Bus Identification System for the Vision Impaired

A thesis report submitted for the degree of Bachelor of Engineering (Honours).

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" Improving the Quality of Life Through Innovation "

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Dear Professor Kaplan

In accordance with the requirements of the degree of Bachelor of Engineering (Honours), in the division of Electrical Engineering, I present the following thesis entitled "Bus Identification System for the Vision Impaired." This work was performed under the supervision of Mr Richard Cocks.

I declare that the work submitted in this thesis is my own, except as acknowledged in the text and footnotes, and has not been previously submitted for a degree at the University of Queensland or any other institution.

Yours sincerely

Ron Wong

Disclaimer

The information presented in this document has been compiled from a factual perspective. This approach has been taken in order to obtain a realistic engineering analysis of the problem. While the context of discussion may be sensitive, all due care has been taken to ensure that the material presented does not offend the reader or the user demographic in consideration.

Abstract

Many commercial products have been developed which allow those with disabilities to substantially improve their *quality of life*. The use of these devices allows the user to experience the freedom of certain aspects of life such as mobility, communication and other fundamental tasks. Examples of such solutions include cochlear implants, prosthetic limbs and text-to-speech devices. The BEACON follows in this same spirit, by providing visually impaired persons (VIPs) the freedom to independently commute via public bus transportation.

Through the use of BEACON transmitters placed on local buses, VIPs are able to safely catch buses with the aid of a portable handheld device and an audio and tactile interface. The wireless communication system between the transmitter and the portable receiver can be achieved through a number of current technologies. With more exotic approaches like Bluetooth still maturing in terms of financial and performance viability, the cheaper and more ubiquitous approach of radio frequency technology points towards a more feasible solution that can be produced at a reasonable cost for either the direct purchase by VIPs or a government subsidised initiative.

With the aid of the current bus transportation system, the BEACON transmitter is able to filter existing vehicle identification information for retransmission to a nearby VIP. The BEACON receiver is thus able to identify buses and their corresponding routes, and consequently inform the VIP of the bus' imminent arrival.

For the purposes of the BEACON prototype, communication is facilitated through FM transmissions at around 90MHz (within the commercial FM broadcast range). In addition, the solution attempts to resolve the problem through one-way communication from bus transmitter to handheld receiver. This project has the potential for vast improvement by implementing a duplex communication system, whereby the bus driver is able to identify the presence of VIPs and vice versa. In this way, the process of catching a bus can be further streamlined for efficiency, convenience and safety.

Acknowledgements

This thesis project could not have been completed without the support and guidance of a number of people. My sincere thanks go to my supervisor, Richard Cocks, whose patience, advice and genuine enthusiasm for the project made it an invaluable and fulfilling experience. The time, resources and knowledge that you shared went beyond the call of duty and the expectations of a thesis supervisor.

I would also like to acknowledge Paul Higgins from Excel Technologies Group, whose assistance and willingness to provide information was gratefully appreciated.

My thanks are also extended to Len Payne and the thesis students of Axon Room 401, for their advice and assistance, and for creating a such a friendly working environment.

Finally, I would like to acknowledge my friends and family for supporting me through what has been my busiest year of university. Thankyou for understanding the sacrifices that I had to make throughout the year.

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List of Abbreviations

AC	Alternating current
AM	Amplitude modulation
ASCII	American Standard Code for Information Interchange
ASK	Amplitude shift keying
BCC	Brisbane City Council
CRO	Cathode ray oscilloscope
DC	Direct current
ETG	Excel Technologies Group
FM	Frequency modulation
FSK	Frequency shift keying
IC	Integrated circuit
ITS	Intelligent transportation system
LCD	Liquid crystal display
OOK	On-off keying
PC	Personal computer
PCB	Printed circuit board
UQ	University of Queensland
RF	Radio frequency
VIP	Vision impaired person
VIT	Vehicle Identification Tag

CHAPTER 1

Introduction

1

1 Introduction

1.1 Project Motivation

The growing emergence of disability aids has stemmed from an increase in social awareness of human impairment. From high-tech products like cochlear implants to general accessibility alternatives, these solutions have allowed those with disabilities to substantially improve their *quality of life*. This project follows in the same spirit, by providing vision impaired persons (VIPs) the freedom to independently commute via bus transportation.

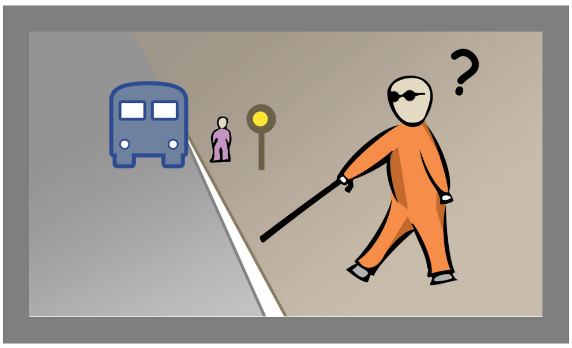
The process of catching a bus involves the combined skills of hearing, sight and cognition. However, if visual cues are removed, the task becomes nearly impossible without the assistance of another person. It can thus be seen that independent commuting is a potentially hazardous proposition for those with vision impairments.

1.2 Project Objectives and Goals

The proposed solution involves the development of a device which allows VIPs to detect the arrival of particular buses. To achieve this, each bus will transmit its route information, while a handheld receiver will be used to notify the VIP through audio and tactile interfaces.

On completion of this project, VIPs will be able to catch public buses with the same ease, convenience and safety of the average commuter. As visual cues no longer constrain the distance required to identify a bus, VIPs will benefit from the additional notification time. Such a system will directly influence the *quality of life* of VIPs, by providing the freedom to travel independently.

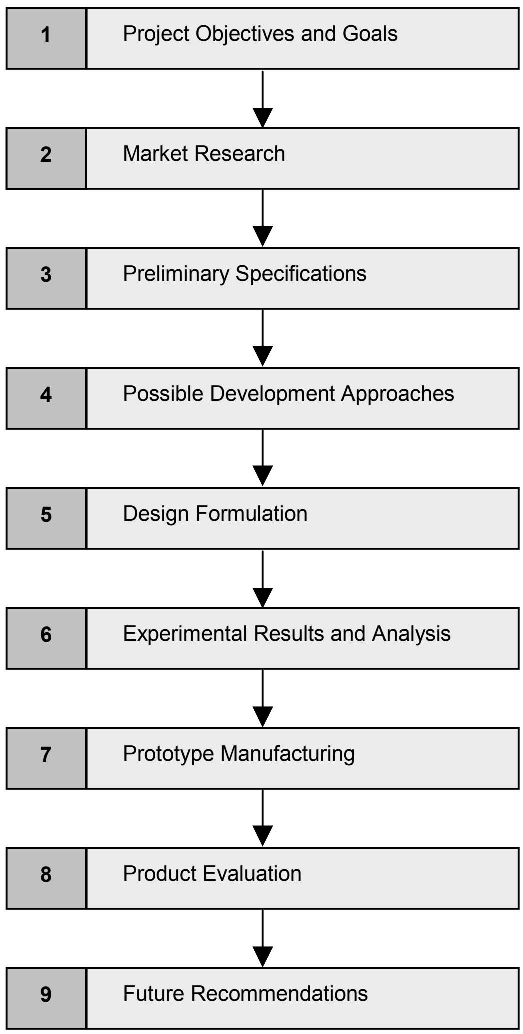
The complete scope of the project includes the tasks of identifying, catching and de-boarding a bus; this thesis will only be involved in facilitating the communication required for bus identification. The interface between the handheld device and the VIP is being considered in a parallel thesis project undertaken by James Cooper.



1.3 Outline of Remaining Chapters

As no previous work has been conducted on this particular project, a complete product development cycle needs to be conceived. However, for the purposes of this thesis, it is only necessary to consider the process required to develop a working prototype. The stages of the development process (illustrated in **Figure 1-1**), directly influence the structure of the remaining chapters.

Figure 1-1: Stages of the Prototype Development Process



The first stage involving the identification of project objectives has already been discussed in this chapter. In order to understand the market needs and expectations of the proposed product, research will be conducted in Chapter 2. Preliminary specifications will be derived in Chapter 3, while Chapters 4 and 5 will focus on generating possible development approaches and formulating a design.

Experimental results will be reported and analysed in Chapter 6. Manufacturing of the prototype will be discussed in Chapter 7, and an evaluation of the produced product will be conducted in Chapter 8. Finally, Chapter 9 will discuss future recommendations for development, with a conclusion of the project completed in Chapter 10.

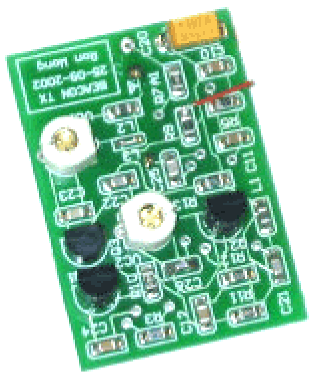
1.4 Overview of Project Outcomes

When the project was initiated, the available platform of knowledge was limited. It was only known that local buses were transmitting a signal containing details about the vehicle and the its corresponding route. The proposed solution thus involved the reception of this signal using a portable handheld receiver carried by a VIP. Upon further investigation, it was discovered that the nature of the bus transmitter generally did not allow the reception of the signal through propagated transmissions.

Although the probability of failure for this approach was high, the development of a solution whereby the existing bus infrastructure was preserved, was such an attractive proposition that the possibility was pursued. A bus transmitter was provided for investigation; however, the device was not allowed to be opened. It was therefore decided that approximately half of the available thesis time would be invested into researching the reception of the bus transmitter.

As a contingency plan, the second half of the available thesis time was reserved for the development of a simple solution that could facilitate communication between the bus and a VIP device. Given the time constraints, it was decided to develop a separate bus transmitter and a VIP receiver using simple FM communication. A solution was reverse-engineered from existing FM transmitter and receiver kits, with the audio I/O replaced with digital I/O. The final prototype was capable of extracting the data from the existing bus identification message, transmitting the information via FM, receiving the FM signal, and finally decoding the data stream into the corresponding bus details. Thus a solid platform was able to be provided for future development of a more robust solution.

Figure 1-2: Photo of the Transmitter Prototype



CHAPTER 2

Market Research

2 Market Research

2.1 Initial Project Influences and Constraints

When the project was first initiated, the following information was known.

- VIPs are directly affected by the problem in consideration.
- The Brisbane City Council (BCC) is responsible for local bus transportation.
- Each BCC bus transmits its bus information.
- The transmitter devices were designed by Excel Technologies Group (ETG).

As the project title suggests, the proposed system is targeted towards those with vision impairments. However, the problem is shared by a larger demographic. In a 1993 national survey, it was estimated that 29% of the Australian population had one or more impairments **[4]**; in comparison, only 3.3% of this population had vision impairments. Other possible beneficiaries includes those with mental disabilities (eg. Down's syndrome), young children, and also those with literary deficiencies.

Although it can be seen that a variety of others share the same problem, the vast differences in functional ability would result in a number of compromises and sacrifices in the final product. The proposed system will thus focus on only meeting the needs of VIPs. In order to reduce the complexity and scope of the project, it was decided to constrain the application of the solution to the local bus transportation system.

2.2 Stakeholders

The stakeholders who have a significant impact on the project design are as follows.

- VIPs – product beneficiaries.
- BCC – local bus transportation service providers.
- ETG – designers of the bus transmitters.
- UQ – research and development team (including thesis students, supervisors and engineering departments).

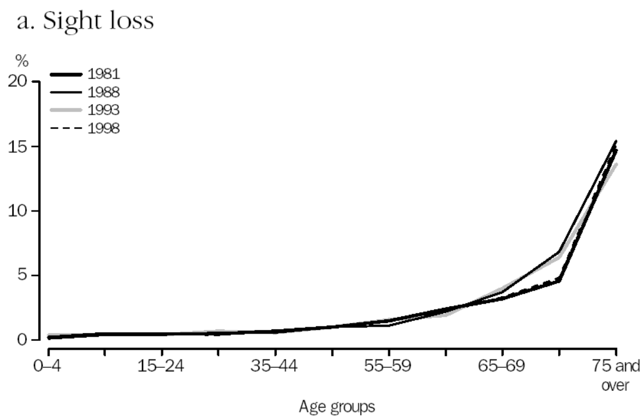
2.2.1 VIP Characteristic Profile

To gain a better understanding of the product's main beneficiary, a profile of VIP characteristics must be developed. These are outlined below.

- Low income – impairment means that it is likely they do not have a high-paying job.
- Has a helper – helpers are commonly used to obtain information and services otherwise inaccessible.
- Sensitive to audible and tactile cues – extremely responsive to senses other than sight.
- Soft target – relatively easy to take advantage of by others.
- Relatively low numbers – proposed changes to the existing bus system would produce minimal inconvenience to other commuters.
- Majority of VIPs are adults – intellectually mature.

In the above profile, it is assumed that the VIPs in consideration do not suffer from any additional impairments or disabilities. It should also be noted that the last profile point (majority of VIPs are adults) was discerned from data collected by the Australian Bureau of Statistics **[9]**, which shows that the deterioration of sight increases exponentially with age. A graph illustrating this point is shown in **Figure 2-1**. It is also important to realise that although the number of VIPs is relatively low in comparison to the general population, there is still a social responsibility to address the problem.

Figure 2-1: Percentage of People Suffering from Loss of Sight With Respect to Age



2.2.2 BCC and Bus Transportation Profile

A profile of the BCC and the bus transportation service they provide is outlined below.

- Provides the public bus transportation infrastructure.
- Responsible for improving public transportation services.
- Services are funded by the local government.
- Buses are currently used in an intelligent transportation system (ITS).
- There are 582 buses in service.
- There are 213 general routes being operated.
- There are 239 school routes being operated.
- There are 6741 council bus stops.
- BCC has a policy of making changes to bus timetables on a quarterly basis, with actual changes varying depending on circumstances.
- VIP bus passes are provided on proof of eligibility. The pass allows free travel for the bearer.
- Since the year 2001 to date, there have been 107 bus passes issued to VIPs.

It should be noted that all statistical data was acquired from the Transport Planning unit of the BCC. All relevant correspondence has been included in **Appendix A**.

2.2.3 ETG and Services Profile

A profile of ETG and the services they provide is outlined below.

- The company is based in Brisbane.
- They develop and manufacture a range of traffic management and public transportation products.
- They developed the vehicle identification transmitters (VITs) used on BCC buses for passenger information and bus priority systems.
- The VITs contain a variety of data including route and service numbers.
- Route numbers are used to uniquely identify bus routes.
- Service numbers contain a flag indicating the inbound or outbound direction of travel.
- The VITs have been designed to transmit the signal via induction. Induction occurs when the bus passes over a receiver embedded beneath the road's surface.
- Road receivers in lanes adjacent to the bus lane are unable to receive the transmitted VIT signal.

Detailed information regarding VITs can be found in the instruction manuals provided by ETG. Specific information regarding the data stored within the VITs is detailed in **Appendix B**.

2.2.4 UQ and Course Profile

A profile of UQ and its engineering thesis course is outlined below.

- The Information Technology and Electrical Engineering department is responsible for organising the thesis project.
- One university year has been allocated to the thesis project.
- Two engineering students (electrical and software) have been assigned the responsibility of prototyping the product this year.
- One thesis supervisor has been allocated to the two engineering students in order to guide research and development.
- The budget available for development is not limited; however, use of the budget must be justified by the student and approved by the supervisor.
- Electrical equipment and engineering laboratories provided on campus are accessible by students once permission is approved by the appropriate person.

