Hardware Development in WLAN Modules

Major Project Report

Submitted in partial fulfillment of the requirements
for the degree of

Master of Technology
in
Electronics & Communication Engineering
(Embedded Systems)

By

Shubham Yadav
(14MECE28)

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Declaration

This is to certify that

a. The thesis comprises my original work towards the degree of Master of Technology in Embedded Systems at Nirma University and has not been submitted elsewhere for a degree.

b. Due acknowledgment has been made in the text to all other material used.

- Shubham Yadav

14MECE28

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Certificate

This is to certify that the Major Project entitled **"Hardware Development in WLAN Modules "** submitted by **Shubham Yadav (14MECE28)**, towards the partial fulfillment of the requirements for the degree of Master of Technology in Embedded Systems, Nirma University, Ahmedabad is the record of work carried out by him under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination.The results embodied in this major project, to the best of our knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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Certificate

This is to certify that Major Project entitled **"Hardware Development in WLAN "** submitted by **Shubham Yadav (14MECE28)**, towards the partial fulfilment of the requirements for the degree of Master of Technology in Electronics and Communication Engineering (Embedded Systems), Institute of Technology, Nirma University, Ahmedabad is the record of work carried by him under our supervision and guidance. In our opinion, the submitted work has reached the level required for being accepted for the examination.

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Abstract

The need for higher data rates and techniques to improve performance of WLANs is becoming crucial to support different types of applications. To get that extra performance when designing a WLAN, the elements to be taken into consideration are throughput, Radio frequency bands ,Transmit power settings, Transmission channel settings ,Data rate settings, Antennas, Amplifiers, Obstacles, Radio signal interference ,Channel width settings, Power Consumption, etc. Radiated Leakage, Inter-modulation products, and base-band frequency distortion tests are very essential in determining the performance , data rates as well as other required criteria .

Making different new setups ,automatic robotic platforms and preparing scripts is an important task in the Lab Analysis. Arranging raw result data in a proper format and plotting it, is an important task to make result analysis easy. Python automaton scripts are also written for these tests. Moreover, existing code is modified to add new functionalities like screenshot capture , making of excel datasheets etc .

At Broadcom, Radiated Leakage Setup compatible with the FCC standards has been designed and different scripts for automation have been prepared. Also a self navigating intelligent Robot has been designed and developed that can carry different DUTs and perform range related tests overnight.This facilitates the automated tests without human presence. Scripting Languages like Python, TCL etc and Broadcom proprietary tools have been used for the same.

Contents

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Abbreviation Notation and Nomenclature

PER .... Packet Error Rate
EDR .... Enhanced Data Rate
NBR .... Narrow Band Radio
WBR .... Wide Band Radio
DUT .... Device Under Test
HCI .... Host Controller Interface
USB .... Universal Serial Bus
UART .... Universal Asynchronous Receiver/Transmitter
GPIB .... General Purpose Interface Bus
RF .... Radio Frequency
BT .... Bluetooth
TSSI .... Transmitter signal strength indicator
SA .... Spectrum Analyzer
Vdet .... Voltage Detector
ADC .... Analog to Digital Convertor
PA .... Power Amplifier
EVM .... Error Vector Magnitude
Tx .... Transmission
Rx .... Reception
CW .... Continuous Wave
IM .... Intermodulation
HS .... High Speed
HD .... Harmonic Distortion
LOFT .... Local Oscillator FeedThrough
IQ .... In phase Quadrature phase
PAPR .... Peak to Average Power Ratio
BR .... Basic Rate

BLE .... Bluetooth Low Energy

ISM .... Industrial, Scientific and Medical

BPF .... Band Pass Filter

OP .... Output Power

FEM .... Front End Module

Chapter 1

Introduction

This chapter deals with company background and an introduction to the other chapters. Also provides the window for the project requirement and other related aspects

1.1 Company Background

Broadcom Ltd. is a Fabless Pioneer company in the field of Networking and Communication with more than 400 Patents and connecting nearly every device that can communicate wire-lessly or wired way.It holds an objective to provide a faster, portable, cheaper and better communication with new inventions and reforms on existing technology.

1.1.1 WLAN Hardware Development Group

This group basically performs the testing operation of various WLAN chips produced by company. As per the requirements of the customers, Company manufactures different WLAN chips as per different Wi-Fi standards such as 802.11 a/b/g/n/ac etc. The testing and verification operation is done by this group. This team also focuses on measuring several parameters of chip like SNR, error vector magnitude, Rx sensitivity, noise figure, phase noise, crystal pulling, spurious radiation, Spectrum mask, ACPR(adjacent channel power rejection ratio), HD2 (harmonic distortion of order 2), IM3(Intermodulation distortion of order 3) etc. In each of the chip, front end module is external to the chip. This group builds the hardware board that contains front end module and WLAN chip. All the different parameters related to the performance of the WLAN chip are measured and verified here. These parameters include transmitter gain, receiver gain, receiver sensitivity, error vector magnitude, noise figure, crystal pulling, Spurious radiation, phase noise, Spectrum emission mask, spectrum flatness etc. This team monitors these parameters and if the results are not proper then take the corrective measures for the correction. Each WLAN chip undergoes various stages of testing and verification, before it goes in final assembly line. There are different testing boards needs to be designed for measuring in different parameters (Just to observe the performance of chip),these boards are not the part of final product. They are just for testing and verification.

1.2 Motivation

The growing demand for high date rate communication in WLAN has driven the market toward the 5GHz IEEE 802.11n and 802.11ac standards. These standards are based on orthogonal frequency division multiplexing modulation consisting of 52 subcarriers, each subcarrier being 256QAM (11ac), 64QAM (11n), 16QAM, QPSK and BPSK modulated. Orthogonal frequency division multiplexing systems demand high peak to average power ratio for the modulated signal so that it satisfies IEEE 802.11a linearity requirement. Therefore, WLAN modules need continuous development [1].

In modern radio telecommunication systems, a fully integrated power amplifiers design with a reasonable output power, high gain and high efficiency remains challenging considering the linearity aspect of the power amplifier. Linearity and efficiency are the two important characteristics of power amplifiers, either of them has to be improved by trading-off for the other parameter [1].

Receiver systems are normally required to process very small signals. The weak signals cannot be processed if the noise magnitude added by the receiver system is larger than that of the received signal. Increasing the desired signals amplitude is one method of raising the signal above the noise of the receiver system. Signal amplitude can be increased by raising the transmitters output power. But this in turn affects the linearity of the system as other factors come into picture and thus degrades the EVM floor.

Higher heat dissipation is typically required to increase transmitter output power. Cost, government regulations, and interference with other channels also limit the transmitter power available for a given application.

1.3 Problem Definition

There are many factors that affect the performance, data rates, throughput, current leakage, radiated leakage etc. These factors if not countered, degrades the performance of the modules and forbid the device to meet the customer specs. To improve degraded performance, it is necessary to know what exactly is causing the problem. Hardware development and Problem elimination helps to discover cause of the problem and find possible solution.

