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March 06, 2008

Mr. Patrick Leung
School of Engineering Science
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Re: ENSC 440, *Design Specifications for the Wireless Parked Car Finding System (UFind)*

Dear Mr. Leung:

The attached document contains the design specifications for UFind. The goal of the project is to create a product that would assist users in finding their cars in parking lots.

The purpose of the design specifications document is to provide an in-depth elaboration on the UFind design development for the proof of concept prototype model. It includes details about hardware and software design strategies as well as the integration of the overall system. Some experimental results are also provided to support the feasibility of the design.

Weiibo Inc. is a company formed by Karl Simard, Hooman Jarollahi, Dennis Xu and Diwaker Malla. We are 3rd or 4th year engineering students and are very motivated about this product. We are confident that the development of this product will allow us to apply the knowledge and experience we have gained in the academic engineering career. Should you have any questions or comments about this document, please do not hesitate to contact us via phone at (778) 862-2242 or e-mail at hjarolla@sfu.ca.

Regards,

Hooman Jarollahi
CEO, Weiibo Inc.

Enclosure: *Design Specifications for the Wireless Parked Car Finding System*

Design Specifications for the Wireless Parked Car Finding System (UFind)

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Abstract

The purpose of this document is to specify the design for the proof-of-concept prototype of the wireless parked car finding system (UFind) device. The design specifications will correspond to the functionalities outlined in the functional specifications document for the wireless parked car finding system (UFind) covered by phases I and II. [1]

The development of this product consists of the design of a hand-held unit and a car module. The hand-held will display relative proximity and direction turns on car lights and activates the beeper upon the user's request. The product will operate in the unlicensed Radio Frequency (RF) spectrum within the band 260 MHz to 470 MHz [2]. Also, the development of the product consists of four major tasks: hardware design, software design, component selection and integration.

The design of this product includes solving many engineering problems. Different design solutions are proposed and the most feasible solution based on the time-line and budget constraints will be selected.

In this document, a summary of numerous amounts of experiments which were conducted to verify the feasibility of the design is also included. Furthermore, a system test plan that will ensure functional and performance requirements during its development has also been included in the document. The system test plan will also ensure that UFind will be able to perform like an end product.

The appendix provides an in-depth description of important background information necessary to understand the design in more details. With the current pace of the development cycle, we are confident that we will accomplish the targeted milestones and complete the development of the proof of concept prototype by the target date April 8, 2008.

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Acronyms

ADC Analog to Digital Converter
DAC Digital to Analog Converter
FSD Functional Specifications Document
FSM Finite State Machine
LADJ Level Adjust
LCD Liquid Crystal Display
LOS Line of Sight
PWM Pulse Width Modulation
RF Radio Frequencies
RSSI Received Signal Strength Indicator
SUV Sport Utility Vehicle
TFLF Time of Flight Loop Frequency
TOF Time of Flight
TPA Transmission Power Adjustment
UUT Unit Under Test

Glossary

TOFLF Method: A method used to calculate proximity between two objects developed by Weiibo Inc. It uses the accumulation of the TOF delays to transmit and receive a message signal by sending the message many times in a fixed period of time and counting the number of received or transmitted messages which would vary with distance.

TPA method: A method used to calculate proximity between two objects developed by Weiibo Inc. It uses the adjustment of transmission power to calculate the reception range and hence the distance approximation of the receiver.

UFind User: Any person who meets all of the following characteristics:

- At least 10 years old or with supervisions by someone older
- Without impairments in visions and hearing for complete usage of the device

1. Introduction

In this document, design specifications of UFind, a device which assists users to find their parked cars, are outlined. The design is based on requirements indicated in FSD. The device consists of two major modules: A car module which will be installed in the car and a portable hand-held with a display system. This document includes specifications on the design of a proof-of-concept prototype developed by team members of Weiibo Inc.

The device displays proximity between the user's location and the car. Furthermore, it will display information about the direction toward the car. It will eliminate the exhaustions and frustrations caused by looking for parked cars especially in busy locations.

1.1 Scope

The scope of this document is to outline the design and development details of UFind. The design details corresponding to the functional requirements for constructing a prototype of the device are elaborated.

1.2 Intended Audience

The intended audience of this document is engineers of Weiibo Inc. for developing the proof of concept model. The design specifications are explained in sufficient depth such that it can be used as a reference for future enhancement and reconstruction of the prototype.

2. Overall System Design

2.1 High-level System Design

Figure 2.1depicts a high level system design diagram for the hand-held and the car modules. The left part of the diagram represents the hand-held and the right side represents the car module.

Each module includes a transmitter and a receiver with different frequencies, 418 MHz and 315 MHz which are paired with the car module transmitter and receiver to make the communication possible. The reason there are two different frequencies used in this design is to avoid interference in the same module communication. Each of these receivers and transmitters are coupled with encoders and decoders to encrypt, decrypt and serialize the data to establish a secure communication channel and avoid interference between multiple copies of the product. Details on the characteristics and functionalities of each module will be explained.

The hand-held will also include an LCD display unit, a microcontroller and user interface buttons for menu navigation and function selection.

Each module will need antennas for signal receptions and transmissions. In order to sense the direction, directional antennas will be used in the hand-held only. The car module will transmit signals in all directions because the location of the user is unknown when the user returns to the car. Therefore, Omni-directional antennas are used in the car and directional antennas will be used in the hand-held.

For the proof-of-concept model, only one directional antenna will be used in the hand-held receiver since these types of antennas are expensive and one proves the directionality sufficiently for experimental purposes. For full performance, two directional antennas will be needed in the hand-held to transmit and receive signals stronger in one direction.

The design of the user interface and the control system requires integration of an LCD display, buttons, I/O ports and a microcontroller to control data flow and implement design algorithms.

AVR-Butterfly evaluation board includes some of the design components required in the hand-held such as the display unit and a joystick. Details on the microcontroller resources and design strategies for the user interface and the control system will be explained later in this document.

The car module will include an interface to the car to perform required functions such as turning on the car lights, activating the beeper, and other optional features. In the design, the car module will be capable of implementing seven functions aside from the proximity detection.

The proximity and directional detection is the most significant part of this design. Therefore, we will use original design solutions and methods to achieve the goal. Details on different design strategies will be explained in the following sections of the document.

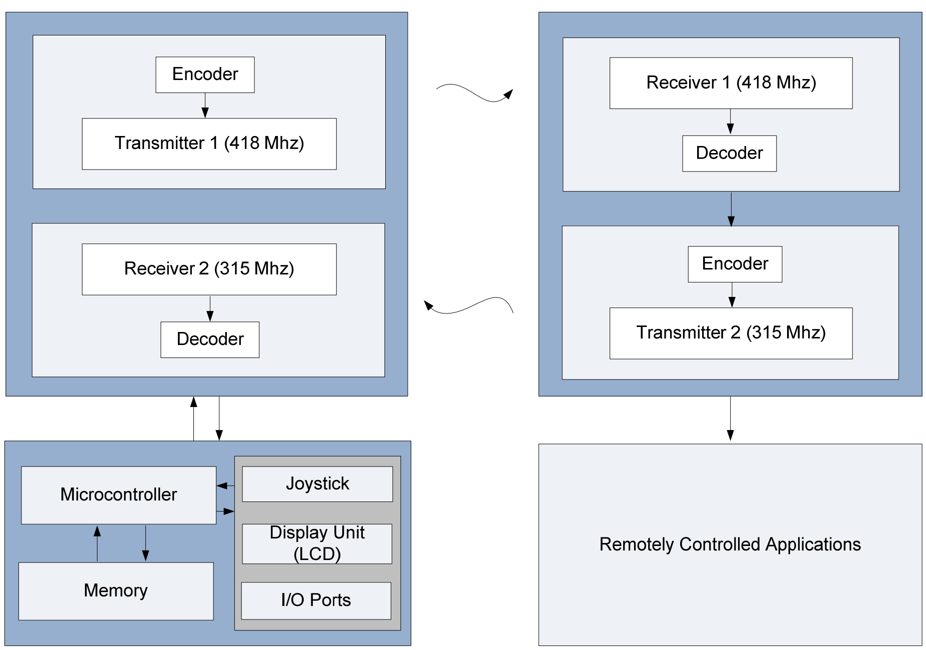


Figure 2.1: High- level Hardware Model System Block Diagram

2.2 Wireless Considerations

2.2.1 Limitations and Constraints

Due to several limitations and constraints existing in the environment and the nature of the RF, the precision of prototype performance and final end user product will be affected.

Multi-path, reflections, absorptions of the communication signals are some of the effects of nature on the RF signals which are inevitable. However, using intelligent methods, the performance can be improved. In general, the performance of the product will be affected by the presence of one or more of the following:

- Signal absorptions/reflections in material such as concrete, tree, metal (bus, large SUVs, trucks, etc) in line of sight (LOS)
- Effects of near-by conductive planes such as the roof of a near-by car or the side of a school bus
- Water in the air, rain, fog, snow, etc.
- Antenna size and orientation
- Near-by human body – hand-held unit's location with respect to the user and the car
- Distance – The device will not detect proximity closer than 1 meter; however, it can still turn on the lights or activate the beep.

3. Hardware Design

3.1 Power Supply Circuitry

Figure 3.1 and Figure 3.2 depict the schematics for the power supply for the car and the hand-held modules. In both schematics, C_4 and C_7 are necessary and recommended by the manufacturer of the voltage regulator chip. C_3 and C_5 are used to smooth the DC voltage. In both cases R_7 and C_6 are required by Linx in order to reduce the noise from the power supply. In the hand-held module, the power to the microcontroller is taken before this low pass filter constructed by R_7 and C_6 due to hardware access convenience on the AVR butterfly kit.

3.1.1 Car Module

Car battery or portable batteries can be used for power supply for the car module. The selected voltage regulators should be capable of handling the voltages, currents driven from the circuits and the power dissipation on the chip. The entire car module circuit excluding the driver circuits for the light, the beeper and other functionalities do not drive more than 100 mA of current. Therefore, 4 AA batteries will be enough to supply the car module provided that the other functions are disabled.

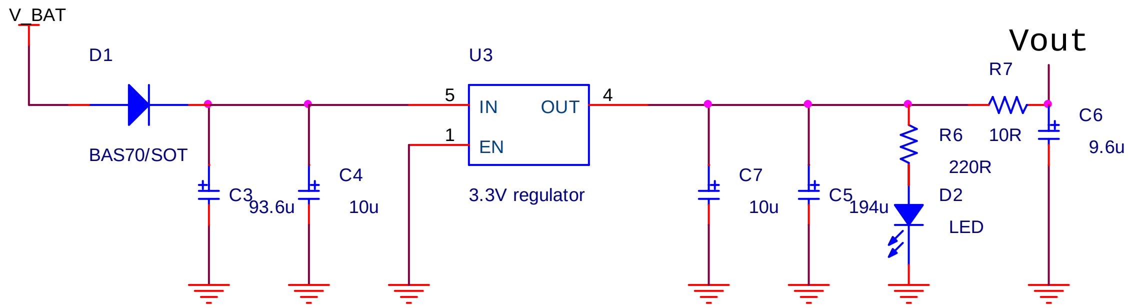


Figure 3.1: Car module power supply [13]

3.1.2 Hand-held module

UCC 283 voltage regulator can be used for the hand-held voltage regulator since it is compliant with the voltage, current and power requirements. From Figure 3.2, it can be seen that the output of the 3.3V voltage regulator will power both the wireless modules and the microcontroller. The microcontroller requires 5.5mA of input current while operating at 8 MHz. The wireless module draws 5.1mA of input current while operating. Therefore, the current limit imposed by the voltage regulator is well above what is required by the device to function properly. The LED is just an indicator of the on/off modes. The diode is to prevent reverse current direction in case the chip is damaged or anything malfunctions.

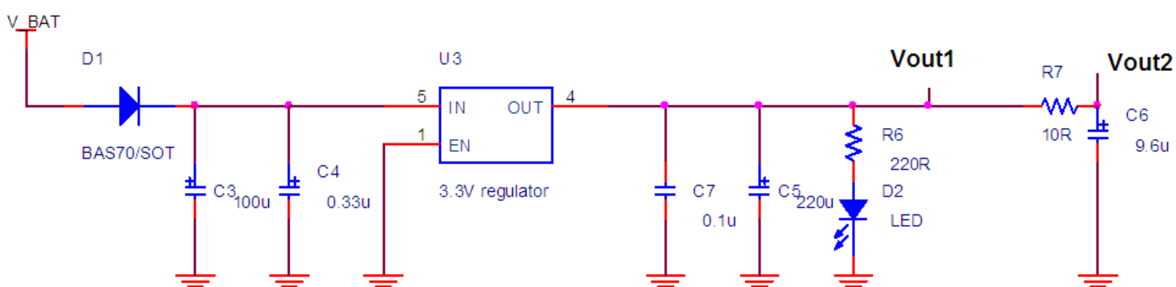


Figure 3.2: Hand-held module power supply [13]

3.2 Receiver Sensitivity Reduction Circuitry

In order to reduce noise received by the car module, it was decided that the sensitivity of the receiver should be reduced. The circuit shown in Figure 3.3 was used for reducing the receiver's sensitivity. This circuit was provided by Linx Technologies. The values of the component used for this circuit operates within 5% of stated values.

The purpose of the comparator is to compare the RSSI voltage with a threshold value so that for values below the threshold, the output will be zero. If the RSSI is high enough, the signal will be considered as a valid signal and that is the purpose of using an AND gate to couple the comparator circuitry. The potentiometer resistance is to control the threshold voltage value. In this case, it is tuned such that a 1.4 V RSSI can pass through. The purpose of the diode is to avoid current to be injected into the receiver chip in case the capacitor or the comparator is damaged for any reasons.

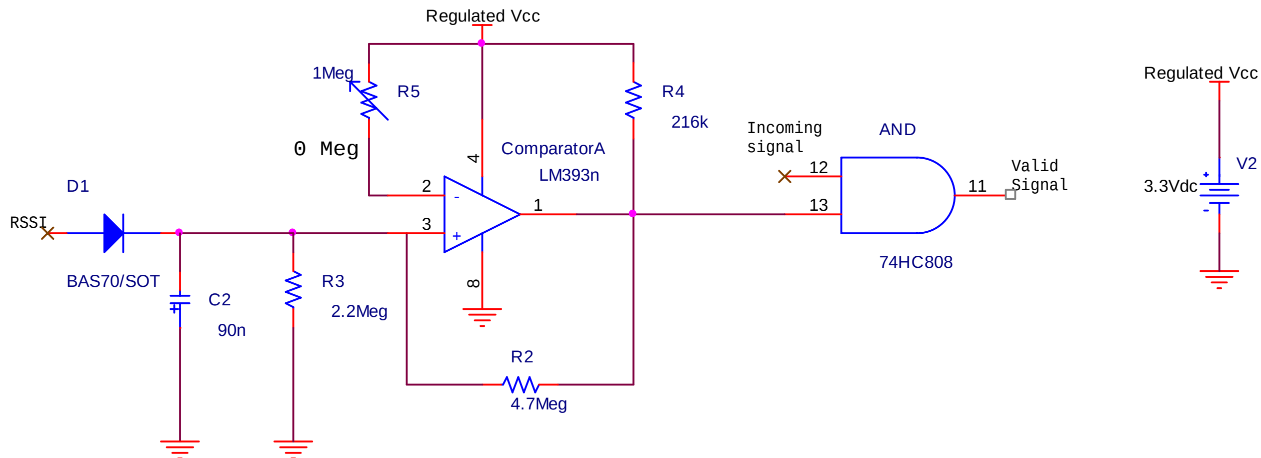


Figure 3.3: Squelching circuit used to reduce the sensitivity of receiver [6]

3.3 TPA Method for Proximity Detection

The Transmission Power Adjustment (TPA) method relies on the fact that the change in transmission power will change the range of operation. This is the basis of calculating the proximity between the car and the user. By increasing the transmission power, the range of reception on the car side will be increased. Certain amount of transmission power will result in the reception in a certain range. By using the threshold power for each region, the proximity is calculated.

