A Modular Approach for Wireless Interface in Smart Products

A Dissertation submitted in partial fulfillment of the requirement for the award of degree of

Master of Engineering
in
Electronic Instrumentation and Control

Submitted by:

Simranjit Singh Chadha
(801151025)

Under the supervision of:

Dr. Mandeep Singh
Associate Professor,
EIED, ThaparUniversity,
Patiala

Dr. Suraj Kumar Pardeshi
Technology Manager
EDC,Global R&D Centre
Crompton Greaves Ltd.,
Mumbai

ELECTRICAL AND INSTRUMENTATION ENGINEERINGDEPARTMENT
THAPARUNIVERSITY
(Established under the section 3 of UGC act, 1956)
Patiala, 147004, Punjab, India

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Declaration

I hereby declare that the work which is presented in this dissertation entitled as, **'Modular Approach For Wireless Interface In Smart Products'** in partial fulfillment for the requirement of the certification of one year project training in Global R&D Centre, Crompton Greaves Limited, Mumbai, is an authentic record of my own work carried out under the supervision and guidance of **Dr. Suraj Kumar Pardeshi** and refer to other researcher's work which are duly listed in the reference section.

The matter embodied in this thesis has not been submitted to any other University/Institute for the award of any Degree or Discipline.

Date: 17th MAY 2013

(Simranjit Singh Chadha)

Place: Mumbai

(801151025)

It is certified that above statement made by the candidate is correct and true to the best of our knowledge.

(Dr. Suraj Kumar Pardeshi)

Sr. Manager Technology

Global R&D Centre

Crompton Greaves Ltd.,

Mumbai

CROMPTON GREAVES LTD. Global R&D Centre Kanjur (E) Mumbai 400042 India

(Mr. Venkata Vaddamanu)

Deputy General Manager

Global R&D Centre

Crompton Greaves Ltd.,

Mumbai

Declaration

I hereby declare that the work which is presented in this dissertation entitled as, **'Modular Approach For Wireless Interface In Smart Products'** in partial fulfillment of the requirements for the award of degree of Master of Engineering in Electronic Instrumentation and Control Engineering, Thapar University, Patiala is an authentic record of my own work carried out under the supervision and guidance of **Dr. Suraj Kumar Pardeshi, Technology Manager, Electronic Design Centre, Global R&D, Crompton Greaves Ltd.** and **Dr. Mandeep Singh, Associate Professor, Thapar University, Patiala** and refer to the other researcher's work which are duly listed in the reference section.

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(Dr. Mandeep Singh)
Associate Professor
Electrical and Instrumentation Department
Thapar University
Patiala

(Dr. Suraj Kumar Pardeshi)
Sr. Manager Technology
Global R&D Centre
Crompton Greaves Ltd.
Mumbai

S. Ghosh

(Dr. Smarajit Ghosh)
Head of Department
Electrical and Instrumentation Engg. Department
Thapar University, Patiala

(Dr. S.K. Mohapatra)
Dean of Academic Affairs
Thapar University, Patiala

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Chadha

SimranjitSingh Chadha

Roll No. – 801151025

ABSTRACT

Management of pole mounted Remote Terminal Units is a very difficult and time consuming process as operator has to shut down power line and has to climb the pole for connecting laptop or Personal Computer (PC) in order to make diagnostic changes in electrical distribution, configuration changes, software upgradation. This dissertation proposes Bluetooth technology for the management of pole mounted Remote Terminal Units (RTU).

ORGANIZATION OF DISSERTATION

Chapter 1 of this dissertation discusses about the importance of work done along with objectives. Further it explains in general the Remote Terminal Units and types of communication standards for short range. Chapter 2 explains the Bluetooth technology and various Bluetooth modules are compared. Some common interfaces available in the Bluetooth modules are also described. The parameters for the selection of an antenna for the Bluetooth modules are explained. In chapter 3, case study of Pole Top Remote Terminal Unit and its configuration is given. Chapter 4 gives problem definition and in chapter 5 solution to the problems in chapter 4 is proposed. Chapter 6 gives part hardware implementation. Chapter 7 describes software stack of BCD110 Bluetooth module. In Chapter 8, results of the hardware testing are given and last but not the least in chapter 9conclusion along with the future scope is given and further thesis ending of the dissertation is with the references and the publications from the research done.

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Symbols

Gbit/s……………………….............. Data rate in giga bit per second

mA………………………............... Current in milli amperes

kb/s……………………………….. Data rate in kilo bit per second

Mb/s……………………… ……… Mega bit per second

cm………………………………… Distance in centimeters

m………………………………….. Distance in meters

GHz………………………………. Frequency in gigahertz

dBm………………………………. Receiver sensitivity in decibels relative to milliwatts

MHz……………………………….Frequency in megahertz

π/4 DQPSK……………….............Method of modulation

μs……………………….................. Time in microseconds

kHz……………………………….. Kilohertz

τ……………………….....................Constant

ω………………………………….. Frequency in radians per second

e……………………….................... Exponent

ln………………………………….. Natural logarithm

f_c ………………………………….. Center frequency

f_d ………………………………….Frequency deviation

dB……………………….................Decibels

%...Percent

Ω……………………….................. Ohm

mW……………………….............. Milliwatts

μVrms…………………………….. Microvolt root mean square

v2.0……………………………............. Version 2.0
g……………………………………... Weight in grams
°C……………………………………Degree Celsius
Vdc……………………………….. ... Dc voltage
mm…………………………….... ... Millimeter
kΩ……………………….............. ... Resistance in kilo ohm
pF……………………………........... Capacitance in picofarad
dBi……………………….................. Decibels relative to isotropic radiator
kV…………………………………… Kilovolt

Abbreviations

3G…………………………………… Third Generation
ACL………………………………… Asynchronous Connectionless
AM………………………………….. Amplitude Modulation
ARQ………………………………… Automatic Repeat Request
ARQN……………………….............. Automatic Repeat Request Number
AT……………………………………Attention
AVRCP…………………….............. Audio/Video Remote Control Profile
BER………………………….......... Bit Error Rate
BR……………………………………Basic Rate
CE…………………………………...ConformitéEuropéenne
CRC…………………………...........Cyclic Redundancy Check
CTS………………………………… Clear To Send
DECT……………………………….. Digital Enhanced Cordless Telecommunications

DH…………………………………... Data High

DIP………………………………….. Dual-in-line Package

DIP……………………………….……..Device ID Profile

DM……………………………….……..Data Medium

DPSK……………………………….. Differential Phase Shift Keying

DQPSK……………………….......... Differential Quadrature Phase Shift Keying

DSR………………………………… Data Set Ready

DSSS CCK…………………………. Direct Sequence Spread Spectrum Complementary Code Keying

DTR………………………………… Data Terminal Ready

DUART…………………………….. Dual Universal Asynchronous Receiver/Transmitter

DUN……………………...... …… Dial-up Networking

DUN DT……………………………. Dial-up Networking Profile Data Terminal

DUN GW………………….............. Dial-up Networking Profile Gateway

DV…………………………………... Data Voice

DVB-H…………………………….... Digital Video Broadcasting – Handheld

EDR……………………................... Enhanced Data Rate

EIA……………………………….…. Electronic Industries Association

EMC………………………............... Electromagnetic Compatibility

ESD………………………………… Electrostatic Discharge

EU……………………..................... European Union

FCC………………………….……… Federal Communications Committee

FEC……………………….............. Forward Error Correction

FH…………………….............. …… Frequency Hopping

FHSS………………….................... Frequency Hopping Spread Spectrum

FM………………………………….. Frequency Modulation

FPC……………………………….... Flexible Printed Circuit

FTP…………………………………. File Transfer Profile

GAP……………………………….... Generic Access Profile

GFSK……………………………….. Gaussian Frequency Shift Keying

GPIO…………………………......... General Purpose Input/Output

GPS………………………….......... Global Positioning System

GSM………………………………… Global System for Mobile Communications

HCI…………………………………. Host Controller Interface

HDP…………………………………. Health Device Profile

HFP…………………………………. Hands-Free Profile

HID………………………………….. Human Interface Device Profile

HMI…………………………….…… Human Machine Interface

HSP…………………………………. Headset Profile

I2C………………………………….. I-squared-C

IC……………………………………. Industry Canada

IED………………………………….. Intelligent Electronic Devices

IEEE……………………….................. Institute of Electrical and Electronics Engineers

IP……………………………………. Internet Protocol

IrDA…………………………………. Infrared Data Association

ISI……………………….................. Intersymbol Interference

ISM…………………….................... Industrial, Scientific and Medical

L2CAP………………………………Logical Link Control and Adaptation Protocol

LAN……………………………..….. Local Area Network

LCD…………………………..…….. Liquid Crystal Display

LMP…………………………..…….. Link Management Protocol

LPF………………………....……... Low Pass Filter

LSB…………………………...…….. Least Significant Bit

LTCC……………………………….. Low Temperature Co-Fired Ceramic

M2M………………………...............Machine-to-Machine

MediaFLO…………...……………… Media Forward Link Only

MIMO………………………………. Multiple-Input Multiple- Output

MMC……………………………..…. Multi Media Card

OBEX………………………………. Object Exchange

OEM………………………………... Original Equipment Manufacturer

OFDM………………………………. Orthogonal Frequency- Division Multiplexing

OPP…………………….................. Object Push Profile

OS…………………………............. Operating System

PAN…………………………………Personal Area Network

PBAP……………………….............Phone Book Access Profile

PC……………………..................... Personal Computer

PCB……………………………….… Printed Circuit Board

PCL…………………………………. Printer Command Language

PCM……………………….............. Pulse Code Modulation

PD……………………..................... Proportional and Derivative Control

PDU………………………............... Protocol Data Unit

PI…………………………………..Proportional and Integral Control

PID……………………………..…. Proportional, Integral and Derivative Control

PIFA…………………………..…..... Planar Inverted –F Antenna

PIO………………………………..… Programmed Input/Output

PPP………………………................ Point-to-Point Protocol

QPSK (CCK)…………………….… Quadrature Phase Shift Keying (Complementary Code Keying)

RAM……………………………......... Random Access Memory

RCC……………………………..... Remote Control Centre

RFCOMM……………..................... Radio Frequency Communication

RFID………………………….. ….Radio-Frequency Identification

ROHS………………………… …. Restriction of Hazardous Substances

RSSI………………………………. Received Signal Strength Indicator

RTC…………………………. ……Real Time Clock

RTS…………………………………..Request To Send

RTU…………………............. …… Remote Terminal Unit

RXD……………………………….Receive Data

SAR……………………………..….. Specific Absorption Rate

SAT………………………………. Site Acceptance Test

SCADA………………................... Supervisory Control and Data Acquisition

SCL………………………………...Serial Clock

SCO………………………………. Synchronous Connection Oriented

SDA……………………………….Serial Data Line

SDP…………………………………. Service Discovery Protocol

SIG…………………………........... Special Interest Group

SMD……………………………….. Surface Mount Device

SMT………………………………… Surface Mount Technology

SPP…………………………........... Serial Port Profile

SRAM………………………………. Static Random Access Memory

SRW………………………………… Short Range Wireless

TCP…………………………………. Transmission Control Protocol

TCS BIN……………………………. Telephony Control Protocol Binary

TDD…………………………. ……Time Division Duplex

TXD…………………………………Transmit Data

UART……………………........ ……Universal Asynchronous Receiver/Transmitter

UDP…………………………………User Datagram Protocol

UHF…………………………............ Ultra High Frequency

U-NII……………………….............. Unlicensed National Information Infrastructure

US…………………….................... United States

USB………………………………… Universal Serial Bus

USD…………………………………United States Dollar

UWB………………………………Ultra-wideband

VHF…………………………............ Very High Frequency

VSWR……………………………...Voltage Standing Wave Ratio

WAE………………………………… Wireless Application Environment

WAP………………………………… Wireless Access Protocol

Wi-Fi……………………………….. Wireless Fidelity

WiMAX………………………… …. Worldwide Interoperability for Microwave Access

CHAPTER 1: INTRODUCTION

1.1 Importance of the work done

Bluetooth is a technology standard in the wireless domain for the exchange of data over short distances from mobile as well as fixed devices by the creation of Personal Area Networks (PAN) with high level of security and less prone to the interference. This Bluetooth technology has vast amount of advantages and applications as can be seen from the incorporation of the Bluetooth in coming gadgets. This project explores technical feasibility to incorporate Bluetooth communication capability to the pole mounted Remote Terminal Unit (RTU) for their management. The manual method used earlier for this purpose had many safety issues and also was very slow in pace. Before Bluetoothsolution, power line had to be shut down and then operator would climb up the pole to connect the laptop for configuration.With the Bluetooth communication capability, operator can manage the Remote Terminal Units wirelessly by connecting laptop having Bluetooth communication capability.

1.2 Objectives

Primary objectives of the work are mentioned as follows

1. Studying Pole mounted Remote Terminal Units (RTU) and to find out how they are managed.
2. Identifying what type of communication will be better for Pole mounted Remote Terminal Unit (RTU) management and in detail study of selected communication type.
3. Analyzing the communication hardware required for implementation in the Pole mounted Remote Terminal Unit (RTU) for their management.
4. Designing of the hardware and its testing.

1.3 Introduction to Remote Terminal Unit (RTU)

Remote terminal units (RTU) collect data automatically and connect directly tothe sensors, meters, loggers or process equipment. They serve as slave units toSupervisory Controllers or Supervisory Control and Data Acquisition (SCADA)masters. RTUs are located near the monitored process andtransfer data to the controller unit on command. They often include integralsoftware, data logging capabilities, a Real-Time Clock (RTC) or totalizer, and abattery backup. Intrinsically safe remote terminal units are designed to operatesafely in hazardous environments. Devices with weather tight enclosures aredesigned to prevent the moisture, dust or other environmental contaminants.Closed loop systems use Proportional, Integral and Derivative (PID) control;Proportional and Integral (PI) control; Proportional and Derivative (PD) control;or Proportional (P) control. Redundant RTUs are complete remote terminal unitsthatcontain all of the transceivers, encoders, and processors needed for properfunctioning in the event that a primary RTU stops working. Important specifications for RTUs includecommunication type, number of ports, and memory size. Serial devices usecommunication protocols such as RS232, RS485, and RS422. Networkedproducts often use Ethernet, a Local Area Network (LAN) protocol that uses a busor star typology and supports data transfer rates of 10 Mbps. RTUs that use radio, video, telephone, or current loop communications are alsoavailable. Fiber optic devices use optical cables to transmit light signals overlong distances. Web-enabled RTUs use the Internet for communications.RTUs differ in terms of features. Devices that include alarms,buzzers, or visual indicators such as blinking lights alert operators about variousconditions. Auto-dialing RTUs automatically call a non-dedicated phone numberwhenever data needs to be transferred. Differential inputs eliminate electricalnoise from small amplitude signals. Isolated inputs convert electrical signalinputs into optical signals which are then converted back to electrical signals.RTUs with anexpansion card provide additional data storage orprocessing power. Devices that are designed for environmental monitoring checkweather conditions or indoor air quality. Some remote terminal units are suitablefor indoor use and mount in standard 19” telecommunications racks. Othersare designed for process monitoring like in distribution of electrical energy as pole-top RTUs[1].

1.4 Types of Communication Standards for short distance

In past few years devices such as laptops, mobile phones, etc. have entered the consumer market. These devices require communication method for short-range data exchange between each other. The communication methods can be based on cable connections, infrared links or radio links, as illustrated in figure. 1.1. Since each has its pros and cons, so each found its way into the products accordingly[2].

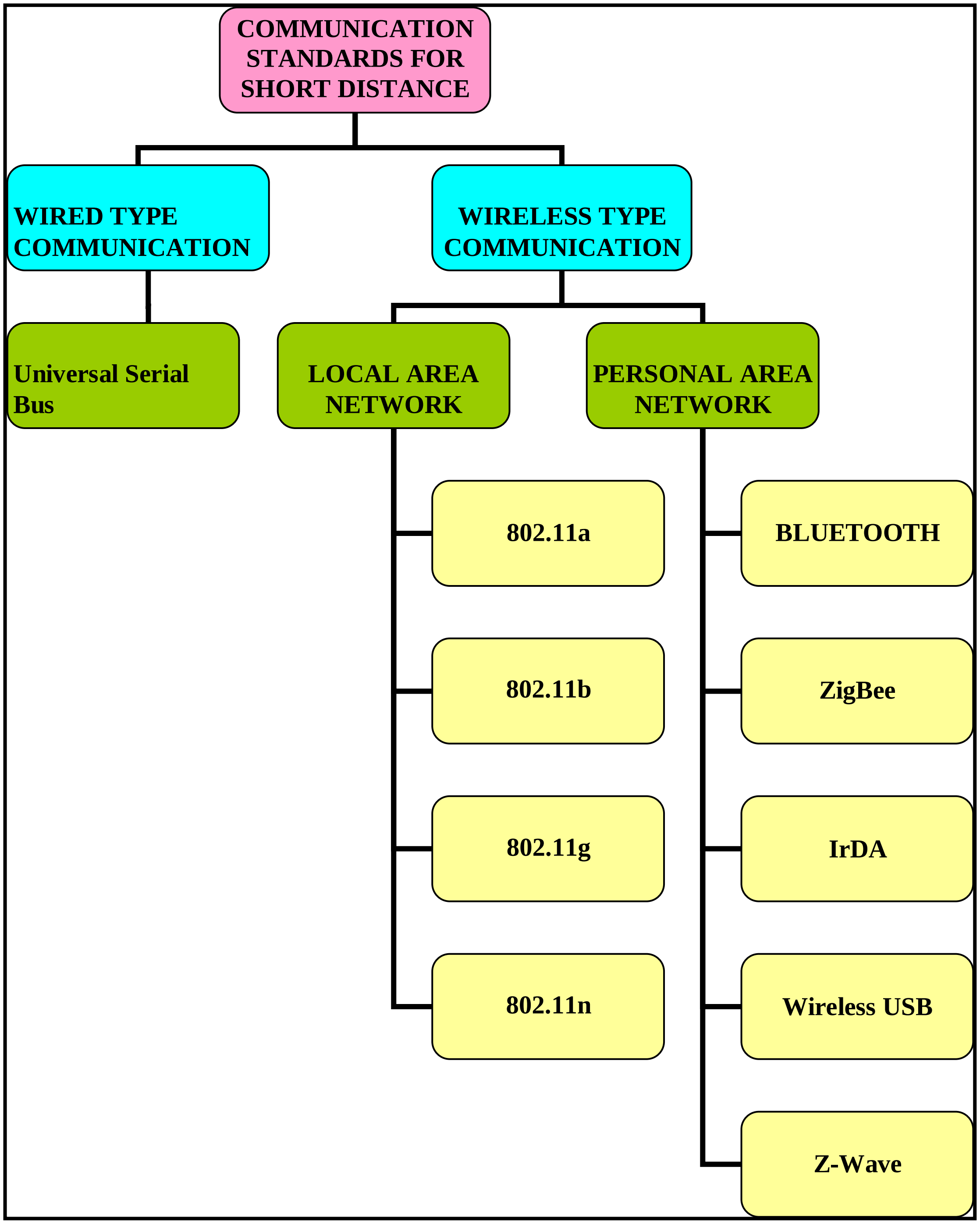

Figure: 1.1 Communication Standards for short distance

1.4.1 Wired Communication for short distance

Universal Serial Bus (USB) has become widely used interface standard having many versions and the latest being USB 3.0 [2]. It excels due to its usable data rate up to 4 Gbit/s. USB 3.0 reduces data transfer time, thereby reducing power consumption [3] but suffers from a drawback of cable connection's limited mobility. Hence, USB is best suited for applications which require high volume data transfer along with stable performance and where the mobility requirements are not very important. An example of such an application would be the connection of a web camera to your personal computer [2].

Same as with previous versions of USB, ports of USB 3.0 come in high-power and low-power variants, providing 900mA and 150mA respectively while simultaneously transmitting data at Super Speed rates [3].

1.4.2 Wireless communication for short distance

Comparing with USB, transmission based on Infrared Data Association (IrDA) standard i.e. infrared transmission due to its line of sight characteristics, enable fast establishment of the connection along with high baud rates up to 16Mb/s, which makes it suitable for the applications requiring point-to-point ad hoc connections. As this technology works only in line of sight point-to-point connections, examples would include downloading of pictures from your digital camera to your laptop or paying for your meal in your company's cafeteria with your mobile phone via IrDA port. IrDA standards were there for decades and were widely implemented in laptops, computers, cell phones, etc. But until recently, either the cost was too high, or infrared technology was having line of sight characteristics, Bluetooth has taken its place in short range communication of data [2].

Radio-based Short-Range Wireless (SRW) communication is an alternative class of growing technologies designed primarily for short distance indoor use. It is intended to provide high speed (tens or hundreds of megabits per second) and low cost, free from cable connection to the internet. SRW features transmission powers of several microwatts up to milliwatts yielding a communication range between 10 and 100 meters. SRW provides connectivity to portable devices such as laptops, cell phones and others. Short-range communication standards fall into two broad but overlapping categories: Personal Area Networks (PAN)and Local Area Networks (LAN).

1.) Personal Area Networks (PAN) - Wireless PAN technologiesemphasize low cost and low power consumption, usually at the expense of range and peak speed. In a typical wireless PAN application, a short wireless link, typically under 10 meters, replaces a computer serial cable or USB cable. Standards, such as Bluetooth, have been created to regulate short-range wireless communications. Bluetooth has appeared recently in many mobile devices. Bluetooth can transmit data through solid nonmetal objects and supports a nominal link range of 10cm-10m at a moderate baud rate up to 720kb/s (raw data rate is 1Mb/s). An optional high power mode in the current specifications allows for range up to 100m. Because of the nature of radio, Bluetooth is a point to multipoint communication system, which supports connection of two devices as well as ad hoc networking between several devices. But in order to prevent unauthorized access, Bluetooth requires sophisticated authentication and encryption mechanisms which hamper fast connection establishment. Therefore, Bluetooth is best for applications that require stable point-to-point or point-to multipoint connections for data exchange at moderate speeds, where mobility is a key requirement [2].

2.) Local Area Networks (LAN) -Wireless LAN technologies, on the other hand, emphasize a higher peak speed and longer range at the expense of cost and power consumption. Typically, wireless LANs provide wireless links from portable laptops to a wired LAN access point. To date, 802.11b has gained acceptance rapidly as a wireless LAN standard. It has a nominal open-space range of 100m and a peak over-the-air speed of 11Mb/s. Users can expect maximum available speeds of about 5.5Mb/s. Other communication standards offer even higher data rates, like 802.11a and 802.11g [2]. Table 1.1 gives comparison between the leading radio-based short-range communication standards.

1.5 What is the basic difference between Bluetooth technology and Wi-Fi?

Wi-Fi is short for "Wireless Fidelity", a nickname for devices that have been certified by an industry group called the Wi-Fi Alliance. Bluetooth technology is built into electronic gadgets and allows them to connect directly with each other wirelessly. Bluetooth technology and Wi-Fi share some pieces of technology, but are used for very different things that is why comparison between both of them is given here. Wi-Fi is often referred to as "Wireless Internet", because that's what it is most often used for, accessing the internet. Bluetooth technology is in lots of the devices and can be used for all sorts of things. It works for both voice–like talking hands-free on a headset or speakerphone–and data like pictures, music and documents [4].

Wi-Fi is used to connect to the internet through a stationary access point. An "access point" is an extra piece of equipment that Wi-Fi generally requires to allow devices to connect and work together. While possible, it's hard to make Wi-Fi products, like a laptop, personal computer and a printer, connect and work together directly. This also means Wi-Fi works primarily in fixed locations, sometimes known as "hot spots"[4].

It may be concluded that Bluetooth is basically a wire replacement wireless technology and on the other hand Wi-Fi is basically for wireless internet connectivity.Hence Bluetooth is mostly used at the places where wire replacement with wireless link is required.

Table 1.1 Comparison between the leading radio-based short-range communication standards [2].

Characteristic	**Bluetooth**	**IEEE 802.11b**	**IEEE 802.11g**	**IEEE 802.11a**
Standard version/status	V 1.1 (Low-Rate)	IEEE approved	Draft	IEEE Approved
Frequency Allocation	2.4GHz (ISM)	2.4GHz (ISM)	2.4GHz (ISM)	5GHz (UNII)
Maximum Distance	10-100m	100m	100m	50m
Modulation	GFSK	QPSK (CCK)	OFDM	OFDM
Number of RF channels	79	3	3	12 (U.S.) 8 (EU) 4 (Japan)
Spreading	FH	DSSS CCK	OFDM	OFDM

Receiver sensitivity	-70dBm	-76dBm for 11Mb/s	-74dBm for 33Mb/s	-65dBm or 54Mb/s
Maximum RF power	0-20dBm	30dBm (U.S.) 20dBm (EU) 10dBm (Japan)	30dBm (U.S.) 20dBm (EU) 10dBm (Japan)	17dBm, 24dBm, 30dBm

2.1 Bluetooth

Bluetooth which is a recently proposed standard for wireless communication over the short range by the consumption ofless powerwas initiallythought of as a wire replacement technology. Most commonly described application of Bluetooth is its use as a "cordless computer" which consists of several devices that include a Personal Computer (PC) that possibly may be a laptop, mouse, keyboard, printer, joystick, scanner, etc., each of which is equipped with a Bluetooth card. No cable connections are there between these devices and Bluetooth enables seamless wireless communication link between all of them, importantly replacing which is today achieved throughuse of combination of serial and parallel cablesor infrared links. Apart from thisBluetoothhas the potential to be used for much more than a technology for wire replacement. Low cost and low power consumptionmake it an attractive solution typically for the mobile devices[5].

2.2 History

HaraldBlatand, who is also known as Harald Bluetooth was a Viking andDenmark king. He was known for his extraordinary ability to make peopletalk to each other and it was during his reign Norway and Denmark were united. So today Bluetooth wireless technology enables electronic devices to talk to each other with the help of a short-range and low cost radio link. The developers of the Bluetooth wireless technology decided to name this wireless technology after king Harald Bluetooth because they hoped that this technology would unite the world same as HaraldBluetooth united Denmark and Norway[6].

The idea of Bluetooth wireless technology came in 1994 when it was decided by Ericsson to check the feasibility of a low-cost, low-power radio interface between the accessories of mobile phones and mobile phones themselves. Basically the idea was to build a small radio into both the laptop and cellular telephone that would replace the cumbersome cables which are usedfor connection of two devices. Today, Bluetooth Special Interest Group (SIG) supports Bluetooth wireless technology. Main players of this group include Ericsson Technology Licensing AB, 3Com Corporation, Intel Corporation, IBM Corporation, Agere Systems, Inc., Motorola Inc., Microsoft Corporation, Nokia Corporation and Toshiba Corporation. And today there are many companies having Bluetooth SIG membership. Support and backing from these companies makes it sure that in wireless market of world, Bluetooth will gain a chance and acceptance and so it is doing also [6].