2.3 Existing VIP Products and Services

A number of products and services are already available to VIPs that improve their quality of life. In terms of assisting orientation and mobility, canes and guide dogs are the most commonly used aids. Electronic mobility aids are also available for use in conjunction with the canes and guide dogs. The Mowat Sensor and Sonic Pathfinder both give indications of how close the user is to an object through vibrational and audio cues respectively **[11]**. Both devices achieve this through the use of ultrasonic pulses.

There are also a number of products and services available in Queensland that assist VIP commuting. Simple products include a variety of bus and taxi hailing signs that can be purchased through the Queensland Blind Association. In terms of VIP commuting services, concessions on public transportation have previously been available to those who held a Centrelink Concession Card indicating Blind Pension.

As of 1 January 2002, Queensland Transport introduced the National Travel Pass – Person with Vision Impairment **[13]**. The pass entitles the holder to free travel on all participating public transportation services including bus, rail and ferry in Australia (except NSW and TAS). In order to obtain a card, a medical practitioner must certify that the person applying is legally blind. A taxi subsidy scheme has also been developed by Queensland Transport; however, the scheme only provides a limited discount on fares.

2.4 Intelligent Transportation Systems

Cities around the world are adopting ITS networks to control traffic, preserve road safety and monitor vehicle fleets. A report on ITS solutions in Australia **[17]** indicates that these systems form a crucial part of the national transport infrastructure and that society will be dependent upon their existence far into the future. It can thus be seen that the proposed VIP aid has long-term and global potential.

CHAPTER 3

Preliminary Specifications

3

3 Preliminary Specifications

3.1 Technical Requirements

The most important requirement of the system is to notify the VIP when they are at a suitable distance from the arriving bus. Through a conversation with a VIP, it was roughly estimated that a notification distance of at least 50 metres is required. This minimum requirement needs to be achieved, with any improvement on this being a bonus. For the purposes of this prototype, the accuracy of the notification distance is not crucial. A few aspects of the problem scenario are outlined below.

- Minimum notification distance is 50 metres.
- Buses travel at a maximum speed of 60 km/h around built-up areas (bus stops are only located in built-up areas).
- Communication between the bus and VIP device must be wireless (in order to satisfy the requirement of a handheld portable receiver).

The following implications are inherent in a wireless communication environment.

- Signal attenuation, multipathing, and interference are significant in an open environment containing moving vehicles, overhead power lines and mobile phones.
- As the bus and VIP are moving, the Doppler effect may have some significance.
- Information security is pertinent when wireless communications is involved.

If a particular bus transmission is corrupted through wireless signal degradation, another transmission burst needs to be sent as soon as possible. To ensure that the VIP receives the notifications bursts in an appropriate amount of time, the transmissions must occur at relatively quick intervals. **Table 3-1** shows the time required for a bus to travel 50 metres at differing speeds.

Table 3-1: Time Taken for a Bus to Travel 50m at Different Speeds

Speed	Time Taken to Travel 50m
20 km/h	9.0 secs
30 km/h	6.0 secs
40 km/h	4.5 secs
50 km/h	3.6 secs
60 km/h	3.0 secs

If a burst is transmitted at every 5m travelled, then the VIP will still have ample time to react, even if one of the transmissions is corrupted. At the maximum bus speed of 60 km/h, the time taken to travel 50m is 3.0 seconds. With transmissions occurring 10 times within this time period (every 5m), the maximum time spent between bursts is 0.3 seconds. The required burst frequency is therefore 3.333 times a second.

If the VIP is to carry a portable handheld device, then the electronics must be powered from a battery. The design must take this into consideration in terms of voltage and current requirements. The largest battery that can accommodate a small device is a 9V battery.

3.2 Mechanical Requirements

Once again, if the user is required to carry a portable handheld device, the total size of the electronics needs to be as small as possible. The complete hardware must have a maximum dimension of $240cm^3$ (the general size of a Walkman).

In addition, the device will be subject to physical stress by the user. The components and mechanical layout of the electronics therefore needs to be structurally stable. A reasonable measurement of stability is the ability to vigorously shake the VIP device without any functional change.

3.3 Summary of Specifications

The following specifications cover the contextual, technical and mechanical requirements identified.

Table 3-2: Preliminary Prototype Specifications

Preliminary Prototype Specifications
1. The prototype must be integrated within the BCC bus transportation system.
2. Communication between bus and VIP device must be wireless.
3. The VIP must be notified of the bus' arrival at least 50m away.
4. The VIP must receive a response at least 3.333 times a second.
5. The VIP device must be powered by at most a 9V battery.
6. The dimensions of the VIP device must not exceed $240cm^3$.
7. The VIP device must operate correctly after vigorous shaking (low impact stress).

CHAPTER 4

Implementation Options

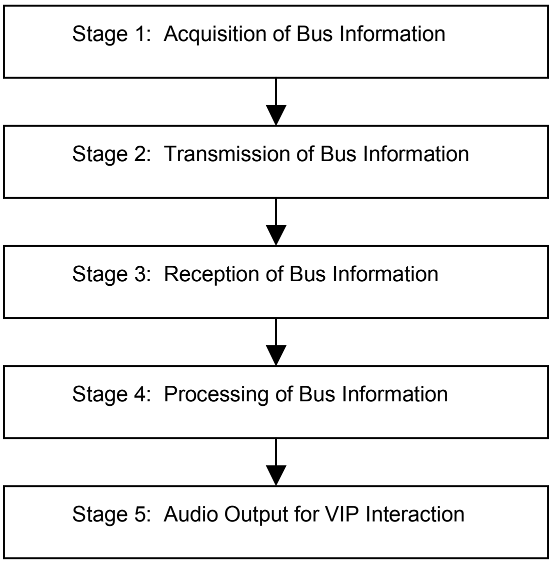
4

4 Implementation Options

4.1 Strategic Options for Communication

In order to solve the problem in consideration, we must start with the user requirement of providing audio notification and then work *backwards* in an attempt to achieve the desired outcome. The five stages of the development process are shown in **Figure 4-1**.

Figure 4-1: Stages of the Actual Development Process



It can be seen that the above situation involves the one-way transmission of data from bus transmitter to VIP receiver. This approach has been guided by the known fact that BCC buses already transmit their details. However, this is not the only approach that can be taken. The three options for communication are detailed below.

4.1.1 Approach 1: VIP Carries a Receiver – Bus Carries a Transmitter

- Advantage: An attractive approach if it is possible to receive the transmitted VIT signal.
- Disadvantage: VIPs will need to locate the bus once it has been identified. This becomes more difficult when there are multiple buses waiting at a common bus stop.

4.1.2 Approach 2: VIP Carries a Transmitter – Bus Carries Receiver

- Advantage: Bus drivers will know if a VIP is in the vicinity and is looking to catch that particular bus. This approach solves the problem with multiple buses, as bus drivers can find a VIP even though a VIP cannot identify a particular bus from a group of possible buses.
- Disadvantage: VIPs have no indication of when and if the bus is arriving.

4.1.3 Approach 3: VIP and Bus Carry a Transceiver

- Advantage: Inherits the advantages and overcomes the disadvantages of the first two approaches.
- Disadvantage: Requires the development of two transceivers. This increases the cost of production and may affect the financial feasibility of the product. It also significantly increases the complexity of the project.

4.1.4 Selection of Communication Approach

It can be seen that the last approach involving a transceiver pair would be the most attractive option in terms of providing the best service to VIPs, whilst solving the "multiple bus" problem. Unfortunately, the development of such a product would require more time than is available for this particular project. The most suitable approach is the first, where the bus has a transmitter and the VIP has a receiver. It provides better service to the VIP than the second approach, as the VIP is given some indication of the arriving bus.

In all communication approaches, it can be seen that either the bus and/or VIP carries a device which acts as a beacon to the other. The system will therefore be called the BEACON system.

Given the choice of communication approach, it can be seen that the development stages in **Figure 4-1** still applies. This structure can now be used to produce different approaches for actual development.

4.2 Strategic Options for Development

The VIT placed on each BCC bus, is updated through a RS-485 communications connection. This is simply a different representation of digital data, where logic-1 and logic-0 bits are represented by differential voltages. The most important aspect of RS-485, is that it is a multi-drop application **[22]**. This means that the information passed to the VIT is able to be intercepted through a tap in the connection.

It can thus be seen that there are two development approaches that can be taken.

1) Use the VIT as a transmitter.
2) Retransmit the bus information using a separate BEACON transmitter.

4.2.1 Approach 1: VIT-Integration

Stage 1: Acquisition of Bus Information

If the signal transmitted by the VIT can be reliably received by a portable device at a distance of around 50 metres, then the acquisition and transmission stages will be satisfied in one fell swoop.

Stage 2: Transmission of Bus Information

As previously mentioned, this particular stage has been covered by the VIT.

Stage 3: Reception of Bus Information

A BEACON receiver needs to be developed which is able to receive the signal that is already being transmitted. Details about the existing transmission scheme is required.

Stage 4: Processing of Bus Information

The received signal needs to be decoded according to the encoding method employed by the existing VIT. The decoded information must then be processed for audio output in the next stage.

Stage 5: Audio Output for VIP Interaction

Once the received signal has been decoded, the data can be used to facilitate the audio interface. This stage forms the scope of a separate thesis project; hence the design will not be considered in this report. To facilitate autonomy between the two theses, a LCD display or PC interface should be used to visually demonstrate the completion of Stage 4.

4.2.2 Approach 2: Retransmission of Information

Stage 1: Acquisition of Bus Information

If the VIT signal cannot be received, the data passed onto the VIT can still be intercepted through a RS-485 tap and processed for retransmission via a separate BEACON transmitter.

Stage 2: Transmission of Bus Information

A BEACON transmitter needs to be developed which is able to send the bus information to a portable handheld receiver.

Stage 3: Reception of Bus Information

A BEACON receiver needs to be designed in tandem with the newly designed transmitter.

Stage 4: Processing of Bus Information

The received signal needs to be processed for audio output in the next stage.

Stage 5: Audio Output for VIP Interaction

As previously mentioned, the design of this stage will be considered in a separate thesis project.

4.2.3 Selection of Development Approach

The VIT-Integration Approach substantially reduces the complexity of the project, as the data acquisition and transmission stages have already been implemented. However, the VIT was specifically designed for signal induction, not propagation. The approach therefore poses a significant development risk as it heavily depends upon untested fringe effects. Nevertheless, the attractiveness of this solution is reason enough for further investigation. Should the VIT-Integration Approach fail, the Retransmission Approach can be pursued as a fallback plan.

4.3 Summary of Implementation Approaches

The general implementation approach that will be taken is as follows.

- Communication is to be achieved through the use of a bus transmitter and a VIP receiver device.
- The VIT-Integration Approach is to be investigated first. If this fails, then the Retransmission Approach is to be pursued.

The revised specifications are shown below, with the new requirement highlighted.

Table 4-1: Revised Prototype Specifications

Preliminary Prototype Specifications	
1.	The prototype must be integrated within the BCC bus transportation system.
2.	Communication between bus and VIP device must be wireless.
3.	**A bus transmitter and VIP receiver must be used to facilitate communication.**
4.	The VIP must be notified of the bus' arrival at least 50m away.
5.	The VIP must receive a response at least 3.333 times a second.
6.	The VIP device must be powered by at most a 9V battery.
7.	The dimensions of the VIP device must not exceed $240cm^3$.
8.	The VIP device must operate correctly after vigorous shaking (low impact stress).

CHAPTER 5

Technical Design

5

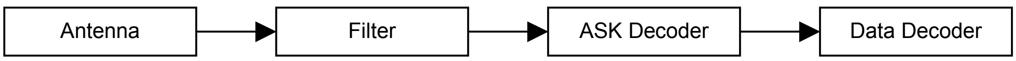
5 Technical Design

5.1 VIT-Integration Approach

An integrated system using bus VITs is a highly desirable solution. As the BEACON receiver would be the only unit requiring development, the solution becomes technically and financially attractive. With the VIT transmitting a 400kHz ASK signal at 4800 baud, the receiver must have the following attributes.

- A suitable antenna to receive the signal.
- A filter to suppress unwanted signals.
- An ASK decoder to convert the analogue data to digital.
- A microcontroller to decode the digital data.

Figure 5-1: Development Blocks for the VIT-Integration Approach



During development, the success of each stage must be verified before the next stage can be investigated. This particular engineering practice ensures that problems can be isolated and investigated without the influence of problems in other stages. The design of each development block (including test procedures) is discussed below.

5.1.1 Stage 1: Antenna Design

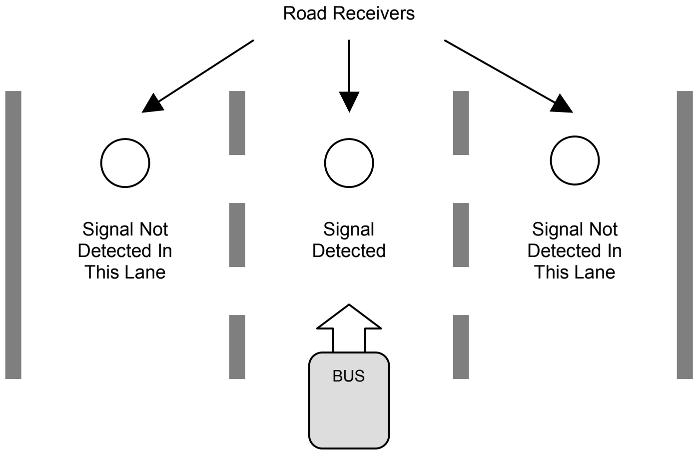
The most critical stage in the VIT-Integration Approach involves the reception of the existing signal. The specifications in Chapter 3 indicated a maximum notification distance of 50 metres.

Assumption: *It is assumed, for now, that the time from signal transmission to VIP notification is minimal. Therefore, the maximum transmission distance is also 50 metres.*

It is known that the VITs have been designed to transmit their signal via induction. In fact, the system has been designed in such a way that the transmitted signal cannot be received by antennas in adjacent road lanes; even with the transmitter placed 20 feet above the road.

It is possible that the VIT is also producing a propagated signal as a fringe effect. Although it is highly unlikely that that the signal can be received 50 metres away, the possibility is certainly worth investigating.

Figure 5-2: Illustration of Existing VIT System

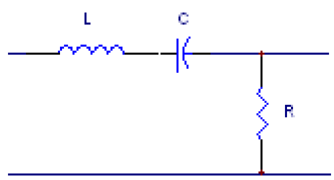


Test Procedure: A loop antenna (eg. diameter of 8 cm, with an unwound length equal to the signal's full wavelength) should be used to test signal reception with a spectrum analyser. If the VIT signal cannot be received by the antenna, then the rest of the design for the VIT-Integration approach can be abandoned.

5.1.2 Stage 2: Filter Design

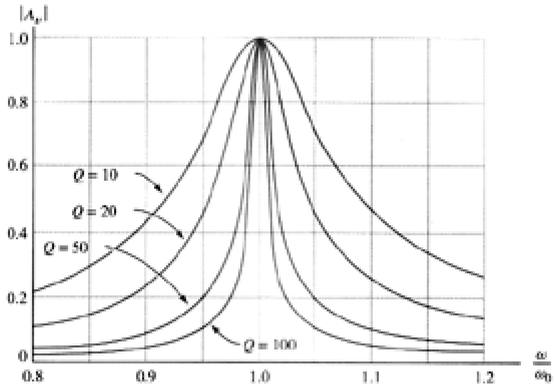
In order to extract the 400kHz signal from the entire collection of received transmissions, a bandpass filter must be constructed. A simple configuration is the series resonant circuit; it reaches its minimum impedance at resonance and can be used to boost the voltage of the 400kHz signal.