The graphical presentation of the range sub-divisions is depicted in Figure 3.4. The darker the blue color, the stronger power level is needed to transmit a signal.

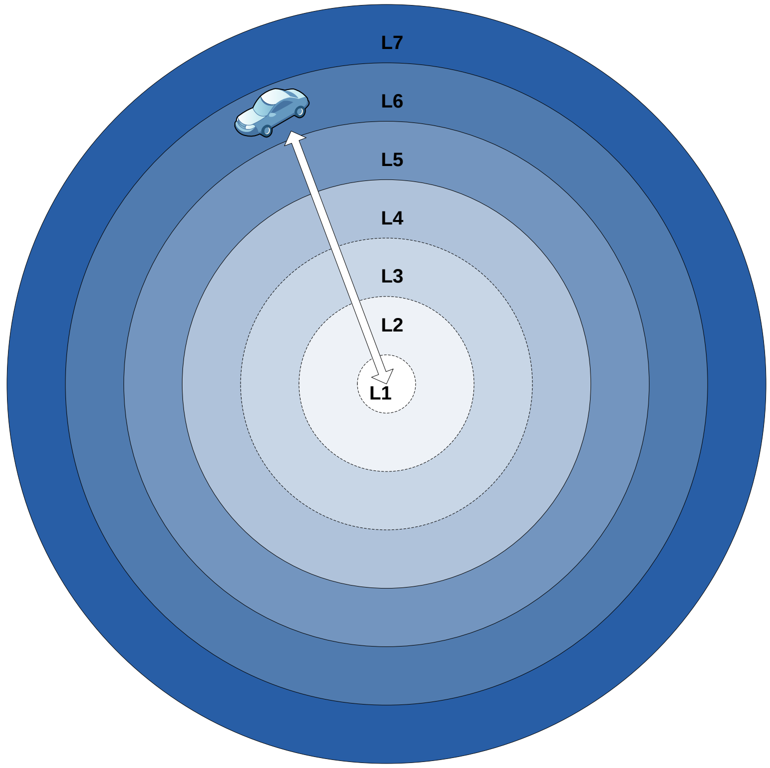


Figure 3.4: Graphical Representation of TPA Method

Linx Technology has designed a transmitter chip that allows control on the transmission power level (see the component selection section for the transmitter for more details). The resistance between the LADJ pin and VCC controls power level. In order to control this resistance, manufacturer recommends using either a DAC or a potentiometer. Since the hand-held unit already integrates a microcontroller, it was decided that the microcontroller be used to control the LADJ voltage. Maximum of 32 reception divisions between the car module and the hand-held is a reasonable design decision to detect proximity for the prototype which can be improved at any time. Generating PWM signals from one pin of the microcontroller and a simple RC filter can replace the operation of the DAC chip. The advantage of the PWM method is the reduction in the number of pins required to control the DAC chip.

In order to integrate a DAC chip to the design of the hand-held module, 5 output pins from the microcontroller should be dedicated to generate 32 power levels. This adds to the disadvantage of using an extra DAC chip in addition to adding a new cost to the circuit.

The use of a filter and PWM from the microcontroller as shown in Figure 3.5 means that the hardware components used are 1 resistor, 1 capacitor, 1 buffer and 1 output pin from the microcontroller. The output of the microcontroller is coupled to a buffer in order to prevent excess current drawn from the microcontroller. The microcontroller can output 10mA from port

B and the RC circuit and the filter requires a current draw of 22mA, which the buffer can provide. In general, it is not appropriate to supply current from the microcontroller. The frequency of the PWM wave is 31.25 kHz. The RC time constant of the low pass filter is 670.5 µs. Therefore using Equation 3.1, given the RC constant used in the DAC circuit the largest voltage ripple is calculated to be 63mV when the circuit operates at 1.35V. This means a 4% error generation by the ripples which can be neglected for this case.

$$V_C(t) = V_i(1 - e^{-t/RC})$$ **Equation 3.1**

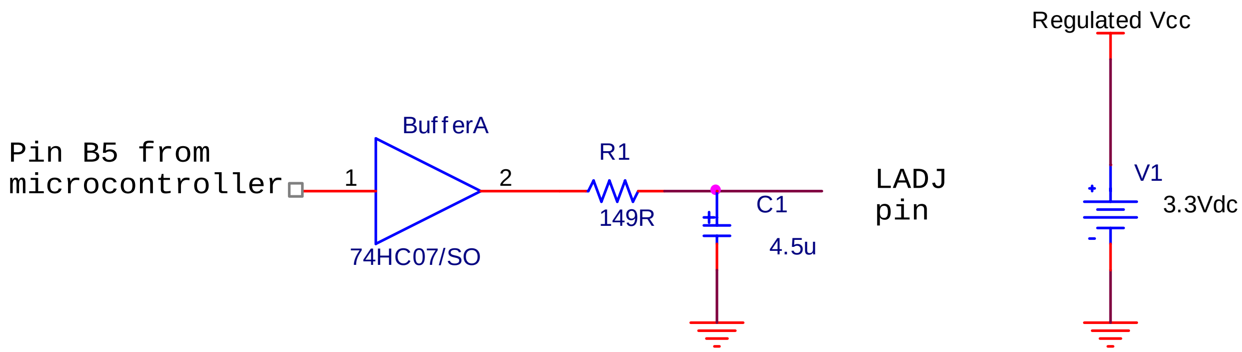


Figure 3.5: DAC Circuit

The following describes how the microcontroller resources will be used in the TPA method.

First of all, the 8 MHz internal clock will be used for the generation of a PWM signal. The maximum frequency that can be used to obtain PWM using the microcontroller is 31.25 KHz. The time constant of the RC circuit will determine the response time, i.e. the delay for a level change after a change in duty cycle of the PWM signal. The values of the capacitor and resistor were chosen to have a reasonably fast response time and also minimal ripples. The delay between two voltage switches is 7 ms. And the maximum ripple will be 16 mV.

The 16-bit high precision timer is used to generate the PWM signal generating a voltage for the LADJ pin on the transmitter. The reason for using a high precision timer is due to the exponential relationship between LADJ voltage and power level [5]. Therefore, when using small voltage, a small change in voltage will result in a large change in distance. Thus a precise PWM signal is necessary.

There are two 8-bit timers on the microcontroller of which one is used for general timing issues such as delays and pulse generation. Since high precision is not necessary for general timing issues, the 8-bit timers are sufficient for the hand-held's purpose.

The communication protocol used between the car module and the hand-held is accomplished using serial interface. For the development of the prototype, encoders and decoders will be used with the receivers and transmitters. However, each encoders and decodes causes an 11 ms delay in the system for each message. Since 4 encoder and decoder chips are required, a total 44 ms delay will be induced in the system. This delay can be improved by removing the encoder and decoder chips and using the microcontroller to design the protocol. However, this is an entirely separate project which is out of the scope of this project. Once the encoders and decoders are removed from the prototype, the microprocessor will be able to handle the protocol description faster.

The definitions and usages of the different general input/output ports are outlined in Table 3.1.

Table 3.1: Port Definition and Usage

Port	Usage	Reason for this particular pin
Port B1	Transmission Enable	Port available
Port B2	Transmission Data out	Port available
Port B4	Joystick Enter	Hard wired on Butterfly board
Port B5	PWM signal	Pin dedicated for timer1 output compare
Port B6	Joystick Up	Hard wired on Butterfly board
Port B7	Joystick Right	Hard wired on Butterfly board
Port E0	Serial Data in (RxD)	Pin dedicated to Serial Data in
Port E1	Serial Data out (TxD)	Pin dedicated to Serial Data out
Port E2	Joystick Left	Hard wired on Butterfly board
Port E3	Joystick Down	Hard wired on Butterfly board
Port E6	Transmission Data in	Port available & easier to generate PCINT from it

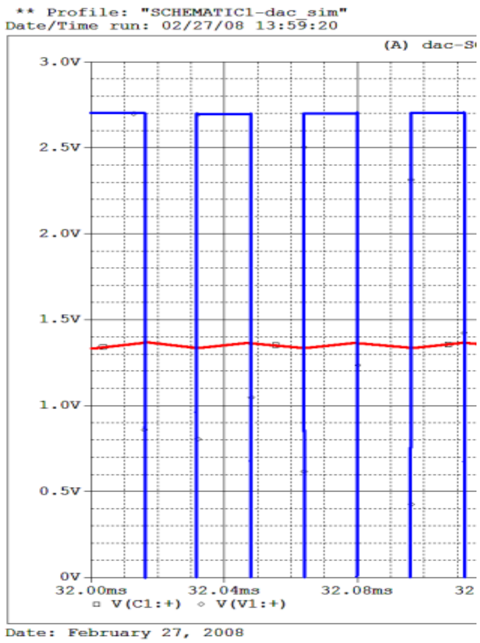


Figure 3.6: Pspice simulation DAC output at 50% duty cycle

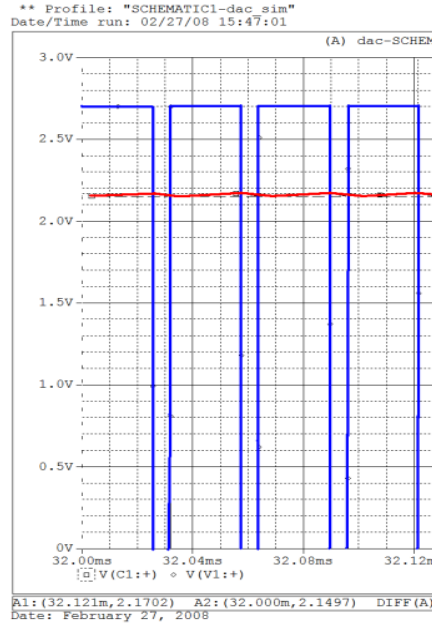


Figure 3.7: Pspice simulation DAC output at 80% duty cycle

3.4 Directionality Detection

Directionality detection is another feature of UFind. For the proof of concept model, only one directional antenna (e.g. Yagi-Antenna) will be used on the hand-held receiver side. This antenna will receive signals stronger at the appropriate direction using RSSI feature of the receiver. Using LCD as the display unit, the user will select the maximum strength and follow that direction. The proximity calculation and directionality detection are concurrent processes which will be updated on the display in real-time.

3.5 Alternative Proximity Detection Design Solution

3.5.1 Time of Flight Loop Frequency (TOFLF)

3.5.1.1 Introduction

This method involves using certain characteristics of the radio frequencies. Radio frequency waves travel at the speed of light which is 299,792,458 m/s [11]. The time of flight (TOF) between two positions is calculated using Equation 3.2.

Equation 3.2

$$T_F = \frac{\mathrm{D}}{299{,}792{,}458}$$

where D is the distance between the transmitter and the receiver and T_F is the TOF. The TOF is extremely short to measure using regular equipment. For instance, for distance of 30 meters, the TOF will be 100.069 ns. In order to be capable of counting this delay, counters with speed of 9.993 GHz is required which is extremely fast and impossible to count unless special laboratory equipment employing atomic clocks for very high accuracy is used. This fact is obviously out of the scope of this project. This issue will become even worse when closer distances are to be measured.

The following section is the proposal of a new method for calculating the proximity.

3.5.1.2 Proposed Design Solution

As discussed in the introduction, the TOF of one transmission between the transmitter and receiver is very short. It is close to impossible to measure the delay using available components in the market and considering the marketability of the device in terms of costs.

Therefore, when TOF for one transmission is too short, one can use multiple transmissions to accumulate the delay. The way the accumulated delay is measurable will be dependant on the number of times a message is sent or received. In this design, 2 transmitter-receiver pairs are needed of which the two pairs have non-interfering frequencies. An inverter must be used on one side, either the hand-held or the car module to establish a loop through the four communication modules which can be used to count the number of times a signal is transmitted received on either side. For this design, the hand-held module is used since it has access to the microcontroller, which can be used to count the loop signals. Figure 3.8 depicts the overall system design for this solution.

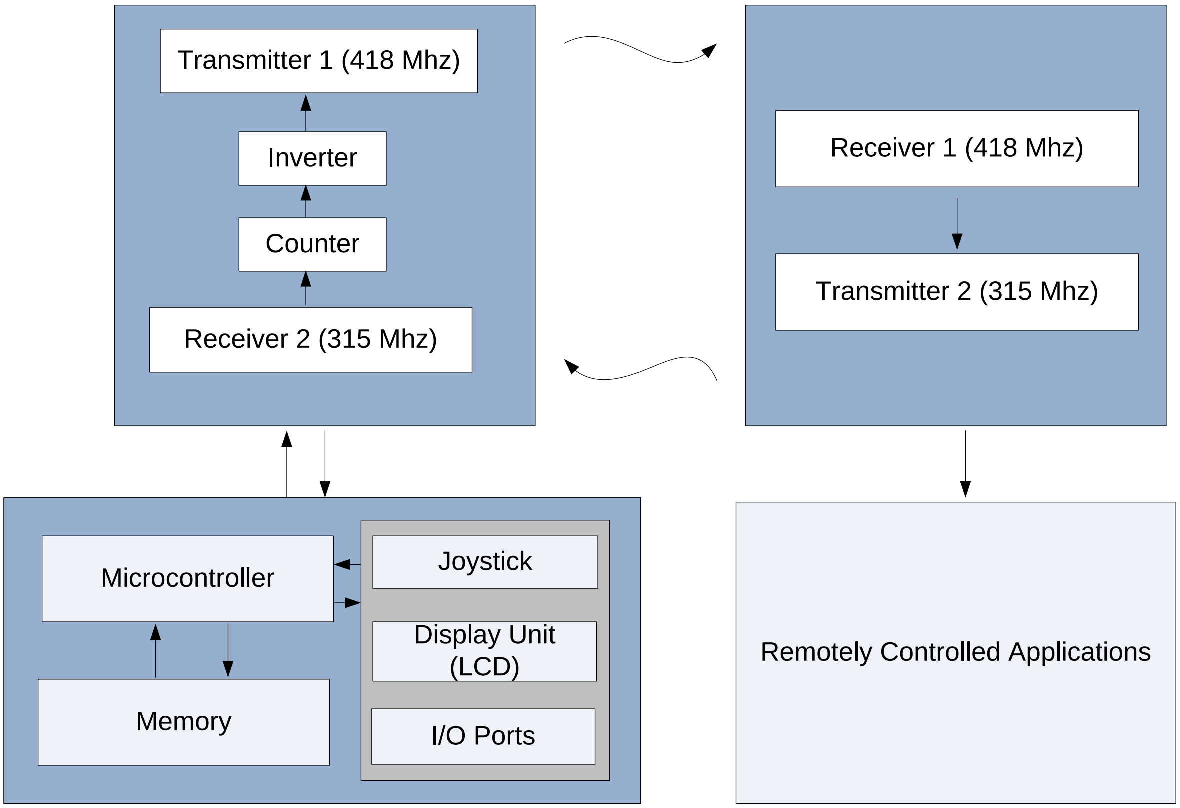


Figure 3.8: High-Level System design for the TOFLF method

The number of counts in the counter will be used as a way to calculate the proximity. In a fixed period of time T_{Fixed}, the number of counts in that period will be calculated using Equation **3.3**

$$N = \frac{T_{Fixed}}{\alpha T_P + \beta T_F}, \qquad \textbf{Equation 3.3}$$

where α is the number of processing elements, i.e. communication modules, β is the number of times the signal will travel between the 2 communication pairs, T_{Fixed} is the fixed period of time the counter will count the number of received pulses, T_F is the time of flight based on distance which is calculated by Equation 3.1, T_P is the processing time of each of the transmitter or receiver modules and finally N is the number of counts the counter will have after T_{Fixed}. Therefore, by comparing the N values for different distances, the proximity will be calculated.