2.3 Brief description of Bluetooth Technology

Bluetooth works inthe Industrial, Scientific and Medical(ISM) band from 2400-2483.5 MHz(including guard bands) from mobile as well as fixed devices by creationof Personal Area Networks (PANs) with high security level.Several devices can be connectedby using this technology, overcoming synchronization problems.Bluetooth uses technology calledFrequency-Hopping Spread Spectrum (FHSS) which is a radio technology. The data to be transmitted is first divided into packets and then each packet is made to transmit on one among the designated 79 Bluetooth channels. Bandwidth of each channel is 1 MHz. The very first channel starts at frequency of 2402 MHz and goes up to 2480 MHz in steps of 1 MHz.Usually it performs 1600 hops per second. Originally modulation method used was Gaussian Frequency-Shift Keying (GFSK) scheme which was the only scheme of modulation available; by the time, since with introduction of Bluetooth 2.0+EDR, 8 DPSK and π/4-DQPSK modulation can also be used between devices that are compatible. Devices that are functioning with GFSK are operating in Basic Rate (BR) mode in which an instantaneous 1 Mbit/s data rate is possible. The term Enhanced Data Rate (EDR) describes π/4-DQPSK and 8DPSK schemes where each is giving 2 and 3 Mbit/s respectively. In Bluetooth radio technology, combination ofBR and EDR modes is classified as "BR/EDR radio"[7].

Piconet - A collection of a number of devices that are connected via Bluetooth radio technology in an ad hoc fashion. To start apiconet requirement is two connected devices, like laptop and cellular phone which may grow to eight connected devices and all other Bluetooth devices are peer units and they also have identical implementations. However, at the time of piconetestablishment, one unit will be acting as a master and the other units as slaves forconnection duration of the piconet [6]. As shown in figure 2.1.

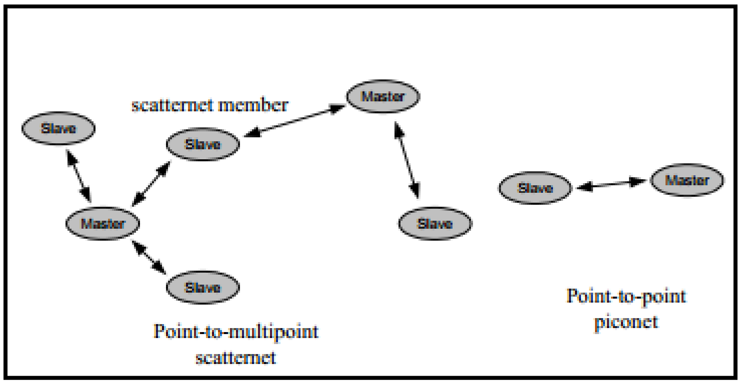

Figure 2.1: Various topologies in Bluetooth

Bluetooth is a packet-based protocol which is having a master-slave structure. In a piconet up to 7 slaves can be communicated by one master[7]. Timing on the network can be controlled by Bluetooth by designating one device as aslave and the other as a master. The unit which initiates communication link is master and the other participants are slaves. After breakdown of link,the designationsof master/slave no longer apply. Fact is that, every Bluetooth device is having bothmaster and slave hardware. The network is called aspiconet, which meansa smallnetwork. When number of slaves is only one, then link is called as point-to-point. In a point-to-multipoint configuration up to seven active slaves can be controlled bya master. Slavesnever communicatedirectly with each other but instead communicate with the master only. Because of timing piconetmembers cannot transmit simultaneously, hencejam problem is not there between these devices. Finally, realization of communication process across thepiconets is done if the Bluetooth radio deviceis a slave in one and master in other or slave in more than one piconet.Configurations of piconet in this manner are called scatternets. The depiction of these various arrangements is in figure. 2.1[2].

Master's clock is shared by all devices. Basic clock which is defined by the master, ticks at intervals of 312.5 μs. Base of packet exchange isbasic clock. A slot of 625 μs is made up of two clock ticks; a slot pair of 1250 μs is made up two slots. Considering a very simple case of packets which are single-slot, the transmission of master is in even slots and reception is in odd slots; for the case of slaves, conversely, its transmission is in odd slots and reception is in even slots. Packet length can be 1, 3 or 5 slots but considering all cases, the transmission of slave is in odd slots and master's transmission will begin in even slots[7].

2.3.1 Format of Modulation

The format of modulation is Gaussian Frequency Shift Keying (GFSK) havingbandwidth×bit time product (BT) equal to 0.5. The index of modulation is having value between0.28 and 0.35.For the data rate of 1Mbps in Bluetooth technology, frequencydeviation value can be from ±140 to ±175kHz.The generation of GFSK signal is asfollows:

First of all the stream of data d(t) is filtered by using aGaussian filter with impulse and frequency responses as follows in equations (1) and (2).

$$h(t) = e^{-\frac{1}{2}\left(\frac{t}{\tau}\right)^2} \quad .....(2.1)$$

$$H(\omega) = \tau \cdot \sqrt{2\pi} e^{-\frac{1}{2}(\tau\omega)^2} \quad .....(2.2)$$

This is having similarity with thee^{-x^2}shape of that of Gaussian, or normal, probability density function. As given in equation, τ is a constant and ωis frequency in rad/sec.Frequency and impulse responses of a Gaussianfilter are Gaussian and it is itspeculiar property. Frequency and impulse responses of a Gaussian LPF are shown in figures 2.3 and 2.2 respectively. Bandwidth of the filter from equation (2.2), can be written as:

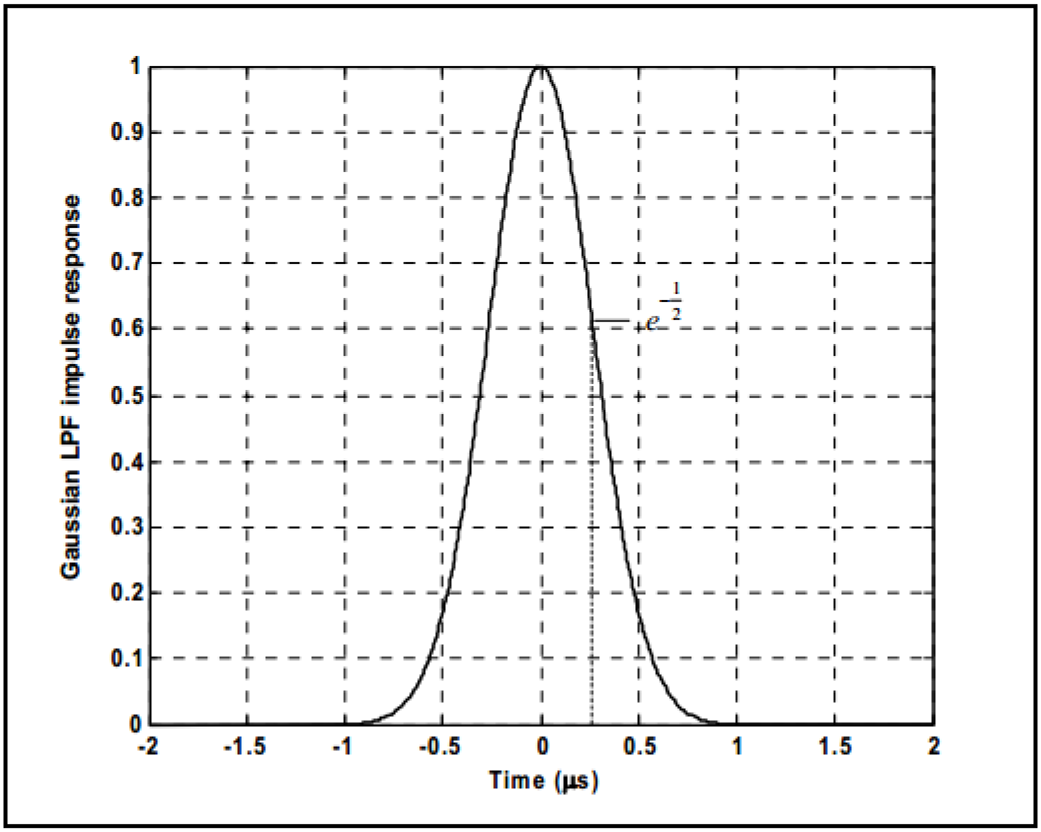

Figure2.2: Impulse response of Gaussian LPF

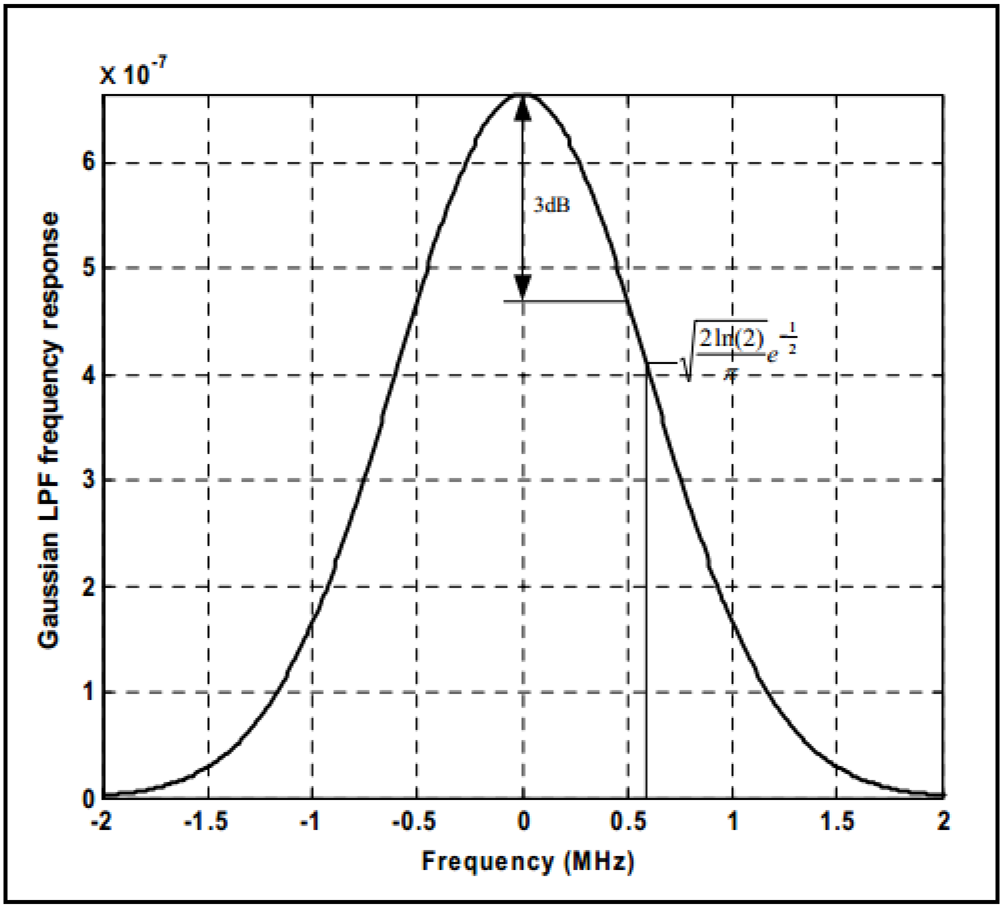

Figure 2.3: Frequency response of Gaussian LPF

$$B = \frac{\sqrt{\ln(2)}}{2\pi}\frac{1}{\tau} \quad .....(2.3)$$

The specification of Gaussian filter is as follows:

$$BT = (\text{Filter Bandwidth}).\,(\text{Bit Period}) = \frac{\text{Filter Bandwidth}}{\text{Bit Rate}} = \frac{T_b}{\tau}\frac{\sqrt{\ln(2)}}{2\pi} \quad .....(2.4)$$

Higher BT means higher bandwidth but lessintersymbol interference (ISI). Taken a good compromise value, BT=0.5 is specified in the Bluetooth standard. Hence the bandwidth is 500kHz. Therefore, the value of output of the Gaussian filter is as under:

$$gf(\mathrm{t}) = \mathrm{d(t)} * e^{-\frac{1}{2}\left(\frac{\pi}{\sqrt{ln\,(2)}}\frac{t}{T_b}\right)^2} \;\ldots..(2.5)$$

The value of` d(t) *and gf*(t) both have a minimum and maximum of -1 and 1 which represents0 and 1 bits, respectively. Carrier is frequency modulated by the Gaussian filtered data *gf*(t). The GFSK signal output is expressed as:

$$gfsk(\mathrm{t}) = \sin\,(2\pi\,(f_c + \; f_d.gf(t))\ldots..(2.6)$$

Wheref_d is frequency deviation andf_c is center frequency.Hence the transition of instantaneous frequency of the GFSK signal is between afrequency$f_c + f_d$, representing binary 1 and$f_c - f_d$, representing binary 0. According to Bluetooth standard, the modulation index of frequency is specified between 0.28 and 0.35. Index of modulation or modulation index signifies ratio between the deviation of frequency $2f_d$ and the bit rate. Thus corresponding$f_d$value must be between range of 140 and 175 kHz.As shown in figure 2.4, representative examples of the unfiltered, Gaussian FSK signal and Gaussian filtered. For the purposes of illustration, the centerfrequency of GFSK signal in figure 2.4 is 1MHz[2].

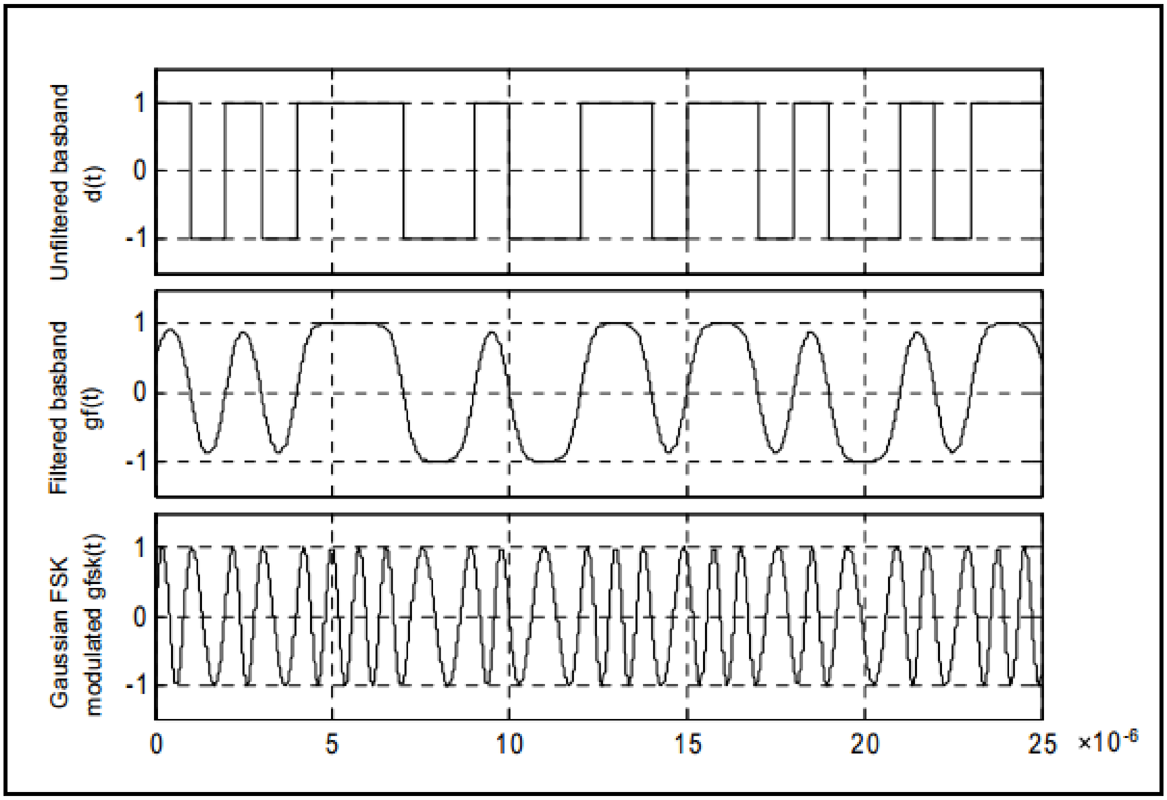

Figure 2.4: Modulation steps of GFSK

2.3.2 Frequency Band

Operationof Bluetooth is in the Industrial Scientific Medical (ISM) 2.4 GHz band. The range of this frequency band in majority of countries around the world is 2400MHz – 2483.5MHz. By the utilization of Time Division Duplex (TDD), receiver and transmitter share the same frequency band. Lots of devices expected by regulators to be using the same spectrum, thus they have made rules for the useof ISM band in order to make it sure that the bandwidth can be shared by devices. According to the rules set, power of your transmissions must be spread across the ISM band somehow. Two main methods that are used for power spreading out are:

1.) Direct Sequence Spread Spectrum (DSSS) and
2.) Frequency-Hopping Spread Spectrum (FHSS)

DSSS smears a transmission at low power across a wide range of frequencies and on the other hand FHSS spectrum hops frequency after each packet but uses a small bandwidth.

Bluetooth makes use of frequency-hopping spread spectrum which is shown in figure 2.5. There are 79 channels and each is of 1MHz.Frequencies of transmitters change 1600 times every second. If two piconetscollided on the same channel, then hopping off to new frequencies takes place and any lost data is retransmitted. Thus this technique also minimizes the risk of disruption of Bluetooth services by portable phones or any other device because the interference effect on a particular frequency lasts only a very small fraction of a second. To determine the frequency hopping pattern algorithmically, Bluetooth uses the master's device ID. This algorithm generates a random and unique pattern whichis exhibited in an extremely long repeat cycle[2].

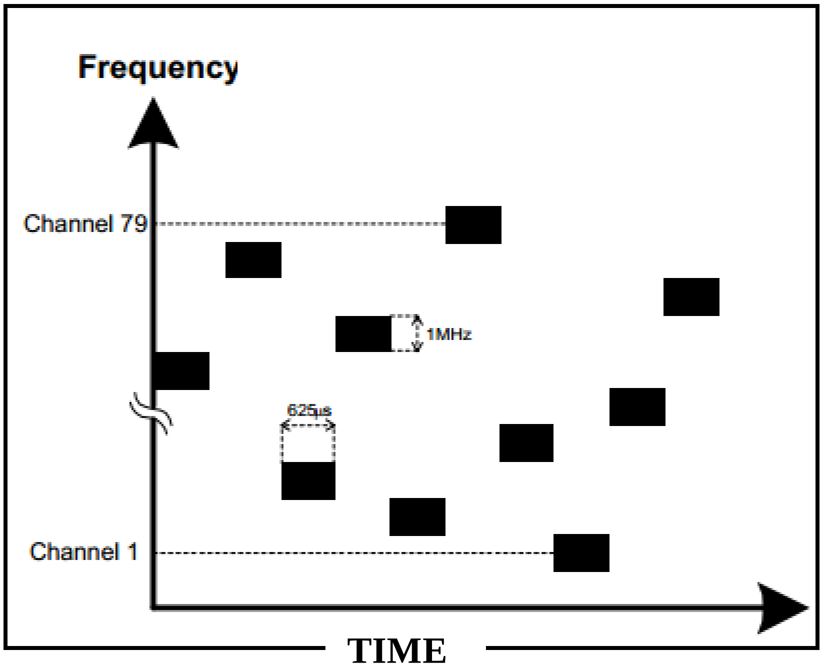

Figure 2.5: Frequency Hopping Technique

2.3.3 Blocking Requirements

For performing the blocking test for Bluetooth, a desired Bluetooth-modulated signal of 10 dB (1 MHz for Co-channel and interference is 2 MHz) or 3 dB (for interference from all other frequencies) is applied over the reference sensitivity level.After this an interferingBluetooth modulated signal at 1 MHz discrete increments from the desired signal is applied to the receiver.At the frequencies with distance of greater than or equal to 2 MHz from the wanted signal, five spurious response frequencies are allowed. A relaxed interference requirement of C/I = -17 dB shall be meton these spurious response frequencies, where I is the interference power and C is the carrier power. Usually, a different set of exceptions is allowed for each channel. If the implementation is of a low-IF receiver, there is degradation of C/I if I represents the image signal. Spurious response frequency can be made use of in low-IF receivers to relax image rejection requirement[2].

2.3.4 Intermodulation Requirements

The performance of adjacent channel immunity test done by the application at f1of one static sine wave signal having a power level of –39 dBm and also one Bluetooth modulated signal at f2 having a power level of –39 dBm at the receiver input whilea 6dB signal which is wanted signal above the reference sensitivity is applied. The BER of 0.1% must be maintained by the receiver. And awareness must be thereat time of performing this intermodulation test; there are also effects of noise in receiver channel. It is necessary alsoto make sure thatC/ (I+N) is high enough in order to maintain the required BER, here N is called as the noise floor level[2].

2.3.5 Sensitivity

Input level which meets 0.1% raw bit error rate (BER) is called as actual sensitivity level -70dBm or better actual sensitivity level is the requirement for a Bluetooth receiver. For 50Ω impedance the power level -70dBm is defined. In terms of impedance and rms voltage this power can be written in as follows:

$$P\ (in\ dBm) = 10log\ (power\ in\ mW) = 10\log\left(\frac{V_{rms}{}^{2}}{R}\right) + 30 \ldots..(2.7)$$

So rms voltage of 70.7µVrms is equivalent of the power level -70dBm. At this point it is importantto make clear the different representations of signal power:

Power in dBm≡ decibels relative to one milliwatt[2]

2.4 Working of Bluetooth devices

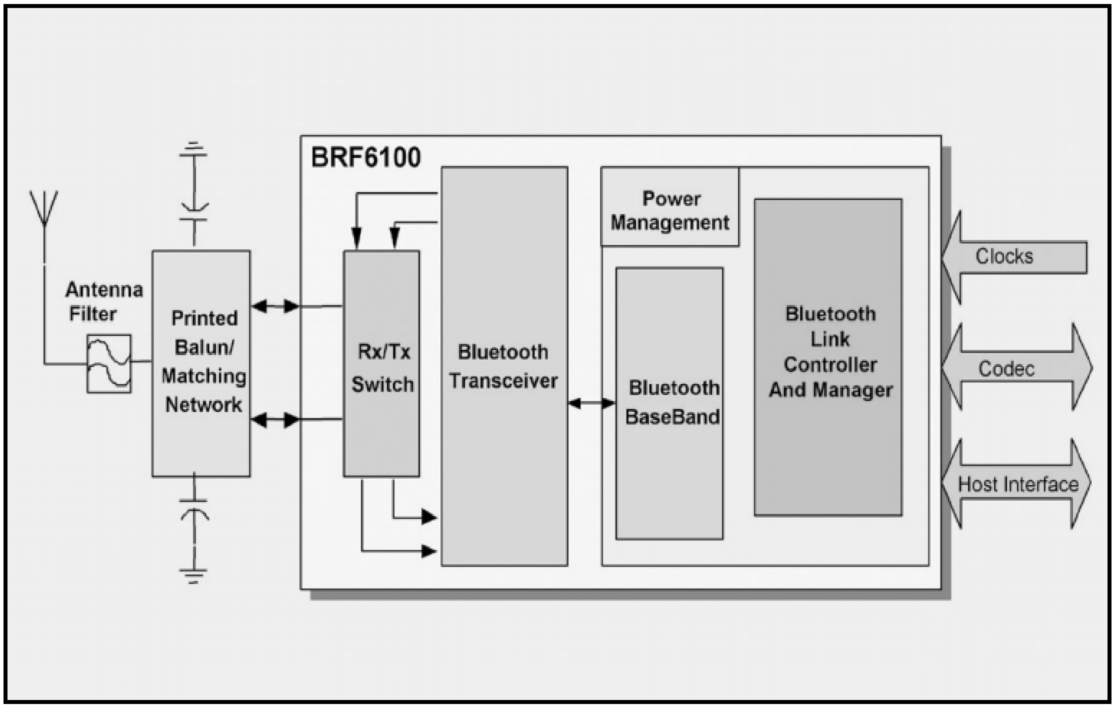

Figure 2.6: Block diagram of Bluetooth

All the devices that are in an electronic discussion need to know what the bits being transmitted and received mean and whether the message they receive is the same message that was sent. In almost every case, this means developing a large collection of commands and responses known as a protocol. Some types of products have a standard protocol used by virtually all companies so that the commands for one product will tend to have the same effect on another. Modems fall into this category of having one protocol. Other products of the same type each speak their own language, which means that commands intended for one specific product will seem like gibberish if received by another product. Printers are like this, with multiple standards, such as Printer Command Language (PCL) and PostScript. Bluetooth, more like modems than printers, has a set standard of its own[6]. Block diagram of Bluetooth is shown in figure 2.6.

2.4.1 Protocols of the Bluetooth

Any Bluetooth device needs exactly four parts to operate properly. These include -

1.) A radio frequency for receiving and transmitting data,
2.) A module with a baseband microprocessor
3.) Memory and
4.) An interface to the host device

To make up these parts, the Bluetooth Special Interest Group has given Bluetooth, seven different protocols. For any device to be qualified as a Bluetooth device, it must satisfy these seven protocols. These seven protocols include -

1.) The radio protocol
2.) The baseband protocol
3.) The LMP protocol
4.) The HCI protocol
5.) The L2CAP protocol
6.) The RFCOMM protocol and
7.) SDP protocol

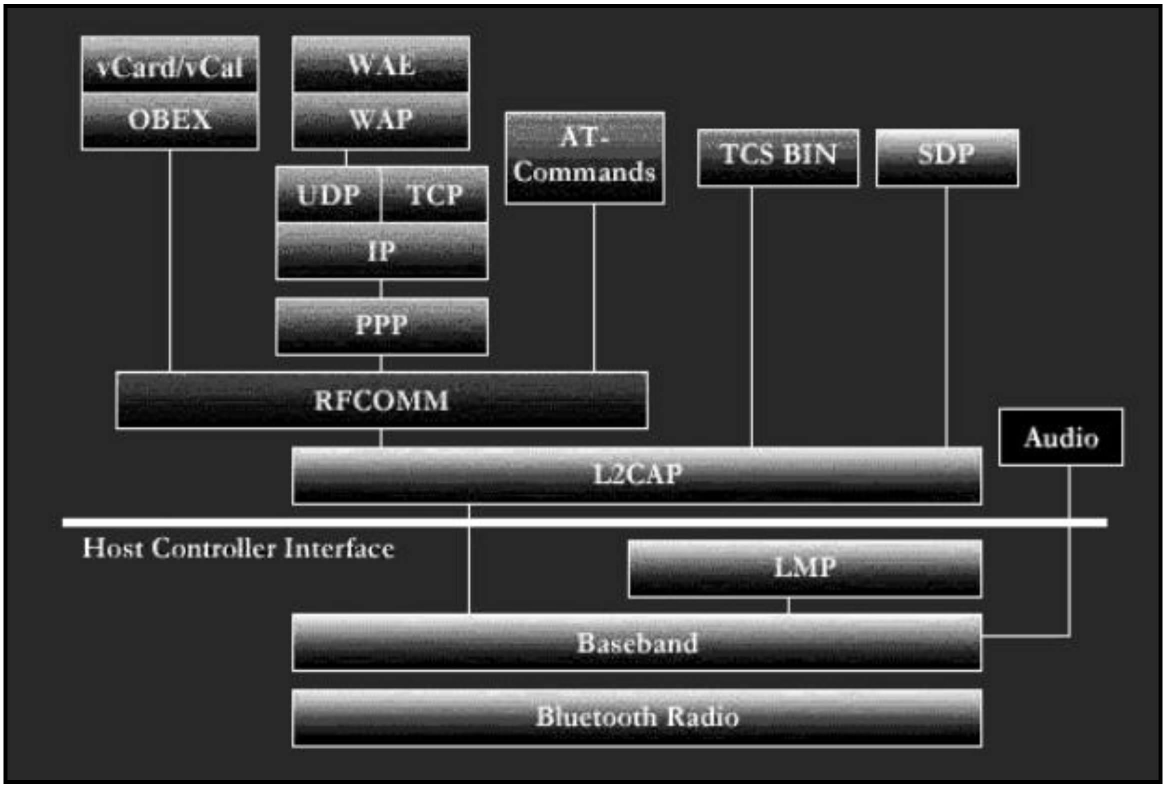

Figure2.7:Protocol stack of the Bluetooth

Figure 2.7 shows how these seven protocols work and fit together amongst each other and with other protocols. Description of protocols is as under –

1. **The Radio protocol** - The radio protocol is basically what makes Bluetooth a wireless device by serving as the digital signal-processing component of the system. It works very similar to other wireless technologies we have today. Bluetooth devices transmit data which is made up of bits (ones and zeros), over a radio frequency, which is an electromagnetic wave frequency found between audio and infrared. Bluetooth devices use Gaussian Frequency Shift Keying or GFSK for short. This means that a binary one is represented by a positive frequency deviation and that a binary zero is represented by a negative frequency deviation. A receiver on another Bluetooth device will pick up the bits that are being sent through air. This is how the

bits or data are transmitted and received. Bluetooth devices use industrial,scientific and medical (ISM) band from [6] 2400-2483.5 MHz (including guard bands) [7] as described earlier. This range is then cut into 79 one MHz channels. Each one of these channels is broken down into time slots of 625 microseconds. This is shown in figure 2.5. This makes for 1,600 different slots per second for Bluetooth devices. It is through these channels and slots that Bluetooth transmits data.

