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X-BAND INDOOR HIGH DATA RATE WIRELESS COMMUNICATION

M.Sc. Thesis by

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M.Sc. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"X-Band Indoor High Data Rate Wireless Communication"** completed by **ZIAOULRAHMAN SEDIQI** under the supervision of **Prof. Dr. Asaf Behzat Şahin** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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X-BAND INDOOR HIGH DATA RATE WIRELESS COMMUNICATION

ABSTRACT

The indoor wireless communication can be achieved by many different technologies such as light, Bluetooth and infrared. However, the data speed is not sufficient to transfer big data within a required range in short time segment. A need for high data rate is required to fulfill todays requirements where, high definition videos need to be sent in a blink of eye. In contrast to other indoor technologies our system carry data in a very high data rate. The system reliability is investigated using eye diagram that shows the system is suitable for wireless communication. This is a directional line of sight system which can be used between two users in an indoor environment. The users are able to share data without any physical wire in terms of seconds that eradicates the need for CD or flash disks to carry data from one point to another. In this thesis, it is aimed to study a very high data rate wireless communication system utilizing X-band. For achieving this goal, a Vivaldi antenna has been drawn and fabricated suitable for the system that is tested by vector network analyzer for its S_{11} and S_{21} parameters which effectively worked at 11.2 GHz. For such system it is essential to establish a convenient experimental setup consist of a transmitter and a receiver, the experimental setup is combined out of suitable RF components in order to achieve a very high data rate. Different modulation schemes are tested on the system namely, binary phase shift keying and on-off keying. The system stability and reliability has been tested up to 3.7 Gbit/s. Since this experiment is purposed to be done inside a room the distance between transmitter and receiver is gradually increased from 5cm up to 160cm.

Keywords: X-band, wireless communication, high data rate, antenna fabrication, receiver and transmitter design, on-off keying, binary phase shift keying.

BİNA İÇİ X-BANDINDA YÜKSEK VERİ HIZLI KABLOSUZ HABERLEŞME

ÖZ

Bina içi kablosuz iletişim, ışık, bluetooth ve kızılötesi gibi birçok farklı teknoloji ile sağlanabilir. Ancak veri hızı, büyük veriyi kısa bir zaman diliminde gerekli bir aralıkta aktarmak için yeterli değildir. Göz açıp kapayıncaya kadar yüksek çözünürlüklü videoların gönderilmesi gereken günümüzün gereksinimlerini karşılamak için yüksek veri hızına ihtiyaç duyulmaktadır. Diğer bina içi teknolojilerinin aksine, sistemimiz verileri çok yüksek veri hızında taşır. Sistemin güvenilirliği, sistemin kablosuz iletişim için uygun olduğunu gösteren göz diyagramı kullanılarak araştırılır. Bu, kapalı bir ortamda iki kullanıcı arasında kullanılabilen yönlü bir görüş hattı sistemidir. Kullanıcılar, verileri bir noktadan diğerine taşımak için CD veya flash disklere olan ihtiyacı ortadan kaldıran saniyeler içinde herhangi bir fiziksel kablo olmadan verileri paylaşabilirler. Bu tezde, X-bandını kullanan çok yüksek veri hızlı bir kablosuz iletişim sisteminin incelenmesi amaçlanmıştır. Bu amaca ulaşmak için, 11.2 GHz'de etkin bir şekilde çalışan S_{11} ve S_{21} parametreleri vektör ağ analizörü tarafından test edilen sisteme uygun bir Vivaldi anteni çizilmiş ve üretilmiştir. Bu tür bir sistem için, bir verici ve bir alıcıdan oluşan uygun bir deney düzeneğinin kurulması önemlidir. Deney düzeneği çok yüksek bir veri hızı elde etmek için uygun RF bileşenlerinden birleştirilir. Sistem üzerinde ikili faz kaydırmalı anahtarlama ve açma-kapama anahtarlama olmak üzere farklı modülasyon şemaları test edilmiştir. Sistem kararlılığı ve güvenilirliği 3.7 Gbit/sn'ye kadar test edilmiştir. Bu deney bir oda içinde yapılması amaçlandığından, verici ile alıcı arasındaki mesafe kademeli olarak 5 cm'den 160 cm'ye çıkarılmıştır.

Anahtar Kelimeler: X-Bandı, kablosuz haberleşme, yüksek veri hızı, anten tasarımı, alıcı ve verici tasarımı, ikili faz kaydırmalı anahtarlama, açma-kapama anahtarlama.

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NOMENCLATURE

Acronyms

RF Radio Frequency

Tx Transmitter

Rx Receiver

SLF Super Low Frequency

ULF Ultra Low Frequency

VLF Very Low frequency

LF Low Frequency

MF Medium Frequency

HF High Frequency

VHF Very High Frequency

UHF Ultra high Frequency

SHF Super High Frequency

EHF Extremely High Frequency

AM Amplitude Modulation

FM Frequency Modulation

PM Phase Modulation

TH Terahertz

GHz Gigahertz

MHz Megahertz

KHz Kilohertz

Hz Hertz

UWB Ultra Wide Band

ADC Analog to Digital Converter

DSP Digital Signal Processing

LSB Least Significant Bit

ENOB Effective Number of Bits

SINAD Signal to Noise and Distortion

SNR Signal to Noise Ratio

ASK	Amplitude Shift Keying
FSK	Frequency Shift Keying
PSK	Phase Shift Keying
BFSK	Binary Frequency Shift keying
QPSK	Quadrature Phase Shift Keying
IQ	In phase Quadrature
BTS	Base Transceiver Station
BS	Base Station
LOS	Line of Sight
dB	decibels
PANs	Personal Area Networks
MIMO	Multiple Input Multiple Output
GEO	Geostationary Orbit
SISO	Single Input Single Output
LO	Local Oscillator
PA	Power Amplifier
PRBS	Pseudo Random Binary Sequence
GUI	Graphical User Interface
BER	Bit Error Rate
DC	Direct Current
PCB	Printed Circuit Board
VNA	Vector Network Analyzer
LNA	Low Noise Amplifier
BPSK	Binary Phase Shift Keying
OOK	On Off Keying

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CHAPTER 1

INTRODUCTION

The burst in wireless communications has ended in new technologies and new implementation for the personal use of radio frequency (RF); personal communication systems are now being developed worldwide. One of the most significant application personal communication system is indoor wireless communication system. This implementation is used for variety of applications such as communication with somebody walking in an office or a building. Sending messages to control tools such as machines and robots in a manufacturing factory. The indoor environment is vulnerable to interference. In debt to reflection, refraction and scattering of radio waves by architecture inside a skeleton structure, the transmitted signal more often arrives to the receiver by multipath, resulting in a circumstance known as multipath fading. Multipath leads in deep fading and pulse scattering of the signal and hence inter symbol interference can be provoked in a digital wireless communication radio system. Since 1990, the significance of the wireless communication has been increasing, as the industry has become a dynamic force capable of performing functions in technological, economic and productive development of developed economies [1].

The ever-increasing wireless data demands place extreme requirements on the future communications systems [2]. The demand for indoor communication has been increasing ever since then extensively. Today, indoor wireless communication systems have become part of our life, many experimental studies have been done in indoor wireless communication. Although, the common use of wireless systems, there are some undesired effects on the transmitted signal for instance, the effect of wall attenuation has been presented in [3] on the uplink performance of an interference limited indoor wireless communication systems. Typically, X-band exploit for satellite communication due to its exclusive location on RF spectrum which allows transmission in rough weather condition. 100 Mbps transmitter has been designed for low earth orbit satellites in X-band [4]. For

the small satellites, a compact 64- asymmetric phase-shift keying X-band transmitter has been developed in [5] and the plan of 2 Gbit/s downlink system is proposed at X-band in the same study. Since most of the traffic is generated indoors, the future systems are expected to rely on a significant number of indoor small cells to massively offload heavy traffic from cellular networks [2]. Indoor wireless communication at a rate of 622 Mbps is achieved in [6].

However, our indoor wireless communications system attains greater than 3 Gbps data rate and it is experimentally demonstrated. Furthermore, the following work aimed to achieve the feasibility of indoor wireless communications at very high data rates and this reliability depends on two maintaining reasonable outage probability with 60 dB factors which are: received signal power margin and delay spread [6]. X-band has been attracted the most attention due to the high-throughput, superiority with small antennas, low probability of interference etc. X-band have been identified as applicable frequency for indoor short-range wireless communications, such as Wi-Fi and device-to-device technologies.

Broadband high gain Vivaldi antennas contribute in increasing the operating distance, raise measure precision and reduce transmission power, etc. Vivaldi antenna has been widely used in many applications including radars, wireless communications, biomedical engineering, radiometry, microwave imaging and radio telescopes since proposed in 1979 by Gibson [7]. Many researches have been conducted on this subject for instance, a high gain Vivaldi array antenna with reliable structure in X-band for airborne reconnaissance and surveillance operations is presented in [8]. Vivaldi antenna on the printed circuit board and the eight-element linear antenna array has been investigated in [9]. The antenna array is providing a broadband input matching in all X-band and broad-angle beam scanning up to 48 degrees from the normal position. In another study, a back-to-back Vivaldi antenna is proposed for a novel vehicle to infrastructure communication system at X-band [10].

Two wideband Vivaldi antennas are arranged in a back-to-back configuration to obtain high gain in both the frontal and rear directions over the entire operative band. Vivaldi

antenna is preferred for this system due to the higher directivity, wide bandwidth characteristics, high efficiency, high gain, low cost and light weight. While the maximum achievable data rate is 2 Gb/s at 60 GHz [11], in our work more than 3 Gb/s data rate has been succeeded however, the carrier frequency is at 11.2 GHz. This work presents the construction of receiver and transmitter as well as Vivaldi antenna for indoor high data rate wireless communication which is empirically demonstrated at X-band.

1.1 Significance of the Study

Short range wireless technologies are getting more significant for multiple reasons. The most import one is eradicating wires within buildings and offices. Therefore, the demand for high speed wireless technologies have sensed for decades. The significance of this study is developing a short-range high-speed wireless technology. The outcome of the research is as follows;

- The study of analog and digital communication.
- A synopsis of Indoor wireless technologies.
- Fabrication of a cost-effective suitable antenna for the system.
- Design of a radio frequency (RF) system for X-band wireless communication.

A comprehensive study has been conducted for wireless communication in the past few decades while a study affecting different factors in terms of the reliability of short-range wireless communication systems and how they can be handled is not mentioned in the literature.

1.2 Motivation

The short-range wireless communication is most appropriate and relevant subject in the last decades for two reasons first, development of solid-state appliances secondly, advancement in digital communication. In our study the fabrication of antenna for the system and combining RF components in the transmitter and receiver part of the system motivated research in its application for high data transfer. This research enables engineers

and scientists to connect devices wirelessly between few meters of distance in gigabit speed. Which removes the barrier of cabling from one point to another. The results are represented experimentally in X-band.

1.3 Scope of the Study

In this experimental work a high data rate is achieved where the receiver and transmitter antennas communicate within few hundreds of centimeters. In up to date scientific researches low power technologies with lower data rate such as Bluetooth developed by Ericsson in 1994. In this study the wireless perspective and as well as RF part of the system is being presented.

1.4 Objectives of the Study

In many building and offices, a huge junk of cables run through floor, walls and sometimes ceiling. This cabling system occupies place, our system helps to transfer data in terms of gigabits therefore, cabling loads can be reduced within buildings and offices. Nevertheless, the study objectives are as follows;

- The fabrication of appropriate antenna for the system.
- Design of transmitter of the system.
- Design of receiver of the system.
- Generation of signal in the range of 8-12 GHz.
- Analyze of the system at different modulation techniques.
- Analyze of the system at different data rates.
- Analyze of the system at different distances between transmitter and receiver.

1.5 Thesis Structure

This study is organized in five chapters; chapter one includes introduction which gives a brief background information, significance of the study, motivation, scope of the study and objectives of the study are given. Chapter two is covering general information about

wireless communication where, analog and digital communication is theoretically covered and especially indoor wireless technologies. Chapter three is talking about experimental setup in details where it shows how experimental transfer data in X-band at the same time the transmitter (Tx) and receiver (Rx) parts of the RF system is demonstrated in detail. Chapter four gives the results acquired from the experimental setup where graphs of data rate, bit error rate and distance between transmitter and receiver is analyzed. Chapter five gives the conclusion and future work for the study.