Table 3.2 shows some numerical values obtained from Equation 3.4 for different distances for T_{Fixed} = 5 sec as an example. T_P has an inverse relationship to the data bandwidth of the communication modules, i.e.:

$$T_P = 1/B \quad \textbf{Equation 3.4}$$

where B is the data bandwidth of the communication modules. For all the modules the bit-rate is at most 10,000 bps. Therefore, T_P is at least 100 µs. Since the free loop oscillation will be operating at the maximum speed possible, the data rate will be at maximum. β is 4 because there are 2 transmitter-receiver pairs and α is 2 since there are 2 flights in the loop for each pair.

Table 3.2: TOFLF method theoretical statistical results

Distance (m)	T_F (µs)	T_P (µs)	α	β	T_{Fixed} (sec)	Counts (N)	Difference
900	3.002076857	100	4	2	5	12315.14494	N/A
800	2.668512762	100	4	2	5	12335.41395	20.26901
700	2.334948666	100	4	2	5	12355.74979	20.33584
600	2.001384571	100	4	2	5	12376.15279	20.403
500	1.667820476	100	4	2	5	12396.62329	20.4705
400	1.334256381	100	4	2	5	12417.16161	20.53833
300	1.000692286	100	4	2	5	12437.76811	20.60649
200	0.66712819	100	4	2	5	12458.44311	20.675
100	0.333564095	100	4	2	5	12479.18696	20.74385
80	0.266851276	100	4	2	5	12483.34402	4.157062
60	0.200138457	100	4	2	5	12487.50385	4.159833
40	0.133425638	100	4	2	5	12491.66646	4.162606
20	0.066712819	100	4	2	5	12495.83184	4.165382
10	0.03335641	100	4	2	5	12497.91557	2.083733

3.5.2 Using RSSI for Proximity Detection

One of the ways to calculate proximity between the car module and the hand-held is to use the RSSI feature of the receiver chip and couple it with "squelching circuit" shown in Figure 3.3. The circuit would perform better if two directional antennas are used on the hand-held module to transmit and receive signals stronger in the right direction. However, it has some draw backs including insecurity. Since the RSSI is an unsecure indication of the signal strength, the risk of having interference is not negligible unless intelligent algorithms are implemented to reduce the risk. This method can be used as a backup to confirm consistency of the calculations.

4. Design requirements and Component Selection

The following sections will describe the core required components and their selection for the design.

4.1 Control system and User Interface

There are many factors that need to be taken into account when selecting the microcontroller which is the brain of the system. It controls the behavior of the modules directly or indirectly. Some of the important peripherals needed by the microcontroller for the design of prototype are categorized in the list below:

- The internal memory of the microcontroller and the external memory
- Analog to Digital Converter (ADC)
- Timers/Counters
- LCD driver
- Number of I/O pins
- Other peripherals

After investigating the required peripherals and also researching on microcontrollers, the microcontroller selected for the proof of concept is Atmel Mega169P. The required I/O pins for the design are summarized in Table 3.1. AVR-Butterfly has an LCD display which is connected to the 4 x 25 Segment LCD Driver of the microcontroller. Details on the LCD display will be explained later in this document. AVR-Butterfly also includes a 5 directional joystick (Right, left, top, bottom, and enter) which can be used for the menu navigation on the LCD.

The 4x25 segment LCD driver included in the evaluation kit facilitates the task of displaying information on the LCD. The microcontroller has 25 registers used for the LCD drivers as well as an independent timer strictly used by the LCD [9].

Atmel Mega 169P is an 8 bit microcontroller that can run with a maximum 8 MHz internal clock frequency. It has a 4x25 segment LCD Driver, 8 channel 10 bit ADC, 1 High precision 16-bit timer which can produce a high precision PWM signal, 2 8-bit counters, 1 serial port interface as well as 16 available general input/output pins [9].

4.2 Wireless Communication System

4.2.1 Transmitters and Matching Receivers

In order to establish the RF communication between the car and the user, transmitter and receiver chips need to be used. Linx LR series transmitters and receivers matched the design requirements. The LR Receiver is suitable for the wireless data transfer including data and control signals. LR series have three operational frequencies: 315 MHz, 418 MHz and 433 MHz, The allowed band for data communication is between 260-470 MHz. As outlined in the FSD, the maximum 3,000 feet range is compliant to the required design. The maximum data rate is 10,000 bps which is only if it is used solely and not coupled with any other chips such as decoders or encoders. If coupled, the slower component will determine the maximum speed. Two frequencies were selected for this design: 315 MHz and 418 MHz to avoid interference.

4.2.1.1 Transmitter

The transmitter component must have the following criteria to suit the design requirements:

- Controllable transmission power: To be able to control the reception range
- Long range: The longer the range the better
- Low cost
- Serial Input interface: To minimize the required pin numbers on the microcontroller
- Low voltage and low power: To be able to use commonly used batteries and reduce power
- Turn off pin: to have a direct control on turn on and power down mode of the transmitter
- Large temperature range: To be able to work in different climates and different seasons since it is an out door product

Linx LR series is what was selected to be most suitable for the transmitter chip after investigating different series and comparing the differences. The reason is that it has the following characteristics [5]:

- Long range: 3000 ft. maximum range
- Low cost
- PLL-synthesized architecture
- Direct serial interface
- Data rates to 10,000bps
- No external RF components needed
- Low power consumption
- Low voltage (2.1 to 3.6 VDC): 2 AA batteries can be used to power it
- Compact surface mount package
- Wide temperature range
- Power-down function
- No production tuning

Therefore, by comparing the design requirements and the features of this chip, it is a good candidate for this design.

Figure 10.5 shows the pin arrangements for the transmitter chip.

One of the important features the transmitter needs to have for the proximity detection is the controllable transmission power. The designers for this chip have suggested that the LADJ pin can be used to control the range covered by the transmitter. Therefore, the relationship between the output power and the LADJ pin voltage will be used for the design. Figure 10.1 shows the relationship between the output power and the LADJ resistance. Changing the resistance will result in changing the voltage drop across the resistor used at the LADJ pin and will result in change of the transmission power.

In order to convert this graph to voltage relationship, current consumption relationship is also necessary since current multiplied by the resistance gives voltage. Figure 10.2 depicts this relationship. Therefore, there is a direct and explicit relationship between power of transmission and the voltage applied to the LADJ pin. Since both graphs are exponential, the multiplication of them is also going to be exponential. Experimental data proves this statement which is elaborated in the experimental results section.

4.2.1.2 Receiver

The receiver chip needs to be capable of receiving serial data in the licensed band. It also needs to match the transmitter so that their data transfer rates match to some extent. The transmitter company suggests using the pairing LR series receiver. Figure 10.6 depicts the pin arrangements key features of this chip that are going to be used in the design of the system are [6]:

- Long range: 3,000 ft. which matches with the transmitter specification
- Low cost
- PLL-synthesized architecture
- Direct serial interface: allows receiving serialized data and only using 1 pin instead of many.
- Data rates to 10,000bps: An important feature since it allows faster transfer rate and hence more sampling will be done in shorter time
- Qualified data output
- No external components needed
- Low power consumption
- Wide supply range (2.7 to 5.2VDC): Should match the transmitter since the power supply will be same for both in the same module, the hand-held or the car module.
- Compact surface-mount package
- Wide temperature range: Same reasoning as the transmitter chip
- RSSI and Power-down functions: This is also an important feature since RSSI will indicate the power level at different distances. However, it’s not a secure feature and will indicate the received signal strength from all other transmitters.
- No production tuning

There is another type of receiver and transmitter pair that could be used in this design, the LC series. However, LR series seem to be better qualified after comparison. Most importantly, the maximum data bandwidth for the LC series is 5,000 bps whereas the LR series has a 10,000 bps bandwidth. The higher the bandwidth, the more samples can be captured in theory. However, the encoder and the decoder chips will slow the transmission rate which will be explained later. Table 4.1 shows the differences between these two series.

Table 4.1: Comparison Chart between LC and LR RF series (Modified version of [7])

	LC			LR		
Parameter	Min	Typ	Max	Min	Typ	Max
Supply Voltage (V)	2.7	—	5.2	2.1	3.0	3.6
Supply Current (mA) 50% Duty Cycle Logic High Logic Low	— — —	1.5 3 0	— 6 —	— — —	3.3 4.8 1.8	— — —
Sleep Current (µA)	—	—	1.5	—	0.005	—
Transmit Frequency Range (MHz) TXM-315-L* TXM-315-L* TXM-315-L*	— — —	315 418 433.92	— — —	— — —	315 418 433.92	— — —
Data Bandwidth (bps)	**100**	—	**5,000**	DC	—	**10,000**
Center Frequency Accuracy (kHz)	**-75**	**—**	**+75**	**-50**	**—**	**+50**
Output Power (dBm)	-4	0	+4	-4	0	+8
Harmonic Emissions (dBc)	—	—	-40	—	-40	—
Output Power Control Range (dBm)	-7	—	0	-80	—	+8
Modulation Delay (µSec)	—	50	—	—	—	1
Operating Temperature Range (C)	**-30**	**—**	**+70**	**-40**	**—**	**+85**

The centre frequency accuracy is also of great significance. The LR series had a higher accuracy in the centre frequency and that will make the precision of the received signals better, with less noise and avoids the interference caused by a less accurate receiver.
The operating temperature range is also larger for the LR series and it leads to more flexibility in terms of climate conditions.

In general the LR series have performance improvements compared to the LC series.

4.3 Security in Communication

4.3.1 Encoder

Since the transmitter and receiver pairs use serial data communication, we will need encoder and decoder chips for two reasons:

1) To be capable of sending multiple non-interfering functions and commands and using same frequency transmitter/receiver
2) To avoid interference with any other existing same frequency communication devices in the environment including multiple UFinds.

Linx recommends using MS series encoders to match with the LR series. MS series are designed biased towards the quality of RF but not the security. That's why they are called MS or Medium Security. The HS (High Security) series are more advanced and more expensive.

Linx has designed MS series encoders and decoders specifically for remote control applications. These chips are capable of encoding 8 different functions for secure transfer which is performed through a secure wireless link. The chip dedicates 24 bit address size to construct a unique transmission and minimize the chance of conflict between multiple devices. The designer will be allowed to define output lines for each transmitter required for the design and coupled with the encoder chip. Figure 10.7 shows the pin arrangements of this chip outlining its capabilities in a high level fashion. The flowchart for the algorithm the internal CPU of this chip processes the data and controls the behavior of the pins is demonstrated in Figure 10.3.

4.3.2 Decoder

The MS decoder chip pairs with the encoder which has similar behavior to the encoder but does the task in reverse i.e. it gets the serialized input and understands the conventions and then decodes the data to the output lines. Baud rates are also controllable which for our design we just set it to 9600 bps as the default value since it is not really of great significance for this design and since we do not interfere with COM port to match the baud rate for instance. A flow chart demonstrating the behavior of this chip and the control over the pins is depicted in Figure 10.4.

4.4 Directional Antenna

A directional antenna receives signals at a greater strength when at the right direction. In order to sense the direction the user needs to move in a circular path and choose the direction based on the indicator on the handheld. A directional antenna will be used on the hand-held receiver side such that using RSSI to indicate different signal strengths at different directions.

Yagi antennas will be used for specific frequencies for the proof of concept prototype and smaller types of antennas such as fractal antennas will be considered for the commercialized product. There are many software programs available that calculate the lengths and the spacing for the Yagi-Antennas.

4.5 Activation of the alarm, turning on the light and other optional functionalities

Since a total number of 8 functions are allowed to be used and one is used for the TPA method, 7 more functions can be implemented such as turning on the light or activation of a beeper to notify the user about the location of the car. Depending on the load, proper driver circuit can be considered to supply the power taken from the car batteries and not the car module itself. A simple relay is an example of a driver circuit.

5. Software Design

5.1 TPA Method Software Algorithm

The idea behind TPA is to subdivide the space surrounding the transmitter such that the location of the car can be determined by changing the transmission power.

In order to execute this task accurately in software, an FSM is designed and depicted in Figure 5.1. A description of each state is provided in Table 5.1. It is important to note that during the operation of finding the car, the FSM is executed approximately every 125µs.

After adjusting the power level, it is necessary to have a delay to the next level. This delay is needed because the power level needs to pass the transient state and become stable. This analog effect is partially due to the output circuit used for generating a voltage at the level adjust pin of the transmitter and partially to the time constant of the RC filter. The delay used here has been determined experimentally based on the RC time constant of the low pass filter. The value of the delay is approximately 7 ms.

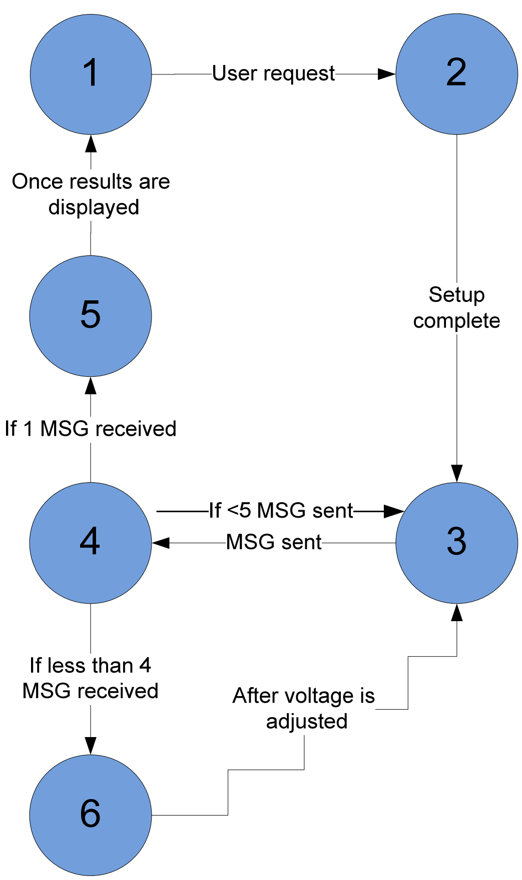


Figure 5.1: FSM for Proximity Calculation using TPA method Software

Figure 5.2 depicts the flowchart for proximity calculation using TPA method. This figure shows in better details the interdependence of each state.