The next question is, inwhat form is this data?

2. **The Baseband protocol -** This brings us to the baseband, which processes the signals that are received and transmitted by the radio. It also controls the links, packets, channels, error correction, and flow control.

I. **Links -** The two different types of links that Bluetooth devices are capable ofmaking are –

a. SCO (Synchronous Connection-Oriented) and

b. ACL (AsynchronousConnectionless)

a. SCO is used primarily for voice packets, and ACL is used primarily for data packets. It is easy to compare these two links with the way that TCP and UDP work, with TCP, like SCO, being connection-oriented, and UDP, like ACL, being connection-less[6].

b. The Asynchronous Connectionless (ACL) links are defined for data transmission(primarily packet data). They support symmetrical and asymmetrical packet-switchedconnections. Multi-slot packets use the ACL link type and can reach the maximum datarate of723 kbps in one direction and 57.6 kbps in the other direction. The master controlsthe ACL link bandwidth and decides how much of the bandwidth a slave can use in apiconet. Broadcast messages are supported in the ACL link, i.e., from the master to allslaves in the piconet.

The Synchronous Connection Oriented (SCO) links support symmetrical, circuit-switched, point-to-point connections and are therefore primarily used for voice traffic. Two consecutive time slots at fixed intervals are reserved for a SCO link The SCO link reserves every sixth slot for a transmitting channel and the subsequent slot for a receiving channel, so there can be up to three simultaneous SCO links. The data rate for SCO links is 64kbps[8].The SCO link is symmetric, allowing for simultaneous uploads and downloads of data between devices, and typically supports time-bounded voice traffic. SCO packets are transmitted over reserved intervals. Once the connection is established, both master and slave units may send SCO packets at will. One SCO packet type allows both voice and data transmission with only the data portion being retransmitted when corrupted[6].

Example: Mixed Links

The following example describes how multiple connections can be handled simultaneously (see figure 2.8). Let us assume that the master is a mobile phone. The phone has already established connections to three slaves (wireless headset, printer, home-lighting system). In time slots1 and 2 (black boxes), a call is ongoing (also in slots 7-8, 13-14, and 19-20). In the following two slots, the user adjusts the volume and the headset acknowledges it. In slots 5 and 6, the user turns on the light in the room and receives an acknowledgement. In slots9-12, the user starts printing out a note from her phone and the printer acknowledges it. And finally, in slots 21 and 22 the call will hang up. For the call, both the phone and the headset have to reserve every sixth slot (the black boxes). That means that between phone/headset links only four slots are free for additional communication. Thus five-slot data packets cannot be sent while having a voice link.

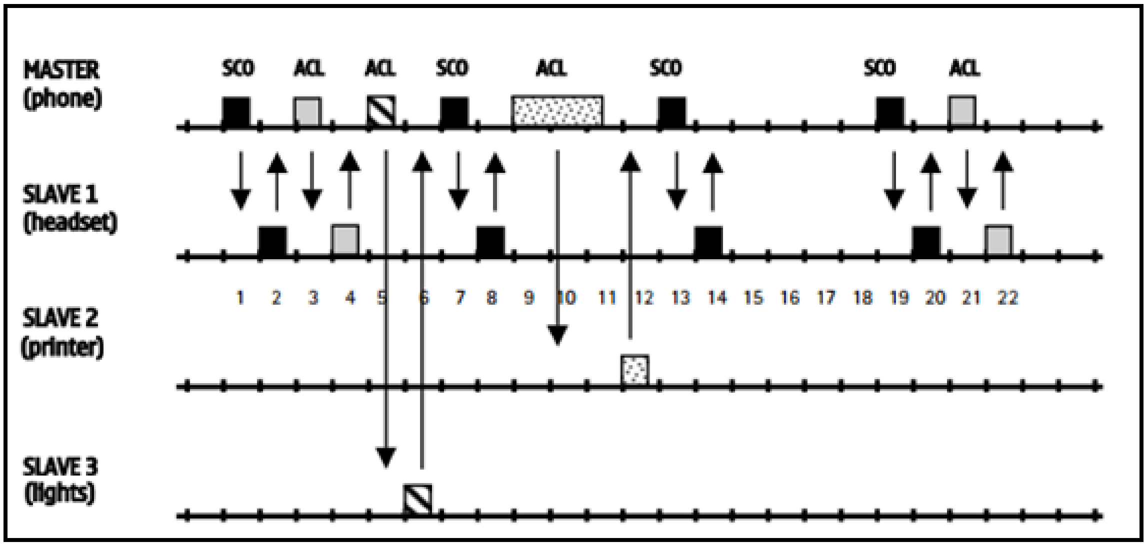

Figure 2.8: Many links simultaneously

This theoretical scenario may not be feasible in practice but it gives a good idea of the multitasking properties of Bluetooth technology, supporting different applications simultaneously without any noticeable effect for the user (In applications where data is transmitted in the background the data transfer speed is irrelevant)[8].

II. Packets - Like all other networking protocols, such as TCP, IP, UDP, and Ethernet, Bluetooth transmits its data in packets. However, unlike the packets in the other protocols, Bluetooth has thirteen different types of packets to handle many different tasks, with these packet types falling under the two categories of links. Bluetooth has a standard packet format that consists of 72 bits for the access code, 54 bits for the header, and 0-2745 bits for the payload. This standard packet format is shown in figure 2.9. For simplicity we will just describe the generic parts of the standard packet format because the other packets still contain the same parts. Each of the separate parts of the packet contains different information that is necessary for the packet to be deciphered.

ACCESS CODE	HEADER	PAYLOAD
72 Bits	54 Bits	0-2745 Bits

Figure 2.9: Format of standard packet

The access code is used for timing synchronization, offset compensation, paging and inquiry. There are three different types of Access code: Channel Access Code, Device Access Code, and Inquiry Access Code. The Channel Access Code identifies a unique piconet while the Device Access Code is used for paging and its responses. Inquiry Access Code is used for inquiry purpose.

The header contains information for packet acknowledgement, packet numbering (for out-of-order packet reordering), flow control, slave address and error checks for header. The packet payload can contain a voice field, a data field, or both. If the packet payload has a data field, it will also contain a payload header

There are nine categories of packets that contain an access code, header and payload just as in the standard packet format. Each of the nine packet types has its own special purpose. Some of the packets differ in the fact that they are specifically made for voice communication, while others are made for high-speed data transfer. Each of the packets has different data rates depending on the type of traffic they are sending [6]. These statistics can be seen in Table 2.1.

Table 2.1: List of all packet types along with their rates of data[6].

Packet Type	Max Payload (Bytes)	Symmetric Rate (Kbps)	Asymmetric Rate (Kbps) Forward	Asymmetric Rate (Kbps) Reverse
DM1	17	108.8	108.8	108.8
DH1	27	172.8	172.8	172.8
DM3	121	258.1	387.2	54.4
DH3	183	390.4	585.6	86.4
DM5	224	286.7	477.8	36.3
DH5	339	433.9	723.2	57.6
HV1	10	64	n/a	N/a
HV2	20	64	n/a	N/a
HV3	30	64	n/a	N/a

III. **Connection States** - The baseband also controls the connection states that the devices use. The two states are Standby and Connection. The Standby state is the default low power state in the Bluetooth unit. Only the native clock is running and there is no interaction with any other device whatsoever. This ability to use low power makes Bluetooth ideal for use in cell phones and laptops where the amount of battery power is limited. In the Connection state, the master and slave can exchange a packet, using the channel access code and the master Bluetooth clock [6].

IV. **Error Correction** - The last task the baseband handles is error correction, which is also handled by the baseband protocol. There are three kinds of error correction schemes used in the baseband protocol: 1/3 rate FEC (Forward Error Correction), 2/3 rate FEC, and the Automatic Repeat Request scheme or ARQ, for short. In 1/3 rate FEC, every bit is repeated three times for redundancy. In 2/3 rate FEC; a generator polynomial is used to encode 10 bit code into a 15 bit code. In the ARQ scheme, DM, DH, and the data field of DV packets are retransmitted until an acknowledgement is received or until the timeout limit is exceeded. Bluetooth uses fast, unnumbered acknowledgement in which it uses positive and negative acknowledgements by setting appropriate ARQN (Automatic Repeat Request Number) values. If the timeout value is exceeded, Bluetooth flushes the packet and proceeds with the next [6].

3.) **Link Management Protocol -** Next, there is the LMP or the link management protocol. The Link Manager controls or manages link setup, authentication, link configuration and other low level protocols. It discovers other remote link managers and communicates with them via the Link Manager Protocol. It basically, with the help of the Baseband, establishes all the connections for all Bluetooth devices [6].

4.) **Host Controller Interface -** Then, there is the HCI (host controller interface). The HCI provides a command interface to the baseband controller and link manager. The HCI also provides access to hardware status and control registers. Essentially this interface provides a uniform method of accessing the Bluetooth baseband capabilities, which is important for all devices to be able to utilize the Bluetooth technology. The HCI exists across three sections, the host, transport layer, and the host controller. Each of the sections has a different role to play in the HCI system. The way in which this communication between host controller interface works is shown in figure 2.10 [6].

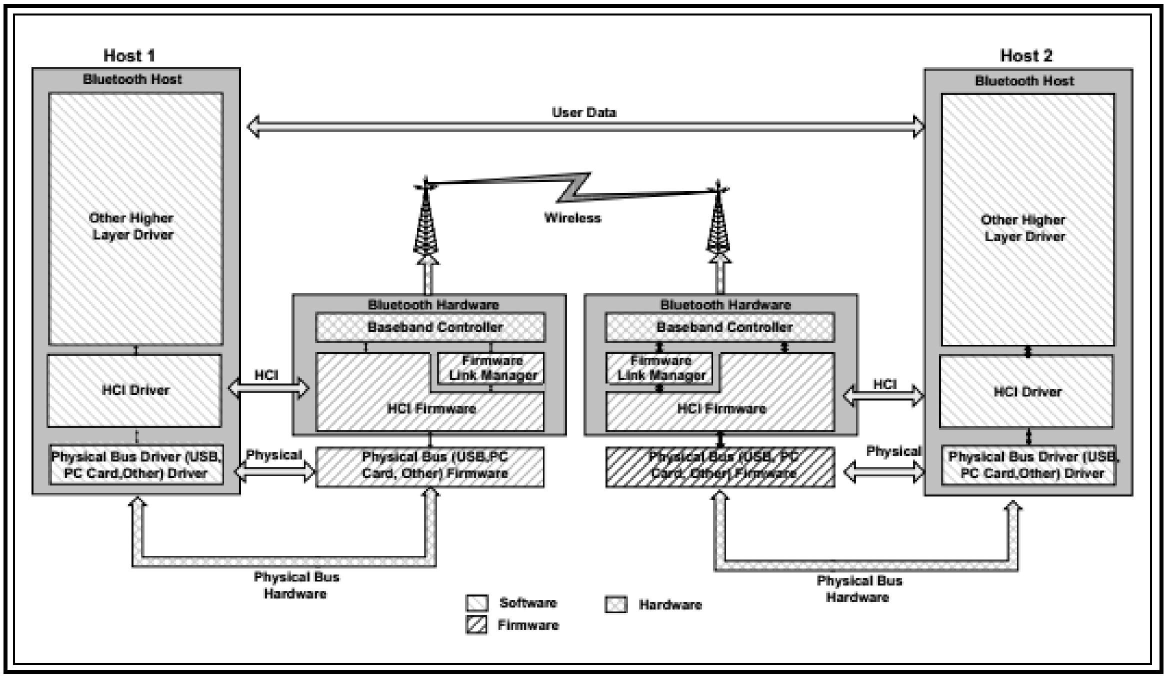

Figure 2.10: Host Controller Communication example

5.) Logical Link Control and Adaptation Layer Protocol (L2CAP) - The Logical Link Control and Adaptation Layer Protocol (L2CAP) is layered over the Baseband Protocol and resides in the data link layer, as can be seen in figure 2.1. The L2CAP is basically a processor that provides connection oriented and connectionless data services to upper layer protocols with protocol multiplexing capability, segmentation and reassembly operation, and group abstractions.In other words, other protocols, such as IP, can send their packets through theBluetooth device and the L2CAP will break their packetsdown into the correct size for Bluetooth transmission, which happens to have a maximum size of 64 kilobytes. When the packet passes through another Bluetooth device's L2CAP, itwill be put back in its original form. L2CAP permits higher-level protocols andapplications to transmit and receive L2CAP data packets up to 64 kilobytes in length. The L2CAP specification is defined for only ACL links and no support forSCO links is planned [6].

6.) RFCOMM -RFCOMM is a simple transport protocol, which provides emulation of RS232 serial ports over the L2CAP protocol. The protocol is based on the ETSI standard TS 07.10. However, only a subset of the TS 07.10 standard is used by the RFCOMM. The RFCOMM protocol supports up to 60 simultaneous connections between two Bluetooth devices. These 60 different connections are similar to ports on a server. There is a different service running on each of the ports. This allows two Bluetooth devices to have up to 60 simultaneous connections. The number of connections that can be used simultaneously in a Bluetooth device is implementation-specific, meaning it is based on what profile is being used. Some profiles will not ever use all of the 60 different ports. For the purposes of RFCOMM, a complete communication path involves two applications running on different devices with a communication segment between them [6].

7.) Service Discovery Protocol (SDP) - Finally, the Service Discovery Protocol, or SDP, is a simple protocol with minimal requirements on the underlying transport. It can function over a reliable packet transport. If the client implements timeouts and repeats requests as necessary, SDP can function over an unreliable packet transport. SDP uses a request/response model where each transaction consists of one request Protocol Data Unit (PDU) and one response PDU. In the case where SDP is used with the Bluetooth L2CAP transport protocol, only one SDP request PDU per connection to a given SDP server may be outstanding at a given instant. In other words, a client must receive a response to each request before issuing another request on the same L2CAP connection. Limiting SDP to sending one unacknowledged request PDU provides a simple form of flow control. Figure 2.6 illustrates an example of how a client and server application communicates using the SDP protocol [6].

2.4.2 Frequency Hopping

Bluetooth technology uses a Frequency Hopping Technique, which means that every packet is transmitted on a different frequency. In most countries, 79 channels can be used. With a fast hop rate (1600 hops per second), good interference protection is achieved. Another benefit is a short packet length. If some other device is jamming the transmission of a packet, the packet is resent in another frequency determined by the frequency scheme of the master. Note that this case only refers to situations where there are two ormore simultaneous active piconetsor a non-Bluetooth device using the samefrequency inrange. The error correctionalgorithms are usedtocorrect the faultcaused byjammed transmissions [8].

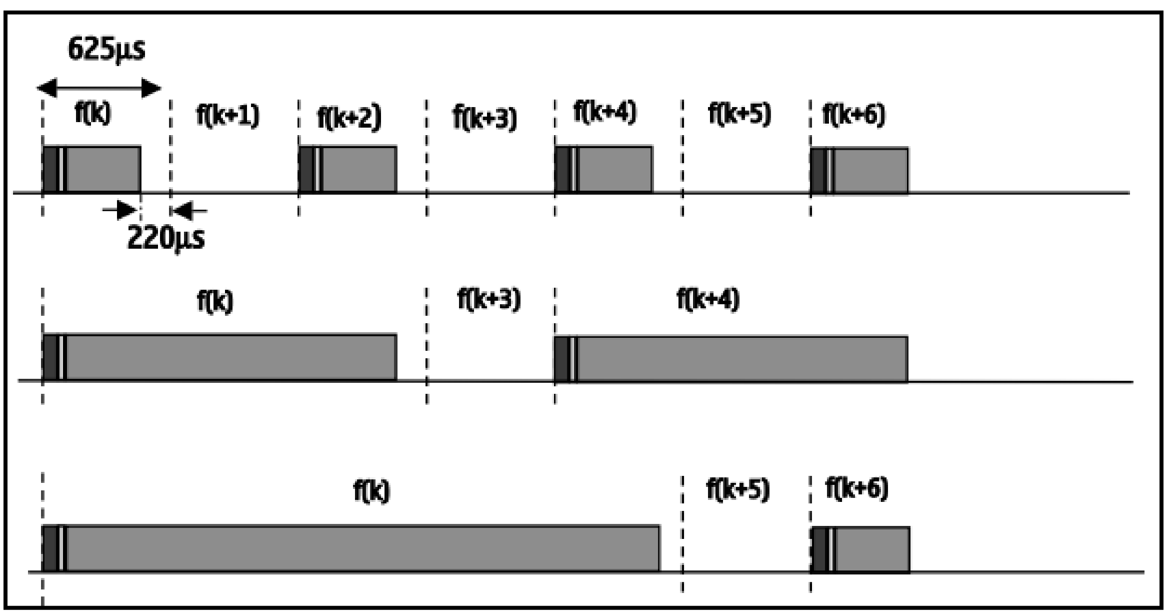

Fig- 2.11: Overhead is reduced by 3-slot and 5-slot packets as compared to 1-slot packets and time duration of 220µs (switching time) after the packet is needed forfrequency changing.

Subsequent time slots are used for transmitting and receiving. The nominal slot length is 625 µs. A packet nominally covers a single slot, but can be extended to cover three or five slots, as depicted in figure 2.11. In multi-slot packets the frequency remains the same until the entire packet is sent. When using a multi-slot packet, the data rate is higher because the header and a 220 µs long switching time after the packet are needed only once in each packet. On the other hand, the robustness is reduced: in a crowded environment the long packets will more probably be lost [8].

2.4.3 Connection establishment and inquiry

The connection to a desired device is made by a page message (figure 2.12). If the address of the recipient is unknown, an inquiry message is needed before paging. Before any connections are made, all units are in standby mode. A unit in a standby mode wakes up every 1.28 seconds to listen to page/inquiry messages. Each time a unit wakes up,listens on one of the 32 defined hop frequencies. The page message will be sent on 32 different frequencies. Initially the message is sent on the first 16 frequencies, 128 times, and if no response is received, the master sends a page message on the remaining 16 frequencies, 128times. The maximum connection time is 2.56seconds. When paging, the master must know the slave's Bluetooth address and system clock to calculate the proper access code and the wake-up sequence phase. That information was provided in the inquiry process. In inquiry, the master sends an inquiry access code, and other devices respond with their identity and system clock. After that, the connection can be made with any of those devices using the paging procedure described earlier. In connection state, the Bluetooth unit can be in several modes of operation. Sniff, hold, and park modes are used to save power or to free the capacity of a piconet:

Active mode: In the active mode, the Bluetooth unit actively participates on the channel.

Sniff mode: In the sniff mode, the duty cycle of the slave's listen activity can be reduced. This means that the master can only start transmission in specified time slots.

Hold mode: While in connection state, the ACL link to a slave can be put in a hold (possible SCO links are still supported). In hold mode, the slave can do other things, such as scanning, paging, inquiring, or attending another piconet.

Park mode: If a slave does not need to participate in the piconet but still wants to remain synchronized to the channel (to participate in the piconet again later), it can enter the park mode. It gives up its active member address. Park mode is useful if there are more than seven devices that occasionally need to participate in the same piconet. The parked slave wakes up regularly to listen tothe channel inorder tore-synchronize and to checkfor broadcast messagessentbythe master [8].

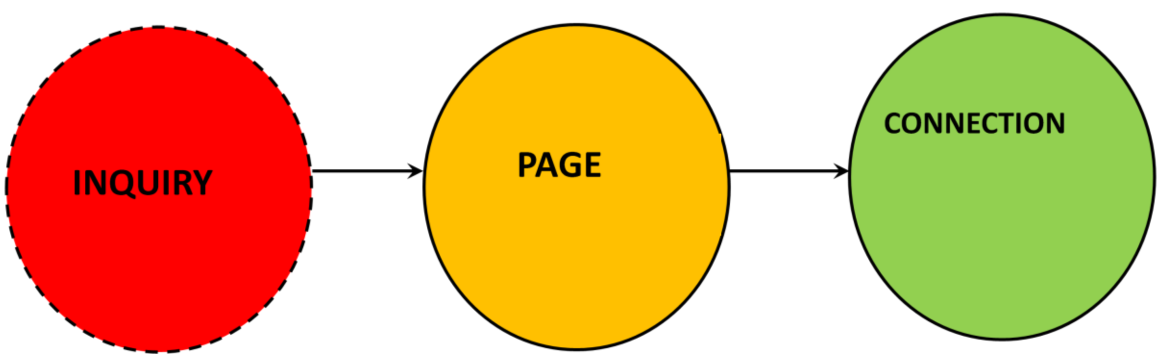

Figure 2.12: How connection takes place by going through inquiry and page procedures.

2.5 Study of various Bluetooth modules

2.5.1 Parani-BCD110

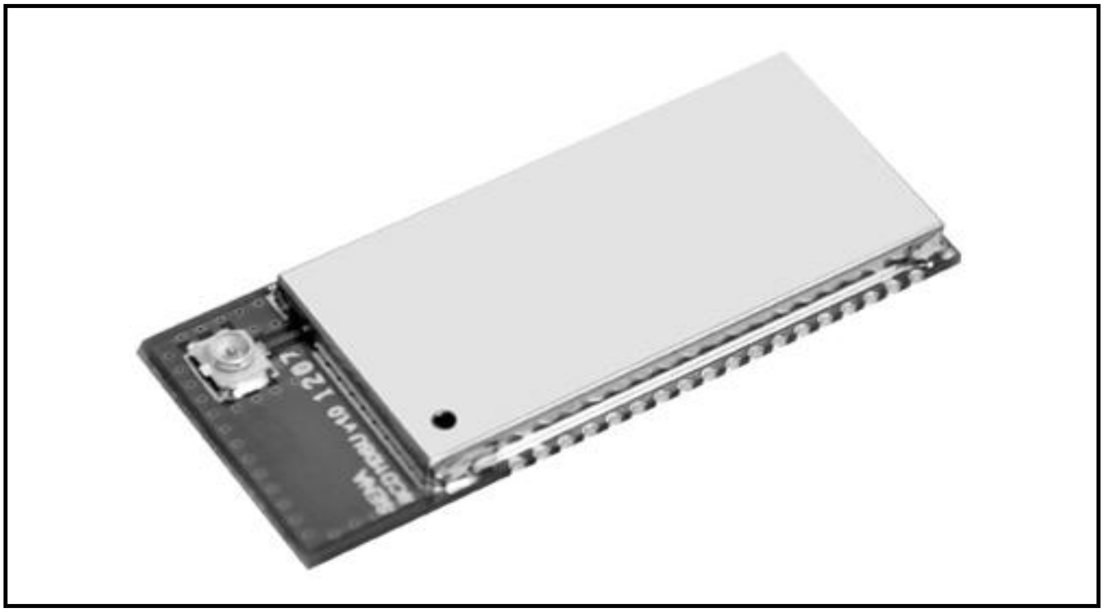

Figure 2.13: Parani-BCD 110 module

The Parani-BCD110 (figure2.13) is a Bluetooth Class1 OEM(Original Equipment Manufacturer) SMD/DIP module combining antenna for OEM manufactures who want to implement Class1 Bluetooth functionality with their products cost effectively and also in timely manner. The BCD110 supports Class1 Bluetooth transmission level for long distance communication typically ranging from 200m up to 1000m at line-up sight. The BCD110 supports UART (Universal Asynchronous Receiver/Transmitter), USB (Universal Serial Bus) [9], I2C (referred to as I-squared-C, inter-IC or I-two-C) [3], PCM (Pulse Code Modulation), PIO (Programmed Input/output) interfaces for the communication with the OEM products. The BCD110 is provided with Bluetooth v2.0+EDR (Enhanced Data Rate) compatible firmware runs internally for SPP (Serial Port Profile) applications by default. The SPP firmware supports up to 4 simultaneous multiple connections and is designed to work out-of-box for real world SPP (Serial Port

Profile) applications such as industrial automation, remote metering and other various applications. Optionally, the BCD110 can be supplied with only software stack up to HCI (Host Controller Interface) level so entire Bluetooth stack runs on the host side for the application such as USB dongles for computers or OEM manufacturers can even develop and embed their own firmware into the BCD110[9].

