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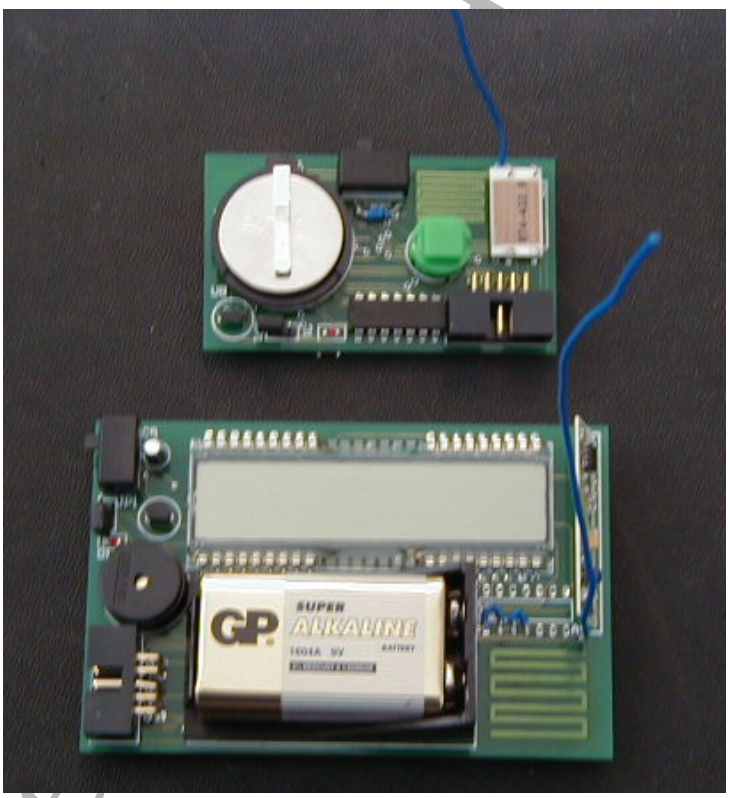
Faculty of Engineering & Information Sciences

BACHELOR OF ENGINEERING DEGREE WITH HONOURS IN ELECTRICAL AND ELECTRONIC ENGINEERING



Project Report

MICROCONTROLLER – BASED DIRECTIONAL TRANSDUCER FOR CHILD LOCATION

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Abstract

This report covers the complete stages of designing a radio wave's (wireless) based child locator from an initial concept to a working printed circuit board (PCB) solution. Hardware and software implementations have been aimed to produce a low cost portable system, in particular the testing and evaluation of the final design is discussed in relation to the product specification outlined in the introduction. Conclusively, the report refers to the effectiveness of the design and issues regarding future developments.

Acknowledgement

I would like to take this opportunity to thank Stuart Archer and his team in Mitsubishi Semiconductors for their support, help and advice.

My thanks also go to my project supervisor Kate Williams for her consistent support and guidance throughout the project period and Tony Crook for his additional advice.

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"Chapter 1 defines the sole purpose of this project in correspondence to the aims and objectives. Information regarding the product specification of the system can be found within this section."

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"The essence of this chapter is to illustrate the background knowledge needed to understand and tackle the project's aim. It will also provide information regarding the current technologies used in relation to object/child location. The results from this section will conclude to the technology chosen for the child locator."

Chapter 3 Hardware Implementation

"This chapter illustrates all the different devices used for both the transmitter (Tx) and receiver (Rx) circuit. It describes and explains why certain devices were used and its relevance to the final design concept."

Chapter 4 Transmitter and Receiver Printed Circuit Board (PCB)

"With the prototype complete, the next stage was to import the schematics of the modules onto PCB. This chapter highlights the stages taken in order to produce the required PCB, which was to be later encapsulated if time permitted, to create the final product as outlined in the original aim."

Chapter 5 Software Development

"The objectives of this chapter are to explain and describe the software code written in 'C' for the transmitter and receiver MCU. It will provide a guide for all the features implemented such as the low power features, ADC battery monitor, signal transmission and reception. In order to appreciate the software developed, an overview of the development environment will also be discussed."

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"Chapter 6 evaluates the full performance of the final design in relation to the project's aim and product specification outlined in chapter 1."

Chapter 7 Conclusion

"Chapter 7 provides a summary of the major findings of this report and discusses recommendations for further work and improvements that could be implemented to the existing system."

Glossary of terms

Amplitude Modulation	AM
Analogue to digital converter	ADC
Clock	Clk
Complimentary Metal-Oxide Semiconductor	CMOS
Direct Current	DC
Digital Multi-Meter	DMM
Frequency Modulation	FM
Full Scale Voltage	FSV
Global Positioning System	GPS
Ground	GND
Input	I/P
Least Significant Bit	LSB
Integrated Circuit	IC
Liquid Crystal Display	LCD
Light Emitting Diode	LED
Interrupt Service Routine	ISR
Inter Symbol Interference	ISI
Microcontroller Unit	MCU
Most Significant Bit	MSB
Output	O/P
Printed Circuit Board	PCB
Radio Frequency	RF
Random Access Memory	RAM
Read Only Memory	ROM
Receiver	Rx
Supply Voltage	Vcc
Surface Mount Devices	SMD
Transistor Transistor Logic	TTL
Transmitter	Tx
Universal Asynchronous Receiver Transmitter	UART
Voltage reference	Vref

Equation [1] Voltage divider rule	**Vout**	$= \mathbf{Vin.R_2 / R_1+R_2}$
Equation [2] ¼ wavelength antenna	λ	$= \mathbf{(C / f) / 4}$
Equation [3] Battery life	$\mathbf{E_{total}}$	$= \mathbf{E_{standby} + E_{send} + E_{off}}$

Chapter 1 Introduction

Chapter contents

1.0 Chapter Overview

Chapter 1 defines the sole purpose of this project in correspondence to the aims and objective. Information regarding the product specification of the system can be found within this section.

1.1 Project aims and objectives

The aim of this project is to design and develop a cost-effective and low power radio frequency (RF) based child locator from initial design to a manufactured product.

The objective is to utilise a pair of RF modules so that the end user (adult/parent) has a transmitter module that can send a signal to the receiver carried by the child to activate an audible signal. The user can therefore locate the origin of the sound hence the location of the child. To produce an efficient system, the transmitter and receiver will be controlled via a microcontroller unit (MCU) which in turn controls the audible speaker unit and a liquid crystal display (LCD).

With the emphasis of the project being cost-effective, low power and a complete product at the end of the project, it has been essential to achieve a reliable RF communication link between the transmitter and receiver unit as early into the project as possible.

1.2 Design limitations

Like all portable systems the power consumption, physical size and weight must be minimal in order to prolong the battery life and limit its overall weight. In order to overcome these issues, the required components were preferred to be in Surface Mount Device (SMD) format, which would largely limit the size and weight of the unit. Current consumption on the other hand was dealt with by setting the respective MCU and other devices into their low power or shut down modes.

With a project budget of only £50, cost limitation was the secondary restriction, which meant precautions were taken in finding the most appropriate devices.

Finally the third restriction was the time limit and in order to produce a satisfactory result at the end of this period, good time planning was essential to any project of this scale. A lot of time was spent planning ahead, keeping to schedule and estimating any contingencies where possible. Appendix D shows the initial Gantt chart produced compared with the actual time spent during the project period.

1.3 Initial product specification

The table below (Table 1.0) illustrates the product specification for the RF based child locator:

Table 1 Product Specification

PHASE 1		
Features	Description	Specification
Receiver (Rx) module	Low power operation	<5mA and <=5V power supply
Transmitter (Tx) module	Low power Operation	<5mA and <=5V power supply
RF range	It seems that parents or adults get concerned over their child when in or outdoors with a separation of around 20M, therefore the maximum range needed must balance the requirements based on the users opinion	Min 15M and Max 25M
MCU	The pin range is large due to the fact that the system may need additional modules listed in phase 2. Flash memory is preferred as it allows the code in the MCU to be updated (i.e. erased and reprogrammed) Minimum of 2 timers may be used to encode and decode the receiving signal	20-100Pin, 8/16 bit core, Flash memory Low power < 30mA Low power Feature, i.e. sleep mode, wait mode < 50uA Min 2 Timers A/D channel
Battery (power supply)	Used in portable equipment such as remote controls, lighters, cameras, etc.	Standard off the shelf 3/6/9V Alkaline Battery Replacement frequency aimed at min 6months
Size	Typical pocket calculator size (except for the depth)	Max dimensions of 150mm*85mm*60mm
Weight	Minimal weight as the RF modules are portable devices	Max of 100g
Speaker	Loud audible sound so that it can be heard from a max range of 25M without any hearing damage/impairment to the child	Audible signal of 80dB
Low battery indicator	Used to warn the users that the unit needs a battery replacement (important feature)	Red flashing Light Emitting Diode (LED)
Environmental and physical considerations	As the unit will be used in and outdoors, it needs to withstand many of the outdoor weather conditions.	Water proof, Shock proof, Vibration proof Temp range: 10C to 50C
Cost	Maximum budget	Max £50
PHASE 2		
Multiple modules	As many parents have more than a single child, or those with many children to look after it is necessary to have multiple receivers to locate each child	Encode signal with unique signature for each unit. Hence a different audible signal used for each child
Diagnostic Test	This software based feature will be programmed into the MCU so that the units can self diagnose themselves by running a routine which test the functions of each module and its RF link	Software based solution to self test the modules to assure that the units are functioning correctly

LCD	As the unit gets more complex, it would be more user friendly for the operator to see the relevant data such as module number, diagnostic details, power consumption, time, calendar, hence resulting in a more attractive multi-purpose device Can also be used to display a menu system for the user to navigate through the different types of functions	8 digit 14 segment alphanumeric display (typically 36 pins)

1.4 Summary

The aim of designing a complete child-locating device opens many doors to the available technologies that can be used to meet the requirements set. Examing the objectives outlined, the following report will illustrate the approaches taken in order to produce a system that will take advantage of the current technologies. In addition, it will provide an overall understanding in both the hardware and software implemented. The summary listed below concludes the main objectives within this project:

- Design and build a system that utilises a reliable wireless RF Link between the transmitter and receiver.
- Write source code for the microcontroller (MCU) to utilise the:
  - low power features within the MCU
  - shut down modes on external components i.e. transceiver ICs, Memory etc.
- Buzzer circuit to produce an audible signal loud enough for the user to hear
  - This section will also include software programming
- Develop, build and test development board and design a Printed Circuit Board (PCB) for the transmitter and receiver
- Design box to encapsulate PCB

Chapter 2 Investigation and Research

Chapter contents

2.0 Chapter Overview

The purpose of this chapter is to illustrate the background knowledge needed to understand and tackle the project's aim. It will also provide information regarding the current technologies used in relation to object/child location. The results from this section will conclude to the technology chosen for the child locator.

2.1 Market potential

The importance of a child's location has become a major concern for many parents over the past few years, with reports showing that between 700 – 800 children go missing every month in the US alone. In order to protect children and help parents or guardians know their whereabouts, many manufacturers are developing wristwatches and pager-sized units that can be used to track lost individuals to within a few feet. Reports also claim that one company intends to unveil a working prototype of an encapsulated Global Positioning System (GPS) device that could be surgically implanted inside a person's arm. It is also estimated that by 2006 the potential market for child detectors will be around $200 billion USD from the president of Wherify Wireless Inc.

"The Wherify Personal Location System includes a wristwatch-sized device that combines SiRF's SiRFstarII GPS technology, along with LSI Logic's Code Division Multiple Access (CDMA) technology, which allows device communication through a national PCS network. As a result, subscribers of the Personal Location System will be able to quickly determine, via a 24x7 location service center accessed through the Internet or by any phone, the location of their children, elderly parents or other at-risk loved ones wearing the device."[1]

2.2 Investigation in location devices

To achieve the knowledge necessary to tackle the project aim, a large scale of time was spent researching into the available location devices in the current market place.

2.2.1 GPS

Many current manufacturers have implemented GPS technology due to their major advantages such as its high efficiency to work under any weather conditions, precision for object location anywhere in the world, its 24 hours a day service with no subscription fees or set up charges.

"The Global Positioning System (GPS) is actually a constellation of 27 Earth-orbiting satellites (24 in operation and three extras in case one fails). The U.S. military developed and implemented this satellite network as a military navigation system, but soon opened it up to everybody else. Each of these 3,000- to 4,000-pound solar-powered satellites circles the globe at about 12,000 miles (19,300 km), making two complete rotations every day. The orbits are arranged so that at any time, anywhere on Earth, there are at least four satellites "visible" in the sky. A GPS receiver's job is to locate four or more of these satellites, figure out the distance to each, and use this information to deduce its own location. This operation is based on a simple mathematical principle called ***t****rilateratio****n.*** *"*[2]

Unfortunately, like many other devices on the market, some system solutions come with a single or multiple flaws. Studying the GPS system further shows that it is difficult for the receiver to receive any signals when operating indoors.

Some of the reasons for this and other problems are listed as follows:

- Signal multipath: This occurs when the GPS signal is reflected off objects such as tall buildings or large rock surfaces before it reaches the receiver. This increases the travel time of the signal, thereby causing errors.
- Visible satellites: The more satellites a GPS receiver can "see," the better the accuracy. Buildings, terrain, electronic interference, or sometimes even dense foliage can block signal reception, causing position errors or possibly no position reading at all. Therefore GPS units typically will not work indoors, underwater or underground.
- Satellite geometry/shading: This refers to the relative position of the satellites at any given time. Ideal satellite geometry exists when the satellites are located at wide angles relative to each other. Poor geometry results when the satellites are located in a line or in a tight grouping.

2.2.2 Indoor location system

The first indoor location sensing system was the Active Badges developed by AT&T Cambridge. This system consisted of an infrared beacon worn by every person that was used to emit a globally unique identifier every 10seconds. The signal is received by an IR receiver, which in turn transmits the data to a central server where the information is converted into useful data. Therefore this solution is purely for indoor purposes only.

2.2.3 Radar and Sonar

Other wireless solutions for object location include Radar and Sonar. These solutions are not appropriate for detecting the location of a child as Radar is unable to detect the exact location of an object but only its radial speed factor, hence its commercial use is in motorway speed cameras. Sonar on the other hand is mainly used to detect objects underwater, such as submarines, vessels etc. Sonar works by sending sound energy through a medium, i.e. water, and if an object is detected the signal is then reflected back to the transducer, hence providing the range information through additional calculations.

2.3 Required RF Distance

The maximum distance that a pair of RF modules can communicate is different from product to product. In order to choose the most appropriate distance a simple survey was carried out regarding the distance the parent and child was apart before they would become concern about their child. The results were some what expected with the range around 15 to 30meters+. Knowing that the receiver system was to utilise a buzzer as the core signal for the parent to locate, it was sensible to limit the distance for communication to the boundaries between 10m (min) to 25m (max).

2.4 Investigation and research Summary

The main aim of this project is to build and design a system to detect the location of a child, while keeping the cost and power consumption to a minimum. This would have been achieved by utilising a low power microprocessor and a form of wireless communication. Knowing that the GPS receivers are extremely precise in outdoor locations while RF communications are efficient indoors, it would be sensible to integrate both systems into one. Unfortunately, GPS receivers are extremely expensive, usually around the price range of £63; therefore it would defy the objective of being low cost. Consequently a singular simplex (one way communication) RF solution was implemented.

The modulation scheme for the RF communication was chosen to be amplitude modulation (AM) and not frequency modulation (FM). The reason for this is because AM has the advantages of being low cost, readily available and AM receivers are simple to tune. Even though their main disadvantage is in its efficiency and its vulnerability to noise, its advantages out weigh the disadvantages, which can be improved in software within this application, hence suiting the requirements for this project.

Chapter 3 Hardware Implementation

Chapter Contents

3.0 Chapter Overview

This chapter illustrates all the different devices used for both the transmitter (Tx) and receiver (Rx) circuit. It describes and explains why certain devices were used and its relevance to the final design concept.

3.1 Transmitter overview

For simplicity, Figure 1 illustrates the fundamental devices necessary for the transmitter unit. The sections thereafter will explain each corresponding sections separately with its respective schematic diagram.

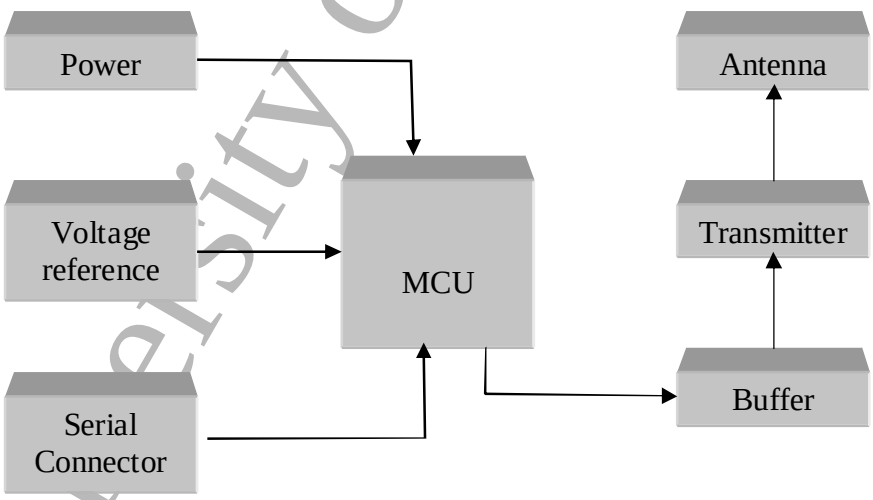


Figure 1 Transmitter Module block diagram

3.1.1 Power supply

The MCU and transmitter data sheet shows that the operating voltages for the devices are around 2.4V – 3.6V and 2V – 14V respectively. The chosen power supply for this module was therefore a standard off the shelf 3V lithium coin cell, because the battery had the appropriate voltage level, adequate current capacity (280mAh (mili amps hours)) and a small surface area and weight of 24mm diameter and 4g respectively.

Having a 3V-battery supply would also eliminate the need of a 3V/3.3V regulator hence reducing the overall cost and power consumption. For safety precautions a standard schottky diode was used in series with the supply voltage (Vcc) to protect the on board devices in case the battery was positioned incorrectly. As with all portable units, SW1 provides a simple means to switch the module on or off as shown on figure 2 below.

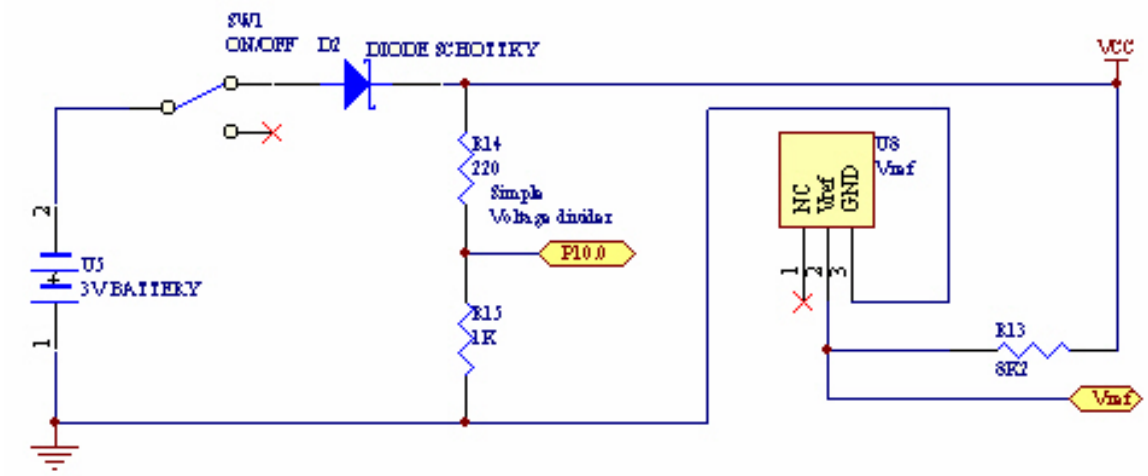


Figure 2 Tx power supply

3.1.2 Voltage reference

An important feature listed in the product specification (please refer to table 1) was a low battery indicator. In order to achieve this, the Analogue to Digital Converters (ADCs) on the MCU was used, without a regulator for the unit, there would be no constant reference voltage (Vref) for the ADC on the MCU therefore the onboard ADC would not be able to operate. To compensate, a 2.5V voltage reference device U8 was used for Vref. This solution has its advantages over using a voltage regulator as it only requires 1mA to provide a constant voltage that can be controlled on or off by the MCU pin "high" or "low" respectively, hence obtaining better power efficiency. More information regarding the ADC can be found in chapter 5 in the software section.

Figure 2 shows a simple voltage divider across the supply rail (Vcc) and ground (GND). The reason for this is so that the ADC monitoring port (Port10.0) has approximately the same voltage level of Vref where it is used to monitor the status of the battery. Below shows the calculations necessary in order to achieve ~2.5V supply to P10.0:

Using the voltage divider equation:

Equation [1]	**Vout**	**$= Vin.R_2 / R_1+R_2$**
Implies that:	**2.5V**	**$= (3 * 1000)/R_1+1000$**
	R_1	**$= (3000 – 2500)/2.5$**
Therefore	**R_1**	**$= 200\Omega$**

Vout = 2.5V
Vin = 3V
Assume R_2 = 1K

Hence the preferred value of 220Ω for R_1 was used to supply P10.0 with 2.56V.

3.1.3 Serial Connector

Figure 3 illustrated on the right shows the 10-pin connector used on the development board and PCB to allow programming and debugging of the MCU. This hardware implementation enables the user to FLASH (write) new code into the MCU memory if updated software is available, as well as allowing connectivity to the PC's RS232 port (COM port) using the MF-TEN-NINE cable shown in Appendix H.

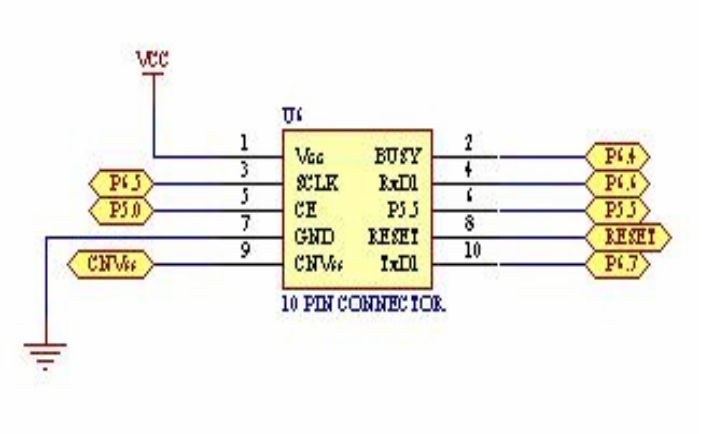


Figure 3 10 pin serial connector

3.1.4 Transmitter M16C/62N MCU

The MCU used for the Tx module is the M16C/62N, Mitsubishi's compact, cost effective low power 16bit MCU that provides high speed processing with RISC like performance. Targeted for many modern applications, it features low operating voltage (3.3V typical), noise immunity, rich on-chip peripherals and C programming efficiency. Additional hardware functions such as its 8/10bit ADC, three UART (Universal Asynchronous Receiver Transmitter) channels and eight programmable Timers are also available hence, it was ideal for the project.

To minimise the amount of time required to implement the MCU onto the Tx module, Mitsubishi's M16C/62N's 3 Diamond board was used. This is an evaluation board produced by Mitsubishi semiconductors, which consists of the following:

- M30624FGNFP (M16C/62N): On-chip 265kB Flash memory, 20kB RAM operating at 5V
- Two external clocks:
  - Main clock speed at 2MHz (replacing standard crystal of 16MHz)
  - Sub clock speed at 32768Hz
- 8 independent LEDs
- 4 Switches connected to INT0, INT1, INT2 and RESET port of the M16C
- Header connectors to allow connection to all port pins of the MCU
- 9 Pin D-type serial socket for PC connection via UART transceiver
- Simple PP3 battery connectors to power the board

Using the 3 Diamonds board as a target board for evaluating the MCU allowed the software written to be compiled, debugged and stepped through. Utilising the available header connectors, allowed the development board to be easily linked together with external devices providing a means of a simple in circuit emulator where the circuit could be tested. Figure 4 shows a simplified diagram of the M16C/62N 3 Diamonds Board.

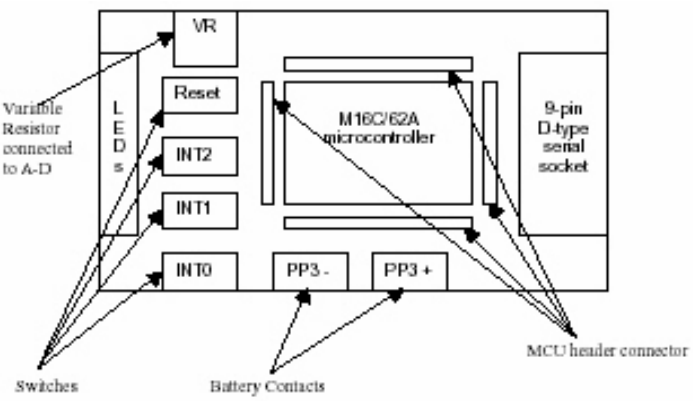


Figure 4 Mitsubishi's M16C 3 Diamonds Board

Information regarding the MCU and can be found in Appendix F.

3.1.5 Buffer

The 74HC buffer, U4C as illustrated below, is a standard off the shelf component with six internal NOT gates. The purpose for the buffer is to clean the signal from the MCU transmit pin before reaching the transmitter and antenna. It also provides a means of isolation between the MCU and transmitter, in case of any spurious errors that may occur.

Figure 5 shows how the buffer is connected to the MCU pin P0.1 via the PNP transistor's base (B). The reason for this is to ensure that the buffer is not directly connected to the supply voltage Vcc hence acting as an open circuit (i.e. no current flow). Once the corresponding port pin goes "low" hence "0", the PNP transmitter switches enabling a direct connection between the emitter (E) and collector (C), hence linking Vcc and pin 14 of the buffer (supply voltage pin) together. This switching method is used so that the operation of the buffer is solely dependent on the code/port pin, therefore providing a means of controlling the buffer's on and off time, resulting in better power efficiency. It can be seen that this technique is also used with the transmitter module U2.

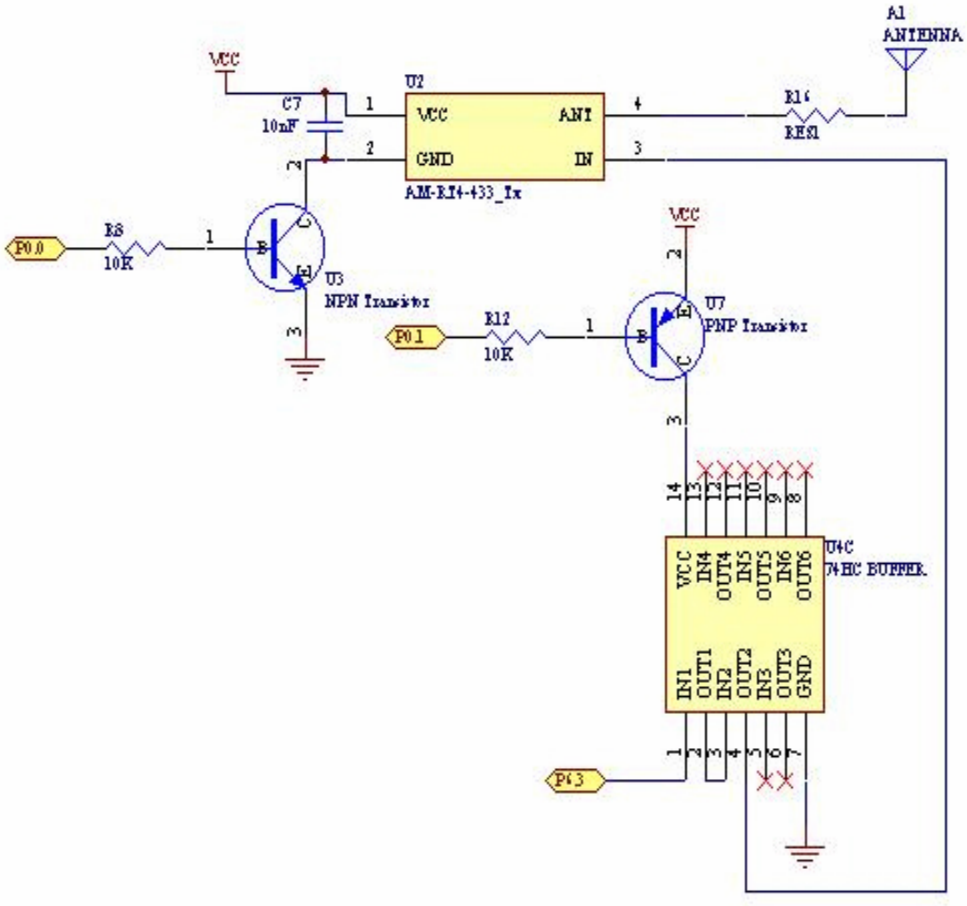


Figure 5 Transmitter module

3.1.6 Transmitter unit

The transmitter unit AM-RT4-433 is a standard off the shelf module from RF Solutions, illustrated in figure 5 as U2. The Tx unit features a wide operating voltage (2-14V), low current consumption of typically 4mA with CMOS (complimentary metal-oxide semiconductor)/TTL (transistor transistor logic) inputs, therefore this hybrid AM transmitter unit provides a complete RF transmitter that can be utilised to transmit data at up to 4KHz directly from the MCU. Its standard 4-pin package, provides a very simple integration to the Tx module and helps minimise the overall size and weight.