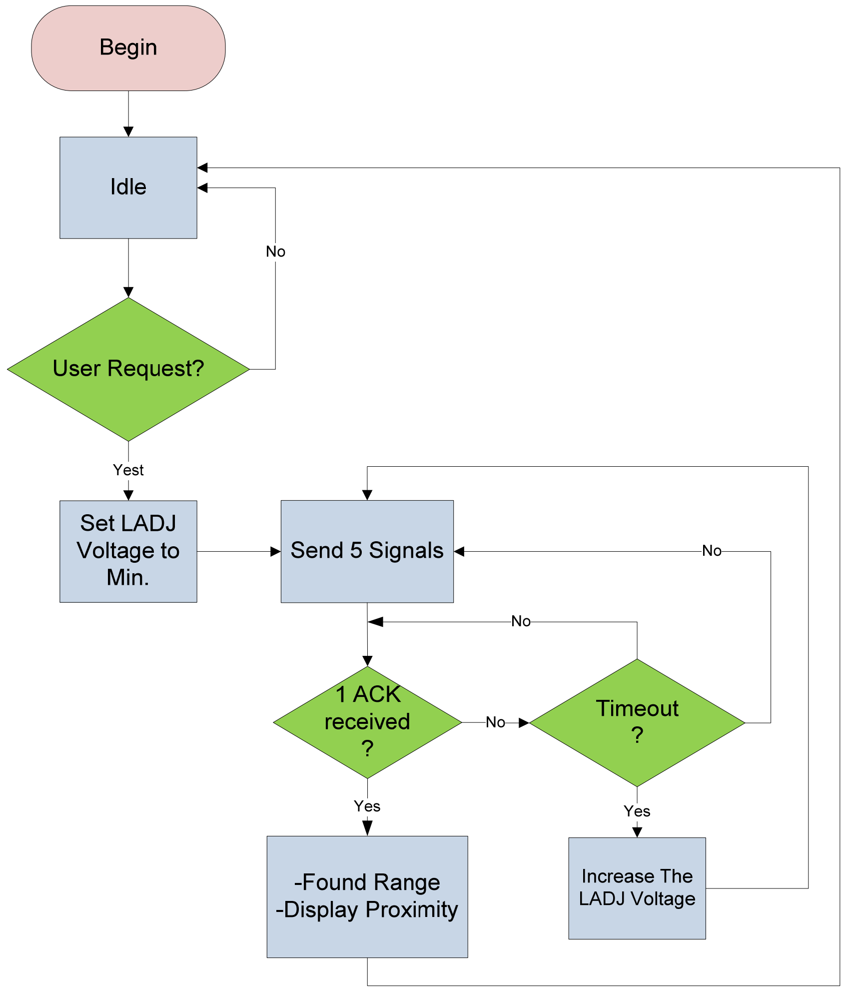


Figure 5.2: Flowchart for TPA method software for proximity detection

Table 5.1: Car finder FSM state description

State	Description	Use	Necessity
1	Idle	Used when finite state machine is not used	Saves CPU clock cycle.
2	Set-up	Used as the first state when FSM is launched	Sets up initial variables & registers needed for search
3	Send Message	Send a message to car module	Takes care of setting up necessary variables when sending a message such as timeout counters
4	Receive message	Wait for the reception of an acknowledgment signal from car module	If a message is received, this state validates the message. On the other hand, if the timeout timer expires, the state will declare the reception of the message as lost.
5	Display results	Displays the distance from user to car.	Displaying the proximity
6	Increase range	Increase the transmission power.	Takes care of timing related to changing the power level such as DAC output settling time.

5.2 Directionality Detection Software

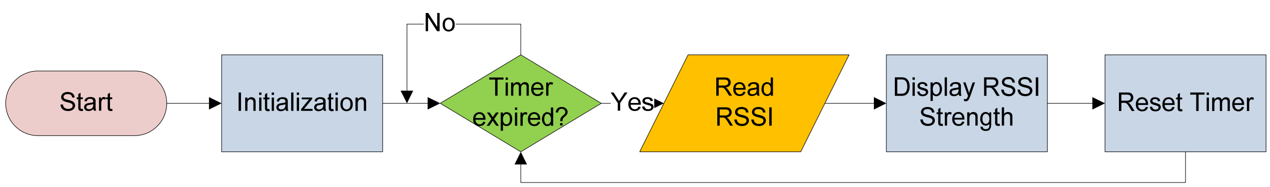


Figure 5.3: Flowchart for directionality indicator software

Using a directional antenna on the hand-held's receiver and reading RSSI value periodically, signal strength is determined as the user moves in a full circle. The number of the top row of the LCD as shown in Figure 5.3 will be used to display the signal strength. User is then expected to make a 360 degree turn and expected to detect the highest displayed signal strength. User is then expected to proceed in the direction with the highest signal strength.

5.3 User Interface Software

5.3.1 LCD Overview

Due to budget constraints and since the demonstration of the proof of concept for the UFind can be accomplished with the LCD that has been supplied with the microcontroller, LCD provided with the microcontroller will be used as the display unit. Since the user interface is an integral part of UFind, the design and operation of LCD will be thoroughly considered in this section.

The LCD has 120 segments in total; however, the built-in LCD driver in the microcontroller is capable of driving only 100 segments. The dark segments in Figure 5.4 shows the segments of the LCD that the microcontroller is capable of driving when STK502 microcontroller is in standard configuration. The appendix goes into further details of the theory of operation of LCD.

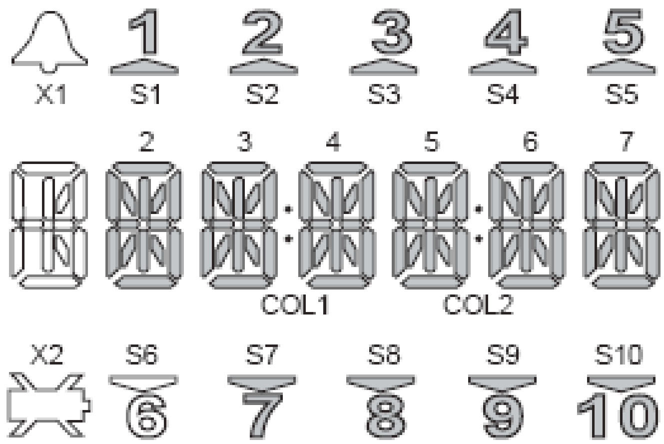


Figure 5.4: LCD segments [9]

5.3.2 FSM for Display System

The finite state machine for the user interface is presented in Figure 5.5. After turning on the device, Weiibo Inc. will be displayed. Upon pushing the joystick to the right, the version of the software shall be displayed. Pushing the button to the left while on "display software version" shall display Weiibo Inc. The transition of the states from "Find Car" to "Display Proximity," "Show Parking Information" to "Show Parking Lot Information," etc. shall adopt the same convention where pushing the button to the left shall bring the FSM back to the former state. However, the states that require entry of data shall be different where entering the button shall bring the FSM to the former state. Details on "Enter Parking Information," "Show Parking Information," "Display Proximity," and "Modify Password" are presented in the following section as flowcharts while flowcharts for other states have been put in the appendix.

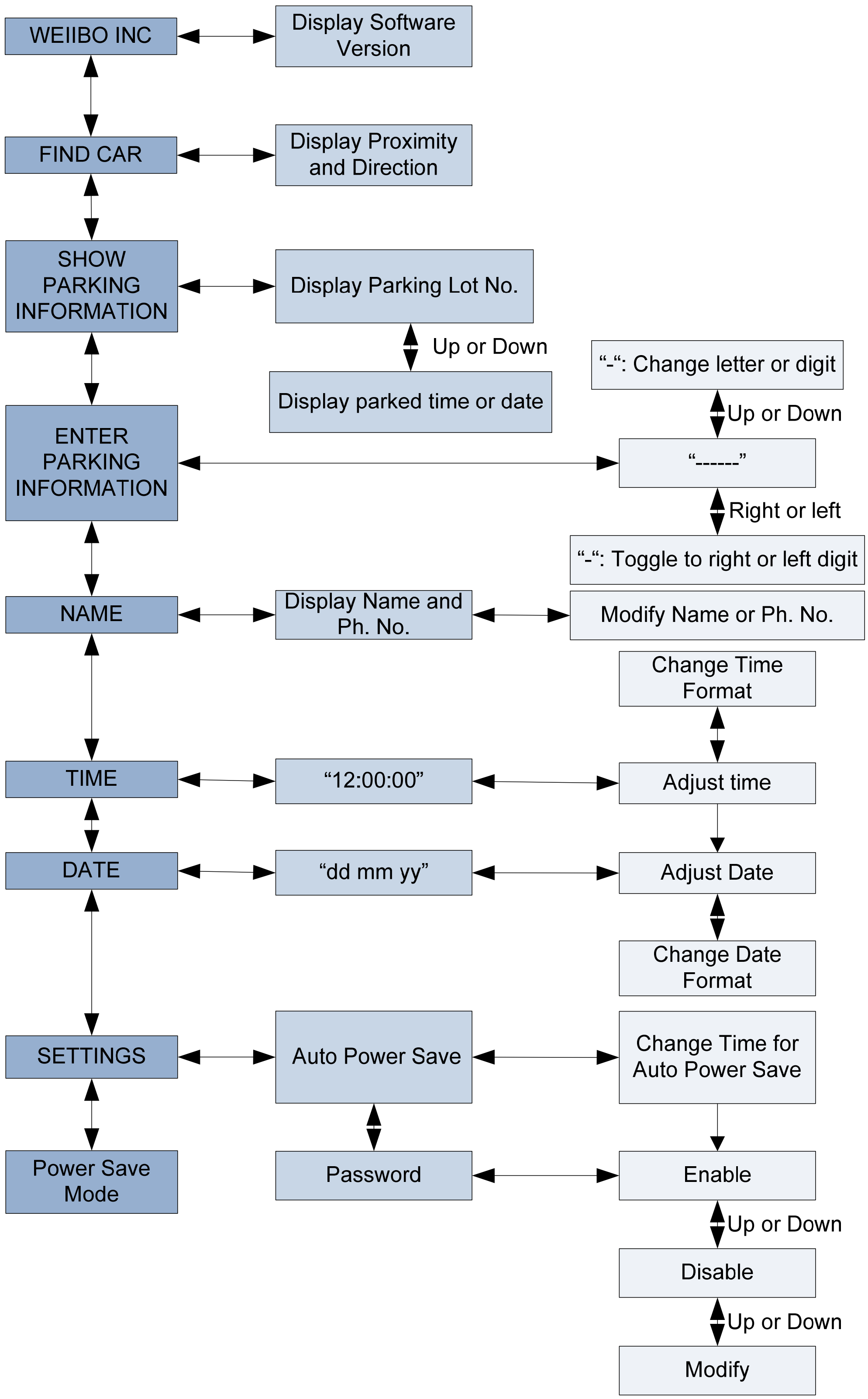


Figure 5.5: FSM for the Display Menu

5.3.3 Menu Subroutines

5.3.3.1 Enter Parking Information

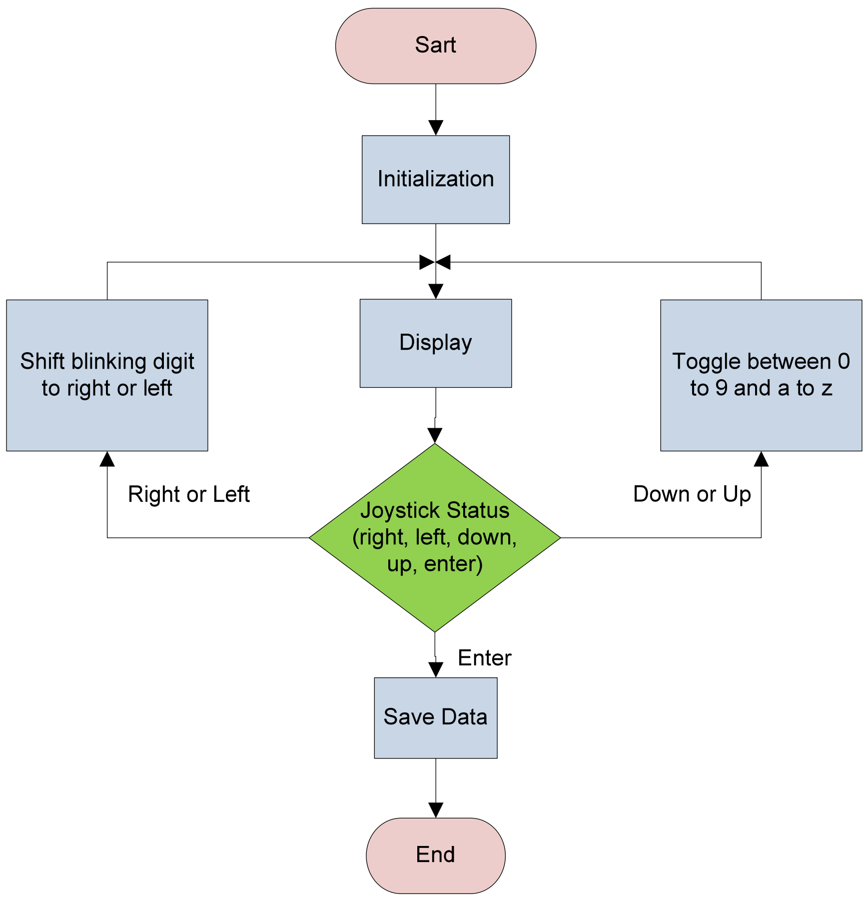


Figure 5.6: Flowchart for Enter Parking Information

Flowchart for "Enter Parking Information" which lets the user choose between letters and numbers on individual digits of the LCD is shown in Figure 5.6. The user shall be limited to six digits on the LCD. In the event that the user needs to input more than 6 digits, "Name" option, which shall support up to 25 digits, can be used. The explanation and flowchart for the subroutine, "Name," has been put in the appendix.

The subroutine for "Enter Parking Information" shall begin with the initialization of an array that will be used to display the six digits of LCD. Initially, the user shall be able to toggle between letters and digits for the first digit. Upon pushing the button to the right, the second digit can be toggled in a similar manner to the first digit. Subsequent pushes to the right shall enable the toggling of letters and numbers on the third, fourth, and fifth digits. However, pushing right while on the sixth digit shall enable the toggling of letters and numbers on the first digit. Pushing the button to the left shall also adopt the same convention as pushing the button to the right.