1.4 Project Workflow

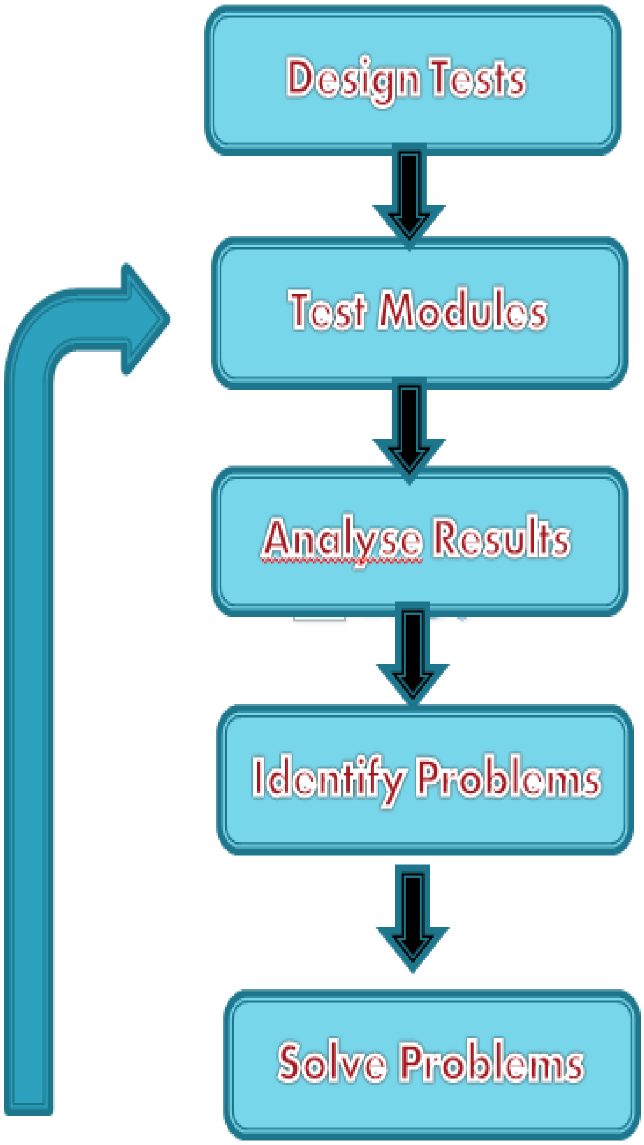

Figure 1.1: Project Workflow

1.5 Contribution

Design of Wi-Fi chips is a complex process and even after fabrication there are many problems that arise. Debugging supports various tests. These tests can be divided in parts: Transmitter test and Receiver test, Digital tests, Packet related tests, Radiated tests, Tuning etc.

In Current Measurement Tests, setups as well as automated Test scripts have been made. Automated Current measurement scripts had several problems related to accuracy of the SMU, split currents etc which have been solved. Different Sensitivity (RxPER) and Noise Figure Tests are performed. In Packet tests throughput tests are performed, aswell as packet current at different rates is also measured. In Radiated tests, aspects of different non-linearities and the interferences were looked upon with tests performed on the same.

Test results have been analyzed for how the result of a particular test looks, whether it needs improvement or not, and if improvements were needed, then what exactly is causing the problem, etc. Some of these tests are explained in detail.

Different automated test set-ups (stations and bench) have been made. Different new problems, that aroused meanwhile posted a requirement of creating new test setups that are conventionally not present.

1.6 Thesis Organization

Rest of the thesis is organized as follows:

Chapter 2 contains brief detail of various IEEE WLAN standards, comparison between standards and some modulation schemes falling into IEEE 802.11b standard.

It also describes the basics of the Packet formation. The essential part in chip design i.e. Debugging of the issues, is describes in this chapter.

Chapter 3, This section deals with the Current measurement tests. It explains steps for performing the tests and their result analysis.Also different problems encountered as well as their solutions are also mentioned in this chapter.
Chapter 4, This section explains the various Radiated Leakage tests like Harmonic leakage, Inter-modulation, Nx frequency base band and their setups. It helps meeting the FCC Limits and improve the design of chip. Problems encountered and their practical solutions are also discussed here.

In Chapter 5, In this Chapter Automated Range tester Robot with its design aspects and technical limitations is discussed.Also Some new experiments are mentioned that required making of new setups and rigorous testing and analysis of the results.

In Chapter 6, Conclusion and Scope for future work is presented.

Chapter 2

Literature Survey

2.1 WLAN standards and types

IEEE 802 executive committee established the 802.11 working group to create a WLAN standard in 1990. The standard specified an operating frequency in the 2.4-GHz ISM (industrial, scientific, and medical) band. The standard supports about 1 to 2 Mbps data rates. But after that the need for higher data rates raised which lead to the invention of more WLAN standards. Authorization requests of two projects for higher rate physical layer extensions to 802.11 were approved by working group. IEEE 802.11b5 GHz and IEEE 802.11a2.4 GHz were the two extensions [1].

IEEE 802.11b operates at 2.4-GHz ISM band and it supports two modulation schemes frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS) implementations. 802.11b is a PHY extension to the original 802.11 standard. It also operates at the 2.40-GHz band and allows for higher data rates of 5.5 and 11 Mbps. It uses a technique known as complementary code keying (CCK). The 802.11a is another PHY extension to the 802.11 standard. It operates at the 5-GHz unlicensed national infrastructure for information (UNII) band and allows for data rates of 654 Mbps. It uses a technique known as orthogonal frequency division multiplexing. The next extension to the 802.11 standard was the 802.11g. Operation of it is done at the 2.4-GHz ISM band and it supports data rates from 1 to 54 Mbps. The 1 and 2Mbps data rates are provided by the DSSS mode whereas the 51, 2 and 11Mbps rates are provided by CCK mode. Moreover, rates at 6 to 54 Mbps are exercised in OFDM mode. The 802.11g standard uses the OFDM technique and 802.11a standard data rates but operation band is the 2.4-GHz ISM band. Therefore, very high data rates are operable while achieving backward compatibility with the 802.11b standard [1].

2.1.1 Comparison of 802.11: b, a, g, n, ac

802.11b, 802.11a, and 802.11g are the three known versions of the 802.11 physical. As explained before, the 802.11g & 802.11a standards provide much higher speed than 802.11b. However, the emergence of 802.11g and a will not cause the end of 802.11b in the near future. Applications are there where the low system cost and low power consumption are required. In these cases 802.11b might yet be the best solution in the near future. At the other side, most system traders have moved to 802.11g standard, which is backward compatible with 802.11b [1].

As an option to 802.11g and b, if one requires higher density of user, higher network capacity and data rate, 802.11a is the one that he or she has to choose because of wider spectrum at 5 GHz and higher data rate offered by this standard. For applications where higher data rates and longer ranges are required, 802.11g is the most suitable. The 802.11g gives the added advantage of backward compatibility with 802.11b, which has the largest existing base [1].

Increase in rate over 802.11a/g can be achieved in IEEE standard 802.11n. This can be achieved through wider signal bandwidth of 40 MHz, MIMO implementation

Table 2.1: Comparison of IEEE Standards

Standard	**Frequency Band**	**Modulation Scheme**	**Data Rate (Mbps)**
802.11	2.4 GHz	DSSS, FHSS	1,2
802.11b	2.4 GHz	CCK	5.5, 11
802.11a	5 GHz	OFDM	6 to 54
802.11g	2.4 GHz	DSSS+CCK+OFDM	1 to 54
802.11n	2.4 + 5 GHz	OFDM	Up to 600
802.11ac	5 GHz	OFDM	Up to 6.933

and higher coding rates. The signal is modulated using OFDM modulation scheme. It uses 77 Modulation and Coding Schemes (MCSs). Up to 600 Mbps data rate can be achieved.

Standard IEEE 802.11ac incorporates MIMO mode configurations, where we have multiple antennas on transmitter and receiver side (2x2 or higher). The total band of emission is 160 MHz, where each antenna emits in 80 MHz band for 2x2 mode. High data rate (in Gigabits) can be achieved.

2.1.2 Performance Factors

Different factors that limit the performance or are point of concern for the development teams of the WLAN modules are such as spurious emissions, Radiated Leakage and Packaging, Current and Associated Leakage, Throughput saturation, FCC Constraints Conducted and Radiated Leakage ,Lesser Throughput than Required ,Bad FCS , Decoding of packets ,Customer Problems and Damages (Post release) ,Size of the final Module etc.These Performance parameters needs to be taken into consideration in each stage of the board and chip design starting from PHY/MAC layer to the post release problems .

2.2 RF Front End

2.2.1 Overview of RF Front End

In a radio receiver circuit, the RF front end is a generic term for all the circuitry between the antenna and the first intermediate frequency (IF) stage. It consists of all the components in the receiver that process the signal at the original incoming radio frequency (RF), before it is converted to a lower intermediate frequency (IF).