3.1.7 Antenna

"There seems to be little information on compact antenna design for the low power wireless field. Good antenna design is required to realize good range performance. A good antenna requires it to be the right type for the application. It also must be matched and tuned to the transmitter and receiver. To get the best results, a designer should have an idea about how the antenna works, and what the important design considerations are."[3]

To reduce the overall size of the length of the antenna and keep an adequate performance level, the system antenna was made by creating a track on the PCB, whilst preserving the performance, by calculating the length of the track using equation [2] below:

Equation [2]: $\lambda = (C / f) / 4$ where C =30000cm/s
$= (30000/433.9)/4$ f = 433.9Hz
$= 69.14/4$ λ measured in cm
$= 17.3cm = 173mm$

It would be very difficult to produce a single straight track on the PCB while trying to minimise the module's size, therefore the antenna was placed on the PCB more like a spiral as shown in chapter 4 in figure 10. To improve the efficiency of the aerial it needs to radiate above a copper based ground plane therefore a PCB fill was used in parallel as shown in figure 11.

3.2 Receiver Overview

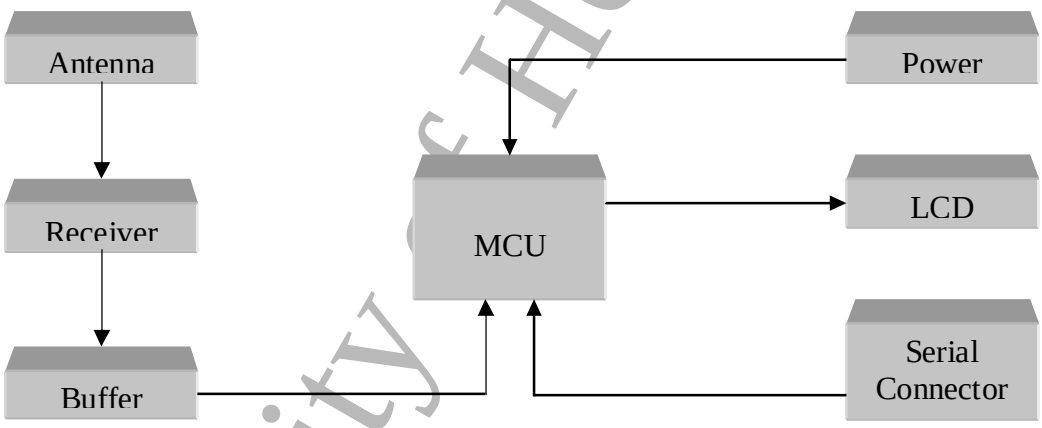


Figure 6 Receiver Module block diagram

3.2.1 Receiver unit

Figure 6 shows the key devices implemented in the receiver unit. The receiver implemented in the project is RF solutions AM-HRR3-433, U4 as shown in figure 7. Similar to that of the transmitter, the receiver has many features suitable for the project's specification such as its CMOS/TTL output, low power consumption and single supply voltage. Originally, the AM-HRR8-433 3V receiver was chosen for this application due to its 3V supply voltage and low current consumption (0.5mA), but unfortunately due to availability and order quantity issues it was unable to be obtained. Therefore AM-HRR3-433, the 5V version was chosen instead. However the design of the receiver module will be able to support the 3V version due to its main advantages described and the beneficial fact that both devices are pin compatible. Ideally if production was to proceed, then the 3V device will be implemented.

The buffer U11 is connected to the receiver unit in the same fashion as it was with the transmitter unit, hence providing the same technique for controlling the receiver's on and off status.

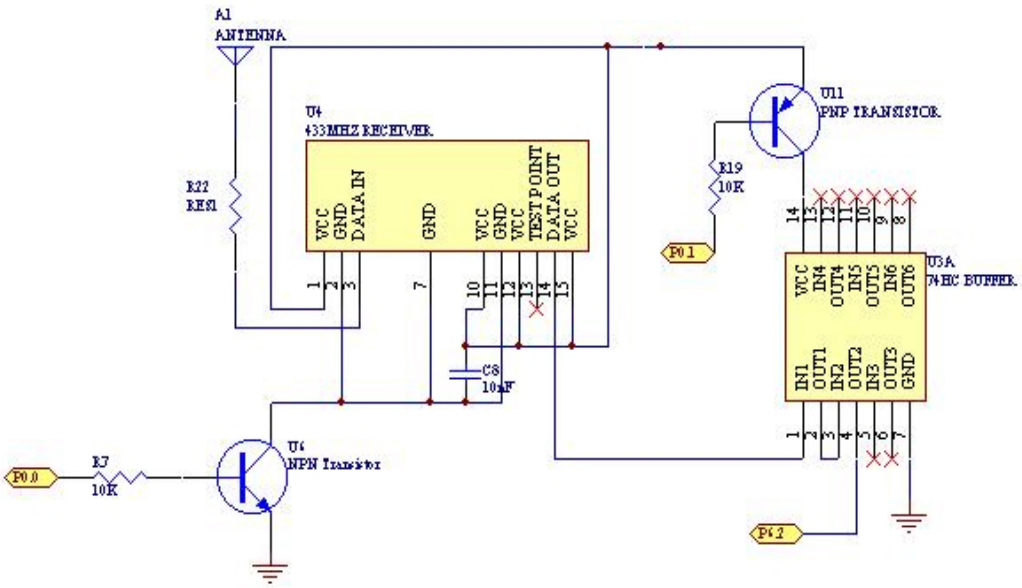


Figure 7 Receiver RX unit

3.2.2 Power supply

The receiver unit requires typically 5V to operate; therefore a standard 9V PP3 battery was used as the main power source. To achieve a reliable and constant supply to the system a 5V regulator LE50CZ was used, U2 in figure 8. Unlike the transmitter module, it was necessary to incorporate this voltage regulator so that the supply voltage for the devices was regulated down to their appropriate operating voltage level.

A 9V supply or a regulated 5V supply to the ADC monitoring channel of the MCU would not allow the MCU to calculate a low battery indication as a 9V supply would damage the MCU and 5V constant voltage would produce no change in the analogue voltage. Consequently a simple voltage divider was used, which is the same technique implemented for the transmitter. If we use equation [1] again for this application we get:

Equation [1] **Vout** $= \mathbf{Vin.R_2 / R_1+R_2}$
Implies that: **5V** $= \mathbf{(9 * 10000)/R_1+10000}$
$\mathbf{R_1} = \mathbf{(90000 – 50000)/5}$
Therefore $\mathbf{R_1} = \mathbf{8000\Omega}$ or $\mathbf{8K\Omega}$

Vout = 5V
Vin = 9V
Assume
$\mathbf{R_2}$ **= 10K**

Hence the available value of 8K2Ω for R_1 was used to supply P10.0 with 4.96V.

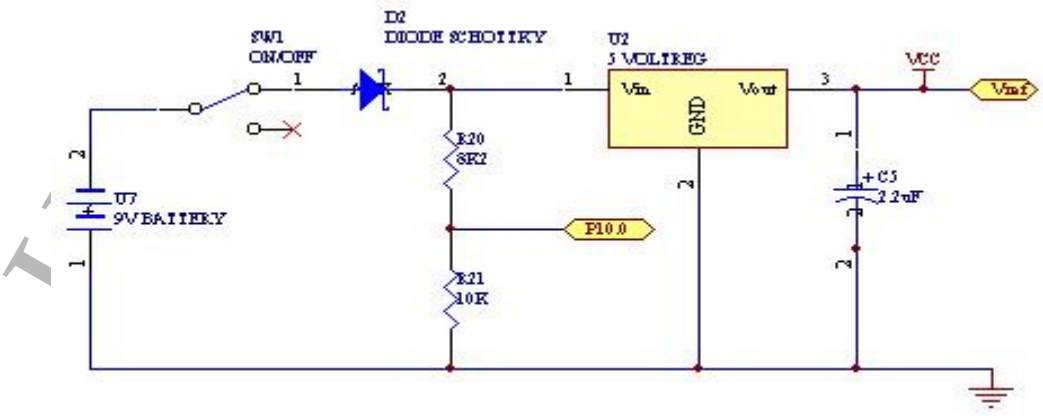


Figure 8 Receiver power supply

3.2.3 LCD

The 36-pin LCD used on the receiver is a 14 segment 8-digit star burst display, which means that it can easily display both numbers and alphabets. The display is also ¼ multiplexed with four common lines to control each segment. The LCD is purely driven in software with no external drivers but only requires two resistors per common line, shown in figure 9. By using the software driven LCD, it would reduce the overall cost as no hardware drivers are needed and would therefore reduce the current consumption.

The LCD was originally planned to display the following:

- Menu
- Time
- Date/Calendar
- Variable Message

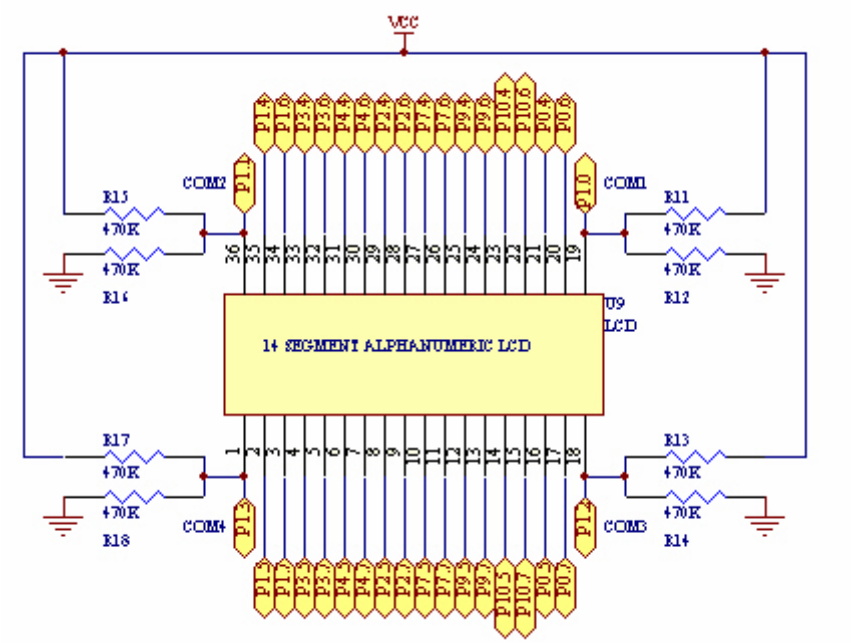


Figure 9 14 segment 8 digit LCD

3.2.4 Receiver M16C/62A MCU

The MCU used for the receiver module is the M16C/62A, another one of Mitsubishi's M16C 3 Diamonds Board family device. Similar to that of the M16C/62N described in section 3.1.4, the M16C/62A consists of the same rich features in the same 100pin package. The reason for using this device is purely due to its similar operating voltage as that of the receiver, i.e. 5V. If the receiver unit was the original recommended 3V version, AM-HRR8-433, then the M16C/62N would have been utilised. The advantage of using the M16C/62A in this design is because it is also pin-compatible with the M16C/62N hence both the 3V devices (AM-HRR8-433 and M16C/62N) can be designed into this application with minimal modifications.

3.2.5 Buzzer

The buzzer chosen to produce the audible signal for the user to trace is a simple 5V operated piezo transducer that is activated by producing a single train of pulses i.e. square waves across the corresponding pins.

3.2.6 Serial connector and Antenna

The serial connector and antenna used in the receiver circuit is a replica of the one described on the transmitter in sections 3.1.3 and 3.1.7 respectively.

3.3 Additional hardware Notes

Note that not all of the components shown within this chapter are described in detail, as they may have been taken from recommended application circuits provided by the original manufacturers. Appendix B shows a complete table listing all the components used with the overall cost while Appendix A-2 shows a picture of the developed development board.

3.4 Hardware implementation summary

Many of the devices chosen for the project suited the original requirements that were necessary to meet the aims. Since many of the devices had no shut down pins to help reduce the overall current consumption, additional components and techniques were used to produce the same effect. Due to availability issues regarding the 3V receiver unit, a 5V version was opted for the development of the receiver module. This in turn resulted in utilising the M16C/62A device for the 5V operated receiver module.

The hardware of both Tx and Rx modules has been kept to the minimal so that it would reduce the overall cost and weight of the modules. In order for the system to provide more functionality, software solutions were opted, as this would have no bearing on the overall hardware cost.

Chapter 4 Transmitter and Receiver Printed Circuit Board

Chapter contents

4.0 Chapter Overview

With the prototype complete, the next stage was to import the schematics of the modules onto PCB. This chapter highlights the stages taken in order to produce the required PCB, which was to be later encapsulated if time permitted, to create the final product as outlined in the original aim.

4.1 Printed Circuit Board

From information provided in Chapter 3, Appendix A - 1 shows the complete schematics for the transmitter and receiver circuit produced on Protel99 SE. One of Protel's powerful features is that it can transfer any complete schematics onto a PCB document provided that all the footprints for the components are present. Once the schematics were complete, footprints for each device were added with their respective electrical characteristics.

In order to minimise the overall layout of the transmitter and receiver module, SMD components were mainly used and situated on the bottom layer of the PCB. This proved successful as a space saving option as it allowed through-hole components to dominate the top layer. Regarding the 3 Diamonds board, only the MCU was taken for the final PCB design, as the other components were not necessary. The PCB layout for both the transmitter and receiver are shown on figure 10 and 11 and figure 12 and 13 respectively.

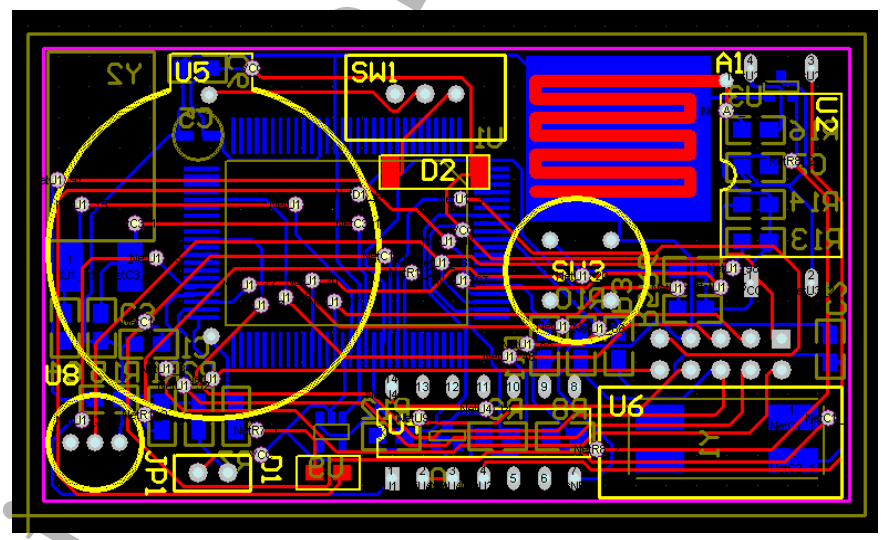
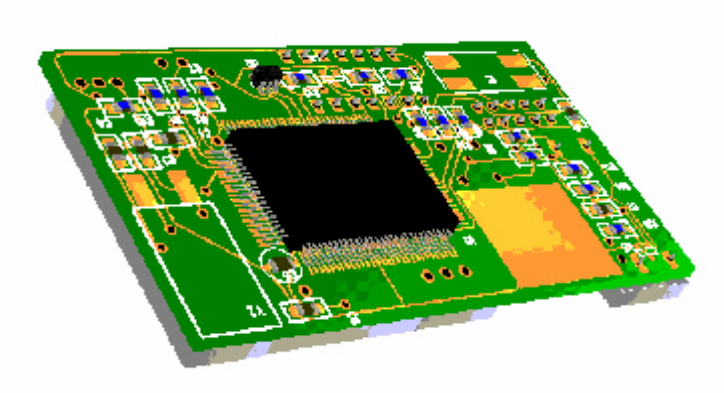


Figure 10 Tx PCB (40mm by 70mm)

Note: The red lines displayed on the PCB illustrate the connection lines on the top layer whereas the blue lines are that of the bottom layer. The yellow boundaries show the component locations.



Note: This 3 Dimensional view of the transmitter board clearly illustrates the main SMD components placed on the bottom layer of the PCB. The plain rectangular copper fill located near the bottom right of the PCB is the copper ground plane needed for the aerial (red spiral like track on figure 10) to radiate.

Figure 11 Tx PCB in 3Dimensional view

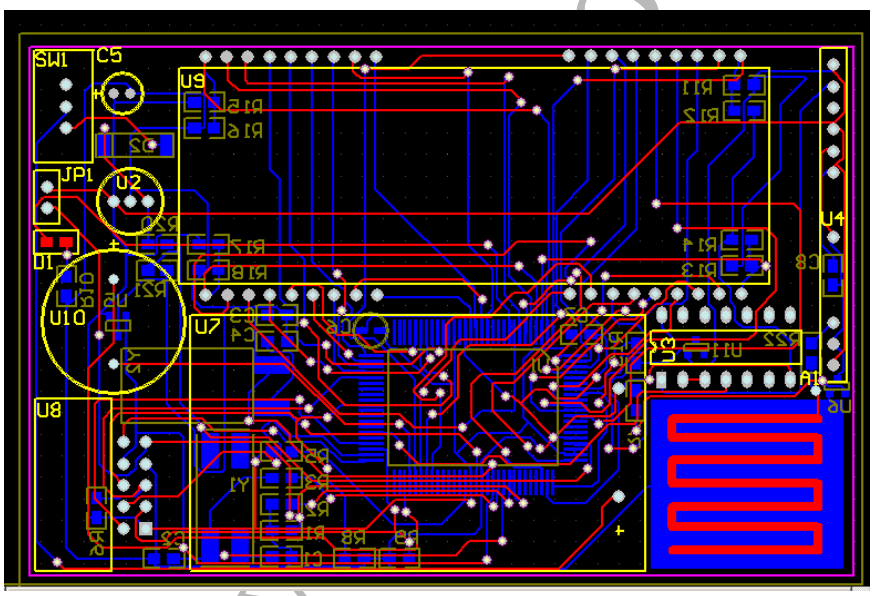


Figure 12 Rx PCB (65mm by 100mm)

Note: The dimensions of the receiver board are larger than that of the transmitter due to the physical size of the PP3 battery and LCD display.

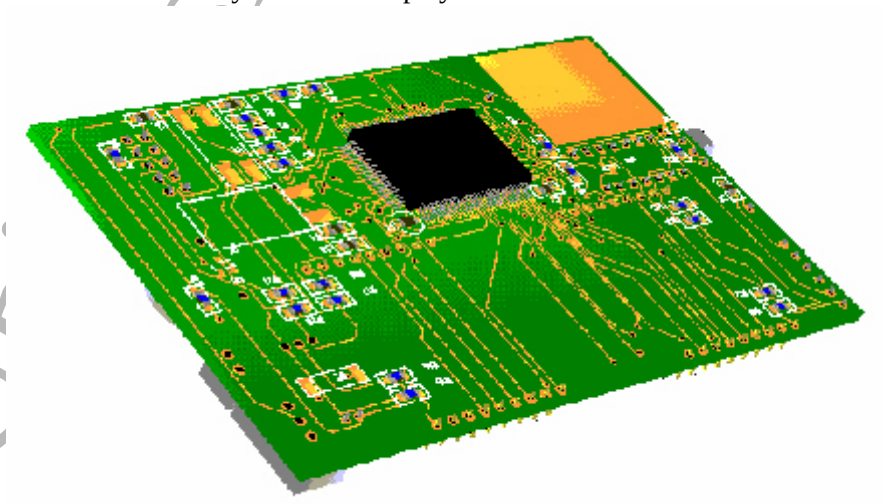


Figure 13 Rx PCB in 3Dimensional view

Note: As mentioned in chapter 3, the aerial of the receiver is similar to that of the transmitter with its respective ground copper plane parallel to it.
If we considered using the original 3V receiver and the 3V lithium battery coin cell, then the dimensional size would be reduced dramatically as shown in figure 14.

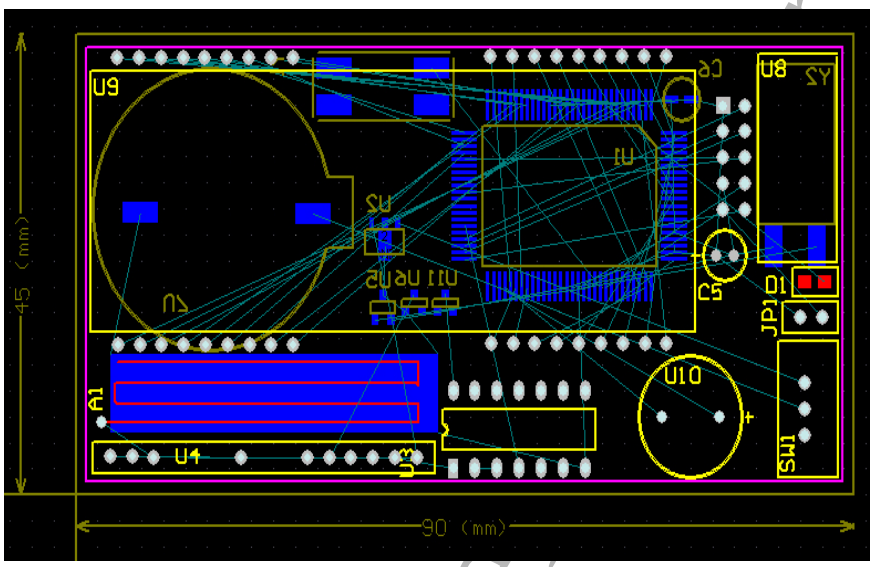


Figure 14 Rx 3V version (45mm by 90mm)

Note: Again the same principle is used with the SMD components on the bottom layer and through-hole devices on the top layer.

4.2 PCB impediment

A great deal of time was spent on the PCB design and the positions of each component to achieve the desired dimensions and layout. Majority of the delay came from the antenna track section, as it had to be independent and isolated from other local links. This was finally achieved by applying a rectangular fill over the existing aerial track during the "autoroute" progress used by Protel to link all the different nets together. Once complete, the fill was removed to produce the results as shown. It should also be noted that the ground plane and aerial track links should be minimal as the links would still act as the radiating ground and aerial, therefore the links for the ground plane and aerial was linked together manually.

Measurements for majority of the component's footprints were recorded and drawn in Protel, as the standard libraries provided did not contain them. Once the PCBs were complete with no errors on the "design rules check" in Protel, they were printed out and physically checked with the external components to make sure each component matched. When all the components were checked, the PCB file was sent to a third party to be manufactured (www.pcb-pool.com).

4.3 PCB summary

The process of converting the complete transmitter and receiver circuit schematic to the printed circuit board in Protel is reasonably straight forward. In practice though, a lot of time was consumed in ensuring that all the components and layout was correct to the specification and external devices.

Chapter 5 Software Development

Chapter contents

5.0 Chapter Overview

The objectives of this chapter are to explain and describe the software code written in 'C' for the transmitter and receiver MCU. It will provide a guide for all the features implemented such as the low power features, ADC battery monitor, signal transmission and reception. In order to appreciate the software developed, an overview of the development environment will also be discussed. Full code listing can be found in Appendix C.

5.1 Development Environment

It has been known that as the structure of a program code increases in the conventional assembly language, the more difficult it is for programmers to comprehend. This is why increasing amounts of embedded applications are now written in the C language. To help develop the software for this project, a full range of development tools including compilers and debuggers were used. Figure 15 illustrates the development environment utilised to compile, debug and test the code.

5.1.1 C compiler

The C language efficient compiler used within the Windows environment is IAR Systems Ltd Embedded Workbench, also known as EWM16C. The full source code and program is designed and implemented within EWM16C, where it is also compiled and edited to produce the object file. These files are then linked with the required libraries to produce either the mot file used to program into the target or the ieee file used for the KD30 debugger.

Libraries such as "Chip_3062x", "iom16c62.h", "intrm16c.h" are all specific files included in the compiler that allows various functions, ports and interrupts to be configured and called. The header file "common_FLASHOFF.h", is an additional file created with all the common and global variables and functions declared. The linker file is also a modified version of the original to allow full RAM operation support as discussed below. For more information regarding these files, please refer to Appendix C.

5.1.2 KD30 Debugger

The next stage after completing the software code is to test and debug the program. KD30 is another Windows based program that allows users to step through the code, place software break points and view information such as memory addresses, C variable information and the program counter.

5.1.3 FLASH starter

This program takes the mot file produced by the compiler and serially programs or flashes the code into the target MCU, hence the software written allows the program to be fully tested on the development prototype and PCB.