Furthermore, pushing the button up shall allow the user to choose between "0" to "9" followed by "A" to "Z" in a sequence. If the button is pushed up again while on "Z," the display shall change back to "0." Pushing the button down shall also toggle between letters and numbers similar to pushing the button down except that the sequence shall be reversed. Upon entering or pressing the button, the data shall be stored for retrieval by "Show Parking Info."

5.3.3.2 Show Parking Information

By retrieving the user-entered information from "Enter Parking Information," "Show Parking Information" will display the parking lot number. A flowchart for "Show Parking Information" is shown in Figure 5.7. To prevent against theft when the user loses UFind, a password feature shall be incorporated into menu options that display parking lot information. These menu options will include find car, show parking information, disable password, and modify password.

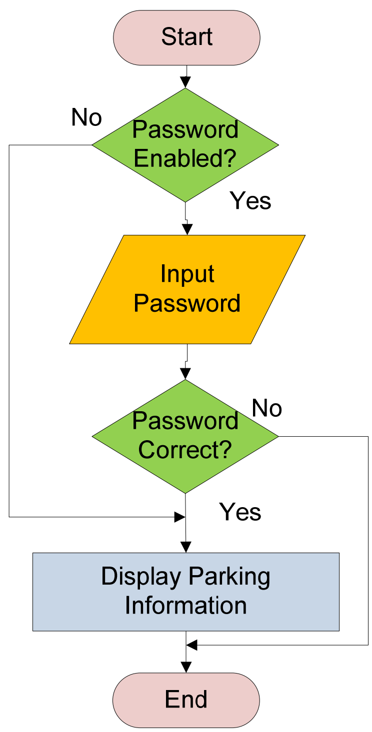


Figure 5.7: Flowchart for "Show Parking Information"

If password has been enabled by the user, "Show Parking Information" will prompt the user to enter password. If the correct password is input, "Show Parking Information" will display the parking lot information. On the other hand, if password has been disabled, when the button is pushed to the right while on "Show Parking Information," the user isn't prompted for a password and the parking lot information is displayed right after.

5.3.3.3 Modify Password

The flowchart for modify password has been presented in Figure 5.8. By choosing “Settings,” “Password,” and “Modify Password” in sequence, user is asked to input the current password. If the password is correct, user is prompted to enter a new password and if incorrect, the subroutine is terminated. After user enters a new password, the information is stored in EEPROM for verification.

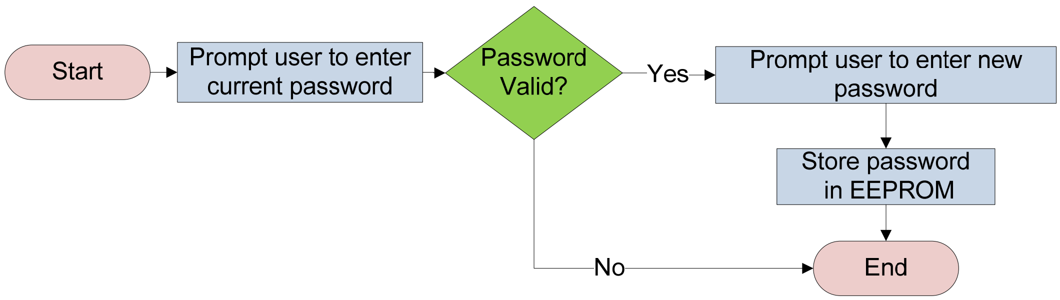


Figure 5.8: Flowchart for Modify Password

5.3.3.4 Find Car and Display Proximity

Figure 5.9 presents a flowchart for displaying proximity when “Find Car” is selected. The subroutine checks to see if the password has been enabled and if enabled prompts user to enter password. If the password is correct, “Start Finding Car” subroutine executes and the proximity is displayed.

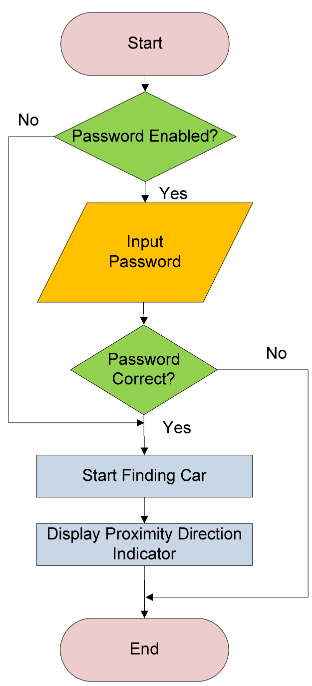


Figure 5.9: Flowchart for Display Proximity and Direction Indicator

6. Experimental Results

6.1 DAC Performance Results

Figure 6.1 and Figure 6.2 show the results obtained from the DAC circuit as outlined in section 3.3. Section 3.3 shows the results simulated using Pspice, whereas the results presented here are from the actual circuit. The experimental results and the results obtained using Pspice are summarized in Table 6.1. It can be seen that the results differs slightly from the simulation. The actual error in the voltage production is 14.5% and it occurs when a low voltage is outputted from the low pass filter. However, after characterizing the voltage VS range given by the receiver, a 14.5% voltage accuracy error translates to a distance error of 3.7meters.

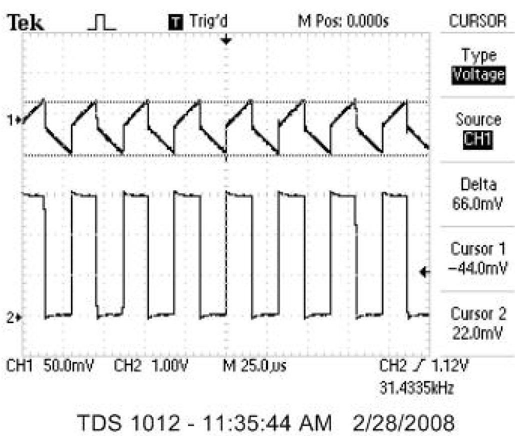


Figure 6.1: Experiment DAC output at 50% duty cycle

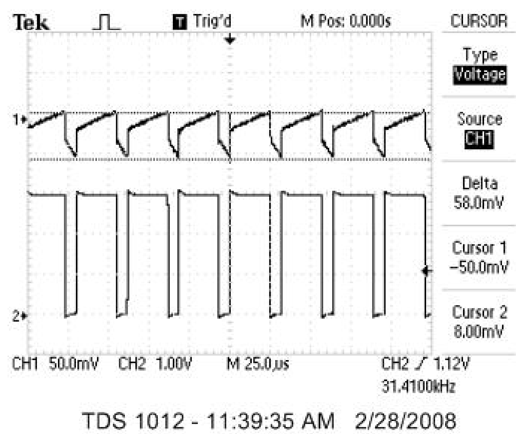


Figure 6.2: Experiment DAC output at 80% duty cycle

Table 6.1: Theoretical and experimental results for DAC output

Pspice Simulation results			Experimental results		
Duty Cycle	Voltage	Ripple	Duty Cycle	Voltage	Ripple
10%	0.264V	15.8mV	10%	0.276V	40mV
20%	0.539V	20mV	20%	0.556V	50mV
30%	0.809V	27mV	30%	0.848	56mV
40%	1.082V	30.7mV	39.3%	1.152V	60mV
50%	1.35V	31.6mV	49.4%	1.466V	66mV
60%	1.62V	30.6mV	59.1%	1.79V	62mV
70%	1.89V	26.3mV	68.8%	2.12V	62mV
80%	2.16V	20mV	78.6%	2.45V	58mV
90%	2.43V	15.8mV	88.3%	2.79V	48mV

6.2 LADJ Voltage vs. Power Level

The purpose of UFind is to be able to determine the distance between the user and his car. The principle on which this detection is based is that there is a relation between transmitted power and distance. This section determines what the relation is between the voltage applied to the LADJ pin of the transmitter and the power transmitted. Figure 6.3 shows the quality of the output power level as seen on the spectrum analyzer tool used to determine output power level.

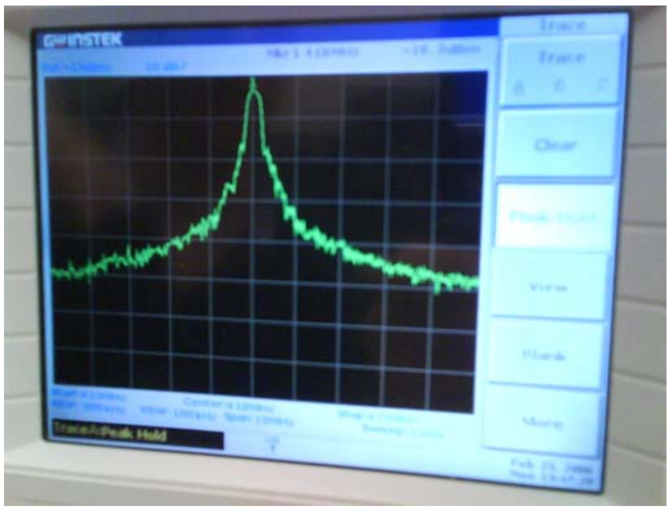


Figure 6.3: Experimental results showing the power sent VS LADJ voltage

Using the microcontroller to generate a voltage on the LADJ pin of the transmitter, we recorded the output power level at the center frequency for different input voltages. The results are shown in Figure 6.4. Equation 6.1 was derived from the trend line added to the graph.

$$P = 8.3858 \bullet \ln(LADJ) - 28.273$$ **Equation 6.1**

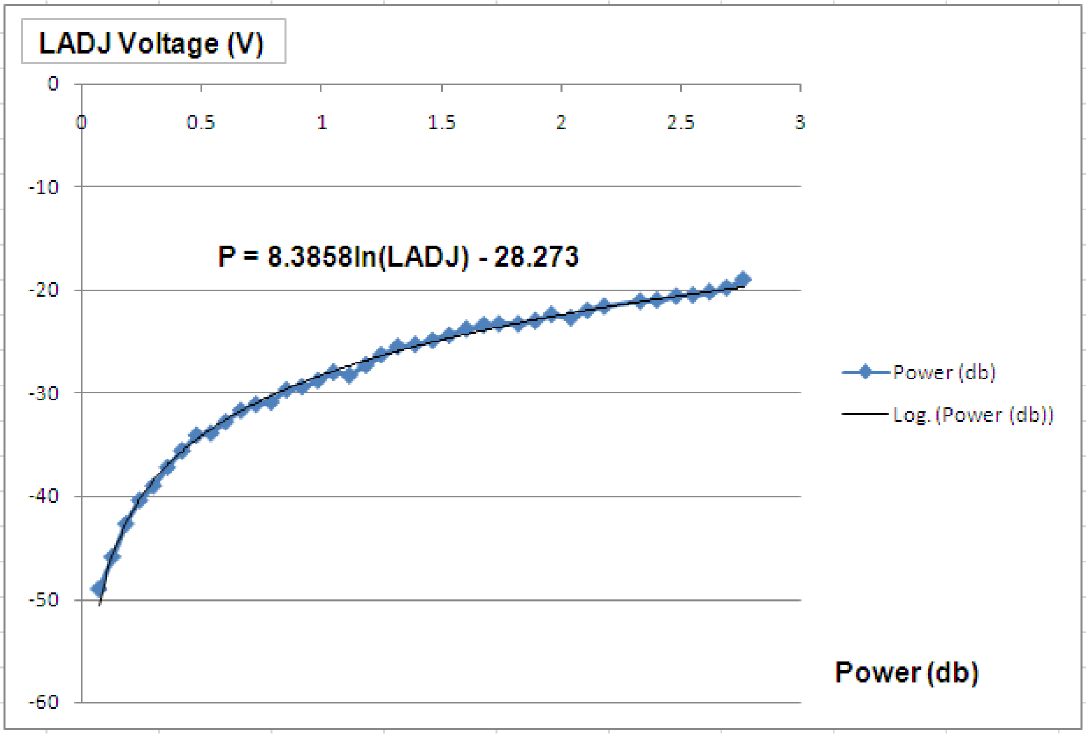


Figure 6.4: Experimental results showing LADJ voltage versus output power

6.3 LADJ Voltage vs. Distance

This section describes the relation between the LADJ voltage and the distance between the transmitter and the receiver. These experimental results were obtained by taking 5 different measurements at the same distance for each different distance. The mean value for each result was then calculated and plotted in Figure 6.5. From this figure, we can see that an exponential relation exists. Equation 6.2 was derived based on the trend line added to the graph. It can be used for predicting the covered distance based on the LADJ voltage.

$$Distance = 23.534 \bullet \ln(LADJ) + 70.8 \quad \textbf{Equation 6.2}$$

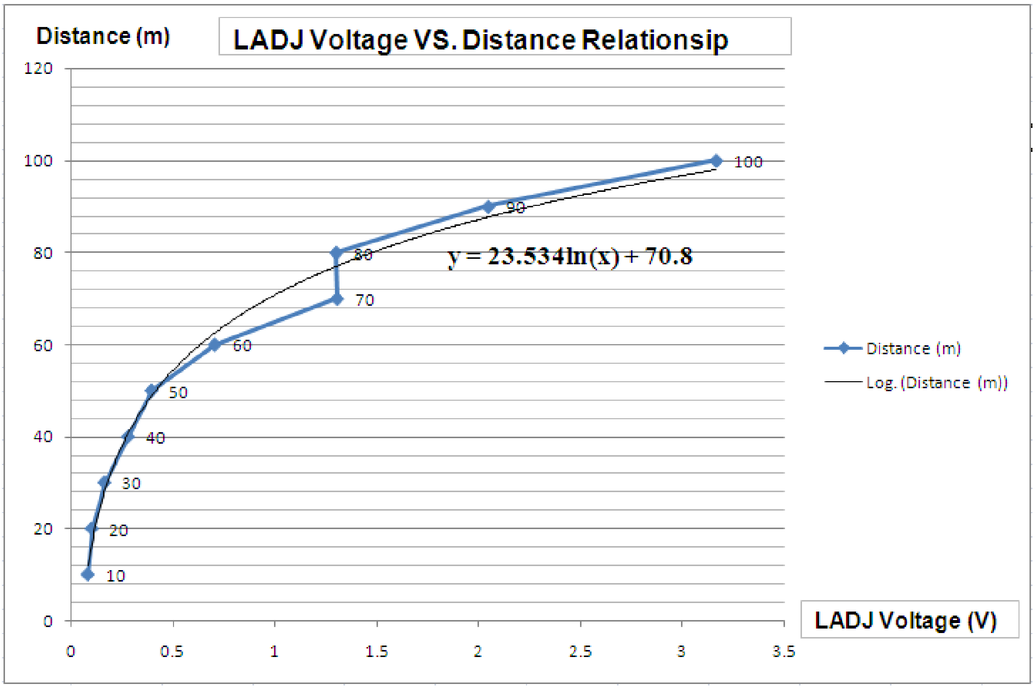


Figure 6.5: Experimental results of LADJ voltage VS. Distance

7. System Test Plan

After the completion of the prototype, UFind will be subjected to a set of comprehensive tests. In addition to these tests, UFind will be tested in stages throughout the development cycle. These tests can be categorized into:

- tests conducted in the development of prototype
- tests conducted after the completion of prototype
  - Verification and validation of hardware and software running in the prototype
  - User-trials

For testing the software protocols, logs will be used to verify each phase of development. For instance, a particular phase of the development where a certain task is set to be accomplished will be tested by making sure that the expected logs are achieved. This shall be repeated for all the different tasks that are to be accomplished in the entire development cycle. Also, the analysis and verification of logs will allow the engineers to find software flaws for various user-environments and scenarios.