For most super-heterodyne architectures, the RF front end consists of:

- An impedance matching circuit to match the input impedance of the receiver with the antenna, so the maximum power is transferred from the antenna;

- A 'gentle' band-pass filter (BPF) to reduce strong out-of-band signals and image frequency response;

- An RF amplifier often called the low-noise amplifier (LNA). Its primary responsibility is to increase the sensitivity of the receiver by amplifying weak signals without contaminating them with noise, so they are above the noise level in succeeding stages. It must have a very low noise figure (NF). The RF amplifier can be omitted (or switched off) on frequencies below 30 MHz, where the signal-to-noise ratio is defined by atmospheric and man-made noise.

- The mixer, which mixes the incoming signal with the signal from a local oscillator (LO) to convert the signal to the intermediate frequency (IF).

A typical RF Front-End is as shown in the figure 2.1. The RF front end is usually defined as everything between the digital baseband system and the antenna. For receiver, this region contains down-conversion mixer(s), filters, low-noise amplifiers (LNAs) required to process the modulated signals received at the antenna into signals appropriate for input into the baseband analog to digital convertor (ADC). This

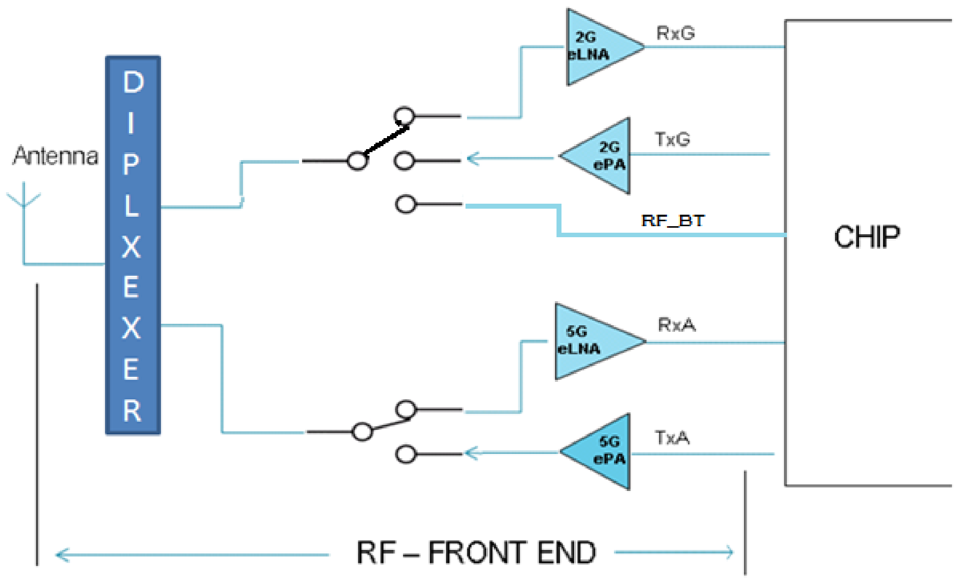

Figure 2.1: RF Front-End Architecture

is the reason why the front end is usually known as the analog to digital or RF to baseband section of a receiver.

Radios work by receiving RF waves containing formally modulated data sent by a RF transmitter. The receiver is essentially a low noise amplifier that down converts the incoming signal. Hence, selectivity and sensitivity are the main concerns in receiver design.

An outgoing signal is up converted by transmitter before power amplifier passage. In such case non linearity of power amplifier is the main concern.

2.2.2 Front-End Module

WLAN (Wi-Fi) Front-End Modules basically integrate multiple devices required to implement an RF front-end. Typically included are one or more power amplifiers with input/output impedance matching (usually matched to 50 ohms), a switch and

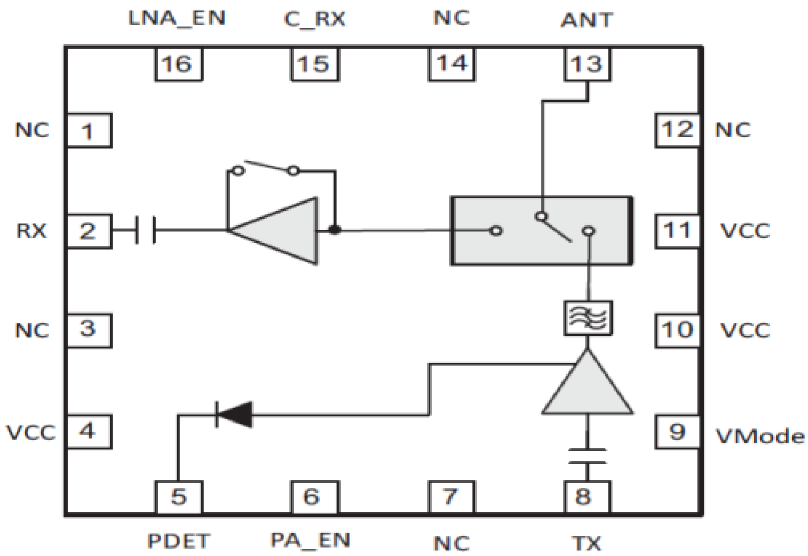

Figure 2.2: Functional Block Diagram of a FEM (Front End-Module)

one or more low noise amplifiers.

Different vendors provide a complete integrated solution in a single front end module (FEM) for Wi-Fi 802.11a/n systems. Figure 2.2 shows the functional block diagram of a FEM. The ultra-small form factor and integrated matching minimizes the layout area in the customer's application and greatly reduces the number of external components. This simplifies the total front end solution by reducing the bill of materials, system footprint, and manufacturability cost.

The FEMs usually integrates a power amplifier (PA), single pole double throw switch (SP2T), LNA with bypass, and a power detector coupler for improved accuracy. These devices are provided in a 2.5mm x 2.5mm x 0.45mm, 16-pin QFN package. Different module meets the RF front end needs of IEEE 802.11 a/n/ac WiFi RF systems.

2.3 Basic Transceiver Block Diagram

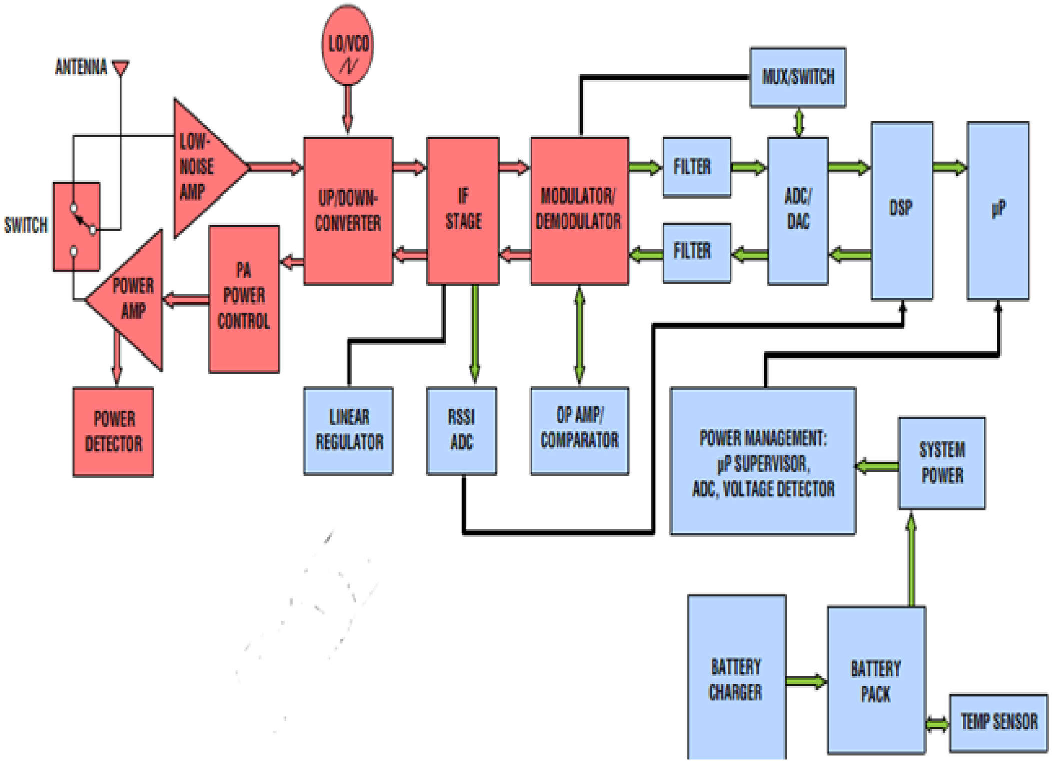

Figure 2.3: Transceiver Block Diagram

Chapter 3

Current Measurement

3.1 Current Measurement Sections

Current measurement illustrates the current consumed by the different sections of the module. This, in one way is an Important debugging parameter while on the other hand it is an important customer criteria for devices run on battery power. The lower the power consumption ,the better the value of the product without compromising with the quality of the communication.

