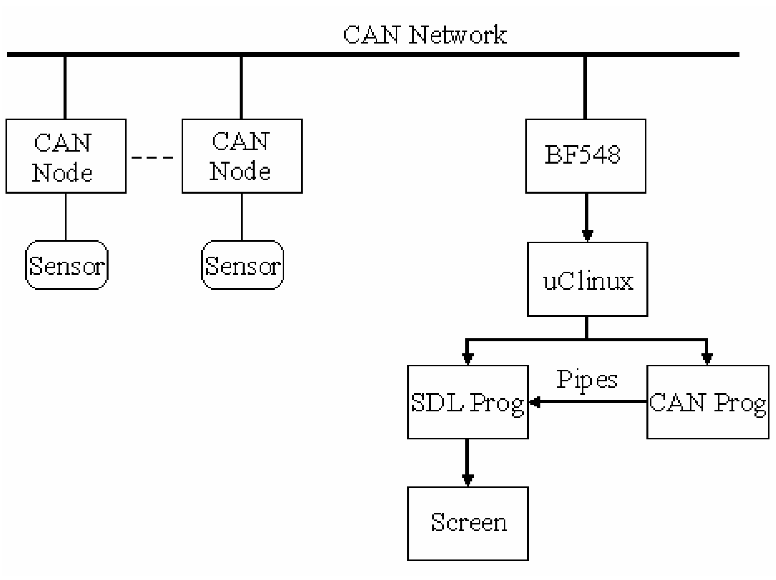


Fig. 4.9 Final System

4.4.1 Initial Testing

During the initial testing, the dials displayed the correct data for each CAN message. When an error was introduced, the display changed to the bar chart and it too displayed the correct data for each CAN message. However, when the CAN ID was set to zero, hence the display changed back to the dials from the bar chart configuration, a visual error occurred on the LCD screen, as shown in Fig. 4.10.

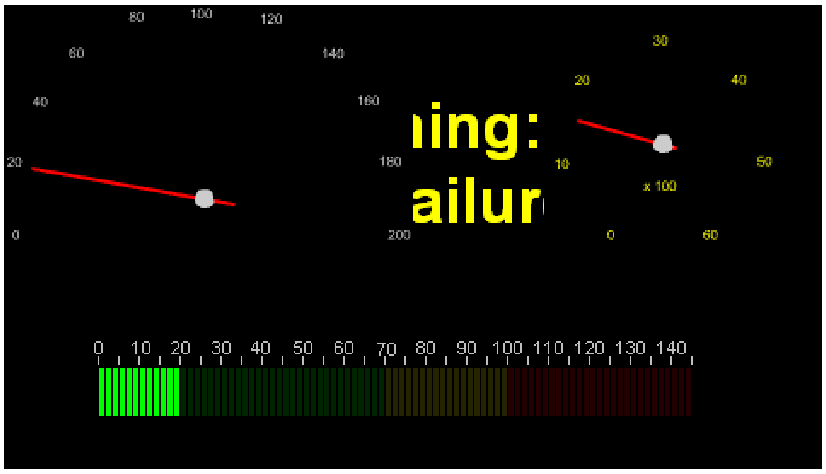


Fig. 4.10 Error displayed during Initial Testing

This error was due to the bar chart using the full LCD screen while running i.e. the background is the same size as the actual LCD screen. When the dials were running, each dial only uses a section of the screen. Due to the fact that the screen was initialised to be black, this error was never observed before. To explain this error in more detail, coloured blocks are used as shown below, where black represents the initial screen, white represents the dials and red represents the bar chart.

(i) The screen is initialised to be fully black.

Fig. 4.11 Initialised Screen

(ii) The dials are applied to the top left and right corners of the screen. As the background of each dial is black, this lead to no visuals errors on the screen

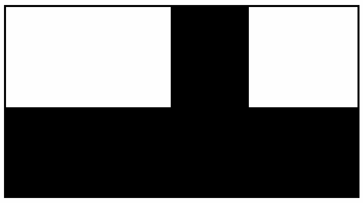


Fig. 4.12 Applying the Dials to the Screen

(iii) The bar chart uses the full screen, so hence the screen is now fully covered by the bar chart's background.

Fig. 4.13 Applying the Bar Chart to the Screen

(iv) When changing back to the dials from the bar chart, the dials are again placed in the top left and right corners. However, nothing is applied to the rest of the screen, so whatever is currently displayed will stay on the screen and hence the error shown in Fig. 4.10.

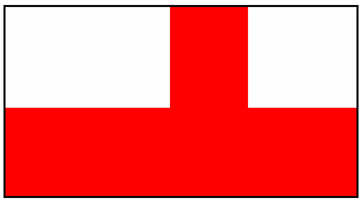


Fig. 4.14 Changing to the Dials from the Bar Chart

To overcome this error, a mask must be applied to the screen when changing to the dials from the bar chart, such that the mask will cover the bar chart background. To do this an image file was created to mask off the bar charts background, and was set to be completely black. Hence when the mask is applied to the screen it will blacken out the bar chart background, while leaving the area for the dials empty.

A variable *lastid* was created and set to the current value of the CAN ID before reading the new value of the CAN ID from the pipes. The new and old CAN IDs were then compared such that, if the last ID was not equal to 0 (use bar chart) and the new ID was equal to 0 (use dials) then the screen had to be masked. To achieve this, the following lines of code were used.

```
if((lastid != 0) && (id == 0))
      {
      //mask screen
      }
```

Due to no delay being introduced in the SDL code when placing the mask, the human eye will not be able to see the mask being applied to the screen. Instead the end user will see a clean transition from the bar chart to the dials as shown in Fig. 4.15, Fig. 4.16 and Fig. 4.17.

(i) The full screen is used when running the bar chart

Fig. 4.15 Applying the Bar Chart to the Screen

(ii) When changing from the bar chart to the dials the mask is applied

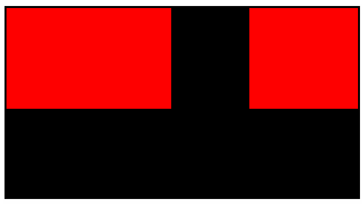


Fig. 4.16 Applying the mask

(iii) Now when the dials are applied over the mask, no visual errors are seen on the screen.

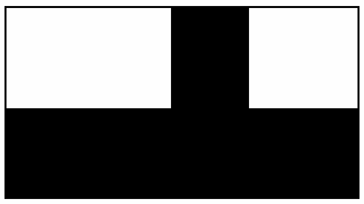
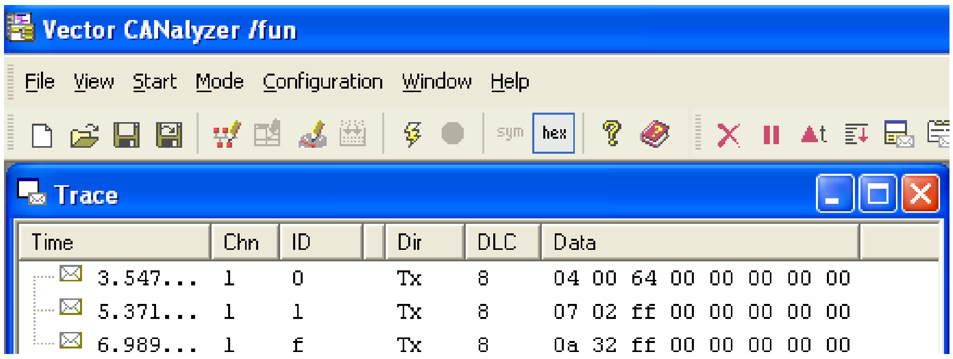


Fig. 4.17 Applying the Dials to the Screen with the Mask

4.4.2 Testing the Final System

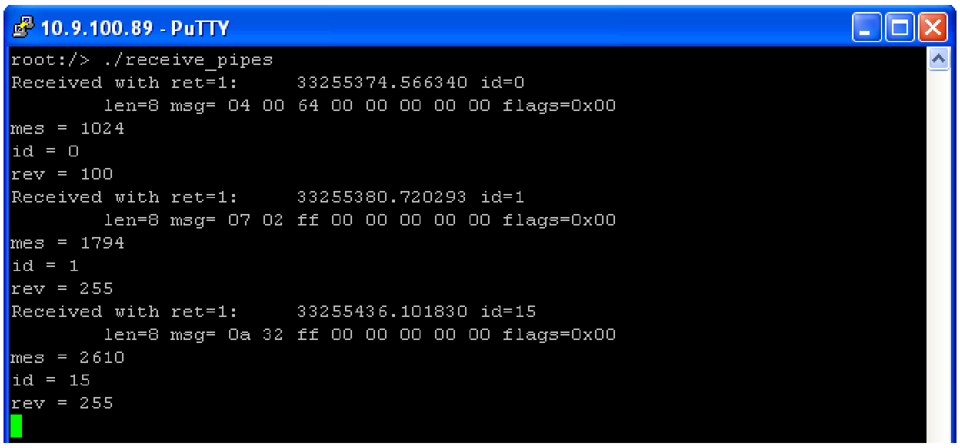
With the error free SDL code, the system was again tested. To test the system, CAN messages were sent using CANalyzer as shown in Fig. 4.18.