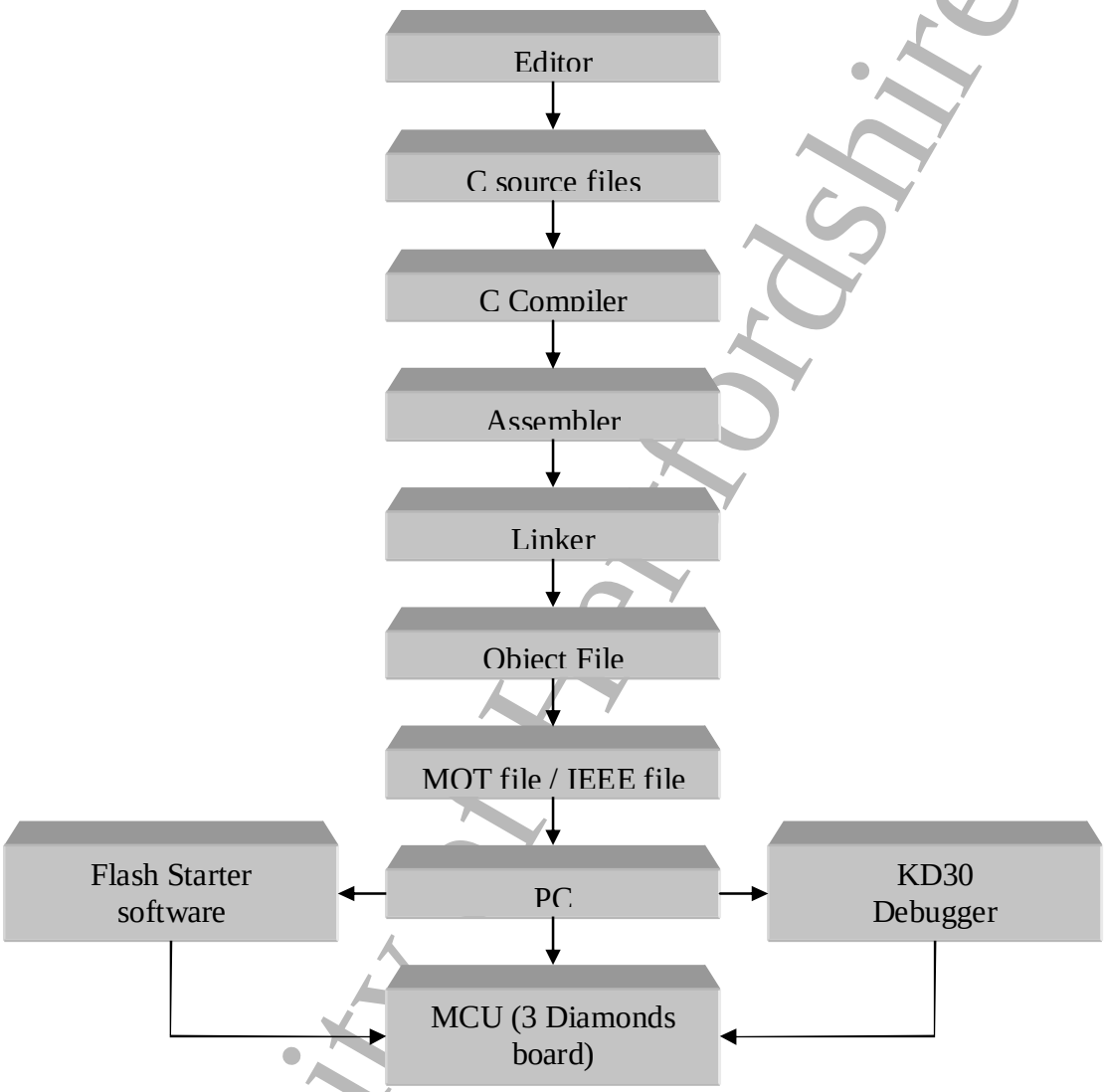


Figure 15 M16C software development environment

5.2 Transmitter Source code

To help understand the transmitter's software operation, a block diagram, figure 16, shown on the following page illustrates each independent function and interrupt service routine (ISR) used in relation to the main function "main ( )".

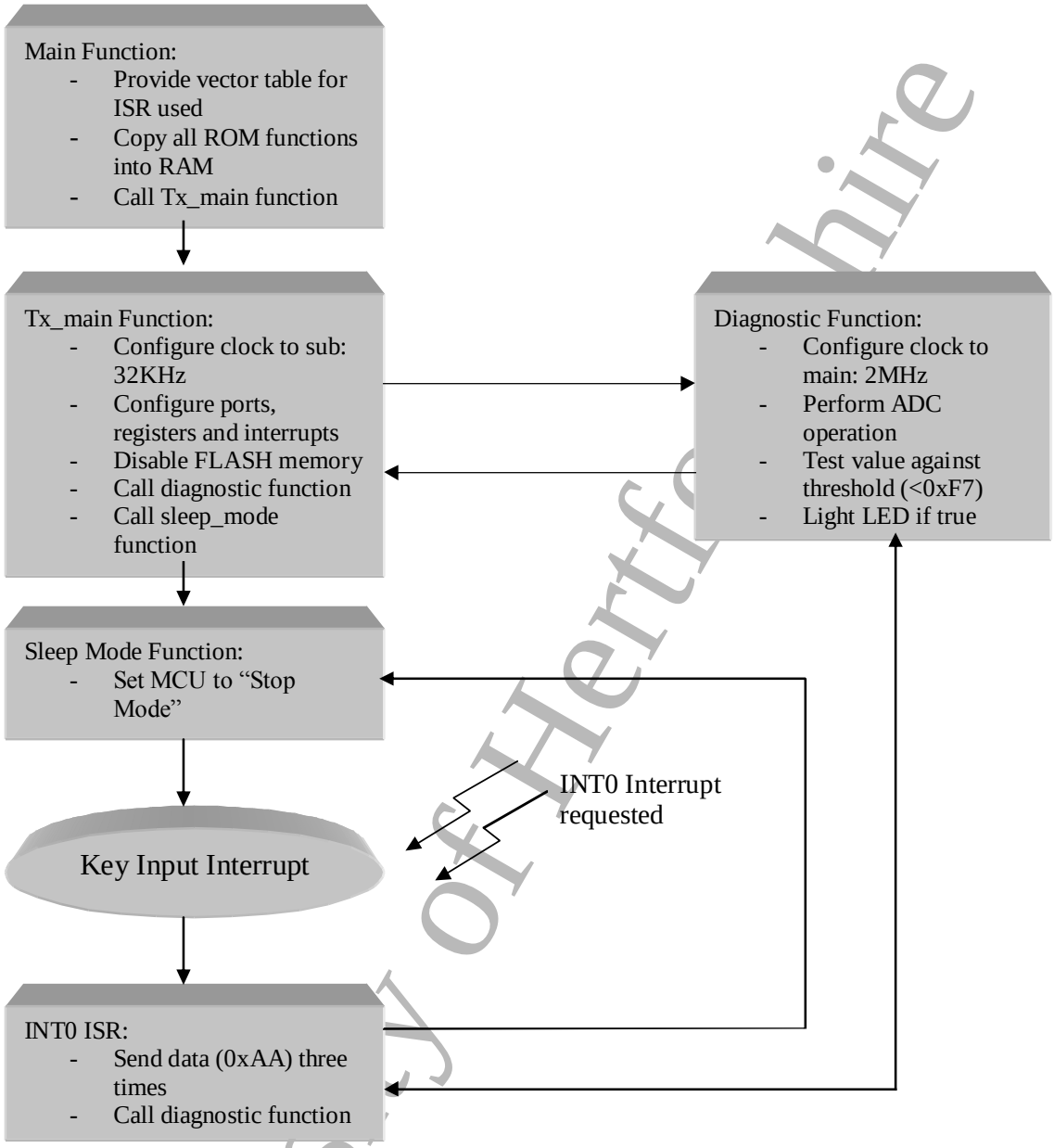


Figure 16 Transmitter source code block diagram

5.2.1 Main function

The objective of the main function is to copy all relevant functions in the read only memory (ROM) to the random access memory (RAM). This is an important part of utilising the low power features as it provides operation of the code in RAM, hence providing the option to switch the FLASH memory circuit off to reduce a large proportion of the current consumption (please refer to the electrical characteristic section in the MCU data sheet). Also in order for selected ISRs to operate correctly, their addresses must also be allocated in a specific location in RAM known as the intvec_tab array, which is declared as a global variable. The code below demonstrates how one of the functions is copied from ROM/FLASH to RAM:

```
// Copy the transmit function program into RAM
for(i=0;i<RAM_TX_MAIN_SIZE;i++)
{
        // Start copy from ROM to RAM
        ((char far *) RAM_TX_MAIN_START)[i] = ((char far *)
        ROM_TX_MAIN_START)[i];
```

}
Once all functions are copied, the function tx_main in RAM is called where all operation from there onwards is solely in RAM.

5.2.2 Tx_main Function

At the beginning of this function, the software code written configures the clock operation circuit so that the main clock is switched off and all operations work under the 32 KHz sub clock, which enables the current consumption to be reduced further. Now that all the functions are copied into Ram, the next stage is to switch the FLASH circuit supply off using register "FMR0". Port P0 through to port P10 are then configured as either input (I/P) or output (O/P) respectively, with all the ports configured, the interrupts, UART and ADC registers are then set to the required configurations.

5.2.3 Diagnostic Function

The function diagnostic ( ) is then called before the sleep_mode ( ) function that is located in a forever loop. In order to achieve an ADC threshold to produce the low battery indication required the value of 2.5V was chosen. This threshold voltage was chosen since the minimum voltage required for the MCU to operate is 2.0V (more details regarding this value can be found in Chapter 6.9). If the operating voltage of the supply falls below 2.5V the transmit module would still have adequate time before the module switches off, hence with a threshold voltage of 2.5V we can convert the analogue threshold into a digital hex value for the MCU to detect. The following calculations show how the values are calculated using an 8bit (2^8) resolution ADC.

When V_{CC} = 2.5V
V_{ref} = **2.2V**
$V_{divider}$ = **1.9V**
$V_{diode\ drop}$ = **0.22V**
Each digital value: = $\mathbf{2.2/2^8}$
= **~10mV**

Recommended digital threshold in decimal: = $\mathbf{2.2 - (1.9 + 0.22)/10*10^{-3}}$
= $\mathbf{0.08/10*10^{-3}}$
= **8**

Therefore the digital threshold is: = **255 – 8**
= **247 = 0xF7**

```
//-------------------------------------------------------------------------------
// Use ADC to measure battery status
//-------------------------------------------------------------------------------
ADCON1.5 = 1;                    // Vref connected
for (pause=0xF;pause!=0;pause--); // Allow software pause for ~1us
ADCON0.6 = 1;                    // Start ADC conversion now
while(ADCON0.6 != 1);            // Poll for ADC to finish
tempvalue = AD0L;                // Store value into local variable
if(tempvalue < 0xF7)
{
  low_battery = ON;              // Check if below threshold
  P2.0 = 1;
}
else
{
  low_battery = OFF;
  P2.0 = 0;
```

```
}
ADCON1.5 = 0;                    // Vref disconnected
```

In order for the ADC to operate it requires the main clock, therefore at the beginning of this function the main clock is resumed and switched off again at the end. This function also provides a test by a LED blinking on the board to indicate to the user that the LED is also working.

5.2.4 Sleep Mode

The sleep mode function is a very simple function that sets the MCU to stop mode by writing to the register "CM1". As the MCU is set into stop mode the FLASH memory is automatically switched off and on once it has "woken". FLASH memory is switched on just before it enters stop mode and off again once it returns.

Stop mode is utilised to produce minimal current consumption as the MCU alone only draws ~1μA at this state.

5.2.5 INT0 Interrupt

INT0 interrupt is configured as an external interrupt or switch press. Hence this interrupt is only called when the user presses the switch. Once called, the main clock is resumed and the RS232/serial data value (0xAA in hexadecimal) is sent three times. The software then checks if the button is still down and the LED creates a blinking effect. Upon release, the main clock is again switched off and the diagnostic function as called to check the battery status (please refer to section 5.2.3). Once complete and returned to the INT0 function, the code returns to the sleep mode function awaiting the next button press to occur.

5.3 Receiver Source code

To help comprehend the code written for the receiver module the following block diagram, figure 17 illustrates the full operation of the functions described below.

5.3.1 Main Function

Similar to the main function of the transmitter, this main function also copies all the ROM functions into RAM including the interrupt vector table. Once complete, it calls the receiver main function located in RAM.

5.3.2 Rx_main function

The operations within this function are again similar to that of the transmitter where all the relevant ports, ISR are set and configured. The main difference between the receiver and transitter source code is the additional timer "TA1" used to call the buzzer function.

5.3.3 Diagnostic function

The purpose of this function is to detect the analogue voltage and to determine whether the battery status is classified as low by comparing it to a predefined value as calculated below:

When V_{CC} = 7V	V_{reg}	= **4.96V**
	$V_{divider}$	= **3.83V**
Each digital value:		= $\mathbf{4.96/2^8}$
		= **~19mV**
Recommended digital threshold in decimal:		= $\mathbf{4.96 – (3.83 + 0.25)/20*10^{-3}}$
		= $\mathbf{0.88/19*10^{-3}}$
		= **~47**
Therefore the digital threshold is:		= **255 – 47**

= **208 = 0xD0**

5.3.4 Standby Function

The standby function is similar to that of the sleep mode function used in the transmitter source code. Instead of setting the MCU into stop mode, this function sets it into wait mode, since the ISR used to wake the MCU up and check the signal does not have a high enough priority in order to wake the MCU from stop mode. The FLASH memory is again switched on prior to entering wait mode as the FLASH memory is automatically switched off once the MCU enters either wait or stop mode.

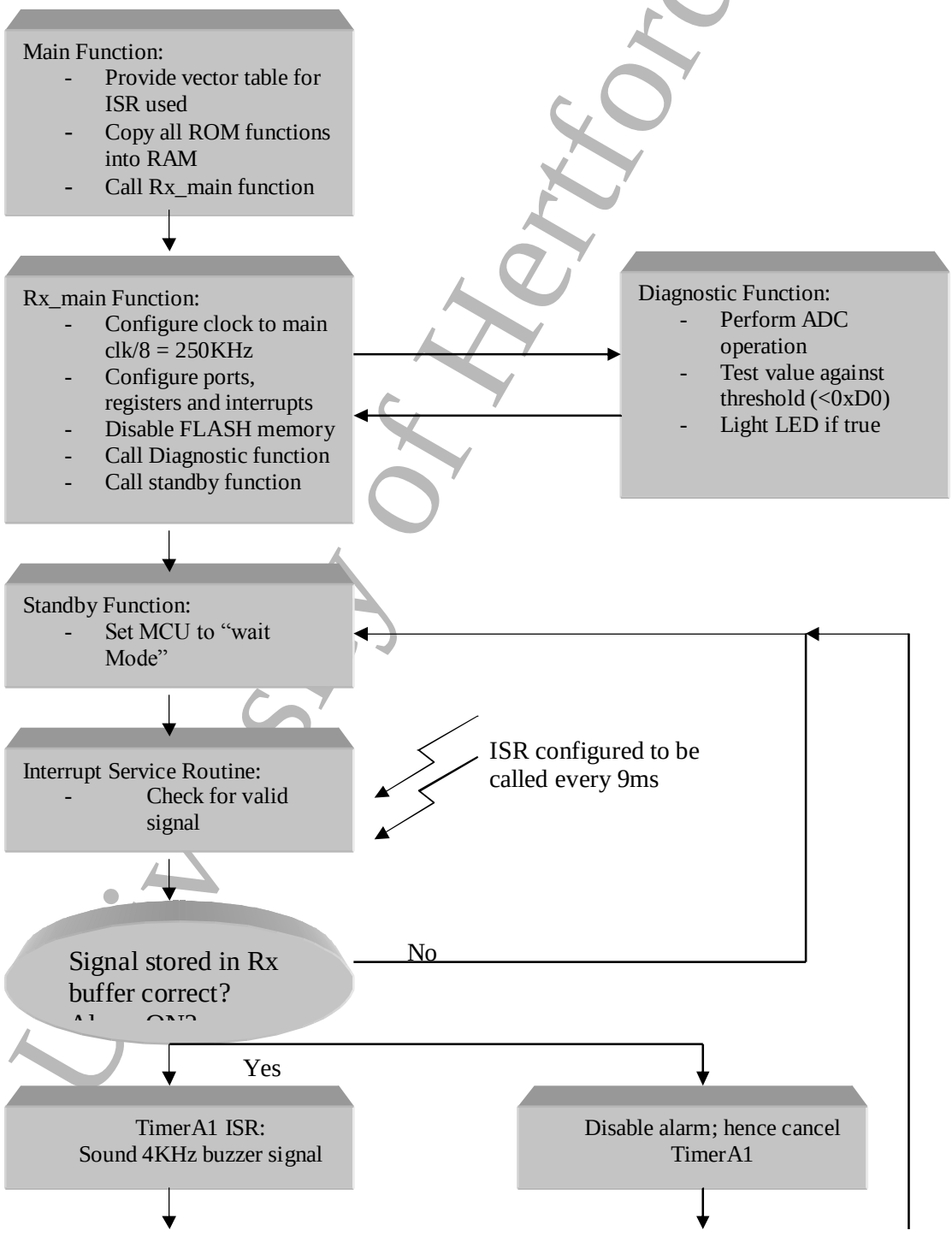


Figure 17 Rx software block diagram

5.3.5 Timer A0 Interrupt Service Routine

TimerA0, the ISR called every 9ms, is used to check if the receiver buffer contains any data. If the data does not equal to the predefined data (0xAA), it is ignored and the function ends by returning to the standby function. If the data is what is expected, it starts timerA1 which is set to interrupt every 10 and 24 KHz, producing an audible signal of 5 and 12 KHz. Once data is received again while the buzzer is active, it will disable the buzzer and return to the standby function waiting for the next signal to arrive.

5.3.6 5 KHz buzzer signal

If the Rx module receives the correct signal, ISR timerA1 is set to start counting from 0 and overflows every time it reaches 25 to produce a 5 KHz tone. The number 25 is calculated from the following:

Main clock	=	2 MHz/8	=	**250 KHz**
5KHz	=	5 KHz * 2	=	**10000**
The required ratio is:			=	$\mathbf{10000^{-1}/250000^{-1}}$
			=	$\mathbf{1*10^{-4}/4*10^{-6}}$
			=	**25**
Hence register TA0			=	**25**

The following source code illustrates the above:

```
// Configure Timer TA1
TA1MR    = 0x40;          // Set TA1 as timer mode with Fx/8
TA1              = 26 - 1;        // ISR to produce 5 KHz tone
TA1IC            = 5;             // Set interrupt priority level to 5
```

5.3.7 Software LCD

Due to time limitations, the hardware for the LCD was implemented onto the Rx module, but limited software was written for it.

5.4 Software summary

With the IAR workbench development environment, source code written could be flashed into the evaluation board, tested and debugged. This produced optimum time management as it reduced the overall development time necessary for developing and testing the code.

Various software techniques were implemented in order to achieve the objective of a reliable RF link. The software written controls the MCU to operate all the code functions in RAM, reducing the overall current consumption, utilising the onboard UART and ADC, with interrupt operated functions (ISR). Consequently, the individual modules provided the required RF link, battery monitor, low power operation and audible tone. These software solutions were preferred as it limits any additional hardware components necessary, hence reducing the overall system cost.

Chapter 6 Testing and Specification comparison phase

Chapter contents

6.0 Chapter Overview

Chapter 6 evaluates the full performance of the final design in relation to the project's aim and product specification outlined in chapter 1.

6.1 Hardware modification

Due to unexpected conditions produced by specific components on the TX and Rx modules, hardware modifications were essential to produce the best results.

6.1.1 Tx module RESET IC

RESET ICs are used in MCU applications to serve as a logic power supply monitor so that when power if fed into the system the RESET IC initiates a low logic reset ("low" for M16C families) to switch on the MCU. Unfortunately the original SMD reset IC ordered, "MC33464N-27CTR" had the required reset threshold of 2.7V, but only when the input voltage was greater than 4V, as shown in figure 3 on its data sheet. Other devices on the current market did not have such a low threshold or was over complicated for the system. As a result a standard switch pulled high via a resistor was used to act as a manual reset button, shown in Appendix A - 1.

6.1.2 Rx buffer

As described in the hardware and software chapters in this report, the receiver module when used needs to be kept on throughout the usage duration. For that reason, it is essential to reduce the current consumption of the system to the minimal. Operating at 5V Vcc, the buffer component draws a total of 10mA, which is more than any other component on the board. As a result, the buffer was removed from the module and new calculations were made for the overall current consumption, illustrated in section 6.2.2.

6.1.3 Tx and Rx Antenna

Utilising the onboard PCB track as the antenna for the modules proved extremely unreliable at distances greater than 2 meters; therefore a simple 17cm wire was implemented to provide the necessary reliability and range. A Spectrum Analyser set to a frequency of 433.9 MHz was used to capture the signal strength for the transmitter and hence to prove which antenna was the most effective solution. The following figures demonstrate the results taken from the spectrum Analyser for each solution.

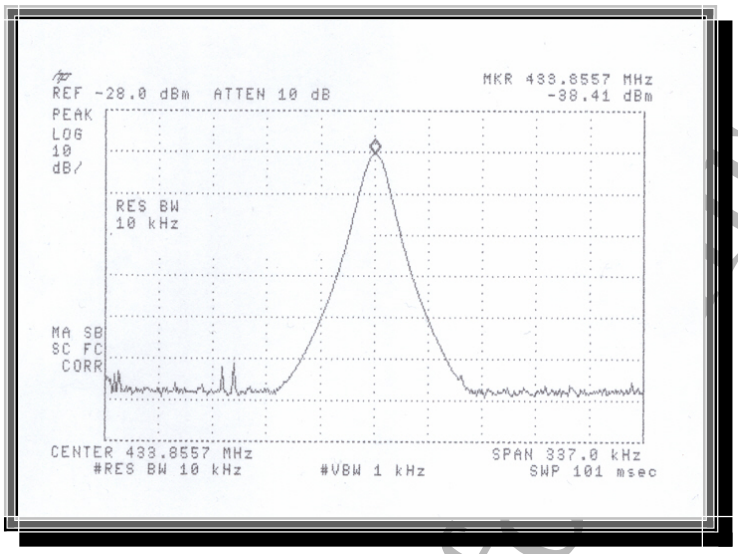


Figure 18 Prototype received signal

Figure 18 shows the signal strength received by the spectrum analyser for the prototype board reached a value of -38.41dBm, which in turn is approximately 0.1µW in power using a dBm to watts comparison table in Appendix G.

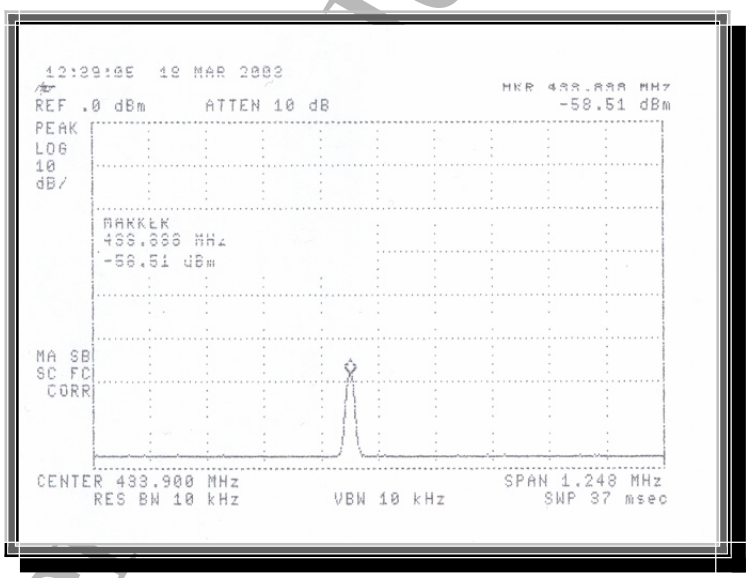


Figure 19 PCB Track antenna signal

With the same test performed with the PCB track as an antenna, figure 19 shows the results obtained. It can be seen that the signal strength of -58.51dBm (~0.001µW) is comparatively a lot smaller than the previously result obtained.

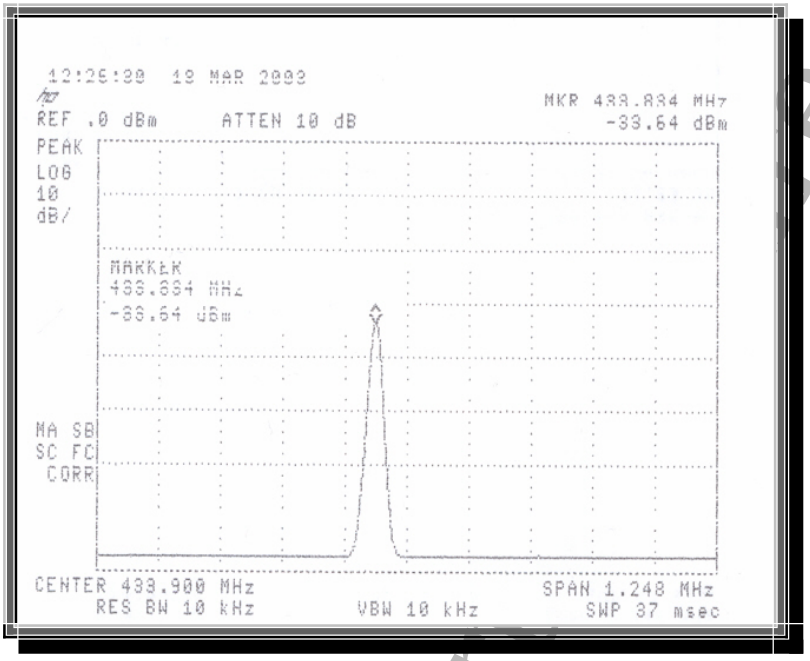


Figure 20 PCB with wire antenna signal

In order to improve the signal strength, an additional wire was used to act as the antenna as described previously. The results were impressive, with signal strengths of around -33.64dBm which in turn is ~0.001mW. Hence the resulting solution was to implement the additional wire onto the final design. Figure 21 below illustrates the radiation pattern similar to that of the antenna implemented.

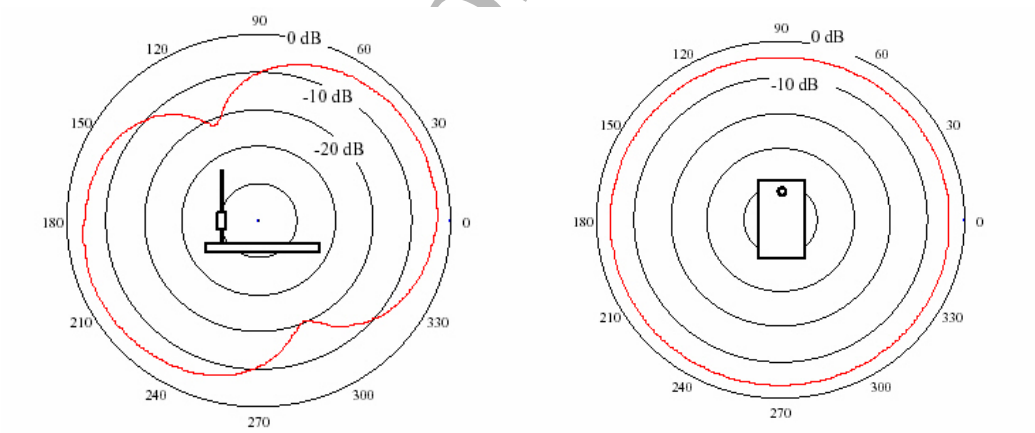


Figure 21 Radiation pattern [4]

6.2 Specification Comparison

The following table illustrates the product specification compared to the actual results obtained from the system.

	PHASE 1	
Features	Specification	Actual Results
Receiver (Rx) module	<5mA and <=5V power supply	5.8mA and 9V supply
Transmitter (Tx) module	<5mA and <=5V power supply	2.48mA and 3V supply
RF range	Min 15M and Max 25M	Min 0m to Max 30+
MCU	20-100Pin, 8/16 bit core, Flash memory, Low power < 30mA Low power Feature, i.e. sleep mode, wait mode < 50uA, Min 2 Timers A/D channel	Tx: M16C/62N MCU Rx: M16C/62A MCU
Battery (power supply)	Standard off the shelf 3/6/9V Alkaline Battery Replacement frequency aimed at min 6months	Tx: 3V lithium coin cell Rx: 9V PP3
Size	Max dimensions of 150mm*85mm*60mm	Tx: 40mm*70mm*20mm Rx:65mm*100mm*32mm
Weight	Max of 100g	Tx: 25g Rx: 85g
Speaker	Audible signal of 80dB	85dB from spec
Low battery indicator	Red flashing Light Emitting Diode (LED)	Achieved in software
Environmental and physical considerations	Water proof, Shock proof, Vibration proof Temp range: 10C to 50C	Not encapsulated
Cost	Max £50	£41.50
	PHASE 2	
Multiple modules	Encode signal with unique signature for each unit. Hence a different audible signal used for each child	Data encryption in future development
Diagnostic Test	Software based solution to self test the modules to assure that the units are functioning correctly	Achieved in software
LCD	8 digit 14 segment alphanumeric display (typically 36 pins)	Hardware implemented, limited software written

Table 2 Product specification comparison table

The following sections here after will describe each of the specifications separately and how each value for the system is achieved.

6.3 System current consumption

For a portable device, it is important that the overall system current consumption can be kept to the minimum, one of the most important features that need to be met in order for the system to be commercially viable.