CHAPTER 2

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 Telecommunications

The word telecommunication is taken from the Greek word ‘tele’ which means ‘at a distance’ and the word ‘communication’ is meaning the science and practice of transmitting data [12]. Long before communication depended on physically transmitting messages by different human developed ways such as horseback and birds or in ocean crossing ships. It might take weeks to pass events or news from long distance areas. This challenging situation was changed by the invention of telegraph that facilitated to almost receive messages instantaneously. The invention of telegraph encouraged engineers and scientists to connect continents through Atlantic Ocean by passing cables through the floor of the ocean. However, this did not solve the problems of moving objects such as ships in the ocean because telegraph was not able to communicate with targets in motion. Also, connecting poorer or rural areas were unable to relate to telegraph wires because it was not economically possible to string wires over lengthy distances. Thus, the invention of RF waves and their rapid growth in wireless communication caused revolution in the history of wireless communication. Wireless communication soon got the leading technology of that era because wireless communication with an equalizing technology empowered extensive territory of less developed regions of the world with long distance wireless communications. When we look to the history of communication, we encounter that wireless communication goes far to the very old form – jungle sounds, and shouts did not need any wire or cable to operate and could be hear from far away. However, with the work of Maxwell and Hertz started how the signal can be transmitted wirelessly by transmission of electromagnetic waves. Short after their innovative work that Tesla showed the transmission of information via these waves [13]. In 1898, Marconi succeeded

the demonstration of wireless communication from a boat to the isle of Wight in the English Channel. Where he was prized with a Nobel prize in 1909 for the tremendous success of transmitting data wirelessly [13].

2.1.1 Electromagnetic Waves

The improvement of wireless communication is debtor to the finding of Oersted, Faraday, Gauss, Maxwell and Hertz [14]. In the past the work of magnet amazed people for many centuries, these "magic stones" could exert a force on metals and extract them from a distance. This force that was affecting other objects was called magnetic field. Also, by rubbing two bodies an electric charge can be produced this could also attract each other at a distance; this force was called electric field. In 1867, Michael Faraday has proved that the two type of fields were relative. The Faraday law demonstrates that an electric field is generated by time varying magnetic field. This can be written as follows

$$\nabla \times \mathbf{E}(r,t) = \frac{-\mu_0 \partial \mathbf{H}(r,t)}{\partial t} \tag{2.1}$$

From equation 2.1 $\mathbf{E}(r,t)$ is the electric field and $\mathbf{H}(r,t)$ is the magnetic field as a function of spatial coordinates r and t respectively. The free space permeability is given by $\mu_0 = 4\pi \times 10^{-7}$Henries/meter. Later the law of Faraday was complemented by James Clerk Maxwell and mathematically demonstrated in 1864 as follows.

$$\nabla \times \mathbf{H}(r,t) = \frac{\varepsilon_0 \partial \mathbf{E}(r,t)}{\partial t} \tag{2.2}$$

Where ε_0 is permittivity constant of free space given by $\varepsilon_0 = 8.854 \times 10^{-12}$ farads/meter. by combining of equation (2.1) and (2.2) a second order equation is obtained in either **E** or **H.**

$$\nabla^2 \mathbf{E}(r,t) - c^{-2} \partial^2 \mathbf{E}(r,t)/\partial t^2 = 0 \tag{2.3}$$

Where $c = 2.998 \times 10^8$ meters/second.

Solving the equation (2.3) in form for the plane wave case where $\mathbf{E}(r,t) = E(z,t)a_x$ in this case equation (2.3) is

$$\mathbf{E}(r,t) = \mathrm{E}_1 \cos(\omega[t - z\,/\,c] + \theta_1)a_x$$

and

$$\mathbf{H}(r,t) = (\mathrm{E}_1\,/\,Z_0)\cos(\omega[t - z\,/\,c] + \theta_1)a_y \qquad (2.4a)$$

or

$$\mathbf{E}(r,t) = \mathrm{E}_2 \cos(\omega[t - z\,/\,c] + \theta_2)a_x$$

and

$$\mathbf{H}(r,t) = -(\mathrm{E}_2\,/\,Z_0)\cos(\omega[t - z\,/\,c] + \theta_2)a_y \qquad (2.4b)$$

From equation (2.4b) $Z_0 = 120\pi = 377\Omega$ is free space wave impedance. Where $\mathrm{E}_{1,2}$ and $\theta_{1,2}$ are electric field amplitudes and phases respectively, and ω is wave angular frequency.

The equation (2.4) describes the waves propagating in either the positive or negative z directions. The wave is propagating through free space at the speed of visible light 2.998×10^8 m/s where the electric and magnetic fields are perpendicular to each other.

The Maxwell equation (2.4) was greater prediction for the existence of electromagnetic waves. RF waves is a term to determine electromagnetic waves over the frequency range 30 kHz to 300 GHz. Where radio waves range from 30 kHz to 300 MHz and microwaves range from 300 MHz to 300 GHz with the subset of microwaves (30 GHz to 300 GHz) being determined as millimeter waves A more decent subdivision of the RF spectral range are shown in table 2.1. The microwave ultra-high frequency (UHF) and super-high (SHF) and millimeter wave extremely high frequency (EHF) parts of the spectrum are subdivided into even smaller parts suitable to standard waveguide sizes with the frequency bands determined by alphabetic letters. It is worth mentioning, the microwave and millimeter-

wave frequency bands are defined by the Radio Society of Great Britain as shown in table 2.2 [15].

Table 2.1 The radio frequency spectrum [15]

Band Designation	Communications Application	Frequency	Wavelength
Super-low frequency (SLF)	Submarine communications	30 – 300 Hz	100 - 1000 km
Ultra-low frequency (ULF)	Audio signal modulation	0.3 - 3 kHz	10 - 100 km
Very low frequency (VLF)	Navigation and position location	3 - 30 kHz	1 - 10 km
Low frequency (LF)	Weather broadcast station	30 – 300 kHz	0.1 – 1 km
Medium frequency (MF)	AM radio, “ground wave”	0.3 – 3 MHz	10 – 100 m
High frequency (HF)	Shortwave radio “sky wave”	3 – 30 MHz	1 – 10 m
Very high frequency (VHF)	FM radio, TV, mobile radio, air traffic	30 – 300 MHz	0.1 – 1 m

Ultra-high frequency (UHF)	UHF-TV, cellular phones, local area networks (LNA), SATCOM, global positioning systems (GPSs)	0.3 – 3 GHz	10 – 100 cm
Super-high frequency (SHF)	Radar, SATCOM	3 – 30 GHz	1 – 10 cm
Extremely high frequency (EHF)	Military radar and SATCOM	30-300 GHz	1 – 10 mm
Sub-millimeter		0.3 – 3 THz	0.1 – 1 mm
Far infrared		3 – 30 THz	10 – 100 μm

Note: kHz = 10^3 Hz, MHz = 10^6 Hz, GHz = 10^9 Hz, THz = 10^{12} Hz.

Table 2.2 Microwave and millimeter-wave waveguide bands [15]

Band Designation	Frequency Range
L-Band	1- 2 GHz
S-Band	2 – 4 GHz
C-Band	4 – 8 GHz

X-Band	8 – 12 GHz
Ku-Band	12 – 18 GHz
K-Band	18 – 26.5 GHz
Ka-Band	26.5 – 40 GHz
Q-Band	30 – 50 GHz
U-Band	40 – 60 GHz
V-Band	50 – 75 GHz
E-Band	60 – 90 GHz
W-Band	75 – 110 GHz
F-Band	90 – 140 GHz
D-Band	110 – 170 GHz

In this study we are concerned about X-Band.

2.2 Analog and Digital Communication

The sample description of communication systems: engaging electrical signals to transmit information from one place to another. Many gadgets in our live somehow uses wireless technology from our cell phones to radios and televisions. In this section, analog and digital communication is taken to consideration. In analog communication the message signal is transmitted in analog form. This analog signal is generated by speech, video and audio where this signal is modulated to higher frequency inside transmitter and is being transmitted via transmitting antenna in order to travel over the channel. However, in digital communication the message signal is transmitted in digital form. Where in transmitter digital methods of data modulation is used and the modulated signal is sent through channel via transmitting antenna.

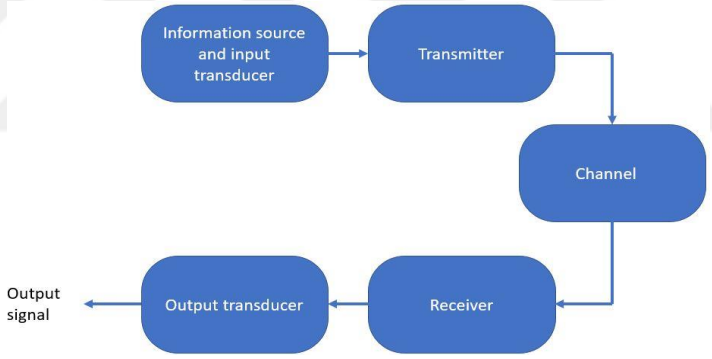


Figure 2.1 Functional diagram of a communication system.

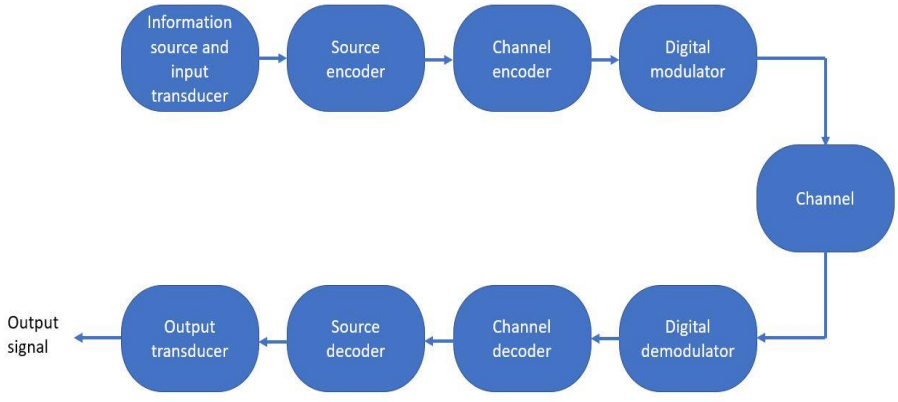


Figure 2.2 Basic elements of a digital communication system.

2.2.1 Amplitude Modulation

Amplitude modulation (AM) is an analog modulation technique where the amplitude of the carrier signal is modulated by message signal. Let's denote the message signal as $m(t)$ and the sinusoidal carrier as $A_c \cos(2\pi f_c t)$, by the multiplication of carrier signal and message signal:

$$x(t) = m(t)\, A_c \cos(2\pi f_c t) \tag{2.5}$$

If the message signal is a single harmonic at f_m with A_m amplitude

$$m(t) = A_m \cos 2\pi f_m t \tag{2.6}$$

Substituting (2.6) into (2.5) results in

$$x(t) = A_c A_m \cos(2\pi f_m t) \cos(2\pi f_c t)$$

$$= \underbrace{\frac{A_c A_m}{2} \cos(2\pi(f_c - f_m)t)}_{\text{Lower sideband}} + \underbrace{\frac{A_c A_m}{2} \cos(2\pi(f_c + f_m)t)}_{\text{Upper sideband}} \tag{2.7}$$

The obtained signal in equation (2.7) has two frequency bands on both sides of the carrier frequency f_c . The lower sideband is below the carrier and the upper sideband is above the carrier [17].