Time	Chn	ID	Dir	DLC	Data
3.547...	1	0	Tx	8	04 00 64 00 00 00 00 00
5.371...	1	1	Tx	8	07 02 ff 00 00 00 00 00
6.989...	1	f	Tx	8	0a 32 ff 00 00 00 00 00

Fig. 4.18 Messages sent using CANalyzer

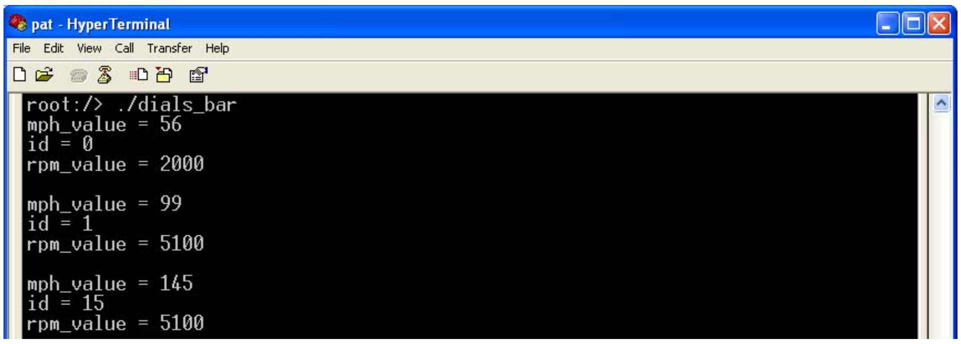
These messages were then received and the desired information was placed into the Named Pipes using the CAN program (receive_pipes). The received messages can be seen in Fig. 4.19.



```
root:/> ./receive_pipes
Received with ret=1:     33255374.566340 id=0
        len=8 msg= 04 00 64 00 00 00 00 00 flags=0x00
mes = 1024
id = 0
rev = 100
Received with ret=1:     33255380.720293 id=1
        len=8 msg= 07 02 ff 00 00 00 00 00 flags=0x00
mes = 1794
id = 1
rev = 255
Received with ret=1:     33255436.101830 id=15
        len=8 msg= 0a 32 ff 00 00 00 00 00 flags=0x00
mes = 2610
id = 15
rev = 255
```

Fig. 4.19 Messages Received by the CAN program

The CAN program prints the values written into each pipe. These values are then used to test if the data was successfully read from the pipes in the SDL program (dials_bar) as shown in Fig. 4.20.



```
root:/> ./dials_bar
mph_value = 56
id = 0
rpm_value = 2000

mph_value = 99
id = 1
rpm_value = 5100

mph_value = 145
id = 15
rpm_value = 5100
```

Fig. 4.20 SDL program Reading Data from Pipes

As can be seen from above, the SDL program has successfully read the data from the pipes. The manipulated data was then displayed on the LCD screen; this data was then used to confirm that the right values are displayed on the screen. Fig. 4.21 shows the display for the first message as shown in Fig. 4.20.

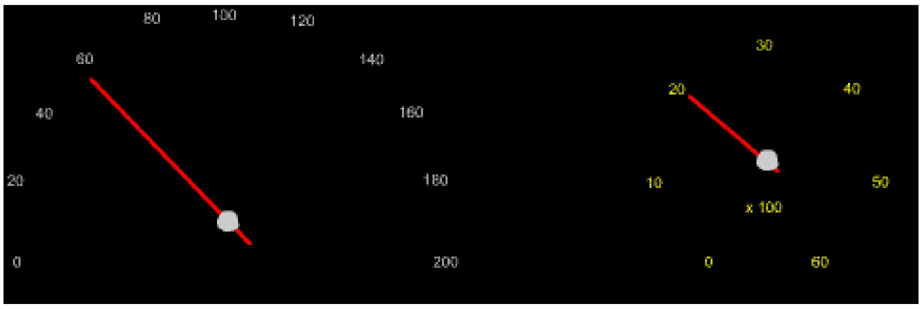


Fig. 4.21 Output on the LCD Screen for Message 1

From Fig. 4.20, the CAN ID is equal to zero, hence the dial configuration was used, also it can be seen that displayed speed and rpm should be 56mph and 2000rpm respectively. Fig. 4.21 shows that all these conditions have being displayed successfully on the screen.

The following was displayed on the screen for the second message. As shown in Fig. 4.20, it can be seen that the CAN ID is equal to 1; hence an error has occurred and the bar chart configuration should be used. Also the speed should be 99mph and the background used should be the tyre pressure warning (error 1). Fig. 4.22 shows that all these conditions have been displayed successfully on the LCD screen.

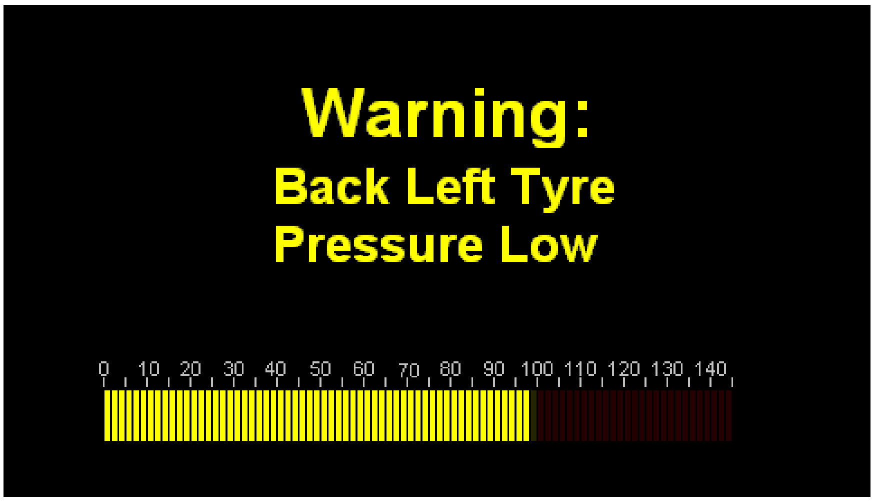


Fig. 4.22 Output on the LCD Screen for Message 2

The following was displayed on the screen for the third message. As shown in the third message in Fig. 4.20, it can be seen that the CAN ID is equal to 15; hence another error has occurred so the bar chart configuration will be again used. The speed should be 145mph and the background used should be the ABS warning (error 15). Fig. 4.23 shows that all these conditions have been displayed successfully.