3.2 Importance of Current Measurement

Current measurement deals with the sectional current consumed within he chip. Current measurement is very important for proper debugging and functioning of the Wi-Fi Modules. One parameter that is concerned with CM is power consumption. Power Consumption is critical parameter for any electronic gadget. As the semiconductor field is advancing the size of the gadgets is decreasing due to which the need for lower power consumption has increased . For Lower Power current should be low. Another point is that , different types of regulators inside chip supply different amount of currents to different segments of the chip . To detect the proper functioning of these regulators , this power should be separately measured. If more current flows through the chip it will get heated up due to increase in junction temperature which will lead to breakdown of the p-n junction and damage of the device .If a section consumes unexpectedly high or low current then we can be sure about the improper functioning of the chip .Also Digital and Radio section currents show us a clear picture of the functioning of the amplifiers like LNA , PA etc . Also the formation of the packet is directly related to the current consumed in the PHY and MAC region .

3.2.1 Types of Current Measurements

Current measurement may be done in different modes such as Rx i.e. actively receiving packets,Listen mode i.e. doing nothing but ready to receive ,Tx i.e. actively transmitting packets , Sleep modes i.e. specific sections of the chip are shut down . There are a few basic methods of measuring currents given below :

- Conventional method using ammeter (Manual Method) :Ammeter is used and the two pins of the ammeter are connected to the probes and the current is measured .This method consumes more time if all the sections are to be measured but accuracy of debug is better;

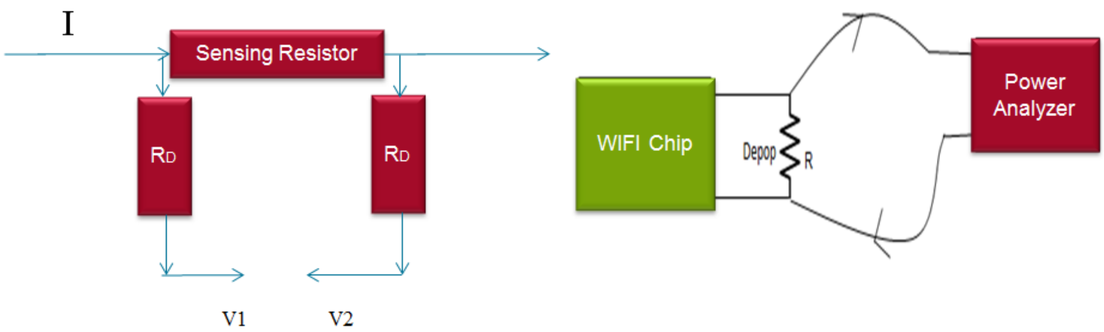

Figure 3.1: CM using Manual DMM method

- This method is used when few currents need to be measured as manual involvement is high and consumes more time.

- Using automatic switching (Automated method) :Ammeter is switched between different loads through automated script .

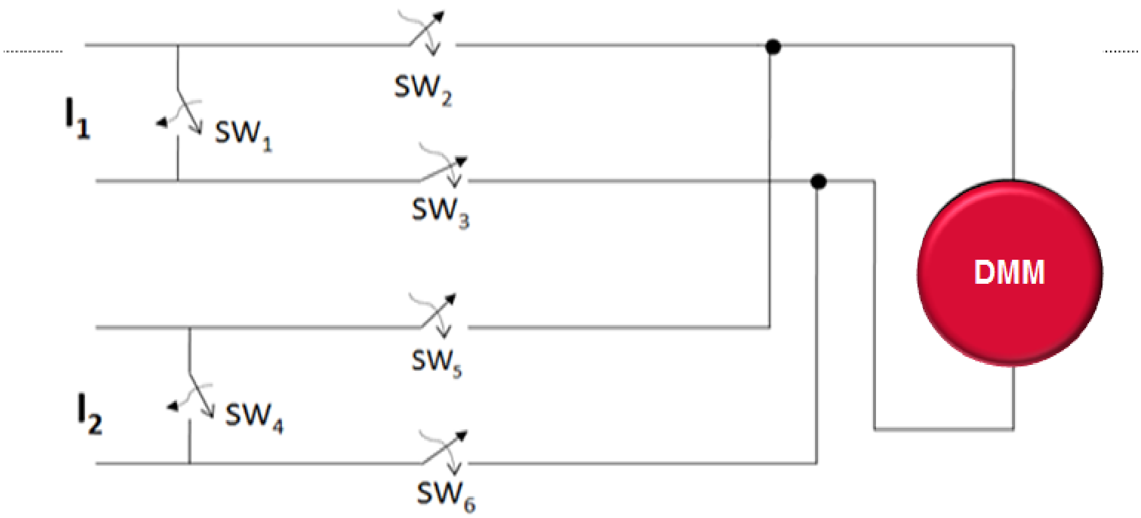

Figure 3.2: CM Using automated switching

- This method is used for measuring low currents like sleep and listen currents .But not suitable for measuring high currents as problem of huge IR drop gets popped up.

- Using differential amplifier (Automated Method) :Voltage across sense resistance is measured and is converted to corresponding current value.

- This method is used to measure high currents where the IR drop is high but its downside being less accurate in measuring low currents.

3.2.2 Current Measurement Setup

The Current Measurement setup contains a few important sections and can be named as follows. The DUT is placed along with the Current measurement boards (having the switch architecture). Usually 30 header pairs are provided on one current measurement board which accounts for altogether 60 header pairs in two CM boards. All these Headers are connected to just one external header.

When the current is measured through SMU, the switches toggle which results in only one sectional current to be measured at a time and only single channel of the SMU can be used for all the 30 current nets. All this operation is controlled with a Controller machine .Sequential Current Measurement results are saved in an excel file which can be used later for analysis. .

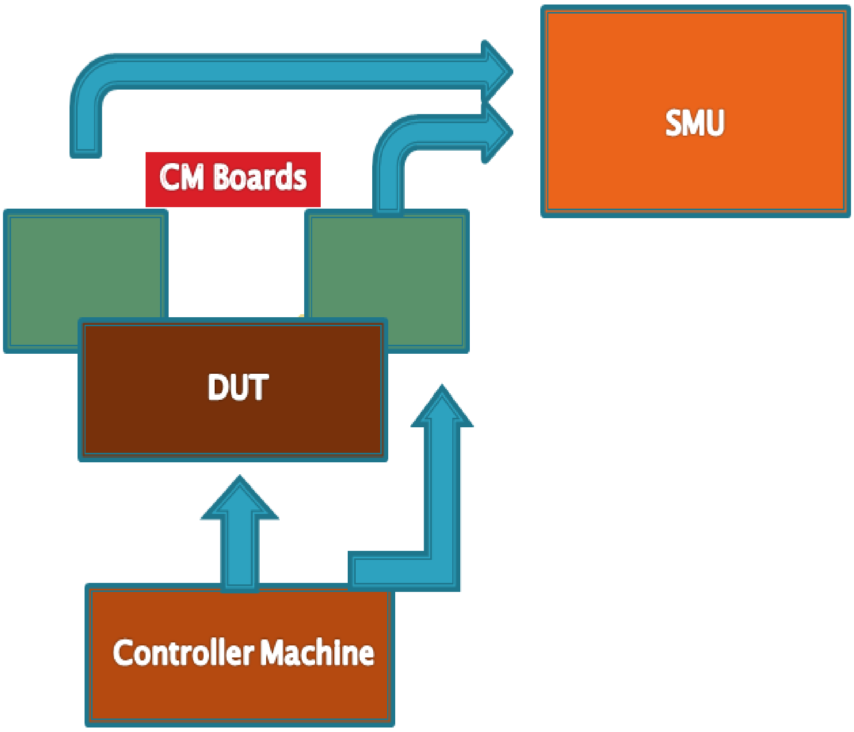

Figure 3.3: CM Setup

Figure 3.3 shows the test setup for current measurement .