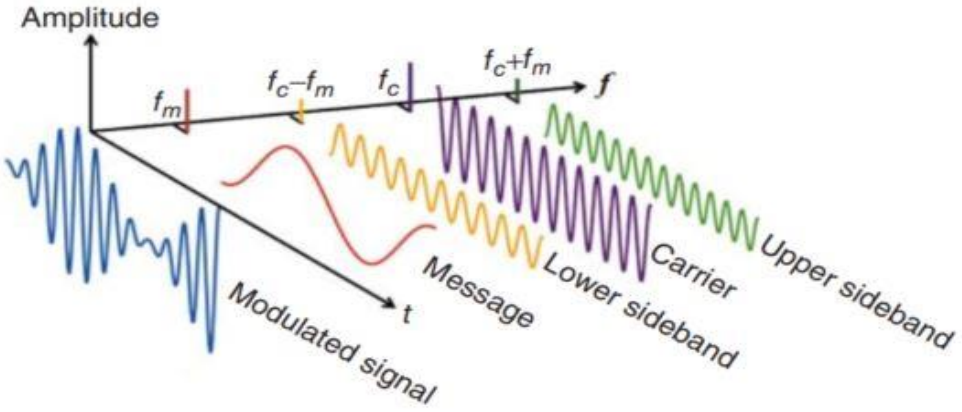


Figure 2.3 Time frequency plot of an AM signal componenets [17].

2.2.2 Frequency Modulation

In frequency modulation (FM) the frequency of the carrier signal is varied proportional to the message signal. The voltage waveform of frequency modulation signal looks like

$$x(t) = A_c \cos\left[2\pi f_c t + 2\pi\Delta f \int_0^t m(\tau)d\tau\right] \tag{2.8}$$

In equation (2.8) Δf is the maximum frequency divergence from f_c. The $m(t)$ is a single harmonic at f_m.

$$m(t) = A_m \cos 2\pi f_m t \tag{2.9}$$

By substituting $m(t)$ to (2.8) and integration yields

$$x(t) = A_c \cos[2\pi f_c t + \beta_{FM} \sin(2\pi f_m t)] \tag{2.10}$$

Where the FM modulation index is

$$\beta_{FM} = \frac{\Delta f}{f_m}$$

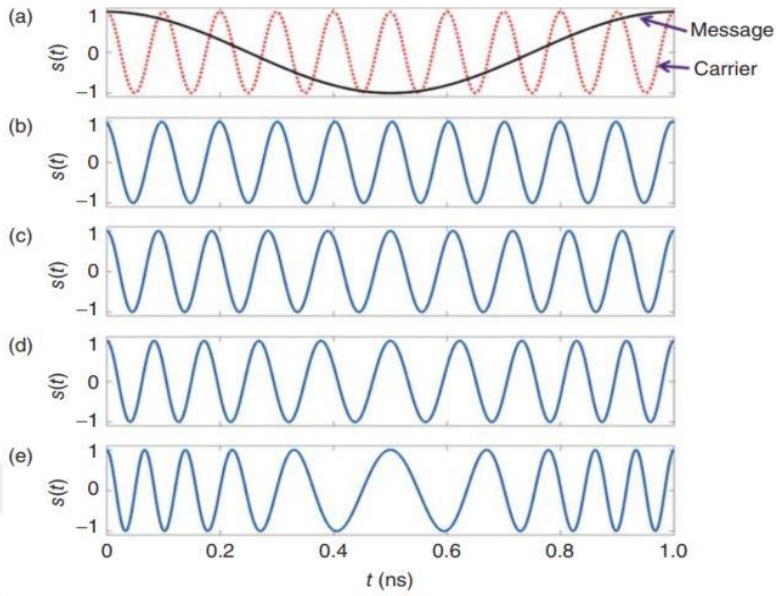


Figure 2.4 FM modulation with f_c = 10 GHz and f_m= 1 GHz (a) message signal superimposed on carrier, (b) β_{FM} = 0.2, (c) β_{FM} = 1.0, (d) β_{FM} = 2.0, and (e) β_{FM} = 5.0. [17].

2.2.3 Phase Modulation

Phase modulation (PM) is a modulation technique where the carrier signal phase is varied as per amplitude variation of message signal.

$$x(t) = \ A_c \cos[2\pi f_c t + \beta_{PM} m(t)] \tag{2.11}$$

Where message signal is $m(t)$

$$m(t) = A_m \cos 2\pi f_m t \tag{2.12}$$

Where β_{PM} $\left(\frac{rad}{v}\right)$, the PM index, equals the peak phase deviation and $\beta_{PM} \propto A_m$. Note that (2.8) and (2.11) look very similar. FM falls into the PM category. Carson's rule also gives the bandwidth for P signals as [17].

$$B = 2(\beta_{PM} + 1) f_m \tag{2.13}$$

In figure 2.5, the message singal contains useful information the carrier signal with higher frequency than message signal is modulated by message signal.

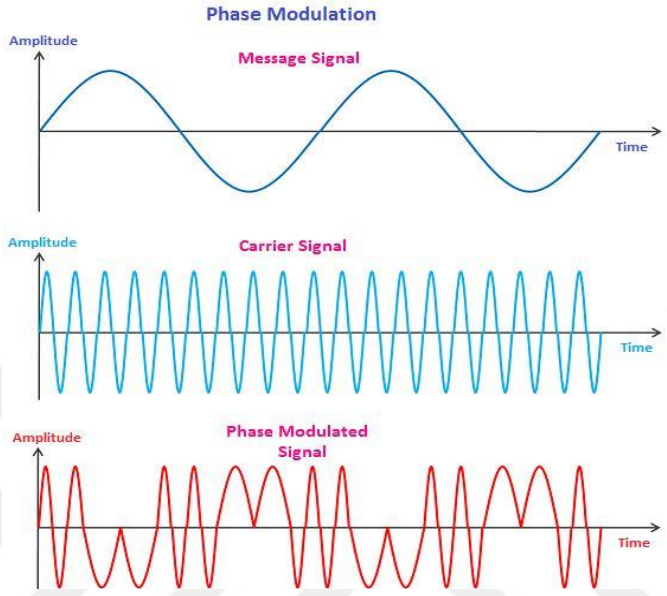


Figure 2.5 Phase modulation [18].

2.2.4 Signals and Bits

Data contains facts which gives information about someone or something. Data is sent by a person to another person or machine to another machine through a communication system. Data transmitted through a communication channel is known to the receiver if the transmitter and receiver understand what the transmitted symbols represent. When the transmitted signal or message is corrupted then the receiver cannot interpret the message.

2.2.4.1 Baseband

In baseband communication system the users share a single channel. As a result of transmitting a message on the channel the entire bandwidth of the channel is occupied by a single user hence, nobody else can use the channel. The signal is placed on the medium without using a high frequency carrier signal as depicted in figure 2.6. In analog signals, such as on an ordinary telephone, the signal is transmitted without modulation or encoding

technique. On the other hand, in digital communication the data (0's and 1's) are encoded as positive and negative voltages.

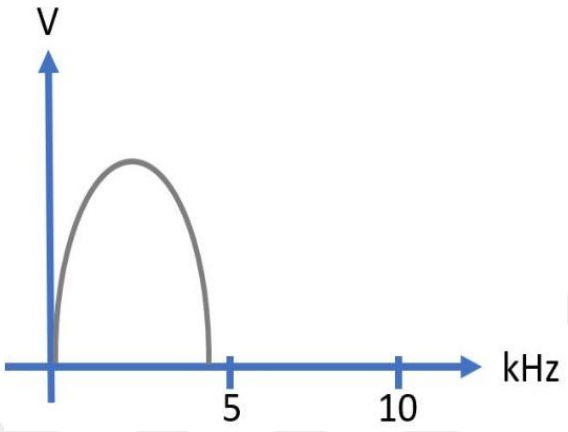


Figure 2.6 Baseband signal.

The advantage of baseband is the simple structure of the system. Less complex modulation and demodulation apparatus are required. On the down-conversion side the signal power should be large enough to be detected by a line receiver. For digital system, let's say at 10 Mbps speed this might limit the distance to maybe few hundred meters. The most significant drawback in baseband communication is; that only one signal can be transmitted at a specific time [12].

2.2.4.2 Broadband

In contrast to baseband, broadband can transmit multiple signals simultaneously over common channel as shown in figure 2.7. This system is achieved by using frequency division multiplexing where systems transmit data using copper or radio or wave division multiplexing where system transmit data using fiber optics. The channel transmit data at different frequencies or wavelengths. Different input signals are utilized to modulate their corresponding carrier signals, for example FM and AM. These modulated carriers are merged and sent across the channel as one mixed signal. Irrespective of digital input the result is still a modulated analog signal. A band-pass filter is used to extract the signal at

the receiving end and the information is retrieved via suitable demodulator or discriminator.

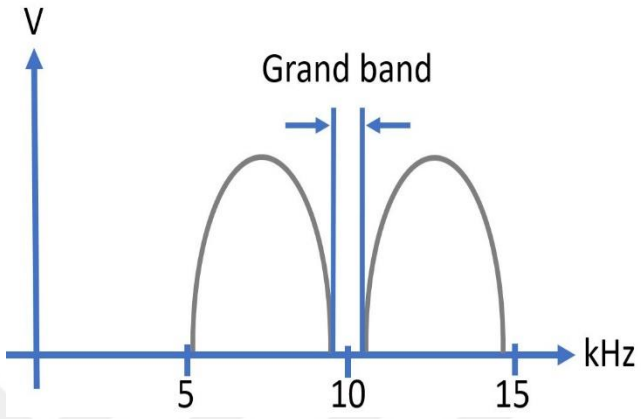


Figure 2.7 Broadband signal.

The benefit of broadband transmission is that multiple channel of data can be sent through a single physical medium. In contrast to baseband, it is possible to retrieve the original signal from very low received signal power, even as low as picovolt range. In opposite to baseband, broadband signals can be sent to millions of kilometers. The drawback of broadband is that it utilizes a more complex circuitry in receiving side compared to baseband system [12].

2.2.4.3 Narrowband

A narrowband system is a system where it uses a small bandwidth. The following systems can be categorized as narrowband:

- Links designed to join teletypewriter with a 300 Hz bandwidth.
- A plain old telephone system (POTS) with 3 kHz bandwidth. With the aid of modems, they can carry data at speeds up to 56 kbps.
- Narrow band integrated services digital networks (ISDN) with two channels for voice or data, at 64 kbps each.
- A digital voice channel with a bandwidth of between 64 kbps and 1.54 Mbps [12].

2.2.4.4 Wideband

Wideband is a communication system that uses a wider portion of the spectrum. In contrast to narrowband wideband communication is used with its greater data capabilities such as for video streaming and surveillance. Narrowband signals occupy much less frequency spectrum and require less transmit power for a given application than wideband signals, while ultra-wideband (U-WB) signals are short pulses that send information while briefly occupying a large portion of the traditional communications frequency spectrum as shown in figure 2.8 [19].

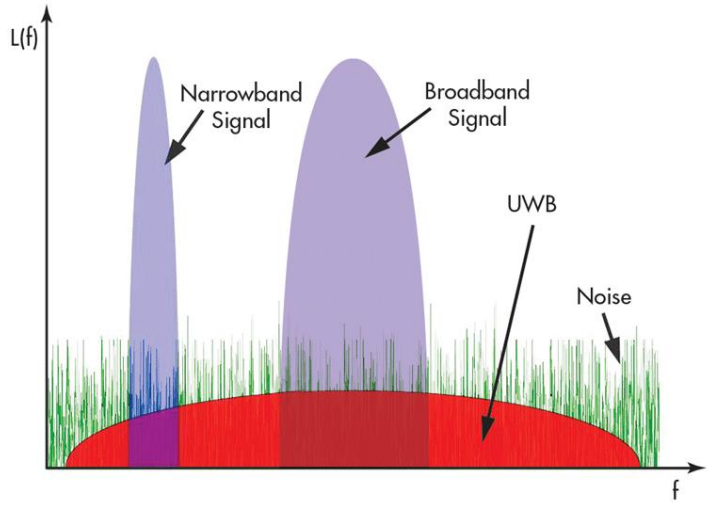


Figure 2.8 Broadband, narrowaband and ultra-wideband signals [19].

As a result, typically higher transmit signal power is needed in a wideband channel to overcome the noise level—as well as other factors, such as signal propagation losses—so that a significant signal level will appear at the receiver and meet the receiver's minimum signal-to-noise-ratio (SNR) performance requirements for reception and processing [19].

2.2.5 Sampling Process

The sampling process is generally, if not exclusively, designated in the time domain. It is a process which is particularly a basic in digital signal processing (DSP) and digital communications. An analog signal is transferred into a corresponding series of samples

that are generally separated uniformly in time. However, for this procedure the sampling rate should be chosen appropriately so that the original analog signal should be recovered from the sequence.