To measure the current consumption of the transmitter and receiver, a standard bench power supply was used to generate the appropriate voltage with a digital multi-meter (DMM) placed in series to display the total current drawn.

6.3.1 Transmitter module

Table 2 below indicates the results obtained from using the method described above.

Voltage Supply (V)	Current consumption – Standby mode (mA)	Current consumption - Transmit mode (mA)
3.0	2.48	8
2.8	2.18	7.2
2.6	2	6.5
2.4	1.87	5.6
2.2	1.71	4.9
2.0	1.55	4.3

Table 3 Transmitter module current consumption

The following calculations illustrate the theoretical battery life for the complete transmitter unit if the module had a 5 hour on period, used 5 times with a transmit duration of 5 seconds:

Capacity of 3V coin cell battery: **280mAh**
Transmitter board when in standby draws: **2.48mA** (from table 2)
Total average battery life using is:

Equation [3] $\mathbf{E_{total} = E_{standby} + E_{send} + E_{off}}$

Where $\mathbf{E_{standby}}$ = **5hours * 2.48mA**
= **12.4mAh**

Where $\mathbf{E_{send}}$ = **5sec * 5events * 8mA**
= **5sec * 5events * 8mA * (1hour/3600sec)**
= **0.2 * (1/3600)**
= **0.056mAh**

Where $\mathbf{E_{off}}$ = **(24day – 5hour) * 0mA**
= **0mAh**

Therefore $\mathbf{E_{total}}$ = **12.4 + 0.056 + 0**
= **12.456mAh = 12.5mAh**

Hence the total battery Life is: = **280mAh/(12.5mAh/day)**
= **22.4 Days**

Assuming that the transmitter is switched on only when the user wants to transmit the signal then the average total battery life would be as follows:

From *Equation [3]* $\mathbf{E_{total} = E_{standby} + E_{send} + E_{off}}$

Where $\mathbf{E_{standby}}$ = **0hours * 2.48mA**
= **0**

Where $\mathbf{E_{send}}$ = **5sec * 5events * 8mA**
= **5sec * 5events * 8mA * (1hour/3600sec)**
= **0.2 * (1/3600)**
= **0.056mAh**

Where $\mathbf{E_{off}}$ = **(24day – 5hour) * 0mA**
= **0mAh**

Therefore $\mathbf{E_{total}}$ = **0 + 0.056 + 0**
= **0.056mAh**
Hence the total battery
Life is: = **280mAh/(0.056mAh/day)**
= **5000 Days / 364 Days**
= **13.7 Years = ~14Years**

6.3.2 Receiver module

Table 3 below indicates the results obtained with the following conditions for the receiver module:

Vcc = 9V MCU Vcc = 5V

Measurement Conditions	Current Consumption (mA)
Standby mode	5.8
Standby with buzzer	8.7

Table 4 Receiver module current consumption

The following calculations below illustrate the theoretical battery life for the complete receiver unit taking the values from table 3 assuming again that the unit is on 5 hours a day with a total alarm duration of 30mins:

Capacity of 9V PP3 battery: **600mAh**
Receiver board when in standby draws: **5.8mA** (from table 3)
Total average battery life using is:

Equation [3] $\mathbf{E_{total} = E_{standby} + E_{alarm} + E_{off}}$
Where $\mathbf{E_{standby}}$ = **5hours * 5.8mA**
= **29mAh**

Where $\mathbf{E_{alarm}}$ = **30min * 8.7mA**
= **30min * 8.7mA * (1min/60min)**
= **261 * (1/60)**
= **4.35mAh**

Where $\mathbf{E_{off}}$ = **(24day – 5hour) * 0mA**
= **0mAh**

Therefore $\mathbf{E_{total}}$ = **29 + 4.35 + 0**
= **33.35mAh = 33.4mAh**
Hence the total battery
Life is: = **600mAh/(33.4mAh/day)**
= **~18 Days**

Modules	Initial specification	Actual results
Transmitter (Tx) module	<=5mA power supply	2.48mA
Receiver (Rx) module	<=5mA power supply	5.8mA

Table 5 Current consumption comparisons

The results from table 4 shows that the Tx module proves to be extremely successful with the actual results for the standby current nearly half that of what was required. On the other hand, the Rx module results for standby is just over the original specification. This is mainly due to

the additional components on the Rx module and that the MCU's main clock was set to operate at a higher bandwidth (2MHz/8) throughout the duration of its operation.

If the 3V Rx and MCU were used as originally planned, than the theoretical battery life for the Rx module would increase as illustrated from the following calculations:

Capacity of 3V coin cell battery: **280mAh**
Receiver board when in standby draws: **5.8mA – 2mA = 3.8mA**
Minus 2mA, as the 3V Rx unit draws 0.5mA compared to 2.5mA from the 5V device.
Total average battery life using is:

Equation [3] $\mathbf{E_{total} = E_{standby} + E_{alarm} + E_{off}}$

Where $\mathbf{E_{standby}}$ = **5hours * 3.8mA**
= **19mAh**

Where $\mathbf{E_{alarm}}$ = **30min * 6.7mA**
= **30min * 6.7mA * (1min/60min)**
= **201 * (1/60)**
= **3.35mAh**

Where $\mathbf{E_{off}}$ = **(24day – 5hour) * 0mA**
= **0mAh**

Therefore $\mathbf{E_{total}}$ = **19 + 3.35 + 0**
= **22.35mAh = 22.4mAh**

Hence the total battery Life is: = **280mAh/(22.4mAh/day)**
= **~12.5 Days**

Even though the final result shows that the total battery duration is less than the 5V results, the main battery supply is 600mA – 280mA = 320mA less. Also, the values shown would be the maximum current, as the 3V MCU would draw less current then that of the 5V MCU. If the same 600mAh battery was used, then the total battery life for the 3V system would be 600/22.4 = ~27days, over ten days more than that of the 5V system.

6.4 Battery monitoring with ADC in Diagnostic feature

Low battery indication is a necessity for portable devices as it warns the user when the power supply is low and a battery replacement is needed. In order to ensure that the software written for the on board ADC was operating correctly, a standard bench power supply was used to supply the modules with the appropriate Vcc. The value of Vcc was then slowly reduced until it passed the ADC threshold. Once the voltage dropped passed the respective threshold the LED lit up instantly giving the low battery warning. This was successfully functional on both the transmitter and receiver boards at the thresholds of 2.5V and 7V respectively, hence obtaining the battery indicator specification.

Low battery indicator	Used to warn the users that the unit needs a battery replacement (important feature)	Red flashing Light Emitting Diode (LED)
Diagnostic Test	This software based feature will be programmed into the MCU so that the units can self diagnose themselves by running a routine which test the functions of each module and its RF link	Software based solution to self test the modules to assure that the units are functioning correctly

The threshold for the receiver was chosen to be 7V due to the characteristic of the 5V regulator used. Figure 22 below indicates that as the supply voltage passes the threshold of 7V, the regulated voltage becomes unstable hence resulting in an unregulated 5V output.

With the ADC function operating correctly, other issues regarding the diagnostic feature were to make sure that the on board LED and the RF link worked. Software was written within the ADC operation to blink the LED to indicate that the LED was operational. The RF link was left out as it was decided that it could easily be a simple procedure for the end user to test each time they first turn on the system.

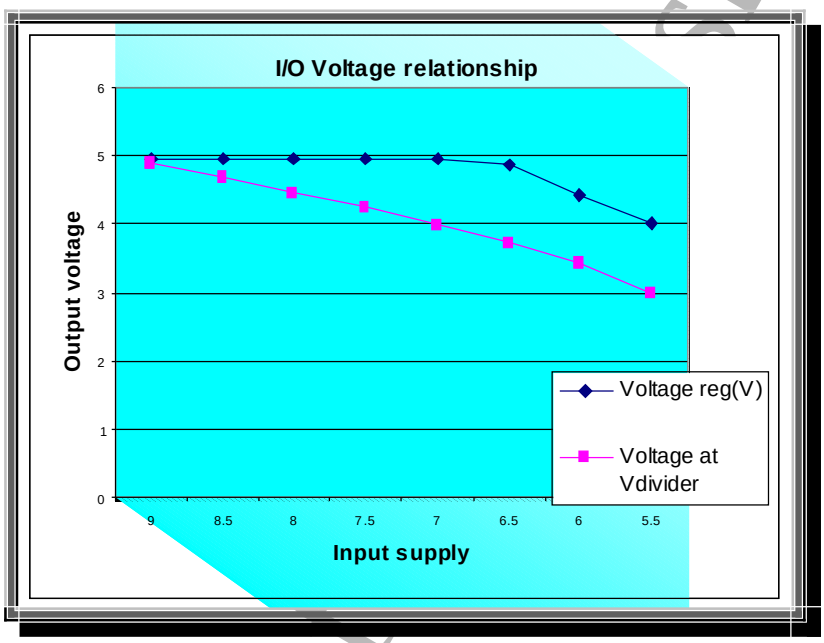
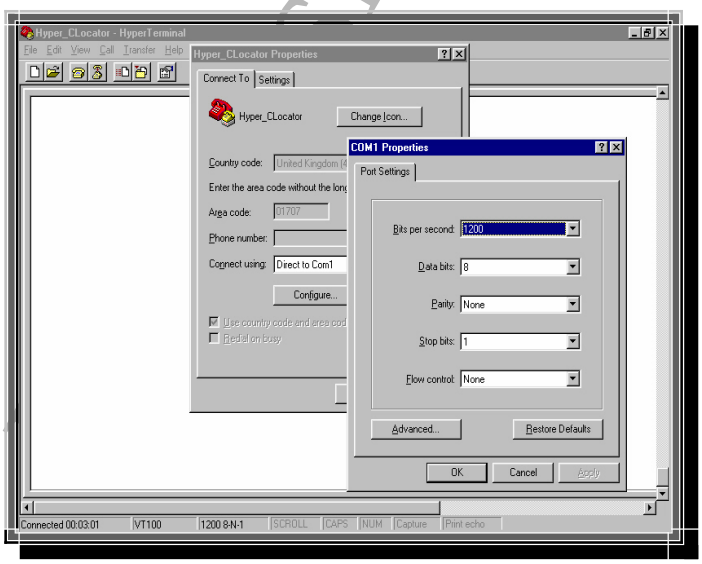


Figure 22 Voltage relationship diagram

6.5 Transmitter and Receiver data

Hyper Terminal, a standard software package that comes with Windows operating system was used in order to test the receiver and transmitter and its relevant code. In order to prove that the transmitter was sending the correct data out, it was connected to the PC via the MF-TEN-NINE cable and each time the button was pressed it would display a certain character onto Hyper Terminal.



The same procedure was repeated for the receiver module but instead, it would detect a specific character from Hyper Terminal and each time it received the correct data, it would light a LED. This procedure proved that the on board UART was transmitting and receiving the correct format of data. The setting used to achieve communication between the modules and the PC is shown in figure 23.

Figure 23 Hyper Terminal Set up

The next testing stage was to transmit and receive the data via the RF link. Figure 24 indicates the waveform obtained from the digital oscilloscope when transmitting the Hex value of 0xAA.

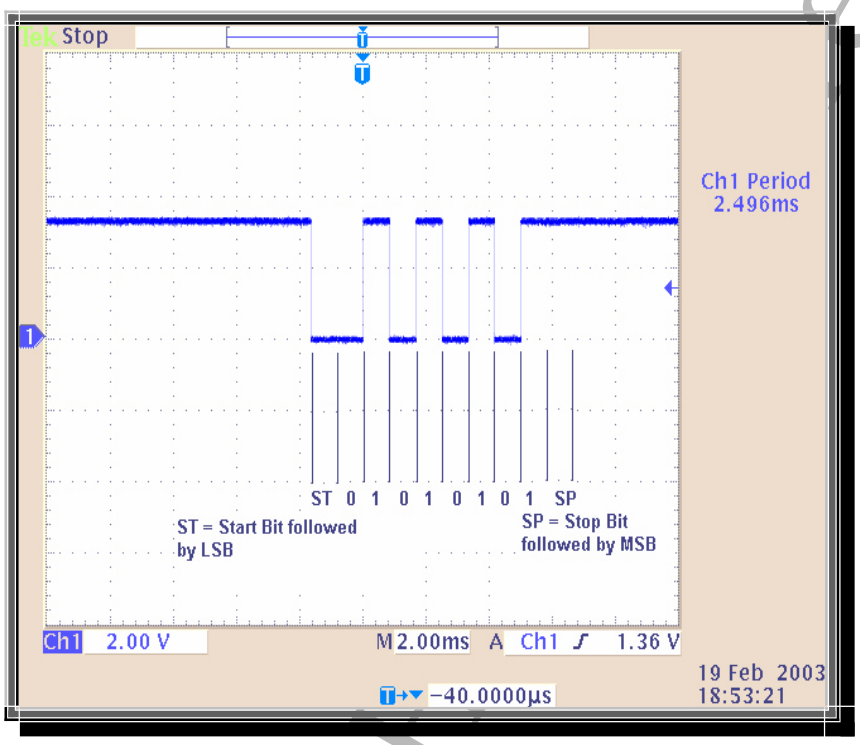


Figure 24 Transmitted 0xAA data

Figure 25 shows the same set of data being received from the receiver pin, pin14 on the Rx module. There are more transitions as the original signal above is sent 3 times consecutively from the Tx module.

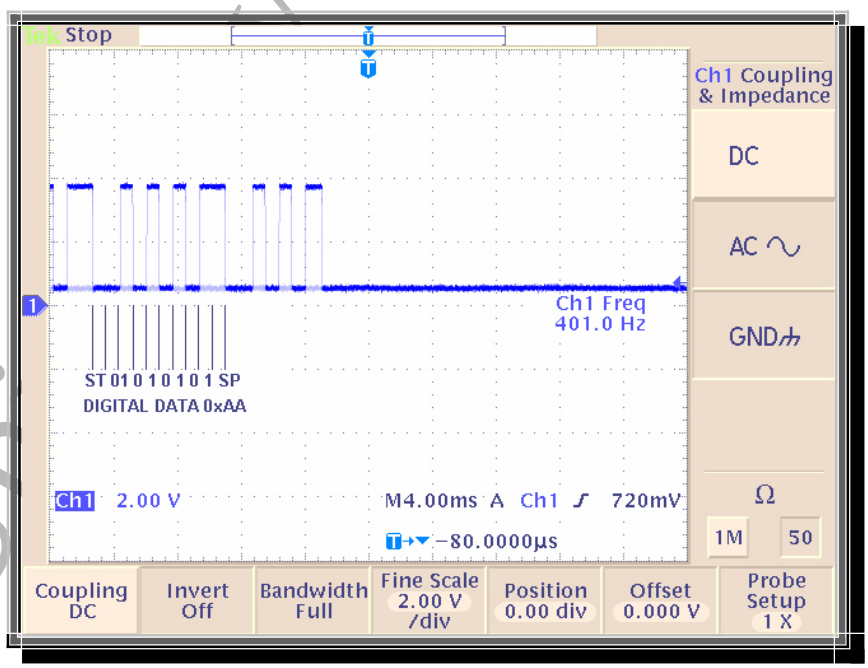


Figure 25 Received data

6.6 RF Range and reliability

Transmitting the signal at various distances tested the RF range of the modules. This was then compared against the reliability of the RF link at that distance. Transmitting the signal ten times and recording the amount of times the receiver received the signal calculated the reliability of the system. The time between transmitting the signal and the receiver receiving the signal was negligible (<1s) therefore it was not of any concern. Table 5 below illustrates the results obtained in outdoor open space environment.

Distance (m)	Reliability (%)	Distance continued	Reliability continued
1	100	16	100
2	100	17	100
3	100	18	80 – 100 **note 1**
4	100	19	80 – 100 **note 1**
5	100	20	80 – 100 **note 1**
6	100	21	80 – 100 **note 1**
7	100	22	80 – 100 **note 1**
8	100	23	80 – 100 **note 1**
9	100	24	80 – 100 **note 1**
10	100	25	80 – 100 **note 1**
11	100	26	80 – 100 **note 1**
12	100	27	80 – 100 **note 1**
13	100	28	80 – 100 **note 1**
14	100	29	80 – 100 **note 1**
15	100	30	80 – 100 **note 1**

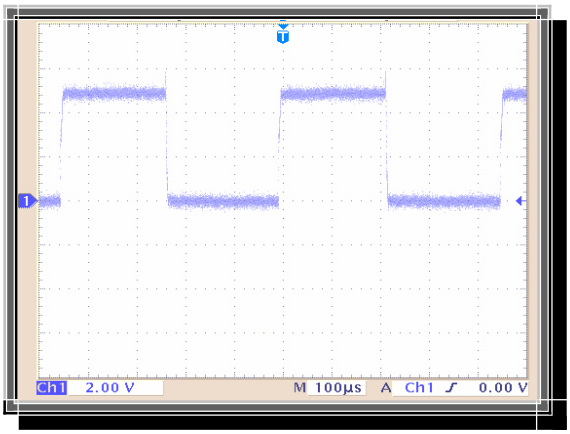
Table 6 RF range and reliability results

Note 1: Rx was placed in one set position whereas Tx was placed in two different positions, hence the two values shown on table 6. From distances greater than 17m, the reliability of the system is very much dependent upon the Tx and Rx antenna position. At the optimum position, 100% reliability for the RF link can easily be achieved for distances greater than 30m. Hence the results from this test illustrates that the RF link achieved is within the specified product specification.

Specification	Condition	Actual results
RF range	Min 15M and Max 25M	Min 0m to 30m+

Placing the Rx module in one room and transmitting the signal at adjacent rooms, lower floor and upper floors were also performed with successful results. Hence, this proves that the system is capable of transmitting and receiving data in the typical operational environment.

6.7 5 & 12 KHz signal



Similar to the test for the transmitted and received signal, two signals 5 and 12 KHz were used for the buzzer tone and ensured they were working correctly by using the digital oscilloscope. Figure 26 on the left indicates the 5 KHz signal captured. Two different audible signals were used because it was found that when a single signal was implemented, the direction of the signal was difficult to trace. This is due to the ear becoming comfortable with a single signal leading to difficulty in tracing it.

Figure 26 5 KHz buzzer signal

Hence another signal was utilised to counteract this property that made the results below possible.

In order to test if the implemented buzzer fits the description above, a simple test was performed by blind folding a candidate and placing the receiver at different positions and distances to see whether the candidate could point out the direction of the receiver. Table 6 shows the results obtained:

Distance (m)	Accuracy range (m of target)
5	<1
10	<1
15	~3
20	~5
25	~8

The results illustrates the success of the buzzer while using different signals instead of a single 5 KHz tone.

It also shows that the accuracy deduces the greater the distance, as expected.

Table 7 Buzzer's effectiveness

6.8 Package dimensions

Information and diagrams shown in chapter 5 and Appendix E – 1 and E – 2 illustrates that the final design concept has the following dimensions:

Modules	Actual Dimensions (mm)	Specified Max dimensions (mm)
Transmitter module	40 * 70 (depth 20)	150*85 (depth 60)
Receiver module	65 * 100 (depth 32)	150*85 (depth 60)
3V receiver module	45 * 90 (depth 22)	150*85 (depth 60)

Table 8 Dimensions comparison

From table 7, it clearly indicates that the resulting module sizes are within the maximum dimensions specified. This is due to the majority of the devices used were SMD format and a lot of space was saved by placing components on both sides of the PCB as described in chapter 5. It is also clear that if the 3V receiver was available, than the overall size of the 3V receiver module would reduce dramatically as the 9V PP3 battery component takes up majority of the space on the PCB receiver board.

6.9 Weight

Using a standard kitchen weighing scale the following table, table 8 illustrates that the weights of the complete Tx and Rx modules are well within the range specified in the product specification.

Module	Specification weight	Actual weight
Tx module	Max of 100g	25g
Rx module	Max of 100g	85g

Table 9 Weight comparison

6.10 Power Supply

The original minimal voltage necessary for the transmitter MCU to operate was 2.4V as stated in the M16C/62N data sheet. Taking the additional programming used to convert all the ROM functions into RAM has resulted in a better operating range for the Tx module, as the minimum voltage necessary for the system to work now is only 2V. This is due to the RAM only requiring 2V for it to maintain constant operation, therefore even though the battery supply falls below 2.5V, the module can still fully function until it exceeds the 2V minimum operating voltage.

Comparing the actual values from the system results and the initial specification proves that the Tx power supply requirement matches those specified. If the Rx module were to contain the 3V devices, then the power supply would be the same as the Tx module, therefore within range as shown on table 9.

Modules	Initial specification	Actual results
Transmitter (Tx) module	<=5V power supply	Range 2V – 3.2V coin cell battery
Receiver (Rx) module	<=5V power supply	9V PP3 battery (If using 3V devices then estimated to be $3V_{MIN}$)

Table 10 Power supply comparison

6.11 Cost Analysis

Table 10 in section 7.1 summarises the total cost of the complete system, which is within the budget range, excluding the PCB manufacturing process costs.

6.12 Chapter Summary

A great deal of time was spent in the testing phase in order to realise whether the final design was feasible and within the specifications laid out in chapter 1. Hence the following sections below were evaluated:

- Hardware modification
- System current consumption
- Battery monitor (ADC)
- Diagnostic feature
- Tx and Rx data
- RF range
- Buzzer
- Module dimensions
- Weight
- Power supply

The results show that the modules designed were well within the specification outlined, apart from the Rx module's current consumption, with a value of 5.8mA, it was 0.8mA greater than that specified. If the Rx module utilised the 3V receiver and MCU, then the current consumption would be reduced to 3.8mA in standby, hence within the product specification.

The testing phase proved that the RF link achieved was extremely reliable up to a distance of 17m. Any distance greater than this was very much antenna position dependant. At the right position for the antenna though, distances of greater than 30m was achieved with 100% reliability.

Features such as the battery monitor and diagnostic functions were all software based, thus it was tested and debugged during the development stage. Other aspects of the testing phase were straightforward procedures, such as measuring and recording values. Due to time limitations, the original software LCD mentioned in the specification was not implemented.

The testing phase proved that the modules were successfully within the specifications outlined, which can provide a 100% reliable RF link within 30m.

Chapter 7 Conclusion

Chapter contents

7.0 Conclusion

The aim of the project was to design and develop a cost-effective, low power radio frequency (RF) based child locator from initial design to a manufactured product, where the transmitter can send a predefined signal to the receiver, which results in an audible tone. This was achieved to a high standard by utilising the appropriate hardware features of the microcontroller (MCU) and additional software techniques. When the transmitter module is switched on, the unit remains in standby mode until a button is pressed. Once action is detected, the MCU wakes up and transmit the signal three times while blinking a light emitting diode (LED) to indicate to the user that the module is transmitting. Similar to that of the transmitter, the receiver is also in standby mode but is programmed to wake up every so often to check for valid signals. If a valid signal is present, the on board MCU on the receiver activates a piezo transducer producing a 5 and 12 KHz tone, any other signals that are not valid to the receiver are discarded.

The hardware implementation throughout this project ran in parallel with the software programming as this allowed both aspects to be tested simultaneously. A lot of time was spent in the software development stage in order to produce a code structure with a maintainable layout. These involved techniques such as creating separate functions for each feature, allocating appropriate segments of random access memory (RAM) for read only memory (ROM) functions and writing efficient and readable code.

The first phase of the project was to design and develop the transmitter module, which required simple links between the MCU and a standard off the shelf transmitter. The original code written caused problems with the transmission of data causing the module to transmit random signals. In order to resolve this problem and capture the data that was being transmitted, the module was connected to a PC via its serial port running Windows Hyper Terminal. This helped to modify the universal asynchronous receiver and transmitter (UART) setup on the MCU correctly to produce the correct data, which was clearly displayed on Hyper Terminal. This method proved very beneficial as it clearly displays the data sent out of the Tx unit onto the computer screen. Similarly the receiver module was also implemented in the same manner utilising Hyper Terminal.

Regarding the Rx module, the original 3V receiver unit that was considered for this application had availability issues; as a result a 5V version with higher current consumption was implemented instead. Fortunately, both receivers have the exact same features and are pin compatible. Therefore if the 3V receiver were to replace the 5V version, the hardware and software of the module would still be fully functional and would further reduce the overall current consumption of the module.

The chosen data value sent “0xAA” in hexadecimal was used for the main transmission owing to two main reasons.

- Due to the characteristics of AM being extremely vulnerable to noise, the data sent should preferably be as short as possible so that it limits the amount of noise it can pick up.

- As it is recommended that the data being sent should maintain a zero direct current (DC) component over a finite time, so that the demodulator in the receiver can properly interpret the received data as either '0' or '1', hence improving its efficiency and reliability.

Encoding techniques for the RF data such as Manchester encoding and decoding could be used between the modules, but this would require twice the communication bandwidth. Due to this fact, it was not considered for the transmission of the predefined signal even though it can easily be implemented into RS232 data (more information about this in section 7.1).

The data rate implemented within the modules is 1200 baud. This was considered as an adequate communication speed between the modules, since the time it took to transmit the signal and the receiver receiving the signal was practically instantaneous as mentioned in the testing phase. Greater bandwidth in RF communication may not always improve the situation as these modules are usually more expensive and factors such as inter-symbol interference may occur.

In order to produce a complete system, both the transmitter and receivers were captured into a schematic, which were ported into a Printed Circuit Board (PCB). As a third party provided the manufacturing process, the main objective in this section was to design the layout of the transmitter and receiver board. This involved either obtaining the footprint for each component or most commonly, creating them from scratch. Due to a limitation in size provided by the product specification created, many of the components were surface mount device (SMD) formats. In order to minimise the size of the modules, devices were placed on both sides of the PCB, where through hole components dominated the top layer and SMD components on the bottom layer. The product specification required the PCBs to be encapsulated into a box due to protection and portability issues. This was not complete due to the time restrictions of this project.

Current consumption can determine the commercial viability of the product, therefore much investigation and techniques were implemented in order to reduce it to the minimal. This involved utilising the MCU pins to provide a means of shut down to external components via either a simple NPN or PNP transistor. Software techniques were used as mentioned previously to copy all the functional code from ROM to RAM. This in effect allows the main FLASH memory to be switched off, hence reducing the current consumption of the MCU. In addition, the MCU on both the Tx and Rx module were set to their respective low power modes, therefore further reducing the current consumed.

The testing phase of this report covered all the aspects required outlined in the product specification in chapter 1. This involved testing the current consumption of the Tx and Rx modules, the reliability of the RF link between them, their size, weight and dimensions. It was found that the current consumption for the Tx module was similar to what was expected with a value of 2.48mA. By using the additional software technique where the functions were copied and operating in RAM, it proved to be even more successful by reducing the minimum operating voltage for the module to as low as 2V, which is the requirement for the operation of the RAM. This technique could not be utilised on the Rx module due to the 5V receiver unit and MCU implemented, hence it was found that the current consumption was a much greater value of 5.8mA compared.

The antenna for the modules proved to be the main factor affecting the reliability of the modules. The results captured for the on-board PCB track antenna showed extremely poor results; hence an additional antenna was required. To keep the overall cost of the system to a minimum, a simple wire was used at the quarter wavelength, this proved more successful with a transmission power ten times that of the PCB track. If more time was available, research and testing would have been performed on various off the shelf antennas from different

manufacturers in relation to the transmission power and reliability if implemented in this system.

From the results, it shows that the RF based wireless child locator is cost effective and reliable within the specifications. It is also future proof as the MCU implemented can be upgraded with new code by simply writing to it via the on board 10pin connector. Nearly every aspect of the product specification was met to a very high standard, with only the receiver current consumption greater than expected. However, as stressed throughout this report, if the 3V receiver was utilised in this system then the preferred overall size and current consumption can be obtained.

7.1 Future Development

This section discusses recommendations for further improvements that could be implemented to the existing system.