2.5.1.1 BCD 110 features[9]:

- Bluetooth Class 1
- Bluetooth v2.0+EDR specification
- Transmit Power: +18dBm Typical
- Receive sensitivity: -90dBm (0.1% BER)
- Integrated 8Mbit Flash Memory
- SupportsSerialPort Profile (SPP)
- Working distance (In an open field): Nom.200m, up to 1000m
- Supports built-in chip, stub and dipole antennas
- 802.11 co-existence
- Standard HCI over UART or USB
- Field-proven SPP (Serial Port Profile) firmware supporting up to 4 simultaneous multiple connections
- Firmware upgrade via windows-based software (ParaniUpdater)
- Easy to use Windows configuration tool available.
- ROHS compliant

2.5.1.2 Specifications of BCD 110[9]:

Bluetooth Specifications	Bluetooth v2.0 + EDR, Class1 Supports up to 1000m (0.62 mile) Profile: SPP(SerialPort Profile)
Physical properties	Weight : Parani-BCD110SU: 2g
Environmental	Operating temperature: -40°C ~ 80°C Storage temperature: -40°C ~ 85°C Humidity: 90% (Non-condensing)
Power	Nominal : 70mA@3.3Vdc Maximum : 150mA@3.3Vdc (200mA@3.3Vdc in Test Mode)
Firmware Update	ParaniUpdater
Configuration	ParaniWIN, ParaniWizard, Modem AT command set
USB Interface	V2.0
Interfaces	UART, USB, I2C, PCM, PIO
Serial Interface	Serial UART speed up to 921.6kbps CTS/RTS flow control, DTR/DSR for loop-back & full transfer
TX Output Spectrum-Frequency range	2402 MHz - 2480 MHz
Receive Sensitivity	-90dBm (0.1% BER)
Transmit Power	+18dBm Typical

2.5.2 Connect blue:CB−OBS410x−04:

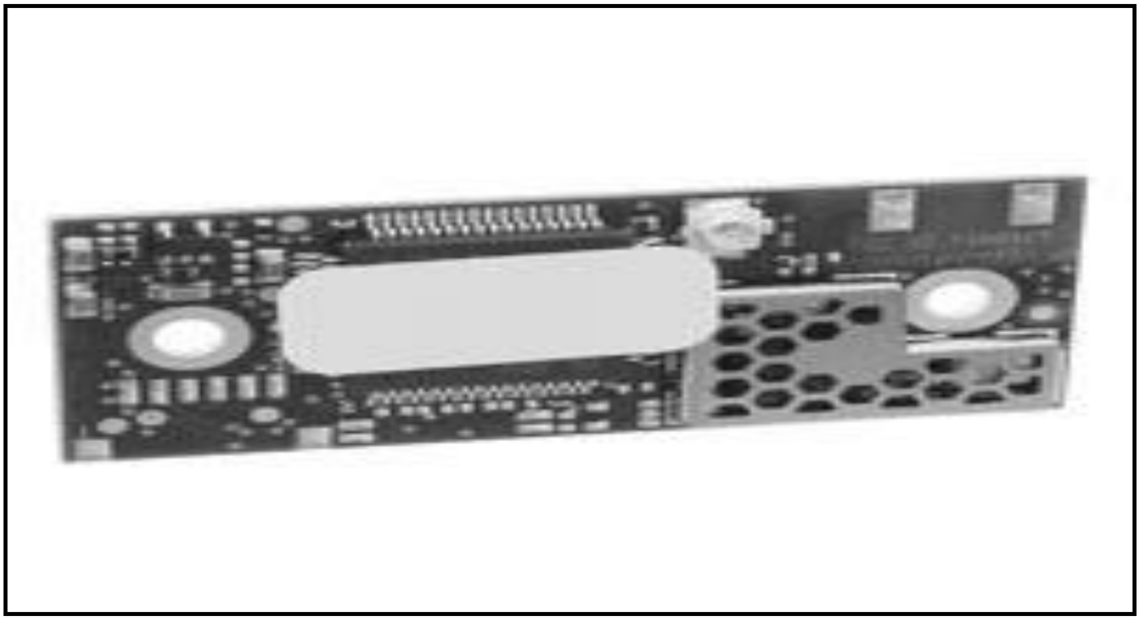

Figure 2.14: Connect blue:CB-OBS410x-04 module

The Bluetooth Serial Port Module OBS410 (figure 2.14) supports the Serial Port Profile (SPP) for secure, fast and transparent serial data transmissions. The form factor of the module is small, low build height, and supports Bluetooth v2.1. With the embedded Bluetooth stack you can run it quickly as there is no need for a driver or stack in your host. The module is fully Bluetooth qualified. It also has the connectBlue standard interface for compatibility over time and radio technologies [10].

2.5.2.1 Connect blue:CB−OBS410x−04 features[10]:

- Embedded Bluetooth stack (SPP, DUN)
- Bluetooth v2.1 Qualified as End Product
- UART interface
- Android support

- High throughput and low latency
- Easy configuration by AT commands
- Compliant with EMC, Safety and Medical standards
- ConnectBlue Low Emission Mode™
- External antenna
- Industrial and Automotive temperature range -30°C to +85°C
- Possible to load customer specific configuration in production
- OEM Serial Port Adapter 410 with u.fl. connector for externalantenna, board-to-board and solder padsand application)
- Configurable via AT commands (via Bluetooth or serialport)
- ConnectBlue Low Emission Mode™ for not disruptingother 2.4GHz radios
- Maximum number of slaves: 1 (point-to-point)
- Supports SPP Bluetooth connection to Google Android OS devices

2.5.2.2 Specifications of Connectblue: CB−OBS410x−04 [11]:

Wireless Standard	Classic Bluetooth technology
Bluetooth Specifications	Bluetooth v2.1 (Qualified and Listed as Product) Supported Bluetooth Profiles: SerialPort Profile (SPP), Dial-up networking Profile (DUN GW, DUN DT) GW- Gateway, DT- Data Terminal
Radio, Chipset and Stack	External antenna (range & max output

	power incl. antenna): 150m & 6dBm 2.4 GHz channels: 1-79 Radio: ST-Ericsson STLC2500DB Microprocessor: ST STM32F10x Stack: connectBlue Embedded Bluetooth Stack
Interface	UART Logic-level Via external transceiver, RS232 and RS422/485 option Max baud rate: 460.8 kbit/s Support for non-standard baud rates Flow control: CTS/RTS (hardware) or none 9 digital I/O pins
Throughput	350 kbps
Power	Power supply voltage: 3.0 - 6.0 VDC Current consumption (minimum): 14 mA @3.0V Currentconsumption (averageTx): 25 mA @3.0V
Mechanical	Operating temperature: -30°C to +85°C Machine mountable

	Mounting holes Dimensions: 16x36x3 mm (2 mm height on request) Weight: 2 g

2.5.3 Bluegiga WT41 Bluetooth Module:

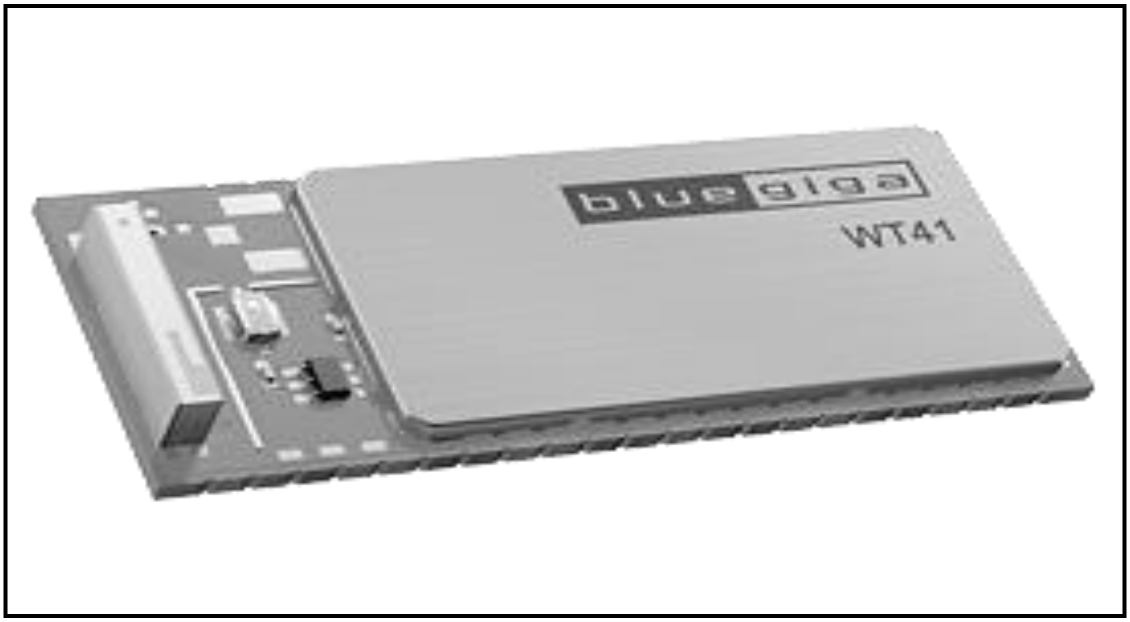

Figure 2.15: Bluegiga WT41 module

BluegigaWT41 (figure 2.15) Long Range Bluetooth® Modules are long range devices offering 1000-meter range between the two WT41 Bluetooth modules. WT41 modules come with Bluegiga'siWRAP firmware, offering users a simple software integration without the need of Bluetooth protocol or profile development. iWRAP is an embedded Bluetooth stack firmware for Bluegiga's Bluetooth module. It exposes a powerful command interface to manage Bluetooth operations. WT41 modules are mainly targeted for use in a variety of applications, including M2M (machine-to-machine), medical devices, barcode readers, PCs, etc [12].

2.5.3.1 Bluegiga WT41 features [13]:

- Bluetooth 2.1+ EDR
- Integrates a Bluetooth radio, Bluetooth stack and profiles
- Exceptional radio performance
    - Transmit power : +20dBm
    - Receiver sensitivity: -90dBm
- Available with high efficiency chip antenna or u.flconnector
- Industrial temperature range -40°C to +85°C
- Supported Bluetooth profiles: SPP, DUN, HFP, HSP, HID, AVRCP, DIP, PBAP, OPP, FTP and HDP
- Standard HCI over UART or USB
- Bluetooth end product, CE, FCC and IC qualified

2.5.3.2 Specifications of BluegigaWT41 [12]:

Class	1
Bluetooth Specification	Bluetooth 2.1+ EDR
Frequency Band	2.4 GHz
Sensitivity	- 90 dBm
Data Rate	2.1 Mbps
Operating Supply Voltage	3.3 V
Output Power	20 dBm
Interface Type	GPIO, UART, USB
Antenna Connector Type	U.FL
Maximum Operating Temperature	+ 85 °C
Dimensions	35 mm x 14 mm x 3.5 mm
Minimum Operating Temperature	- 40 °C
Mounting Style	SMD/SMT

2.6 Comparison of specifications of different Bluetooth modules. [9-16]

Sr. No	Specification	Parani-BCD110	CONNECT BLUE: cB-OBS410x-04	Bluegiga WT41
1.	**Bluetooth Specifications**	Bluetooth v2.0 + EDR	Bluetooth v2.1	Bluetooth 2.1+ EDR
2.	**Operating Supply Voltage**	3.3Vdc	3.0 - 6.0V dc	3.3 V dc
3.	**Interface**	UART, USB, I2C, PCM, PIO	UART Logic-level	GPIO, UART, USB
4.	**Operating Temperature**	-40°C to 80°C	-30°C to +85°C	- 40 °Cto 85 °C

5.	**Dimensions**	DIP type:34.6 x 16.8 x 7.5 mm (0.661 in x 1.362 in x 0.295 in) SMD type:34.6 x 14.8 x 3.0 mm	16x36x3 mm (2 mm height on request)	35 mm x 14 mm x 3.5 mm
6.	**Frequency Band**	2.4 GHz	2.4 GHz	2.4 GHz
7.	**Receive Sensitivity**	-90dBm	-84dBm	-90 dBm
8.	**RF output power**	+18dBm Typical	max 4dBm	+20 dBm
9.	**Supported Bluetooth profiles**	SPP(SerialPort Profile)	Generic Access Profile (GAP), SerialPort Profile (SPP),Dial-up Networking Profile (DUN GW, DUN DT)	SPP, DUN, HFP, HSP, HID, AVRCP, DI, PBAP, OPP, FTP and HDP
10.	**Cost**	30.00 USD	39.6 USD	35.0 USD

2.7 Study of some common interface available in Bluetooth modules

2.7.1 UART (Universal Asynchronous Receiver/Transmitter):

A Universal Asynchronous Receiver/Transmitter (UART) is an integrated circuit which has the most important role in serial communication. It handles the conversion between serial and parallel data. Serial communication reduces distortion of a signal, hence making data transfer between two systems separated by great distance possible. It contains a parallel-to serial converter for data transmitted from the computer and a serial to parallel converter for data coming in via the serial line. UART has a buffer for temporary storageof data from high speed transmissions. In addition to the basic job of converting data from parallel to serial for transmission and from serial to parallel on reception, a UART will usually provide additional circuits for signals that can be used to indicate the state of transmission media and to regulateflow of data in the event that the remote device is not ready to accept more data.

The UART serial communication module is divided into three sub-modules:

1.) The baud rate generator

2.) Receiver module and

3.) Transmitter module

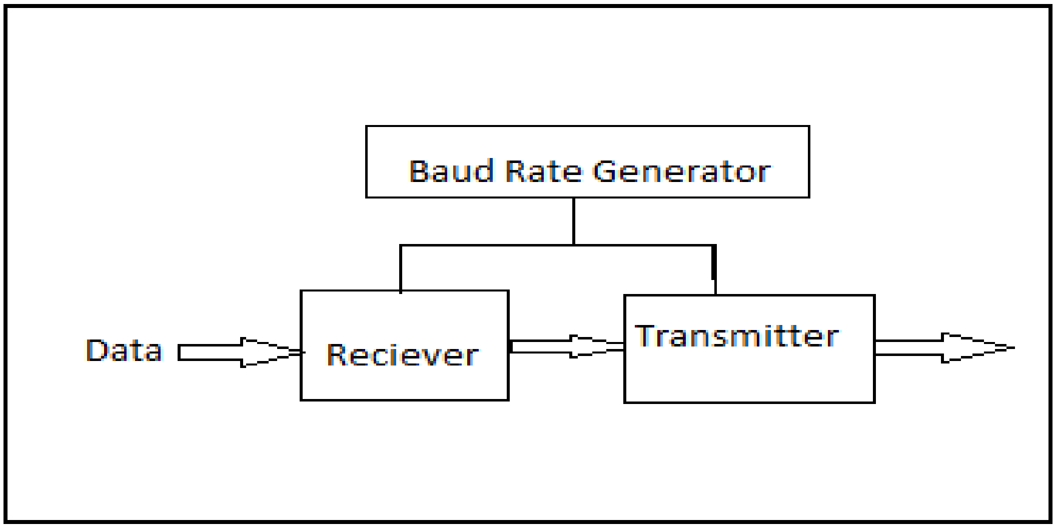

Figure 2.16: Module of UART

So, the implementation of the UART communication module is actually the realization of the three sub-modules (figure 2.16). The baud rate generator is used to produce a local clock signal which is much higher than the baud rate to control the UART receive and transmit; The UART receiver module is used to receive the serial signals at RXD and convert them into parallel data; The UART transmit module converts the bytes into serial bits according to the basic frame format and transmits those bits through TXD [17]. UARTs are used commonly with communication standards such as EIA, RS-232, RS-422 or RS-485. The electric signaling levels and methods (such as differential signaling etc.) are handled by a driver circuit which is external to the UART.A dual UART, or DUART, combines two UARTs into a single chip [18].

Complete serial transmission process is based upon the principle of shift register. There are primary twoforms of serial transmission which are:

Synchronous transmission and asynchronous transmission.

Synchronous serial transmission requires that the sender and receiver share a clock with one another, or that the sender provide a strobe or other timing signal so that the receiver knows when to “read” the next bit of the data. In most form of Serial Synchronous Communication, if there is no data available at a given instant to transmit, a fill character must be sent instead so that data is always being transmitted. Asynchronous transmission allows data to be transmitted without the sender having to send a clock signal to the receiver. Instead, the sender and receiver must agree on timing parameters in advance and special bits are added to each word thatare used to synchronize the sending and receiving units. Asynchronous serial communication has advantages of less transmission line, high reliability, and long transmission distance, hence is widely used for data exchange between computer and peripherals. This Asynchronous serial communication is usually implemented by UART [19].

UART Transmission Protocol:

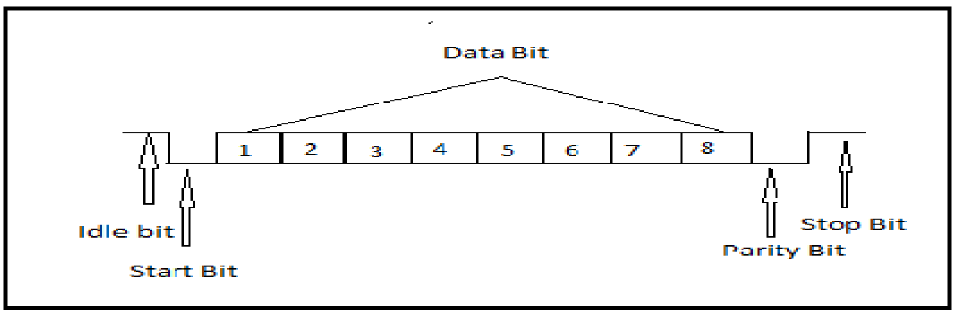

Figure 2.17 Frame format of UART data

It usually includes start bit, data bit, parity bit, stop bit and idle state as shown in figure 2.17. When a word is given to the UART for Asynchronous transmissions, a bit called the "Start Bit" is added to the beginning of each word that is to be transmitted. The Start Bit is used to alert the receiver that a word of data is about to be sent, and to force the clock in the receiver After the Start Bit, the individual bits of the word of data are sent, with the Least Significant Bit (LSB) being sent first into synchronization with the clock in the transmitter. When the entire data word has been sent, the transmitter may add a Parity Bit that the transmitter generates. The Parity Bit may be used by the receiver to perform simple error checking. Then at least one Stop Bit is sent by the transmitter. If incorrectly formatted data is received, the UART may signal a framing error. If another byte is received before the previous one is read, the UART will signal an overrun error [17].

2.7.2 USB (Universal Serial Bus)

Universal Serial Bus (USB) (figure 2.18) is an industry standard developed in the mid-1990s that defines the cables, connectors and communications protocols used in a bus for connection, communication and power supply between computers and electronic devices.USB was designed to standardize the connection of computer peripherals(including keyboards, pointing devices, digital cameras, printers, portable media players, disk drives and network adapters) to personal computers, both to communicate and to supply electric power. The Universal Serial Bus (USB) is fast interface for connecting devices to computers [3].

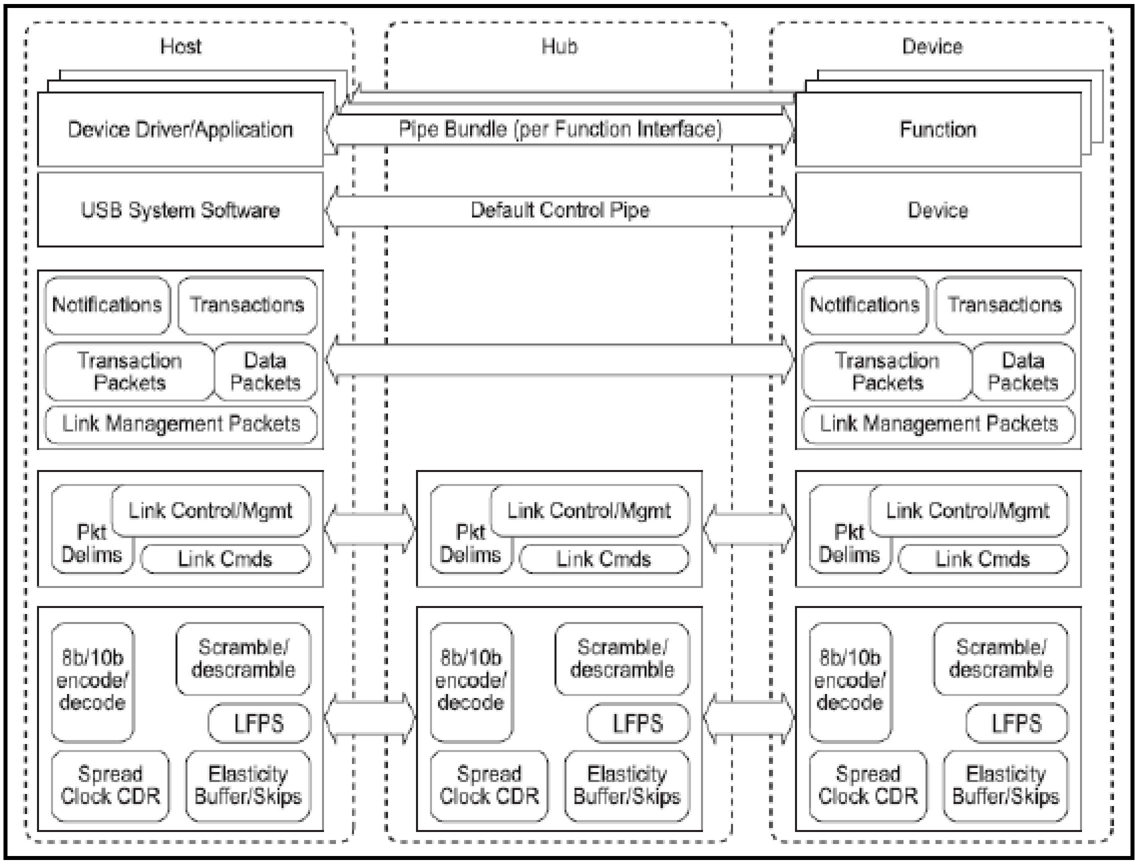

Figure 2.18USB super speed version layered architecture

A USB device may use any of four types of transfer namely control, isochronous, bulk, and interrupt and three speeds. On attaching to a PC, a device must respond to series of requests that enable the PC to learn about the device and establish communication with it. In a PC, every device must have a low-level driver to manage communications between applications and the system's USB drivers.USB communication takes place between the host and endpoints located in the peripherals. An endpoint is a uniquelyaddressable portion of the peripheral that is the source or receiver of data. Four bits define the device's endpoint address; codes also indicate transfer direction and whether the transaction is a "control" transfer. Endpoint 0 is reserved for control transfers, leaving up to 15 bi-directional destinations or sources of data within each device. The idea of endpoints leads to an important concept in USB transactions, that of the pipe. All transfers occur through virtual pipes that connect the peripheral's endpoints with the host.

When establishing communication with the peripheral, each endpoint returns a descriptor, a data structure that tells the host about the endpoint's configuration and expectations. Descriptors include transfer type, max size of data packets, perhaps the interval for data transfers, and in some cases, the bandwidth needed. Given this data, the host establishes connections to the endpoints through virtual pipes, which even have a size (bandwidth), to make them analogous to household plumbing.

Control transfers exchange configuration, setup, and command information between the device and the host. CRCs check the data and initiate retransmissions when needed to guarantee the correctness of these packets.

Bulk transfers move large amounts of data when timely delivery isn't critical. Typical applications include printers and scanners. Bulk transfers are fillers, claiming unused USB bandwidth when nothing more important is going on. CRCs protect these packets. Finally, isochronous transfers handle streaming data like that from an audio or video device. It is time sensitive information so, within limitations, it has guaranteed access to the USB bus. No error checking occurs so the system must tolerate occasional scrambled bytes [20].

2.7.3 I2C(referred to as I-squared-C, inter-IC or I-two-C):

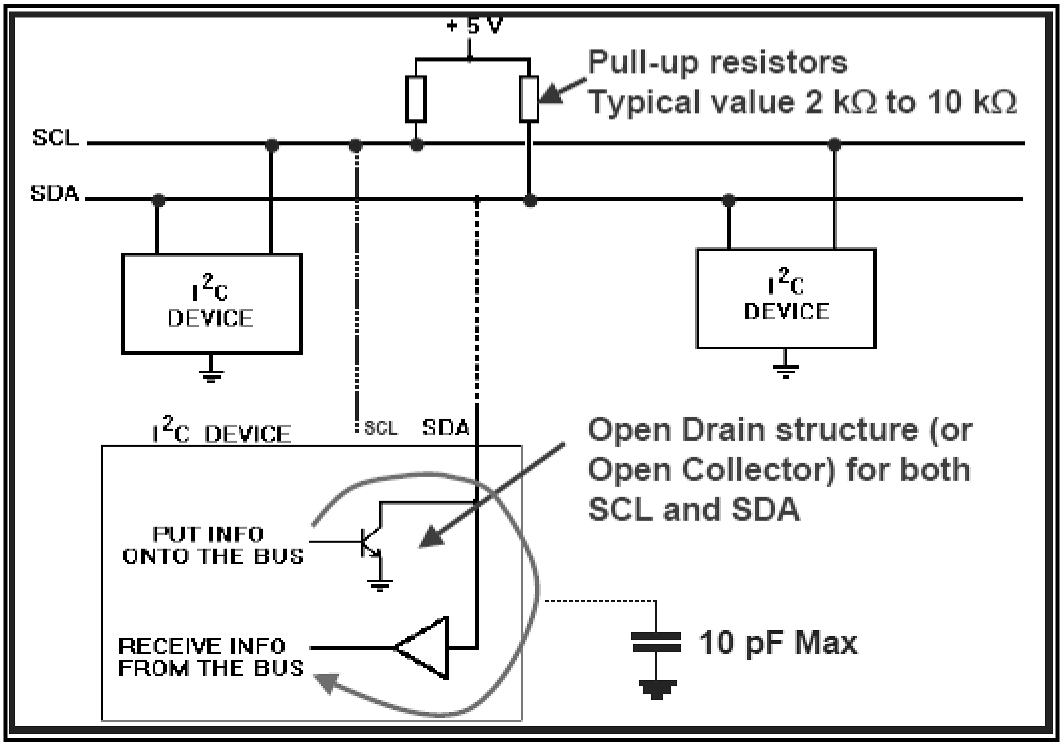

Figure 2.19: I2C Hardware architecture

I²C (referred to as I-squared-C, inter-IC or I-two-C) (figure 2.19) is a multimasterserialsingle-endedcomputer bus invented by Philips used for attaching low-speed peripherals to a motherboard, embedded system, cellphone, or other electronic device [21].

It provides a simple way to talk between IC's by using a minimum number of pins and having simple hardware standards as well as simple software protocol standard. No specific wiring or connectors are needed often it's just PCB tracks has become a recognized standard throughout industry and is used now by all major IC manufacturers. It is a multi-master capable bus with arbitration feature, master-slave communication etc.

Each IC on the bus is identified by its own address code. The slave can be areceiveronly device or transmitter with the capability to both send and receive data. Following are few features of I2C.

1.) Only two bus lines are required: a Serial Data Line (SDA) and a Serial Clock Line (SCL).

2.) Each device connected to the bus is software addressable by a unique address and simple master/slave relationships exist at all times; masters can operate as master-transmitters or as master-receivers.

3.) It is a true multi-master bus including collision detection and arbitration to prevent data corruption if two or more masters simultaneously initiate data transfer.

4.) Serial, 8-bit oriented, bi-directional data transfers can be made at up to 100 kbit/s in the Standard-mode, up to 400 kbit/s in Fast-mode or up to 3.4 Mbit/s in High-speed mode.

5.) On-chip filtering (50 ns) rejects spikes on the bus data line to preserve data integrity.

6.) The number of ICs that can be connected to the same bus segment is limited only by the maximum bus capacitive loading of 400 pF.