Let's consider an arbitrary signal $g(t)$, that is specified for all time t. A portion of the signal $g(t)$ is depicted in figure 2.9 (a). Assume we sample the signal instantaneously and at a uniform rate, once at every T_s second. An infinite number of samples spaced at T_s will be obtained which are denoted by $\{g(nT_s)\}$, where n can take all possible positive and negative integer values. T_s is referred as sampling interval where $f_s = \frac{1}{T_s}$ is the sampling rate. If $g_\delta(t)$ denote the signal acquired by separately weighting the elements of a periodic series of Dirac delta functions spaced T_s seconds apart by the series of numbers $\{g(nT_s)\}$, as depicted in figure 2.9 (b) [20].

$$g_\delta(t) = \sum_{n=-\infty}^{\infty} g(nT_s)\delta(t - nT_s) \tag{2.14}$$

$g_\delta(t)$ is called instantaneously sampled signal. In equation (2.14) the term $\delta(t - nT_s)$ represents a delta function stationed at time $t = nT_s$. From the description of delta function, recall that such a function has a unit area. The multiplying factor $g(nT_s)$ in equation (2.14) as a mass assigned to the delta function $\delta(t - nT_s)$. The delta function weighted in this manner is closely estimated by a rectangular pulse of duration Δt with an amplitude of $\frac{g(nT_s)}{\Delta t}$; the smaller the Δt gets the better the approximation will be [20].

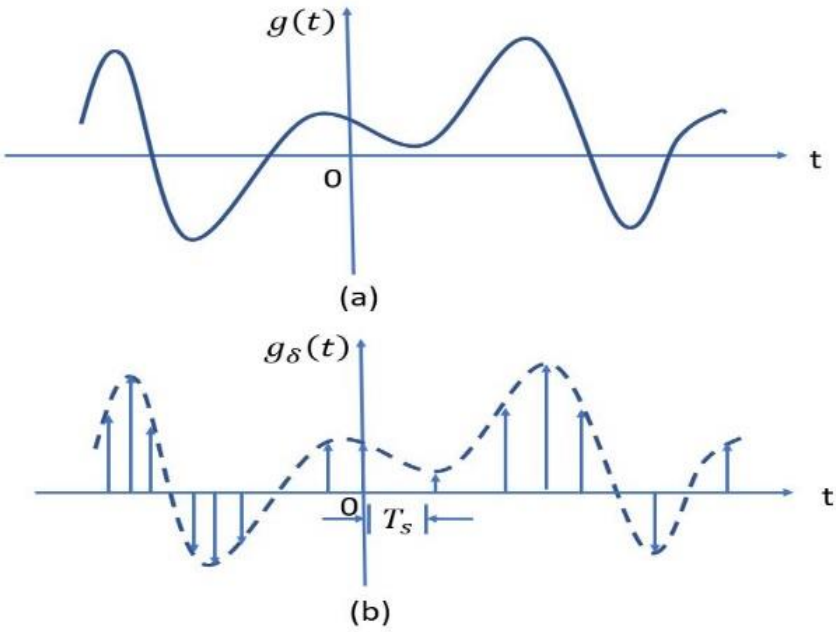


Figure 2.9 Illustration of the sampling process. (a) Analog waveform $g(t)$. (b) Instantaneously sampled representation of $g(t)$.

2.2.6 Analog to Digital Conversion

Analog to digital conversion (ADC) has been exits in almost all technological devices around us. In all electronic devices the analog to digital converters connect our physical world to digital computing machines. Converting an analog signal to a sequence of 1's and 0's (digital signal) requires a sampling procedure where an ADC samples the analog signal at a rate faster than the highest frequency, to be precise it should be sampled at least two times the highest frequency of the analog signal. The ADC output has N_{bits} which specifies the quantized voltage levels.

$$N_{lev} = 2^{N_{bits}} \tag{2.15}$$

The samples fall into one of the quantized voltage levels represented by N_{bits} bits. A 10-bit ADC guide to $N_{lev} = 1024$. The dynamic range of ADC's widen from the minimum detectable voltage (V_{ADCmin}) to the maximum voltage (V_{ADCmax}). ADC input voltage resolution assign the ADC sensitivity of the analog signal [17].

$$V_{ADCresolution} = \frac{V_{ADCmax} - V_{ADCmin}}{N_{lev}} \tag{2.16}$$

The ADC output bits for the input voltages between $V_{ADCmin} = 0$ to $V_{ADCmax} = V_{max}$ is depicted in figure 2.10. The least significant bit (LSB) is modified in the binary sequence by the minimum change in voltage. In practice the noise distorts the theoretical resolution of the ADC therefore, the effective number of bits (ENOB) determines the ADC resolution in practice with $N_{bits} \geq ENOB$ [17].

$$ENOB = \frac{\text{SINAD} - 1.76}{6.02} dB \tag{2.17}$$

Signal to noise and distortion (SINAD) is total power ratio: where signal is P_s, noise is P_N and distortion is P_D. The unwanted power is

$$SINAD = 10 \log\left(\frac{P_s + P_N + P_D}{P_N + P_D}\right) \tag{2.18}$$

The SINAD shows the ADC dynamic performance, because it contains all components of noise and distortion.

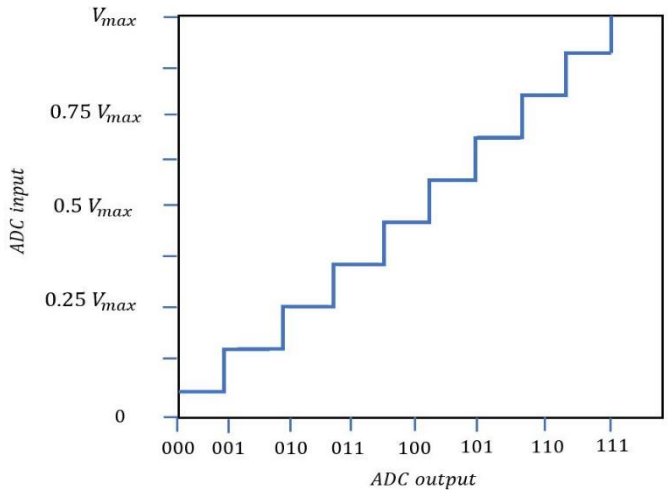


Figure 2.10 The bits assigned to the quantization levels [17].

Quantization error is the rounding error between the analog input voltage and the quantized output voltage corresponding to the bits. The signal to noise ratio (SNR) "6 dB rule" assumes a uniformly distributed quantization error between -1/2 LSB and +1/2 LSB [17]:

$$SNR = 20\log(2^{N_{bits}}) \approx 6.02N_{bits}dB \tag{2.19}$$

2.2.7 Introduction to Digital Modulation

The modern wireless communication uses digital modulation techniques because digital systems accomplish better spectral efficiency with better noise and fade-rejection capability and require less transmit power compared to analog systems. In addition to this, digital systems have the ability of error correction and encryption rather than analog systems. The digital systems have similar modulation techniques as analog systems that, amplitude, frequency and phase of the carrier signal is modulated via digital data. The tree basic digital modulation techniques are amplitude shift keying (ASK), frequency shift keying (FSK) and phase shift keying (PSK) [21].

2.2.7.1 Amplitude Shift Keying

Amplitude shift keying (ASK) is a modulation technique where data signal modulates the amplitude of the carrier signal. In straightforward ASK modulation technique, the presence of the carrier signal is showing a "1" and its absence that shows "0". One of the most common digital modulation techniques: binary amplitude shift keying (BASK) is one of the earliest types of digital modulation utilized in radio telegraphy at the beginning of the 20th century. Let's consider $b(t)$ as a binary bit steam

$$b(t) = \begin{cases} \sqrt{\mathrm{E}_b}, & for\ binary\ symbol\ 1 \\ 0, & for\ binary\ symbol\ 0 \end{cases} \tag{2.20}$$

$$V_c = \sqrt{\frac{2}{T_b}} \tag{2.21}$$

$$c(t) = V_c \cos(2\pi f_c t + \phi_c) \tag{2.22}$$

Multiplication of $b(t)$ with the carrier signal equation (2.22) we get the BASK wave

$$s(t) = \begin{cases} \sqrt{\dfrac{2E_b}{T_b}} \cos(2\pi f_c t + \phi_c), & for\ symbol\ 1 \\ 0, & for\ symbol\ 0 \end{cases} \tag{2.23}$$

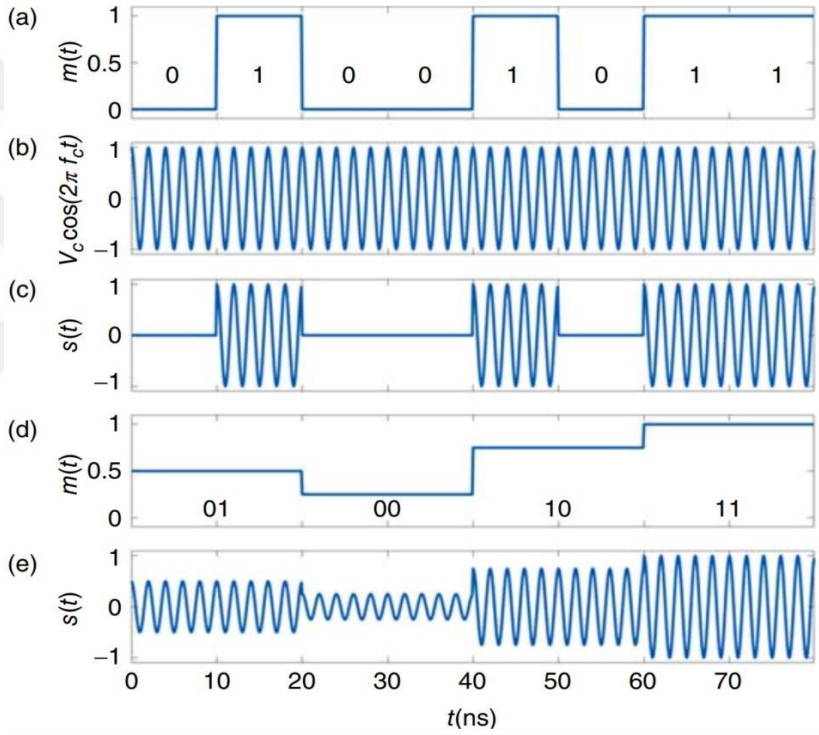


Figure 2.11 ASK modulation. (a) 8 bits, (b) carrier, (c) OOK, (d) symbols with 2 bits, and (e) 4-ASK [17].

figure 2.11a shows a bit stream multiplied with the carrier in figure 2.11b results to ASK depicted in figure 2.11c. M-ASK modulation utilizes $M = 2^{N_{bits}}$ amplitude levels to represent symbols which have N_{bits} bits. Different symbols can also be presented with different data levels showed in figure 2.11d where this can be multiplied by the carrier signal to get the 4-ASK signal depicted in figure 2.11e. The benefit of AM is simple and cheap, and the drawback is low power efficiency, lower bandwidth and higher sensitivity to noise.

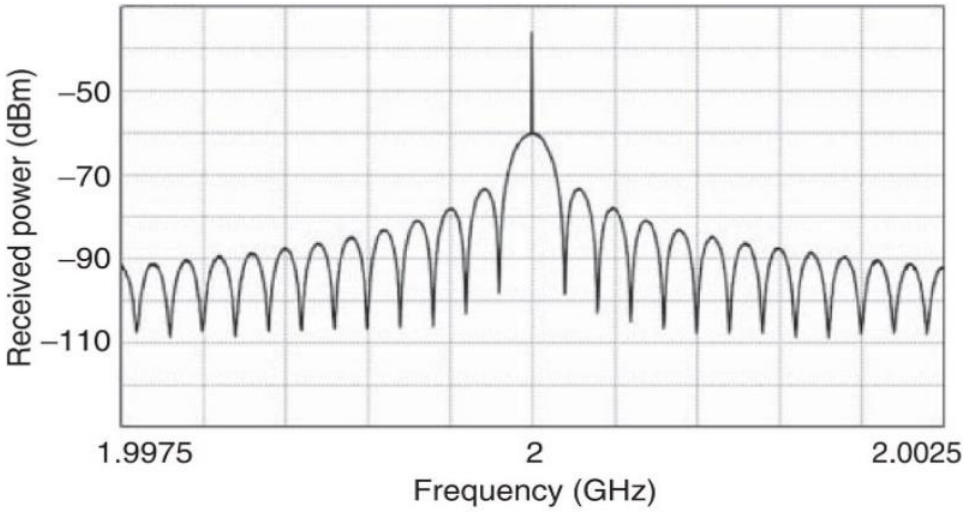


Figure 2.12 Spectrum of BASK with a carrier frequency of 2 GHz and a symbol rate of 200 kbps [17].