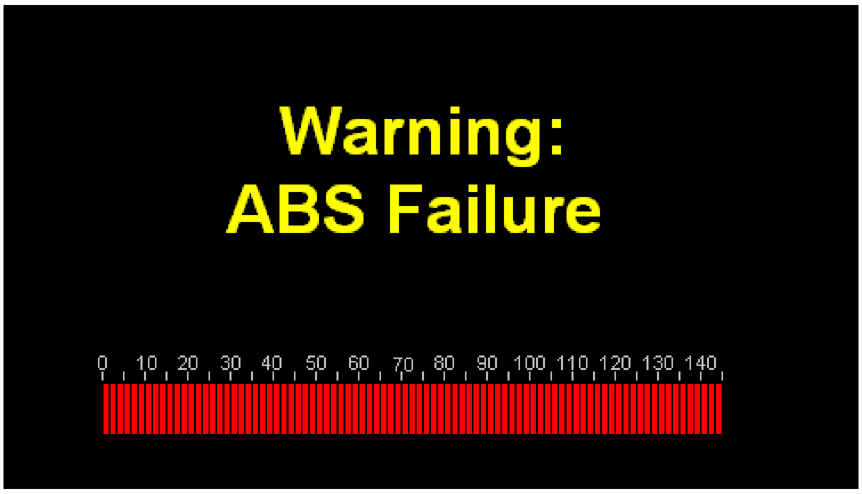


Fig. 4.23 Output on the LCD Screen for Message 3

After transmitting many different CAN messages from CANalyzer it was confirmed that the final system was functioning as desired. A flow chart of the finished system is shown in Fig. 4.24.

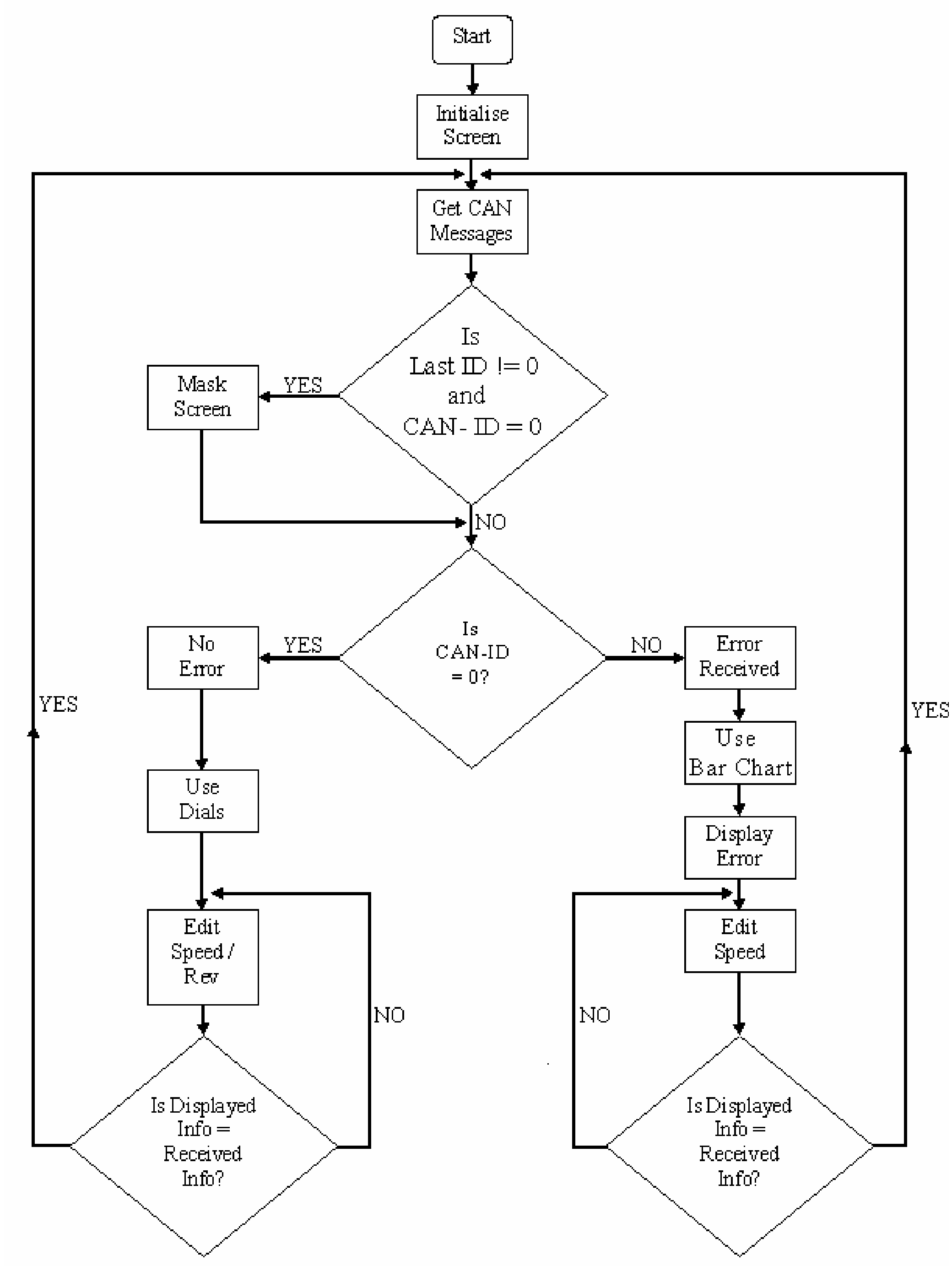


Fig. 4.24 Flow Chart of End System

4.5 Stress Testing the End System

One of the design criteria used was that the speedometer should be capable of displaying a speed variation of 0 to 60 mph in six seconds. This constraint was used as most vehicles cannot achieve this standard. When stress testing the final system, CAN messages were transmitted with different time periods to:

(i) Test if the system could achieve the initial goals.

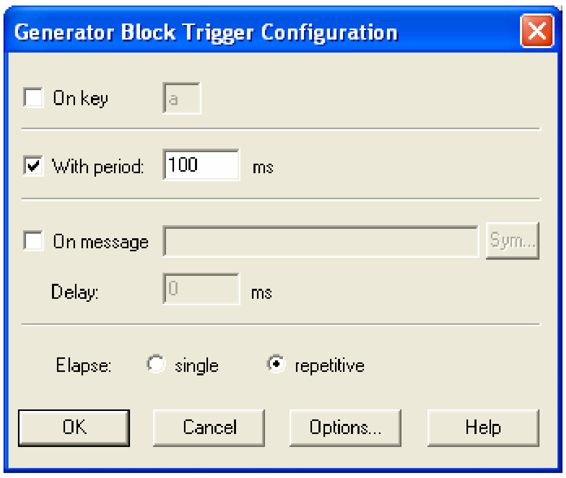
(ii) Test the system for any limitations.

4.5.1 Testing System for Initial Goals

As mentioned previously, the system was designed such that it could achieve the display of 0 to 60mph in six seconds. It was decided that each CAN message would increment the speed by 1mph, therefore to go from 0 to 60mph, 60 CAN messages would be needed. To calculate the desired period for each CAN message to achieve 0 to 60mph in six seconds, in the following equation (4.6) was used.

$$period = \frac{time}{speed} = \frac{6}{60} = 0.1s = 100ms \tag{4.6}$$

Using the calculated period for each message, the system was then tested for successful operation. The period of each message was set to 100ms in CANalyzer, as shown in Fig. 4.25.