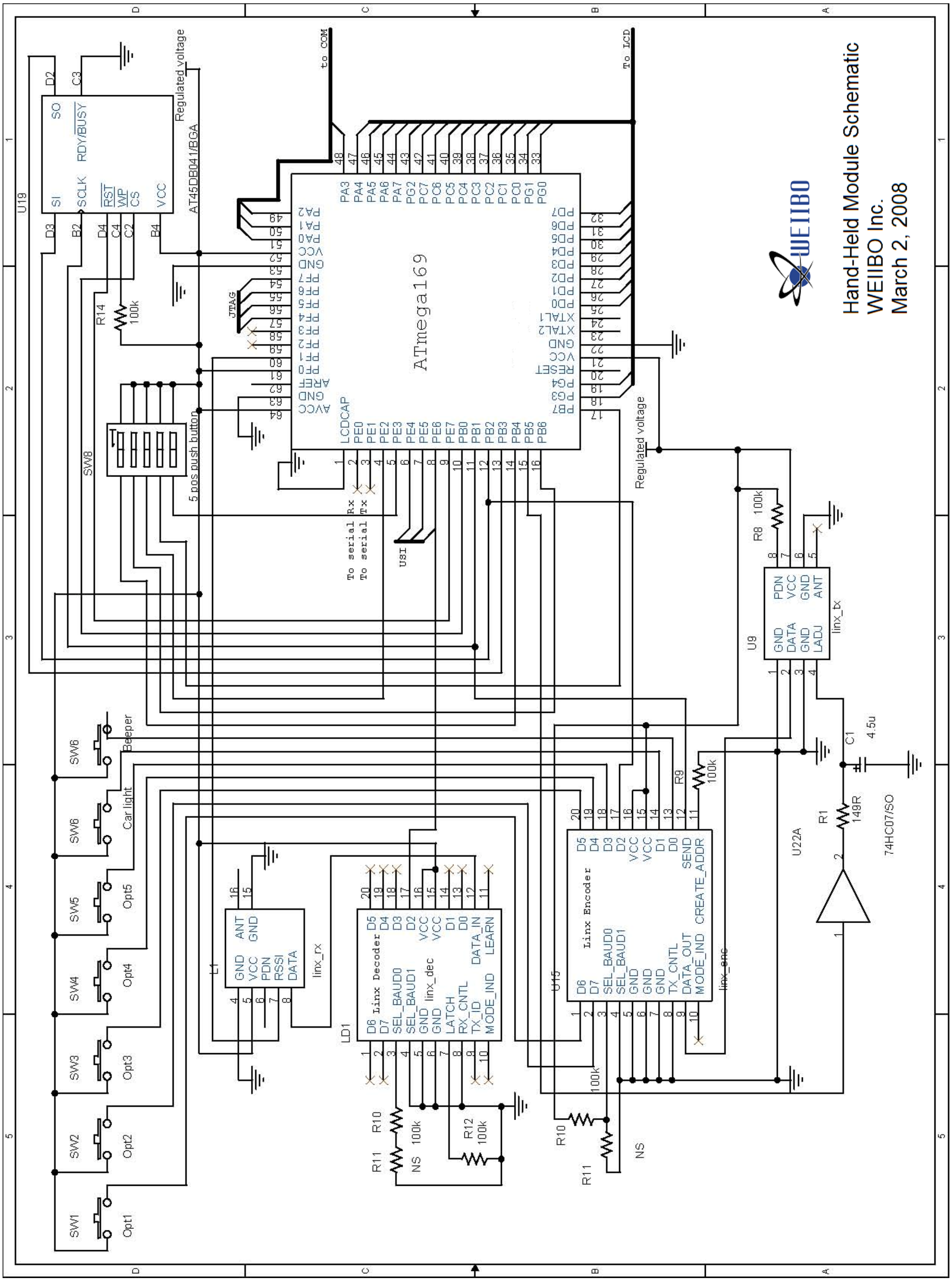
While conducting tests on UUT, software and hardware performances will play equally important roles in determining the limitations of various functions. To test the limitations posed by the hardware, generation of logs capable of keeping track of the limitations will be implemented. Hardware and software are closely knit in the case of UFind and in many aspects,

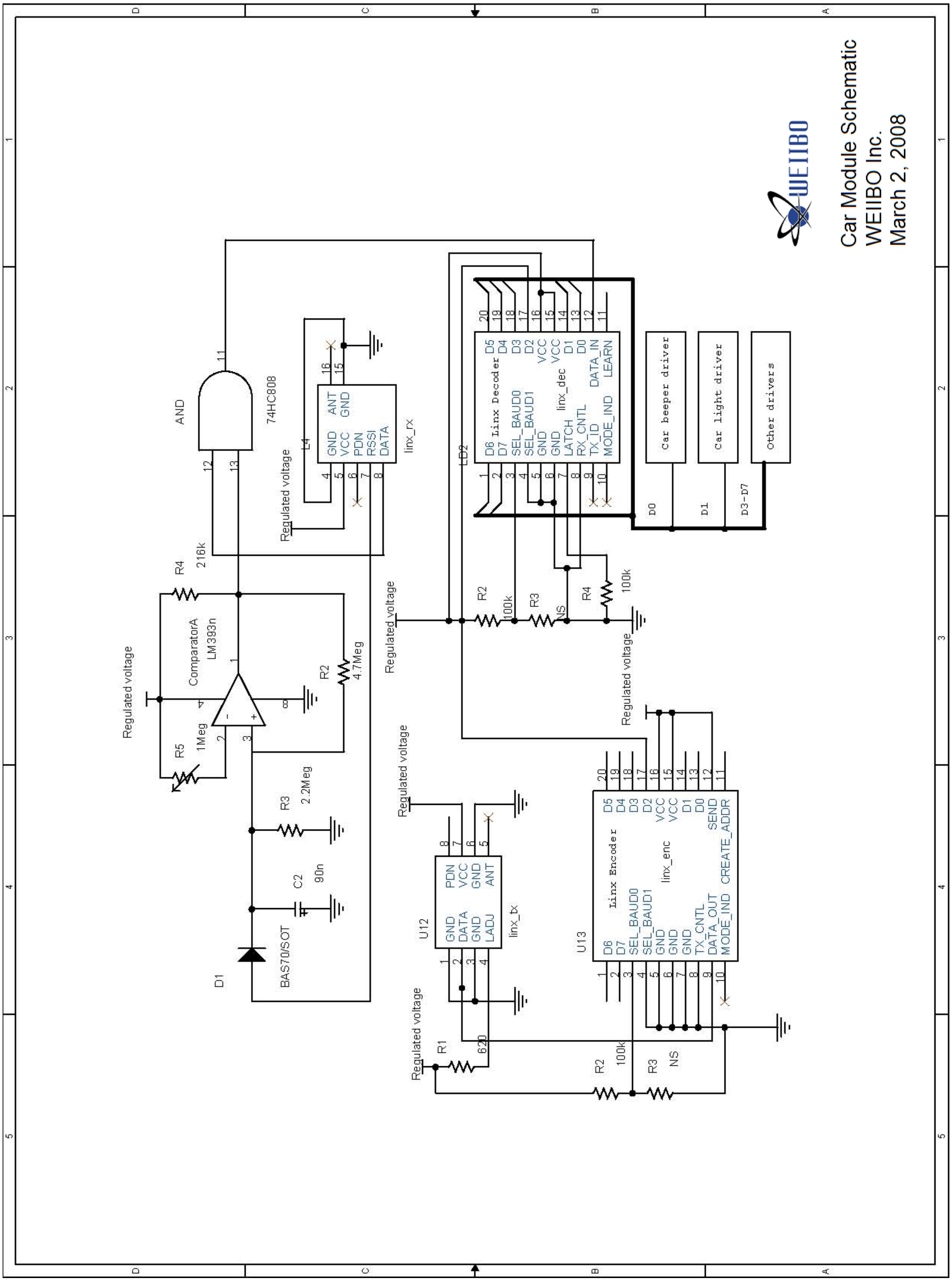
testing the software by analyzing logs and keeping track of the limitations posed by the hardware would also apply to testing the hardware.
Aside from testing hardware with the help of logs to verify limitations posed by the hardware, prototyping boards, connections, and integration of components will be carefully conducted and tested for any errors in connections and integrations prior to its development with the software. Verification and validation of the software/hardware will be carried out after the design of the prototype. This phase will involve black box testing in a user-trial like environment and will be conducted by engineers of Weiibo Inc. The logs shall again be used to help debug any issues that will be detected in the course of the verification phase. After satisfactory completion of the verification tests, the software shall be considered for user-trials. User-trials on the UFind will then be conducted where users will be asked to provide feedback on the impression in terms of appearance and functionalities of UFind.

8. Overall Design Schematics

Hand-held and Car Module Schematics

The following schematics demonstrate the overall designs for the hand-held and the car modules excluding minor parts such as voltage regulator schematic and some microcontroller sub-circuits provided in data sheets.


Hand-Held Module Schematic
WEIIBO Inc.
March 2, 2008
ATmega169
Linx Encoder
Linx Decoder
linx_tx
linx_rx
AT45DB041/BGA
5 pos push button
To serial Rx
To serial Tx
to COM
To LCD
Regulated voltage
74HC07/SO


Car Module Schematic
WEIIBO Inc.
March 2, 2008
Linx Decoder
linx_dec
Linx Encoder
linx_enc
linx_rx
linx_tx
AND
74HC808
ComparatorA
LM393n
Car beeper driver
Car light driver
Other drivers
Regulated voltage
BAS70/SOT

9. Conclusion

The design specification document outlines the design details corresponding to the functional specifications presented in the FSD for the proof of concept prototype. It has been written to resemble as close as possible to the designs pertaining to the functional specifications. The TPA method and the TOFLF method will be both developed in parallel and the best performance will be selected as the final design.

Furthermore, the system test plan will be used in the development cycle as well as after the completion of the proof of concept prototype to ensure correct functionality of the UFind. We have been achieving more than the target milestones for product test and development, and we are certain that we will be able to complete the proof of concept prototype by the specified target date April 08, 08.

10 Appendices

10.1 Power Level and LADJ Voltage Relationship curves

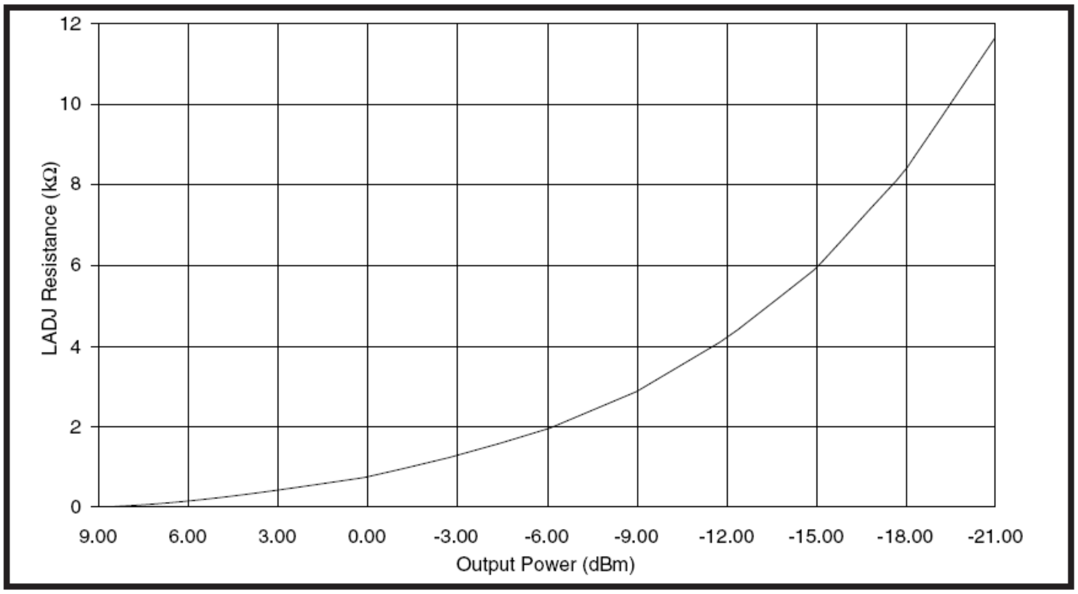


Figure 10.1: Relationship between Output power and LADJ resistance [5]

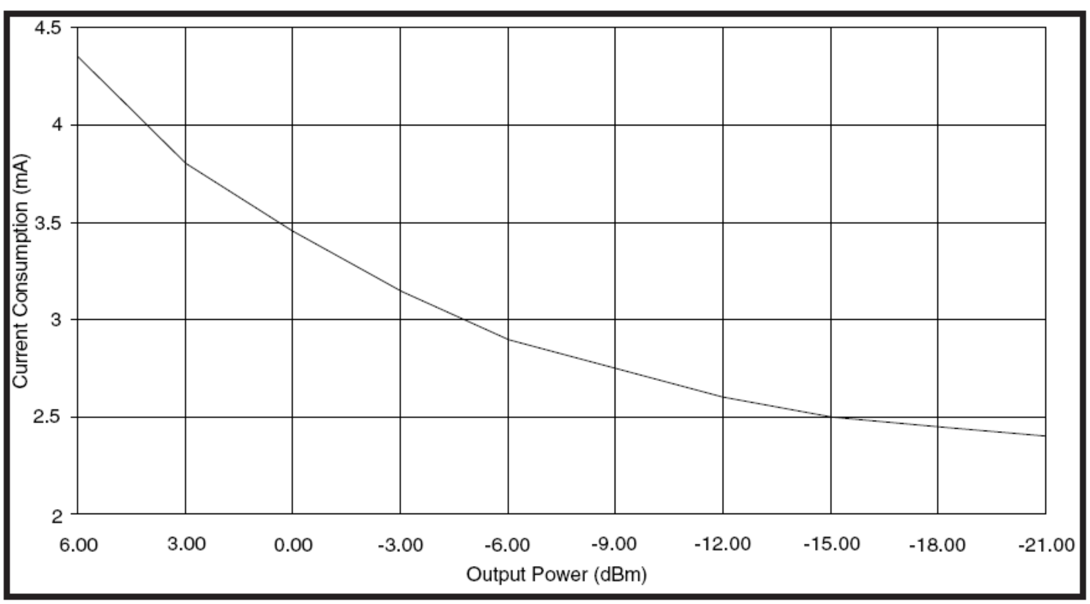


Figure 10.2: Relationship between Output power and Current Consumption [5]