3.3 Problems encountered and Solutions

3.3.1 Core to Core variations

Sometimes due to some unwanted reasons, one core current consumption may be different from the other core despite having the same configuration and hardware design . This problem needs to be tackled as uniformity needs to be introduced in the architecture .

3.3.2 Low transmitted power

Power is directly proportional to the voltage and current supplied through the biasing circuit to the amplifiers . If there is inappropriate current or voltage supply then the output power will not be as per expectation . This will lead to reduced performance .

3.3.3 Power Saturation

The digital segment of the wifi chip consists of combination of Digital to analog and analog to digital converters and other digital logic circuits . These cannot handle very high power signals . If supplied high power signals then these get saturated and then the changes in the amplitude will not be reflected in the further stages . So bias voltage and current needs to be controlled very accurately in these stages in order to prevent the saturation.

3.3.4 Bad Frame Check Sequence

During the packet transmission and reception , in order to decode the packet correctly there should be a proper FCS. This ensures that the packet is not corrupted and is same as what is transmitted. When the Bad FCS count increases then the chip is unable to decode packets hence affecting the communication.To avoid this we vary the Packet size ,attenuation, Inter frame spacing , rate etc in order to get the receiver decoding properly. This is significant as while current measurement we want to measure the current when real time communication is going through . For that proper communication must occur .

3.4 New current measurement setup

With the analysis of the current waveforms and the CM results , it was found that sometimes some unwanted factors cause the current waveform to distort . These factors like interference from other devices caused the appearance of glitches which changed the average current consumed and thus led to misleading results .

These interference signals required high isolation in order to be stopped . Thus the new current measurement setup was built in an isolation chamber with the isolation as high as 80 dB . This prevented the other devices to interfere with the Device under test and hence more isolation was provided . Apart from this different new current logging devices were also used and their automation scripts were also made in python .The new devices had a higher resolution as well as better current recording capability .

3.5 Summary

The different types of currents consumed in the chip , their significance and the methods to measure them have been explained. Also the script flow for the setup improvement and relation with packets is also explained.Different Problems encountered and their solutions are also mentioned .These current related issues are associated with every new or old WI-FI chip that come after manufacturing for testing . Thus this step is considered asd one of the most important steps in the bring up of the chip.

Chapter 4

Emissions from WLAN Modules

Generally in a Wifi chip two main factors are responsible for the unexpected emissions namely , Non linearity and Coupling .Due to the non-linearity of components in the chips , a lot of irregularities arise that interfere with the proper functioning and communication of the WLAN modules .One such irregularity arises due to the radiation of unwanted signals at very high frequencies .The other irregularity is conducted emissions which occur at relatively lower frequencies . FCC , the standard governing body for deciding the Limits for these emissions has given limits for both conducted as well as radiated emissions.

4.1 Conducted Emissions

Conducted emissions are internal electromagnetic emissions propagated along a power or signal conductor, creating noise. The noise is subsequently transferred to the equipment. Usually conducted emissions travel through the power chords and wires at lower frequency . These emissions affect other component and devices attached to the PD network. FCC regulation is defined for these emissions in WLAN modules .

DC/DC converters in all the devices are a great high frequency noise source. This noise may affect other system components or the AC mains. It is not desirable to have this noise affect other devices . Even more than that, these noise sources should not degrade product performance.

4.1.1 FCC Regulations for Conducted Emissions

There are two categories of Devices Marked by FCC and different regulations have been given for each . Class A digital devices are those digital devices that are marketed for use in a commercial, industrial or business environment, exclusive of a device which is marketed for use by the general public or is intended to be used in the home.While Class B digital devices are those device that are marketed for use in a residential environment notwithstanding use in commercial, business and industrial environments. Examples of such devices include, but are not limited to, personal computers, calculators, and similar electronic devices that are marketed for use by the general public.

Table 4.1: FCC Limits for Conducted Emissions

Frequency of Emission (MHz)	**FCC Limits (dBuV)**
0.15 to 0.5	56 to 66
0.5 to 5	54
5 to 30	50

4.2 Radiated Emissions

Radiated emission is the electromagnetic energy propagated through space. These test methods are used to determine a device's ability to operate in the presence of radiated emission. Usually any unwanted radiation interfering the communication needs to be eliminated or prevented. These radiations may be harmful to humans as well as cause interference in other devices , thus FCC has regulations specified for both category A and B devices .

4.2.1 Problems associated with Radiated Emissions

There are several problems that are associated with these unwanted radiations like OOB noise , Saturation of the Receiver on same device or the other device , Interference with the signal being transmitted or received etc .These things in turn degrade the EVM as well as Sensitivity of the Transmitters as well as receivers.

4.2.2 FCC Regulations for Radiated Emissions

Table 4.2: FCC Limits for Radiated Emissions

Frequency of Emission (MHz)	**FCC Limits (dBuV/m)**
30 to 88	40
88 to 216	43.5
216 to 960	46
Greator than 960	54

4.2.3 Types of Radiated Emissions

Radiated emission may be of different types depending upon the cause of emission. The main factors responsible for these emissions are oscillator coupling with Carrier/other frequencies , non-linearities etc. Depending upon the cause of Leakage these may be categorized as shown below:

4.2.3.1 Inter Modulation Distortion

This is a result of non linearity of the system.A non linear system generates different frequencies that were originally not present in the original input.Parameters often used to characterize the non-linearity of a circuit are the harmonic distortion (HD) and intermodulation distortion (IM) numbers.Specifically, the second- and third-order harmonic distortion numbers. When two different frequencies cause harmonics which interferes with other signal frequency then it is called as the Inter-modulation distortion .These frequencies distort the main signal and thus hampers the communication.Usually filters with such a sharp cutoff are practically not possible so we cannot eliminate this totally.It is important that, although HD3 components can typically be rejected by filtering, IM3 components can fall in band (or very close in to the band) and are therefore difficult to practically filter

4.2.3.2 Nth Frequency Base-Band Distortion

When the nth Harmonics of the main tone interferes/rises inband to the main tone then it is called as the nFBB interference . This interference causes problems in communication. Thus , needs to be tested and eliminated .This gives idea about fluctuation of the constellation points around reference (ideal) constellation points in the EVM. These frequencies increase and decrease exponentially with the tone power . [1].

4.2.3.3 Harmonic Coupling Leakage

A low Oscillator gain is desirable in order to maintain a good PN and high rejection of noise coupling on the Oscillator control line and the supplies. When the gain is high then some non linearities are introduced in the system. Thus when center frequency or its second harmonics gets coupled with signal frequency and turns into a radiated emission then it is called as Harmonic radiated Leakage .