2.2.7.2 Frequency Shift Keying

Digital FM or frequency shift keying (FSK) is another digital modulation technique where its suitable for channels that lack phase stability. In coherent detection that is used in linear modulation techniques phase estimation is significant. However, in non-linear modulation techniques such as FSK, it takes a higher bandwidth than the amplitude and phase modulations do. Binary frequency shift keying (BFSK) has two signals with different frequencies.

$$S_1(t) = A_c \cos(2\pi f_1 t) \tag{2.24}$$

$$S_2(t) = A_c \cos(2\pi f_2 t) \tag{2.25}$$

In equation (2.24) the signal is for binary "1" and in equation (2.25) the signal is for binary "0".

Where $f_1 = f_c + \Delta f$ and $f_2 = f_c - \Delta f$. A bit stream of 01001011 with $1\mu s$ bit duration is depicted in figure 2.13.

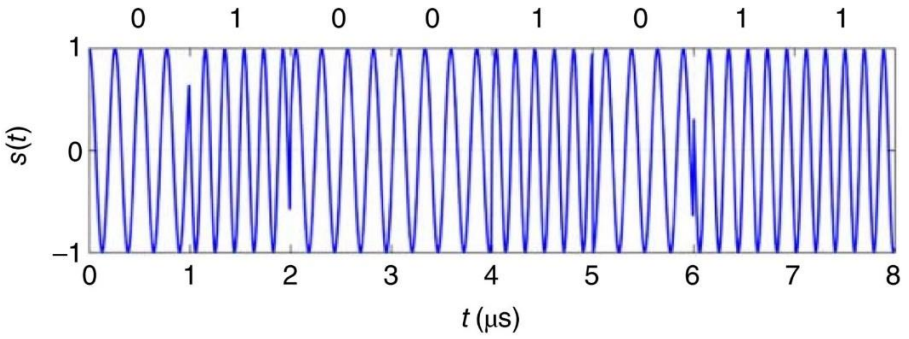


Figure 2.13 Binary phase shift keying signal [17].

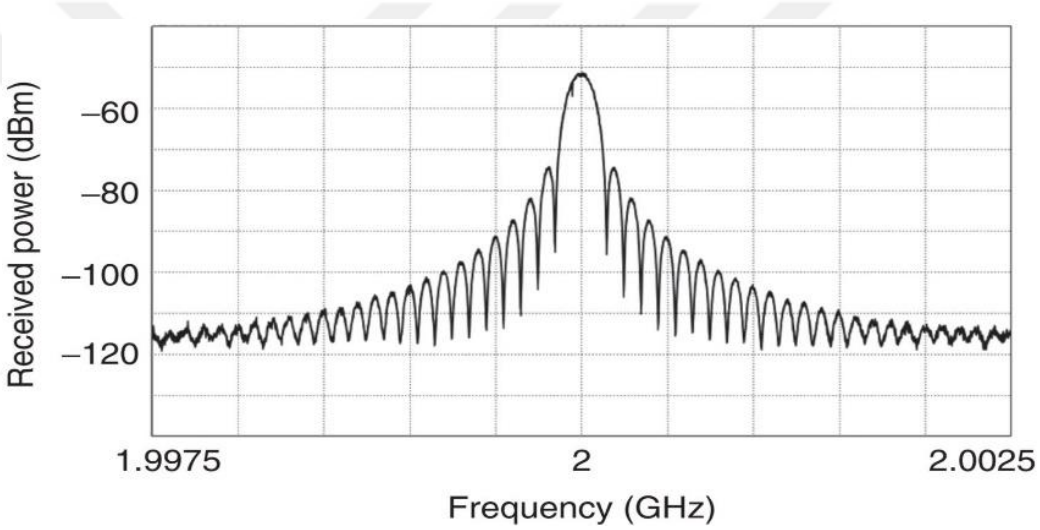


Figure 2.14 Spectrum of an FSK with a carrier frequency of 2 GHz and symbol rate of 200 kbps [17].

Figure 2.14 demonstrates the power acquired as a function of frequency for 2 GHz FSK signal where the symbol rate is 200 kbps. The advantage of FSK is that noise do not distort the frequency of the signal and it degrades the amplitude of the signal hence, FM is more advantageous than AM. The drawback of FM is that it has a more complicated circuits for modulation and demodulation.

2.2.7.3 Phase Shift Keying

Phase shift keying is a digital modulation technique where its extensively used in communication systems in the industry. PSK is a technique that conduct data by modulating the phase of the carrier signal. In binary phase shift keying (BPSK) the data

signal is generated between minus and plus value where this changes the phase of the carrier signal by 0 and π. The signals are

$$s_1(t) = A\cos(2\pi f_c t)\ , \qquad 0 \le t \le T, \qquad \text{for "1"}$$

$$s_2(t) = -A\cos(2\pi f_c t)\ , \qquad 0 \le t \le T, \qquad \text{for "0"} \qquad (2.26)$$

The signals in equation (2.26) are called antipodal. These signals have the same frequency and energy. The constellation diagram of the BPSK is

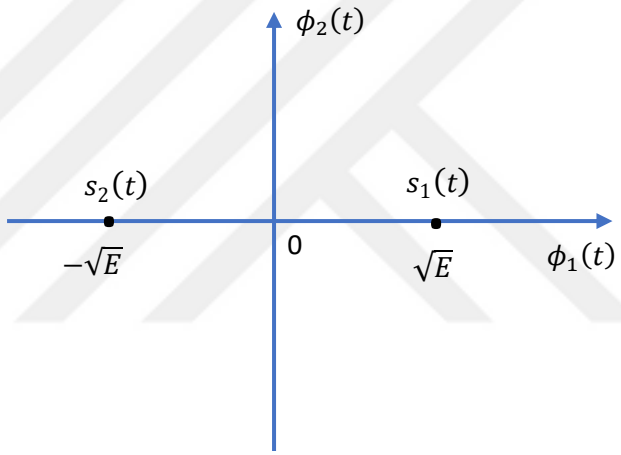


Figure 2.15 BPSK signal constellation.

All BPSK signals can be expressed by a signal constellation in a 2-dimensional coordinate system with

$$\phi_1(t) = \sqrt{\frac{2}{T}}\cos(2\pi f_c t)\,, \qquad 0 \le t \le T \qquad (2.27)$$

and

$$\phi_2(t) = -\sqrt{\frac{2}{T}}\cos(2\pi f_c t)\,, \qquad 0 \le t \le T \qquad (2.28)$$

The example of an 8-bit BPSK signal is depicted in figure 2.16. the phase change doesn't occur when the consecutive bits remain the same. Symbol samples are displayed in the real-imaginary or in phase-quadrature (IQ) plane by constellation diagram. Measured constellation and eye diagram plots for BPSK is depicted in figure 2.17. The eye minifies as signal-to-noise ratio (SNR) decreases with respect to the noise. As the signal energy decreases for the constant noise in the system, the ellipses increase in size to a limit where it overlaps. Therefore, the symbols get inconvenient to be differentiated. In quadrature phase shift keying (QPSK) symbols having 2 bits are mapped into four unique carrier phases [17]. Where these are given as

$$s(t) = \begin{cases} A_c \cos(2\pi f_c t - 45^o) & for\ 00 \\ A_c \cos(2\pi f_c t - 135^o) & for\ "01" \\ A_c \cos(2\pi f_c t - 315^o) & for\ "10" \\ A_c \cos(2\pi f_c t - 225^o) & for\ "11" \end{cases} \tag{2.29}$$

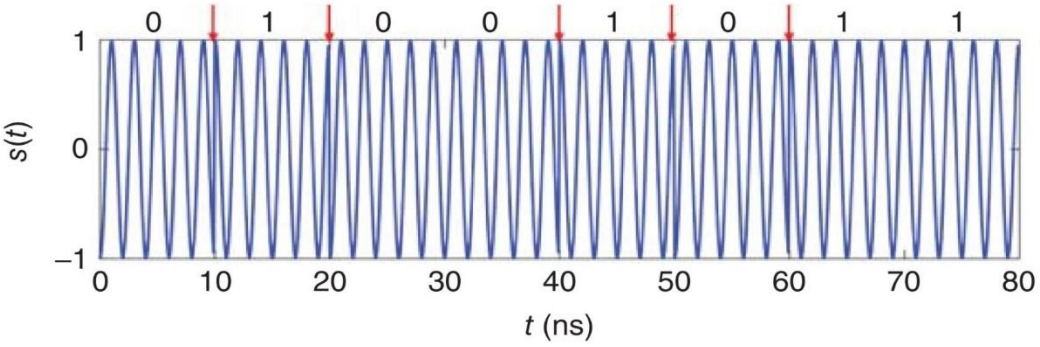


Figure 2.16 BPSK where the 2-bit values are 180◦ out of phase [17].

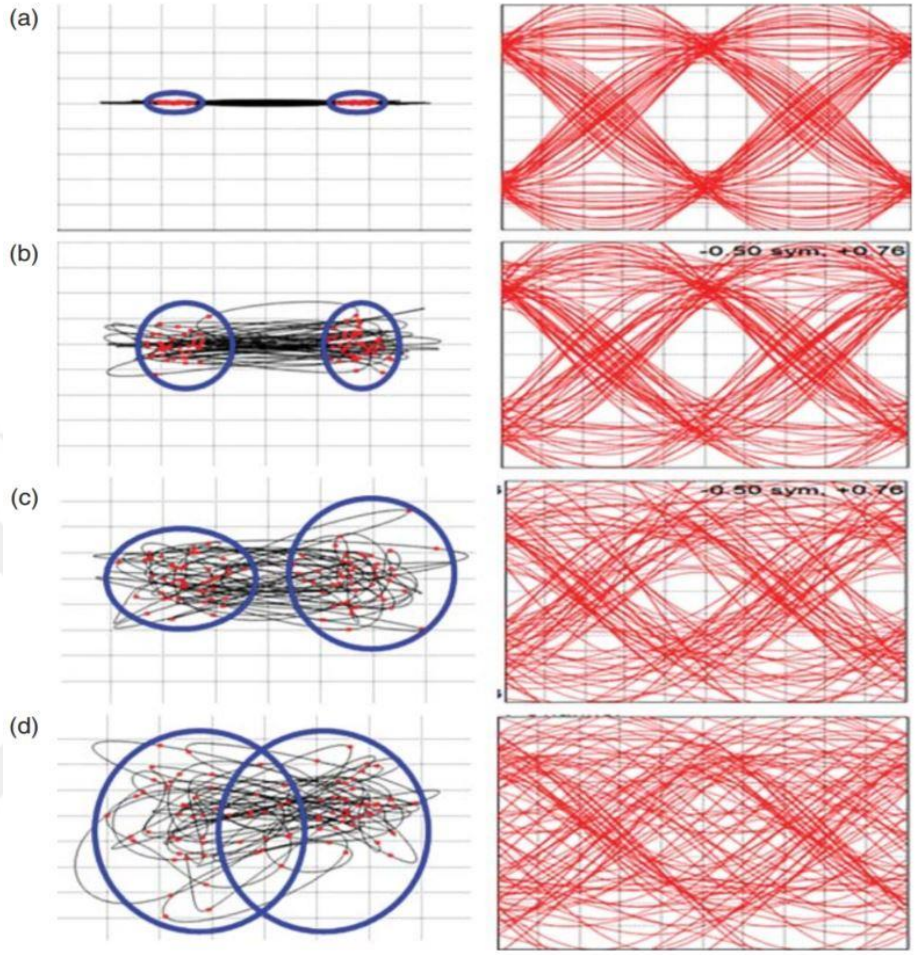


Figure 2.17 Constellation plot on the left and eye diagram on the right for BPSK as the transmitted signal SNR level decreases a) 10 dBm, b) -35 dBm, c) -40 dBm d) -43 dBm [17].