Generator Block Trigger Configuration

[ ] On key: a

[✓] With period: 100 ms

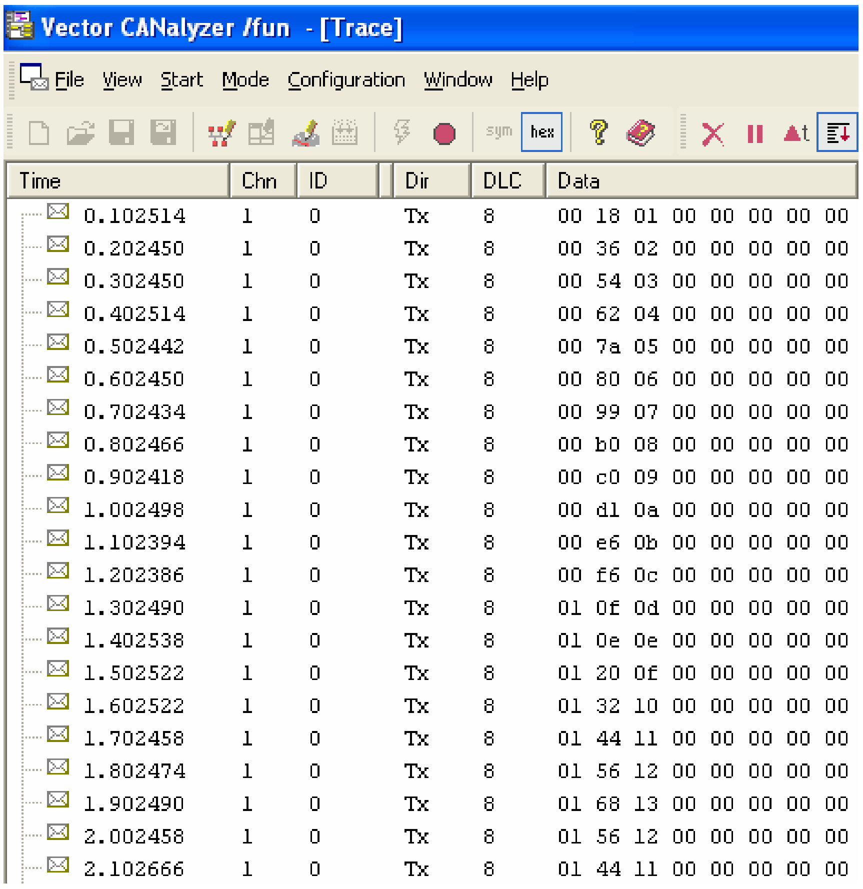
[ ] On message: Sym...

Delay: 0 ms

Elapse: ○ single [● repetitive]

Fig. 4.25 Setting the Period of each CAN Message to 100ms in CANalyzer

With the period of each CAN message set to 100ms, with a variation of 1 mph per message, the speed was varied from 0 to 20mph and back down again repetitively using the CAN messages. If the system was capable of displaying these variations in speed, this would hence prove that the system was capable of a 0 to 60mph change in 6 seconds. The sent messages are shown in Fig. 4.26, with a time period of 100ms.


Vector CANalyzer /fun - [Trace]
File View Start Mode Configuration Window Help
sym
hex

Time	Chn	ID	Dir	DLC	Data
0.102514	1	0	Tx	8	00 18 01 00 00 00 00 00
0.202450	1	0	Tx	8	00 36 02 00 00 00 00 00
0.302450	1	0	Tx	8	00 54 03 00 00 00 00 00
0.402514	1	0	Tx	8	00 62 04 00 00 00 00 00
0.502442	1	0	Tx	8	00 7a 05 00 00 00 00 00
0.602450	1	0	Tx	8	00 80 06 00 00 00 00 00
0.702434	1	0	Tx	8	00 99 07 00 00 00 00 00
0.802466	1	0	Tx	8	00 b0 08 00 00 00 00 00
0.902418	1	0	Tx	8	00 c0 09 00 00 00 00 00
1.002498	1	0	Tx	8	00 d1 0a 00 00 00 00 00
1.102394	1	0	Tx	8	00 e6 0b 00 00 00 00 00
1.202386	1	0	Tx	8	00 f6 0c 00 00 00 00 00
1.302490	1	0	Tx	8	01 0f 0d 00 00 00 00 00
1.402538	1	0	Tx	8	01 0e 0e 00 00 00 00 00
1.502522	1	0	Tx	8	01 20 0f 00 00 00 00 00
1.602522	1	0	Tx	8	01 32 10 00 00 00 00 00
1.702458	1	0	Tx	8	01 44 11 00 00 00 00 00
1.802474	1	0	Tx	8	01 56 12 00 00 00 00 00
1.902490	1	0	Tx	8	01 68 13 00 00 00 00 00
2.002458	1	0	Tx	8	01 56 12 00 00 00 00 00
2.102666	1	0	Tx	8	01 44 11 00 00 00 00 00

Fig. 4.26 Messages when Stress Testing the End System

Each CAN message also increments/decrements the rpm (data byte 2) as well as the speed (data byte 0 and 1). As the speed and rpm dials are edited using the same "do-while" loop, hence if both were changing, the loop's iteration time would be longer than if only one was changing.

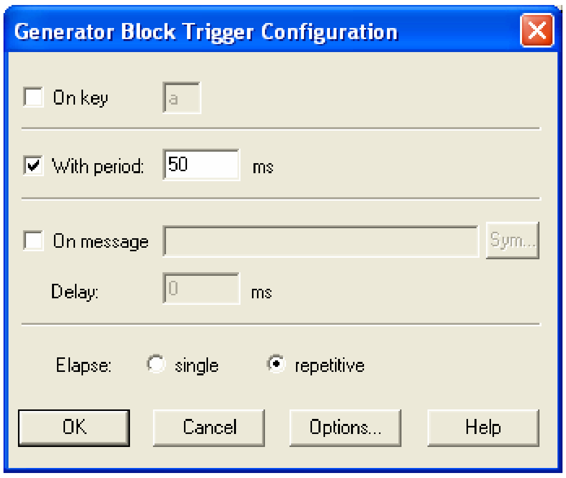
During this testing no errors were received on the virtual console or no glitches were observed on the actual LCD display. Hence this proved that the final system can operate correctly with a period of 100ms for each CAN message and therefore can display a variation in speed of 0 to 60mph in 6 seconds.

4.5.2 Testing the System for Limitations

As nearly all road vehicles can not achieve 0 to 60mph in 3 seconds, with the exception of a very small number of high end sports cars, the system was then tested for correct functionality at this data rate. The equation (4.7) was used to calculate the period of each message for a variation of 0 to 60mph in 3 seconds.

$$period = \frac{time}{speed} = \frac{3}{60} = 0.05s = 50ms \tag{4.7}$$

The period of each message was then set to 50 ms in CANalyzer.


Generator Block Trigger Configuration

☐ On key: a

☑ With period: 50 ms

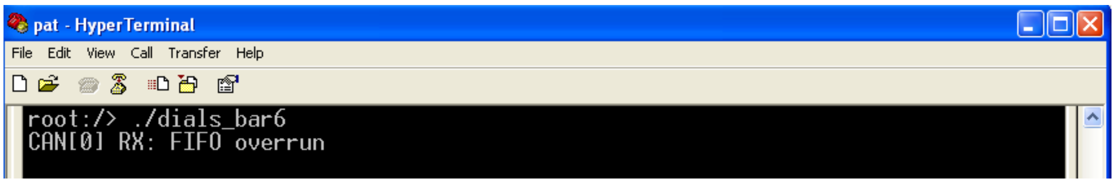
☐ On message: Sym...

Delay: 0 ms

Elapse: ○ single [✓ ● repetitive]

Fig. 4.27 Setting the Period of each CAN Message to 50ms in CANalyzer

The same message sets that had been sent previously were used again, this time with each messages period being 50ms, as seen in Fig. 4.26. While testing the final system using a period of 50ms and the messages shown in Fig. 4.26, with both the dials and bar chart configurations, errors were received on the virtual console and glitches were observed on the actual display. The error received on the virtual console is shown in Fig. 4.28.



```
root:/> ./dials_bar6
CAN[0] RX: FIFO overrun
```

Fig. 4.28 Received Error using a Message Period of 50ms

Despite the message shown in Fig. 4.28 identifying that the error was caused by the receiving CAN0 port's FIFO (Named Pipe) being overrun, it was believed that this error was due to the screen not updating at a fast enough rate. This theory was established due to the fact that the Named Pipes used in this project were set to be blocking, i.e. a process can not write new data into the Named Pipe until the previous data had been read from the Named Pipe by a different process. It was believed that the display code (dials_bar) was not capable of updating the screen and reading the new data from the Named Pipe at a fast enough rate such that the CAN code (receive_pipes) is not waiting to write new information into the Named Pipe. If this was the case then the CAN code would get an overrun error as it trying to write information into the Named Pipe but it is still blocked. To test this theory, the Named Pipes in this project were changed to be non-blocking by editing the CAN code (receive_pipes), the CAN ID section is shown below.

```
fp1 = open(SPEEDFIFO_FILE, O_WRONLY | O_NONBLOCK);
write(fp1, mes, 100);
close(fp1);
```

With the Named Pipes set to be non-blocking, the CAN code could overwrite the data contained in the Named Pipe if it was not read by the display code. When the system was re-tested using the non-block Named Pipes, the error was not received in the virtual console, however glitches were still seen on the display. These glitches were caused by the screen not being able to keep up with the volume of CAN messages being received. This showed the display code was responsible for the error message received earlier.