Figure 5-3: Series Resonant Circuit



The quality factor (or simply the Q) determines the range and sharpness of the bandpass filter, as seen in **Figure 5-4**.

Figure 5-4: Filter Characteristics with a Varied Q Factor



The values for the resistor (R), inductor (L) and capacitor (C) determine the resonant frequency (f) and the Q of the filter. The calculations are as follows.

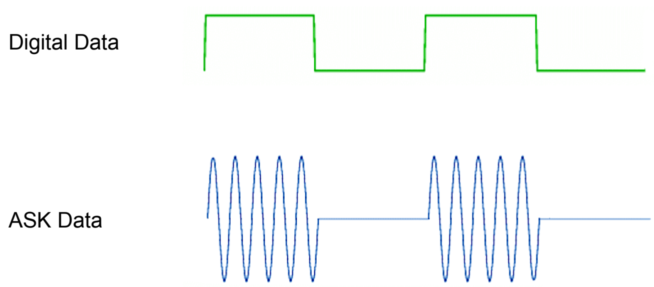
$$f = \frac{1}{2\pi\sqrt{LC}} \qquad Q = \frac{\sqrt{LC}}{RC}$$

<u>Test Procedure</u>: Observe the frequency spectrum of the signal when a series resonant filter is connected to the antenna. If the 400kHz signal is clearly the dominant peak, then the next stage of design can be investigated.

5.1.3 Stage 3: ASK Decoder Design

ASK (amplitude shift keying) is an analogue representation of digital data. The VIT transmitter uses a variation of ASK called on-off keying (OOK). The digital and OOK representations for a square wave is shown in **Figure 5-5**.

Figure 5-5: Binary ASK (OOK) Encoding



ASK decoding can be achieved through the use of a simple diode detector. This configuration works by taking an analogue signal (representing a logic level), clipping the bottom half to generate a DC signal, and then smoothing the transitions with the help of an RC filter. A comparator can then be used to achieve the fixed voltage for the appropriate logic level. **Figure 5-6** illustrates the diode detector configuration.

Figure 5-6: Diode Detector Circuit

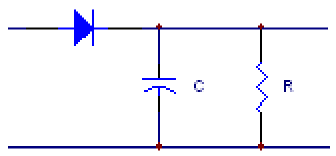
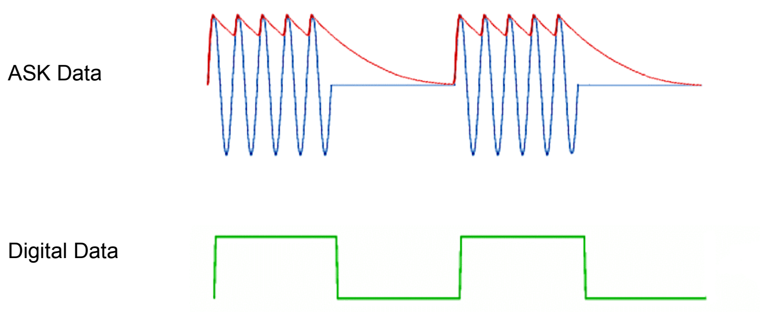


Figure 5-7 shows how ASK data can be converted into digital data. The top outline of the ASK data shows the output of the diode detector. The jagged signal can be passed through a comparator to yield the corresponding digital data.

Figure 5-7: ASK Decoding



Test Procedure: Generate an 400kHz ASK signal by switching a function generator on and off. Construct a diode detector and use a CRO to observe the output signal. If the fixed voltage levels correspond to the input ASK signal, then the final stage of the design can be investigated.

5.1.4 Stage 4: Data Processor Design

The final stage of the VIT-Integration Approach involves the decoding of the digital data. As the bus details are transmitted as 8-bit ASCII characters, a microcontroller needs to be used to convert the incoming bit stream. Once the data is decoded, it can then be used to feed the audio interface. The message format of the transmitted signal can be found in **Appendix B**.

Test Procedure: Use a microcontroller to generate a bit stream representing ASCII characters. Receive the data through an input pin of another microcontroller and decode the received bit stream. If this is successful, then the VIT-Integration Approach can be achieved.

5.2 Retransmission Approach

If any of the stages in the VIT-Integration Approach cannot be achieved, then the entire transmitter-receiver communication link needs to be redesigned. Before the Retransmission Approach can be pursued, further research needs to be completed including the generation of additional specifications and implementation options.

5.2.1 Selection of Communication Technique

The redesign of the communication link presents the opportunity for a number of different approaches. These are outlined below in **Table 5-1**.

Table 5-1: Communication Options for the Retransmission Approach

Communication Technique	Characteristics
Infrared Laser	Signal is too line of sight (LOS)
Radio Frequency (AM)	Reasonable distance and not LOS
Radio Frequency (FM)	Reasonable distance and not LOS
Radio Frequency (Spread Spectrum)	Takes too long to initiate transmission
Microwave	UHF processing is too complicated
Ultrasonic	Signal propagation is too directional
Bluetooth	Too costly

From the above information, it can be seen that the characteristics of FM and AM communication is appropriate for the VIP problem scenario. As wireless communication channels are susceptible to amplitude variations, AM is an inappropriate approach to consider. FM is therefore the preferred communication technique.

5.2.2 Selection of Signal Data Type

The next decision to be made is the type of signal that is to be transmitted.

<u>Audio Data Transmission</u>

- <u>Advantage</u>: If the audio signal becomes distorted, the information may still be understood by the VIP.
- <u>Disadvantage</u>: The audio signal takes too long to transmit. Also the signal can be easily intercepted by anyone listening at that particular frequency.

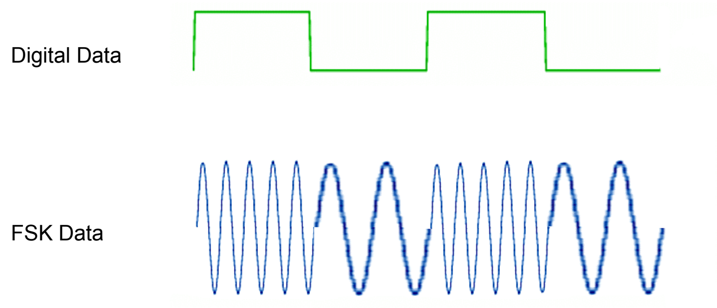
Digital Data Transmission

- Advantage: Digital data is quick and easy to transmit. The generated audio in the receiver will have no distortions.

- Disadvantage: If a digital transmission is distorted, it is most likely unrecoverable. Another transmission is therefore required.

It can be seen that digital data transmission is the more attractive option, as it takes less time to transmit the signal and the generated audio will be perfectly clear. The digital equivalent of FM is frequency shift keying (FSK), where bit levels are represented by two different frequencies. The lower frequency is called the "mark", and the higher frequency is called the "space". This is illustrated in **Figure 5-8**.

Figure 5-8: FSK Encoding

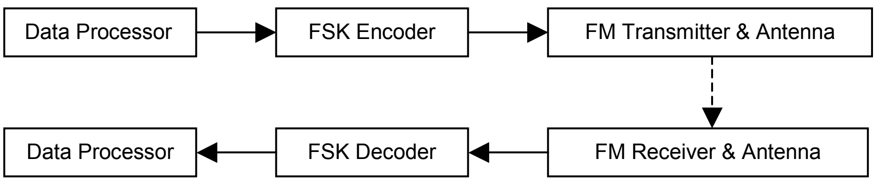


5.2.3 Development Strategy

To achieve FSK communication between the transmitter and receiver, the following development blocks are required.

- A data processor to intercept and filter the existing bus information.
- An FSK encoder to convert the digital data to analogue.
- An FM transmitter used to modulate the signal.
- A suitable antenna used to transmit the signal.
- A suitable antenna used to receive the signal.
- An FM receiver used to demodulate the signal.
- An FSK decoder used to convert the analogue data to digital.
- A data processor to decode and validate the digital data.

Figure 5-9: Development Blocks for the Retransmission Approach



Once again, the success of each stage must be verified before the next stage can be investigated. The design of each development block (including test procedures) is discussed below.

5.2.4 Stage 1: Data Processor Design (Transmitter)

A microcontroller needs to be used to intercept the data being sent to the VIT. It can be seen in **Appendix B**, that there are a total of 19 characters that are stored in the bus VITs. The only information that is required is the route number and the service number, as these two values provide enough information to identify the route that the bus follows and the direction the bus is travelling (inbound/outbound). If one character is included for synchronisation, there are eight characters in total that need to be transmitted.

- 3 char – route number
- 4 char – service number
- 1 char – synchronisation

Given that there are 8 bits per character (64 bits in total), and that each transmission takes 0.3 seconds (as identified in the preliminary specifications), the minimum data baud rate is approximately 215 baud.

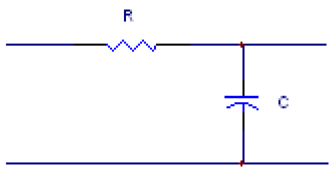
As the electronic bus system is not available to physically intercept the data, the bus identification message can be explicitly stored in a microcontroller (as if it had been acquired).

Test Procedure: Use a microcontroller to hardcode the complete bus identification message. Extract the route and service numbers from the message and convert the data into a single bit stream. As a test, transmit a bit stream representing a square wave; use a CRO to check the output of the microcontroller. If this is successful, then the next stage of design can be investigated.

5.2.5 Stage 2: FSK Encoder Design

In order to convert the digital bit stream into a FSK signal, a microcontroller can be used to generate the two square-wave frequencies. As the near-instantaneous transitions of digital data cannot be correctly represented by a Fourier Series, square-wave frequencies cannot be used for frequency modulation. A simple RC configuration can be used to smooth the transitions into a curved triangle wave.

Figure 5-10: RC Smoothing Circuit

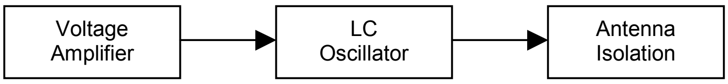


Test Procedure: Use a microcontroller to convert logic levels to square waves of different frequencies. Construct the RC circuit, shown in **Figure 5-10**, and connect it to the output of the microcontroller. If the output resembles a triangle wave, then the next stage of design can be investigated.

5.2.6 Stage 3: FM Transmitter & Antenna Design

There are many FM transmitter configurations which are used in amateur kits. The basic structure of a three stage transmitter involves amplification, modulation and propagation of the signal. All three stages can be achieved with transistors. Amplification is achieved using a voltage amplifier, whilst modulation is achieved by using the output of the amplifier to change the frequency of an LC oscillator. The final stage involves isolating the antenna from the oscillator in order to improve frequency stability.

Figure 5-11: Block Diagram of FM Transmitter



Test Procedure: Reverse engineer an existing audio FM transmitter kit by replacing the microphone input with the FSK encoded data. As the existing transmitter kit will most likely operate in the commercial radio broadcast range, an unoccupied frequency range must be chosen. Construct a loop antenna, with the unwound length equal to the signal's full wavelength, and connect it to the output of the transmitter. Use a commercial radio receiver to receive the transmitted signal; a receiver should not be constructed to test the transmitter as any encountered problems could be attributed to either the transmitter and/or receiver. In this way, the number of unknown variables is reduced and the task of problem solving becomes easier. Check the output of the receiver using a CRO connected to the receiver's earphone jack. If the received signal corresponds to the transmitted signal, then the next stage of design can be investigated.

5.2.7 Stage 4: FM Receiver & Antenna Design

Demodulating FM signals is significantly more complicated than FM modulation, as the process involves recognising the different frequencies in the signal using a phase lock loop configuration. Most FM receiver kits use a single IC chip which achieves the demodulation process; this stage is usually cascaded with an audio amplifier to drive an external speaker.

Test Procedure: Construct a FM receiver kit and test the audio output by tuning into a commercial radio station. Reverse engineer the receiver kit by removing the audio output stage. The same antenna used in the transmitter can be constructed for the receiver. Use the previously constructed BEACON transmitter to test the receiver circuit. Use a CRO to check the output of the BEACON receiver. If the received signal corresponds to the signal being transmitted, then the next stage of design can be investigated.

5.2.8 Stage 5: FSK Decoder Design

Decoding FSK signals also requires the precise recognition of the different frequencies. A single IC chip can be used to perform the FSK decoding stage, with the data baud rate and the mark/space frequencies set by resistor and capacitor values.

Test Procedure: Construct the FSK decoding circuit using an appropriate IC chip. Feed the signal from a function generator into the FSK chip and observe the output on a CRO. If the logic levels in the output correspond to the mark and space frequencies, then the final stage of design can be investigated.

5.2.9 Stage 6: Data Processor Design (Receiver)

A microcontroller needs to be used to receive the bit stream from the FSK decoder stage. The data can then be decoded into the required ASCII characters representing the route and services numbers. As this is the final stage in the Retransmission Approach, a LCD display or PC interface can be used to demonstrate that the entire system operates correctly.

Test Procedure: Use a microcontroller to poll the input pin that receives the FSK decoded bit stream. Convert the bit stream into the corresponding ASCII characters and then output the information to a LCD display or PC interface.

CHAPTER 6

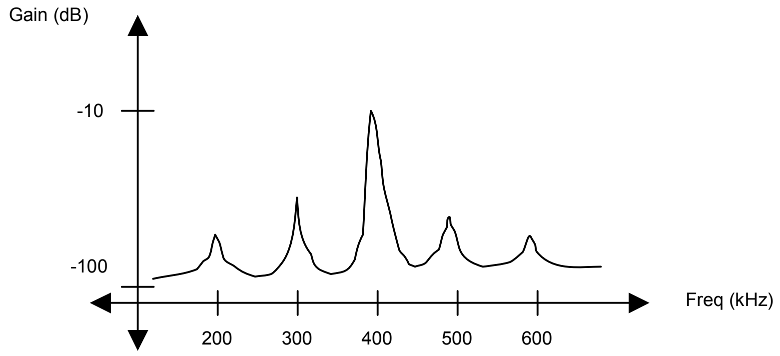
Experimental Results

6 Experimental Results

6.1 VIT-Integration Approach

As the bus VIT was designed for inductive transmissions, the reception of the signal via rogue propagations was the most significant risk in the design. To test reception, a loop antenna was constructed from multicore hookup wire wound in a loop (diameter of 8cm). As the signal frequency is 400 kHz, the unwound length of the wire was cut to 187.5m (¼ wavelength). The two ends were then connected to a spectrum analyser for investigation; the result can be seen in **Figure 6-1**. This frequency response is only an approximation; the measurements from the spectrum analyser could not be electronically captured.

Figure 6-1: Frequency Response of the VIT (loop antenna placed directly over the VIT)



From the frequency response plot, it can be seen that there are harmonics centred around the 400kHz centre frequency. This is due to the fact that the response was measured without any filters; the extraneous peaks can be removed through the use of a bandpass filter.

If the loop antenna was moved 10cm laterally from the face of the VIT, the signal strength of the centre frequency degraded from -10dB to -50dB. After this point, the signal to noise ratio was too small to recognise the peaks. If the antenna was moved perpendicularly, the centre frequency signal was unrecognisable at distances further than 20cm. This shows that the signal was indeed being inducted into the antenna and not received through signal propagations. The loop antennas used in the roads are able to receiver the inductive signal at further distances, because the loop dimensions are around 3 × 2 metres.