10.2 MS Encoder and Decoder Flow Charts

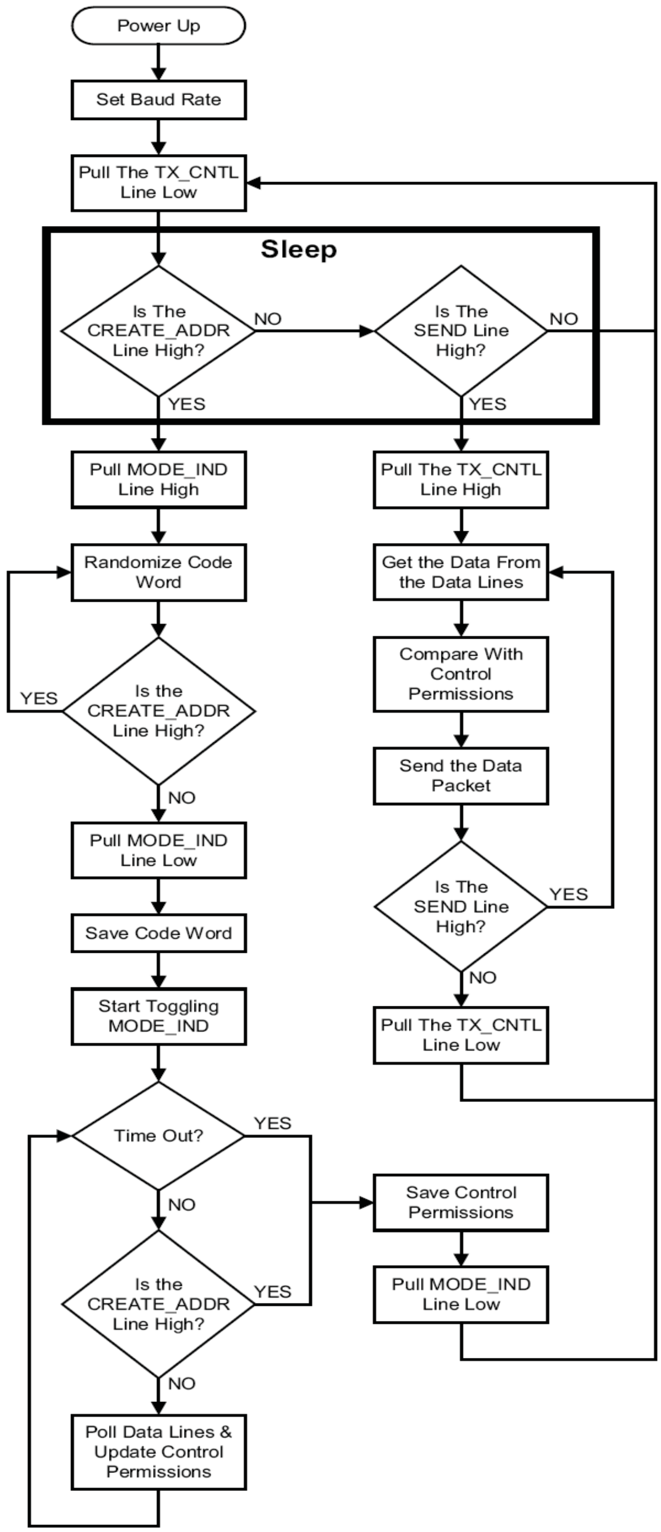


Figure 10.3: Linx MS Series Encoder Flowchart [3]

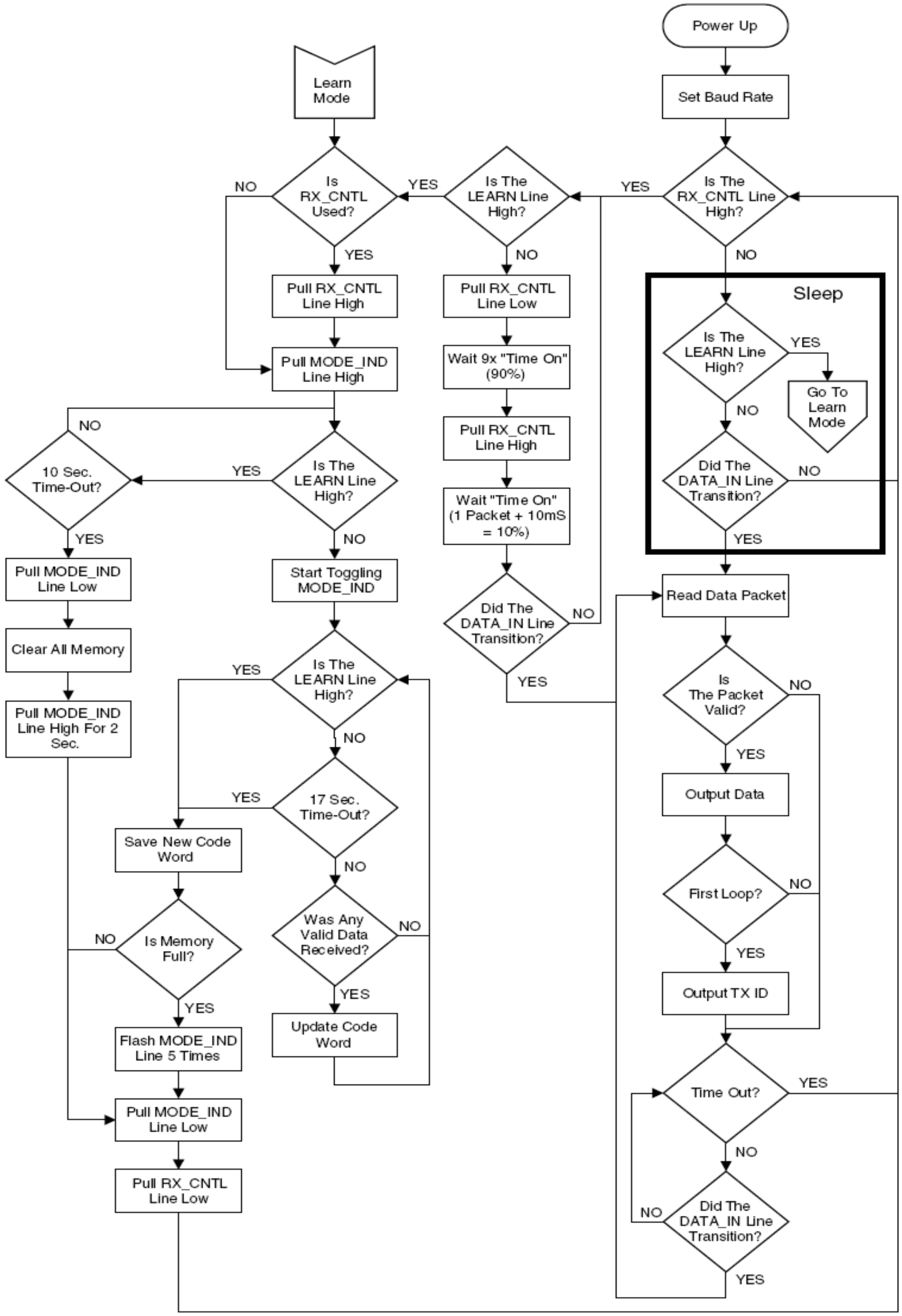


Figure 10.4: Linx MS Series Decoder Flowchart [4]

10.3 Communication Chips Pin Arrangements [2, 3, 4, 5]

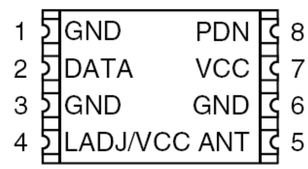


Figure 10.5: Linx LR Series Transmitter[5]

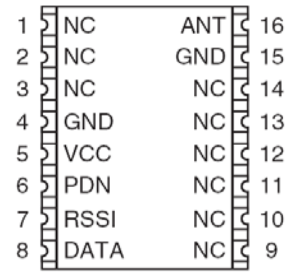


Figure 10.6: Linx LR Series Receiver[6]

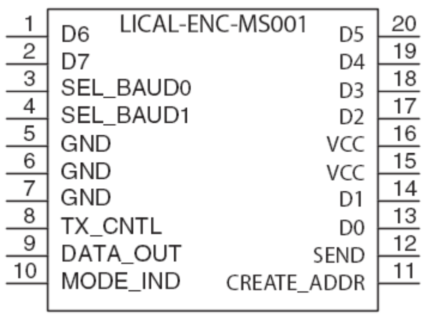


Figure 10.7: Linx MS series encoder [3]

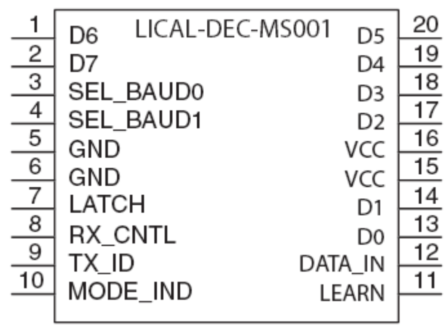


Figure 10.8: Linx MS series Decoder [4]

10.4 LCD

10.4.1 Theory of Operation

The LCD is based on the technology that employs rod-like molecules or liquid crystals that bend light. When the crystals are energized, they redirect light such that the light is absorbed by one of the polarizer. The un-energized crystals let the light pass through polarizing filters which results in a standard background color. Since driving the LCD by direct current (DC) causes electrophoresis effects (dispersion of particles under a uniform electric field), it is important that the LCD be driven by alternating current (AC) [8].

The LCD can be clocked by either an external asynchronous or an internal clock source. The LCD driver by default uses internal clock source which is equal to the system clock, $clk_{I/O}$ as shown in Figure 10.9. The external clock source can be taken by assigning the clock source to the TOSC pin. [8]

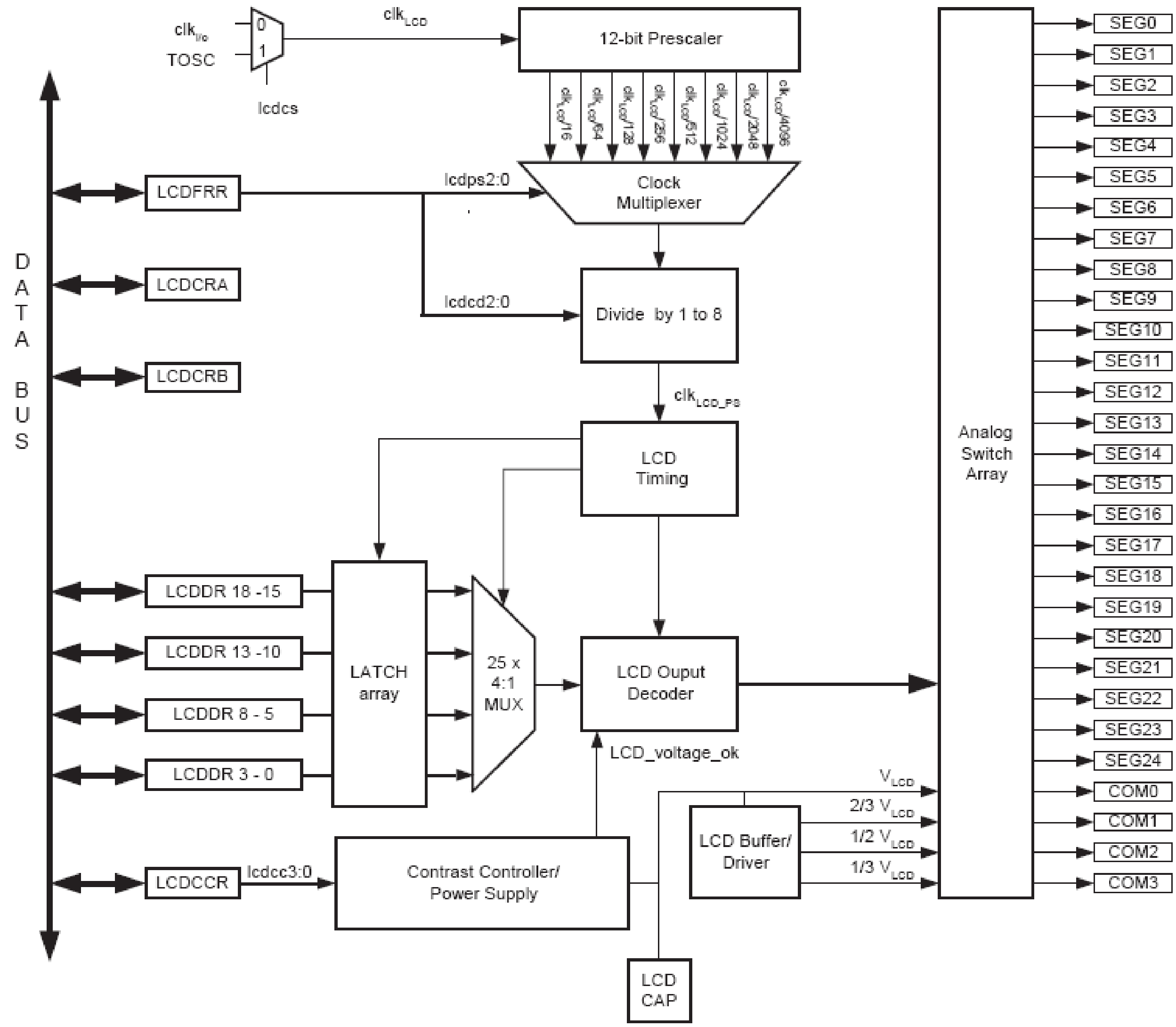


Figure 10.9: Overview of the LCD module [9]

One LCD segment has two terminals. While one terminal is connected to a segment driver, the other terminal is connected to a common terminal. By supplying AC between the segment driver and common terminal, the segment gets polarized and becomes visible.[9]

LCD segments can be turned on and off by writing to the I/O registers. Writing 1 to the I/O register energizes the LCD segment and a 0 de-energizes the LCD segment. Various LCD segments (SEG0 to SEG24) share the same common terminal (COM0 to COM1). Since twenty five segments share the common terminal, a waveform as shown in Figure 10.10 and Figure 10.11, needs to be applied for controlling the 100 segments individually. If one segment were to share one common terminal, a segment can be energized by applying an absolute differential voltage (different phases at segment and common terminal pins) across the segment pin and common terminal. However, to control 100 segments that share four common terminals, a waveform of the type shown in Figure 10.10 needs to be applied. [9]

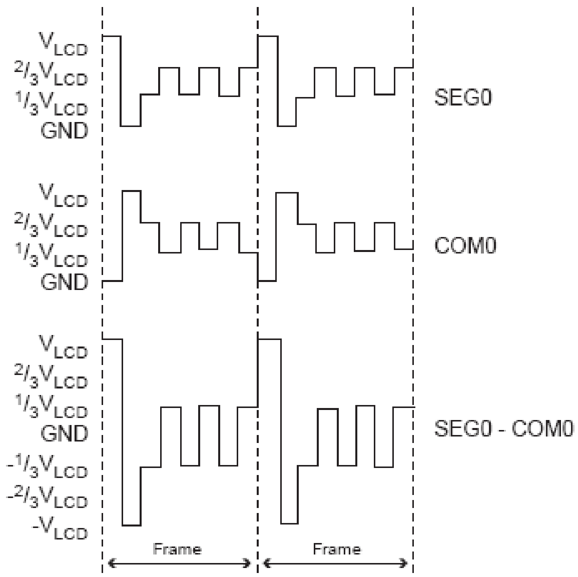


Figure 10.10: SEG0 energized with differential voltage[8]

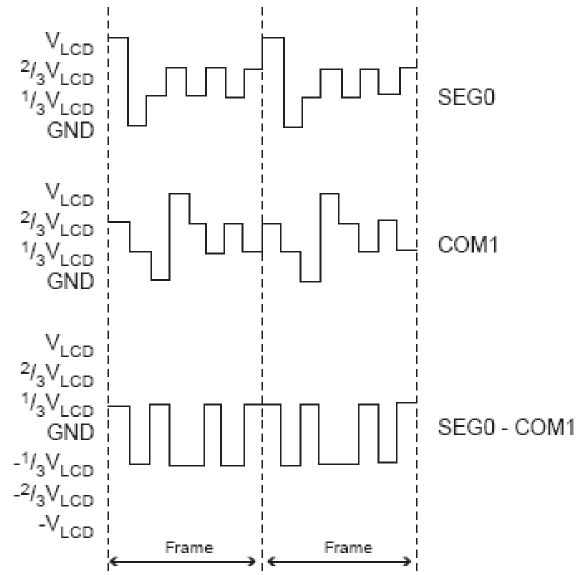


Figure 10.11: SEG0 de-energized with same voltage[8]

In Figure 10.10, SEG0 and COM0 have two different phases, thus, SEG0 is energized. In Figure 10.11, SEG0 and COM1 have the same phase, thus SEG0 is de-energized. Since 100 segments share 4 common terminals, the waveform with ¼ duty cycles is used to apply a different phase for energizing a segment and same phases for de-energizing segments.