From the stress testing it can be seen that the system is not functioning correctly when the CAN messages were sent with a period of 50ms, hence the final system does contain some limitations. However it is believed that these limitations could be reduced/eradicated by tweaking the current SDL code or by enabling a different sampling system for the CAN messages.

4.6 Summary

This chapter reviewed the methods used and choices made when implementing the proposed system. In this chapter the system implementation was outlined from the design to the final system. The main points covered in this chapter were:

- The implementation of the CAN code, including the capabilities of writing to Named Pipes which were used to pass the received data to the graphical display process.
- The implementation of the graphical display process in SDL, this included the capabilities of reading from Named Pipes in order to receive the data from the CAN network.
- The testing of the final system and the eradication of any errors that may have being present.
- The stress testing of the final system and any comments made on the outcomes of this testing.

5 Conclusion

5.1 Introduction

This chapter summarises the research and methodologies carried out for this thesis. It outlines the results and conclusions that have been drawn from the project and offers suggestions on how to possibly further the research.

- Chapter 2 outlined the researched literature used in the design of this project. This chapter described the selection of a processing system, along with the OS to run on top of the selected processor. The display technologies and IPC used in the project were also outlined. Finally the CAN protocol was investigated.
- Chapter 3 described the configuration and design of the final system. The first part of the chapter described the configuring of the development host, coLinux, and the configuration and compilation of the OS and bootloader, uClinux and U-Boot respectively. The second part of the chapter outlined the system synthesis. This included the design of the CAN process, video processes and IPCs.
- Chapter 4 documented the implementation and testing of the final system. This included the development of communications between the CAN network and video processes using Named Pipes as the IPC. The testing and elimination of any errors encountered was also outlined. Finally the system was stress tested to observe any limitations.

5.2 Conclusions

With the advances in electronics digital dashboards are now becoming available for use in the automotive industry. The main difference between analog dashboard and digital dashboard configurations is that the latter may easily be reconfigured. In the digital type of configuration information can be displayed either numerically or via a digital representation of an analog dial.

The criterion was to create a flexible digital display for use in an automotive setting using open source hardware and software. The hardware used was an off the shelf development board, in this case the Analog Devices Blackfin BF548. This was combined with open source software, which included an OS, uClinux, and graphical libraries, SDL. The system received its data from a CAN network, which was simulated using the automotive industry standard tool “CANalyzer”.

To develop and compile the OS and application software, a Linux derivative, coLinux, was used. CoLinux was selected for use in the project as it is the first Linux release to run natively on a Windows machine. This offered many benefits, principally among them being that only one PC was needed for all software development in Linux, while still operating on the Windows OS. The configuration of coLinux included configuring the network for communications between both OS and the Ethernet. The appropriate toolchains for the compilation of uClinux, U-Boot and application code were also installed. Lastly the “PATH” was set in coLinux to point to the proper library and linker files when compiling any program code.

Both uClinux and U-Boot were compiled under coLinux. In the project, U-Boot was first compiled to boot using the UART. After successfully porting this version of U-Boot to the BF548, a second version was compiled. This version was compiled to boot from flash memory. Using the UART U-Boot which was ported to the development board, the flash U-Boot was saved in the BF548 flash memory. This version of U-Boot now runs on power up. Lastly, an Ethernet connection was established in U-Boot such that it can download the kernel on boot up. The fully configured Development Host and Environment are shown in Fig. 5.1. For uClinux, this involved configuring a kernel to be executable for the BF548, as well as to include all desired functionality.

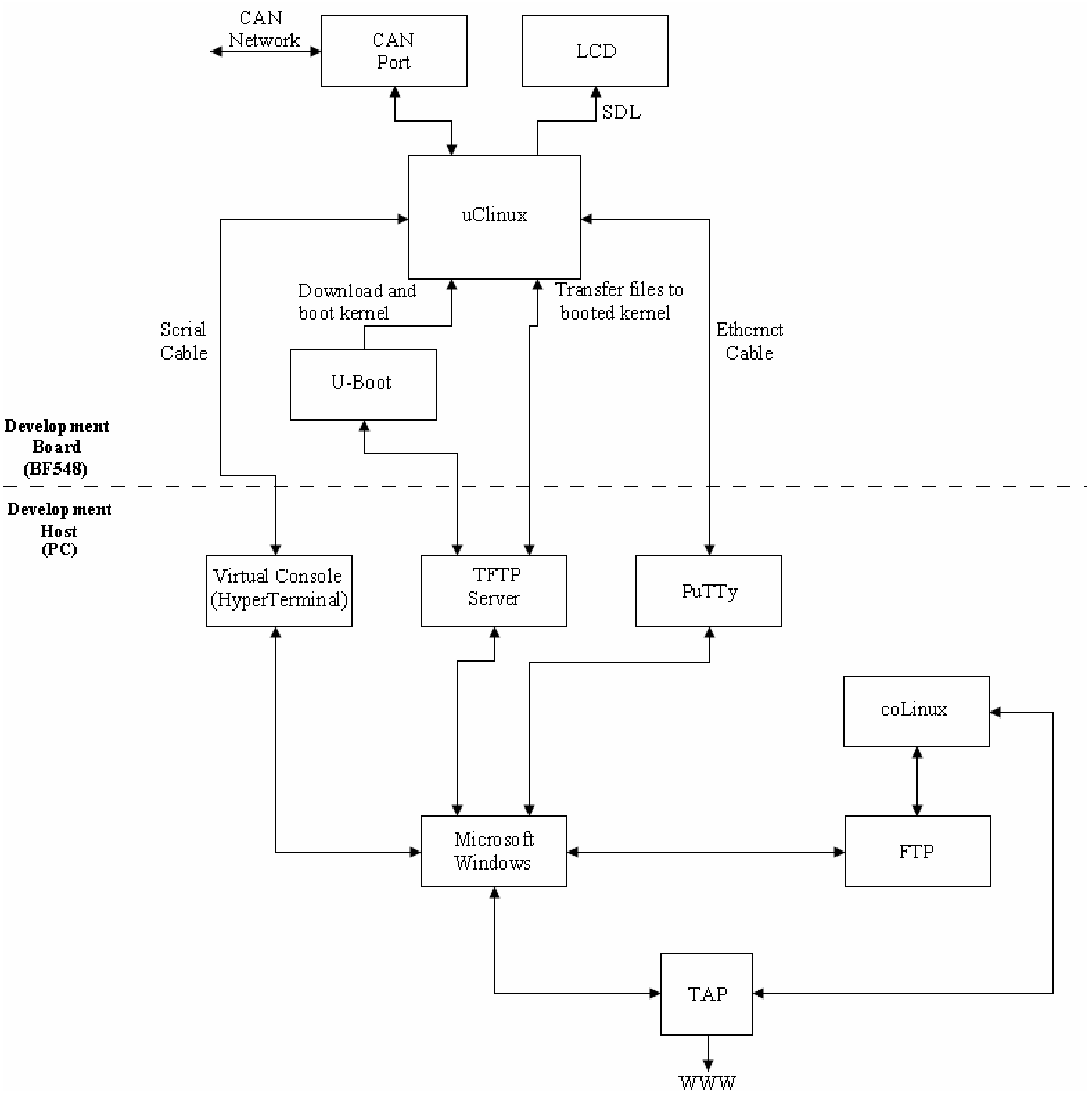


Fig. 5.1 System Configuration Overview

Due to BF548 being the latest generation of Blackfin development boards, some of the functionality had not been fully tested in the uClinux kernel. For example, the CAN drivers had to be edited such that the uClinux kernel would support the CAN network. These problems were eliminated through the combination of the review of pertinent literature, consultation with the relevant bodies and software debugging. After correcting the errors contained in the drivers, initial testing of the CAN network revealed that the CAN timings were also incorrect. To correct this, new CAN variable values were calculated, with the CAN header file been edited to include these new calculated values. After all problems in relation to the CAN network were rectified, application code was developed in ANSI C for the CAN process. The implemented code was used to receive data from the CAN network, parse the desired information from the received CAN data and transmit it to the SDL process.