Figure 6-2: Perpendicular and Lateral Movement of Antenna with Respect to VIT

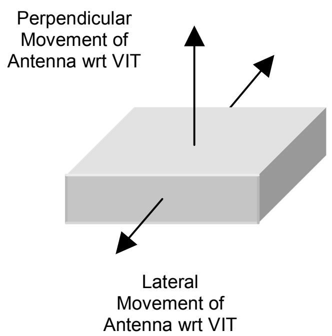
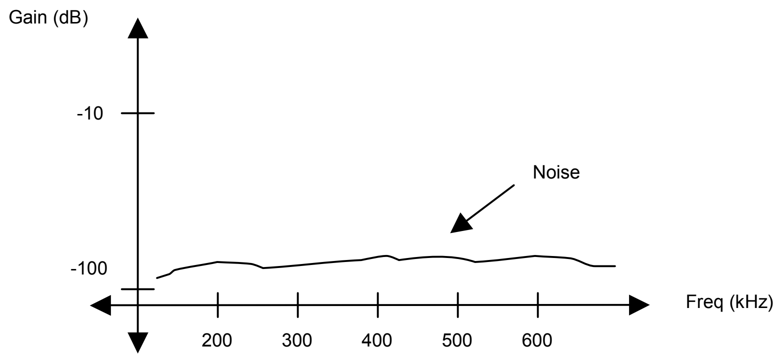


Figure 6-3: Frequency Response of the VIT (loop antenna placed at distances > 20cm)



As the VIT signal could not be received by the antenna at distances further than 20cm, it was concluded that the VIT-Integration Approach was not a feasible solution. Further investigation into this approach was therefore abandoned. In order to achieve the required specifications, investigation of the Retransmission Approach was required.

6.2 Retransmission Approach

6.2.1 Stage 1: Data Processor Design (Transmitter)

As the electronic bus system was not available to perform the actual extraction of the data, the bus identification message was hardcoded into a microcontroller. The AT90S8535 Atmel microcontroller was chosen, because it the Atmel programmer board was available at the time. In addition, the Atmel microcontroller is capable of in-circuit programming.

As it was known that the complete bus message consisted of 19 ASCII characters, a character count was performed, followed by an ASCII character check. It was also known that the service number occupied the character positions 9 to 12. The characters were extracted and tested to see whether they were numeric.

The route number occupied the character positions 16-18; these characters were therefore extracted and tested to see whether they were alphanumeric ASCII characters.

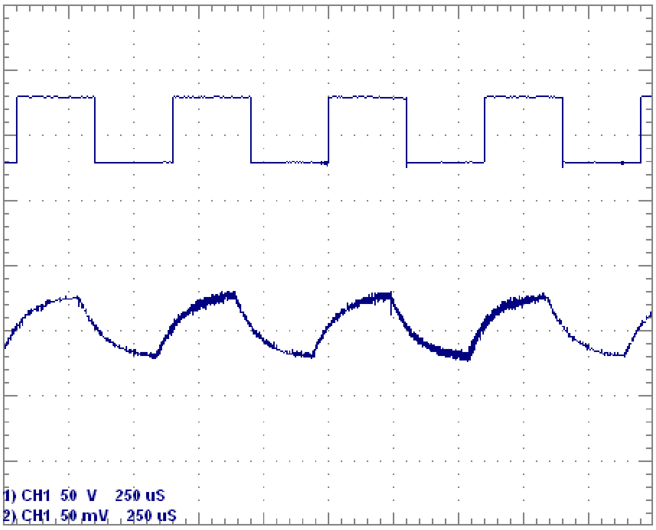
The firmware code for the transmitter microcontroller can be found in **Appendix C**.

6.2.2 Stage 2: FSK Encoder Design

In order to convert the extracted bus information into a bit stream, each byte was picked using an AND operator. To achieve FSK encoding, it was decided that the mark and space frequencies were to be 1.667kHz and 2.333kHz. These values were decided upon by finding an appropriate FSK decoder (the XR2211 FSK decoder) and using the datasheet to find appropriate values with the IC's capability.

Implementing the mark/space frequencies was accomplished by using a COMPARE A interrupt (of higher frequency) and counting the number of interrupts required to achieve the frequencies. When a logic bit was prepared for transmission, the corresponding frequency was sent to an output pin. In this way, the FSK encoding could be achieved with the use of a square wave. The RC circuit specified in Chapter 5 was used to smooth the transitions of the square wave. The values for the R and C were chosen to be 1kΩ and 0.1uF respectively. The square wave and RC wave are shown below in **Figure 6-4**.

Figure 6-4: Generated Square Waveform and the Resulting RC Waveform



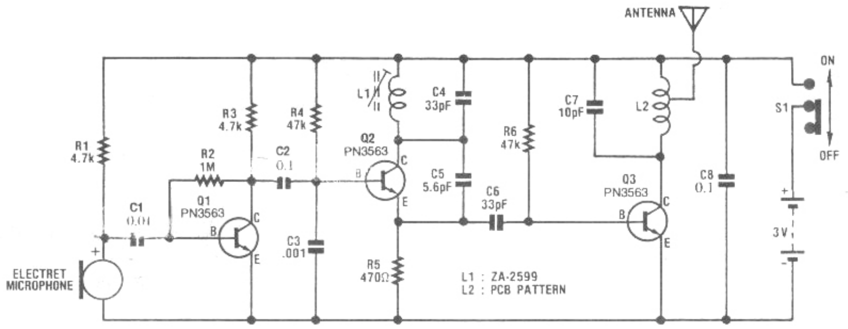
Once again, the firmware code for transmitter microcontroller can be found in **Appendix C**.

6.2.3 Stage 3: FM Transmitter & Antenna Design

Circuit Design

The transmitter design that was used as a basis for the BEACON transmitter is the "FM Wireless Microphone" kit designed by Silicon Chip and stocked by Dick Smith Electronics.

Figure 6-5: Circuit Diagram for the Original FM Transmitter Kit



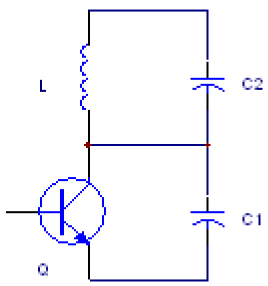
From the above circuit diagram, it can be seen that the input is driven by an electret microphone through the resistor R1. The audio signal is then coupled to a common emitter amplifier through an AC coupling capacitor. The voltage amplifier is self biased through the feedback resistor R2; the purpose of the amplifier is to increase the weak microphone signal (around 50mV to 100mV peak to peak). The second stage is a Colpitts oscillator which produces the sinusoid signal. L1, C4 and C5 are used to generate the carrier frequency, while transistor Q2 is used to modulate the carrier with the audio signal received through the transistor base. The output signal of the modulator is AC coupled to a final transmitter stage which acts as a tuned collector load. The purpose of this stage is to filter the signal for transmission and to isolate the antenna from the oscillator stage. This prevents instability of the modulator.

Testing and Experimental Modifications

The above circuit was assembled and its operation was tested using a Walkman that was previously purchased. In addition, the Walkman was used to locate an unoccupied frequency range. It was found that the 90MHz was an appropriate range for the BEACON transmitter to operate in.

Through rigorous testing, it was found that the transmitter kit was susceptible to frequency drift. The cause of this drift was found to be the variable inductor which consisted of a ferrite core surrounded in a coil. It was therefore decided to replace the variable inductor with a fixed value inductor. The inductor and the two capacitors (C4 and C5) formed part of the Colpitts oscillator. The general configuration is shown below with the corresponding equation for frequency.

Figure 6-6: Colpitts Oscillator



$$f = \frac{1}{2\pi\sqrt{L\left(\frac{C_1 C_2}{C_1 + C_2}\right)}}$$

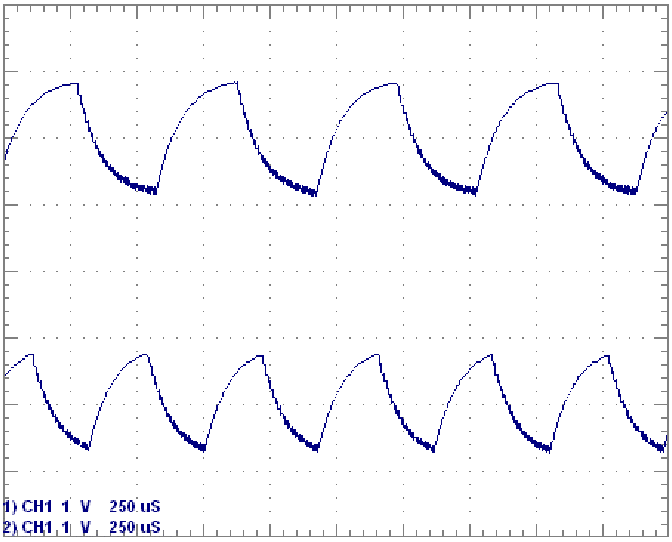
Through experimentation and a required frequency of 90MHz, it was found that the values for L, C_1 and C_2 were chosen to be 0.22μH, 20pF and 47pF respectively. A variable capacitor was placed in parallel with C_1 in order to facilitate frequency tuning.

Based on the knowledge of the circuit, the design was modified to facilitate the FSK signalling. The electret microphone and its resistor (R1) were replaced with the RC waveform output from the microcontroller.

The signal wire antenna provided in the kit caused significant signal fluctuations. A loop antenna (of diameter 8cm) was therefore constructed with an unwound length equal to the full wavelength of a 90MHz signal. Through the simple equation, $\lambda = c/f$, the wavelength is equal to 3.333m. The idea behind the loop antenna is that interference in one part of the antenna is cancelled out interference in another part.

The transmitter was then tested with the FSK signal as an input, the variable inductor replaced, and the loop antenna attached. The audio jack of the radio receiver was connected to a CRO for investigation. The received mark and space signals are shown below. The top waveform represents the 1.666kHz signal, whilst the bottom represents the 2.333kHz signal.

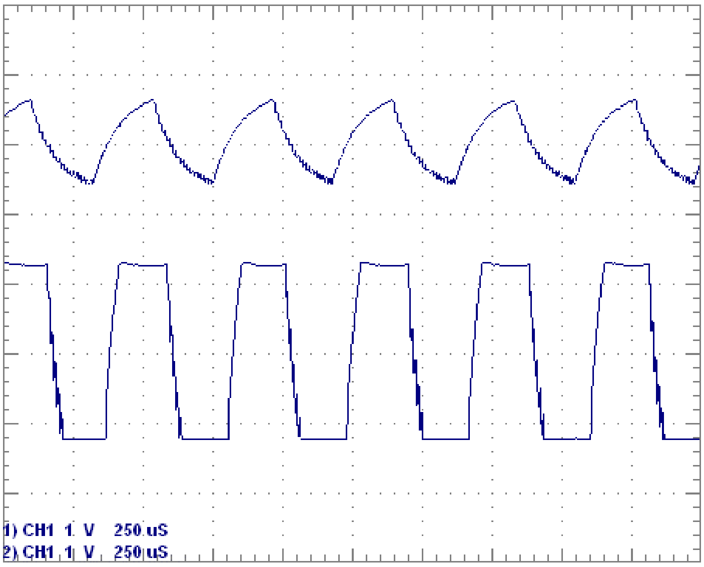
Figure 6-7: Received Waveforms from a Commercial Radio Receiver



It can be seen that the 2.333kHz signal has a smaller amplitude. On further investigation, it can be seen that the RC circuit used to smooth the square wave input is causing this change. As capacitors are essentially frequency-dependent resistors, it can be seen that as the frequency increases, the resistance of the capacitance decreases.

Another important finding, was that when the volume dial on the commercial receiver was moved to the highest level, the signal looked like that which is shown in **Figure 6-8**.

Figure 6-8: Received Waveform from a Commercial Radio Receiver with High Volume



It can be seen that the waveform is being capped at a peak-to-peak amplitude of just under 3V. The signal is therefore being limited to the power of the 3V battery supply used in the commercial radio receiver. This is an interesting finding, as any instabilities in the tips of the received waveform can be removed through capping.

The last test to be performed was the range that the transmissions could be received. As the CRO and power supplies was not able to be moved, testing could only be performed in the confines of the laboratory. The size of the laboratory is around 10m × 15m. It could be found that there was significant interference in specific parts of the lab, as the signal was able to be picked up in places beyond the interference spots. It can thus be seen that the transmitter was capable of transmitting its signal to at least 10m.

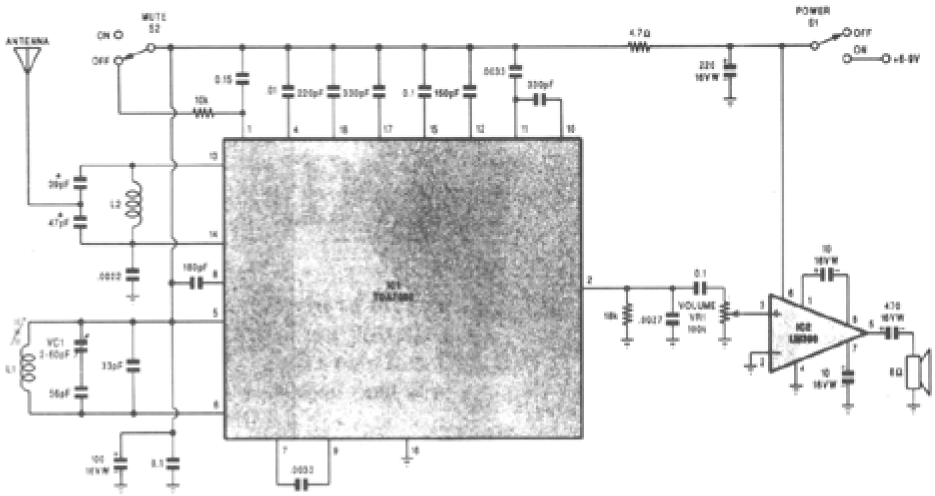
6.2.4 Stage 4: FM Receiver & Antenna Design

Circuit Design

With the transmitter now in operation, a receiver was required to detect the transmitted signal. Once again, a receiver kit was used (designed by Silicon Chip and stocked by Dick Smith Electronics) as the basis for the design. Although, it was already proven that the commercial radio receiver was capable of reliably demodulating the transmission, the construction of a custom-built receiver was still pursued.

The receiver circuit of the FM receiver kit is shown below in **Figure 6-9**.

Figure 6-9: Circuit Diagram for the Original FM Receiver Kit



The circuit is based around two ICs, the TDA7000 which is a FM demodulator, and the LM386 RF audio amplifier. The external components surrounding the TDA7000 are those specified by the datasheets. The output of the demodulator exists at pin 2 of the TDA7000. The RC filter configuration is used to provide the de-emphasis need for audio recovery. The potentiometer is used to control the volume of the audio output for the speaker. The audio amplifier circuit is used to amplify the signal so that the signal can be outputted to the speaker. With the capacitor values shown, the amplification is set to a gain of 200.

Testing and Experimental Modifications

To test the operation of the receiver, the radio broadcast transmissions were used as a signal source. Once this operation was verified, further experimentation was performed.

As the speaker output was not required, the output of the audio amplifier was connected straight to a CRO for investigation. The audio amplifier was retained, as it formed part of the volume control of the receiver. From previous findings, the volume control could be used to cap the peaks of unstable signals. The single wire antenna provided in the kit was replaced with a loop antenna (similar to the transmitter antenna) for improved reception. The output signal received by the circuit design was exactly the same as that received by the commercial radio receiver.