By using the following trigonometric identity

$$\cos(x + y) = \cos x \cos y - \sin x \sin y \tag{2.30}$$

Becomes,

$$s(t) = \begin{cases} 0.707A_c[\cos(2\pi f_c t) + \sin(2\pi f_c t)] \quad for\ 00 \\ 0.707A_c[-\cos(2\pi f_c t) + \sin(2\pi f_c t)] for\ 01 \\ 0.707A_c[\cos(2\pi f_c t) - \sin(2\pi f_c t)] \quad for\ 10 \\ 0.707A_c[-\cos(2\pi f_c t) - \sin(2\pi f_c t)] for\ 11 \end{cases} \tag{2.31}$$

2.3 Short Range Wireless Technologies

Short range or indoor wireless technologies have significant role in providing wireless connection within a building or a local area. Short range communications enable the data transfer from few millimeters to a couple hundreds of meters. The mobile usage is around 70% inside buildings and there are some predicts that 90% of the mobiles will be used inside the buildings for indoor communication purposes.

2.3.1 Cellular

The cellular concept has revolutionized the developments in communication industry in recent decades. The concept of cost-effective portable device for having conversation was possible since the invention of fixed telephony and other wired communication systems. With the increase of data rate in wireless communication systems its feasible to transfer data by utilizing the spectrum more efficiently. The main objective of cellular communication was to deliver information with enough signal strength within a geographical region. As voice was the main issue of communication through cellular networks this seemed enough for few years. However, massive facilities need higher data rates such as airports and shopping centers. In the years around 1950s a system called base transceiver station (BTS) was used to provide services to the users within a specified area, able to radiate enough power to illuminate this area. However, this had a problem because of the limited capacity and the number of users were restricted as well. This restriction motivated scientists to develop the concept of frequency reuse [23].

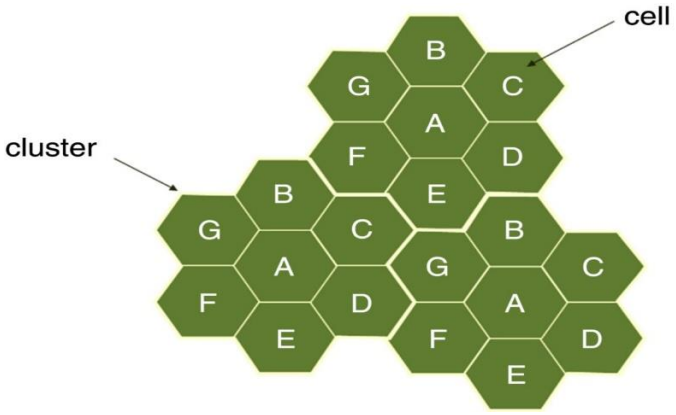


Figure 2.18 Frequency reuse [23].

The main purpose of frequency reuse is the division of the radio access network into overlapping cells as shown in figure 2.18. By giving services to more user the cluster of frequencies can be used for a specified area, aiming to minimize the level of interference. The cluster can be reused with seven cells from (A-G) each having different channels as depicted in figure 2.18. In cellular communication two types of cells configuration is considered. Omnidirectional cell is a cell where the base station (BS) is shown at the middle of the cell and omnidirectional antennas are utilized as depicted in figure 2.19a. In the second cell configuration called sector; the BS is located on three of the six cell vertices, as depicted in figure 2.18b. The BS is depicted in figure 2.20 where it's like the three or six cell sectors which are used in cellular networks [23].

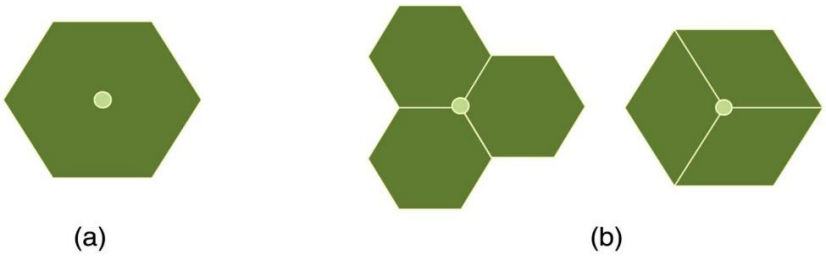


Figure 2.19 Cell configuration: (a) omnidirectional (b) sector [23].



Figure 2.20 Cellular base station [23].

2.3.2 Wi-Fi

Wi-Fi uses the same concept as wireless communication that receive and send digital signals. The abbreviation Wi-Fi was first developed by the Wi-Fi Alliance where its technical name is IEEE 802.11. The technology relies on the transmission and reception of radio waves in frequency of Gigahertz range. The converted data is either send or received by the router or adapter as Wi-Fi radio waves. The received encoded radio signal is decoded in the original data by the router or adapter. The wireless local area networks (WLANs) is around for many year, its developed from low data rates to more advance and powerful protocols as depicted in figure 2.21.

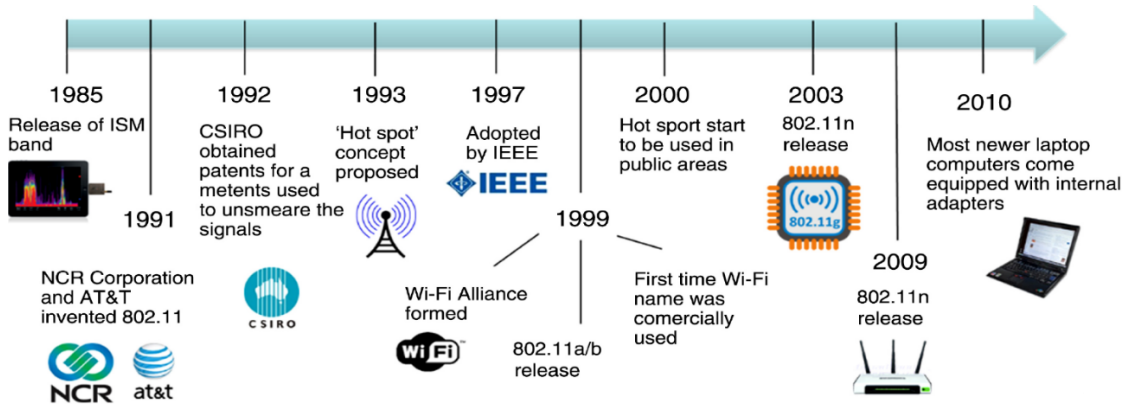


Figure 2.21 History of Wireless Local Area Networks (WLAN) [23].

Wi-Fi utilizes different frequencies in the range of 2.4 GHz, 3.6 GHz and 5 GHz. These frequencies are produced and maintained by IEEE LAN/MAN standards committee (IEEE 802).



Figure 2.22 Generic Wi-Fi block diagram [23].

2.4 Radio Propagation

The radio waves are introduced by the British physicist James Clerk Maxwell in 1873. Where he defined the nature of electromagnetic field in terms of space and time. Maxwell described the propagation of radio wave in free space. At the same time, he explained the variation of electric and magnetic fields in conducting and insulating materials and waveguides conduct he waves [24].

2.4.1 Free Space Propagation

The free propagation is considered as signal propagation in a vacuum with zero barriers. The satellite communication has also face to some obstacles such as reflections and diffraction from the satellite and ground. The line of sight (LOS) communication in figure 2.23 has lower number of barriers. However, for antennas in free space the received power is shown by Friis transmission formula

$$P_r = \frac{P_t G_t A_e}{4\pi R^2} \tag{2.32}$$

This formula in equation 2.32 is considered as the fundamental model for a communication link [25].

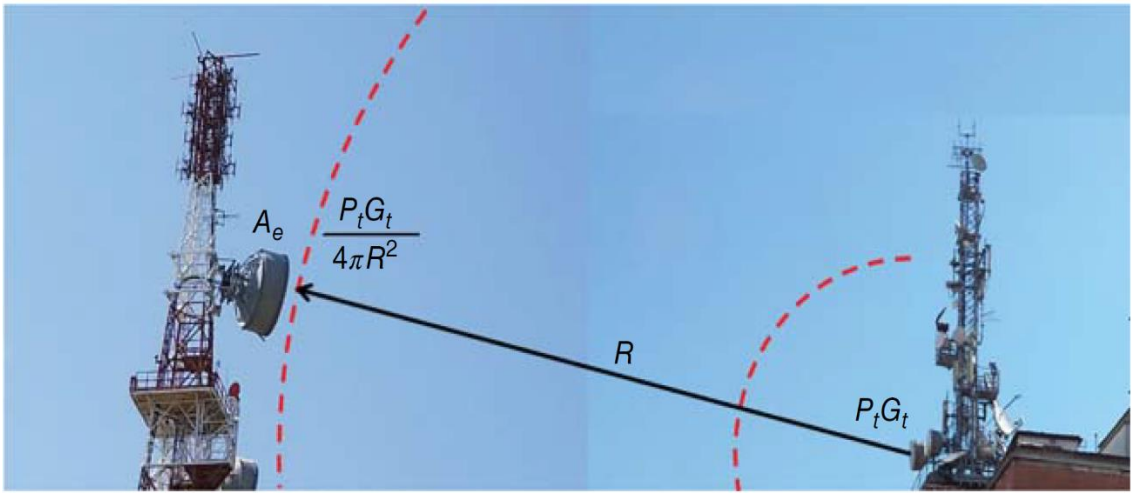


Figure 2.23 Friis transmission formula [17].

2.4.2 Loss and Skin Effect

The medium has a huge impact on the amplitude of the wave where it travels. With the significant conductivity of the medium the amplitude of the wave decreases as it travels by a specific distance. The constitutive parameters of the materials effect wave. As the wave travel in the medium the field strength decreases exponentially as depicted in figure 2.24 [23].

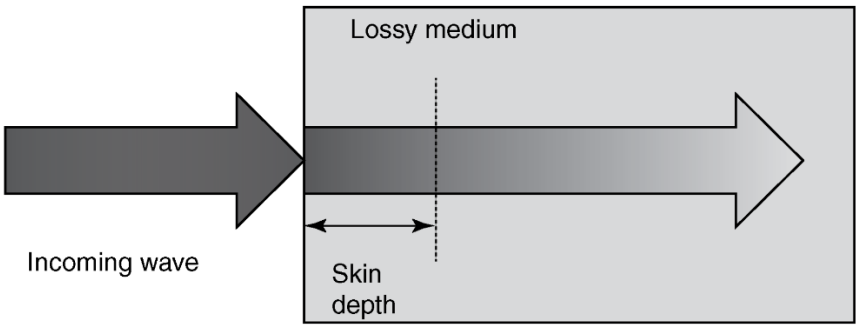


Figure 2.24 Skin effect [23].

When a plane wave travels through conductive material the charges inside the material are oscillated back and forth with the same frequency as the striking field. These movements generate a very quick alternating current where this reduces the field in strength.

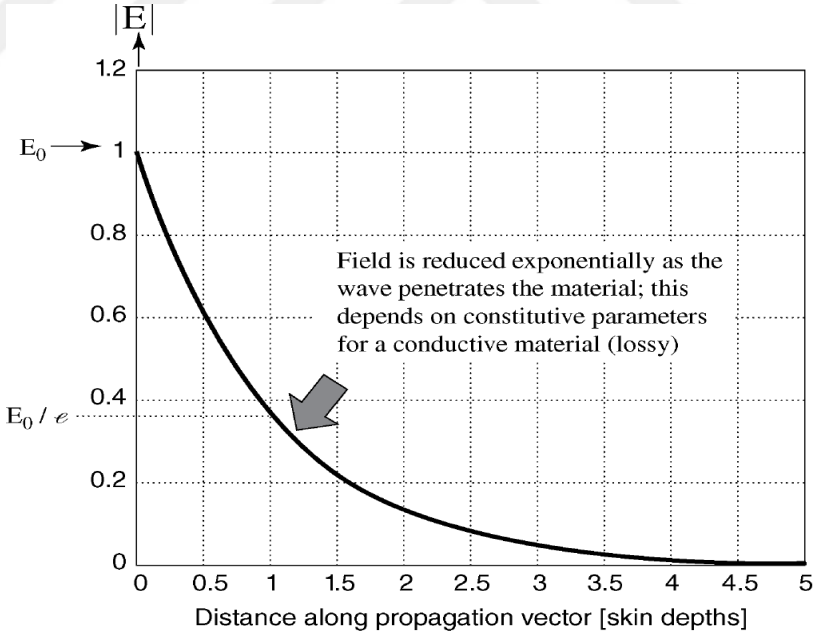


Figure 2.25 Calculation of skin depth [23].