2.7.3.1 Communication procedure of I2C

One IC that wants to talk to another must:

1.) Wait until it sees no activity on the I2C bus. When SDA and SCL are both high. The bus is 'free'.

2) Put a message on the bus that says 'its mine' - I have STARTED to use the bus. All other ICs then LISTEN to the bus data to see whether they might be the one who will be called up (addressed).

3.) Provide on the CLOCK (SCL) wire a clock signal. It will be used by all the ICs as the reference time at which each bit of DATA on the data (SDA) wire will be correct (valid) and can be used. The data on the data wire (SDA) must be valid at the time the clock wire (SCL) switches from 'low' to 'high' voltage.

4.) Put out in serial form the unique binary 'address' (name) of the IC that it wants to communicate with.

5.) Put a message (one bit) on the bus telling whether it wants to send or receive data from the other chip. (The read/write wire is gone!)

6.) Ask the other IC to ACKNOWLEDGE (using one bit) that it recognized its address and is ready to communicate.

7.) After the other IC acknowledges all is OK, data can be transferred.

8.) The first IC sends or receives as many 8-bit words of data as it wants. After every 8-bit data word the sending IC expects the receiving IC to acknowledge the transfer is going OK.

9.) When all the data is finished the first chip must free up the bus and it does that by a special message called 'STOP'. It is just one bit of information transferred by a special 'wiggling' of the SDA/SCL wires of the bus [22].

2.8 Antenna selection parameters to be considered for the Bluetooth module

For the successful implementation of a robust, reliable and high-performing wireless system, it is necessary to carefully and thoroughly consider the selection of an antenna and also review the requirements of the system at a very early design stage of the product. This will avoid numerous unnecessary iterations and system redesigns. For the designer, selecting supplier of an antenna at an early stage provides access to detailed antenna implementation guidelines regarding footprints, mechanical aspects, and contact issues. On the business side, it is advisable to pick a solution that meets cost target or that provides a good balance between performance and cost.

Various parameters for selection of an antenna:

1.) **MechanicalLayout** - The mechanical layout of the design of device will determine the size and type of antenna needed. The typical mechanical properties of an antenna are the form factor (external or internal), construction, requirement of size, mounting requirement, connection type, aesthetics, and other mechanical considerations along with the mechanical durability and reliability of the antenna component. Material selection and mechanical design of both the device and the antenna have direct impact on manufacturability. Competent selection leads to cost effective, easy-to-manufacture solutions, especially for very high product volumes. It is significant to note that a bigger antenna does not correlate with better antenna performance. This is demonstrated by small, ceramic-chip antennas that can outperform much larger antennaswhen implemented following design guidelines.

Most hand-held portable devices will need an internal antenna, instead of an external one, for purely aesthetic reasons. In fact, more than one antenna will be needed depending on the applications and functions of the device. The typical construction of the internal antennas are stamped metal, printed circuit board (PCB), Flexible Printed Circuit (FPC) on plastic carrier, meander line, Low Temperature Co-fired Ceramic (LTCC), ceramic, quadrifilar, and patch antenna. The size and mechanical constraints of the device, as well as the electrical requirements, also determine the type of construction and technology to use. Most of these internal antennas can be mounted through a SMD process, SMT process, pogo pins, spring contact, mini u.fl/I-Pex connector, or direct solder. When long feed cables are used, it is important to factor in signal loss from the cable, which can be several decibels. This has a big impact on the system's total link budget. Manufacturing considerations should be taken into account in antenna selection.

2.) **Electrical Properties**-The other major criteria to consider while selecting an antenna are the electrical properties. These consist of operating frequency, bandwidth, maximum gain, average gain, efficiency, return loss or Voltage Standing Wave Ratio (VSWR), polarization, directivity, side and back lobe levels, front to back ratio, radiating patterns, impedance, and power rating of an antenna.

The operating frequency is determined by the type of application. For example, Wi-Fi 802.11 b/g, ZigBee, and Bluetooth use the same 2.4GHz ISM band that has a bandwidth of approximately 80MHz (2.4GHz~2.48GHz), while a commercial GPS system uses the L1 1.575GHz band with a bandwidth of 2MHz (1575.42MHz +/-1MHz). Depending upon the region of the world, a GSM system uses the 850MHz/1900MHz or 900MHz/1800MHz bands. 3G systems use a variety of bands which also depend on region.Other applications include, but are not limited to, WiMAX, UWB, ISM900, ISM5/5.8GHz, DVB-H, MediaFLO, DECT, RFID, VHF, UHF, AM, and FM. Multi-antenna systems, like diversity and Multi In Multi Out (MIMO), are used in applications where enhanced data rates are needed. With multiple antennas, it is crucial to design and characterize the whole antenna system, including antenna-to-antenna isolation andcorrelationcoefficient testing.

3.) **Range and Performance**-The efficiency, maximum (max) gainand average gain, determine the range and performance of an antenna. The higher these numbers, the better the range and performance of an antenna. An antenna should have sufficient return loss or VSWR in the operating frequency range. Typically a -10dB return loss (2.0:1.0 VSWR or better) is a respectable number. Max gain with efficiency or average gain should be considered in order to get a better picture of the overall performance of an antenna. Care should be taken by not falling into the trap of looking at just one of these properties and jumping to a conclusion. Maximum or peak gain is a good gauge in evaluating directive antennas, but can be a misleading term if used as the primary criteria to determine general antenna performance.Often, in more complex devices, the gain is lower, so there is implementation loss when an antenna is placed and connected to the actual device. This is because high peak gain always means some level of directivity and may result in antenna gain that is much lower in some other direction due to nulls in the radiation pattern. Selecting an antenna that has a margin over the recommended decibels ensures that it will meet system requirements in a real-life application. An antenna should match theimpedance of the wireless system as closely as possible for minimum mismatch/loss in the system. Take into account polarization type (vertical, horizontal, or circular) of anantenna and the radiation patterns (in XZ, ZY, and XY planes) in order to fully characterize an antenna. Most hand-held, portable devices need a linearly polarized antenna with omni-directional radiating patterns for 360 degreesof omni-directional coverage. True omni-directional radiating patterns exist only in theory, because in most cases, the device mechanics affect the antenna patterns, causing nulls and directivity in the patterns. In many cases, the best way to determine true antenna performance is the total 3D radiated efficiency of an antenna as it indicates how much of an antenna's energy can be transferred to radio waves and how much is lost due to mismatch and radiation losses. Especially in small portable or hand-held devices, 3D efficiency is a much better parameter to compare than maximum gain because, in actual use, the device can be in any orientation that's possible. In addition, because in use, the max gain peak beam can be directed towards the user's body and the gain is lost due to body attenuation.

4.) **Size and Performance Challenges-** The ability to solve some of the most demanding design issues in small, hand-held devices with multiple radio applications will narrow an antenna selection and the type of technology needed. Some of these challenges are isolation, minimum (min) gain and efficiency, hand/body effect, and Specific Absorption Rate (SAR) requirements. Isolation becomes an issue when multiple antennas are located close together in a small hand-held device. Antennas that operate in the same or in a close frequency range couple among themselves and cause a reduction in performance. The minimum gain and efficiency requirement becomes an issue in small devices due to proximity to other components such as LCD, metal shields, battery and other electronic components. The lower frequency applications, such as 850MHz and 900MHz bands, are challenging due to the longer wavelength in the lower operating frequencies. Hand/body effect requirements need consideration due to frequency detuning when the device is held close to human body tissue. The resonance frequency will be shifted out of band and cause a high attenuation in the signal due to impedance mismatch and degradation in antenna performance. Moreover, the tissue near it absorbs the radiated energy from an antenna and prevents the signal from propagating to the open air. Likewise, SAR requirements should be considered due to regulatory requirements.

5.) **Material Considerations-** The materials selected and the actual radiator RF design also contributes to the final electrical performance of an antenna. The materials used need to have low loss (tangent) and good conductivity. Care needs to be taken when choosing a ceramic antenna. While there are many different types of ceramics, such as low temperature co-fired ceramic (LTCC) and ceramic monopole, performance varies and results might differ when compared to the proprietary ceramic designs of individual antenna fromcompanies. Consistency of design and performance specifications isvery critical. Even with miniature ceramic antennas, a 70%~80% efficiency, 1dBi~2dBi max gain, and better than -3dBi average gain can be achieved if the right antenna is selected and design is implemented.

Testing - All antenna products should be fully field tested to ensure quality and reliability. These tests include mechanical and reliability testing, such as mechanical and temperature shock, vibration, and extreme temperature testing, as well as testing the pre-designed mechanical interface prior to assembly.

Antenna parameter measurements are very involved and require state-of-the-art measurement equipment such as anechoic chambers, testers, and sophisticated software for data analysis.One needs to know and understand how antennas are tested to truly appreciate the meaning of the performance numbers. It is not as straightforward as comparing antennas based on the specifications on the datasheets. For example, sometimes the test setup used and the test board size are not clearly noted, which can have a large impact on real antenna performance, especially in small devices with internal antennas where the actual device chassis and mechanics need to be understood as part of the antenna structure.

6.) **Applying Antenna Selection Criteria**-An example of how to apply these criteria is in the selection of antennas for an advanced hand-held device that has Bluetooth, Wi-Fi 802.11 a/b/g/n, antennas. Diversity antennas might also be incorporated for added performance on received diversity. These antennas need to be small in size, yet big in performance. A high-performing ceramic PIFA antenna can be used for Wi-Fi (10x3.2x1.5mm), Bluetooth (3.2x1.6x1.1mm), WiMAX (3.2x1.6x1.1mm), UWB (13.4x10.2x0.8mm), and DVB-H (45x6.6x5mm) functions. Due to the high isolation property and distributed near field radiation of these special ceramic antennas, SAR and body/hand effect can be reduced to a minimum and excellent isolation can be accomplished for these antennas, even in a small, hand-held device.

So in any wireless communication system, the antenna plays a major role in the reliability and performance of the system. Today's small hand-held devices challenge with demands for ultra-thin, compact sizes and high-performance devices that have the ability to meet multiple standards. Selecting the antenna that best meets the required electrical and mechanical criteria is critical. Planning for the antenna and determining the best one to use during the design phase will save time and money and go a long way towards ensuring it will function optimally [23].

CHAPTER 3: CASE STUDY: POLE TOP REMOTE TERMINAL UNIT

3.1 Introduction

The supervision and remotely control of transmission system of electrical power is a system which is balanced between electricity consumption and generation, taking power supply consumption stability responsibility. So for the tasks mentioned here, the device needed is a Remote Terminal Unit in a properly configured state.

Main parts of supervisory and telemechanical controls for power grid are IEDs (Intelligent Electronic Devices), Remote Control Centre (RCC), measurement transducers, RTU, communication paths and local reference clock device. Substation Remote Terminal Unit is used for reacting immediately on objects of information (status, control, measurement messages). On local side the connections of RTU are with the executing device, that gives response on the SCADA system's control or parameter set action. The device that sends the measurement operationaldata to SCADA system via RTU is called asmeasurement transducer.

3.2 The principle of configuration of RTU

Main parts of the RTU are:

•Hardware which commonly includes power supply module, I/O-modules, processor module, communication modules etc)

• The links for communication

• Firmware, which is a small program that controls different components of hardware module internally

• Parameterization

The RTU hardware components should be selected according to technical requirements. The software of RTU should afford all thefeatures of parameterization so that all the needed RTU adjustments can be done. According to rule RTU configuration software's parameterization featuresare divided into following four groups:

1. The Hardware group

2. The logic function group

3. The interface for Communication with external telematics devices

4. The information objects exchange group with telematics system participants

1. The Hardware group - The hardware of RTU should be correctly defined by software of the RTU. The reason being, ensuring internal communication between modules of RTU via system bus in addition to different RTU extension module's location for use in coupling with external telematics devices properly.

2. The logic function group - The realization of logic also requires usingthe standard elements of logice.g.OR, NOR, AND, and/or someextended block-elements. Example of this is measurement converter in RTU.

3. The Communication interfaces with external telematics devices – The RTU's communication interfaces support all possible connections of RTU with SCADA system, measurement transducers, IEDs, and GPS time synchronization system.

4. The group of information objects exchange with telematics system participants - The most hindering part of the parameterization of RTU is the signal definition (information objects) received and transmitted by the RTU. Base of that is the various number information object parameter's adjustment.

The basic principles of RTU parameterizing handle is shown in figure 3.1.

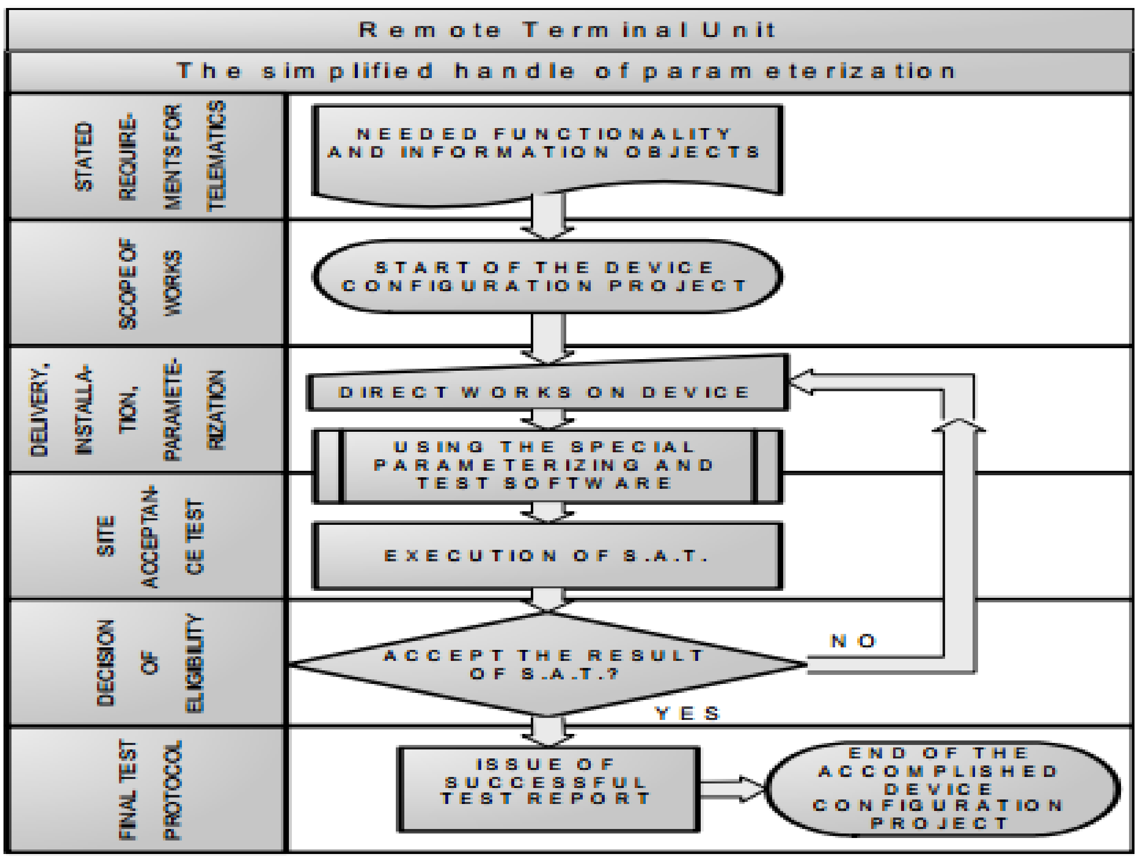

Figure 3.1 Remote Terminal Unit simplified parameterization structure

Each manufacturer for parameterization of his RTU uses his own RTU software. There is availability of lots of different RTU software tools which are having features specific for human-machine interface (HMI). Due to its result, many possibilities are therefor presentingin configuration software the image of the internal structure of RTU. To make the RTU software easy for understanding purpose by the Client personnel, IEC standard compatibility should be met.Thus Client personnel do not get confused by the data types, objects, logic, function blocks, etc.defined by RTU software. If RTU parameterization is ready in whole or part (substation extension) for implementation, detection of any internal mistake or conflict in the RTU parameterization can be done by preliminary test. It can be performed by using several software programs available for testing. Two solutions are there for this:

• Use check functions that are implemented in the RTU parameterization software.

• Use of external testsoftwaresfor testingthe RTU configuration end results.

After above mentioned processes for the testing,Site Acceptance Test (SAT) for configuration of RTU is needed to be fulfilled. Some of common routine tests are –

- Site Acceptance Test
- Design test
- Special test (necessity dependence on the requirements of the user).

By the SAT execution,thetarget of theRTU which is functional should be checked. There are manytelematics devices that are connected to the RTU and need to react adequately to the behavior of RTU. Hence for the case of precursory RTU parameterization, participants of the telematics system like IEDs (e.g. protection relays) also need to be parameterized correctly. Also care should be taken because for a single modification of telematics participant device's parameters because it will cause a failure of non-up-to-date parameterization of RTU. For the best case failure of some of the remote control functions for the SCADA system can be caused. For the worst case human accident will be caused like the case ofenergizing operation of remote high voltage power overhead line servicing done by the maintenance personnel. Thus the RTU configuration process includes more steps concerning the other telematics devices as shown in figure 3.2.

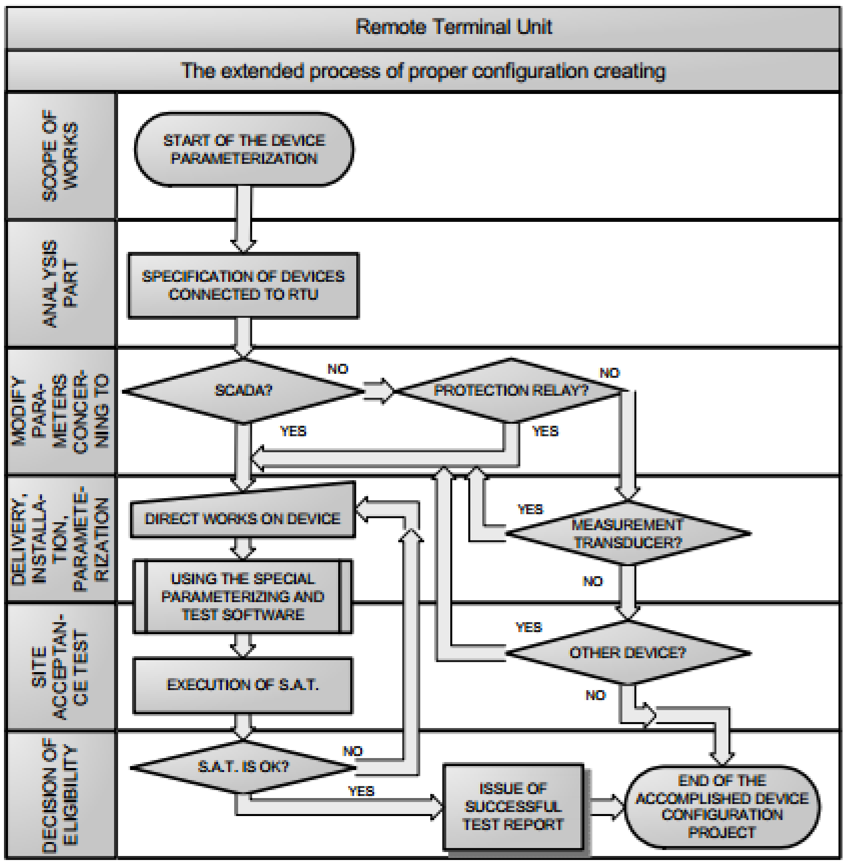

Figure 3.2 Remote Terminal Unit configuration process (extended)

Conclusion –Software updation and parameterization in Remote Terminal Unit is a complex procedure as there are many parameters which need to be configured. There are many steps to perform this and consumes a lot of time and care which can save any accident chances and loss of the life.

CHAPTER 4: PROBLEM DEFINITION

Management of pole mounted Remote Terminal Units is a very difficult and timeconsuming process as operator has to shut down power line and has to climb the pole for connecting laptop or PC in order to make diagnostic changes in electrical distribution, configuration changes, software upgradation. Apart from this it is very risky for operator while working with very high voltage electrical distribution system to do such a task.

So the problem has three major parts:

1.) Risk of life of operator when working with high voltage distribution system.
2.) Time consuming process of climbing up the pole for doing any configuration changes, software upgradation etc.
3.) Power line is to be shut down.

Hence, such a solution is required which can:

1.) Ensure safety of the operator.
2.) Decrease the downtime at the time of maintenance of Remote Terminal Unit.
3.) Increase the maintenance efficiency
4.) It should be secure (means from hacking etc.)

CHAPTER 5: PROPOSED SOLUTION

According to the problem definition, there are three key needs which should be fulfilled and these are-

1.) The solution should be such that risk of operator life should be as low as possible.

2.) Secondly time required for configuration, software upgradation or making any diagnostic changes of Remote Terminal Unit should be less.

3.) And last but not the least; the solution should be secure in terms of hacking etc.

The proposed solution is to use the Bluetooth wireless technology which can solve all the purposes given above. As Bluetooth is a wireless technology so operator has no need to climb the pole to connect the configuration PC. Any laptop or PC having Bluetooth communication capability can be used for this purpose. Apart from this Bluetooth communication is a secure communication because of its inherent nature. Distance of operation is nominally 200 meters and can be extended up to 1 kilometer. The proposed hardware design here works on the serial port profile of the Bluetooth wireless technology.

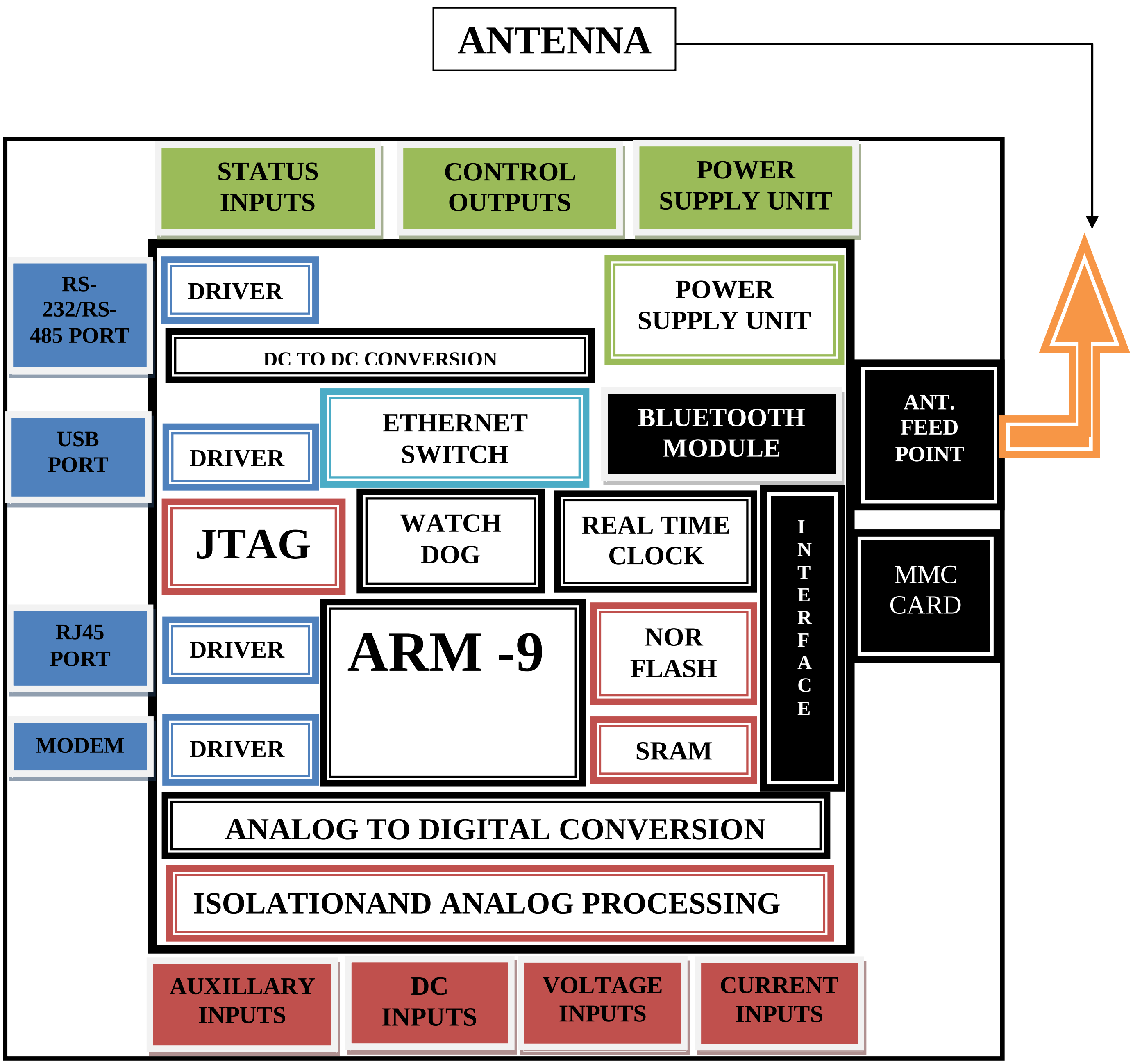

Figure 6.1: Basic Block Diagram of Pole Top Remote Terminal Unit

Figure 6.1 shows the basic block diagram of Pole Top Remote Terminal Unit. The Bluetooth module shown in figure 6.1 in our proposed solution is of SENA technologies

BCD110. It is basically proposed here for the purpose of configuration of the Pole mounted Remote Terminal Unit. Hardware implementation of the testing circuit of Bluetooth communication module’s interfacing is shown below (figures 6.2 and 6.3).Here Bluetooth communication is tested for Serial Port Profile (SPP) communication with a remote Bluetooth device.