The variable inductor used to tune the frequency of the receiver was exactly the same as the one that was used in the original transmitter circuit. However, in the receiver kit, the inductor was not used in a Colpitts oscillator, but as a resonant LC circuit. The frequency of such a configuration is calculated by the following equation.

$$f = \frac{1}{2\pi\sqrt{LC}}$$

Given the existing capacitor values and a frequency of 90MHz, the fixed inductor value was found to be 0.27μH. The reason for replacing the variable inductor was to reduce the susceptibility of the circuit to frequency drift.

Once the loop antenna was attached, the variable inductor replaced and the external speaker removed, the modified receiver was tested again. After tuning the variable capacitors to match the modified transmitter, the signal was able to be received at a distance of 10m. As before, this distance was limited to the confines of the laboratory.

6.2.5 Stage 5: FSK Decoder Design

Circuit Design

The design of the FSK decoder was taken directly from the datasheet of the XR2211 FSK decoder IC. Through the selection of certain resistor and capacitor values, the chosen baud rate was 1300 baud, with the mark and space frequencies set to 1.667kHz and 2.223kHz. These values are ideal for FSK encoding with the microcontroller as the frequencies are quite low.

Testing and Experimental Modifications

In order to test the FSK decoder, the circuit was breadboarded and a frequency generator was used to feed a sinusoidal input. By varying the frequency of the input, the corresponding FSK decoded output could be seen. The following range of frequencies were shown to represent the required logic levels.

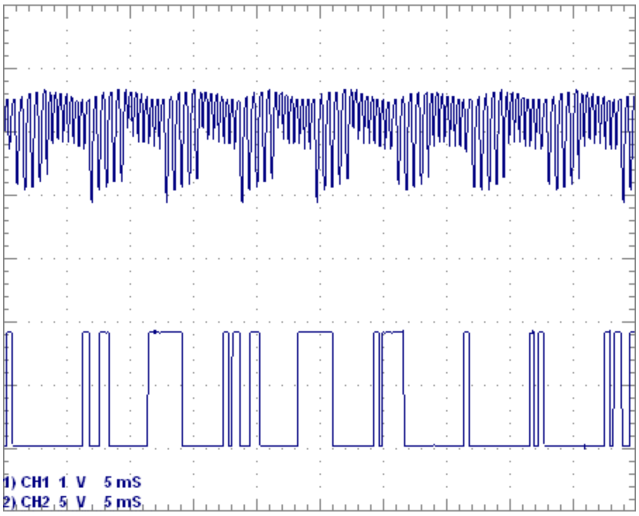
Table 6-1: Mark/Space Frequency Ranges

Logic Representation	Frequency Range
Mark – logic 0	1.3kHz to 1.8kHz
Space – logic 1	2.2kHz to 2.4kHz

It can be seen that the chosen mark/space frequencies (1.667kHz/2.333kHz) are appropriately placed within these frequency regions.

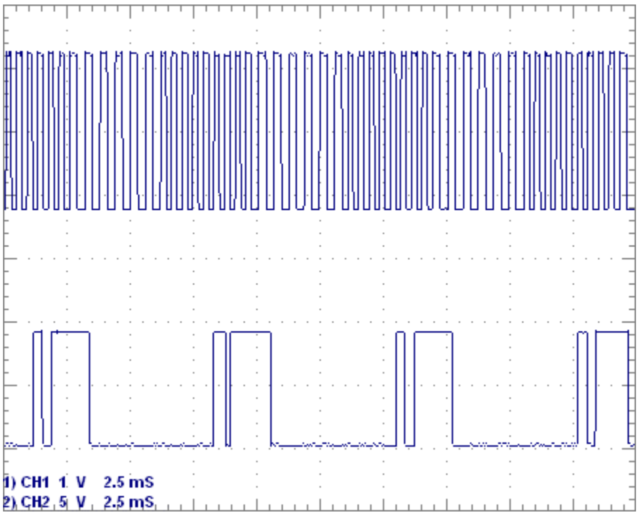
The modified transmitter (with FSK encoded data) could now be used to test the performance of the FSK IC. With the output of the FM receiver connected to the input of the FSK decoder, the output of the FSK decoder could be observed. It was found that the decoded signal was did not represent the transmitted signal. The baud rate of transmission was therefore slowed down from 1300 baud to 285 baud. Figure X shows the inputs and outputs of the FSK decoder at 285 baud. As previously discussed, the higher frequency representing the space frequency has a decreased amplitude due to the nature of the capacitor. From the results, it can be seen that the decoded FSK signal is still quite poor. The expected output is a square wave.

Figure 6-10: Input and Output of the FSK Decoder at 285 Baud.



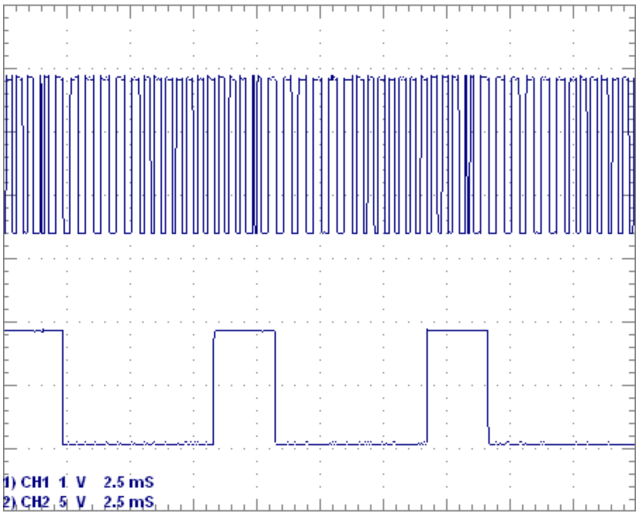
The baud rate was further reduced to 266 baud. In addition, the volume level of the FM receiver was set to the highest level. The resulting input into the FSK IC was therefore a constant amplitude signal. The results are shown in **Figure 6-11**.

Figure 6-11: Input and Output of the FSK Decoder at 266 Baud.



It can be seen that the FSK decoded output is beginning to resemble the expected square wave signal. The baud rate was reduced even further to 210 baud. The results are as shown in **Figure 6-12**.

Figure 6-12: Input and Output of the FSK Decoder at 210 Baud.



It can be seen that the signal clearly represents the expected square wave signal. Surprisingly, the baud rate is over 6 times slower than the anticipated 1300 baud. With a baud rate of 210 baud and a total of 64 transmission bits, the time taken to transmit a message burst is 0.305 seconds. The corresponding notification frequency is thus 3.281 times a second. This is only slightly slower than the required notification frequency of 3.333 times a second. Given the time constraints, an improved baud rate could not be achieved.

6.2.6 Stage 6: Data Processor Design (Receiver)

In order to convert the decoded bit stream into the the correct ASCII characters, a AT90S8535 Atmel microcontroller was used to poll an input pin. Once the synchronisation bits were recognised, each following byte was checked to see if they were valid ASCII characters. Once the route and service numbers were extracted, they were outputted to a PC using an RS-232 serial connection. The data was then transferred to a Hyperterminal window for visually inspection.

The firmware code for receiver microcontroller can be found in **Appendix C**.

CHAPTER 7

Prototype Manufacturing

7 Prototype Manufacturing

7.1 PCB Production Process

In order to improve the aesthetic and professional presentation of the prototype, printed circuit boards (PCBs) were produced. More importantly, the task of converting the experimental hardware to a structurally stable PCB ensured the repeatability and reliability of the final prototype's performance. The final schematic and PCB layouts are shown in **Appendix D**.

The software used to design the PCB was a Windows-based software package called Protel 99 SE. Although Protel provides its own library of components and footprints, the accuracy of these could not be trusted. A strategy for developing a reliable PCB is to gather as much information as possible and to personally certify each stage of the process before continuing onto the next. By transferring all information and knowledge to a controlled domain and by taking ownership of each stage in the design process, the quality of the PCB can be guaranteed.

Based on these engineered principles, a PCB production process was identified.

7.2 Schematic Design

The processes involved in the design of the schematic are as follows.

1. Collecting Data
2. Creating the Schematic in Protel
3. Checking the Schematic

A checklist of specific tasks for each process is outlined in **Appendix E-1**.

7.3 PCB Design

Once the schematic has been created and checked, the PCB layout can be designed. The processes involved in the design of the PCB are as follows.

1. Creating the PCB Layout in Protel
2. Checking the PCB Layout

A checklist of specific tasks for each process is outlined in **Appendix E-2**.

7.4 PCB Component Population

Once the ordered components and the manufactured PCB have been collected from the university, population of the PCB can be performed. A checklist of specific tasks for the PCB population process is outlined in **Appendix E-3**.

CHAPTER 8

Evaluation of Project Outcomes

8

8 Evaluation of Project Outcomes

8.1 Results of Prototype Performance

Table 8-1 compares the performance of the experimental and final prototype against the preliminary product specifications identified in Chapter 3. Compliance of each specification was measured using the test procedures outlined in Chapter 5.

Table 8-1: Comparison of Prototype Performance Against Preliminary Specifications

Product Specifications	Experimental Prototype	Final Prototype
1. The prototype must be integrated within the BCC bus transportation system.	? Existing bus information was able to be used. Physical integration with existing bus system was not tested.	? Existing bus information was able to be used. Physical integration with existing bus system was not tested.
2. Communication between bus and VIP device must be wireless.	✓ Communication is facilitated with a wireless FM link.	✓ Communication is facilitated with a wireless FM link.
3. A bus transmitter and VIP receiver must be used to facilitate communication.	✓ An FM transmitter and receiver is used to facilitate communication.	✓ An FM transmitter and receiver is used to facilitate communication.
4. The VIP must be notified of the bus' arrival at least 50m away.	? A response distance of 10m was achieved. Performance at further distances was not tested.	? A response distance of 10m was achieved. Performance at further distances was not tested.
5. The VIP must receive a response at least 3.333 times a second.	✓ A response frequency of 3.281 was only achieved (just under, but within reason).	✓ A response frequency of 3.281 was only achieved (just under, but within reason).
6. The VIP device must be powered by at most a 9V battery.	✓ The BEACON receiver is powered by a 9V battery.	✓ The BEACON receiver is powered by a 9V battery.
7. The dimensions of the VIP device must not exceed $240cm^3$.	× The dimensions are $562cm^3$.	✓ The dimensions are $72cm^3$.
8. The BEACON receiver must operate correctly after vigorous shaking (low impact physical stress).	× Frequency tuning is required after vigorous shaking.	✓ Correct operation is preserved after vigorous shaking

Legend:
✓ = compliance with specifications
× = non-compliance with specifications
? = specification was not tested for compliance

8.2 Evaluation of Prototype Performance

From the above comparisons, it can be seen that the final prototype achieves five of the eight product requirements. The requirement of wireless communication was able to be met through the use of FM transmissions. In terms of satisfying characteristics of the VIP device, the BEACON receiver was able to be powered from a 9V battery, was tolerant to low impact physical stress, and had physical dimensions that were 3.333 times smaller than that of a typical Walkman. The repeatability, reliability and physical size of the final prototype was significantly better than that of the experimental prototype.

The first specification that was not tested, was the integration of the prototype within the existing bus transportation system. As access to the electronic bus system was not available at the time, the information that would have been extracted was hardcoded into the system. The second untested specification was the 50m notification distance. As the available test equipment was only accessible within the laboratory, field tests could not be performed. Nevertheless, the prototype was able to achieve notification at all positions within the laboratory (an maximum distance of approximately 10m). As these specification results are untested, compliance cannot be verified until further testing can be conducted.

The only product specification that could not be precisely achieved, was the response frequency (3.333 times a second). A response was able to be received, but it was slightly under at 3.281 times a second. This is well within reason, as notifications would occur every 5.083m instead of the specified 5.000m (a 1.6% difference). Given the time restrictions on development, further investigation into improving the notification frequency was abandoned in favour of completing other aspects of the prototype.

8.3 Suitability of Prototype as a Real-World Application

The design of the transmitter-receiver circuit was influenced by the time required to create a functional solution. As a result, the developed prototype is not suitable as a real-world solution; the reasons are outlined below.

8.3.1 Need For Manual Frequency Tuning

The transmitter-receiver designs are based upon tuneable FM configurations that operate within the commercial radio broadcast band. For the problem in consideration, it is only necessary to communicate at one specific frequency.

By eliminating the need for manual frequency tuning, the devices will become less susceptible to frequency drift and maintenance of the devices will become minimal. The developed prototype could have been designed for communication at a specific frequency; however, it is too difficult to choose precise inductor and capacitor values.

8.3.2 Susceptibility to Frequency Drift

The transistor-based design of the transmitter is susceptible to frequency drift. This is partly due to the fact that transistor characteristics vary dramatically with a change in temperature. This becomes a significant issue, as the transmitters are to be placed in buses that are exposed to the sun.

Although the tolerant temperature of the PN3563 transistor ranges from -55°C to 150°C, the DC current gain does not remain constant. A slight change in the current gain can easily shift the frequency of the transmitted signal; thus, the inherent design of the transmitter is a poor choice as a real-word solution.

CHAPTER 9

Future Recommendations

9

9 Future Recommendations

The experimental findings have clearly shown that the prototype has achieved most of the preliminary product specifications. However, there are many opportunities for improvement and areas that would benefit from redesign. In addition, certain issues have not been considered in this project and thus require further investigation and research.

9.1 Opportunities for Further Development

9.1.1 Further Investigation into the Notification Distance

The approximated distance required for notification was specified at 50m. However, the research conducted to yield this number simply involved a brief conversation with a VIP. It is clear that a more comprehensive research and analysis is required in order to gain a more accurate estimate of the time and/or distance requirements of a VIP.

In addition, further field studies are required to observe the actual performance of the system at distances greater than that which was tested (up to 10m).

Recommendations: Conduct further research into the notification requirements of VIPs, and measure the actual response distance of the system through field studies.

9.1.2 Improvement on the Data Transmission/Reception Rate

The maximum rate at which data can transferred is dependent upon the limitations of the transmitter and receiver. By increasing the data rate (and the notification frequency), the effect of corrupted transmission bursts will be minimised.

Recommendation: Improve the current data rate, and hence the notification frequency, of the communication system.

9.1.3 Extraction of Data from the Existing Bus System

The data extraction stage (which precedes the retransmission stage) was not developed, as access to the electronic bus system was not available at the time of development. It is already known that the multi-drop nature of the RS-485 provides a potential solution for data extraction. However, if this fails, the signal can still be acquired through the construction of a small receiver placed adjacent to the VIT.

Recommendation: Use the existing electronic bus system to perform the data extraction stage required for retransmission.

9.1.4 Elimination of Manual Tuning

By eliminating the need to manually tune the transmission and reception frequencies, the BEACON system will be able to operate with improved repeatability. This means that periodic device maintenance and calibration will be significantly reduced, resulting in a cheaper and more convenient product.

Recommendation: Develop a system where the transmitter and receiver use a fixed frequency for communication.

9.1.5 Reduction of Frequency Drift

Compensation or tolerance to temperature fluctuations need to be addressed in order to reduce the susceptibility of the BEACON system to frequency drifting. By achieving this, the repeatability and reliability of the system can be significantly improved.

Recommendation: Design the transmitter and receiver using components that have a consistent response with variations in temperature.

9.1.6 Development of a Transceiver Pair

In order to provide the best service to VIPs, a duplex communication system must be developed through the use of a transceiver pair (ie. both the bus and VIP carry transceiver devices). By achieving this, the process of hailing a bus is made easier, as the bus driver will be aware of VIPs looking to catch that particular bus. This also solves the problem of VIPs being unable to identify a particular bus from a group of possible buses.