2.4.3 Path Loss

Path loss is the ratio between transmitted and received power in terms of decibels. The loss is caused by the elements between transmit and receive antennas. There are many factor that effect path loss therefore, it is not feasible to calculate. Link budget has to be considered, is a procedure that estimates the received power by taking into account the transmitted power, gains and losses. Median path loss plays an important rule where, in-building systems has been effected by multipath effects. To find the path loss in a system, the gains and losses have to be considered. The elements of wireless link are depicted in figure 2.26.

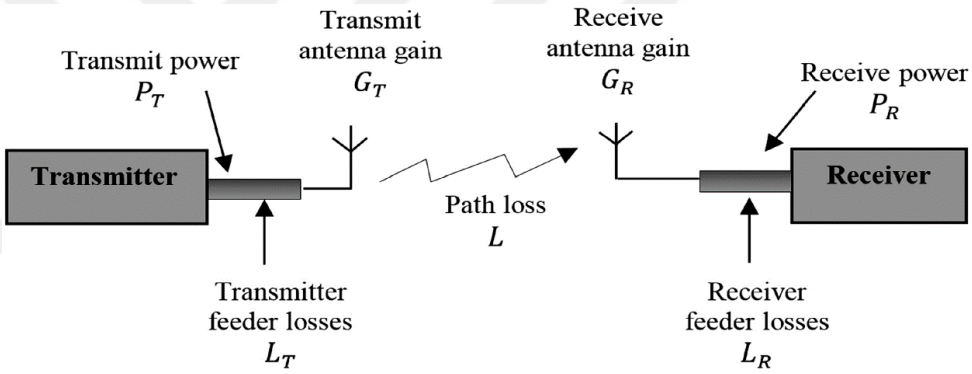


Figure 2.26 Elements of a wireless communication system [23].

- P_T is the transmit power, is the amount of power at the output of the transmitter which is demonstrated in terms of watts or decibels.
- L_T is feeder loss, these losses are due to cables connectors in the transmitter and demonstrated in dB.
- G_T is transmit antenna gain where, its demonstrated in dBi or dBd and it is unit less.
- L is path loss, the unit is showed in dB.
- G_R is receiver antenna gain, is demonstrated in dBi or dBd and unitless.
- L_R is feeder loss, these losses are related to the receiver side of the system and its located between the receiver antenna and receiver. Feeder loss is expressed in dB.
- P_R is the received power, demonstrated in watts, milliwatts or in decibels.

2.4.4 Indoor Propagation Models

The outdoor propagation mechanism is the same as indoor model, because the situation is more complex inside buildings. A general model is difficult to be developed due to their different internal and external structures. Measurements for different building materials for indoor structures has been studied in [26]. Total path loss for inside building propagation has been given by [27]

$$L = 20\log_{10} f_c + 10\gamma \log_{10} r + L_f(n_f) - 28 \qquad (dB), \qquad (2.33)$$

Where γ is the path loss exponent, $L_f(n_f)$ is the floor penetration loss, that differs with the number of penetrated floors n_f [21]. The same model has also been presented by COST-231 where, indoor and multi wall propagation has been studied [28]. Floors in a building can be lossy, in [29] a loss of 1.9 dB has been introduced to each floor. An additional 10 dB loss can be introduced to basement. However, the elevators are very lossy therefore the signal strength can be dropped up to 20 dB. Underground and tunnels are one of the major issues that faces difficulties as result of lack of radio propagation. Mine trolleys through tunnels are suffering from radio connections. Small tunnels can be covered by two antennas at both ends of the tunnel. However, for lengthy tunnels a radiator that runs through the whole length of the tunnel is placed in order to provide illumination. The frequency range from 438 MHz to 24 GHz has been studied in [30].

For wireless personal area networks (PANs) in case of indoor wideband wireless body to body multiple input multiple output (MIMO) channel path loss has been measured less than 2, where, a log normal distributed shadowing a standard deviation of 4.8 dB [31]. These shows that body shadowing causes a noticeable power loss in short range body to body communications. The scattering causes a small path loss. A 2.45 GHz on body channel characterization for wireless body area networks (BANs) has been investigated in [32]. Different antenna positioning and posture changes can cause up to 50 dB in propagation [21]. For UWB channels the on-body propagation has been measured in [33],

on the other hand different frequency (868 MHz) measurements has been investigated in [34].

2.5 Antenna Theory

Antenna is a device that converts a current existed in a waveguide, feeder cable or transmission line into waves that travel in free space or vice versa as depicted in figure 2.27.

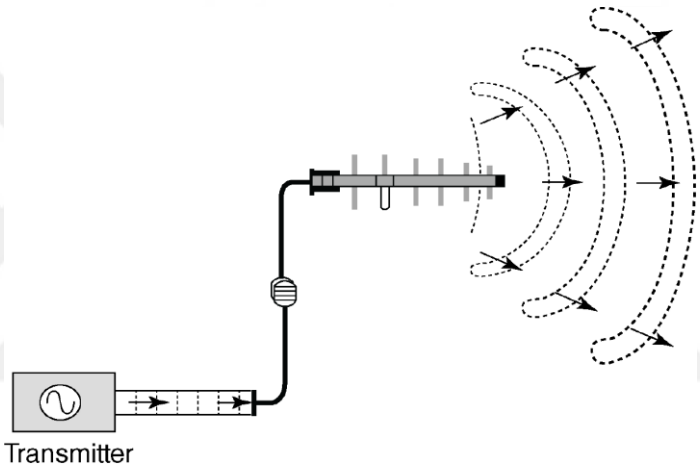


Figure 2.27 Antenna seen as a transition region between guided and unguided waves [23].

The field moves in one-dimension through the line towards the antenna, where it converts to radiating waves that transmits power in three-dimension through the transmitting antenna into free space. The antenna design ensures that the processes that the transmission takes place is as much efficient as possible so, that the antenna transmits as much power as it can into the desired direction. For example, a satellite in geostationary orbit (GEO) is located approximately 36000 km above our head therefore, the signal travels by the same distance. If the receiver antenna is not designed in a way that receives the transmitted signal hence, the signal will be suppressed by noise and will degrade to the level of the antenna efficiency. Before going on to the antenna that is used in our system it is important to decide what type of antenna should be utilized for a particular

application. Despite multiple characteristics of an antenna it is crucial to choose the right size antenna appropriate for your system.

2.5.1 Impedance

The antenna is the major interface between circuitry and free space. It makes it easy for the system to transfer power between space and transmitting antenna or receiving antenna. The antenna impedance is the load for the transmitter or the input impedance or the receiver [24]. The antenna impedance is demonstrated by complex number as follows

$$Z_{ant} = R_r + R_L + jX_a \tag{2.34}$$

Where, R_L is resistive loss that converts some of the wireless energy to heat. R_r is radiation resistance and X_a is the antenna reactance. The signals coming at the transmit antenna reflects, converts to heat or radiates [17]. The bandwidth of the antenna is specified by impedance of the antenna. For maximum power radiation between transmitter and receiver the impedance should be matched with the feedline.

2.5.2 Radiation Pattern

The radiation pattern is figure of the power radiated from an antenna per unit solid angle. The radiation pattern is also a reception pattern because of the antenna reciprocity. The normalized field pattern has been characterizing the radiation pattern. The normalized power pattern is demonstrated by

$$P_n(\theta, \emptyset) = \frac{S(\theta, \emptyset)}{S(\theta, \emptyset)_{max}}, \tag{2.35}$$

Where $S(\theta, \emptyset)$ [watts/m^2] is the power per unit area or the amplitude of the Poynting vector,

$$S(\theta, \emptyset) = \frac{E_\theta^2(\theta, \emptyset) + E_\emptyset^2(\theta, \emptyset)}{Z_0} \tag{2.36}$$

and $Z_0 = E/H = 376.7$ ohms is the free space impedance. Radiation pattern has main lobes and minor lobes. The important pattern parameters are half power beamwidth (HPBW), that 3 dB beamwidth, and first null beamwidth (FNBW). The parameters and beam pattern are depicted are in figure 2.28 [21].

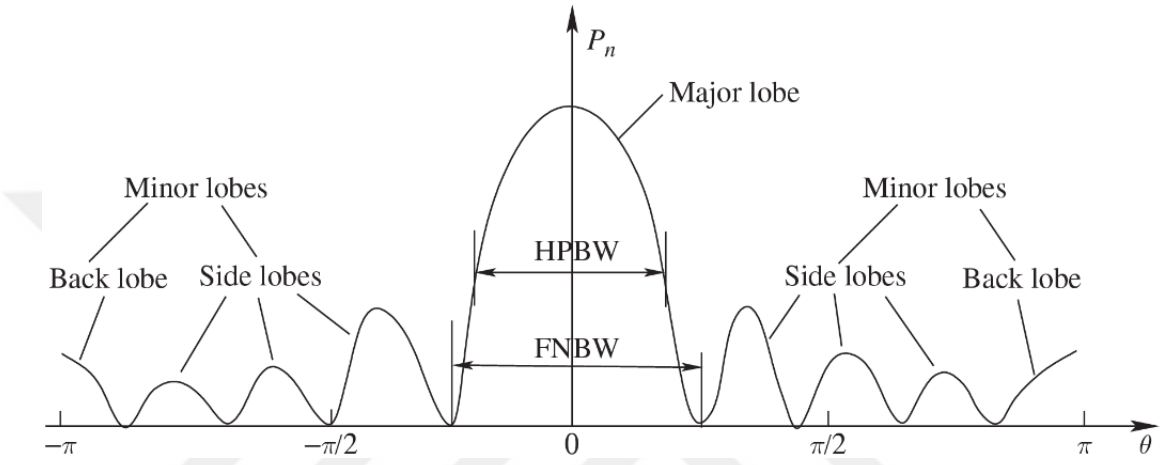


Figure 2.28 Antenna radiation pattern [21].

2.5.3 Radiation Intensity

The radiation intensity is referred to the power radiated from an antenna per unit solid angle where its represented by U, showed in watts/radian^2. The power pattern is

$$P_n(\theta, \emptyset) = \frac{U(\theta, \emptyset)}{U(\theta, \emptyset)_{max}} \tag{2.37}$$

Different from equation 2.35, where the amplitude of the Poynting vector varies with the distance from the antenna. However, the radiation intensity is independent of the distance [21].

CHAPTER 3

METHODOLOGY AND EXPERIMENTAL SETUP

3.1 Research Methodology

The main goal of this research is to transmit data with very high speed between two points inside a room using a transmitter equipped with data generator, a power amplifier and our self-laboratory fabricated Vivaldi antenna. On the receiver side, again the same type of Vivaldi antenna, as used in the transmitting side, is utilized in order to receive the transmitted wave for the further process.

Nevertheless, a literature survey was conducted to realize some specific objects including; analog and digital communication, sampling process, modulation techniques and short range wireless communication. The research methodology used for this thesis is as follows

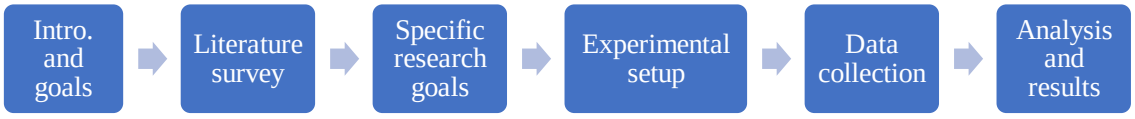


Figure 3.1 Methodology.

In the research methodology above an introduction with main objectives has been represented. After that a literature survey was done to get a comprehensive insight of the subject. Experimental setup was established in order to collect data, where the data is analyzed in a device called LUCEO.