The graphical representation of the CAN data was implemented using SDL program code. When implementing the video process, two programmes were initially developed. The first implemented a digital representation of a standard analog display, which included a speedometer and a tachometer. The second implemented a digital bar chart configuration which also displayed any error messages. After testing the two initial programs, these were then integrated to make one video process. With the output display configuration depending on the information received from the CAN network.

To allow communications between the CAN process and the video process, Inter Process Communications were used, with the IPC chosen for this project being Named Pipes. The design of the Named Pipes was achieved by writing programme code to read and write between two processes. After fully testing this code, the same methodologies were use to transmit information between the SDL and video processes. A basic block diagram of the final system is shown in Fig. 5.2.

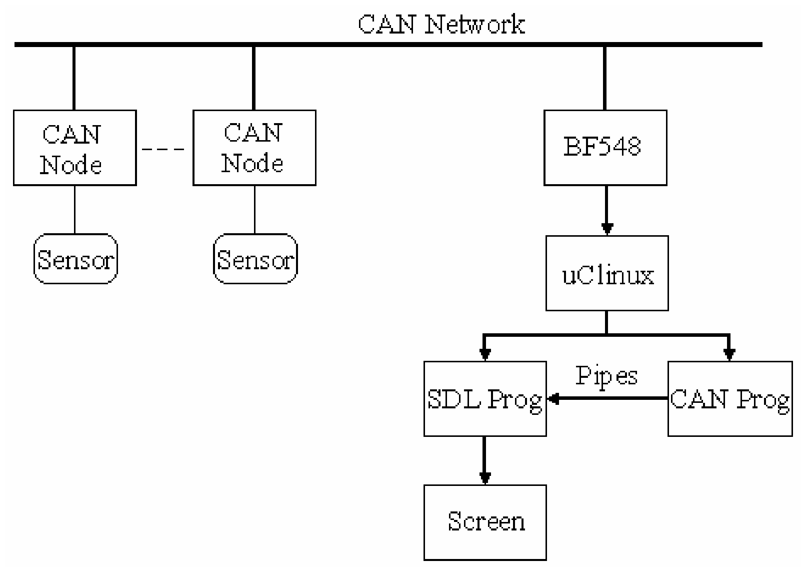


Fig. 5.2 Final System

In conclusion, it is believed that the devised system, should; (i) facilitate a significant reduction in the design cycle time and manufacturing costs of such systems, (ii) significantly add to the body of research and development reported to date in this field.

An actual implementation of this system could lead to a standardised LCD display installed in every vehicle. Style variations between models can be easily maintained by simply changing the images used in the video process (SDL code). Due to the open source nature of the project, it is also believed, that its implementation would lead to reduction in manufacturing costs and time.

5.3 Recommendations for further Research and Development

While stress testing the final system, glitches were observed on the LCD screen when transmitting CAN data with a small time period. After some investigation into the errors it was discovered that these glitches were due to the video process not being able to respond fast enough to the incoming data. A recommendation to improve the response time of the video process could be to use a graphic accelerator.

A graphic accelerator can be achieved in two ways on the BF548. The first option would be to use the open GL libraries in conjunction with the current SDL code. The second option would be to implement DirectFB on the BF548. The video code could then be re-written to run on DirectFB or the current SDL code can run on top of DirectFB. Either option should improve the response time of the current SDL code.

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Appendix A – Write to Pipes Program

wrpipes_test.c

```
// The headers
#include <stdio.h>
#include <stdlib.h>
#include <sys/types.h>
#include <sys/stat.h>
#include <sys/time.h>
#include <sys/ioctl.h>
#include <fcntl.h>
#include <unistd.h>
#include <string.h>

//define pipe
#define RFIFO_FILE "RECFIFO"

int main ()
{
        int fp, i;
        //char mes[21];

// create pipe
mknod(RFIFO_FILE, S_IFIFO|0666, 0);


// open and write to pipe
  char mes[] = "Hello World\n";
  fp = open(RFIFO_FILE, O_WRONLY);
  write(fp, mes, 16);
  close(fp);

  printf("%c", mes[40]);


return 0;

}
```

Appendix B – Read from Pipes Program

rdpipes_test.c

```
// The headers
#include <stdio.h>
#include <stdlib.h>
#include <sys/types.h>
#include <sys/stat.h>
#include <sys/time.h>
#include <sys/ioctl.h>
#include <fcntl.h>
#include <unistd.h>
#include <string.h>

// define pipe
#define RFIFO_FILE "RECFIFO"

int main ()
{
        int fp1;
        char readbuf1[16];

   // open and read pipe
   fp1 = open(RFIFO_FILE, O_RDONLY);
   read(fp1, readbuf1, 16);
   close(fp1);
   printf("%s",readbuf1);

return 0;
}
```