Recommendation: Design a transceiver which can be used as a bus BEACON and a VIP BEACON.

9.2 Issues That Were Not Considered

9.2.1 Minimisation of Power Consumption in the Receiver

Due to time constraints, the battery voltage specification was chosen as the only power requirement to ensure the portability of the BEACON receiver. In order to calculate the battery life for the BEACON receiver, the current consumption of the device needs to be identified and optimised.

Recommendation: Optimise the power consumption of the BEACON receiver to achieve a reasonable battery life for the device.

9.2.2 Investigation into the Doppler Effect

As both the bus and the VIP are moving in the context of operation, the communication system may be affected by the Doppler effect. This means that the actual frequency detected by the receiver may be different to the expected communication frequency. This issue needs to be investigated, as it affects the ability to sustain communication between the buses and the VIPs.

Recommendation: Investigate and justify the significance of the Doppler effect with results obtained from field studies.

9.2.3 Investigation into Sources of Communication Interference

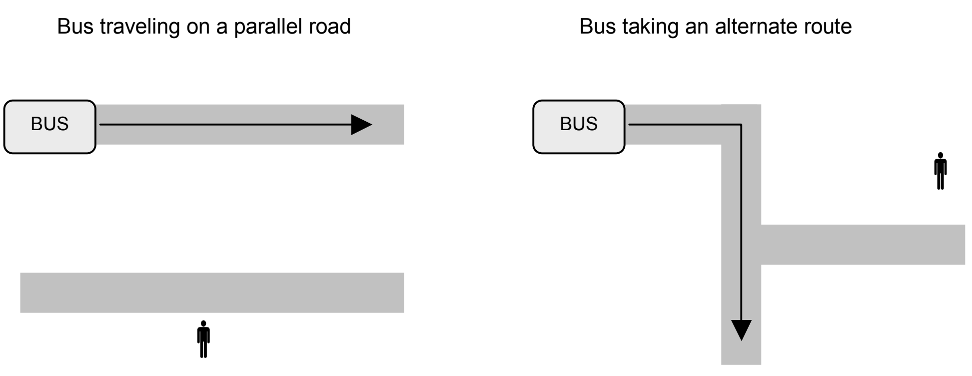
The communication link may be susceptible to a variety of interference sources, such as mobile phones, overhead powerlines and the existing VIT. To ensure that the system can tolerate a real-world environment, these effects need to be investigated.

Recommendation: Investigate the presence of communication interference and make design decisions based on their relevance.

9.2.4 Resolution of the "False Notification" Problem

The "False Notification" problem involves different scenarios where the bus signal may be received by the VIP, but the bus may not actually travel along the road where the VIP is waiting. **Figure 9-1** shows two examples that illustrates this point.

Figure 9-1: Illustration of the "False Notification" Problem



Recommendation: This problem needs to be resolved through the inherent system design.

CHAPTER 10

Discussion and Conclusion

10

10 Discussion and Conclusion

The objective of the project was to provide vision impaired persons with the ability to safely and conveniently catch public buses. Through the use of transmitter and receiver devices, communication between the buses and VIPs could be established.

Upon reflection of the prototype's developmental outcomes, it can be seen that the project has made significant progress in terms of understanding and profiling the situation and the needs of VIPs. The resulting prototype was able to successfully demonstrate the concept of bus identification via a one-way communication link between a BEACON transmitter and BEACON receiver.

Although it was found that the prototype's inherent design was not suitable as a final solution to the problem, the two approaches investigated yielded valuable information. The VIT-Integration and Retransmission Approaches were identified as the two most attractive approaches in terms of financial feasibility and technical complexity. The work completed in this engineering project is therefore relevant and supports further work on the entire project.

Through an analysis of the experimental results, it can be seen that the prototype has many opportunities for improvement. These include the elimination of manual frequency tuning, the reduction of frequency drift, and an improvement on the data transmission rate. Recommendations for further development are centred around the prototyping of a duplex communication link involving a transceiver pair.

By understanding the value of the conducted research and development, the prototype can be carried into the next stage of product development. Further approaches therefore need to be investigated and evaluated against the needs and expectations of VIPs. If development of these prototypes leads to the launch of a commercial product, then this thesis project would have contributed to the original goal of improving the *quality of life* of those with vision impairments.

APPENDICES

Appendix A: BCC Email Enquiries

From: BCC Internet Enquiries
Sent: Tuesday, March 19, 2002 11:30 AM
Subject: Re: VIPs using Brisbane Buses

Dear James,

Thank you for submitting your enquiry to the Brisbane City Council.

To be eligible for a Blind Pass, the Vision Impaired Person (VIP) is required to apply in person at any Brisbane City Council Customer Service Centre and :

hold a Pensioner Concession Card (PCC) stating 'Blind' and ;
be a resident of a Brisbane City Council administered area

The photographic pass once issued entitles the bearer plus a guide (either a person or a dog) to free travel on all Brisbane City Council buses and ferries, except for special tour buses or ferries.

I investigated your enquiry regarding how many "blind" passes have been issued by the Brisbane City Council, and discovered that in the years 2001/2002 to date, our Customer Service Centres have issued some 107 passes to our Brisbane VIP''s.

I hope and trust that this information has been of some assistance toy ou.

If you have any further Brisbane City Council enquiries, please complete the Contact Us page available from the home page at www.brisbane.qld.gov.au or phone our 24 hour Contact Centre on (07) 3403 8888.

Yours faithfully,

Tim
Customer Contact Centre
Reference: CCC27

Date: Tue, 06 Aug 2002 16:40:32 +1000
From: "BCC Internet Enquiries" <ENQUIRIES@brisbane.qld.gov.au>
Subject: Re: Bus Transportation Enquiries

Dear Mr Wong,

Thank you for submitting your enquiry to the Brisbane City Council.

Brisbane Transport has 582 peak buses in service on a weekday. We operate 213 general routes and 239 school routes. Unfortunately, we do not keep statistics on how often timetables on any given route are changed. However, our policy is to make changes on a quarterly basis, with anywhere from a few up to a quarter of the general routes being affected, depending on the scale and nature of the changes.

If you have any further Brisbane City Council enquiries, please complete the Contact Us page available from the home page at www.brisbane.qld.gov.au or phone our 24 hour Call Centre on (07) 3403 8888.

Yours faithfully,

Brian Bothwell
Brisbane City Council
Reference: NPMT

Date: Wed, 02 Oct 2002 17:54:28 +1000

From: "Tom Savage" <STPT@brisbane.qld.gov.au>
Subject: Re: Bus Transportation Enquiries

Ron

Some answers for you:

Council has 6741 bus stops.

The nomenclature is a mix of
a) non numbered CBD/Valley and Regional Centre/ Bus Interchange Lexan Stops
b) numbered route stops - yellow board or blue J pole
c) named express and Great Circle Line route stops - white J pole

a) The CBD and Regional Centre/ Bus Interchange stops are referred to within Council as Lexan Stops. The term "Lexan" comes from the name of the polycarbonate exterior to these double sided rectangular information signs.

In the CBD/Valley the lexans do not have a route based stop number. They have a sequential number (1 to 230) for customer information purposes.

b) the bulk of the Council bus stops are based on the traditional tram stop numbers. The logic is that they nominally start in the CBD as "stop 1" then increase in number as the route proceeds outbound. Given that Lexans have replaced the old CBD stops 1 to about 5 the first numbered stop is often stop number 6 radiating out on each corridor from the CBD. The number keeps getting larger the further you go from the CBD ending either at the route terminus or at an interchange such as Toombul.

This means that stop 10 will occur in a 360 degree radius around Brisbane. There will be a bus stop 10 outbound and a stop 10 inbound on the other side of the road. Where a stop has been removed (say stop 9) the number will appear as 8/10. Where two routes coincide or cross over in the suburbs both sets of route numbers will be shown eg 26/38.

In the case of routes further out past (and feeding into) the interchange such as Toombul, the number sequence is typically reset to 1 and then increases again to the end of the feeder route.

c) In the early 1980's Council introduced a new route structure called Cityxpress and then added the Great Circle Line. Under this marketing concept selected bus stops and shelters were painted white and named for the first time. The naming policy was the locality name or a major cross street for easy recognition. The spacing of these stops was originally similar to rail stations (over 1km apart) but additional stops have been added over time.

While retaining traditional stop numbers has its merit, Council is seeking a unique number for its stops. This unique numbering system may be added to the existing traditional number or name so that customers can use it when accessing timetable information via the web or telephone.

We are working with Queensland Transport and other service providers in SEQ under a Translink banner to co-ordinate service delivery and marketing efforts. The stop numbering issue will be considered as part of this development so that there is one numbering system in use. This will enable Council and other PT service providers to provide easier access to timetabled and real time information specific to individual bus stops in SEQ.

Happy to discuss if you need more info.

Good luck with your thesis.

Tom Savage
Senior Program Officer
Urban Transport
ph 3403 4394

Date: Thu, 03 Oct 2002 09:42:01 +1000
From: "Tom Savage" <STPT@brisbane.qld.gov.au>
Subject: Re: Bus Transportation Enquiries

Ron

The service number has a flag of inbound or outbound. However, a number of services are through running eg inbound to the City then outbound to the terminus.

I think you should contact our Electronic Ticketing gurus as the data gets tricky.

Please email or contact Richard Eichhorn at BTFMS5@brisbane.qld.gov.au or 3407 2209.

Tom

Appendix B: VIT Message Format

VEHICLE IDENTIFICATION TAG MESSAGE FORMAT 'B' (42H)

The message data format is an (8 bit) character based format:-

1	2-3	4-7	8	9-12	13-15	16-18	19
B	Owner	Bus Number	,	Service Number	Start Time	Route Number	Priority

B is the first character transmitted, to uniquely identify the message format. 'B' is equivalent to 42H.

Owner is the two character vehicle owner code, where:-

- LB Local Government - Brisbane
- QT Queensland Department of Transport
- EI Excel Infotech Pty Ltd
- BT Brisbane Transport
- FB Fire Brigade
- AM Ambulance
- ZZ Test

Bus Number is a unique four digit number to identify a bus. Range 0000-9999.

to separate the fixed and variable parts of the message

Service Number is a four digit number that describes the physical bus route. Range 0000-9999

Start Time is the scheduled start time of the service. Range 00:00-23:59 which is coded as: A0 - X59

Route Number is the route number of the bus (3 characters)

Priority is the priority level of the bus. Range 0-9.

0 - No Priority (On time - any number of passengers)

1 - >10% Passengers + Behind schedule
2 - >25%
3 - >45%
4 - >65%

5 - >10% Passengers + Ahead of schedule
6 - >25%
7 - >45%
8 - >65%

9 - Reserved special application (as yet undefined)

Appendix C: Microcontroller Firmware

C-1 Transmitter Firmware

```
/*********************************************
Project : BEACON Transmitter
Version :
Date    : 23/08/2002
Author  : Ron Wong
Company : -
Comments:


Chip type           : AT90S8515
Clock frequency     : 4.000000 MHz
Memory model        : Small
Internal SRAM size  : 512
External SRAM size  : 0
Data Stack size     : 128
*********************************************/

#include <90s8515.h>
#include <stdio.h>                          // Standard C input/output functions
#include <stdio.h>                          // Standard C input/output functions
#include <stdlib.h>                         // Standard library functions
#include <ctype.h>                          // Character type functions
#include <string.h>                         // String functions


// Global constants
#define bit7 0x80
#define true 1
#define false 0


int transferFlag = 0;
char byteBuffer = 0x00;
char pickedBit = bit7;
int bitCounter = 0;
char message[] = "BBT1234,5678H104570";     // bus message received from system
int messageAuthentic = 0;                   // indicates whether the bus message is correct
char routeNumber[] = "000";                 // route number of the bus
char serviceNumber[] = "0000";              // service number of the bus
char syncPattern = 0xAA;                    // synchronisation pattern for transmissions


// Iterations
char timerHigh = 0x00;
char timerLow = 0x0F;                       // timer set at 16.667 kHz


// Define transmission characteristics
int MSIterations = 0;
int markIterations = 10;
int spaceIterations = 7;
int baudIterations = 140;


int MSCounter = 0;
int baudCounter = 0;
int bitValue = 0;


// ***********************************************************************************
// Timer 1 output compare A interrupt service routine
// ***********************************************************************************

interrupt [TIM1_COMPA] void timer1_compa_isr(void)
{
   baudCounter++;
   if (baudCounter == baudIterations) {
                 baudCounter = 0;
                 bitValue = (byteBuffer & pickedBit);
```

```
                if (bitValue == 0) {
                        MSIterations = markIterations;
                } else {
                        MSIterations = spaceIterations;
                }
                pickedBit >>= 1;
                bitCounter++;
   }

   MSCounter++;
   if (MSCounter == MSIterations) {
                MSCounter = 0;
                PORTB.1 ^= 1;
   }

   if (bitCounter >= 8) {
                transferFlag = 0;
   }
}

// ***************************************************************************************
// Initialisation Code
// ***************************************************************************************

void initialisation(void)
{
    // Input/Output Ports initialization
    // Port A
    PORTA=0x00;
    DDRA=0x00;

    // Port B
    PORTB=0xFF;
    DDRB=0xFF;

    // Port C
    PORTC=0x00;
    DDRC=0x00;

    // Port D
    PORTD=0x00;
    DDRD=0x00;

    // Timer/Counter 0 initialization
    // Clock source: System Clock
    // Clock value: Timer 0 Stopped
    // Mode: Output Compare
    // OC0 output: Disconnected
    TCCR0=0x00;
    TCNT0=0x00;

    // Timer/Counter 1 initialization
    // Clock source: System Clock
    // Clock value: 500.000 kHz
    // Mode: Output Compare
    // OC1A output: Discon.
    // OC1B output: Discon.
    // Timer/Counter 1 is cleared on compare match
    // Noise Canceler: Off
    // Input Capture on Falling Edge
    TCCR1A=0x00;
    TCCR1B=0x0A; // (0000 0010) - CK/8
    TCNT1H=0x00;
    TCNT1L=0x00;
    OCR1AH=0x00;
    OCR1AL=0x00;
    OCR1BH=0x00;
    OCR1BL=0x00;

                // UART initialization
        // Communication Parameters: 8 Data, 1 Stop, No Parity
        // UART Receiver: Off
        // UART Transmitter: On
        // UART Baud rate: 9600
        UCR=0x08;
        UBRR=0x19;

    // External Interrupt(s) initialization
    // INT0: On
    // INT0 Mode: Falling Edge
    // INT1: Off
    GIMSK=0x40;
    MCUCR=0x02;
    GIFR=0x40;
```

```
    // Timer(s)/Counter(s) Interrupt(s) initialization
    TIMSK=0x40;              // was 0x40 for compare a

    ACSR=0x80;  // switches off the analogue comparator for power saving

    // Global enable interrupts
    #asm("sei")              // enable global interrupts

   OCR1AH=timerHigh;
   OCR1AL=timerLow;

}


// ************************************************************************************
// Extracts and verifies the data within the VIT message string
// ************************************************************************************
void extractData(void)
{
   // checks to see if the message length is correct
   if (strlen(message) == completeMsgLength) {

                // extract "route number"
                if (isprint(message[15]) && isprint(message[16]) && isprint(message[17]))
{
                              routeNumber[0] = message[15];
                              routeNumber[1] = message[16];
                              routeNumber[2] = message[17];
                              // extract "service number"
                              if (isdigit(message[8]) && isdigit(message[9]) &&
isdigit(message[10]) && isdigit(message[11])) {
                                            serviceNumber[0] = message[8];
                                            serviceNumber[1] = message[9];
                                            serviceNumber[2] = message[10];
                                            serviceNumber[3] = message[11];
                                            // indicates that the message is authentic
                                            messageAuthentic = 1;
                              }
                }
   }
}


// ************************************************************************************
// Transfers one byte (or character)
// ************************************************************************************

void transferByte(char localBuffer)
{
   if (transferFlag == 0) {
                byteBuffer = localBuffer;
                pickedBit = bit7;
                bitCounter = 0;
                transferFlag = 1;
   }
}



// ************************************************************************************
// Main code that is run
// ************************************************************************************

void main(void)
{
   initialisation();
   extractData();
   if (messageAuthentic == 1) {
        while (true) {
                transferByte(syncPattern);
                transferByte(routeNumber[0]);
                transferByte(routeNumber[1]);
                transferByte(routeNumber[2]);
                transferByte(serviceNumber[0]);
                transferByte(serviceNumber[1]);
                transferByte(serviceNumber[2]);
                transferByte(serviceNumber[3]);
        }
                }
}
```