4.2.4 Test Setup

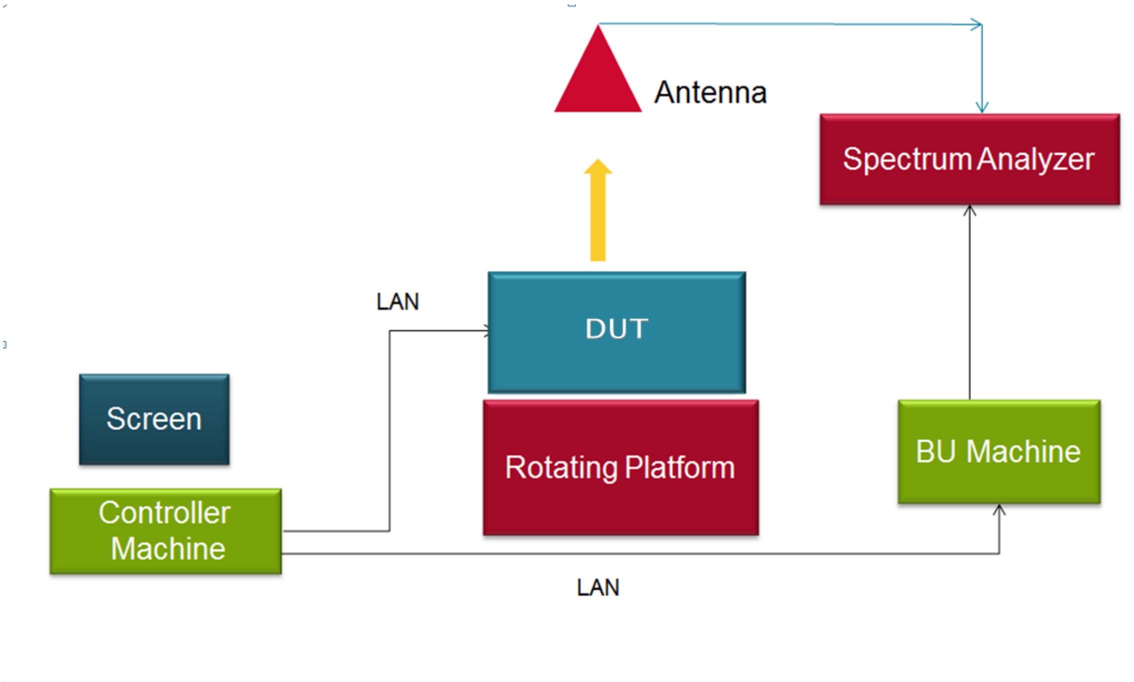

Figure 4.1: Radiated Leakage Setup

Test Procedure

1. DUT is kept on a rotating platform that can rotate 360 degree .

2. Orientation is fixed in x , y or z direction

3. Driver is then loaded with the desired channel configuration and then it is isolated into the Anechoic chamber .

   Radiated Leakage is seen at second harmonic

4. The device is rotated in all the directions on each of the three axis to ensure that in no direction the Leakage exceeds the FCC Limits .

5. If the device violates the FCC limits then some measures are taken for decreasing the radiated leakage .

4.2.5 Test Script Flow

The Script made in python configures the Spectrum analyser , the DUT and the Rotating platform . Then initiates the test and captures the Radiated emission peak and records the observations in a CSV format file . Then the Macros written in Visual Basic sort the data , format it properly and then plot the different graphs.

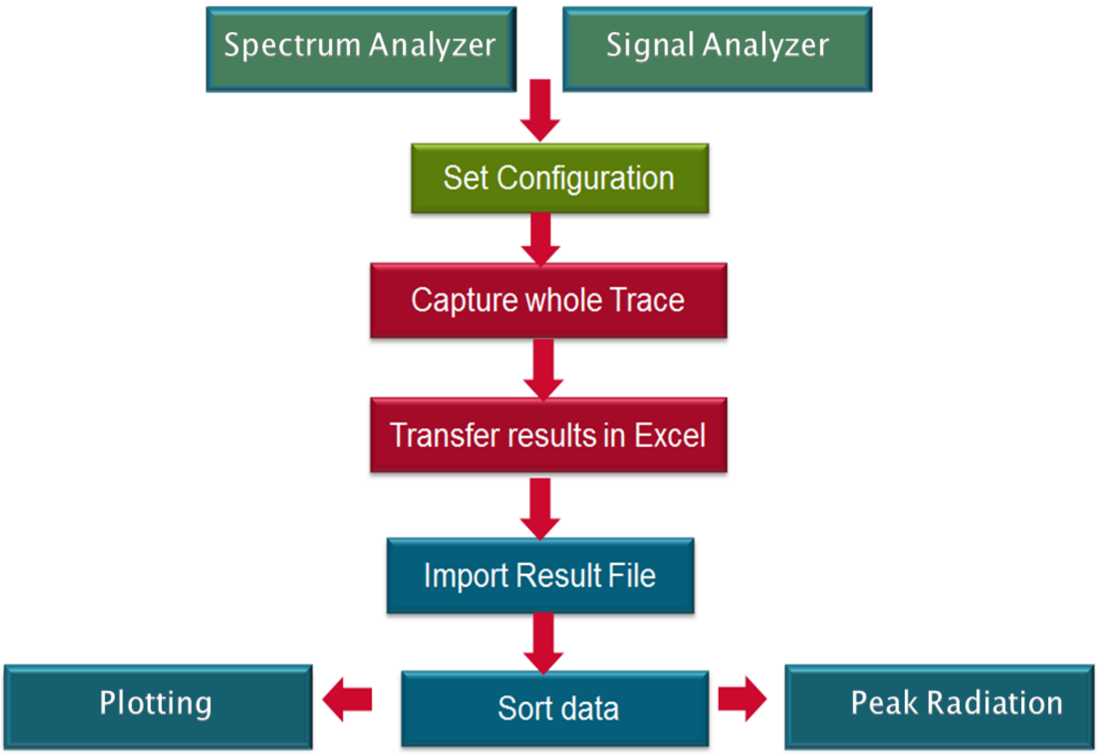

Figure 4.2: Radiated Leakage Script Flow

4.3 Problems Encountered and Solutions

During the test process many problems were encountered and their solutions were also found.These are described below.

4.3.1 SCPI Automation script

The main problem with the Automation of the setup is related to the system getting stuck due to inappropriate delay time given between two SCPI commands . Certain amount of time is required for the system to execute the command . This time needs to be known before-hand from the Programming manual of the device . Also there is some inherent delay of the GPIB connections which delay the execution of the commands. These delays if not considered in the script , leads to the system crash.

4.3.2 Reduction of Radiated Leakage

Radiated Leakage radiation can be suppressed by different methods as mentioned under the EMC Guidlines[8] . First method is Shielding where we cover the Chip with a Metallic Shield that is grounded . This transfers all the radiation collected on the shield surface to the ground thus preventing Emission.

Table 4.3: Effects of Shielding

Module	**value**
Unshielded	higher
Shielded	8 dB lower

4.3.3 Side effects of shielding

Although the shield reduces the radiated leakage by 8- 10 dB but it increases the reflections at other frequencies and thus IM3 interference degrades by 4 or 5 dB which ultimately degrades the EVM floor . This overall affect reduces the performance of the module thus needs to be checked. Thus we must have an optimized shielding vs Reflection Method with which we can have the best performance . Also we need to pass the FCC test for radiated leakage with a greater margin so that the product will have an advantage over other competitor products.

4.4 Summary

Here in this chapter we have seen various Radiated as well as Conducted Emissions , their cause and Measurement Methods. Also we have seen FCC Regulations regarding these Emissions .We have also seen the pros and cons of the Shielding and grounding which puts limitations on the suppression of the radiated leakage completely.

Chapter 5

The Automated Range Tester Robot

There are several factors that affect the communication between two wireless LAN chips , such as the environmental factors , orientation ,distance etc . These factors limit the communication in terms of range and quality. Some of the main tests in this aspect are Signal Strength Test ,Signal Quality test etc. This becomes more important as quality and signal strength gets more priority when the power is very low .Practical limitations and different environmental conditions affect the performance of the WLAN chips , which makes it necessary for the chip manufacturers to test the robustness of the products in different environmental conditions.

Limitation of Time and manpower , leads to the need of automated test setups. One such setup is the Automated Range tester robot prototype . Prior to this setup , employees used to setup the test environment and then used to carry the Test device on a moving table from one section or the other to perform different signal related tests.This Process was very time consuming as well as free space and no disturbance was required . These conditions were only available during the night hours , leading to inconvenience to the testers .So this Robot was made capable of moving without human intervention in the test area carrying the DUT.