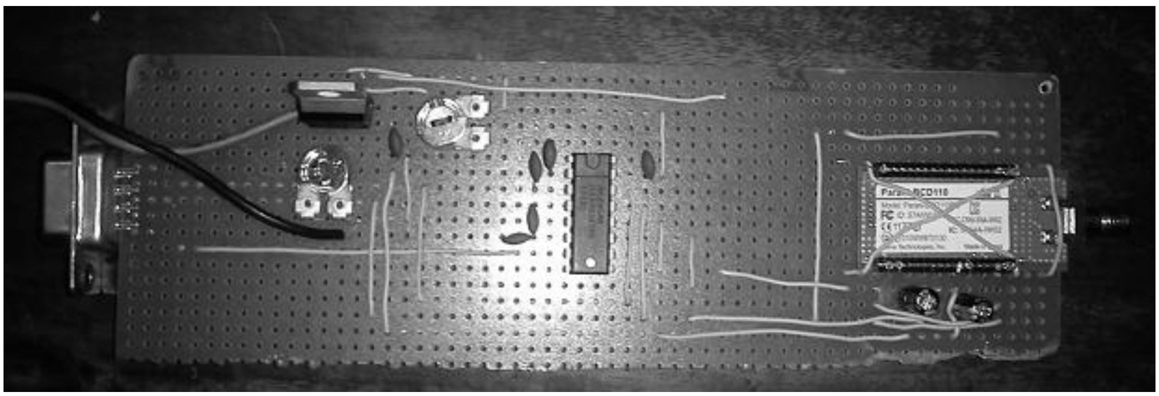

Figure 6.2: Practical hardware implementation of testing circuit (top view)

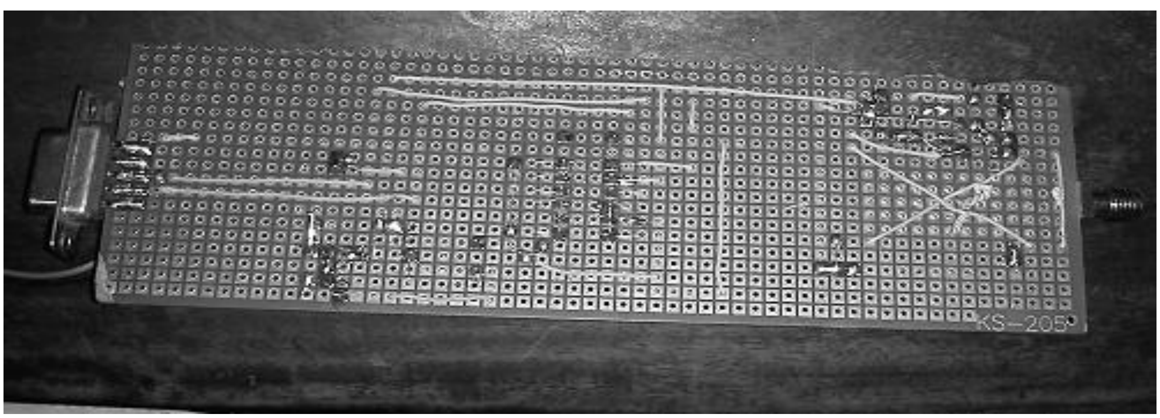

Figure 6.3: Practical hardware implementation of testing circuit (bottom view)

Serial cable (figure 6.4) is used for connecting serial port of the personal computer with the hardware of Bluetooth module via. proper interfacing through integrated circuit MAX 3232 which is multi channel RS-232 line driver/receiver having ±15kV ESD protection.

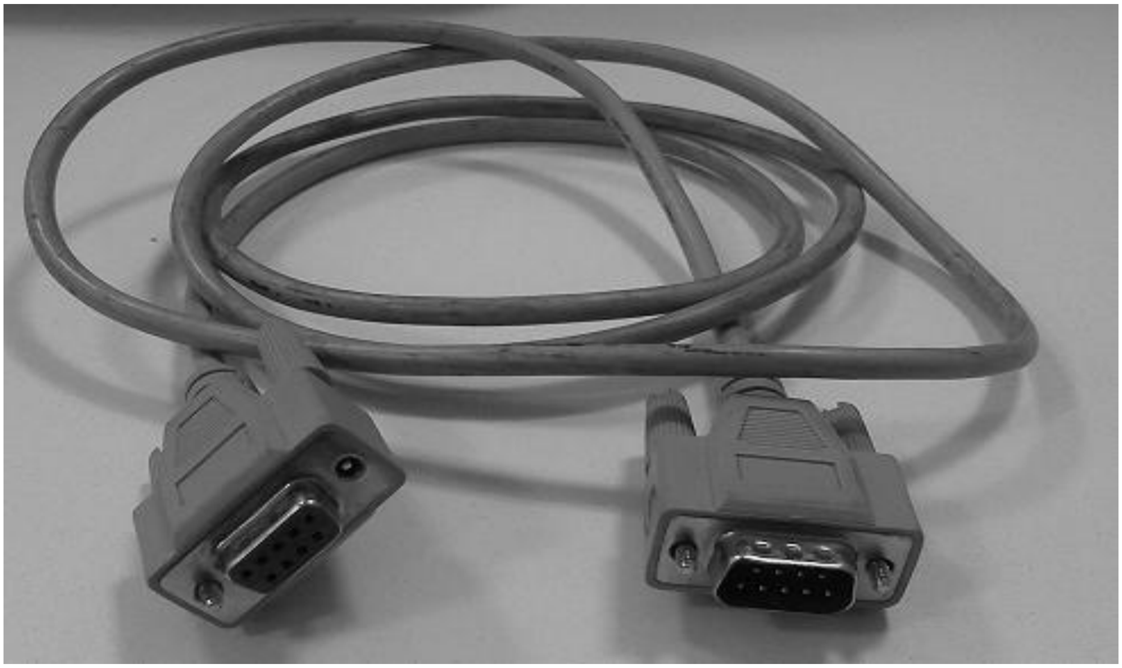

Figure 6.4: Serial cable used for connection of personal computer with Bluetooth module hardware.

Figure 6.5 shows block diagram interfacing of Bluetooth module with personal computer. MAX3232 is used as an interface between PC and BCD110 Bluetooth module.

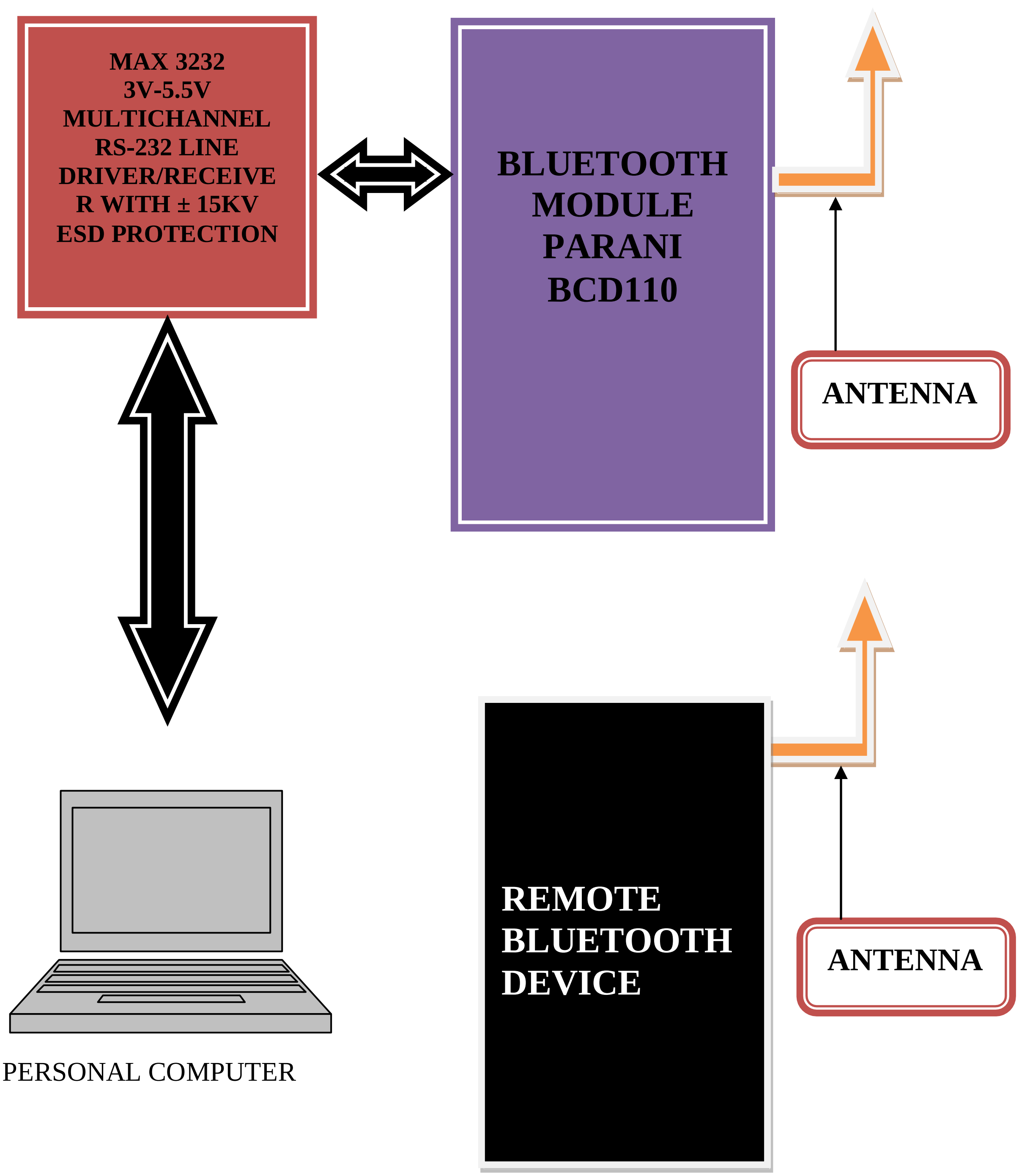

Figure 6.5: Block diagram of the testing circuit.

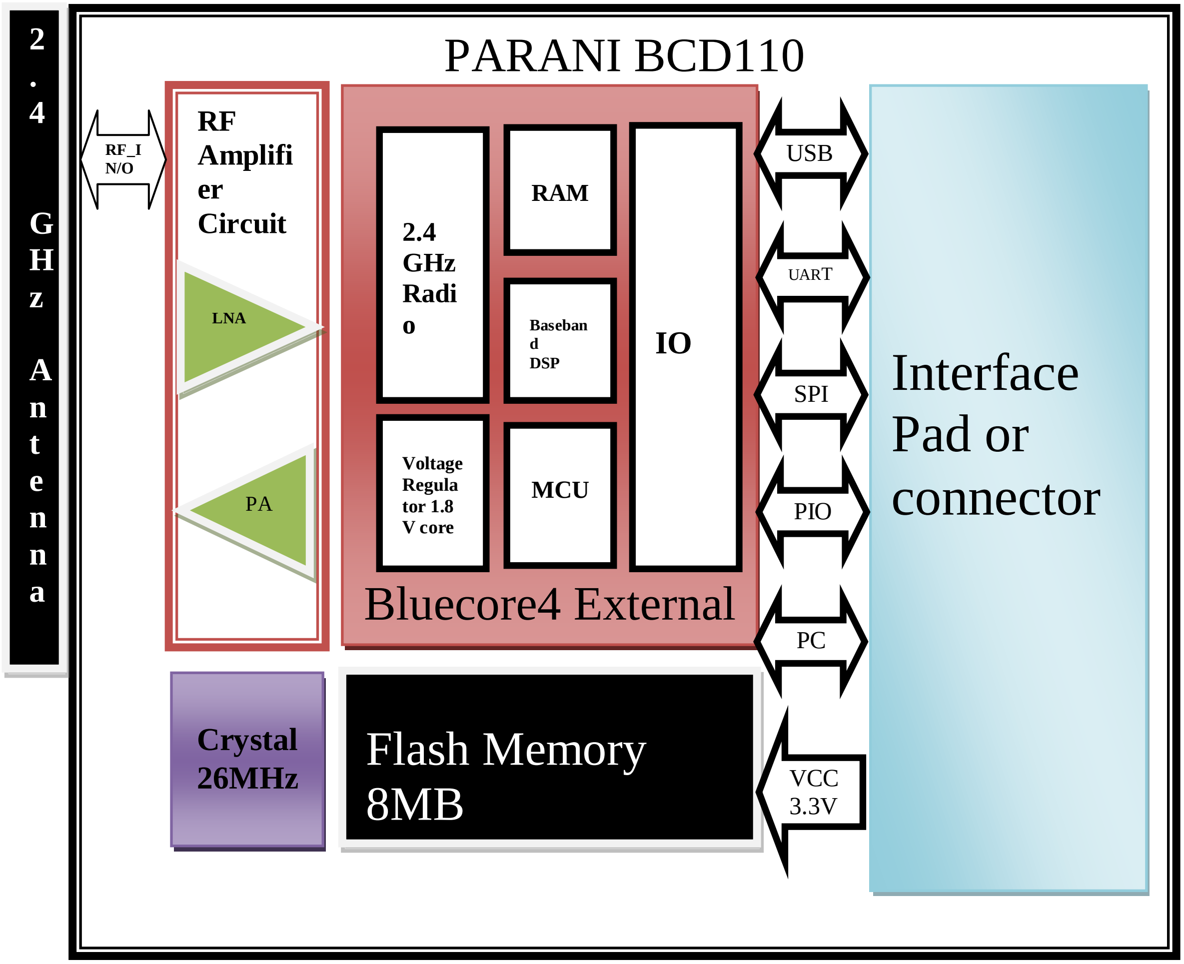

Figure 6.6: Block diagram of PARANI BCD110 (Bluetooth module)

Figure 6.6 shows the block diagram of the Bluetooth module BCD110 which is having many interfaces as shown in the block diagram. It is having USB, UART, SPI, PIO, PCM interface but for proposed solution in this thesis UART is used.The BCD110 Bluetooth module is a class 1 Bluetooth module for long distance communication of range up to 1 km. The firmware of BCD110 runs by default for SPP (Serial PortProfile) applications. The SPP firmware gives support to 4 simultaneous multiple connections.BCD110 contains RF amplifier, crystal, flash memory and Bluecore4 External which implements Enhanced Data Rate (EDR) Bluetooth specification which enhances the data rate up to three times as compared to v1.2 Bluetooth devices.

CHAPTER 7: SOFTWARE STACK

BCD110 contains Bluetooth v2.0 compatible firmware that runs for SPP (Serial Port Profile) basedapplications by default as shown in figure 7.1. This firmware is designed so as to work for the real world SPP applications likeindustrial automation, remote metering etc.The SPP firmware can be controlled and configured by typical AT commands. BCD110 can be configured by using software like terminal program similar as HyperTerminal and thusBluetooth wireless communicationcan be used without modifying user's existing serial communication program. In addition to basic AT commands,Bluetooth module BCD110 provides some of the expanded AT commands for use in various functions. To run AT commands on BCD110 Bluetooth module, it should be connected to serial port of user's board or equivalent for making theBCD110 to work.Optionally, it is also possible that BCD110 can be supplied with software stack only up to HCI level as shown in figure 7.2 so that theusers can embed anddevelop their own firmware version in the BCD110 or possibility is also there so that entire Bluetooth stack runs on host side for applicationslike USB dongle for computers etc.

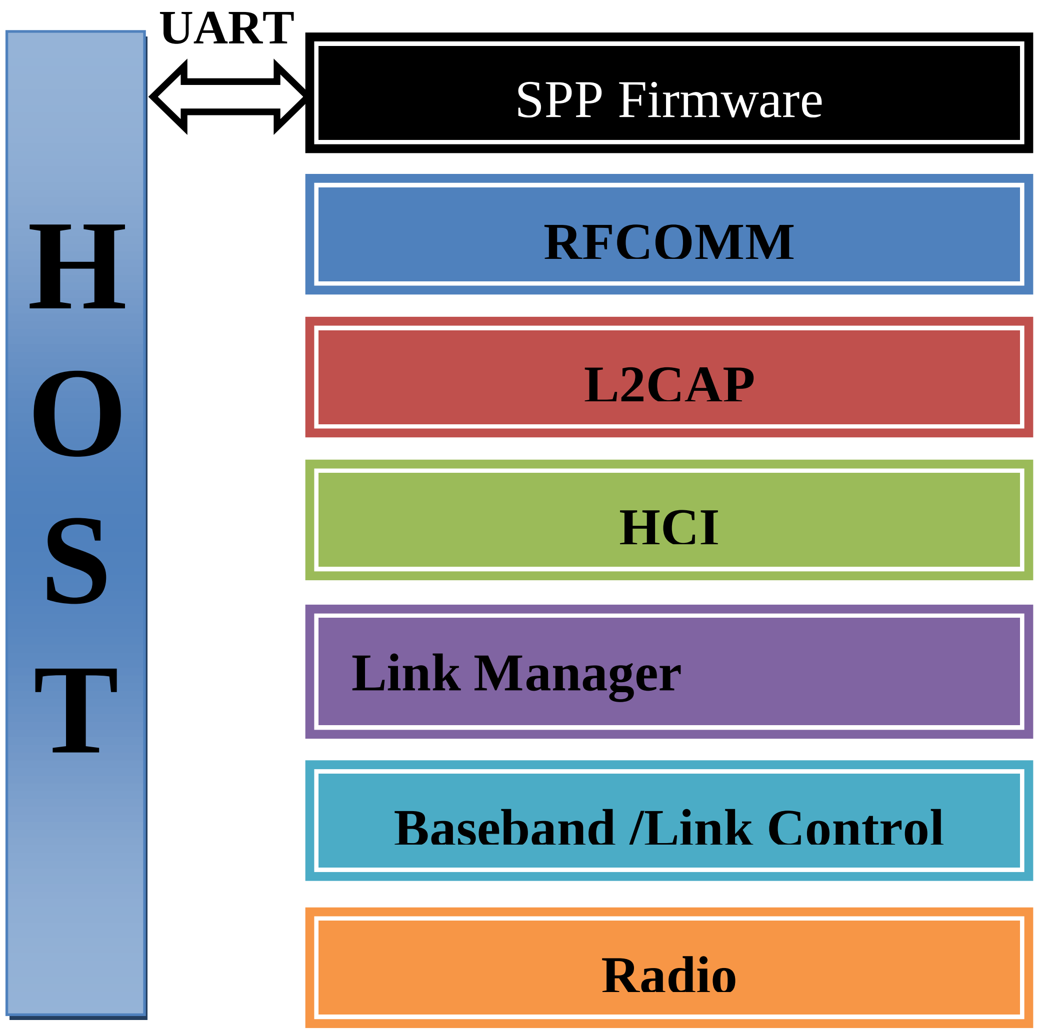

Figure 7.1: Bluetooth software stack (SPP firmware)

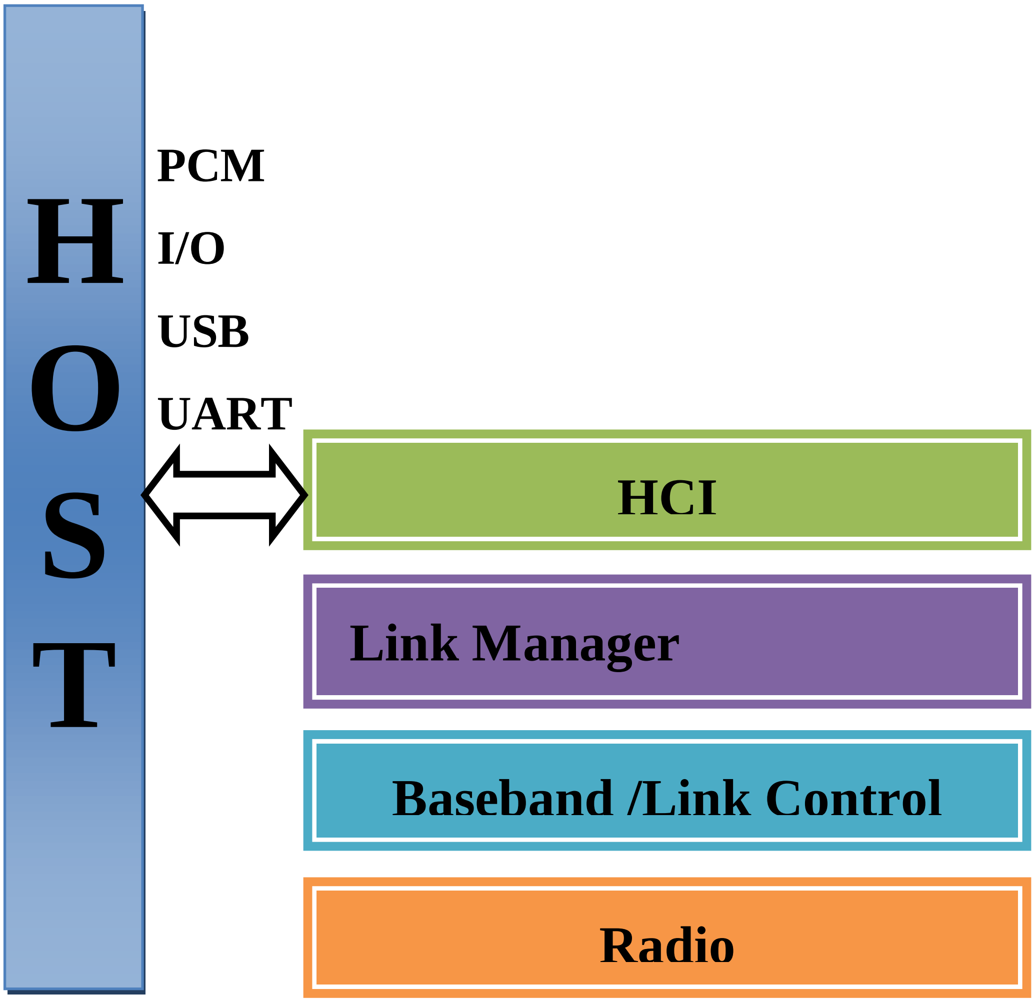

Figure 7.2: Bluetooth software stack (HCI firmware)

CHAPTER 8: RESULTS

Results of testing of communication of Bluetooth module with remote Bluetooth device are shown here. Testing was done by sending characters “a”, “b” and number “5” from Bluetooth of a mobile phone to Bluetooth module PARANI BCD110 and vice versa, where BCD110 is interfaced with personal computer (PC)at its serial port andParaniWIN version 1.0.4 software installed on PC was used as user interface from PC side to make configuration and connection settings of the BCD110 and apart from this terminal software was used to monitor and make it sure that the sent data was correctly received and also data was sent from PC to mobile phone which was also correctly received.On mobile phone Bterm software was used as a user interface Figure 8.1 shows completion of search process for remote Bluetooth device by BCD110 using ParaniWIN software. Figure 8.2 shows successful connection establishment of remote Bluetooth device and BCD110 using ParaniWIN software. Figure 8.3 shows use of ParaniWIN for RSSI and link quality check. Figure 8.4 shows terminal software used for monitoring sent and received data.

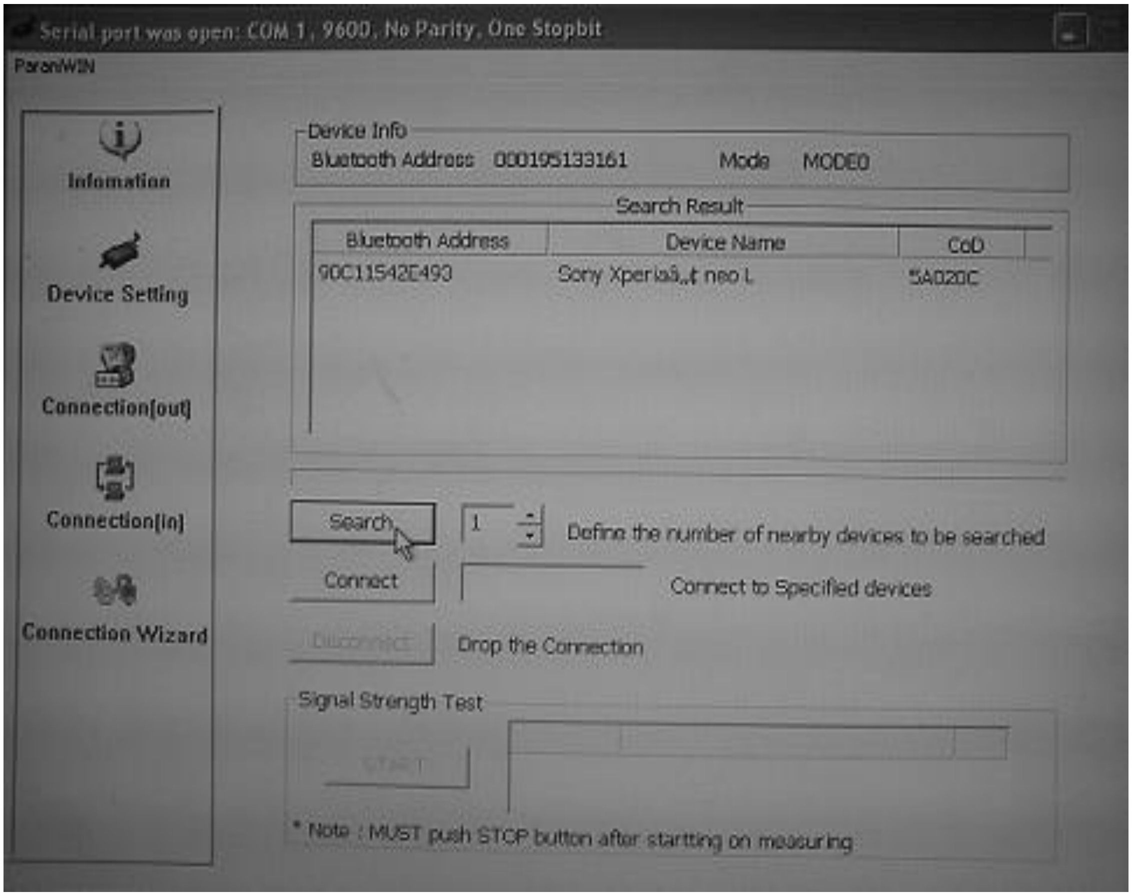

Figure 8.1:ParaniWIN software used for establishing connection between personal computer serial port and the Bluetooth module hardware.

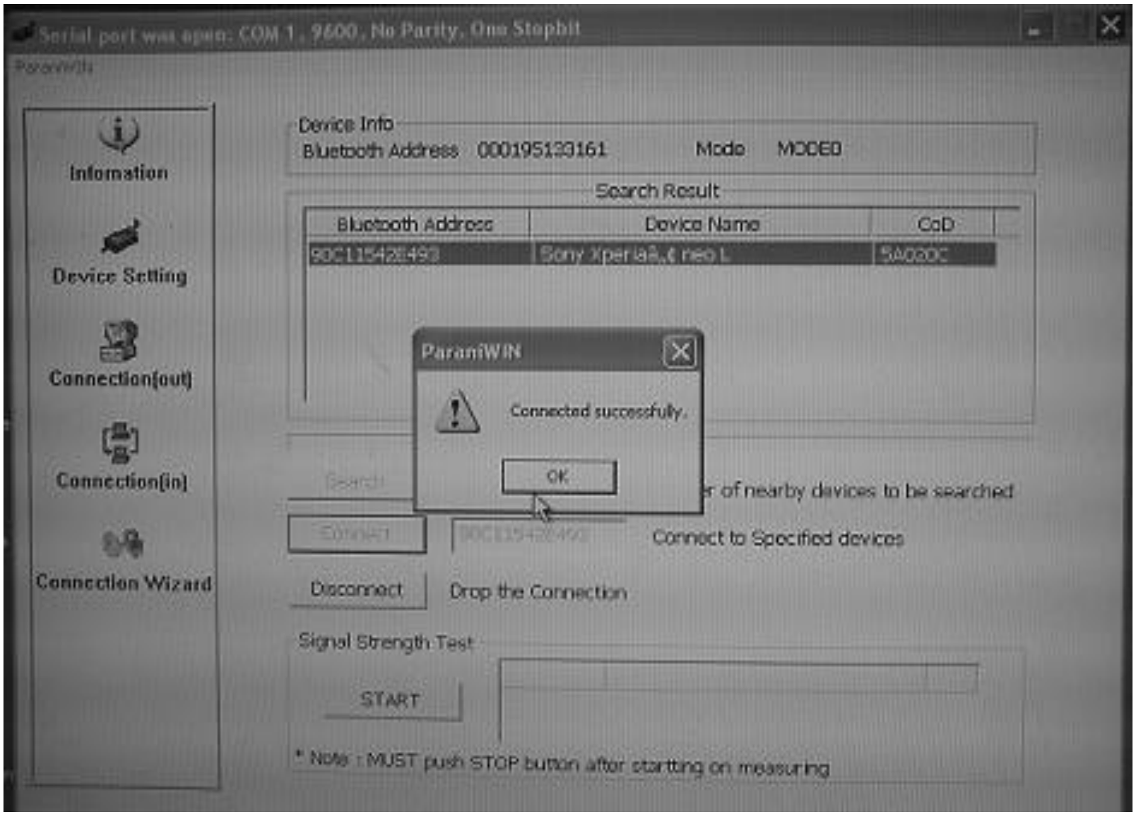

Figure 8.2:ParaniWIN software screen showing successful connection establishment with remote Bluetooth mobile phone.