7.1.1 Software LCD

The hardware for the software LCD was implemented into the final PCB design of the receiver module, but software was not written for the MCU to control it due to time constraints. To produce an attractive system, software for the LCD should be written so that it can display a menu system, time and date/calendar similar to those used on mobile phones. Another important feature that was not implemented, again due to time limitations was a simple text message one-way communication from the transmitter to the receiver. Originally, it was planned that the transmitter module could be connected to a PC and the user could simply type a short message in Hyper Terminal to be sent to the receiver. Once sent, the receiver would store the information in a circular buffer and display the full message onto the LCD. As shown below in figure 27, the software for storing the message in Hyper Terminal for the transmitter side was complete, therefore only software coding is required at the receiving end.

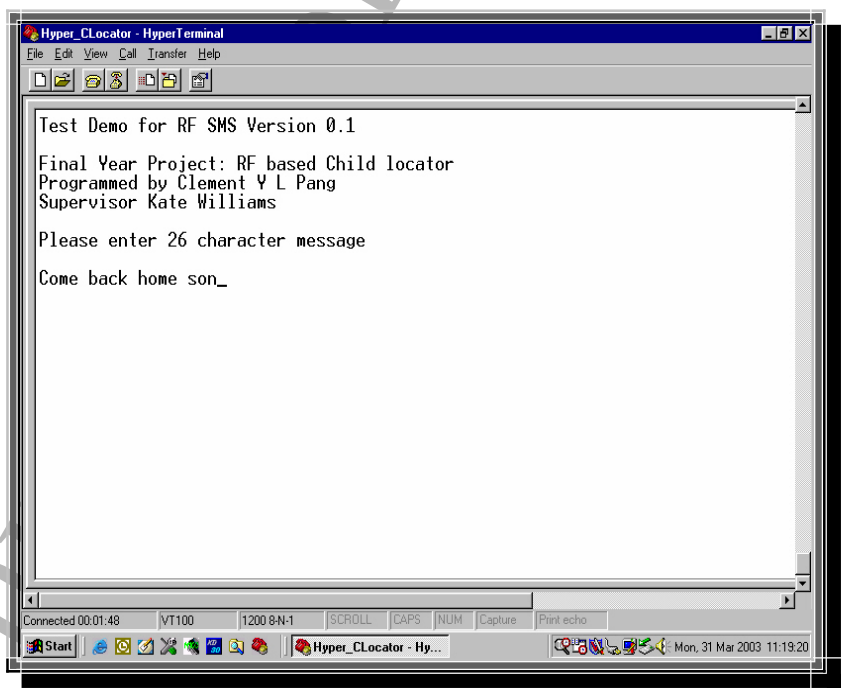


Figure 27 Hyper Terminal message setup

Manchester encoding and decoding when transmitting the customised message should be implemented as the data to be sent will probably no longer consist of frequent transitions of '0'

and '1's and a zero DC component. As the UART has been set up to transmit the original signal, Manchester encoding can be performed by splitting the original byte (8bits) into two separate words (4bits) and encoding each word into a byte, hence resulting in two bytes of Manchester encoded data.

The following shows a simple example of how the implementation of Manchester Encoding in serial RS232 data would be performed:

Original Data:	**0x56 = MSB 0101 0110 LSB** (Hex 56 is the letter V in ASCII)
MSB word:	**0101**
Manchester Encoded:	**01100110**
LSB word:	**0110**
Manchester Encoded:	**01101001**
Data to be sent:	
First:	**01101001 = 0x69**
Second:	**01100110 = 0x66**

At the receiver side, the data received should be masked according to the bits required and masked together to obtain the original data. This example also shows why Manchester Encoding requires twice the original communication bandwidth.

7.1.2 Tx and Rx MCU

The MCU used for the transmitter and receiver is both 100-pin packages where for instance in the transmitter side, many of the port pins were left unused. If this system was to be commercially viable, lower pin count MCU would be used in order to reduce size and cost. In addition, the 3V receiver and MCU should be implemented in order to reduce the size weight and current consumption of the Rx module. Another option that can be considered is to use one time programmable (OTP) MCUs which would also reduce the cost of the system dramatically.

7.1.3 Antenna Design

The results on the simple antenna used indicated that even though the system can communicate over 30m in distance, the reliability is very much dependent upon the antenna. Hence further research and design on standard and PCB antenna is required.

7.1.4 Data Encryption

Providing a safe means of communication is essential, therefore preferable software or hardware encryption should be implemented so that the sent data, even though known by a third party would not be able to alter the receiver alarm status as the signal transmitted is not always the same.

7.1.5 Product Durability

In order to facilitate increased durability of the system, encapsulation would be required as discussed in the product specification. Standard of the shelf boxes from companies such as "Maplin electronics" could be used in order to provide a means of protection for the individual modules. This would therefore allow the modules to operate successfully under the different environments listed in table 1.

Reference List

[1] SiRF Press release: www.sirf.com/mar19_2.html

[2] GPS operation http://electronics.howstuffworks.com/gps1.htm

[3] ANTENNAS FOR LOW POWER APPLICATIONS By Kent Smith; Page 1.

[4] ANTENNAS FOR LOW POWER APPLICATIONS By Kent Smith; Page 4.

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- M16C/62 Group User's manual
- M16C/62A Data Sheet
- M16C/62N Data Sheet
- 3 Diamonds Board User Manual
- 3 Diamonds Board Schematic

www.iar.com

- IAR Embedded workbench compiler
- IAR user manual
- IAR linker and object files

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- Third Party PCB manufacturer

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- Protel User manual and tutorial

www.radiometrix.co.uk

www.maxim-ic.com

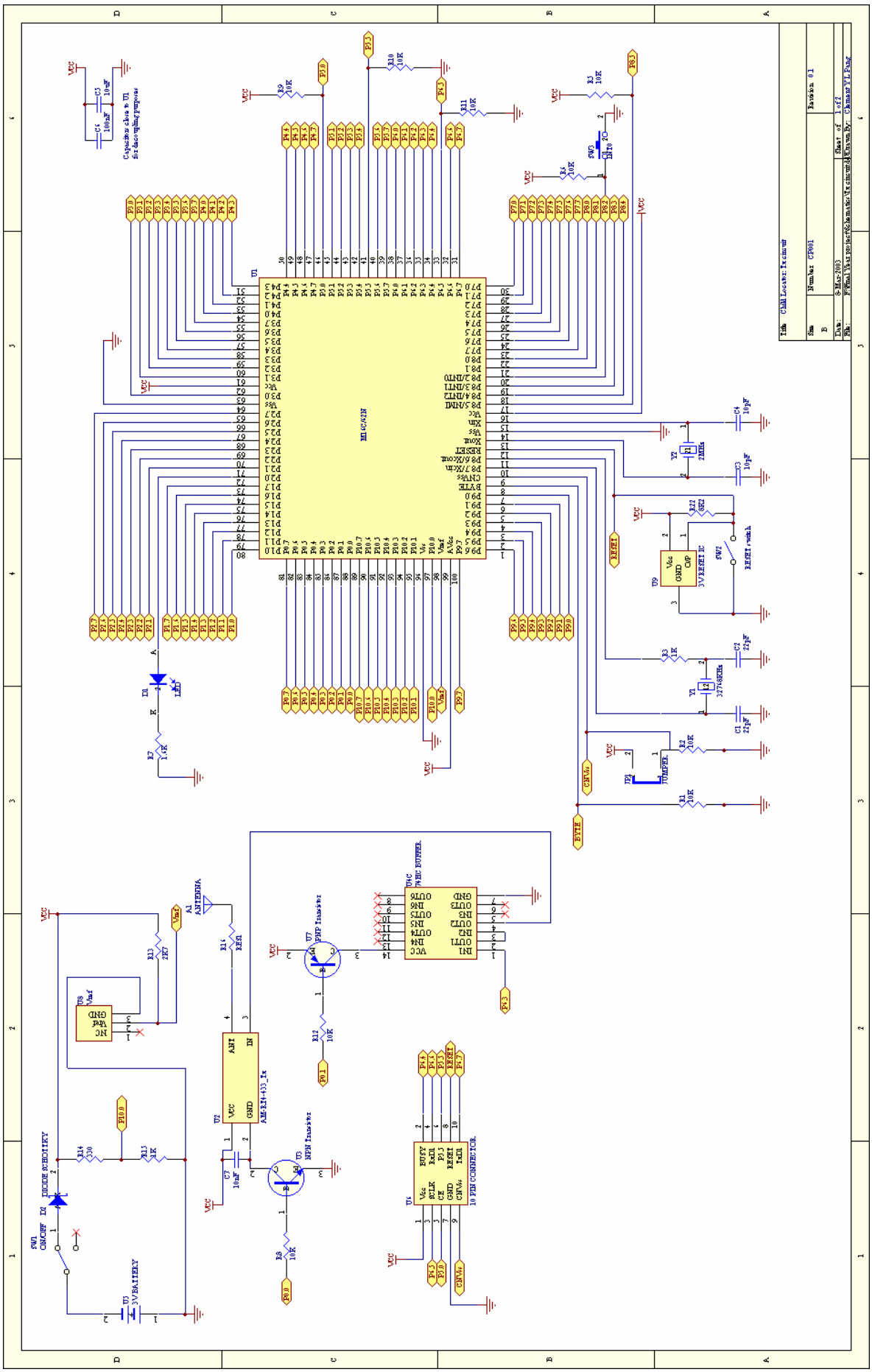
http://mathforum.org/dr.math/

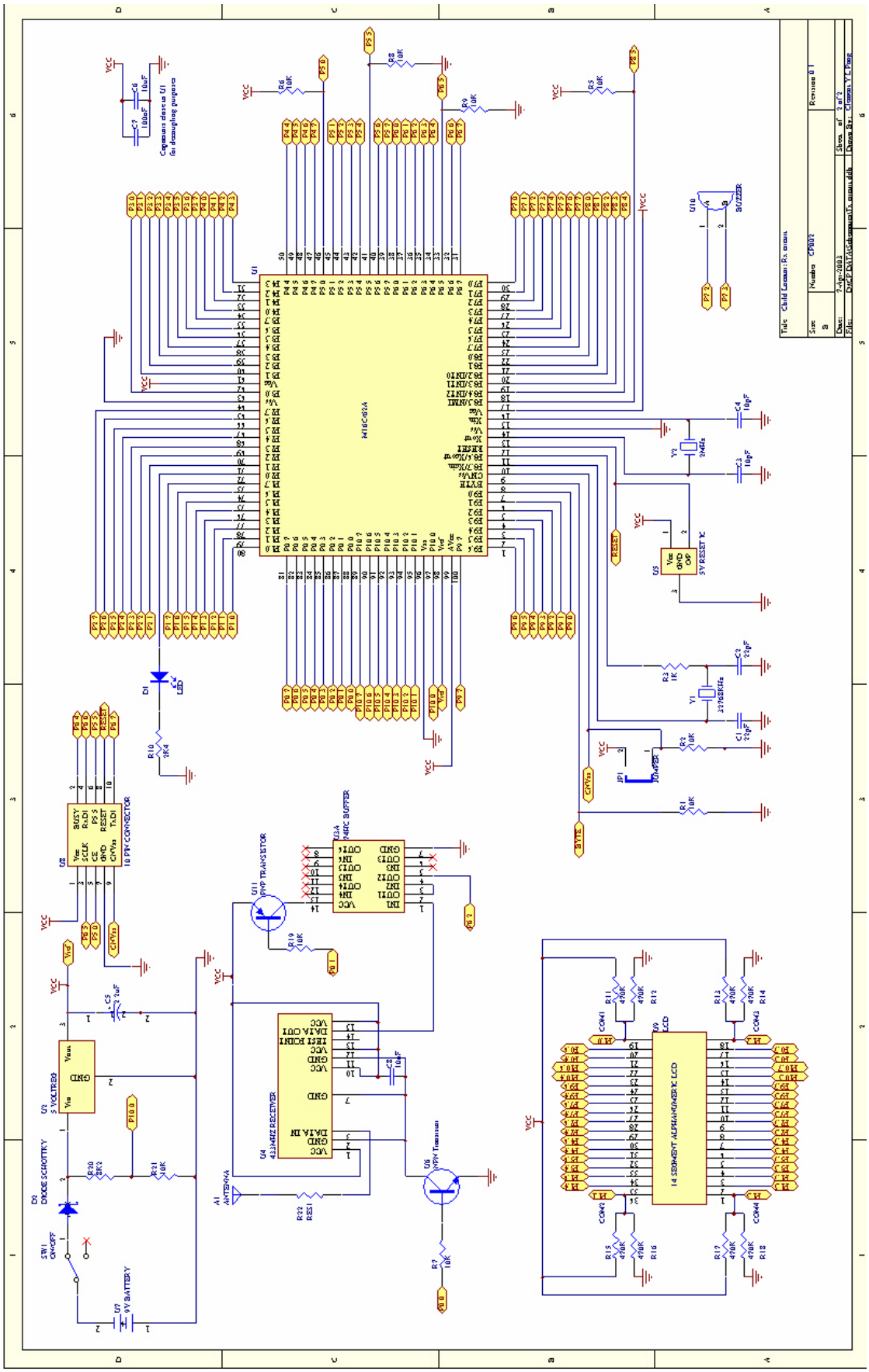
http://www.rfsolutions.co.uk/datasheets/datasheets.htm

- Tx Data Sheet
- Rx Data Sheet

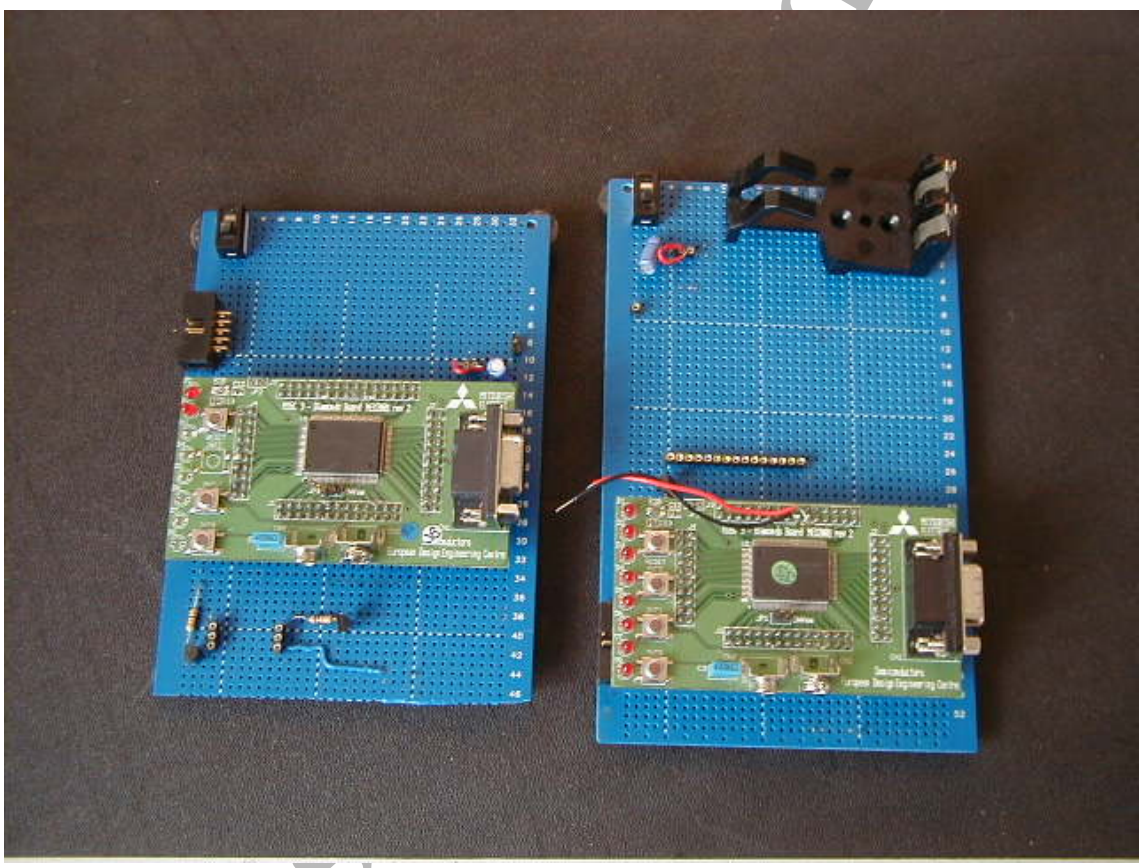
Appendix A - 1: Tx and Rx circuit diagram

The following pages contain the full schematic diagrams fro the transmitter and receiver module produced in ProtelSE99.





Appendix A - 2: Tx and Rx Development Board



Appendix B: Component Listing and Cost

Part Type	Price	Quantity
22pF	0.012	4
10pF	0.012	4
10uF	0.0095	2
100nF	0.039	2
2.2uF	0.05	1
10nF	0.013	1
330	0.008	2
10K	0.008	18
1K	0.008	1
1.6K	0.008	1
2K7	0.008	3
8K2	0.008	1
470K	0.008	9
Tx Rx Pair	9.99	1
M16C/62A	7	1
M16C/62N	7	1
5 VOLTREG	0.66	1
5V RESET IC	0.38	1
9V PP3 Battery	2.1	1
10 PIN CONNECTOR	0.28	1
74HC BUFFER	0.25	2
BUZZER	0.45	1
JUMPER	0.07	2
3V BATTERY	0.75	1
3V RESET IC	0.58	1
INT0 Switch	0.32	1
Vref	0.3	1
LCD	5	1
ON/OFF	0.58	2
NPN Transistor	0.08	2
PNP Transistor	0.08	2
3V RESET IC	0.64	1
2MHz Crystal	0.25	2
32768KHz	1.05	2
LED	0.1	2
Schotty Diode	0.3	2
Total £	**41.506**	81

Appendix C: Software Listing

The following pages contain the source code for each function used for the transmitter and receiver module. This will also include the xcl, linker file that has been modified from the original provided by the IAR compiler.

Transmitter XCL file:

```
// ------------------------------------------------------------
// LNKM16CY.XCL - Example file to be used with ICCM16C.
// This file shows a set up for the 'near' memory model
// where there is no ROM in the default (near) area.
// Read 'farconst.htm' for more information on how on-chip
// ROM can be used.
//
// Usage:  XLINK  your_file(s) -f lnkm16cy
//
// IMPORTANT:
//  Use a COPY of this file and, if needed, customize
//  for your own purposes.
//
//  $Id: lnkm16cy.xcl 1.10 2001/05/16 11:09:01 John Exp $
// ------------------------------------------------------------
// ------------------------------------------------------------
// Defines used by m16c.xcl, all values are in hex.
// (customize according to your specific derivative).
// ------------------------------------------------------------
// Stack sizes
-D_USER_STACK_SIZE=200
-D_INTR_STACK_SIZE=40
// Change this to the starting address of your internal ROM
-D_FAR_ROM_ADDRESS=FA000
// First available RAM address
-D_NEAR_RAM_ADDRESS=400
// Bit variables, range
-D_FIRST_BITVAR=2000 // 8*400 hex
-D_LAST_BITVAR=FFFF
// ------------------------------------------------------------
// Define CPU
// ------------------------------------------------------------
-cm16c
// ------------------------------------------------------------
// Create a 2-byte checksum using crc16. This option requires
// that we fill unused code bytes, so we fill with zero.
// ------------------------------------------------------------
-J2,crc16
-H0
// ------------------------------------------------------------
//   Place SEG_RAMTX at logical address 700
// ------------------------------------------------------------
-Z(CODE)SEG_RAMTX=1000-11DE
-Z(CODE)SEG_ROMTX=FAC22-FADFF
-QSEG_RAMTX=SEG_ROMTX
// ------------------------------------------------------------
//  Place SEG_RAMSLEEPMODE at logical address 900
// ------------------------------------------------------------
-Z(CODE)SEG_RAMSLEEPMODE=900-9FF
-Z(CODE)SEG_ROMSLEEPMODE=FA500-FA5FF
-QSEG_RAMSLEEPMODE=SEG_ROMSLEEPMODE
// ------------------------------------------------------------
//   Place SEG_RAMINT0 at logical address A00
```

```
// ------------------------------------------------------
-Z(CODE)SEG_RAMINT0ISR=A00-AFF
-Z(CODE)SEG_ROMINT0ISR=FA600-FA6FF
-QSEG_RAMINT0ISR=SEG_ROMINT0ISR
// ------------------------------------------------------
//   Place SEG_RAMDIAGNOSTIC at logical address B00
// ------------------------------------------------------
-Z(CODE)SEG_RAMDIAGNOSTIC=B00-BFF
-Z(CODE)SEG_ROMDIAGNOSTIC=FA700-FA7FF
-QSEG_RAMDIAGNOSTIC=SEG_ROMDIAGNOSTIC
// ------------------------------------------------------
//   Place SEG_RAMHYPERTERMINAL at logical address C00
// ------------------------------------------------------
-Z(CODE)SEG_RAMHYPERTERMINAL=C00-DFF
-Z(CODE)SEG_ROMHYPERTERMINAL=FA800-FAAFF
-QSEG_RAMHYPERTERMINAL=SEG_ROMHYPERTERMINAL
// ------------------------------------------------------
//   Place SEG_RAMPUTC at logical address D00
// ------------------------------------------------------
-Z(CODE)SEG_RAMPUTC=E00-E20
-Z(CODE)SEG_ROMPUTC=FAB00-FAB20
-QSEG_RAMPUTC=SEG_ROMPUTC
// ------------------------------------------------------
//   Place SEG_RAMPRINTF at logical address D21
// ------------------------------------------------------
-Z(CODE)SEG_RAMPRINTF2=E22-F21
-Z(CODE)SEG_ROMPRINTF2=FAB22-FAC21
-QSEG_RAMPRINTF2=SEG_ROMPRINTF2
// ------------------------------------------------------
// Re-locatable "bit" segment.  As BITVARS contains bit addresses,
// the desired (byte) address has to be multiplied by 8.
// ------------------------------------------------------
-Z(BIT)BITVARS=_FIRST_BITVAR-_LAST_BITVAR
// ------------------------------------------------------
// Set up user stack and interrupt stack
// ------------------------------------------------------
-Z(NEAR)CSTACK+_USER_STACK_SIZE=_NEAR_RAM_ADDRESS
-Z(NEAR)ISTACK+_INTR_STACK_SIZE=_NEAR_RAM_ADDRESS
// ------------------------------------------------------
// Near, far and huge data segments (in RAM)
// These are actually all placed in near RAM.
// ------------------------------------------------------
-Z(NEAR)IDATA0,UDATA0=_NEAR_RAM_ADDRESS
-Z(FAR)IDATA1,UDATA1=_NEAR_RAM_ADDRESS
-Z(HUGE)IDATA2,UDATA2=_NEAR_RAM_ADDRESS
// ------------------------------------------------------
// Initialisation data segments (in ROM)
// ------------------------------------------------------
-Z(FARCONST)CCSTR,CDATA0,CDATA1=_FAR_ROM_ADDRESS
-Z(HUGECONST)CDATA2=_FAR_ROM_ADDRESS
// ------------------------------------------------------
// CHECKSUM segment
// ------------------------------------------------------
-Z(FARCONST)CHECKSUM=_FAR_ROM_ADDRESS
```

```
// ------------------------------------------------------------
// CODE segment
// ------------------------------------------------------------
-Z(HUGECODE)CODE=_FAR_ROM_ADDRESS
// ------------------------------------------------------------
// Fixed interrupt table
// ------------------------------------------------------------
-Z(HUGECONST)INTVEC1=FFFDC-FFFFF
// ------------------------------------------------------------
// Set up the tiny-func table
// ------------------------------------------------------------
-Z(HUGECONST)FLIST=FFE00-FFFDA
// ------------------------------------------------------------
// See configuration section concerning
// printf/sprintf/scanf/sscanf
// ------------------------------------------------------------
-e_small_write=_formatted_write
-e_medium_read=_formatted_read
// ------------------------------------------------------------
// Segments that has to be in RAM, reachable for default pointers
// ------------------------------------------------------------
-Z(NEAR)NO_INIT,ECSTR=_NEAR_RAM_ADDRESS
// ------------------------------------------------------------
// Constant segments (in ROM)
// ------------------------------------------------------------
-Z(FARCONST)FAR_CONST,CONST=_FAR_ROM_ADDRESS
-Z(HUGECONST)HUGE_CONST=_FAR_ROM_ADDRESS
// ------------------------------------------------------------
// Special page vector table
// ------------------------------------------------------------
-Z(HUGECONST)INTVEC=FB000
// ------------------------------------------------------------
// Select C library.
// ------------------------------------------------------------
clm16cy
// ------------------------------------------------------------
// Select for ieee-695 format required for KD30, PD30 & PD30SIM
// ------------------------------------------------------------
//-ylmba
// ------------------------------------------------------------
// End of file LNKM16CY.XCL
```