5.1 Features and Capabilities

This Robot built capable of carrying the Device under test as well as a laptop weighing around 4 Kg .Once Programmed according to the requirement the Robot is able to move in the testing territory with the help of different sensors .The Bot would move according to a nxn matrix having the path defined in terms of one's and zero's .It would measure the distance travelled with the help of rotary encoders as well as avoid any obstacle in its path which are sensed through the Ultrasonic distance sensors .Would take help of the Digital Compass IC to take accurate turns and will also use the same to correct its direction if it deviates slightly from its original desired path . This uses Arduino(atmega328) as the base microcontroller with 32 kb memory for code .

The hardware includes 4 DC geared motors capable of delivering 6 kg-cm torque. These 4 motors are controlled through the arduino with the help of 2 L293D motor controller IC . The power for the Arduino and the whole setup is taken from 1 4000 mAH rechargeble Li-PO battery , thus making it a totally wireless and portable robot . The speed of the motors can be controlled through the Pulse Width Mechanism through Arduino PWM pins . Once the Arduino is programmed it can be left in the testing fields .

5.1.1 2D Area Mapping Feature

With the Ultrasonic Sensors and a rotating servo motor , this robot can analyse given area and can create a map of the same . Although this feature is currently not required , but it opens the scope of using the robot for some more purposes. This also includes path finding feature . This makes this robot capable of looking at the obstacles and then act accordingly.Also it does not need any pre-setting of the environment such as a line to be built .

5.1.2 Wireless Operation

This Robot has every sensor and all the required hardware on board , thus is free of any kind of wires that may hinder the motion . Also Serial port communication is possible through blue-tooth devices that will be the next part of the project.

5.1.3 Low cost Setup

As some very common and cheap sensors as well as hardware are used to make this setup , it justifies the significance of Automation at reduced cost .Mostly things were available in the local Electronic market at very low cost , while the chasis was made from already available boards and clamps , further reducing the Robot cost.

5.1.4 Self Reliant Intelligent Robot

This setup has different sensors that makes it independent of any human help in finding its own path . The added intelligence makes it capable of making decisions if any obstacle is encountered in its path .