Appendix C – CAN Program

receive_pipes.c

```
//The headers
#include <stdio.h>
#include <stdlib.h>
#include <sys/types.h>
#include <sys/stat.h>
#include <sys/time.h>
#include <sys/ioctl.h>
#include <fcntl.h>
#include <unistd.h>
#include <string.h>
#include <math.h>

#include </uClinux-dist-2008R1-RC8/linux-2.6.x/drivers/char/can4linux/can4linux.h>

#define STDDEV "can0"
#define COMMANDNAME "receive"
#define VERSION "1.2"

#define RXBUFFERSIZE 100

#define SPEEDFIFO_FILE "SPEEDFIFO"
#define IDFIFO_FILE "IDFIFO"
#define REVFIFO_FILE "REVFIFO"

#ifndef TRUE
# define TRUE  1
# define FALSE 0
#endif
```

```

int sleeptime           = 1000;   /* standard sleep time */
int debug               = FALSE;
int baud                      = -1;             /* dont change baud rate */
int blocking                  = TRUE;       /* open() mode */

/* -------------------------------------------------------------------- */

void usage(char *s)
{
static char *usage_text  = "\
 Open CAN device and display read messages\n\
 Default device is /dev/can0. \n\
Options:\n\
-d   - debug On\n\
       swich on additional debugging\n\
-b baudrate (Standard uses value of /proc/sys/Can/baud)\n\
-n   - non-blocking mode (default blocking)\n\
-s sleep sleep in ms between read() calls in non-blocking mode\n\
-V   version\n\
\n\
";
    fprintf(stderr, "usage: %s [options] [device]\n", s);
    fprintf(stderr, usage_text);
}



/*********************************************************************
*
*
* set_bitrate - sets the CAN bit rate
*
*
```

```
* Changing these registers only possible in Reset mode.
*
* RETURN:
*
*/

int     set_bitrate(
        int fd,                 /* device descriptor */
        int baud                /* bit rate */
        )
{
Config_par_t  cfg;
volatile Command_par_t cmd;


   cmd.cmd = CMD_STOP;
   ioctl(fd, CAN_IOCTL_COMMAND, &cmd);

   cfg.target = CONF_TIMING;
   cfg.val1   = baud;
   ioctl(fd, CAN_IOCTL_CONFIG, &cfg);

   cmd.cmd = CMD_START;
   ioctl(fd, CAN_IOCTL_COMMAND, &cmd);
   return 0;
}


/***********************************************************************
*
*
* main -
*
*
```

```
*/

int main(int argc,char **argv)
{
int fd;
int got;
int c;
char *pname;
extern char *optarg;
extern int optind;

canmsg_t rx[RXBUFFERSIZE];
char device[50];
int messages_to_read = 1;

    pname = *argv;

    /* parse command line */
    while ((c = getopt(argc, argv, "b:dhs:nV")) != EOF) {
            switch (c) {
                case 'b':
                        baud = atoi(optarg);
                        break;
                case 's':
                        sleeptime = atoi(optarg);
                        break;
                case 'd':
                        debug = TRUE;
                        break;
                case 'n':
                        blocking = FALSE;
                        messages_to_read = RXBUFFERSIZE;
                        break;
                case 'V':
                        printf("%s %s\n", argv[0], " V " VERSION ", " __DATE__ );
                        exit(0);
                        break;

                        /* not used, devicename is parameter */
                case 'D':
                        if (
                            /* path ist starting with '.' or '/', use it as it is */
                                optarg[0] == '.'
                                ||
                                optarg[0] == '/'
                                ) {
                            sprintf(device, "%s", optarg);

                      } else {
                            sprintf(device, "/dev/%s", optarg);
                        }
                        break;
                case 'h':
                default: usage(pname); exit(0);
            }
    }

    /* look for additional arguments given on the command line */
    if ( argc - optind > 0 ) {
            /* at least one additional argument, the device name is given */
            char *darg = argv[optind];

            if (
                /* path ist starting with '.' or '/', use it as it is */
                        darg[0] == '.'
                        ||
                        darg[0] == '/'
                        ) {
```

```
                sprintf(device, "%s", darg);
            } else {
            sprintf(device, "/dev/%s", darg);
            }
        } else {
            sprintf(device, "/dev/%s", STDDEV);
        }

        if ( debug == TRUE ) {
            printf("%s %s\n", argv[0], " V " VERSION ", " __DATE__ );
            printf("(c) 1996-2006 port GmbH\n");
            printf(" using canmsg_t with %d bytes\n", sizeof(canmsg_t));
            printf(" CAN device %s opened in %sblocking mode\n",
                device, blocking ? "" : "non-");

        }

        sleeptime *= 1000;

        if(blocking == TRUE) {
            /* fd = open(device, O_RDWR); */
            fd = open(device, O_RDONLY);
        } else {
            fd = open(device, O_RDONLY | O_NONBLOCK);
        }
        if( fd < 0 ) {
            fprintf(stderr,"Error opening CAN device %s\n", device);
            perror("open");
            exit(1);
        }
        if (baud > 0) {
            if ( debug == TRUE ) {
              printf("change Bit-Rate to %d Kbit/s\n", baud);
            }
            set_bitrate(fd, baud);
        }

        /* printf("waiting for msg at %s\n", device); */

        ////////////// Start Of Edit ////////////////
        while(1) {
          got=read(fd, &rx, messages_to_read);
          int fp1, fp2, fp3;
          umask(0);
          mknod(SPEEDFIFO_FILE, S_IFIFO|0666, 0);
          mknod(IDFIFO_FILE, S_IFIFO|0666, 0);
          mknod(REVFIFO_FILE, S_IFIFO|0666, 0);
          char x[10];
          char w[10];
          char id[10];
          char mes[10];
          char y[10];
          char rev[10];
          int byte1, byte2, speed, byte3;

          if( got > 0) {
            int i;
            int j;

            for(i = 0; i < got; i++) {
              printf("Received with ret=%d: %12lu.%06lu id=%ld\n",
                      got,
                      rx[i].timestamp.tv_sec,
                      rx[i].timestamp.tv_usec,
                      rx[i].id);

                      sprintf(w, "%d", rx[i].id);
            strcpy(id, w);
```

```


                printf("\tlen=%d msg=", rx[i].length);
                for(j = 0; j < rx[i].length; j++) {
                        printf(" %02x", rx[i].data[j]);
                }

                   byte1 = ("%d", rx[i].data[0]);
         byte2 = ("%d", rx[i].data[1]);
         byte3 = ("%d", rx[i].data[2]);

         speed = byte1*pow(16,2) + byte2;

        sprintf(x, "%d", speed);
        strcpy(mes, x);

        sprintf(y, "%d", byte3);
        strcpy(rev, y);

                printf(" flags=0x%02x\n", rx[i].flags );
                fflush(stdout);
            }
      } else {
            printf("Received with ret=%d\n", got);
            fflush(stdout);
      }
      if(blocking == FALSE) {
              /* wait some time before doing the next read() */
              usleep(sleeptime);
      }

        fp1 = open(SPEEDFIFO_FILE, O_WRONLY);
        write(fp1, mes, 100);
        close(fp1);
        printf("mes = %s\n", mes);

        fp2 = open(IDFIFO_FILE, O_WRONLY);
        write(fp2, id, 100);
        close(fp2);
        printf("id = %s\n", id);

        fp3 = open(REVFIFO_FILE, O_WRONLY);
        write(fp3, rev, 100);
        close(fp3);
        printf("rev = %s\n", rev);

    }
    ////////// End Of Edit ///////////////

    close(fd);
    return 0;
}
```

Appendix D – Video Program

dials_bar.c

```
//The headers
#include "SDL.h"
#include "SDL_image.h"
#include "stdlib.h"
#include "stdbool.h"
#include <stdio.h>
#include <stdlib.h>
#include <sys/types.h>
#include <sys/stat.h>
#include <sys/time.h>
#include <sys/ioctl.h>
#include <fcntl.h>
#include <unistd.h>
#include <string.h>
#include <math.h>

#define SPEEDFIFO_FILE "SPEEDFIFO"
#define IDFIFO_FILE "IDFIFO"
#define REVFIFO_FILE "REVFIFO"

char readbuf1[10];
char readbuf2[10];
char readbuf3[10];

//The attributes of the screen
const int SCREEN_WIDTH = 480;
const int SCREEN_HEIGHT = 272;
const int SCREEN_BPP = 16;
```

```

//The surfaces that will be used
SDL_Surface *message1 = NULL;
SDL_Surface *message2 = NULL;
SDL_Surface *message3 = NULL;
SDL_Surface *background = NULL;
SDL_Surface *mask = NULL;
SDL_Surface *screen = NULL;

bool quit = false;
int fp1,fp2,id,fp3,z,t,m,j,i,k,s,lastid;
int del = 5;
int rpm_value;
int last_rpm = 0;
int mph_value;
int last_mph = 0;
int rpm_finished = 0;
int mph_finished = 0;
char rpm[25];
char mph[25];
char c[25];
char d[25];
char bground[50];
char mk[25]= "images/mph/mask.PNG";



//The event structure
SDL_Event event;

void apply_surface( int x, int y, SDL_Surface* source, SDL_Surface* destination )
{
   //Make a temporary rectangle to hold the offsets
   SDL_Rect offset;
```

```

    //Give the offsets to the rectangle
    offset.x = x;
    offset.y = y;

    //Blit the surface
    SDL_BlitSurface( source, NULL, destination, &offset );
}

bool init()
{
    //Initialize all SDL subsystems
    if( SDL_Init( SDL_INIT_EVERYTHING ) == -1 )
    {
        return false;
    }

    //Set up the screen
    screen = SDL_SetVideoMode( SCREEN_WIDTH, SCREEN_HEIGHT,
SCREEN_BPP, SDL_SWSURFACE );

    //If there was an error in setting up the screen
    if( screen == NULL )
    {
        return false;
    }

    //If everything initialized fine
    return true;
}

void quit_prog()
{
   // SDL_FreeSurface( message1 );
   //Quit SDL
   SDL_Quit();
   exit(0);
}

void mask_screen()
{
   mask = IMG_Load( mk );
   apply_surface( 0, 0, mask, screen );
   SDL_FreeSurface( mask );
}

int get_can(t, mph_value, id, lastid, rpm_value)
int *t, *mph_value, *id, *rpm_value, *lastid;
{
          //////////// Speed Pipe /////////////
          fp1 = open(SPEEDFIFO_FILE, O_RDONLY);
                 read(fp1, readbuf1, 10);
                        close(fp1);

                        z = atoi(readbuf1);
          *mph_value = ceil(z/18);
          printf("mph_value = %d\n",*mph_value);
          if (*mph_value > 145)
            {
            *mph_value = 145;
            }

          *t = ceil(z/30);
          if (*t > 87)
            {
            *t = 87;
            }