Transmitter Source Code:

```
#define  Chip_3062x  /* For iom16c62.h M16C/62N*/
#include "common_FLASHOFF.h"
#include <iom16c62.h>
#include <intrm16c.h>

interrupt [29*4] void int0_isr(void);
//interrupt [21*4] void timer_a0(void);
void sleep_mode(void);
void tx_main(void);
void diagnostic(void);
void hyper_terminal(void);
void printf2(char *str);

char low_battery;

//-----------------------------------------------------------------------------
// INTVECB table address for Interrupt Service Routines stored in RAM
//-----------------------------------------------------------------------------
unsigned char invec_tab[]     =  { 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
                           0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
                           0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
                           0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
                           // Interrupt address for KD30
                           // to allow BP and Debugging
                           0,0,0,0,0,0,0,0,0,0,0,0x6B,0xCB,0x0F,0x00,
                           0x6B,0xCB,0x0F,0x00,0x22,0x0D,0x00,0x00,0,0,0,0,0,0,0,0,
                           0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
                           // RAM INT0 address = 0x0000200F
                           0,0,0,0,0x00,0x0A,0x00,0x00,0,0,0,0,0x0F,0x20,0x00,0x00 };

//-----------------------------------------------------------------------------
// Start of main
//-----------------------------------------------------------------------------
void main(void)
{
  unsigned int i;
//-----------------------------------------------------------------------------
// Copy ROM functions into RAM
//-----------------------------------------------------------------------------
  // Copy the transmit function program into RAM
  for(i=0;i<RAM_TX_MAIN_SIZE;i++)
  {
    // Start copy from ROM to RAM
    ((char far *) RAM_TX_MAIN_START)[i] = ((char far *) ROM_TX_MAIN_START)[i];
  }
  // Copy sleep mode function into RAM
  for(i=0;i<RAM_SLEEP_MODE_SIZE;i++)
  {
    ((char far *) RAM_SLEEP_MODE_START)[i] = ((char far *)
ROM_SLEEP_MODE_START)[i];
  }
  // Copy the interrupt service routine into RAM
  for(i=0;i<RAM_INT0_ISR_SIZE;i++)
  {
```

```
    ((char far *) RAM_INT0_ISR_START)[i] = ((char far *) ROM_INT0_ISR_START)[i];
  }
  // Copy diagnostic function into RAM
  for(i=0;i<RAM_DIAGNOSTIC_SIZE;i++)
  {
    ((char far *) RAM_DIAGNOSTIC_START)[i] = ((char far *)
ROM_DIAGNOSTIC_START)[i];
  }
  // Copy HyperTerminal function into RAM
  for(i=0;i<RAM_HYPERTERMINAL_SIZE;i++)
  {
    ((char far *) RAM_HYPERTERMINAL_START)[i] = ((char far *)
ROM_HYPERTERMINAL_START)[i];
  }
  // Copy GETC function into RAM
  for(i=0;i<RAM_PUTC_SIZE;i++)
  {
    ((char far *) RAM_PUTC_START)[i] = ((char far *) ROM_PUTC_START)[i];
  }
  // Copy PRINTF2 function into RAM
  for(i=0;i<RAM_PRINTF2_SIZE;i++)
  {
    ((char far *) RAM_PRINTF2_START)[i] = ((char far *) ROM_PRINTF2_START)[i];
  }
  tx_main();          // Call tx function in RAM
}

//-------------------------------------------------------------------------------
// Low level innit called first, before main by cstartup
//-------------------------------------------------------------------------------
unsigned char __low_level_init(void) {

  // Select full speed operation
  PRCR = 0x01;      // Unlock CM0 and CM1
  PM0  = 0x00;      // Single chip mode
  CM0  = 0x40;      // Disable divider set Fin/8 at low drive mode
  PRCR = 0x00;      // Relock CM0 and CM1

  return 1;             // Force cstartup to initialise RAM etc.
}

void tx_main(void){

  unsigned char pause;

//-------------------------------------------------------------------------------
// Switch Sub clock ON and main clock OFF
//-------------------------------------------------------------------------------
  PRCR   = 0x01;                    // Unlock Protect
  CM0    = 0x50;                    // Set Xc generation
  PRCR   = 0x00;                    // Relock Protect
  for (pause=0xFF;pause!=0;pause--);       // Software wait: to stabilise sub clock
  PRCR   = 0x01;                    // Unlock protect
  CM0    = 0xD0;                    // Set Xc as system clock
  CM0    = 0xF0;                    // Switch off the main clock
```

```
  PRCR   = 0x00;                    // Relock protect

//-------------------------------------------------------------------------------------
// Switch Flash memory off
//-------------------------------------------------------------------------------------
  // Set to CPU rewrite mode
  FMR0.1 = 0;
  FMR0.1 = 1;
  // Set Flash reset bit to turn Flash off
  FMR0.3 = 0;
  FMR0.3 = 1;

//-------------------------------------------------------------------------------------
// Configure ports
//-------------------------------------------------------------------------------------
  P0   = 0x02;              // All segments off except P0.1
  PD0  = 0x07;               // Set all as inputs except bit0,1&2
  P1   = 0x00;              // All segments off
  PD1  = 0x00;               // Set as inputs
  P2   = 0x00;              // All segments off
  PD2  = 0x03;               // Set as inputs except P2.0 and P2.1
  P3   = 0x00;              // All segments off
  PD3  = 0x00;               // Set as inputs
  P4   = 0x00;              // All segments off
  PD4  = 0x00;               // Set as inputs
  P6   = 0x00;              // Set port low
  PD6  = 0x88;               // Set as input except P6.3
  P7   = 0x00;              // All segments off
  PD7  = 0x00;               // Set as inputs
  P8.2 = 1;                 // Set port8.2 high
  P8.3 = 1;                 // Set port8.3 low
  P8.5 = 1;                 // Set port 8.5 High (NMI)
  P8.6 = 0;                 // When XCin is set, port P8 bit 6 and 7 have to
  P8.7 = 0;                 // be set low
  PD8    = 0xC3;             // Port 8 all outputs except b2,3,4&5
  PRCR   = 0x04;             // Port9 write enabled
  PD9    = 0x00;             // Set as inputs
  P9     = 0x00;             // All segments off
  P10    = 0x00;             // All segments off
  PD10   = 0x00;             // Set as inputs
  PUR0   = 0xFF;              // Pull up resistors for Port0,1.4-7,2 and 3
  PUR1   = 0xFF;              // Pull up other port4,5,6&7
  PUR2   = 0x3C;              // Without Pull-up for P8.0-P8.7, P9,10 pull up
  ADCON1.5 = 0;               // Set Vref no connect

//-------------------------------------------------------------------------------------
// Set up hardware and software interrupts (Timers)
//-------------------------------------------------------------------------------------
  disable_interrupt();
  set_interrupt_table(0x0640);  // Set interrupt table @ address 0x070A

  // Configure external INT0 user button
  INT0IC = 0x00;            // Disable INT0 interrupt - Priority level = 0
  INT0IC = 0x05;            // Set polarity select bit at falling edge
  //INT0IC = 0x06;            // Enable interrupt
```

```
  // Configure UART0
  U0MR  = 0x05;              // 0000 0101: 8N1 format
  U0C0  = 0x11;              // No handshaking, FXin/8 clock source
  U0C1  = 0x00;              // 0000 xxxx: Simple mode
  U0BRG = (CRYSTAL_FREQUENCY / 8 / 16 / UART0_BAUD_RATE) - 1;  // Set the baud
rate
  U0C1  = 0x01;              // 000x x0x1: Enable transmission disable reception ..0x03
  PD6.3 = 1;                // Set TxD0 as an output

  /* Configure UART0 */
  U1MR = 0x05;               // 0000 0101: 8N1 format
  U1C0 = 0x11;               // 00x1 x100: No hardware handshaking, f8 clock source
  U1C1 = 0x00;               // 0000 xxxx: Simple mode
  U1BRG = (CRYSTAL_FREQUENCY / 8 / 16 / UART1_BAUD_RATE) - 1;  // Set the baud
rate
  U1C1 = 0x05;               // 000x x1x1: Enable transmission and reception
  PD6.7 = 1;                // Set TXD1 as an output

  // Configure ADC for battery monitor
  ADCON2.0 = 1;              // Set with sample and hold function
  ADCON0   = 0x80;           // Software; One shot; Fad/2 mode
  ADCON1   = 0x00;           // Set as 8bit resolution

  // Configure Timer TA0
  //TA0MR   = 0xC0;           // Set TA0 as timer mode with 0xC0 for Fc32
  //CPSRF.7 = 1;              // Set reset prescaler
  //UDF.0   = 0;              // Count down flag on
  //TA0     = 1024 - 1;       // ISR to occur every second
  //TA0IC   = 5;              // Set interrupt priority level to 5   */
  P2 = 0x01;
  enable_interrupt();
  diagnostic();
  hyper_terminal();

  INT0IC = 0x06;             // Enable INT0 interrupt

  for(;;)
  {
    sleep_mode();            // Call function to set MCU to stop mode
  }
}

//-------------------------------------------------------------------------
// Function to set MCU into stop mode
//-------------------------------------------------------------------------
void sleep_mode(void){

  unsigned char pause;       // Local variable

  FMR0.3 = 0;                // Return to normal operation
  FMR0.1 = 0;                // Return to normal mode
  for(pause=0xF;pause!=0;pause--); // Software wait

  PRCR.0 = 1;    // Unlock protect
```

```
  CM1.0  = 1;    // Enter stop mode
  nop_instruction();nop_instruction();nop_instruction();
  nop_instruction();nop_instruction();

  PRCR.0 = 0;    // Relock protect

//-----------------------------------------------------------------------------------
// Upon returning from stop mode, Flash is automatically switched on
//-----------------------------------------------------------------------------------
  // Set to CPU rewrite mode
  FMR0.1 = 0;
  FMR0.1 = 1;
  // Set Flash reset bit to turn Flash off
  FMR0.3 = 0;
  FMR0.3 = 1;

  PRCR   = 0x01;                  // Unlock Protect
  CM0.3  = 0;                     // Set clock to LOW drive
  PRCR   = 0x00;                  // Relock protect
}

void diagnostic(void){

  unsigned int pause;
  unsigned char adcvalue;
  low_battery = OFF;

//-----------------------------------------------------------------------------------
// Switch Sub clock OFF and main clock ON
//-----------------------------------------------------------------------------------
  PRCR   = 0x01;                  // Unlock Protect
  CM0    = 0xD0;                  // Set Xin generation
  PRCR   = 0x00;                  // Relock Protect
  for (pause=0xFF;pause!=0;pause--);      // Software wait: to stabilise sub clock
  PRCR   = 0x01;                  // Unlock protect
  CM0    = 0x50;                  // Set Xin as system clock
  CM0    = 0x40;                  // Switch off the sub clock
  CM0    = 0x48;                  // Set high drive capacity
  PRCR   = 0x00;                  // Relock protect

  P0.2 = 1;                       // Switch Vref on
  P2.0 = 1;                       // Light LED
  for(pause=0xFF;pause!=0;pause--);
  P2.0 = 0;                       // Disable LED

//-----------------------------------------------------------------------------------
// Use ADC to measure battery status
//-----------------------------------------------------------------------------------
  ADCON1.5 = 1;                   // Vref connected
  for (pause=0xF;pause!=0;pause--);       // Allow software pause for ~1us
  ADCON0.6 = 1;                   // Start ADC conversion now
  while(ADCON0.6 != 1);               // Poll for ADC to finish
  adcvalue = AD0L;                // Store value into local variable
  if(adcvalue < 0xF7)
  {
```

```
    low_battery = ON;    // Check if below threshold
    P2.0 = 1;
  }
  else
  {
    low_battery = OFF;
    P2.0 = 0;
  }
  ADCON1.5 = 0;                    // Vref disconnected
  ADCON0.6 = 0;                    // Disable ADC conversion
  P0.2 = 0;                      // Switch Vref off

//-------------------------------------------------------------------------------
// Switch Sub clock ON and main clock OFF
//-------------------------------------------------------------------------------
  PRCR   = 0x01;                   // Unlock Protect
  CM0    = 0x58;                  // Set Xc generation
  PRCR   = 0x00;                   // Relock Protect
  for (pause=0xFF;pause!=0;pause--);       // Software wait: to stabilise sub clock
  PRCR   = 0x01;                   // Unlock protect
  CM0    = 0xD8;                   // Set Xc as system clock
  CM0    = 0xF8;                  // Switch off the main clock
  CM0    = 0xF0;                  // Set low drive capacity
  PRCR   = 0x00;                   // Relock protect
}

void hyper_terminal(void){

  unsigned int pause;
  char lcd_char[26], lcd_new_char, i, test;
  test = 0;

  P2 = 0x01;
//-------------------------------------------------------------------------------
// Switch Sub clock OFF and main clock ON
//-------------------------------------------------------------------------------
  PRCR   = 0x01;                   // Unlock Protect
  CM0    = 0xD0;                   // Set Xin generation
  PRCR   = 0x00;                   // Relock Protect
  for (pause=0xFF;pause!=0;pause--);       // Software wait: to stabilise sub clock
  PRCR   = 0x01;                   // Unlock protect
  CM0    = 0x50;                  // Set Xin as system clock
  CM0    = 0x40;                  // Switch off the sub clock
  CM0    = 0x48;                  // Set high drive capacity
  PRCR   = 0x00;                   // Relock protect

  i  = 0;

  printf2 ("%E[2J%E[HTest Demo for RF SMS Version 0.1\n\n");
  printf2 ("Final Year Project: RF based Child locator\n");
  printf2 ("Programmed by Clement Y L Pang\n");
  printf2 ("Supervisor Kate Williams\n\n");
  printf2 ("Please enter 26 character message\n\n");

  while(SW1 == 1)
```

```
  {
    if((U1C1.3 != 0)&&(i<26))
    {
      lcd_new_char = U1RBL;
      if((lcd_new_char >= ' ')&&(lcd_new_char <= 'z'))
      {
        while (U1C1.1 == 0);          // Wait if the buffer is full
        U1TBL = lcd_new_char;         // Send the next character
        lcd_char[i] = lcd_new_char;
        i++;
      }
    }
    if(i>=26)
    {
      printf2 ("%E[2J%E[HCOMPLETE  READY TO SEND!\n");
      for(i=0;i<26;i++)
      {
        while (U1C1.1 == 0);          // Wait if the buffer is full
        U1TBL = lcd_char[i];          // Send the next character
      }
    while(SW1 ==1);               // Stay in while loop till button pressed
    }
  }
  if(low_battery == ON) P2 = 0x01;
  else P2 = 0x00;

//-----------------------------------------------------------------------------
// Switch Sub clock ON and main clock OFF
//-----------------------------------------------------------------------------
  PRCR   = 0x01;                      // Unlock Protect
  CM0    = 0x50;                      // Set Xc generation
  PRCR   = 0x00;                      // Relock Protect
  for (pause=0xFF;pause!=0;pause--);       // Software wait: to stabilise sub clock
  PRCR   = 0x01;                      // Unlock protect
  CM0    = 0xD0;                      // Set Xc as system clock
  CM0    = 0xF0;                      // Switch off the main clock
  PRCR   = 0x00;                      // Relock protect

}

interrupt [29*4] void int0_isr(void)
{
  unsigned char i = 0;
  unsigned int pause;

//-----------------------------------------------------------------------------
// Switch Sub clock OFF and main clock ON
//-----------------------------------------------------------------------------
  PRCR   = 0x01;                      // Unlock Protect
  CM0    = 0xD0;                      // Set Xin generation
  PRCR   = 0x00;                      // Relock Protect
  for (pause=0xFF;pause!=0;pause--);       // Software wait: to stabilise sub clock
  PRCR   = 0x01;                      // Unlock protect
  CM0    = 0x50;                      // Set Xin as system clock
  CM0    = 0x40;                      // Switch off the sub clock
```

```
  CM0    = 0x48;                    // Set high drive capacity
  PRCR   = 0x00;                    // Relock protect

//-------------------------------------------------------------------------------
// Set I/O line high to turn on Transmitter and Buffer
//-------------------------------------------------------------------------------
  P0.0 = 1;                 // Set output high to turn on Tx
  P0.1 = 0;                 // Set output low to turn buffer on
  for(pause=0;pause<0xFF;pause++);        // Set delay for Tx turn on time

//-------------------------------------------------------------------------------
// Send data
//-------------------------------------------------------------------------------
  if(SW1 == 0){
    for(i=0;i<3;i++){
      while(U0C1.1==0);      // wait if transmit buffer is full
      U0TBL = 0xAA;          // Send preamble data three times
      }
    while(SW1 == 0){
    P2 = 0x01;              // Light LED
    for(pause=0;pause<0xFFF;pause++);
    P2 = 0x00;
    for(pause=0;pause<0xFFF;pause++);
    }
  }
  if(low_battery == ON) P2 = 0x01;
  else P2 = 0x00;

//-------------------------------------------------------------------------------
// Switch Sub clock ON and main clock OFF
//-------------------------------------------------------------------------------
  PRCR   = 0x01;                    // Unlock Protect
  CM0    = 0x58;                    // Set Xc generation
  PRCR   = 0x00;                    // Relock Protect
  for (pause=0xFF;pause!=0;pause--);      // Software wait: to stabilise sub clock
  PRCR   = 0x01;                    // Unlock protect
  CM0    = 0xD8;                    // Set Xc as system clock
  CM0    = 0xF8;                    // Switch off the main clock
  CM0    = 0xF0;                    // Set low drive capacity
  PRCR   = 0x00;                    // Relock protect

//-------------------------------------------------------------------------------
// Set I/O line low to turn off Transmitter
//-------------------------------------------------------------------------------
  P0.0 = 0;                 // Set output low to turn off Tx
  P0.1 = 1;                 // Set output high to turn off Buffer

//-------------------------------------------------------------------------------
// Check battery condition
//-------------------------------------------------------------------------------
  diagnostic();
}
```

Common header file:

```
/* General Definitions */
#define SW1 P8.2
#define SW2 P8.3
#define CRYSTAL_FREQUENCY 2000000
#define UART0_BAUD_RATE 1200
#define UART1_BAUD_RATE 1200
#define ON  1
#define OFF 0
#define ESC 27
#define LF  10
#define CR  13

/* Definition for RAM copying */
#define RAM_TX_MAIN_SIZE        0x001DE
#define RAM_TX_MAIN_START       0x01000
#define ROM_TX_MAIN_START       0xFAC22

#define RAM_SLEEP_MODE_SIZE     0x000FF
#define RAM_SLEEP_MODE_START    0x00900
#define ROM_SLEEP_MODE_START    0xFA500

#define RAM_INT0_ISR_SIZE       0x000FF
#define RAM_INT0_ISR_START      0x00A00
#define ROM_INT0_ISR_START      0xFA600

#define RAM_DIAGNOSTIC_SIZE     0x000FF
#define RAM_DIAGNOSTIC_START    0x00B00
#define ROM_DIAGNOSTIC_START    0xFA700

#define RAM_HYPERTERMINAL_SIZE  0x000FF
#define RAM_HYPERTERMINAL_START 0x00C00
#define ROM_HYPERTERMINAL_START 0xFA800

#define RAM_PUTC_SIZE  0x00020
#define RAM_PUTC_START 0x00E00
#define ROM_PUTC_START 0xFAB00

#define RAM_PRINTF2_SIZE   0x000FF
#define RAM_PRINTF2_START  0x00E22
#define ROM_PRINTF2_START  0xFAB22
/* Declare interrupts */
interrupt [29*4] void int0_isr(void);
interrupt [21*4] void timer_a0(void);
/* Declare functions */
void battery_status(void);
void diagnostic(void);
void hyper_terminal(void);
char getc(void);
void putc(char c);
void sleep_mode(void);
void tx_main(void);
void printf2(char *);

extern char low_battery;
```

Receiver XCL file:

```
// ------------------------------------------------------------
// LNKM16CY.XCL - Example file to be used with ICCM16C.
// This file shows a set up for the 'near' memory model
// where there is no ROM in the default (near) area.
// Read 'farconst.htm' for more information on how on-chip
// ROM can be used.
//
// Usage:  XLINK  your_file(s) -f lnkm16cy
//
// IMPORTANT:
//  Use a COPY of this file and, if needed, customize
//  for your own purposes.
//
//  $Id: lnkm16cy.xcl 1.10 2001/05/16 11:09:01 John Exp $
// ------------------------------------------------------------
// ------------------------------------------------------------
// Defines used by m16c.xcl, all values are in hex.
// (customize according to your specific derivative).
// ------------------------------------------------------------
// Stack sizes
-D_USER_STACK_SIZE=200
-D_INTR_STACK_SIZE=40
// Change this to the starting address of your internal ROM
-D_FAR_ROM_ADDRESS=FA000
// First available RAM address
-D_NEAR_RAM_ADDRESS=400
// Bit variables, range
-D_FIRST_BITVAR=2000 // 8*400 hex
-D_LAST_BITVAR=FFFF
// ------------------------------------------------------------
// Define CPU
// ------------------------------------------------------------
-cm16c
// ------------------------------------------------------------
// Create a 2-byte checksum using crc16. This option requires
// that we fill unused code bytes, so we fill with zero.
// ------------------------------------------------------------
-J2,crc16
-H0
// ------------------------------------------------------------
//   Place SEG_RAMRX at logical address 700
// ------------------------------------------------------------
-Z(CODE)SEG_RAMRX=700-8FF
-Z(CODE)SEG_ROMRX=FA100-FA2FF
-QSEG_RAMRX=SEG_ROMRX
// ------------------------------------------------------------
//   Place SEG_RAMSTANDBY at logical address 900
// ------------------------------------------------------------
-Z(CODE)SEG_RAMSTANDBY=900-9FF
-Z(CODE)SEG_ROMSTANDBY=FA300-FA3FF
-QSEG_RAMSTANDBY=SEG_ROMSTANDBY
// ------------------------------------------------------------
//   Place SEG_RAMTIMERA0 at logical address A00
// ------------------------------------------------------------
```

```
-Z(CODE)SEG_RAMTIMERA0=A00-AFF
-Z(CODE)SEG_ROMTIMERA0=FA400-FA4FF
-QSEG_RAMTIMERA0=SEG_ROMTIMERA0
// ---------------------------------------------------------
//   Place SEG_RAMDIAGNOSTICS at logical address B00
// ---------------------------------------------------------
-Z(CODE)SEG_RAMDIAGNOSTIC=B00-BFF
-Z(CODE)SEG_ROMDIAGNOSTIC=FA500-FA5FF
-QSEG_RAMDIAGNOSTIC=SEG_ROMDIAGNOSTIC
// ---------------------------------------------------------
//   Place SEG_RAMTIMERA1 at logical address C00
// ---------------------------------------------------------
-Z(CODE)SEG_RAMTIMERA1=C00-C1F
-Z(CODE)SEG_ROMTIMERA1=FA600-FA61F
-QSEG_RAMTIMERA1=SEG_ROMTIMERA1
// ---------------------------------------------------------
// Re-locatable "bit" segment.  As BITVARS contains bit addresses,
// the desired (byte) address has to be multiplied by 8.
// ---------------------------------------------------------
-Z(BIT)BITVARS=_FIRST_BITVAR-_LAST_BITVAR
// ---------------------------------------------------------
// Set up user stack and interrupt stack
// ---------------------------------------------------------
-Z(NEAR)CSTACK+_USER_STACK_SIZE=_NEAR_RAM_ADDRESS
-Z(NEAR)ISTACK+_INTR_STACK_SIZE=_NEAR_RAM_ADDRESS
// ---------------------------------------------------------
// Near, far and huge data segments (in RAM)
// These are actually all placed in near RAM.
// ---------------------------------------------------------
-Z(NEAR)IDATA0,UDATA0=_NEAR_RAM_ADDRESS
-Z(FAR)IDATA1,UDATA1=_NEAR_RAM_ADDRESS
-Z(HUGE)IDATA2,UDATA2=_NEAR_RAM_ADDRESS
// ---------------------------------------------------------
// Initialisation data segments (in ROM)
// ---------------------------------------------------------
-Z(FARCONST)CCSTR,CDATA0,CDATA1=_FAR_ROM_ADDRESS
-Z(HUGECONST)CDATA2=_FAR_ROM_ADDRESS
// ---------------------------------------------------------
// CHECKSUM segment
// ---------------------------------------------------------
-Z(FARCONST)CHECKSUM=_FAR_ROM_ADDRESS
// ---------------------------------------------------------
// CODE segment
// ---------------------------------------------------------
-Z(HUGECODE)CODE=_FAR_ROM_ADDRESS
// ---------------------------------------------------------
// Fixed interrupt table
// ---------------------------------------------------------
-Z(HUGECONST)INTVEC1=FFFDC-FFFFF
// ---------------------------------------------------------
// Set up the tiny-func table
// ---------------------------------------------------------
-Z(HUGECONST)FLIST=FFE00-FFFDA
// ---------------------------------------------------------
// See configuration section concerning
```

```
// printf/sprintf/scanf/sscanf
// ---------------------------------------------------------
-e_small_write=_formatted_write
-e_medium_read=_formatted_read
// ---------------------------------------------------------
// Segments that has to be in RAM, reachable for default pointers
// ---------------------------------------------------------
-Z(NEAR)NO_INIT,ECSTR=_NEAR_RAM_ADDRESS
// ---------------------------------------------------------
// Constant segments (in ROM)
// ---------------------------------------------------------
-Z(FARCONST)FAR_CONST,CONST=_FAR_ROM_ADDRESS
-Z(HUGECONST)HUGE_CONST=_FAR_ROM_ADDRESS
// ---------------------------------------------------------
// Special page vector table
// ---------------------------------------------------------
-Z(HUGECONST)INTVEC=FB000
// ---------------------------------------------------------
// Select C library.
// ---------------------------------------------------------
clm16cy
// ---------------------------------------------------------
// Select for ieee-695 format required for KD30, PD30 & PD30SIM
// ---------------------------------------------------------
//-ylmba
// ---------------------------------------------------------
// End of file LNKM16CY.XCL
```