5.2 Algorithm of operation

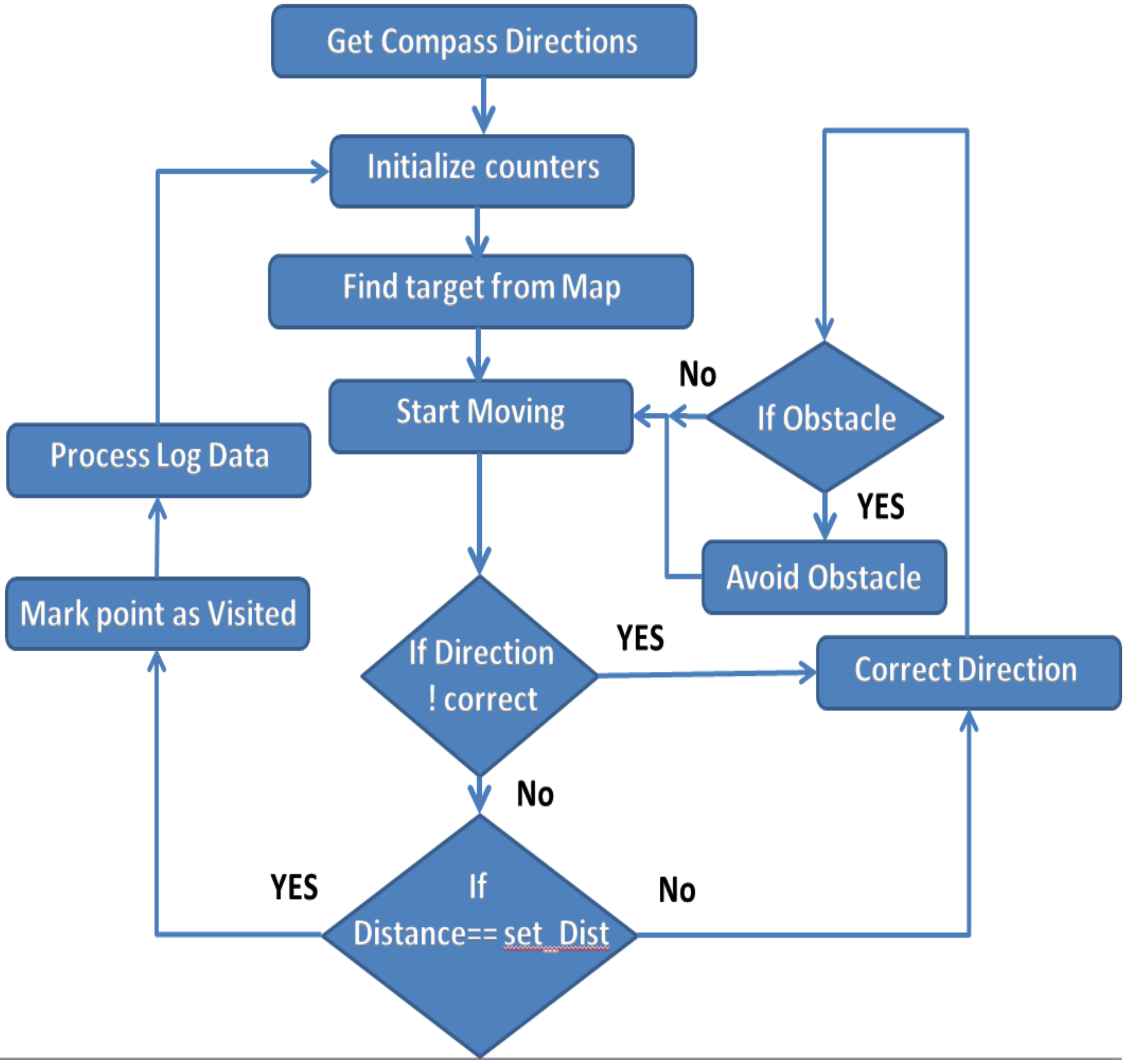

Figure 5.1: Flow Diagram of Algorithm

5.3 Hardware Schematic and connections

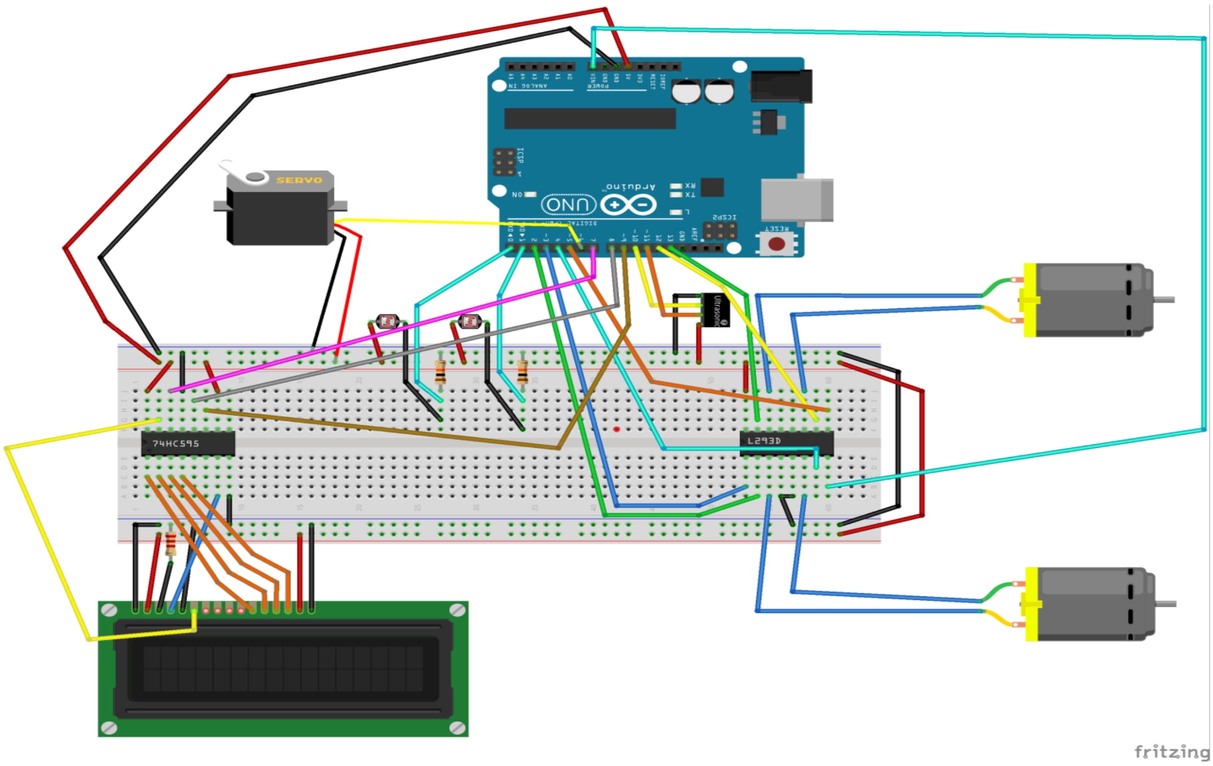

Figure 5.2: Schematic 1

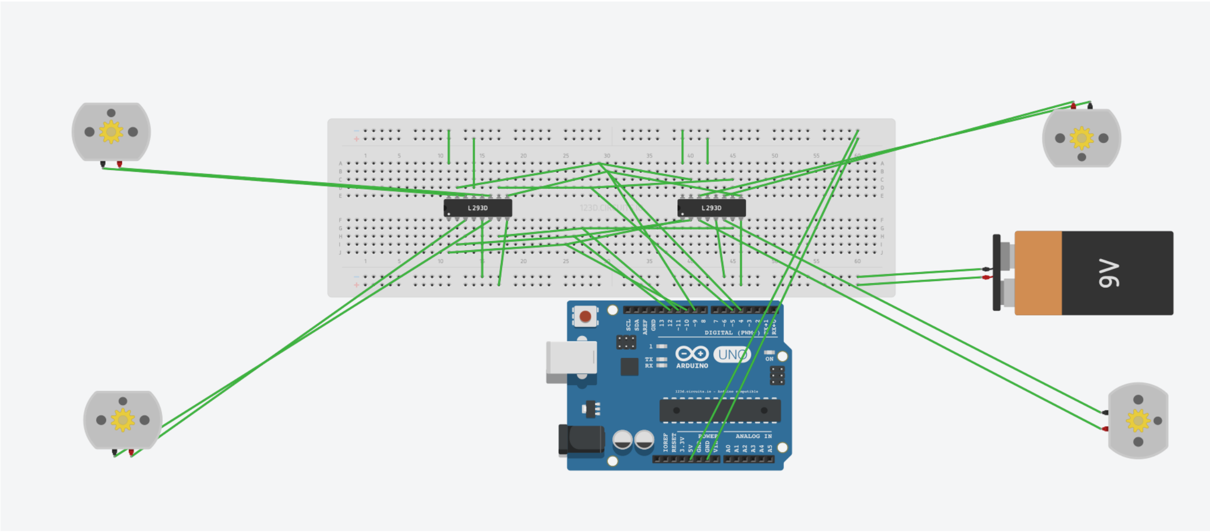

Figure 5.3: Schematic 4 motors

5.4 Problems Encountered and Solutions

As every project has some bugs as well as problems , the Robot also faced some issues that were required to be solved in order to make the robot work correctly.The following are the issues that were encountered and along-with are given the final solutions to remove those bugs .

5.4.1 Requirement Evaluation

With the Project requirements in hand , the next step was to gather the components that will suit the requirement. As the test devices were to be accompanied by a laptop and an adapter card or phone , the robot had to be capable of carrying his own weight as well as the payload of 3 kg.Also in order to make it wireless a battery was also required . With the calculation of the wheel size and the circumference torque it was decided that the 6 kg cm and 30 rpm motors could be used successfully . Later it was found that all the 4 wheels need to be driven by motor in order to avoid the burning of the motors .This led to the increased power consumption and hence decreased battery life .

5.4.2 Battery Capacity and Power Savings

For powering 4 motors the battery needed had to be of greater capacity . It was observed that the DC 12 v geared motors with full load condition consumed 250 mA each of current . Thus the Battery capacity had to be at-least 4000 mAh in order to run it for at-least 2 hours. In order to further increase the battery life the power saving algorithm was also incorporated in the code . This algorithm reduces the turning on of all the four motors at a time , i.e. when the turning angle is less then it only triggers two motors and stops the other two motors .

5.4.3 5V servo vs 12 V DC motors

A decision was to be taken between selecting the DC Geared motors and the full rotation servo motors. Geared DC motors were cheap as well as offered greater control of direction and speed but demanded 12 V battery , while their counterparts were initially expensive but were easy to program and had lesser voltage demand (5V). Finally looking at the overall price constraints the DC geared motors along with the H bridge motor driving IC were used .

5.4.4 Compass calibration

Due to running of different wireless RF tests , the Earths magnetic fields get influenced and thus vary from place to place and direction to direction. So for a particular place , specific value of offset was needed to be given in order for the ROBOT to function properly.

5.4.5 Wheel Alignment

As the Robot chassis was made from already available material and was made completely in the local lab , there were many issues including the wheel alignment .This led to the deviation of the BOT from the original path . This created a need for a directional control mechanism ,which could control and correct the direction .This role was fulfilled by the HM5883L digital compass IC.

5.4.6 Load distribution

As the test device was not the only thin that was kept on the ROBOT, there was an issue with the load distribution on the bot which resulted in causing the damage to the motors .The miss-alignment of the wheels added to the problem further resulting in the damage of 3 motors on the rear side .The solution for this problem was found and the alignment issues were resolved also the coding was changed so as not to strain a specific motor . Also the Tyre friction was also reduced by changing to the lesser width tyres.

5.4.7 Servo motor current drawing limit

Usually the Arduino UNO board I/O pins have some limited current supplying capacity . If exceeded , the Arduino gets stuck at one place and is unable to perform other tasks . This problem was seen when the servo motor was connected and the Arduino got stuck . The solution for this problem was either to disconnect the servo or to connect the servo through external supply.

5.4.8 Range Limitation for Ultrasonic Sensors

As the Ultrasonic sensors have a narrow line of sight range , all the obstacles cannot be detected if they are not in range of the sensors . this creates a vulnerability resulting in the ROBOT getting stuck somewhere .To resolve this issue two Ultrasonic sensors were mounted on a servo motor that gave a 180 degree coverage .

5.4.9 Mapping Algorithm

Mapping algorithm was the most important part of the functioning , as without a map the area to be swept was limited and thus limiting the functionality of the ROBOT.Putting a map takes many aspects into consideration ,like Marking the visited points/landmarks as done , searching for new map points instead of the old ones, Etc. Also sometimes the robot doesn't behave as expected so the Serial Debug log needs to be monitored regularly to find the point where it is behaving abnormally.

Chapter 6

Conclusion and Future Scope

WLAN is the technology that is being used for many new electronic gadgets , Hand-held devices , wear-ables , etc for near and far field communication . Thus requirement of smaller size , low power consumption , proper communication , high data rates etc becomes more stringent. Due to which there arises a need for improving the performance and eliminating the performance issues , This can be only done when the root cause of the problem is known . The Board test team does this important debugging task that involves everything from designing of the board to the post release problems .Different setups that facilitate the automated tests like the device automation , self navigating robot , Radiated leakage setup were made .

In future, up-gradation of the range tester robot needs to be done and the following features needs to be added. Blue-tooth interface will be added so that it can log all the traces directly to some computer system and later the relation can be established between the distance moved and the acquired readings .Also some more sensors can be added in order to increase the functionality . The ultimate aim of this project is to make the robot self reliant and independent of human control .

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