C-2 Receiver Firmware

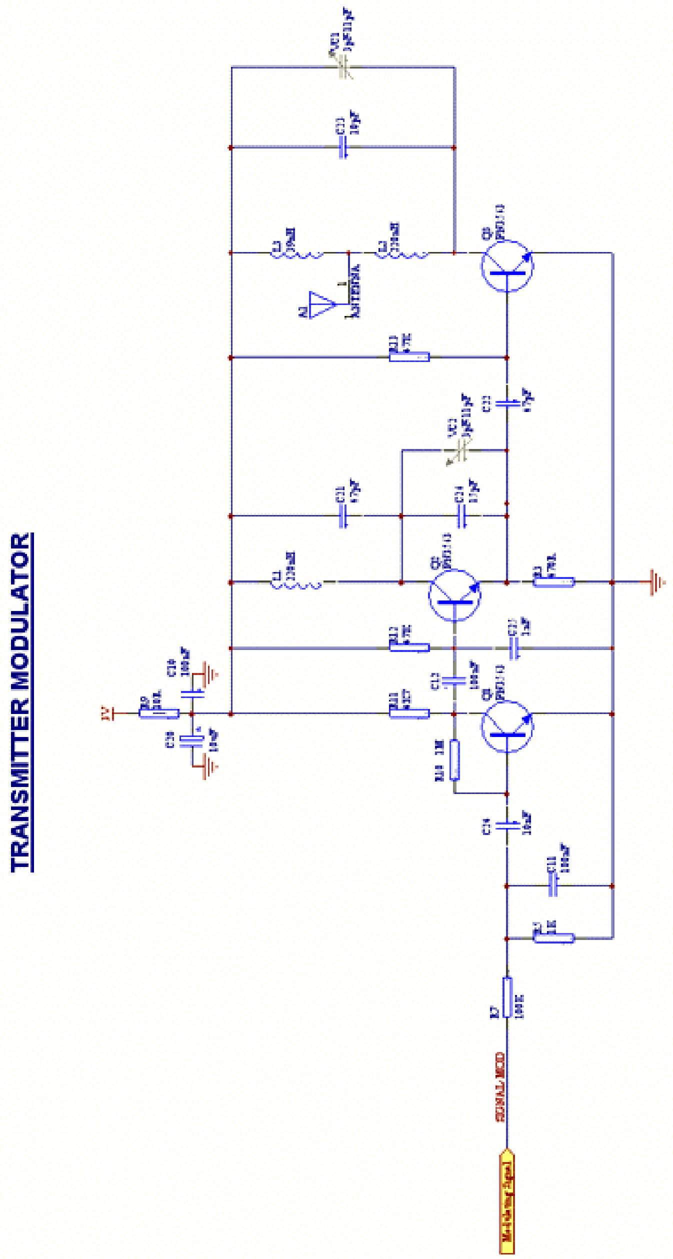
```
/*********************************************
Project : BEACON Receiver
Version :
Date    : 23/08/2002
Author  : Ron Wong
Company : -
Comments:


Chip type           : AT90S8515
Clock frequency     : 4.000000 MHz
Memory model        : Small
Internal SRAM size  : 512
External SRAM size  : 0
Data Stack size     : 128
*********************************************/

#include <90s8515.h>
#include <stdio.h>                       // Standard C input/output functions
#include <stdio.h>                       // Standard C input/output functions
#include <stdlib.h>                      // Standard library functions
#include <ctype.h>                       // Character type functions
#include <string.h>                      // String functions


// Global constants
#define bit7 0x80
#define true 1
#define false 0


char byteBuffer = 0x00;
int syncDetected = 0;
char routeNumber[] = "000";              // route number of the bus
char serviceNumber[] = "0000";           // service number of the bus
char syncPattern = 0xAA;                 // synchronisation pattern for transmissions


// Iterations
char timerHigh = 0x00;
char timerLow = 0x0F;                    // timer set at 16.667 kHz
int baudIterations = 140;
int baudCounter = 0;
int bitValue = 0;
int bitCounter = 0;
int byteCounter = 0;


// ******************************************************************************************
// Timer 1 output compare A interrupt service routine
// ******************************************************************************************

interrupt [TIM1_COMPA] void timer1_compa_isr(void)
{
              baudCounter++;
              if (baudCounter == baudIterations) {
                            baudCounter = 0;
                            byteBuffer >>= 1;
                            if (PORTB.1 == 1);
                            byteBuffer = (byteBuffer & bit7);
                            if (syncDetected == 1) {
                                          bitCounter++;
                                          if (bitCounter == 8) {
                                                        byteCounter++;
                                                        if (byteCounter == 1) {
                                                                      routeNumber[0] == byteBuffer;
                                                                      if (isprint(byteBuffer))
{ printf("%X", byteBuffer);}
                                                        } else if (byteCounter == 2) {
                                                                      routeNumber[1] == byteBuffer;
                                                                      if (isprint(byteBuffer))
{ printf("%X", byteBuffer);}
                                                        } else if (byteCounter == 3) {
                                                                      routeNumber[2] == byteBuffer;
                                                                      if (isprint(byteBuffer))
{ printf("%X", byteBuffer);}
                                                        } else if (byteCounter == 4) {
                                                                      serviceNumber[0] == byteBuffer;
                                                                      if (isdigit(byteBuffer))
{ printf("%X", byteBuffer);}
                                                        } else if (byteCounter == 5) {
                                                                      serviceNumber[1] == byteBuffer;
```

```
                                                            if (isdigit(byteBuffer))
{ printf("%X", byteBuffer);}
                                                } else if (byteCounter == 6) {
                                                            serviceNumber[2] == byteBuffer;
                                                            if (isdigit(byteBuffer))
{ printf("%X", byteBuffer);}
                                                } else if (byteCounter == 7) {
                                                            serviceNumber[3] == byteBuffer;
                                                            if (isdigit(byteBuffer))
{ printf("%X", byteBuffer);}
                                                }
                                                bitCounter = 0;
                                                if (byteCounter == 7) {
                                                            byteCounter = 0;
                                                            syncDetected = 0;
                                                }
                                    }
                        } else {
                        if (byteBuffer == syncPattern) {
                                    syncDetected = 1;
                                    bitCounter = 0;
                                    byteCounter = 0;
                        }
                        }

                        bitValue = (byteBuffer & pickedBit);
                        if (bitValue == 0) {
                                    MSIterations = markIterations;
                        } else {
                                    MSIterations = spaceIterations;
                        }
                        pickedBit >>= 1;
                        bitCounter++;
            }


            if (bitCounter >= 8) {
                        transferFlag = 0;
            }
}

// ******************************************************************************************
// Initialisation Code
// ******************************************************************************************


void initialisation(void)
{
    // Input/Output Ports initialization
    // Port A
    PORTA=0x00;
    DDRA=0x00;

    // Port B
    PORTB=0x00;
    DDRB=0xFF;

    // Port C
    PORTC=0x00;
    DDRC=0x00;

    // Port D
    PORTD=0x00;
    DDRD=0x00;

    // Timer/Counter 0 initialization
    // Clock source: System Clock
    // Clock value: Timer 0 Stopped
    // Mode: Output Compare
    // OC0 output: Disconnected
    TCCR0=0x00;
    TCNT0=0x00;

    // Timer/Counter 1 initialization
    // Clock source: System Clock
    // Clock value: 500.000 kHz
    // Mode: Output Compare
    // OC1A output: Discon.
    // OC1B output: Discon.
    // Timer/Counter 1 is cleared on compare match
    // Noise Canceler: Off
    // Input Capture on Falling Edge
    TCCR1A=0x00;
    TCCR1B=0x0A;           // (0000 0010) - CK/8
    TCNT1H=0x00;
```

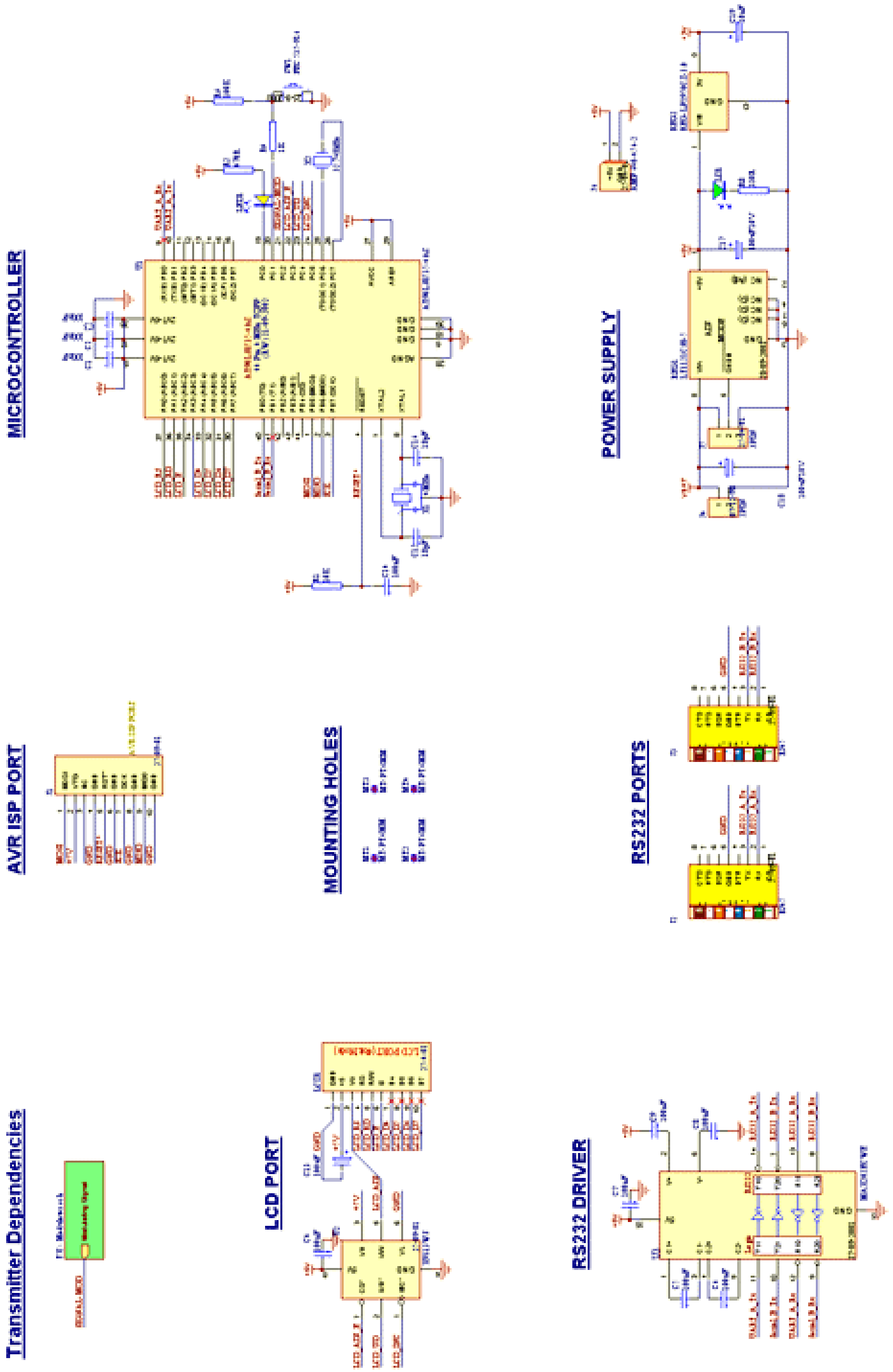
```
    TCNT1L=0x00;
    OCR1AH=0x00;
    OCR1AL=0x00;
    OCR1BH=0x00;
    OCR1BL=0x00;

              // UART initialization
        // Communication Parameters: 8 Data, 1 Stop, No Parity
        // UART Receiver: Off
        // UART Transmitter: On
        // UART Baud rate: 9600
        UCR=0x08;
        UBRR=0x19;

    // External Interrupt(s) initialization
    // INT0: On
    // INT0 Mode: Falling Edge
    // INT1: Off
    GIMSK=0x40;
    MCUCR=0x02;
    GIFR=0x40;

    // Timer(s)/Counter(s) Interrupt(s) initialization
    TIMSK=0x40;                          // was 0x40 for compare a

    ACSR=0x80;             // switches off the analogue comparator for power saving

    // Global enable interrupts
    #asm("sei")                          // enable global interrupts

              OCR1AH=timerHigh;
              OCR1AL=timerLow;

}


// ************************************************************************************
// Main code that is run
// ****************************************************************************************

void main(void)
{
              initialisation();
    while (true) {
              }
}
```