Receiver Source Code:

```
#define  Chip_3062x  /* For iom16c62.h M16C/62N*/
#include "common_FLASHOFF.h"
#include <iom16c62.h>
#include <intrm16c.h>
// Global Variables
signed char alarm, buzzer, low_battery;
unsigned int delay;
void diagnostic(void);
void standby_mode(void);
void rx_main(void);

//-----------------------------------------------------------------------------
// INTVECB table address for Interrupt Service Routines stored in RAM
//-----------------------------------------------------------------------------
unsigned char invec_tab[]     = { 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
                          0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
                          0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
                          0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
                          // Interrupt address for KD30
                          // to allow BP and Debugging
                          0,0,0,0,0,0,0,0,0,0,0,0x6B,0xCB,0x0F,0x00,
                                    // Interrupt Address for TA0

0x6B,0xCB,0x0F,0x00,0x00,0x0A,0x00,0x00,0x00,0x0C,0x00,0x00,0,0,0,0,
                          0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
                          0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0 };

//-----------------------------------------------------------------------------
// Start of main
//-----------------------------------------------------------------------------
void main(void)
{
  unsigned int i;
//-----------------------------------------------------------------------------
// Copy ROM functions into RAM
//-----------------------------------------------------------------------------
  // Copy the transmit function program into RAM
  for(i=0;i<RAM_RX_MAIN_SIZE;i++)
  {
    // Start copy from ROM to RAM
    ((char far *) RAM_RX_MAIN_START)[i] = ((char far *) ROM_RX_MAIN_START)[i];
  }
  // Copy sleep mode function into RAM
  for(i=0;i<RAM_SLEEP_MODE_SIZE;i++)
  {
    ((char far *) RAM_SLEEP_MODE_START)[i] = ((char far *)
ROM_SLEEP_MODE_START)[i];
  }
  // Copy the interrupt service routine into RAM
  for(i=0;i<RAM_TA0_ISR_SIZE;i++)
  {
    ((char far *) RAM_TA0_ISR_START)[i] = ((char far *) ROM_TA0_ISR_START)[i];
  }
  // Copy the TIMERa0 isr into RAM
```

```
  for(i=0;i<RAM_TIMERA1_SIZE;i++)
  {
    ((char far *) RAM_TIMERA1_START)[i] = ((char far *) ROM_TIMERA1_START)[i];
  }
  // Copy the diagnostic function into RAM
  for(i=0;i<RAM_DIAGNOSTIC_SIZE;i++)
  {
    ((char far *) RAM_DIAGNOSTIC_START)[i] = ((char far *)
ROM_DIAGNOSTIC_START)[i];
  }
  rx_main();          // Call lcd function in RAM
}

//---------------------------------------------------------------------------
// Low level innit called first, before main by cstartup
//---------------------------------------------------------------------------
unsigned char __low_level_init(void) {

  // Select full speed operation
  PRCR = 0x01;              // Unlock CM0 and CM1
  PM0  = 0x00;              // Single chip mode
  CM0  = 0x40;              // Disable divider set Fin/8
  //CM0  = 0x00;
  //CM1  = 0x00;
  PRCR = 0x00;              // Relock CM0 and CM1

  // Configure UART receive interrupt
  //S0RIC = 0x00;           // Set Rx to 0 IPL
  //S0RIC = 0x06;           // Set IPL to 6
  //S0RIC = 0x0E;           // Interrupt request enabled
  return 1;               // Force cstartup to initialise RAM etc.
}

void rx_main(void){

  unsigned int pause;             // Declare local variable
  unsigned char i = 0;

//---------------------------------------------------------------------------
// Switch Sub clock ON and main clock OFF
//---------------------------------------------------------------------------
  //PRCR   = 0x01;                  // Unlock Protect
  //CM0    = 0x58;                  // Set Xc generation
  //PRCR   = 0x00;                  // Relock Protect
  //for (pause=0xFF;pause!=0;pause--);       // Software wait: to stabilise sub clock
  //PRCR   = 0x01;                  // Unlock protect
  //CM0    = 0xD8;                  // Set Xc as system clock
  //CM0    = 0xF8;                  // Switch off the main clock
  //CM0    = 0xF0;                  // Set low drive capacity
  //PRCR   = 0x00;                  // Relock protect

//---------------------------------------------------------------------------
// Switch FLASH circuit off to reduce power consumption
//---------------------------------------------------------------------------
  FMR0.1 = 0;
```

```
  FMR0.1 = 1;
  FMR1.3 = 0;              // FLASH memory power supply on
  FMR1.3 = 1;              // FLASH memory power supply off

//-----------------------------------------------------------------------------
// Configure ports
//-----------------------------------------------------------------------------

  P0   = 0x00;             // All port pins low
  PD0  = 0x07;             // Set all as inputs except bit0&1
  P1   = 0x00;             // All port pins low
  PD1  = 0x00;             // Set as inputs
  P2   = 0x00;             // All segments off
  PD2  = 0x01;             // Set as inputs except bit0
  P3   = 0x00;             // All port pins low
  PD3  = 0x00;             // Set as inputs
  P4   = 0x00;             // All port pins low
  PD4  = 0x00;             // Set as inputs
  P6   = 0x00;             // Set port low
  PD6  = 0x00;             // Set as inputs
  P7   = 0x00;             // All segments off
  PD7  = 0x0C;             // Set as inputs except bit2&3
  P8.2 = 1;                // Set port8.2 high
  P8.3 = 1;                // Set port8.3 low
  P8.5 = 1;                // Set port 8.5 High (NMI)
  P8.6 = 0;                // When XCin is set, port P8 bit 6 and 7 have to
  P8.7 = 0;                // be set low
  PD8  = 0xC3;             // Port 8 all outputs except b2,3,4&5
  PRCR = 0x04;             // Port9 write enabled
  PD9  = 0x00;             // Set as inputs
  P9   = 0x00;             // All segments off
  P10  = 0x00;             // All segments off
  PD10 = 0x00;             // Set as inputs
  PUR0 = 0xFB;             // Pull up resistors for Port0,1.4-7,2 and 3
  PUR1 = 0xF9;             // Pull up other port4,5,6&7
  PUR2 = 0x3C;             // Without Pull-up for P8.0-P8.7, P9,10 pull up
  ADCON1.5 = 0;            // Set Vref no connect

//-----------------------------------------------------------------------------
// Set up hardware and software interrupts (Timers)
//-----------------------------------------------------------------------------
  disable_interrupt();
  set_interrupt_table(0x0640);  // Set interrupt table @ address 0x070A

  // Configure ADC for battery monitor
  ADCON2.0 = 1;            // Set with sample and hold function
  ADCON0   = 0x80;         // Software; One shot; Fad/2 mode
  ADCON1   = 0x00;         // Set as 8bit resolution

  // Configure UART0
  U0MR = 0x05;             // 0000 0101: 8N1 format
  U0C0 = 0x11;             // No handshaking, f1/8 clock source
  U0C1 = 0x00;             // 0000 xxxx: Simple mode
  U0BRG = (CRYSTAL_FREQUENCY / 8 / 16 / UART0_BAUD_RATE) - 1;  // Set the baud
rate
```

```
  U0C1 = 0x04;              // 000x x1x0: Disable transmission enable reception
  PD6.2 = 0;               // Set RxD0 as an input

  // Configure UART receive interrupt
  //S0RIC = 0x00;          // Set Rx to 0 IPL
  //S0RIC = 0x06;          // Set IPL to 6
  //S0RIC = 0x0E;          // Interrupt request enabled

  // Configure Timer TA0
  TA0MR   = 0x40;           // Set TA0 as timer mode with 0xC0 for Fc32
  //CPSRF.7 = 1;            // Set reset prescaler
  UDF.0 = 0;               // Timer to count down
  TA0     = 2250 - 1;       // ISR to occur every 9 9ms 2250 for 2Mhz/8
  TA0IC   = 6;             // Set interrupt priority level to 5   */

  // Configure Timer TA1
  TA1MR   = 0x40;           // Set TA0 as timer mode with 0xC0 for Fc32
  //CPSRF.7 = 1;            // Set reset prescaler
  TA1     = 32 - 1;         // ISR to produce 4KHz buzz
  TA1IC   = 5;             // Set interrupt priority level to 5   */

  low_battery = OFF;
  buzzer   = OFF;
  alarm    = 0;            // Initialise variable
  delay    = 0;
  enable_interrupt();       // Enable all interrupts
  diagnostic();

  P0.0 = 1;                // Set port high to turn Rx ON
  for(i=0;i<0xFF;i++);      // Set delay for Rx turn on time

  TABSR.0 = 1;             // Start Timer A0 interrupt
  //TABSR.1 = 1;            // Start Timer A1 interrupt

  for(;;)
  {
    standby_mode();         // Call wait function
  }
}

//-------------------------------------------------------------------------------
// Function to set MCU to wait mode for low power feature
//-------------------------------------------------------------------------------

void standby_mode(void){

//-------------------------------------------------------------------------------
// Switch FLASH circuit ON
//-------------------------------------------------------------------------------
  FMR0.1 = 1;
  FMR0.1 = 0;
  FMR1.3 = 1;              // FLASH memory power supply off
  FMR1.3 = 0;              // FLASH memory power supply on

  wait_for_interrupt();     // Enter wait_mode
```

```
  nop_instruction();nop_instruction();nop_instruction();
  nop_instruction();nop_instruction();

//-------------------------------------------------------------------------------------
// Switch FLASH circuit off to reduce power consumption
//-------------------------------------------------------------------------------------
  FMR0.1 = 0;
  FMR0.1 = 1;
  FMR1.3 = 0;              // FLASH memory power supply on
  FMR1.3 = 1;              // FLASH memory power supply off

  PRCR   = 0x01;           // Unlock Protect
  CM0.3  = 0;              // Set clock to LOW drive
  PRCR   = 0x00;           // Relock protect
}

void diagnostic(void){

  unsigned char pause;
  unsigned char tempvalue;

/*//-----------------------------------------------------------------------------
// Switch Sub clock OFF and main clock ON
//-----------------------------------------------------------------------------
  PRCR   = 0x01;                  // Unlock Protect
  CM0    = 0xD0;                  // Set Xin generation
  PRCR   = 0x00;                  // Relock Protect
  for (pause=0xFF;pause!=0;pause--);      // Software wait: to stabilise sub clock
  PRCR   = 0x01;                  // Unlock protect
  CM0    = 0x50;                  // Set Xin as system clock
  CM0    = 0x40;                  // Switch off the sub clock
  CM0    = 0x48;                  // Set high drive capacity
  PRCR   = 0x00;                  // Relock protect
*/
  if(low_battery == OFF){
  P2.0 = 1;                 // Light LED
  for(pause=0xFF;pause!=0;pause--);       // Software delay to view LED blink
  P2.0 = 0;                 // Disable LED
  }
//-------------------------------------------------------------------------------------
// Use ADC to measure battery status
//-------------------------------------------------------------------------------------
  ADCON1.5 = 1;                   // Vref connected
  for (pause=0xFF;pause!=0;pause--);      // Allow software pause for ~1us
  ADCON0.6 = 1;                   // Start ADC conversion now
  while(ADCON0.6 != 1);               // Poll for ADC to finish
  tempvalue = AD0L;                // Store value into local variable
  if(tempvalue < 0xD0)
  {
    low_battery = ON;             // Check if below threshold
    P2.0 = 1;
  }
  else
  {
    low_battery = OFF;
```

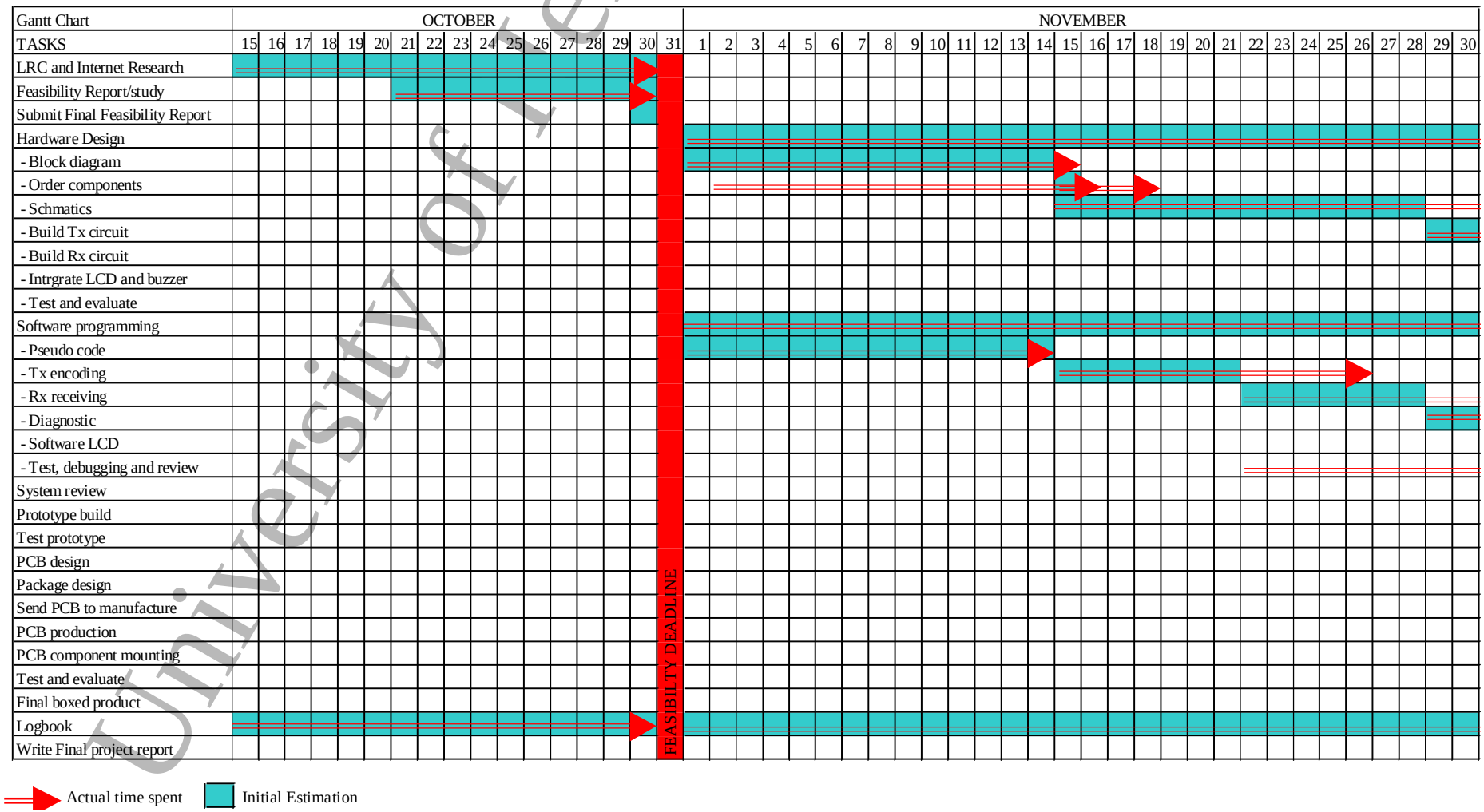
```
    P2.0 = 0;
  }
  if(low_battery == ON) P2.0 = 1;

/*//-----------------------------------------------------------------------------
// Switch Sub clock ON and main clock OFF
//-----------------------------------------------------------------------------
  PRCR   = 0x01;                    // Unlock Protect
  CM0    = 0x58;                    // Set Xc generation
  PRCR   = 0x00;                    // Relock Protect
  for (pause=0xFF;pause!=0;pause--);       // Software wait: to stabilise sub clock
  PRCR   = 0x01;                    // Unlock protect
  CM0    = 0xD8;                    // Set Xc as system clock
  CM0    = 0xF8;                    // Switch off the main clock
  CM0    = 0xF0;                    // Set low drive capacity
  PRCR   = 0x00;                    // Relock protect
*/
  ADCON1.5 = 0;                     // Vref disconnected
  ADCON0.6 = 0;                     // Disable ADC conversion
}

//-----------------------------------------------------------------------------
// Timer TA0 interrupt to handle receiving data
//-----------------------------------------------------------------------------
interrupt [21*4] void timer_a0(void)
{
  unsigned int pause, i;            // Declare local variables

  //P0.0 = 1;                       // Set port high to turn Rx on
  //for(i=0;i<0xFF;i++);            // Set delay for Rx turn on time

/*//-----------------------------------------------------------------------------
// Switch Sub clock OFF and main clock ON
//-----------------------------------------------------------------------------
  PRCR   = 0x01;                    // Unlock Protect
  CM0    = 0xD0;                    // Set Xin generation
  PRCR   = 0x00;                    // Relock Protect
  for (pause=0xFF;pause!=0;pause--);       // Software wait: to stabilise sub clock
  PRCR   = 0x01;                    // Unlock protect
  CM0    = 0x50;                    // Set Xin as system clock
  CM0    = 0x40;                    // Switch off the sub clock
  CM0    = 0x48;                    // Set high drive capacity
  PRCR   = 0x00;                    // Relock protect
*/
//-----------------------------------------------------------------------------
// Check Uart receive buffer for data
//-----------------------------------------------------------------------------
  if(U0RBL == 0xAA){
  while(U0RBL == 0xAA);             // See if there is any data in receive buffer
  //if(U0RBL == 0xAA){              // Check if preamble detected
    for (pause=0xFF;pause!=0;pause--);// Software wait 0X271
    if(alarm == 0){                 // Signal received to activate buzzer?
      //delay = 0;                  // Set delay variable
      P7.2  = 0;                    // Initialise buzzer pin
      P7.3  = 0;                    // Initialise buzzer pin
```

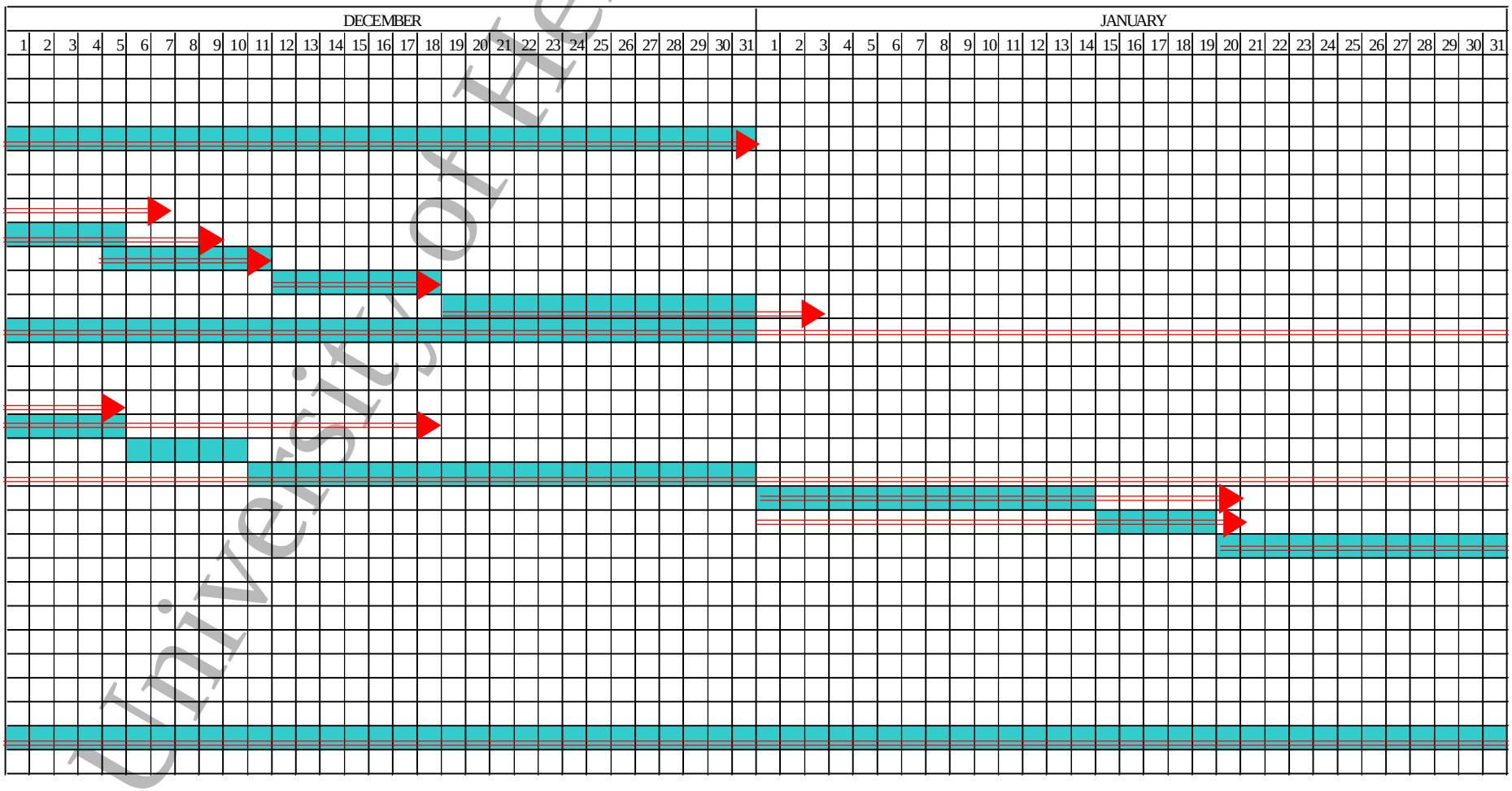
```
        //P7.2  = 1;
        //P7.3  = 1;
        P7 |= 0xF4;                 // Set buzzer pin high
        TABSR.1 = 1;
        buzzer = ON;                // Set variable to indicate buzzer active
        }
      alarm++;                      // Increment status variable
      if(alarm >= 2){               // Signal variable used to deactivate buzzer
        P7 &= 0xF3;                 // NOR buzzer pins to 0
        TABSR.1 = 0;
        P7.2  = 0;
        P7.3  = 0;
        alarm   = 0;                // Reset alarm value
        buzzer = OFF;               // Variable to indicate variable disabled
        //P2 = 0x00;
        }
      //}
    //if (U0RBH.7 == 1) P2 = 0x80;
    //if (U0RBH.6 == 1) P2 = 0x40;
    //if (U0RBH.5 == 1) P2 = 0x20;
    //if (U0RBH.4 == 1) P2 = 0x10;

    //P0.0 = 0;                     // Set port low to turn Rx off
    //for(i=0;i<0xF;i++);           // Set delay for Rx turn on time
    }
/*//-------------------------------------------------------------------------------
// Switch Sub clock ON and main clock OFF
//-------------------------------------------------------------------------------
    PRCR   = 0x01;                  // Unlock Protect
    CM0    = 0x58;                  // Set Xc generation
    PRCR   = 0x00;                  // Relock Protect
    for (pause=0xFF;pause!=0;pause--);      // Software wait: to stabilise sub clock
    PRCR   = 0x01;                  // Unlock protect
    CM0    = 0xD8;                  // Set Xc as system clock
    CM0    = 0xF8;                  // Switch off the main clock
    CM0    = 0xF0;                  // Set low drive capacity
    PRCR   = 0x00;                  // Relock protect
*/
    //diagnostic();                 // Call diagnostic function
    //if(buzzer == ON)P7 ^= 0x0C;       // Toggle buzzer pin if signal detected

}


interrupt [22*4] void timer_a1(void)
{
    //delay++;
    P7 ^= 0x0C;

}
```

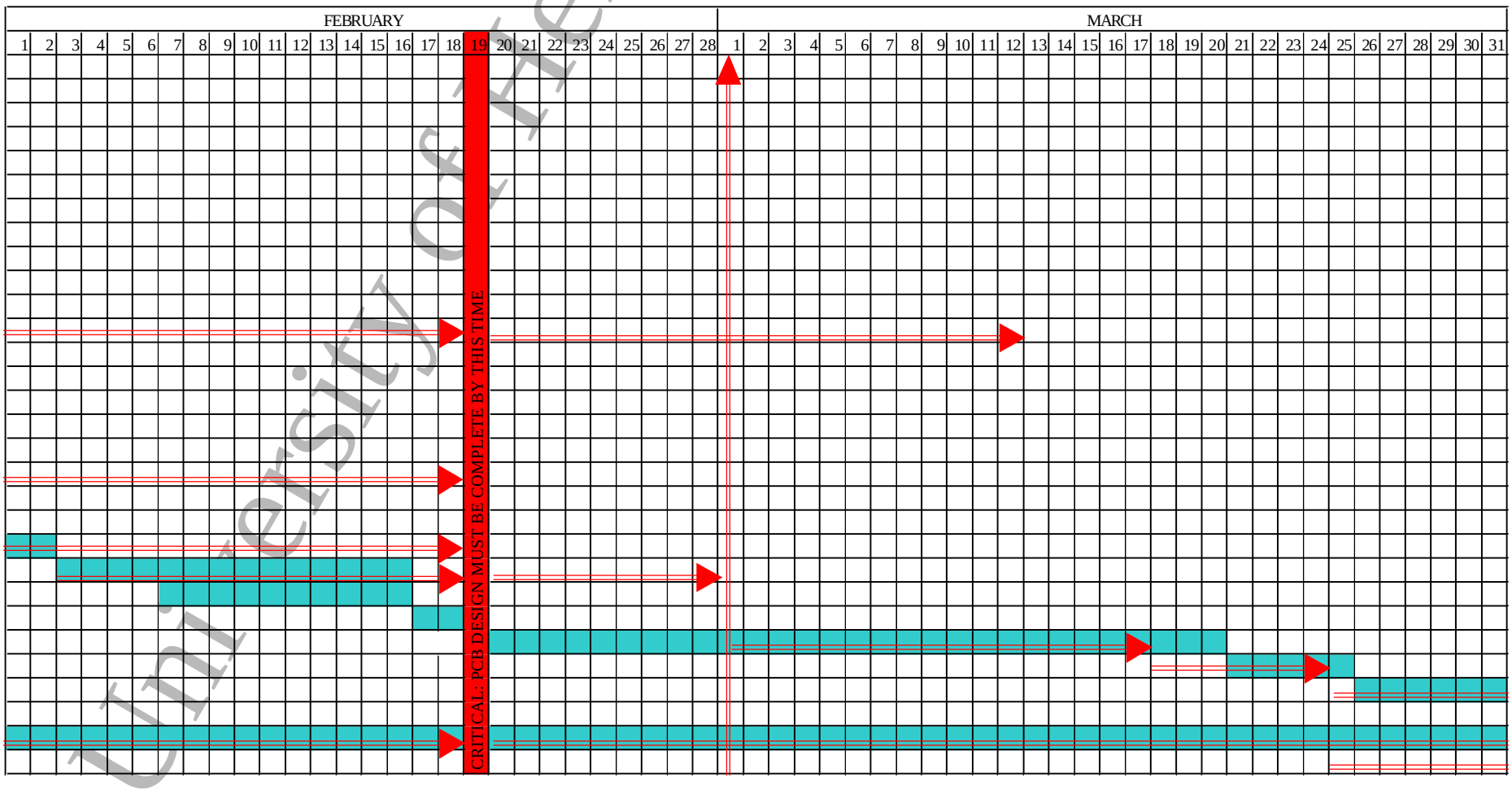
Common Files:

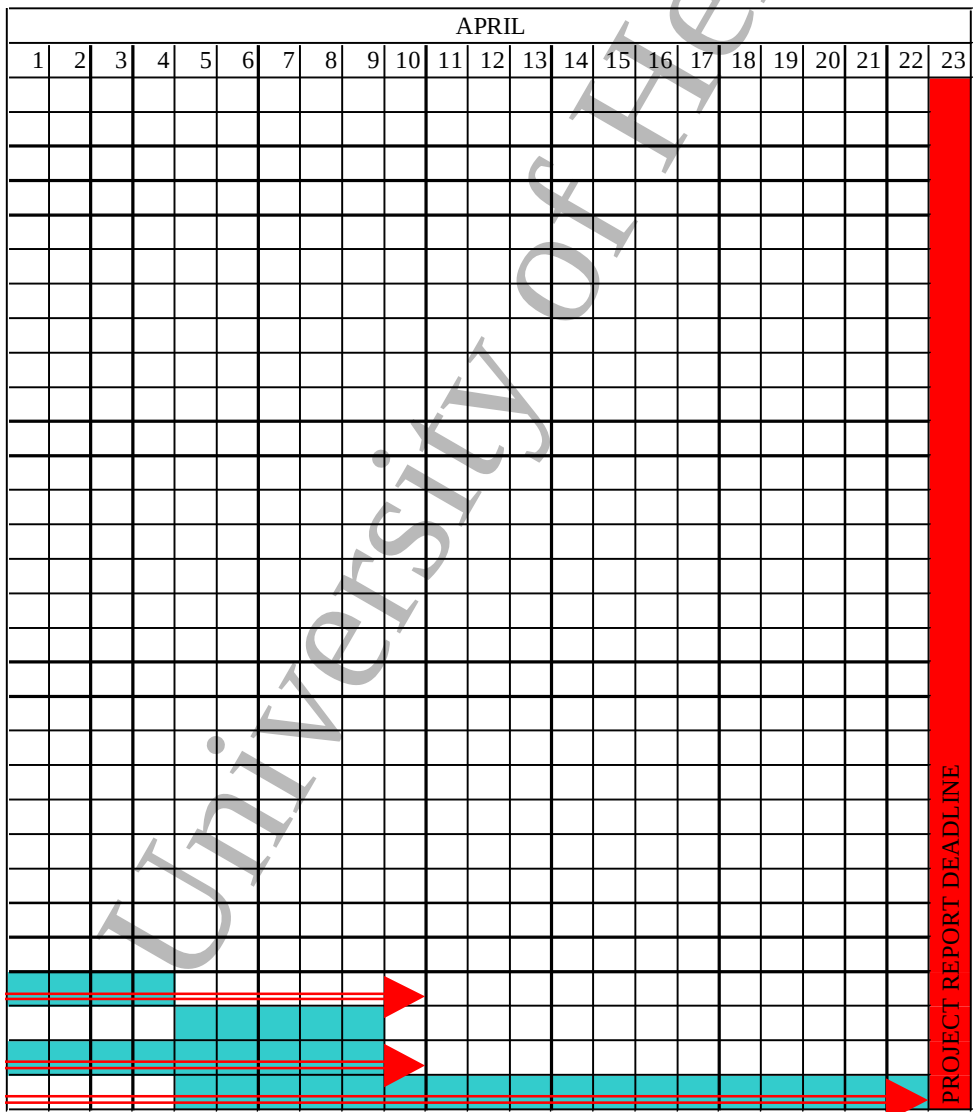
```
/* General Definitions */
#define SW1 P8.2
#define ON  1
#define OFF 0
#define CRYSTAL_FREQUENCY 2000000
#define UART0_BAUD_RATE 1200
#define FREQUENCY 2000000

interrupt [21*4] void timer_a0(void);
interrupt [22*4] void timer_a1(void);
interrupt [23*4] void timer_a2(void);
interrupt [24*4] void timer_a3(void);
interrupt [18*4] void uart0_rx(void);

void diagnostic(void);
void standby_mode(void);
extern signed char alarm, buzzer;

/* Definition for RAM copying */
#define RAM_RX_MAIN_SIZE        0x001FF
#define RAM_RX_MAIN_START       0x00700
#define ROM_RX_MAIN_START       0xFA100

#define RAM_SLEEP_MODE_SIZE     0x000FF
#define RAM_SLEEP_MODE_START    0x00900
#define ROM_SLEEP_MODE_START    0xFA300

#define RAM_TA0_ISR_SIZE        0x000FF
#define RAM_TA0_ISR_START       0x00A00
#define ROM_TA0_ISR_START       0xFA400

#define RAM_DIAGNOSTIC_SIZE     0x000FF
#define RAM_DIAGNOSTIC_START    0x00B00
#define ROM_DIAGNOSTIC_START    0xFA500

#define RAM_TIMERA1_SIZE        0x0001F
#define RAM_TIMERA1_START       0x00C00
#define ROM_TIMERA1_START       0xFA600

/* Declare timers */
interrupt [21*4] void timer_a0(void);
interrupt [22*4] void timer_a1(void);
interrupt [23*4] void timer_a2(void);
interrupt [24*4] void timer_a3(void);

/* Declare external functions */
void standby_mode(void);

/* Include global variables */
extern signed char alarm, buzzer, low_battery;
extern unsigned int delay;
//extern unsigned int tone_freq[12];
//extern unsigned char *freq_ptr;
```