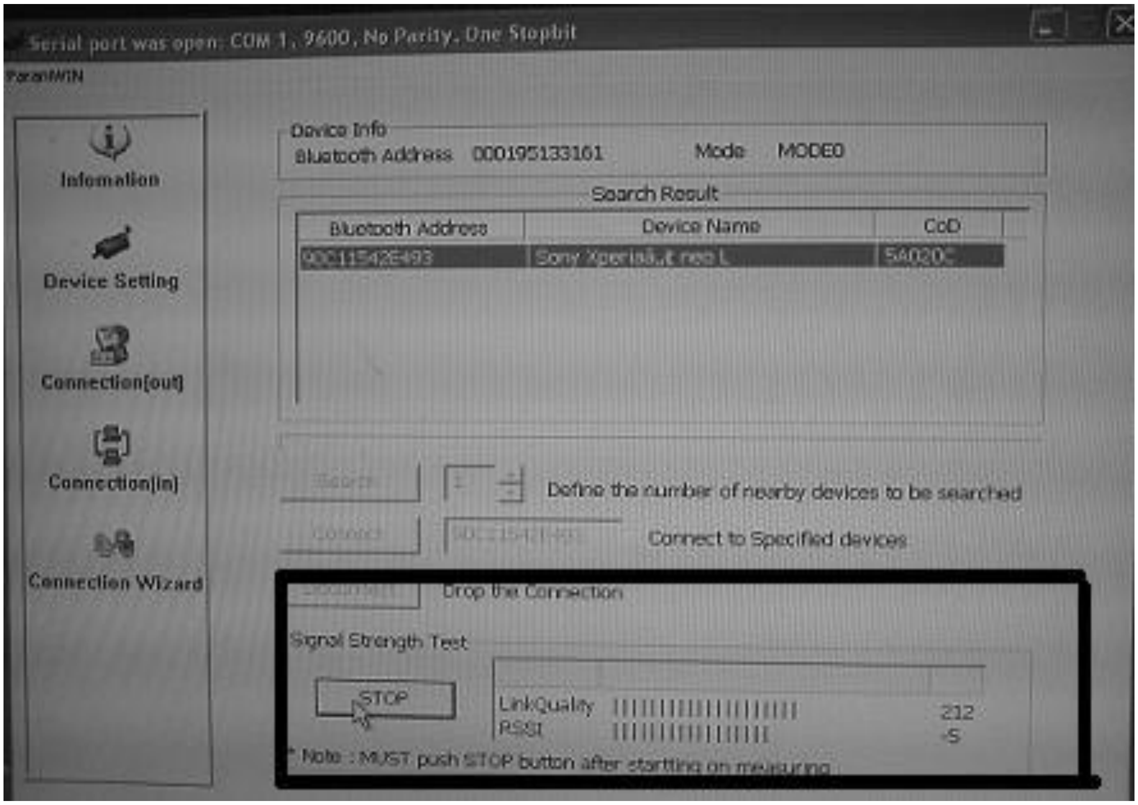

Figure 8.3: ParaniWIN software used for RSSI and link quality check.

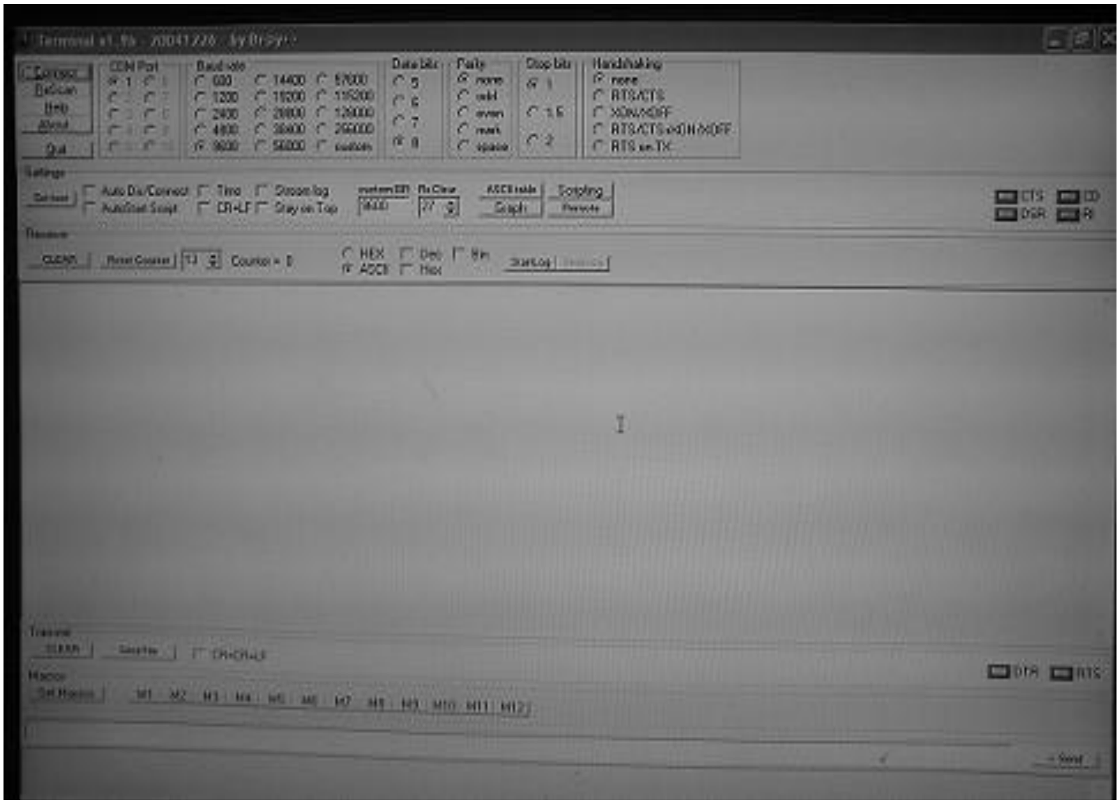

Figure 8.4: Terminal software used for monitoring sent and received data.

Waveform of character “a” sent from Bluetooth of a mobile phone to SENA technologies BCD110 Bluetooth module interfaced with serial port of personal computer through MAX3232 integrated circuit. Serial port profile of Bluetooth technology is used here. As shown in the schematic of Bluetooth interfacing with MAX3232. Below shown (figure 8.5) waveform is taken at pin number 11 of MAX3232.

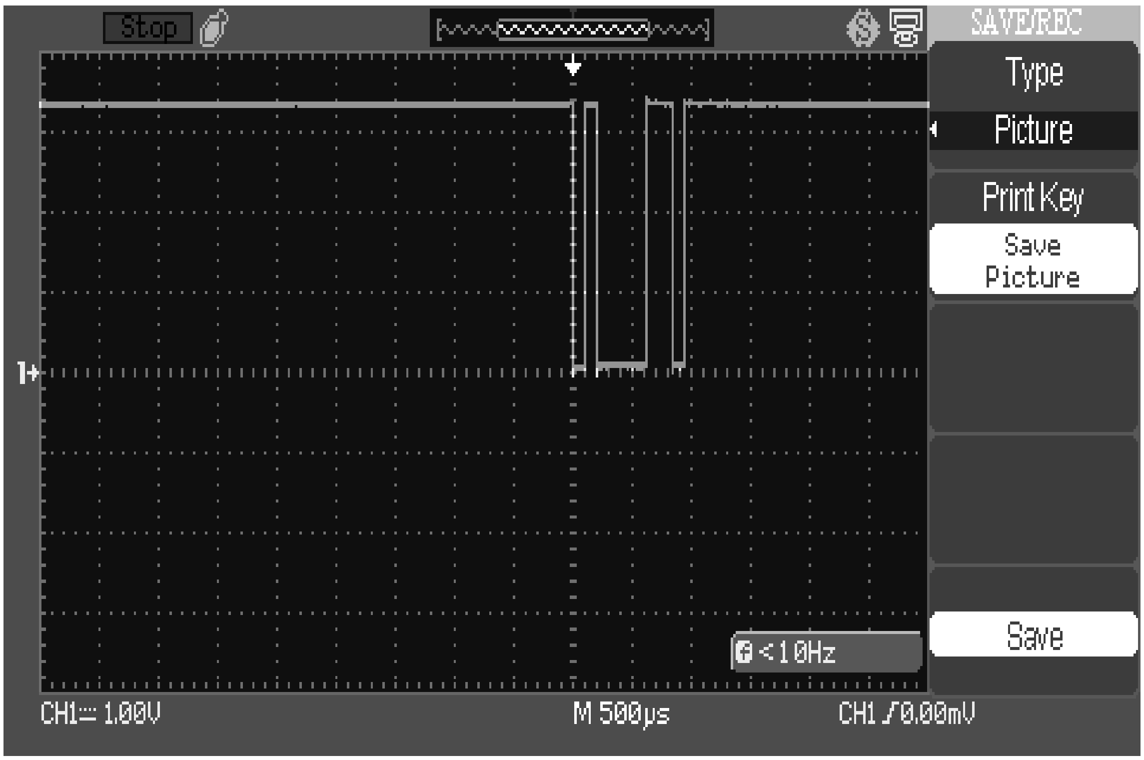

Figure 8.5:Waveform at pin number 11 of MAX3232 of character “a” received successfully from mobile phone.

Waveform of character “a” sent from Bluetooth of a mobile phone to SENA technologies BCD110 Bluetooth module interfaced with serial port of personal computer through MAX3232 integrated circuit. As shown in the schematic of Bluetooth interfacing with MAX3232. Below shown (figure 8.6) waveform is taken at pin number 14 of MAX3232.

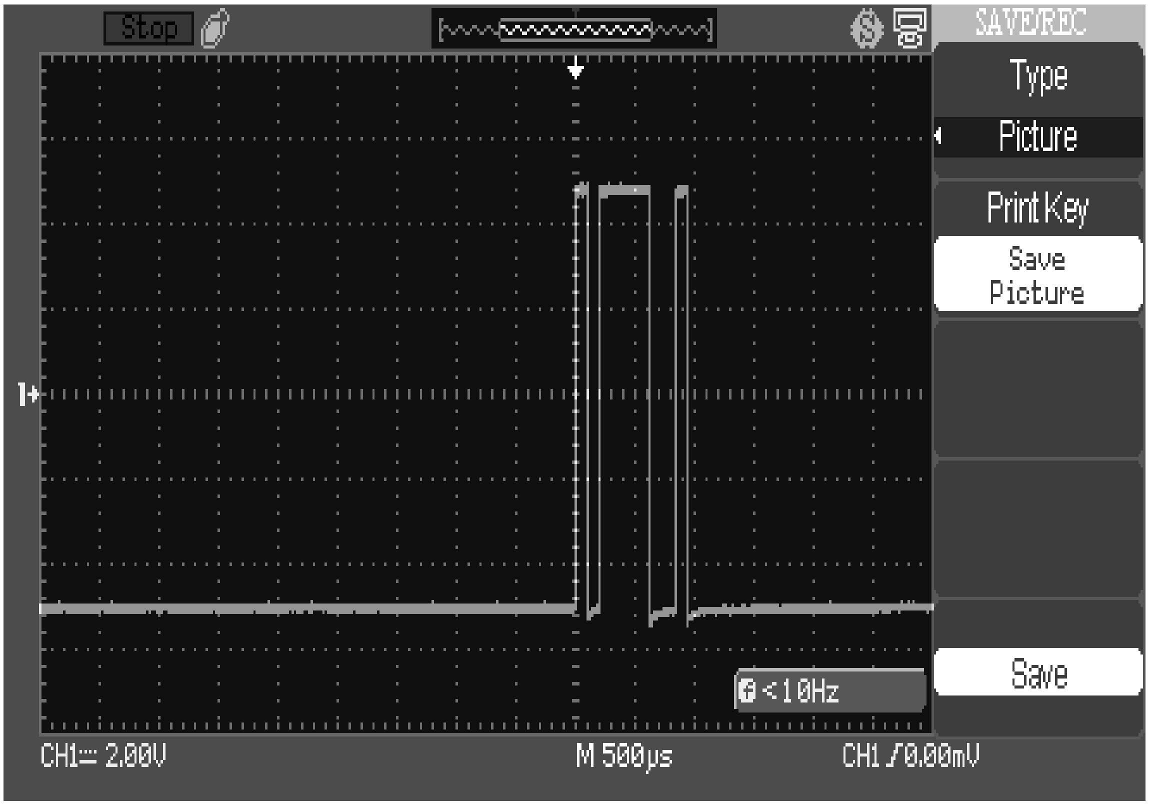

Figure 8.6:Waveform at pin number 14 of MAX3232 of character “a” received successfully from mobile phone.

Waveform of character "b" sent from Bluetooth of a mobile phone to SENA technologies BCD110 Bluetooth module interfaced with serial port of personal computer through MAX3232 integrated circuit. As shown in the schematic of Bluetooth interfacing with MAX3232. Below shown (figure 8.7) waveform is taken at pin number 11 of MAX3232.

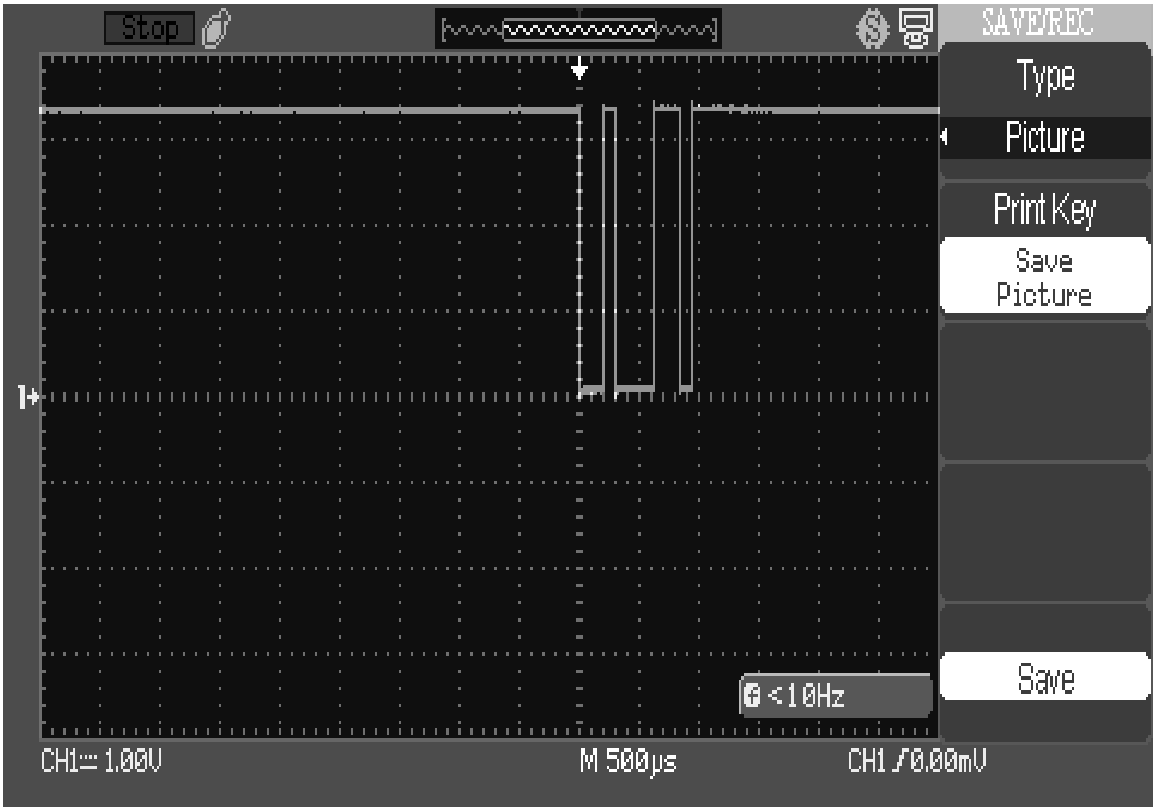

Figure 8.7:Waveform at pin number 11 of MAX3232 of character "b" received successfully from mobile phone.

Waveform of character “b” sent from Bluetooth of a mobile phone to SENA technologies BCD110 Bluetooth module interfaced with serial port of personal computer through MAX3232 integrated circuit. As shown in the schematic of Bluetooth interfacing with MAX3232. Below shown (figure 8.8) waveform is taken at pin number 14 of MAX3232.

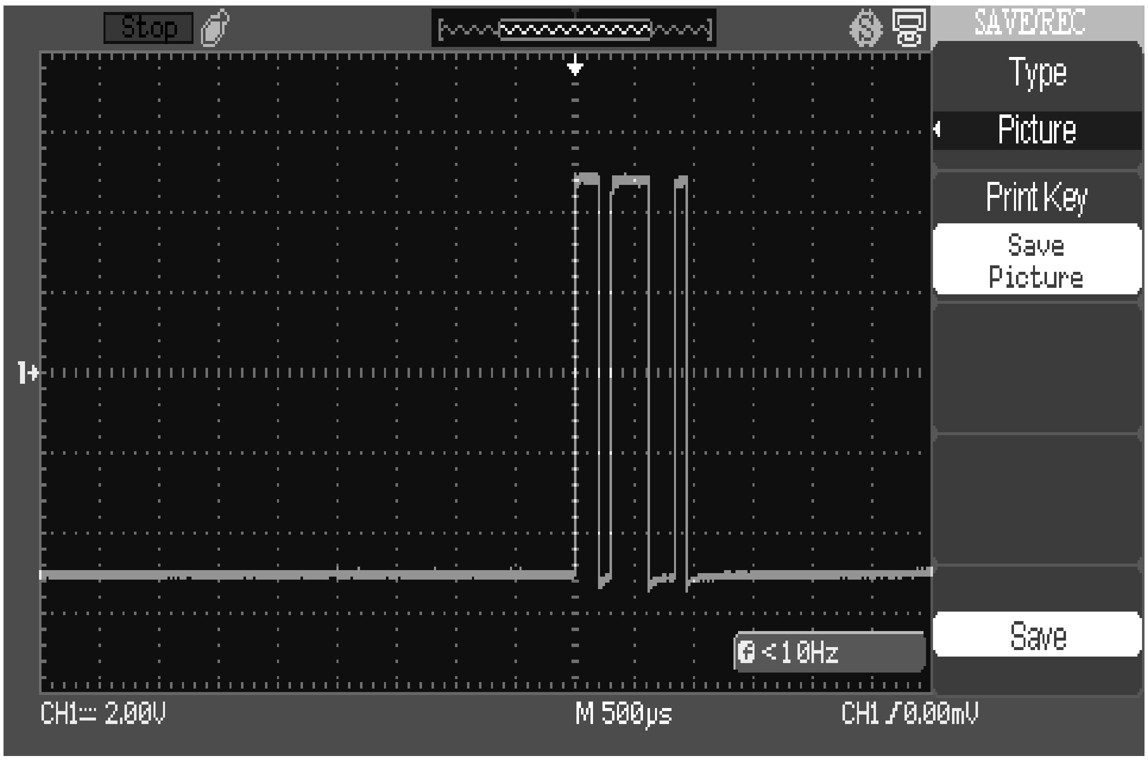

Figure 8.8:Waveform at pin number 14 of MAX3232 of character “b” received successfully from mobile phone.

Waveform of number “5” sent from Bluetooth of a mobile phone to SENA technologies BCD110 Bluetooth module interfaced with serial port of personal computer through MAX3232 integrated circuit. As shown in the schematic of Bluetooth interfacing with MAX3232. Below shown (figure 8.9) waveform is taken at pin number 11 of MAX3232.

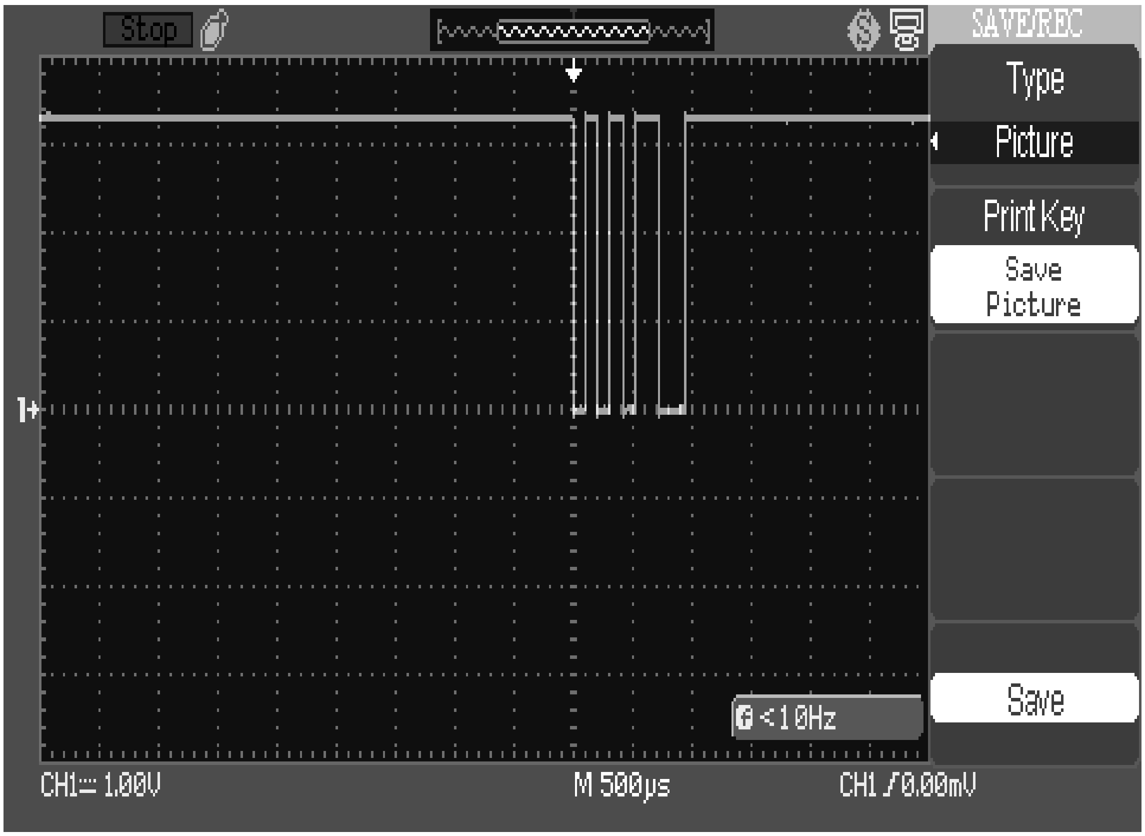

Figure 8.9:Waveform at pin number 11 of MAX3232 of number “5” received successfully from mobile phone.

Waveform of number “5” sent from Bluetooth of a mobile phone to SENA technologies BCD110 Bluetooth module interfaced with serial port of personal computer through MAX3232 integrated circuit. As shown in the schematic of Bluetooth interfacing with MAX3232. Below shown (figure 8.10) waveform is taken at pin number 14 of MAX3232.

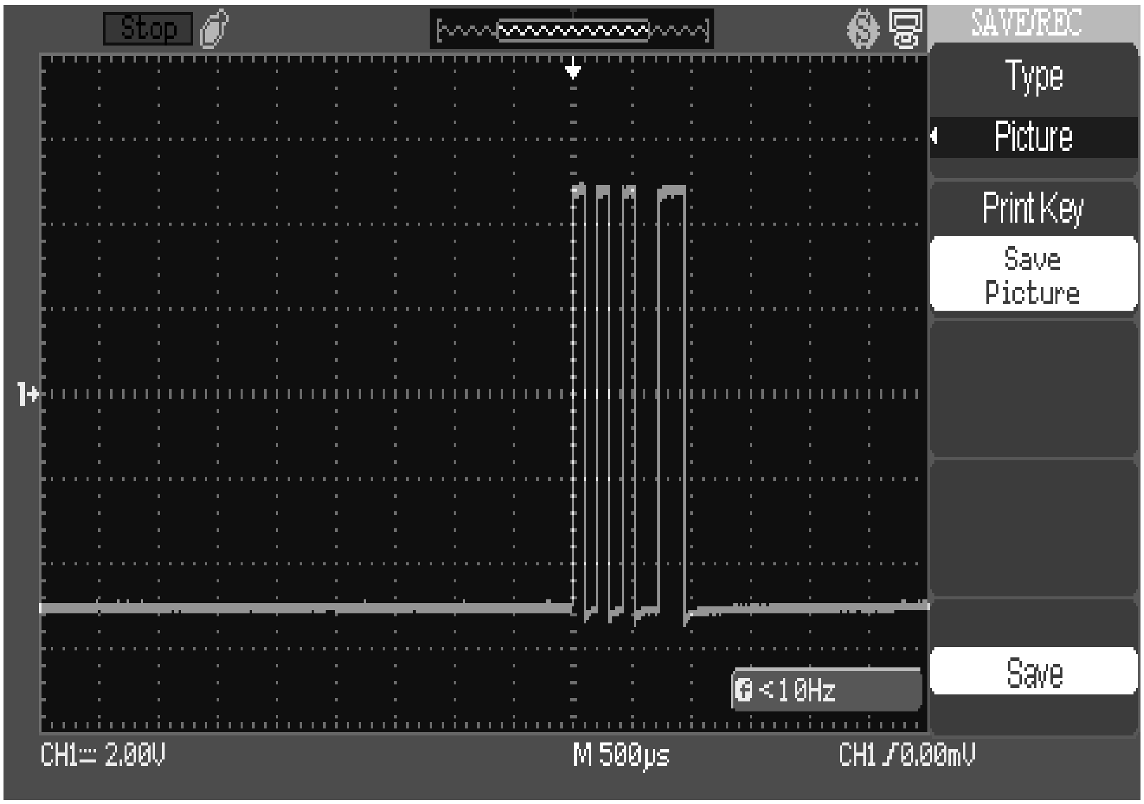

Figure 8.10:Waveform at pin number 14 of MAX3232 of number “5” received successfully from mobile phone.