The LCD has 120 segments which are controlled by 30 segment lines and four back-planes, but the microcontroller is only capable of driving 100 segments as the microcontroller in standard configuration has 25 segments shared with one COM terminal.

10.4.2 Main LCD Driver functions

This section will present a brief overview of the LCD driver subroutines that will be used with the LCD subroutines for UFind.

The LCD driver functions are:

10.4.2.1 Initialization of LCD (LCD_init)

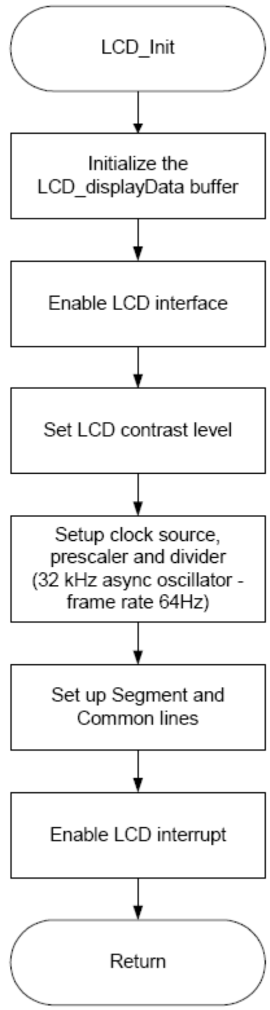


Figure 10.12: Flowchart of the LCD_init function [9]

Figure 10.12 presents a flowchart of the initialization of LCD. Firstly, the data buffer of the LCD is cleared after which the contrast level is assigned. This is followed by setting of the external asynchronous clock to 32 Hz and LCD pre-scaler and divider to generate a frame rate of 64 Hz. Lastly, the LCD start of frame (SOF) interrupt is enabled. [9]

10.4.2.2 LCD start of frame interrupt

The LCD SOF interrupt handles the connection of data from the LCD display data buffer to the LCD data registers when an interrupt occurs. When the LCD SOF interrupt subroutine is executed, the time for the LCD is decremented. After the timer reaches zero and an update request flag is set, the LCD timer is reloaded followed by the LCD display data buffer latching to the LCD data registers. Upon completion of latching, LCD status update request flag is set to true. In the event that the LCD status update request flag is false for various reasons, timer of the LCD is set to the smallest value and the LCD status update complete flag is set to false. This will allow the LCD to update in the next first execution of the LCD SOF interrupt. [9]

10.4.2.3 Writing Digit to the LCD (LCD_WriteDigit)

The LCD_WriteDigit converts an ASCII character to be displayed on the LCD and copies it into the LCD display data buffer. The LCD display data buffer is latched to the LCD data registers which is taken care of by the LCD SOF interrupt. [9]

10.4.3 LCD subroutines

10.4.3.1 Enter Name

Figure 10.13: Flow chart for Enter Name

The subroutine for "Name" is very similar to the subroutine for "Enter Parking Information." However, "Name" subroutine will be able to input and display letters or digits as dictated by

"STRLENGTH" which has been set to 25 for the proof of concept prototype. The "Name" function can be used by the user to input miscellaneous information one of which can be the contact number of the user.

10.4.3.2 Show Clock and Date

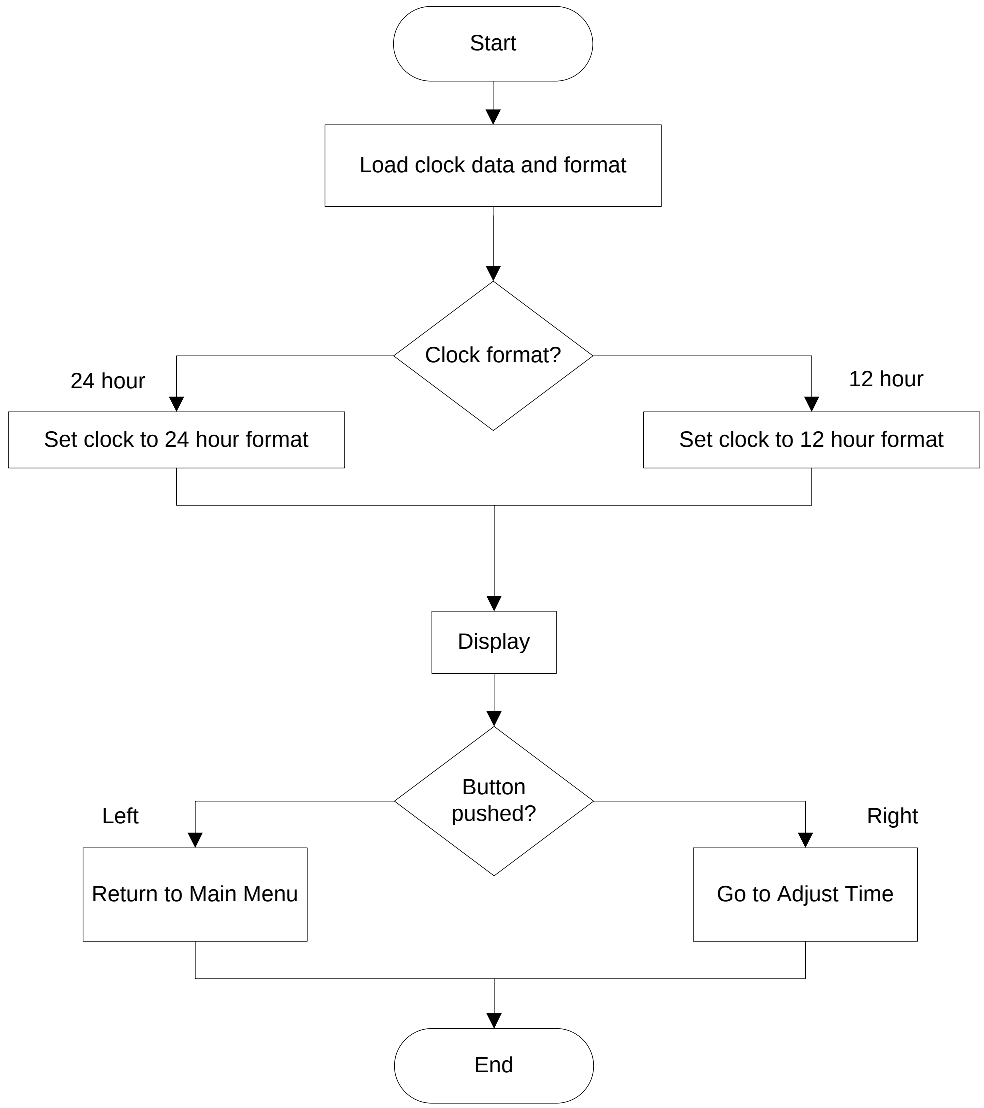


Figure 10.14: Flowchart for showing the clock

The flowchart for showing the clock in six digits of the LCD is shown in Figure 10.14. The display of date is very similar to the flowchart for showing the clock except that the first process would need retrieval of day, month, and year as opposed to hour, minute, and second. The display would also differ depending on the user's choice on what date format he/she has chosen.

10.4.3.3 Adjust Time and Date

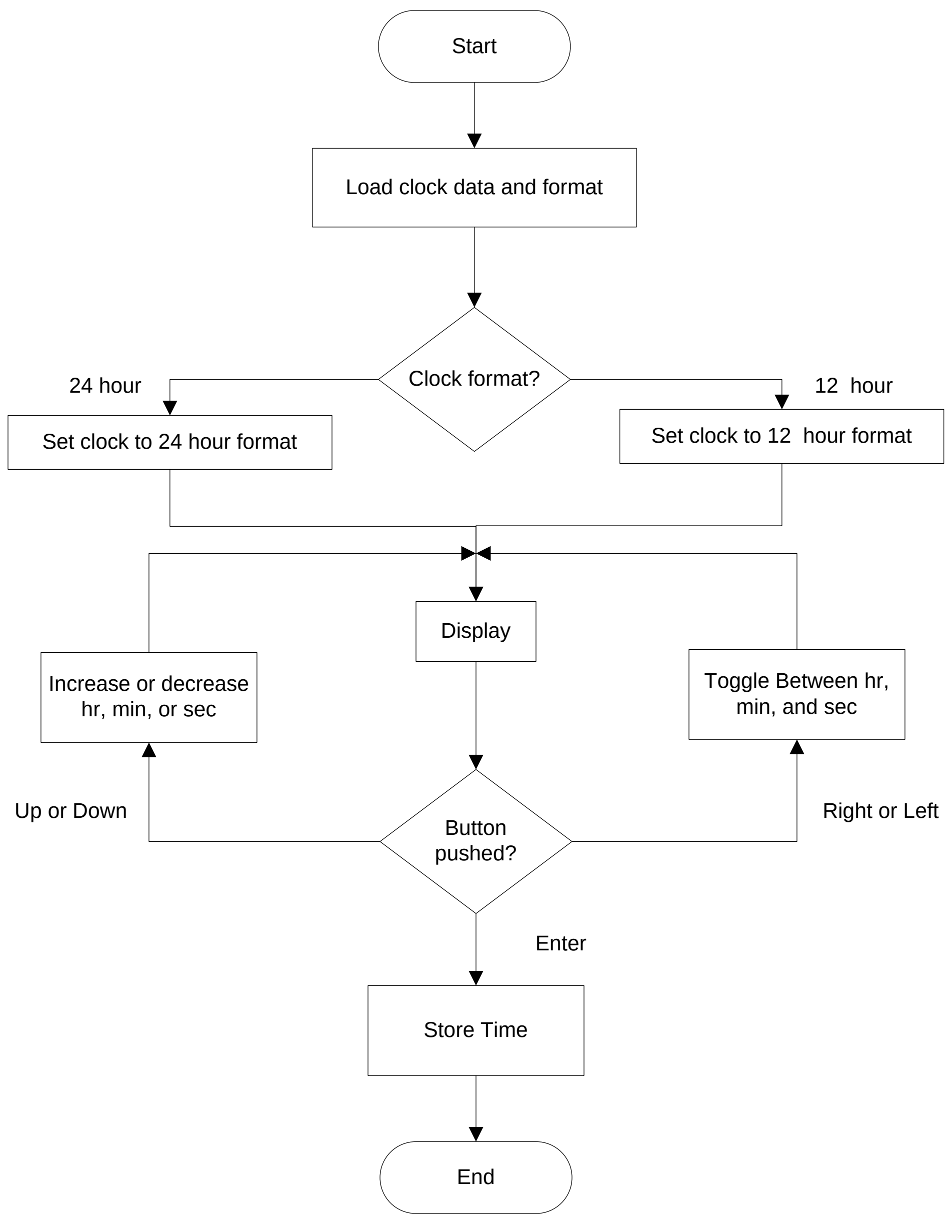


Figure 10.15: Flowchart for adjusting the time

The flowchart for adjusting time is shown in Figure 10.15. The user will be able to move to the hour digits, minute digits, or second digits by pressing right or left. The user will also be able to increase or decrease the time for hour, minute, or seconds by pressing up or down respectively. The flowchart for adjusting date is also similar to Figure 10.15 except that the hour, minute, and seconds are replaced by day, month, and year.

10.5 Joystick

The joystick that comes with the microcontroller kit will be used to take user inputs. The joystick is capable of five different types of inputs which are left, right, up, down, and center-push. The shared line for all the movements shared a common ground. Hence, a port in the microcontroller needs to be established as an input pin to detect the interrupts. A schematic for the joystick is presented in Figure 10.16 [12].

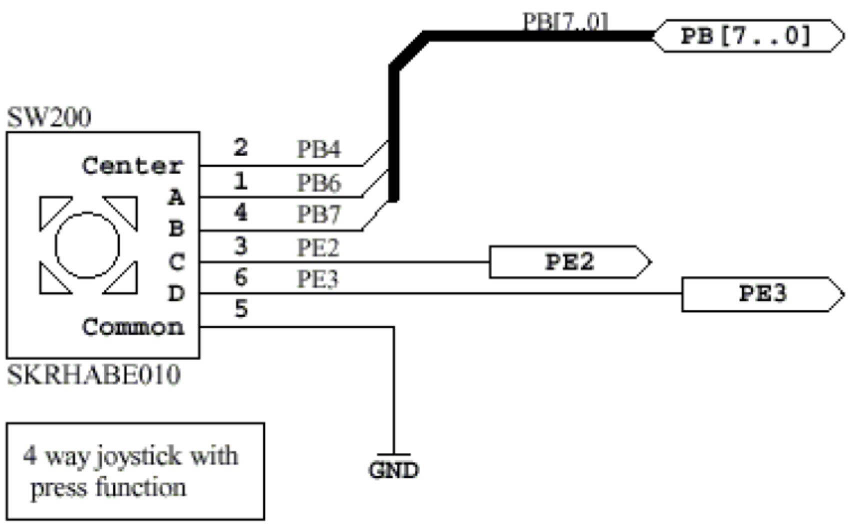


Figure 10.16: Schematic for the Joystick [12]

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