Appendix D: Schematics & PCBs

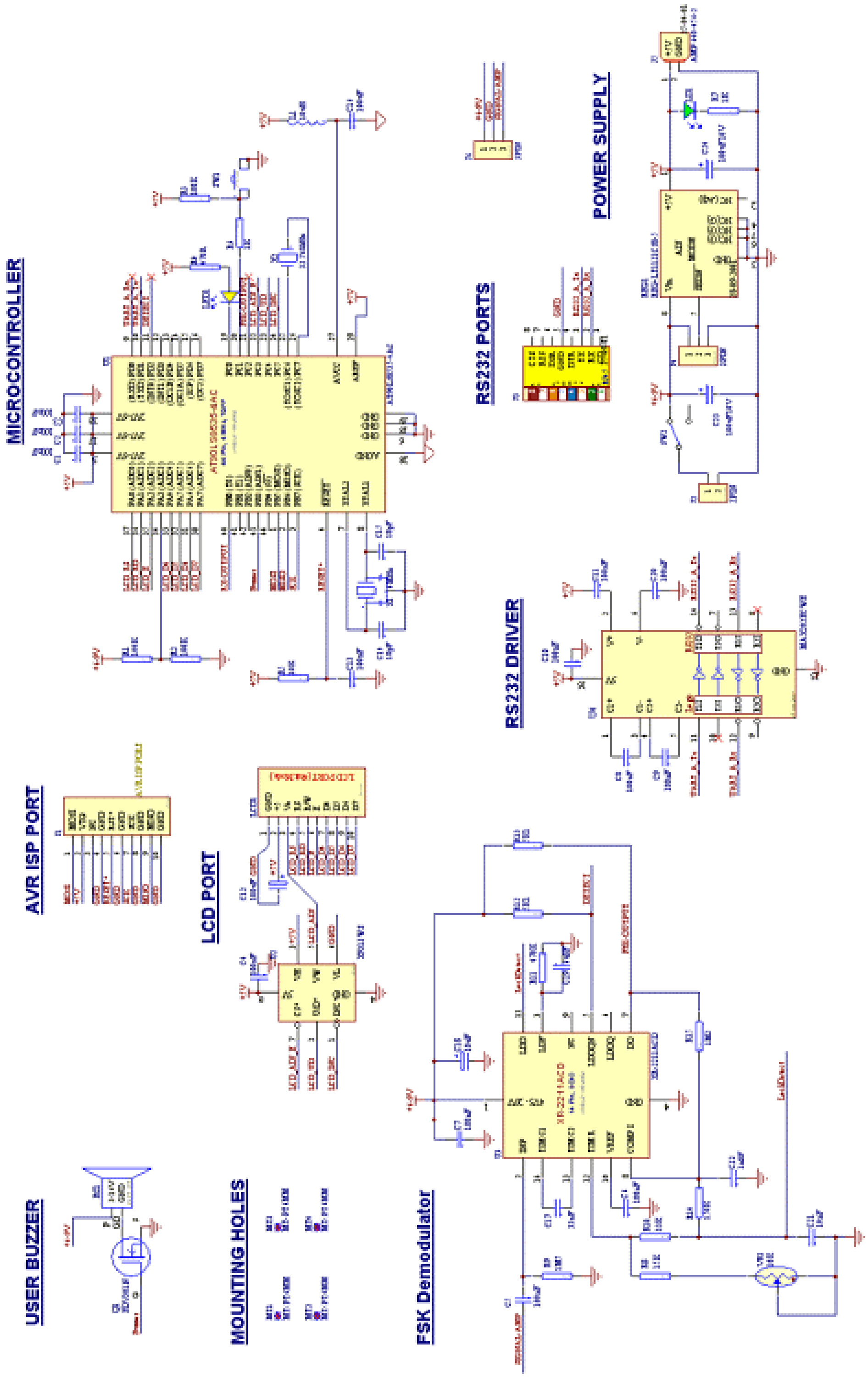
D-1 Schematic Design – Transmitter Modulator



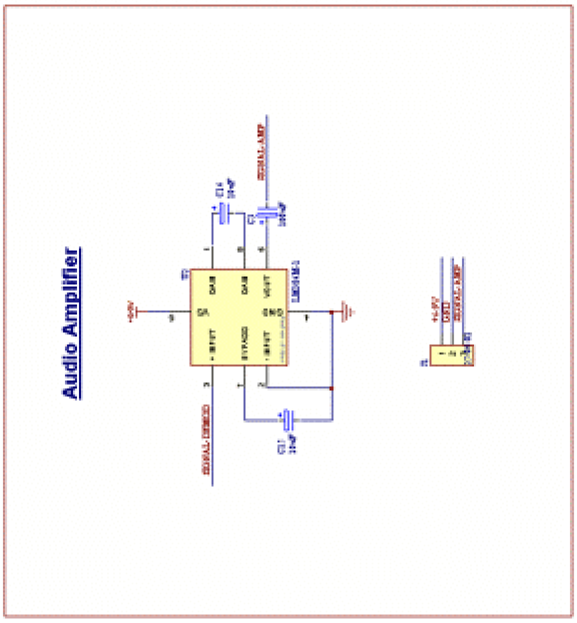
D-2 Schematic Design – Transmitter Microcontroller

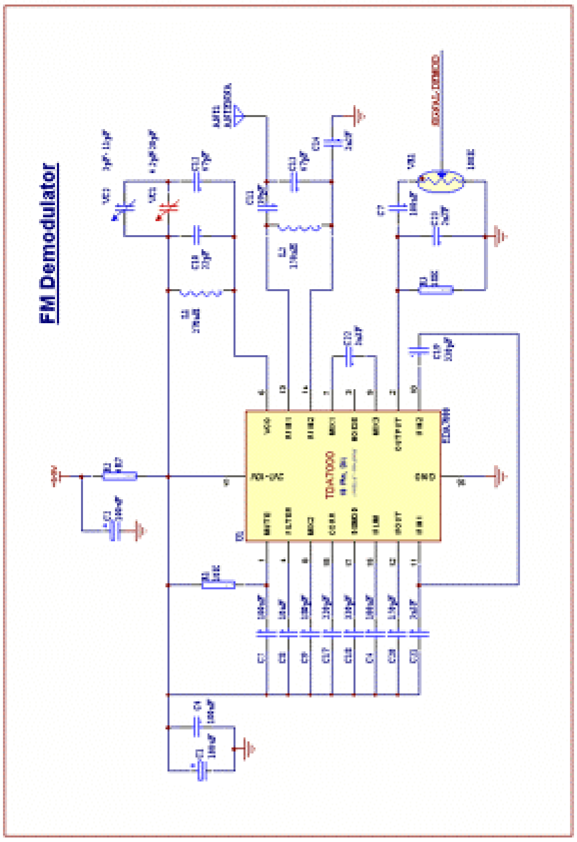


D-3 Schematic Design – Receiver Microcontroller & FSK

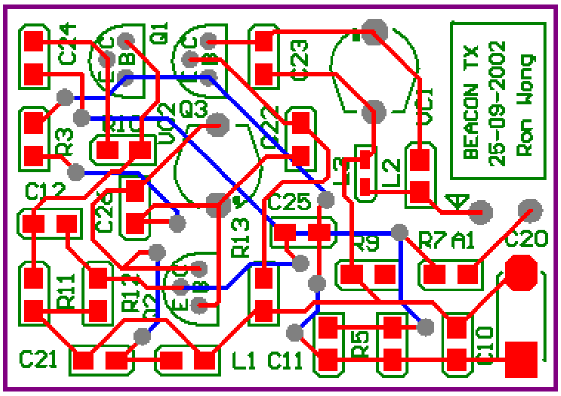


D-4 Schematic Design – Receiver Demodulator

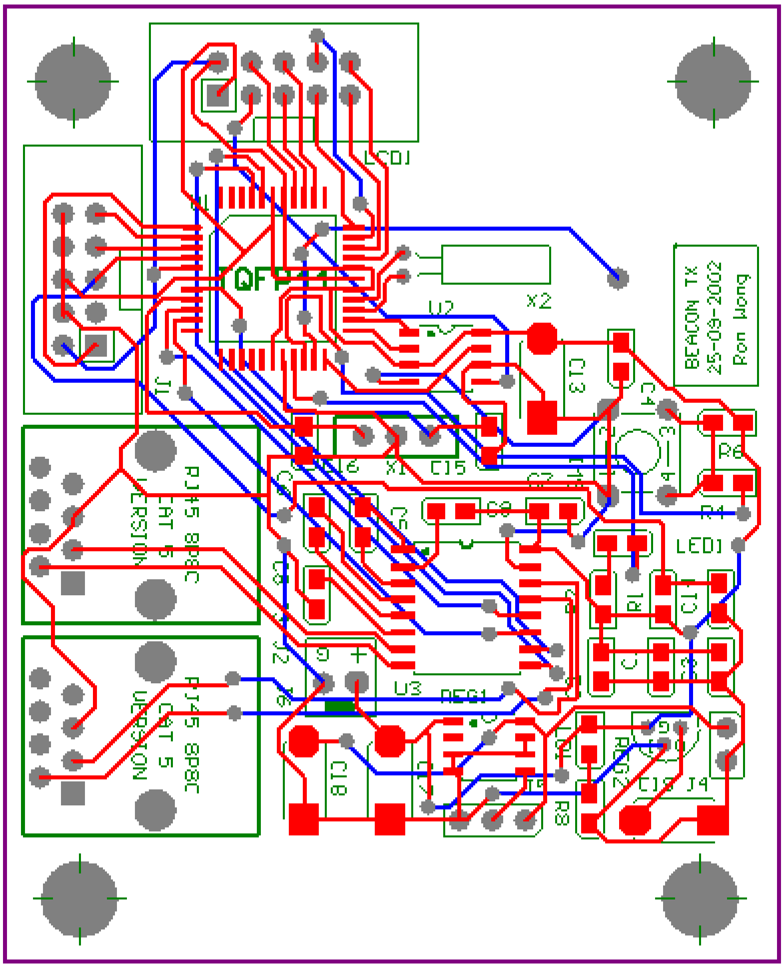




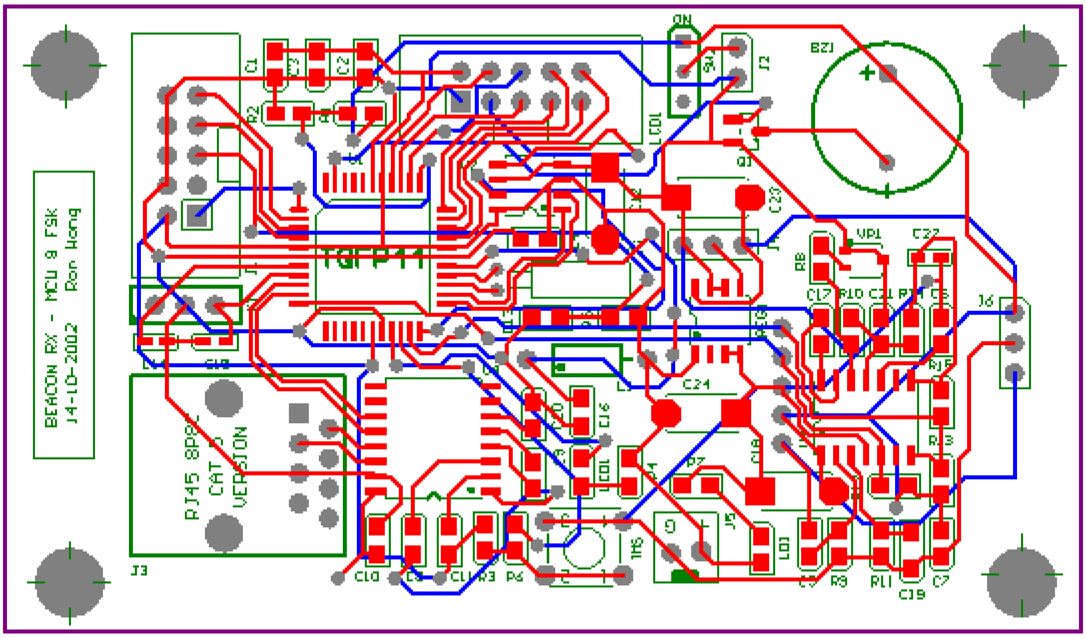
D-5 PCB Design – Transmitter Modulator



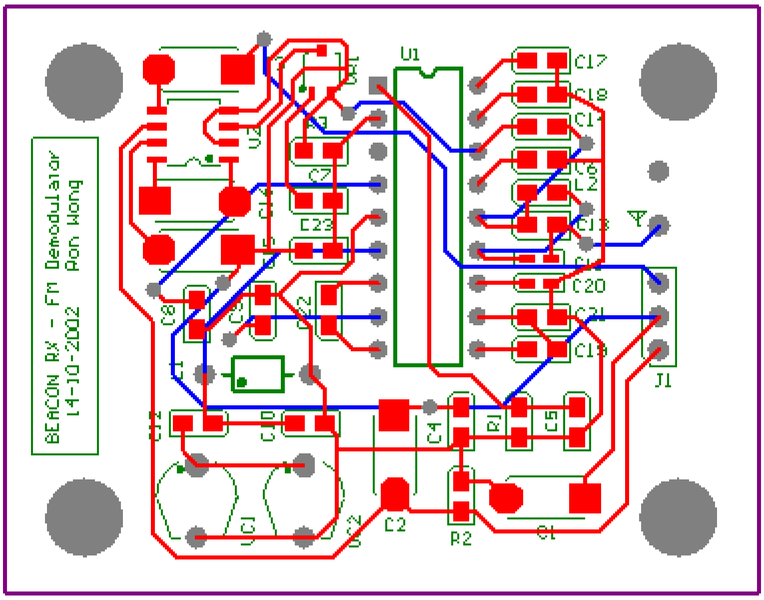
D-6 PCB Design – Transmitter Microcontroller



D-7 PCB Design – Receiver Microcontroller & FSK



D-8 PCB Design – Receiver Demodulator



Appendix E: PCB Production Checklist

E-1 Schematic Design

Process for Collecting Data

- ❑ Collect all circuit designs on paper.
- ❑ Identify a list of all components in the circuit design.
- ❑ Identify the mechanical and electrical requirements for each component.
- ❑ Make sure the components are available for purchase through the university's suppliers.
- ❑ Procure datasheets for each component and make note of physical footprints.
- ❑ Order the components.

Process for Creating the Schematic in Protel

- ❑ Create a new schematic library containing each component being used.
- ❑ Assign each component pin with a type (eg. power, input, output, passive)
- ❑ Create a new PCB library containing each footprint used.
- ❑ Use overlay lines to indicate the physical space that the component requires (not just the copper pad space).
- ❑ Use overlay lines to indicate component orientation, so that it clear which way the components are to be placed duration PCB population.
- ❑ Draw the circuit diagram in a new schematic document.
- ❑ When using common netlabels, copy the netlabel text to ensure that they are the same (do not retype the name).
- ❑ Assign values to each component, ensuring that no decimal points are used (eg. instead of 4.7uF, use 4u7F).

Process for Checking the Schematic

- ❑ Visually inspect the schematic and correct any errors detected.
- ❑ Reset all designators and automatically reassign them.
- ❑ Run an Electrical Rule Check (ERC) on the schematic design and correct any errors detected.
- ❑ Create a netlist.
- ❑ Create a Bill of Materials, and check the footprint of each component.

E-2 PCB Design

Process for Creating the PCB Layout in Protel

- ❑ Set the PCB design rules as specified by the university.
- ❑ Comply to any other rules as specified by the university.
- ❑ Load the previously generated netlist into a new PCB document.
- ❑ Correct any macro errors detected in the netlist.
- ❑ Group the components into appropriate sections (eg. group all RS-232 components together).
- ❑ Make sure that components affected by positional change are located appropriately (eg. ensure crystals are positioned close to the microcontroller).
- ❑ Position the components as they are to appear on the final PCB layout.
- ❑ Manually route the PCB.
- ❑ Include overlay text that describes the title of the board, the designer and the date the design was completed.

Process for Checking the PCB Layout

- ❑ Visually inspect the PCB layout and correct any errors detected.
- ❑ Run a Design Rule Check (DRC) on the PCB layout and correct any errors detected.
- ❑ Export a netlist based on the PCB connections.
- ❑ Compare the generated PCB netlist against the original schematic netlist. If the two netlists match, then the PCB is ready to be manufactured. If not, then the anomalies need to be corrected; all relevant checks need to be performed again.
- ❑ Submit the PCB for manufacturing.

E-3 PCB Component Population

Process for Populating the PCB

- ❑ Ensure that the ordered components (type, value and footprint) match those that are required.
- ❑ Visually inspect the PCB to make sure that there are no short circuits or broken tracks.
- ❑ Solder the components in stages, so that the operation of each stage can be tested and verified. Complete population of the PCB is undesirable, as an error would be difficult to trace.
- ❑ Once population is complete, a full test of the PCB circuit is required.
- ❑ If there are any errors that can be solved by wire patching, ensure that the wires have been correctly stripped and will not break. Make sure that patch wires are fixed to the board (using glue or hot melt), so that they cannot be accidentally pulled off.

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