Waveform of character “a” sent from personal computer to a mobile phone through SENA technologies BCD110 Bluetooth module interfaced with serial port of personal computer through MAX3232 integrated circuit. As shown in the schematic of Bluetooth interfacing with MAX3232. Below shown (figure 8.11) waveform is taken at pin number 13 of MAX3232.

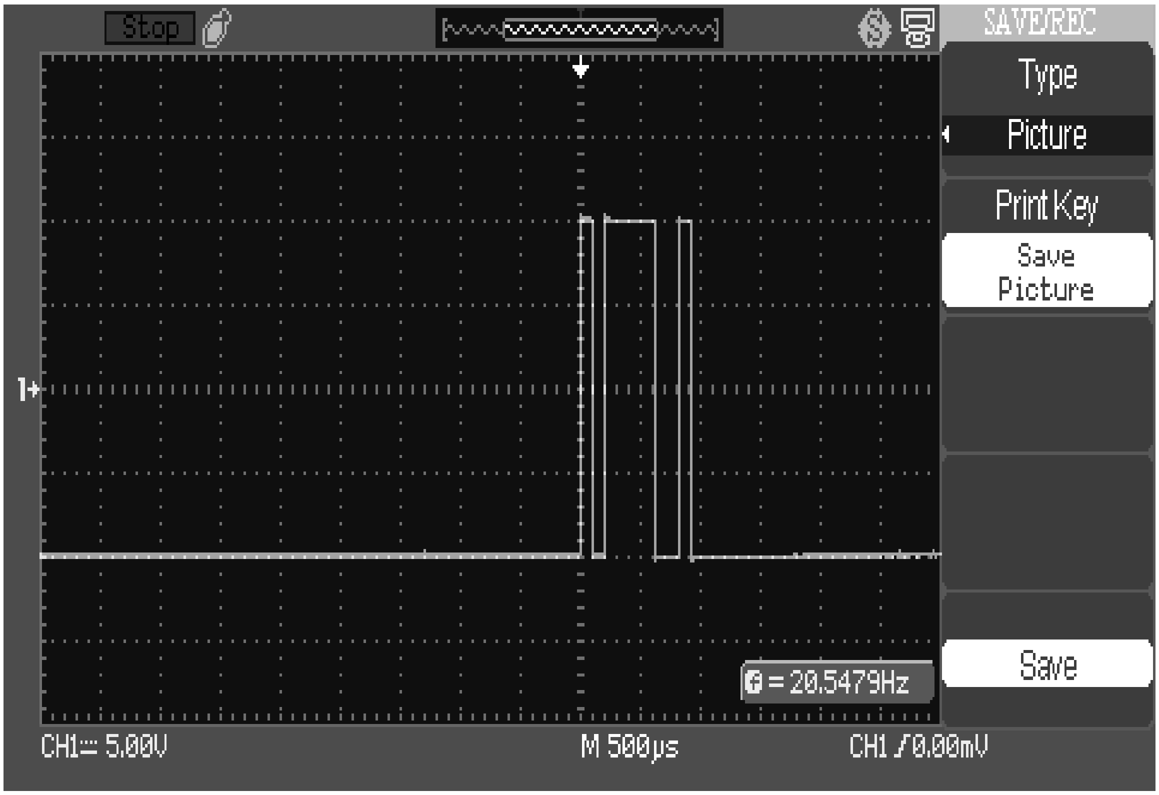

Figure 8.11:Waveform at pin number 13 of MAX3232 of character “a” received successfully from mobile phone.

Waveform of character “a” sent from personal computer to a mobile phone through SENA technologies BCD110 Bluetooth module interfaced with serial port of personal computer through MAX3232 integrated circuit. As shown in the schematic of Bluetooth interfacing with MAX3232. Below shown (figure 8.12) waveform is taken at pin number 12 of MAX3232.

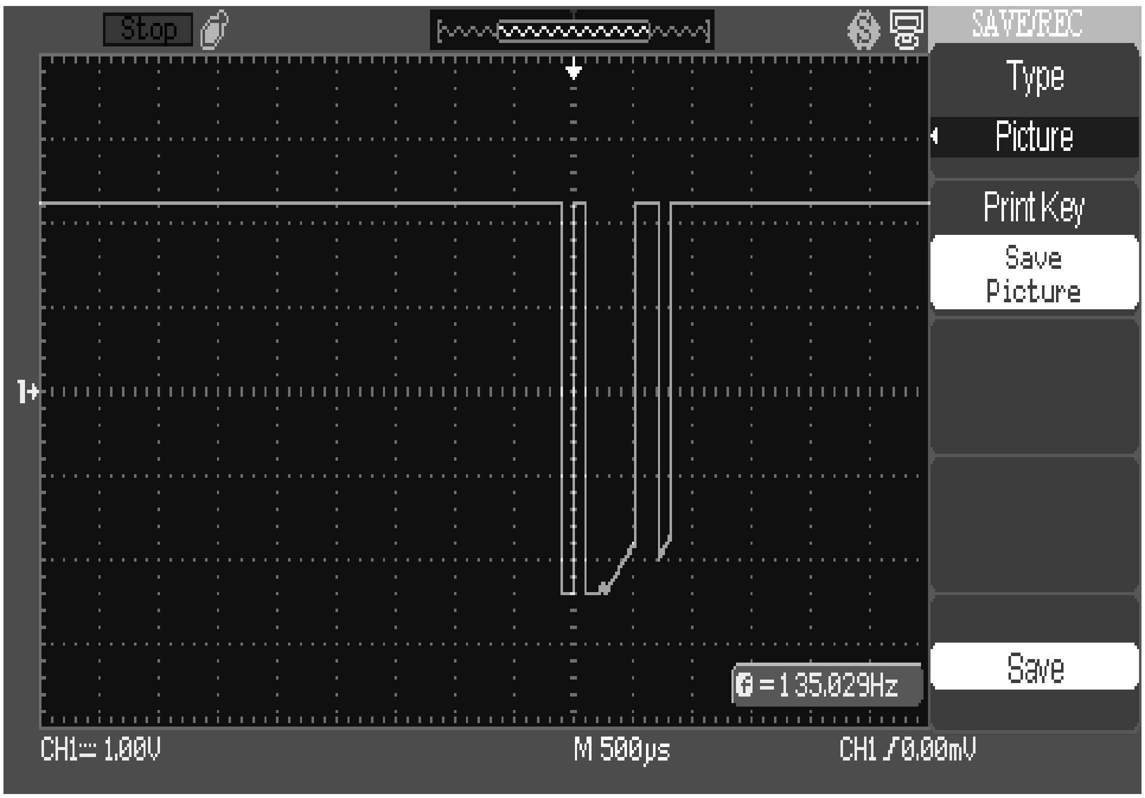

Figure 8.12:Waveform at pin number 12 of MAX3232 of character “a” received successfully from mobile phone.

Waveform of character “b” sent from personal computer to a mobile phone through SENA technologies BCD110 Bluetooth module interfaced with serial port of personal computer through MAX3232 integrated circuit. As shown in the schematic of Bluetooth interfacing with MAX3232. Below shown (figure 8.13) waveform is taken at pin number 13 of MAX3232.

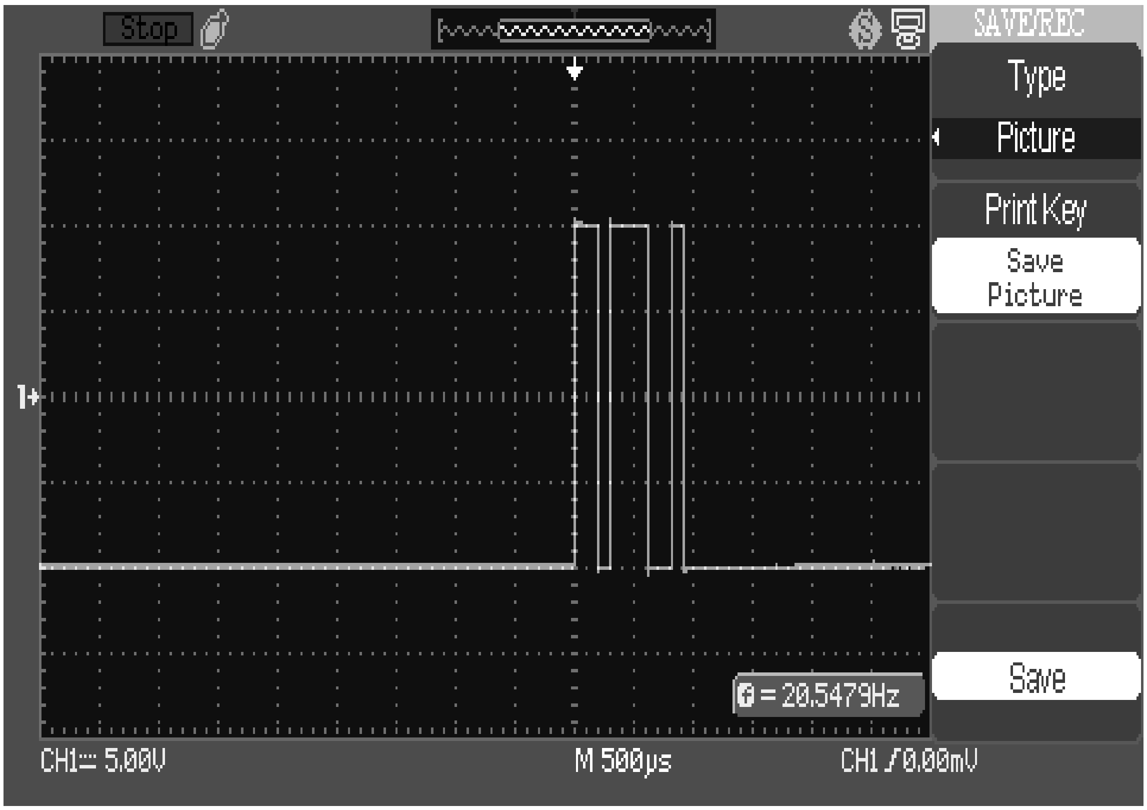

Figure 8.13:Waveform at pin number 13 of MAX3232 of character “b” received successfully from mobile phone.

Waveform of character “b” sent from personal computer to a mobile phone through SENA technologies BCD110 Bluetooth module interfaced with serial port of personal computer through MAX3232 integrated circuit. As shown in the schematic of Bluetooth interfacing with MAX3232. Below shown (figure 8.14) waveform is taken at pin number 12 of MAX3232.

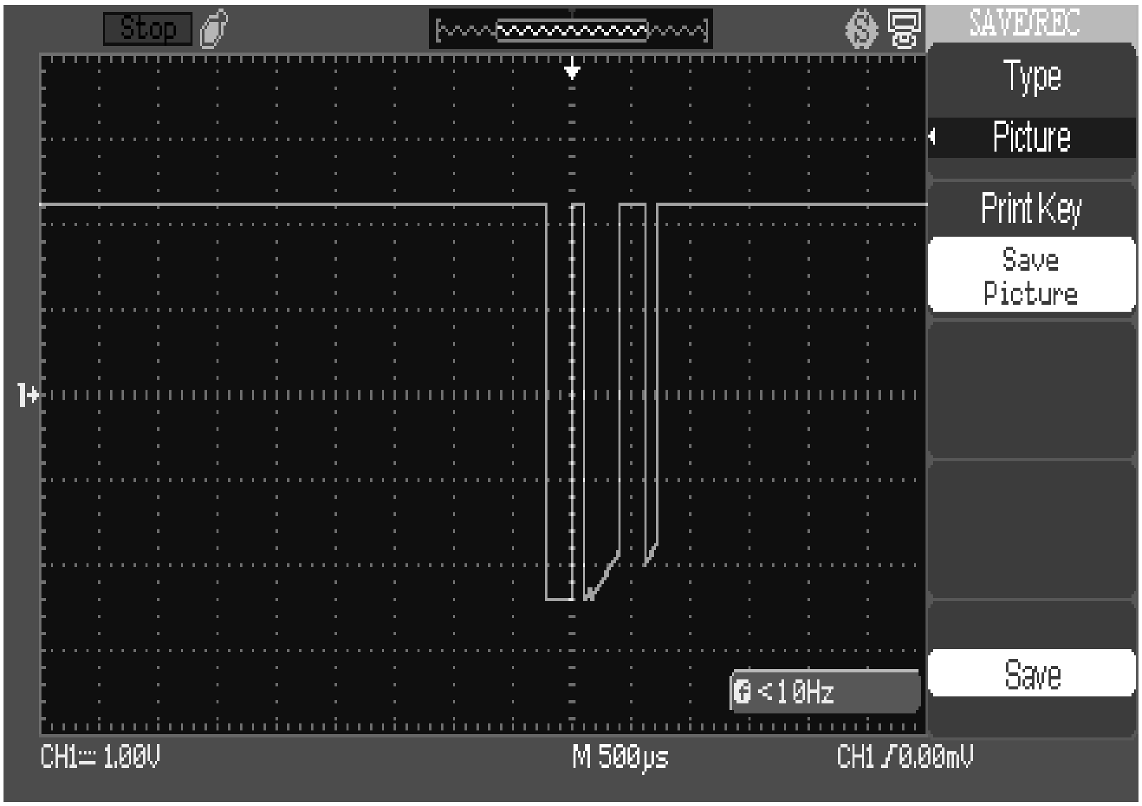

Figure 8.14:Waveform at pin number 12 of MAX3232 of character “b” received successfully from mobile phone.

Waveform of number “5” sent from personal computer to a mobile phone through SENA technologies BCD110 Bluetooth module interfaced with serial port of personal computer through MAX3232 integrated circuit. As shown in the schematic of Bluetooth interfacing with MAX3232. Below shown (figure 8.15) waveform is taken at pin number 13 of MAX3232.

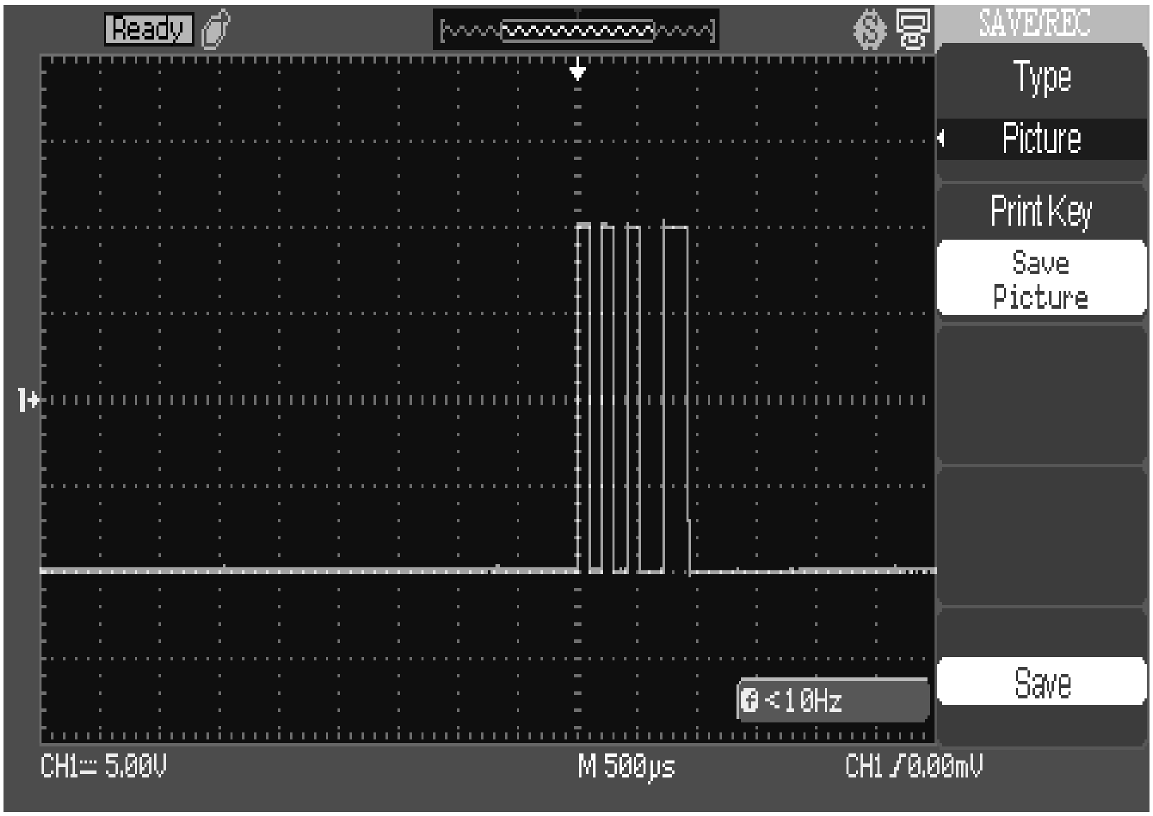

Figure 8.15:Waveform at pin number 13 of MAX3232 of number “5” received successfully from mobile phone.

Waveform of number "5" sent from personal computer to a mobile phone through SENA technologies BCD110 Bluetooth module interfaced with serial port of personal computer through MAX3232 integrated circuit. As shown in the schematic of Bluetooth interfacing with MAX3232. Below shown (figure 8.16) waveform is taken at pin number 12 of MAX3232.

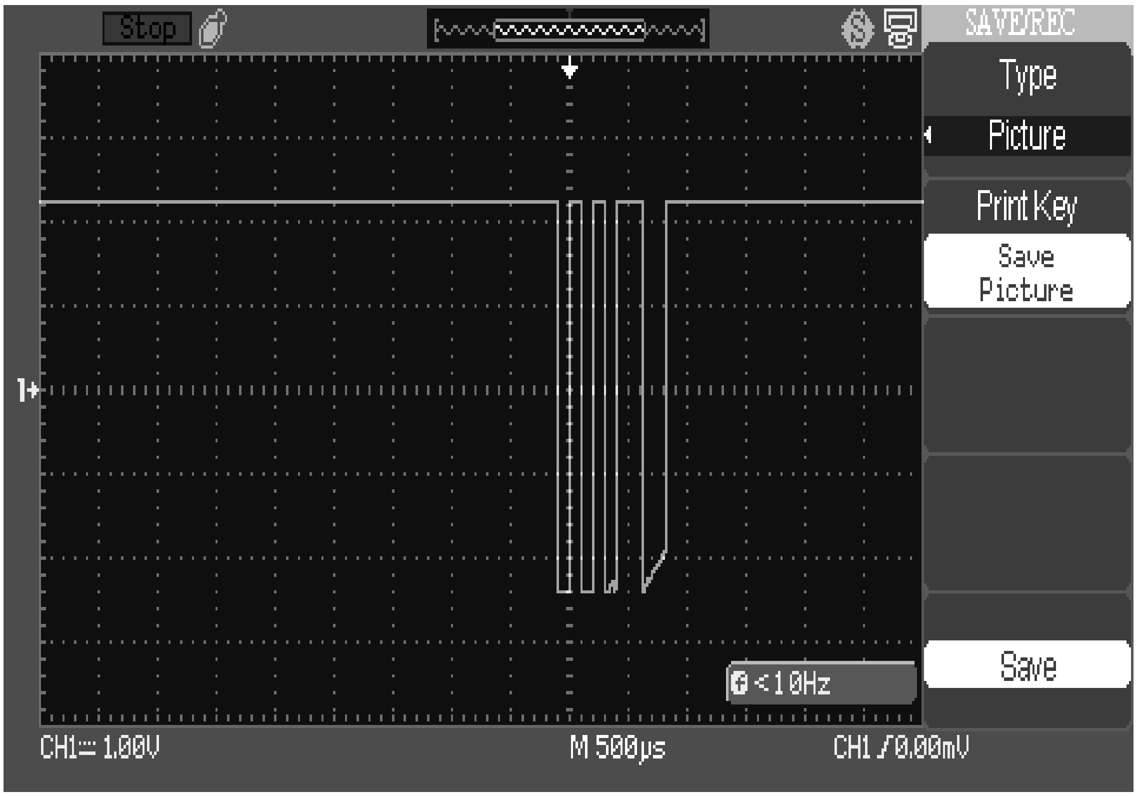

Figure 8.16:Waveform at pin number 12 of MAX3232 of number "5" received successfully from mobile phone.

CHAPTER 9: CONCLUSION AND FUTURE SCOPE

Popularity of Bluetooth can be seen easily in the market from a range of products incorporating this wireless technology. Security of Bluetooth makes it an attractive solution to be incorporated in the products. In this dissertation, principle of working of the Bluetooth is explained along with protocols of the Bluetooth. Apart from this three different Bluetooth modules have been specified for their features and specifications and also comparison between the three is done on the basis of many parameters such as Bluetooth specification, operating voltage, receiver sensitivity, RF output power, supported Bluetooth profiles and last but not the least is cost which is a very significant parameter for selection of Bluetooth module which is a major deciding factor of product cost.

It is concluded that the Incorporation of Bluetooth in pole mounted Remote Terminal Units is the need of time as can be seen from the problems of management of RTU. There are many advantages of Bluetooth incorporation in these units as discussed in the dissertation like safety of the maintenance personnel, reduction in the downtime at the time of maintenance of RTUs etc.

Present work checks for the feasibility of incorporation of the Bluetooth technology in the Remote Terminal Units for their management. Further this work can be extended to incorporate various other wireless communication technologies e.g. Wi-Fi.

REFERENCES

[1] MohdNurYassieen Bin Mat Zaki, “REMOTE TERMINAL UNIT (RTU) BASED ONELECTRICAL LOAD CONTROLLER”, Report submitted In Partial Fulfillment Of Requirement For The Degree of Bachelor In Electrical Engineering (Industrial Power),FakultiKejuruteraanElektrikUniversitiTeknikal Malaysia Melaka, 7 May 2008.

[2] Ahmed AhmedEladawyEmira, “BLUETOOTH/WLAN RECEIVER DESIGN METHODOLOGY AND IC IMPLEMENTATIONS”, A Dissertation Submitted to the Office of Graduate Studies of Texas A&M University in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY.

[3] Universal Serial Bus (USB) article
Available at - http://en.wikipedia.org/wiki/Universal_Serial_Bus

[4] Bluetooth Technology and WiFi
Available at - http://www.bluetooth.com/Pages/Wi-Fi.aspx

[5] Guérin, Roch, Enyoung Kim, and SaswatiSarkar. "Bluetooth technology key challenges and initial research." In Proc. SCS Comm. Networks and Distributed Systems Modeling and Simulation CNDS, pp. 157-163. 2002.

[6] Blasdel Justin, and KianPokorny. "The Future of Bluetooth Technology" (2004).

Available at –

http://monde-diplomatique.si/test/sale/FAX/Angle%9A%E8ina/Bluetooth.pdf

[7] Bluetooth Article

Available at - http://en.wikipedia.org/wiki/Bluetooth

[8] Bluetooth Technology Overview - F O R U M N O K I A, Version 1.0; April 4, 2003

Available at - http://lms.uni-mb.si/~meolic/ptk-seminarske/bluetooth2.pdf

[9]Parani BCD110, Online product catalog of SENA Technologies

Available at - http://www.sena.com/products/industrial_bluetooth/bcd110.php

[10] OEM Bluetooth Serial Port Module OBS410, Online product catalog of connectBlue

Available at - http://www.connectblue.com/products/classic-bluetooth-products/classic-bluetooth-modules/bluetooth-serial-port-module-obs410/

[11] ConnectBlue, Product Brief OEM Bluetooth Serial Port Module OBS410

Available at - http://www.connectblue.com/nc/products/classic-bluetooth-products/classic-bluetooth-modules/bluetooth-serial-port-module-obs410/?pdf=1&format=LETTER&pageId=1189

[12] Bluegiga Technologies WT41-E-HCI3, Online price catalogue of Mouser Electronics

Available at - http://in.mouser.com/ProductDetail/Bluegiga-Technologies/WT41-E-HCI3/?qs=%2fha2pyFadugxuV1o%2fw7lyyid6XpN0tY2VKm1o4h3viv3V%2fJ5D26P%252bw%3d%3d

[13] WT41 Long Range Bluetooth Module, Online product catalogue of Bluegiga Technologies

Available at - http://www.bluegiga.com/WT41_Long_Range_Bluetooth_Module

[14] Bluegiga Technologies WT41-E-AI4, Online price catalogue of Mouser Electronics

Available at - http://in.mouser.com/ProductDetail/Bluegiga-Technologies/WT41-E-AI4/?qs=R6JvMBAljWcxHe3vRdkh2w==

[15] Parani-BCD110 Bluetooth embedded OEM module DIP type, Class 1 with U.FL connector, HCI Firmware, Online product price catalogue of SENA Technologies

Available at - http://www.buysena.com/catalogsearch/result/?q=bcd+110

[16] CB-OBS410X-04-0, SERIAL PORT ADAPTER, Online product price catalogue of Digi-Key Corporation

Available at - http://www.digikey.com/product-detail/en/CB-OBS410X-04-0/809-1037-ND/2617077

[17]Ms. Neha R. Laddha, Prof. A.P.Thakare, “A Review on Serial Communication by UART”, International Journal of Advanced Research in Computer Science and Software Engineering, Volume 3, Issue 1, January2013.

[18] Universal Asynchronous Receiver/Transmitter (UART) article

Available at - http://en.wikipedia.org/wiki/Universal_asynchronous_receiver/transmitter

[19]AmanpreetKaur, AmandeepKaur, “An Approach For Designing A Universal Asynchronous Receiver Transmitter (UART), International Journal of Engineering Research and Applications, Vol. 2, Issue 3, May - Jun 2012, pp.2305-2311.

[20] M. A. Naeem, Rizwan Khan, “A Frame Work for Virtual USB Devices under Linux Environment”, International Journal of Computer Science and Telecommunications, Volume 1, Issue 1, November 2010.

[21] I²C (Inter-Integrated Circuit) article
Available at - http://en.wikipedia.org/wiki/I%C2%B2C

[22] Jean-Marc Irazabal, Steve Blozis, “Application Note I2C Bus”, Philips Semiconductors, March 24, 2003.
Available at - http://www.cs.unc.edu/Research/stc/FAQs/Interfaces/I2C-AN10216_1.pdf

[23] KimmoKoskiniemi,“Antenna Selection for Wireless Communication Systems”, Article, September 2008.
Available at - http://www.mpdigest.com/issue/Articles/2008/sept/Pulse/

PUBLICATIONS

[1] Simranjit Singh Chadha, Mandeep Singh &Rohit Kumar Arora, "A Review of Bluetooth and Wi-Fi Based upon Coexistence Opportunities and Challenges in 2.4 Ghz Band ", Proceedings, International Conference on Electronics and Communication Engineering, 7th April, 2013,Bengaluru,India,pp 76-81.

[2] Simranjit Singh Chadha, MandeepSingh, Suraj Kumar Pardeshi, "Bluetooth Technology: Principle, Applications and Current Status", International Journal of Computer Science & Communication, Vol.4, No. 2, Sept 2013 (in press).

[3] Simranjit Singh Chadha, MandeepSingh, Suraj Kumar Pardeshi, "Bluetooth for managing Pole Mounted Remote Terminal Unit", International Journal of Computer Science & Communication, Vol.4, No. 2, Sept 2013 (in press).