```

```
           ////////// ID Pipe ////////////////
           fp2 = open(IDFIFO_FILE, O_RDONLY);
                           read(fp2, readbuf2, 10);
                           close(fp2);
                           *lastid = *id;
                           *id = atoi(readbuf2);
                           printf("id = %d\n",*id);
           sprintf(bground, "images/bar/err%d.PNG", *id);



          ///////////// RPM Pipe //////////////////
          fp3 = open(REVFIFO_FILE, O_RDONLY);
          read(fp3, readbuf3, 10);
          close(fp3);
          *rpm_value = atoi(readbuf3);

           if (*rpm_value > 300)
                      {
                       *rpm_value = 300;
                       }
           *rpm_value = *rpm_value * 20;
           printf("rpm_value = %d\n\n",*rpm_value);
}


int dials(rpm_value, last_rpm , mph_value, last_mph, rpm_finished, mph_finished)
int  *rpm_value, *last_rpm, *mph_value, *last_mph, *rpm_finished, *mph_finished;
{
  do{
      if(*rpm_finished != 1)
      {
       if(*rpm_value > *last_rpm)
            {
            *last_rpm = *last_rpm + 20;
            }
       else if(*rpm_value < *last_rpm)
            {
            *last_rpm = *last_rpm - 20;
            }
            sprintf(rpm, "images/rpm/%d.png", *last_rpm);

            message2 = IMG_Load( rpm );
            apply_surface( 280, 0, message2, screen );
            if( SDL_Flip( screen ) == -1 )
                {
                return 1;
                }
                SDL_FreeSurface( message2 );

       if(*last_rpm == *rpm_value)
            {
            *rpm_finished = 1;
            }
       }
       if(*mph_finished != 1)
       {
       if(*mph_value < *last_mph)
            {
            *last_mph = *last_mph - 1;
            }
      else if (*mph_value > *last_mph)
            {
            *last_mph = *last_mph + 1;
            }
            sprintf(mph, "images/mph/%d.png", *last_mph);

            message1 = IMG_Load( mph );
            apply_surface( 0, 0, message1, screen );
            if( SDL_Flip( screen ) == -1 )
               {
               return 1;
               }
            SDL_FreeSurface( message1 );

       if(*last_mph == *mph_value)
            {
            *mph_finished = 1;
            }
       }
       }
       while((*rpm_finished != 1) || (*mph_finished != 1));
}

int green_up(i,t)
int *i,*t;
{
s = *i;
if (s <= *t)
{
for (s=*i;((s<42)&&(s<*t));s++)
{
background = IMG_Load( bground );
message1 = IMG_Load( "images/bar/green.PNG" );
apply_surface( 0, 0, background, screen );
for (k=0;k<=s;k++)
{
apply_surface( j, 212, message1, screen );
j=j+4;
}
if( SDL_Flip( screen ) == -1 )
{
    return 1;
}
SDL_Delay( del );
SDL_FreeSurface( message1 );
SDL_FreeSurface( background );
j = 56;
}
*i=s;
}
}

int yellow_up(i,t)
int *i,*t;
{
s = *i;
if (s <= *t)
{
for (s=*i;((s<60)&&(s<*t));s++)
{
background = IMG_Load( bground );
message2 = IMG_Load( "images/bar/yellow.PNG" );
apply_surface( 0, 0, background, screen );
for (k=0;k<=s;k++)
{
apply_surface( j, 212, message2, screen );
j=j+4;

}
if( SDL_Flip( screen ) == -1 )
{
    return 1;
}
SDL_Delay( del );
SDL_FreeSurface( message2 );
SDL_FreeSurface( background );
j = 56;
}
*i=s;
}
}


int red_up(i,t)
int *i,*t;
{
s = *i;
if (s <= *t)
{
for (s=*i;((s<88)&&(s<*t));s++)
{
background = IMG_Load( bground );
message3 = IMG_Load( "images/bar/red.PNG" );
apply_surface( 0, 0, background, screen );
for (k=0;k<=s;k++)
{
apply_surface( j, 212, message3, screen );
j=j+4;

}
if( SDL_Flip( screen ) == -1 )
{
    return 1;
}
SDL_Delay( del );
SDL_FreeSurface( message3 );
SDL_FreeSurface( background );
j = 56;
}
*i=s;
}
}

int red_down(i,t)
int  *i, *t;
{
s = *i;
if (s >= *t)
{
for (s=*i;((s>=60)&&(s>*t));s--)
{
background = IMG_Load( bground );
message3 = IMG_Load( "images/bar/red.PNG" );
apply_surface( 0, 0, background, screen );
for (m=1;m<s;m++)
{
apply_surface( j, 212, message3, screen );
j=j+4;

}
if( SDL_Flip( screen ) == -1 )
{
    return 1;
}
SDL_Delay( del );
SDL_FreeSurface( message3 );
SDL_FreeSurface( background );
j = 56;
}
*i=s;
}

}
```

```

int yellow_down(i,t)
int  *i, *t;
{
s = *i;
    if (s >= *t)
    {
    for (s=*i;((s>=42)&&(s>*t));s--)
    {
    background = IMG_Load( bground );
    message2 = IMG_Load( "images/bar/yellow.PNG" );
    apply_surface( 0, 0, background, screen );
    for (m=1;m<s;m++)
    {
    apply_surface( j, 212, message2, screen );
    j=j+4;

    }
    if( SDL_Flip( screen ) == -1 )
    {
        return 1;
    }
    SDL_Delay( del );
    SDL_FreeSurface( message2 );
    SDL_FreeSurface( background );
    j = 56;
    }
    *i=s;
    }
 }

int green_down(i,t)
int  *i, *t;
{
```

```
s = *i;
   if (s >= *t)
   {
   for (s=*i;((s>=0)&&(s>*t));s--)
     {
     background = IMG_Load( bground );
     message1 = IMG_Load( "images/bar/green.PNG" );
     apply_surface( 0, 0, background, screen );
     for (m=1;m<s;m++)
     {
     apply_surface( j, 212, message1, screen );
     j=j+4;
     }
     if( SDL_Flip( screen ) == -1 )
     {
        return 1;
     }
     SDL_Delay( del );
     SDL_FreeSurface( message1 );
     SDL_FreeSurface( background );
     j = 56;
     }
     *i=s;
     }

}

int main( int argc, char* args[] )
{
   //Make sure the program waits for a quit //////////////
   bool quit = false;

   ///////////Initialize ///////////////
```

```
    if( init() == false )
    {
        return 1;
    }

    while( quit == false )
    {

    /////mask screen when going from bar graph to dials//////////
    if((lastid != 0) && (id == 0))
      {
      mask_screen();
      }

    ///// id = 0; no errors; use dials //////////////////////
    if(id == 0)
      {
      dials(&rpm_value, &last_rpm ,&mph_value, &last_mph, &rpm_finished,
&mph_finished);

      rpm_finished = 0;
      mph_finished = 0;
      i = ((last_mph*18)/30);
      }

    ///// id != 0; errors; use bar graph and dispaly error //////////////////////
    else if (id != 0)
            {
            do{
            j=56;
            if ((i>=0) && (i<42) && (t>i))
                    {
                    green_up(&i, &t);
                    }
```

```
              else if ((i>=0) && (i<42) && (t<i))
                      {
                      green_down(&i, &t);
                      }
              else if ((i>=42) && (i<60) && (t>i))
                      {
                      yellow_up(&i, &t);
                      }
              else if ((i>=42) && (i<60) && (t<i))
                      {
                      yellow_down(&i, &t);
                      }
              else if ((i>=60) && (i<88) && (t>i))
                     {
                      red_up(&i, &t);
                      }
               else if ((i>=60) && (i<88) && (t<i))
                      {
                      red_down(&i, &t);
                      }
                }
                while (t != i);
                last_mph = ((i*30)/18);
                last_rpm = rpm_value;
              }

////////// Get Info from CAN ////////////////
get_can(&t,&mph_value, &id, &lastid, &rpm_value);

while( SDL_PollEvent( &event ) )
     {
        //If the user has Xed out the window
         if( event.type == SDL_QUIT )
         {
                //Quit the program
                quit_prog();
            }
        }
    }


    return 0;
```