Appendix D: Gantt Chart



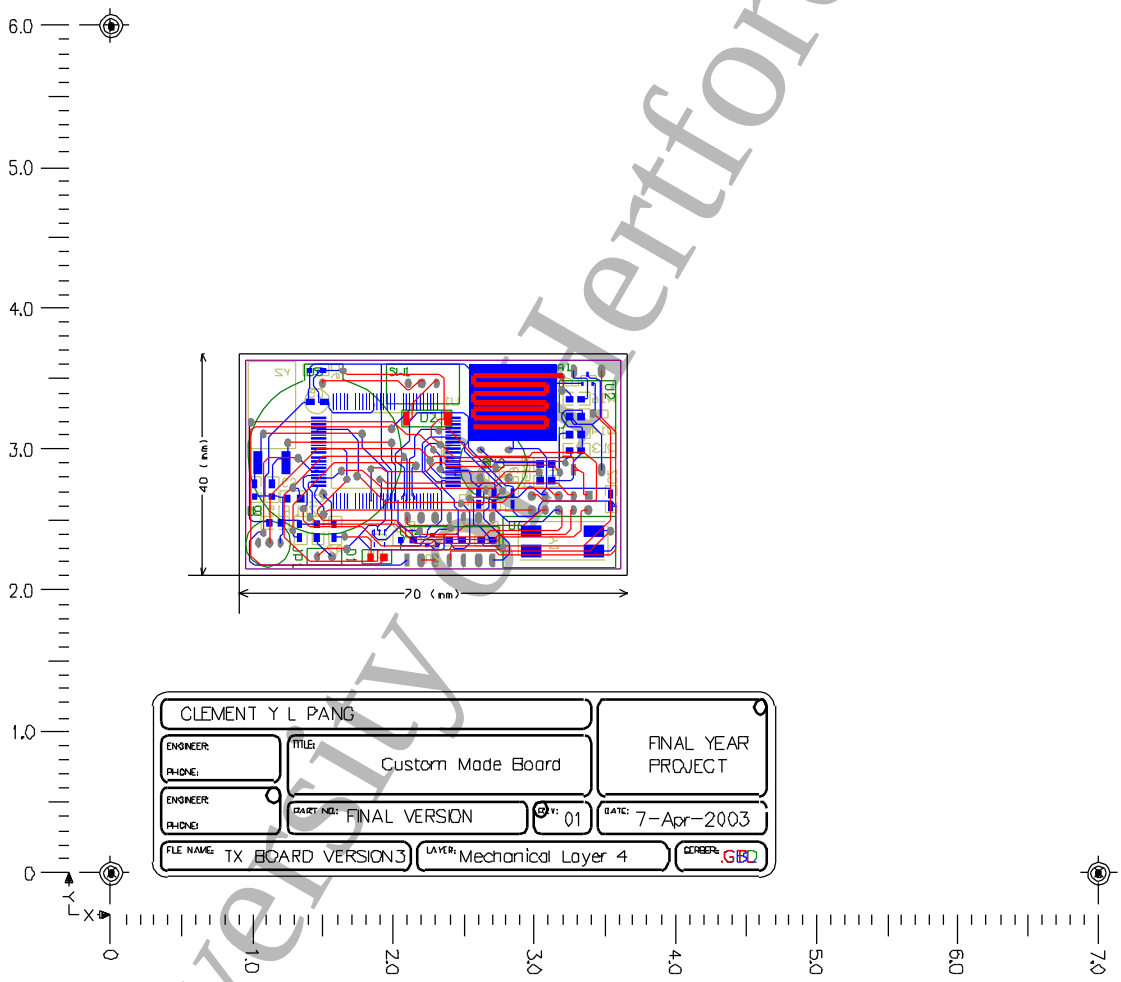




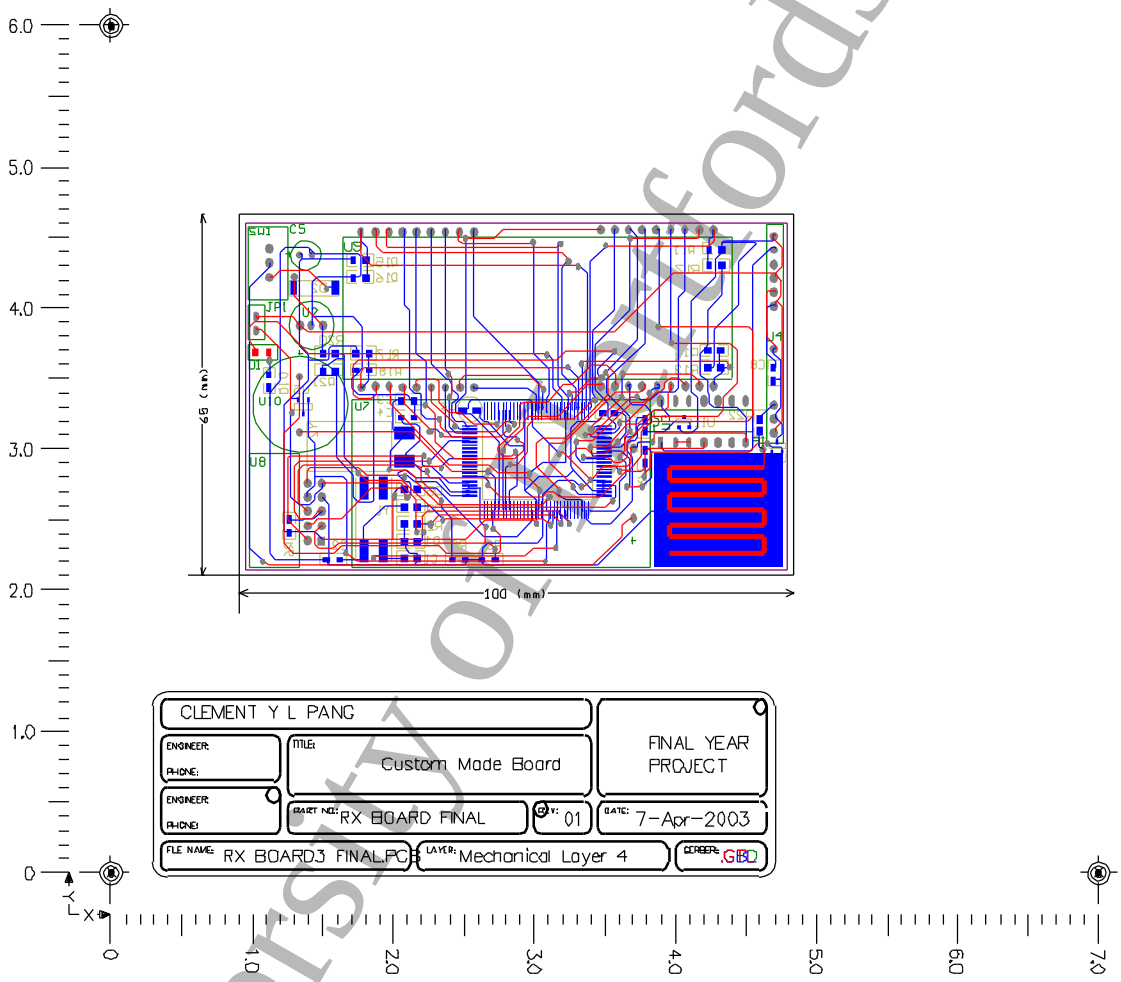


Appendix E – 1: Rx and Tx PCB layout

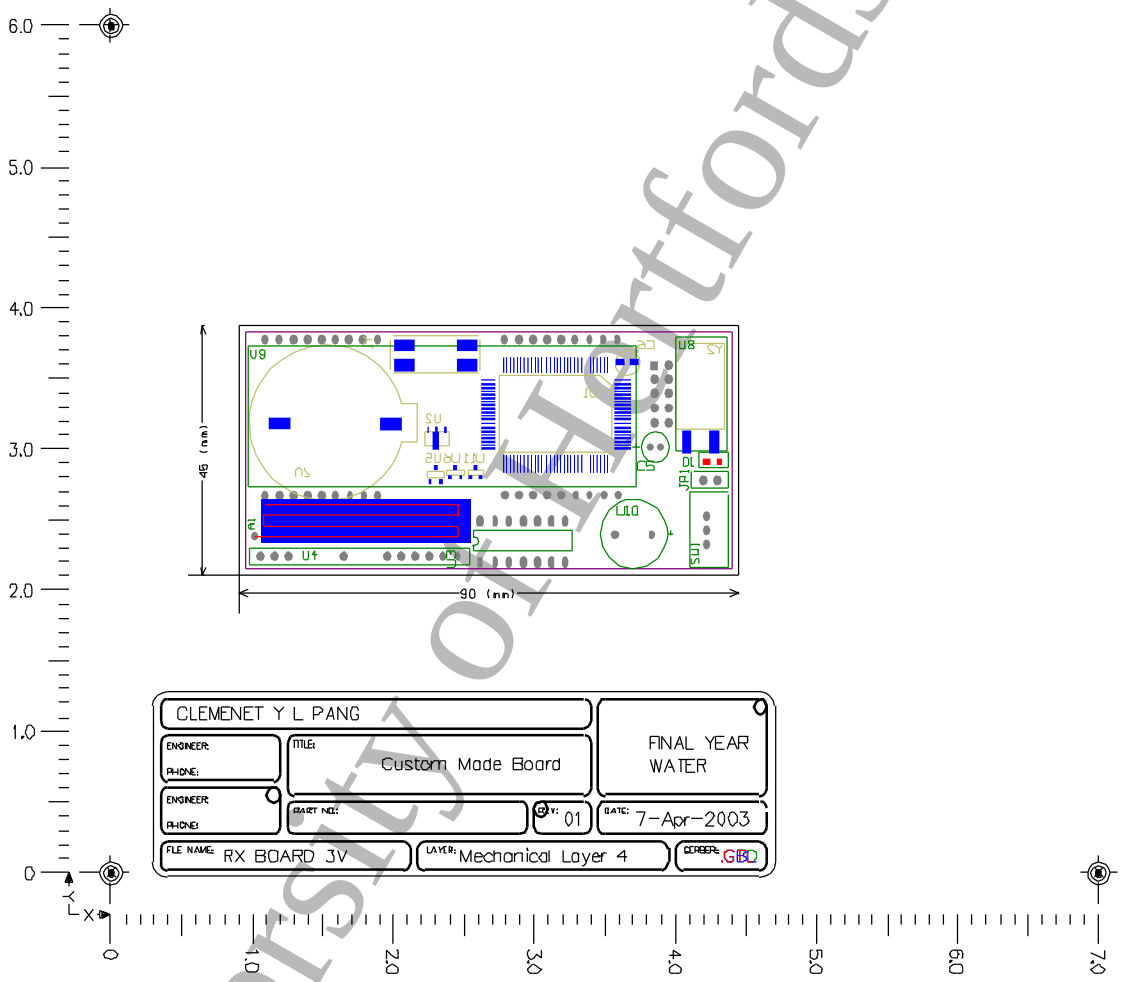
Transmitter PCB layout:



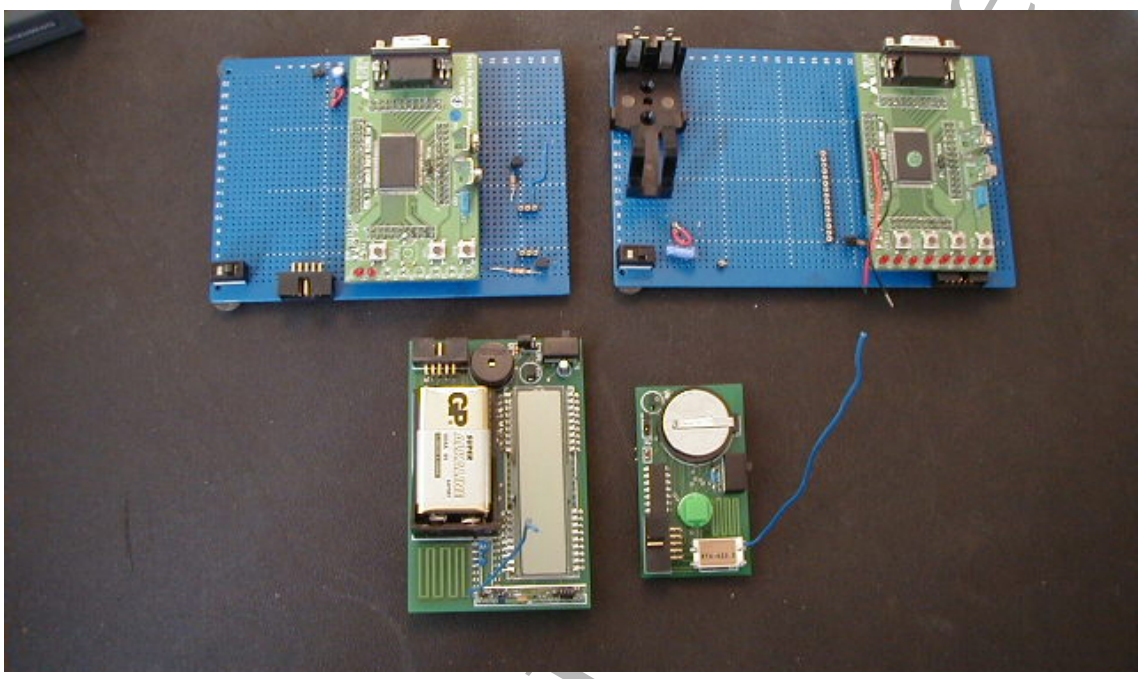
Receiver PCB layout:

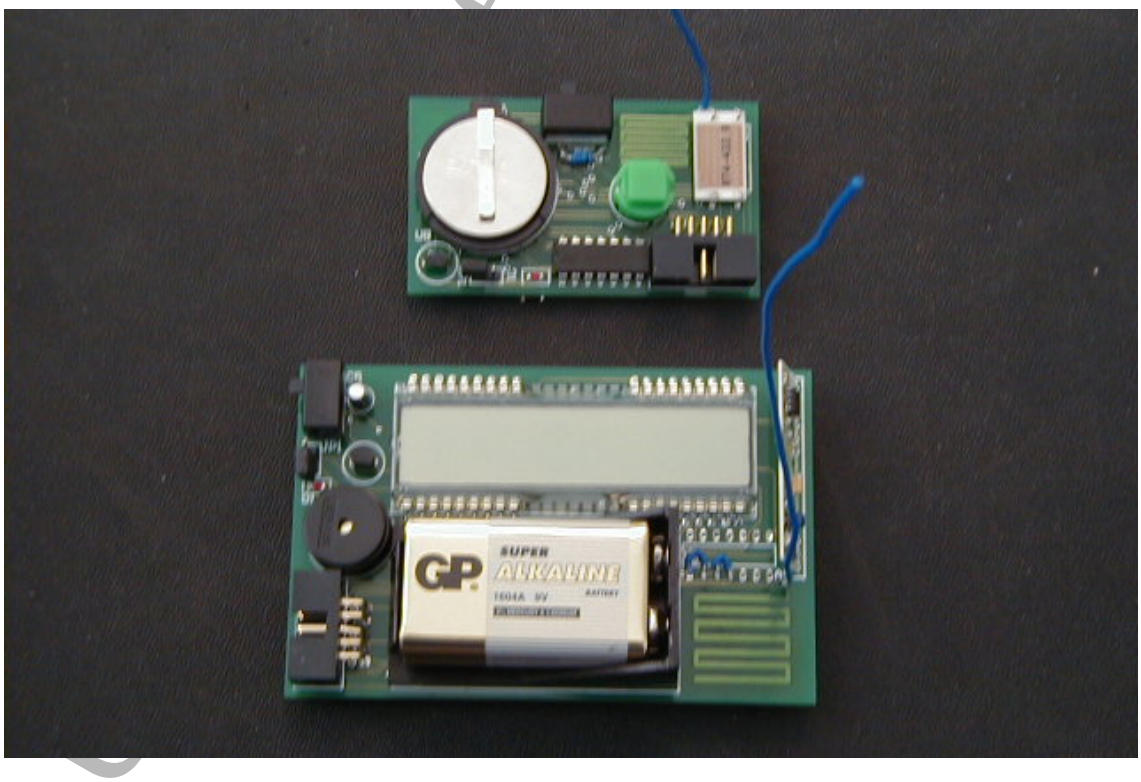


Receiver 3V PCB layout:



Appendix E – 2: Rx and Tx PCB





Appendix F: M16C User Manual

Description

The M16C/62A group of single-chip microcomputers are built using the high-performance silicon gate CMOS process using a M16C/60 Series CPU core and are packaged in a 100-pin plastic molded QFP. These single-chip microcomputers operate using sophisticated instructions featuring a high level of instruction efficiency. With 1M bytes of address space, they are capable of executing instructions at high speed. They also feature a built-in multiplier and DMAC, making them ideal for controlling office, communications, industrial equipment, and other high-speed processing applications.

The M16C/62A group includes a wide range of products with different internal memory types and sizes and various package types.

Features

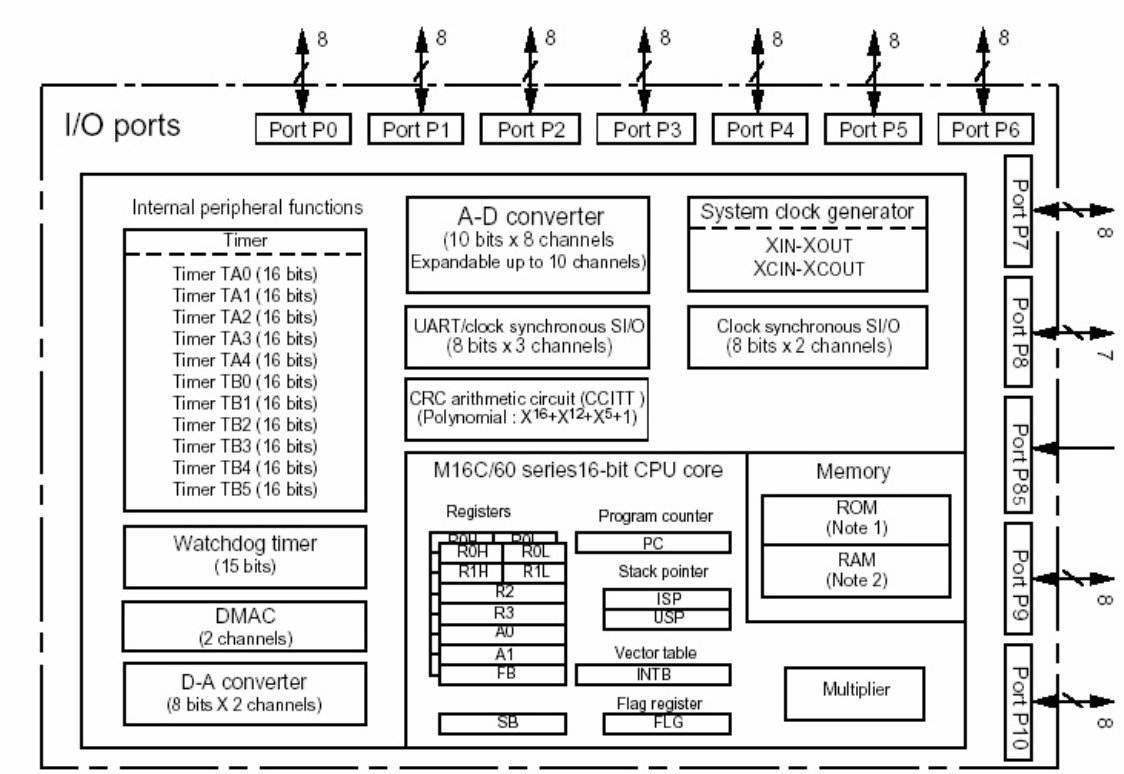
- Memory capacity ..... ROM (See Figure 1.1.4. ROM Expansion)
  RAM 3K to 20K bytes
- Shortest instruction execution time ..... 62.5ns (f(XIN)=16MHz, VCC=5V)
  100ns (f(XIN)=10MHz, VCC=3V, with software one-wait) : Mask ROM, flash memory 5V version
- Supply voltage ..... 4.2V to 5.5V (f(XIN)=16MHz, without software wait) : Mask ROM, flash memory 5V version
  2.7V to 5.5V (f(XIN)=10MHz with software one-wait) : Mask ROM, flash memory 5V version
- Low power consumption ..... 25.5mW (f(XIN)=10MHz, with software one-wait, VCC = 3V)
- Interrupts ..... 25 internal and 8 external interrupt sources, 4 software interrupt sources; 7 levels (including key input interrupt)
- Multifunction 16-bit timer ..... 5 output timers + 6 input timers
- Serial I/O ..... 5 channels (3 for UART or clock synchronous, 2 for clock synchronous)
- DMAC ..... 2 channels (trigger: 24 sources)
- A-D converter ..... 10 bits X 8 channels (Expandable up to 10 channels)
- D-A converter ..... 8 bits X 2 channels
- CRC calculation circuit ..... 1 circuit
- Watchdog timer ..... 1 line
- Programmable I/O ..... 87 lines
- Input port ..... 1 line (P85 shared with $\overline{NMI}$ pin)
- Memory expansion ..... Available (to a maximum of 1M bytes)
- Chip select output ..... 4 lines
- Clock generating circuit ..... 2 built-in clock generation circuits
  (built-in feedback resistor, and external ceramic or quartz oscillator)

Applications

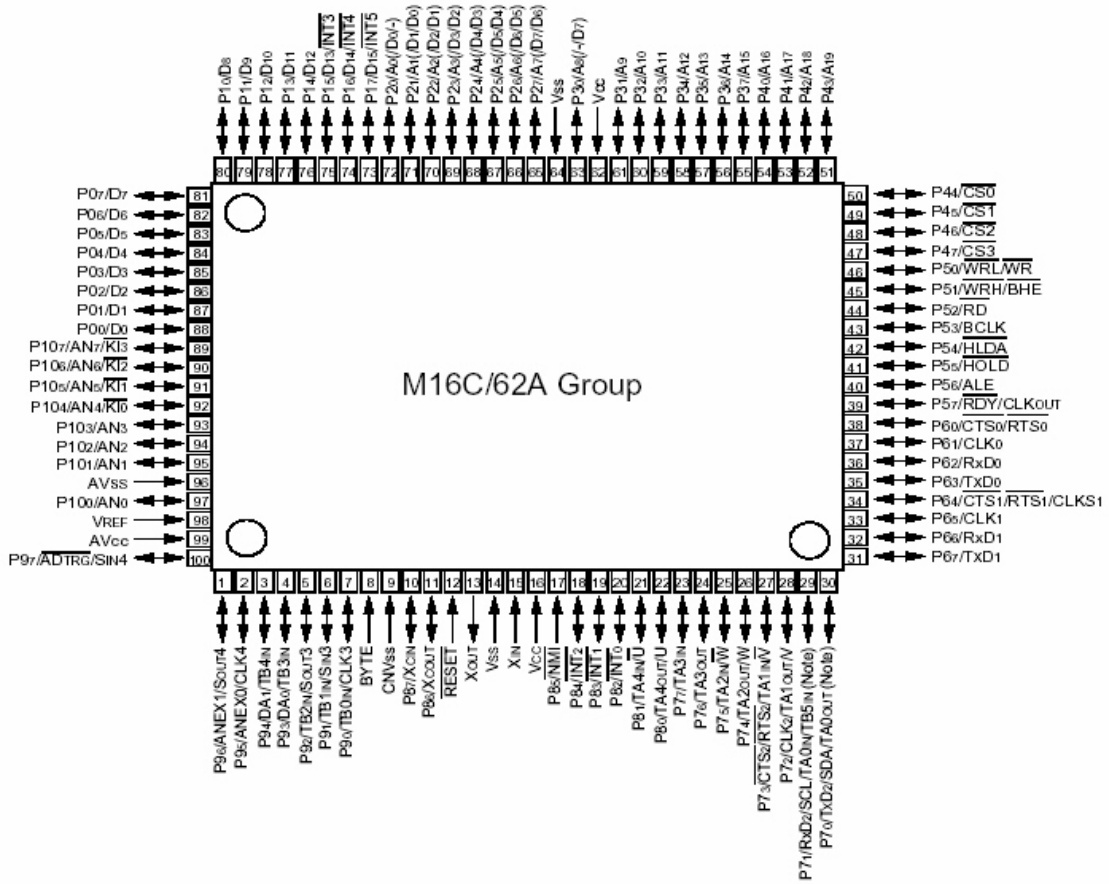
Audio, cameras, office equipment, communications equipment, portable equipment

------Table of Contents------

Pin Configuration and block diagram of M16C/62 A and N device:



Note 1: ROM size depends on MCU type.
Note 2: RAM size depends on MCU type.



Performance Outline:

Item		Performance
Number of basic instructions		91 instructions
Shortest instruction execution time		62.5ns(f(XIN)=16MHz, VCC=5V) 100ns (f(XIN)=10MHz, VCC=3V, with software one-wait) : Mask ROM, flash memory 5V version
Memory capacity	ROM	(See the figure 1.1.4. ROM Expansion)
	RAM	3K to 20K bytes
I/O port	P0 to P10 (except P85)	8 bits x 10, 7 bits x 1
Input port	P85	1 bit x 1
Multifunction timer	TA0, TA1, TA2, TA3, TA4	16 bits x 5
	TB0, TB1, TB2, TB3, TB4, TB5	16 bits x 6
Serial I/O	UART0, UART1, UART2	(UART or clock synchronous) x 3
	SI/O3, SI/O4	(Clock synchronous) x 2
A-D converter		10 bits x (8 + 2) channels
D-A converter		8 bits x 2
DMAC		2 channels (trigger: 24 sources)
CRC calculation circuit		CRC-CCITT
Watchdog timer		15 bits x 1 (with prescaler)
Interrupt		25 internal and 8 external sources, 4 software sources, 7 levels
Clock generating circuit		2 built-in clock generation circuits (built-in feedback resistor, and external ceramic or quartz oscillator)
Supply voltage		4.2V to 5.5V (f(XIN)=16MHz, without software wait) : Mask ROM, flash memory 5V version 2.7V to 5.5V (f(XIN)=10MHz with software one-wait) : Mask ROM, flash memory 5V version
Power consumption		25.5mW (f(XIN) = 10MHz, VCC=3V with software one-wait)
I/O characteristics	I/O withstand voltage	5V
	Output current	5mA
Memory expansion		Available (to a maximum of 1M bytes)
Device configuration		CMOS high performance silicon gate
Package		100-pin plastic mold QFP

Appendix G: dBm to watts conversion chart

dBm	V	Po	dBm	mV	Po
0	.225	1.0 mW	-49	0.80	
-1	.200	.80 mW	-50	0.71	.01 µW
-2	.180	.64 mW	-51	0.64	
-3	.160	.50 mW	-52	0.57	
-4	.141	.40 mW	-53	0.50	
-5	.125	.32 mW	-54	0.45	
-6	.115	.25 mW	-55	0.40	
-7	.100	.20 mW	-56	0.351	
-8	.090	.16 mW	-57	0.32	
-9	.080	.125 mW	-58	0.286	
-10	.071	.10 mW	-59	0.251	
-11	.064		-60	0.225	.001 µW
-12	.058		-61	0.200	
-13	.050		-62	0.180	
-14	.045		-63	0.160	
-13	.050		-64	0.141	
-16	.0355				
			dBm	µV	
dBm	mV		-65	128	
-17	31.5		-66	115	
-18	28.5		-67	100	
-19	25.1		-68	90	
-20	22.5	.01 mW	-69	80	
-21	20.0		-70	71	.1nW
-22	17.9		-71	65	
-23	15.9		-72	58	
-24	14.1		-73	50	
-25	12.8		-74	45	
-26	11.5		-75	40	
-27	10.0		-76	35	
-28	8.9		-77	32	
-29	8.0		-78	29	
-30	7.1	.001mW	-79	25	
-31	6.25		-80	22.5	.01 nW
-32	5.8		-81	20.0	
-33	5.0		-82	18.0	
-34	4.5		-83	16.0	
-35	4.0		-84	11.1	
-36	3.5		-85	12.9	
-37	3.2		-86	11.5	
-38	2.85		-87	10.0	
-39	2.5		-88	9.0	
-40	2.25	.1µW	-89	8.0	
-41	2.0		-90	7.1	.001 nW
-42	1.8		-91	6.1	
-43	1.6		-92	5.75	
-44	1.4		-93	5.0	
-45	1.25		-94	4.5	
-46	1.18		-95	4.0	
-47	1.00		-96	3.51	
-48	0.90		-97	3.2	

Appendix H: MF-TEN-NINE CABLE