3.2 Experimental Setup

The experimental setup is basically consisting of a transmitter and a receiver. Where, a single-input and single-output (SISO) communication system was constructed to achieve the goal. The system operates at X-band (8-12 GHz).

3.2.1 Transmitter of the System

The transmitting unit of the system is consisting of a pattern generator, bias tee, LO, RF mixer, power amplifier (PA) and Vivaldi antenna. The transmitting unit is depicted in figure 3.2.

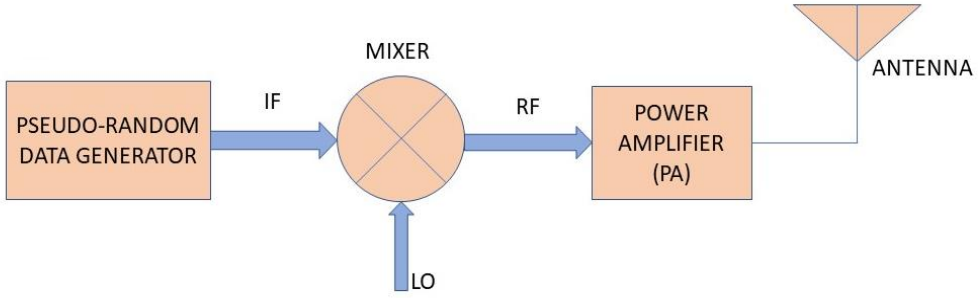


Figure 3.2 Transmitting unit of the system.

3.2.1.1 LUCEO Technologies

XBERT is a Bit Error Rate (BER) test platform used for verification and test of up to 14.4 Gbps optical and electrical chip, sub assembly and system designs. ParalleX allows users to perform several BER tests at once using a single clock source.

The pattern for the system is generated by LUCEO technologies Pattern Generator Module, namely PN L -6001 –EPG10-6, is an Electrical Pattern Generator module that fits into the XBERT and ParalleX^{TM} Chassis. EPG10-6 generates electrical data from 2 Gb/s, up to 13 Gb/s, optionally up to 14.5 Gb/s. user programmable pseudorandom binary sequence (PRBS) patterns can be varied via a basic to use graphical user interface (GUI).

A pattern trigger output provides an electrical trigger synchronous with the pattern for use with an oscilloscope or other test equipment. From panel indicators give immediate status for Tx Data. The module and the functional block diagram of the device is depicted in figure 3.3 [35].

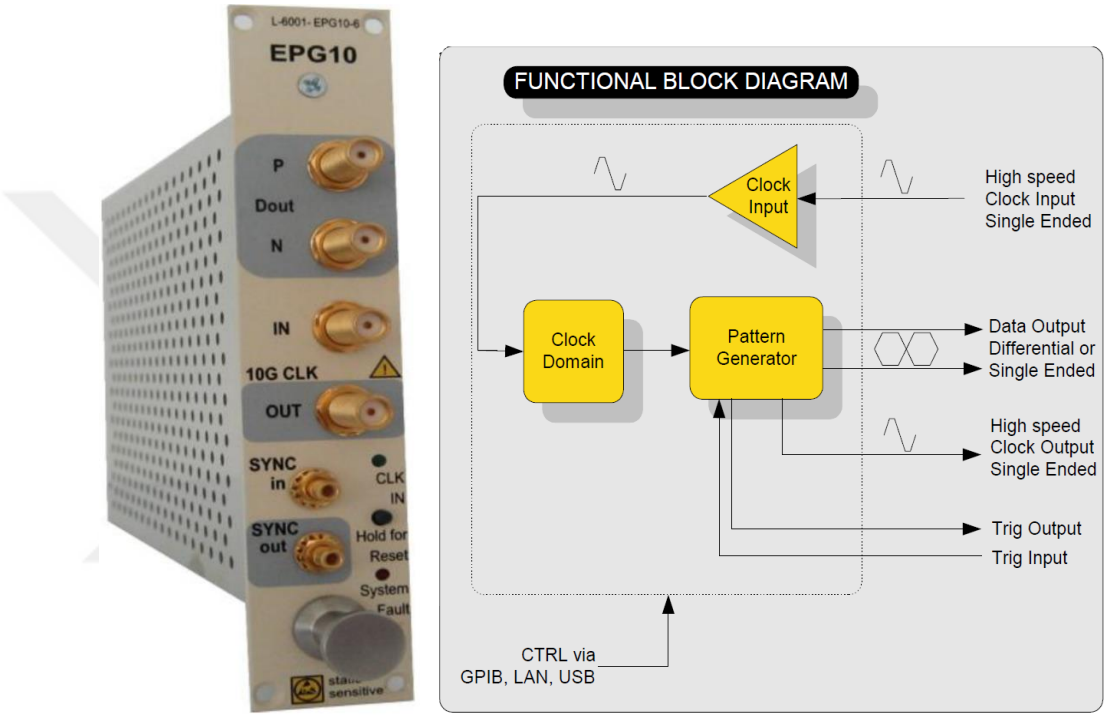


Figure 3.3 Pattern generator module and its functional block diagram [35].

The key features for the pattern generator module is

- Data rates from 2 to 13 Gbps
- Optional operation up to 14.5 Gbps
- Differential electrical pattern generator
- Output voltage adjustable from 0.5V to 1.0V in 0.1V steps
- PRBS: 7, 9, 10, 11, 15, 21, 23, 31
- User- pattern: 8Bit -8Kbyte
- Clock- pattern: 1/1, 1/2, 1/4, 1/8
- Data input and output polarity swap [35]

For high speed data transfer an accurate clock should be generated. For this purpose, Clock Source Module p/n L-6001- CLK20-3 of LUCEO technologies has been utilized. CLK20 is a clock source module that plugs into the PARALLEX chassis. The clock works over a continuous range from 78.125 MHz to 20 GHz. The clock module and functional block diagram is depicted in figure 3.4 [35].

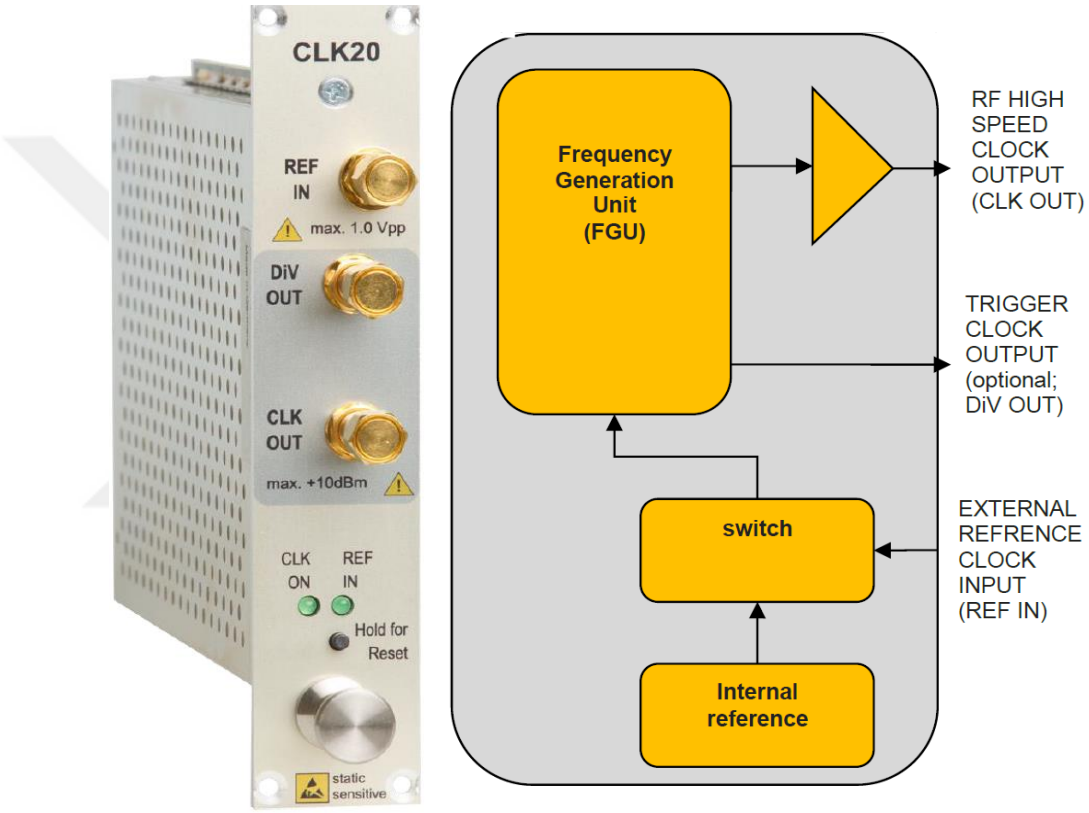


Figure 3.4 Clock source module and its functional block diagram [35].

Key features of this module are as follows

- Internal or external reference clock generator
- Clock multiplier function
- Output voltage 200….600 mV
- Clock output 78.125 MHz to 20 GHz
- Trigger clock output 78.125 MHz to 5 GHz
- Single ended output

Error detection is crucial in communication systems, for this system an Error Detection Module namely PN L-6001-EED10-6 of LUCEO technologies has been used to calculate the bit error rate of the system. EED10-6 is an Electrical Error Detector module that plugs into the XBERT and Parallex chassis. EED10-6 is able to receive electrical data from 2 Gbps up to 13 Gbps, optionally up to 14.5G. Front panel indicators give immediate status for Rx data. The error detector module and functional block diagram is depicted in figure 3.5 [35].

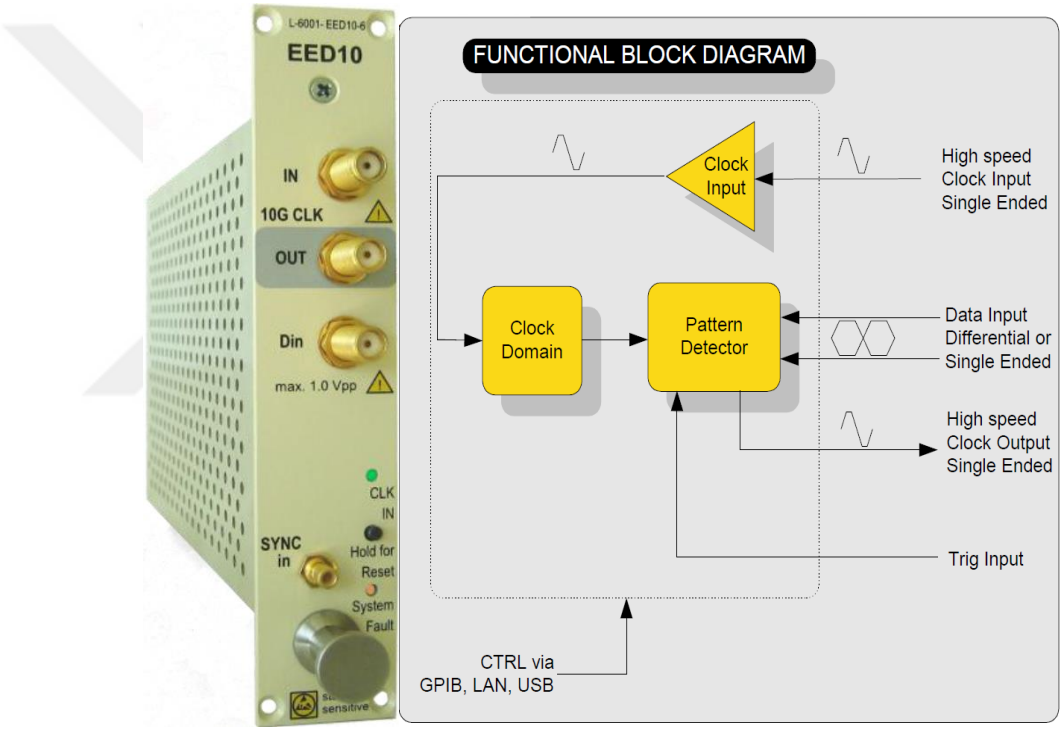


Figure 3.5 Error detector module and its functional block diagram [35].

Key features of the module are as follows

- Data rates 2 to 13 Gbps
- Optional operation up to 14.5 G
- Differential Electrical Error Detector (SMA connector)
- PRBS: 7, 9, 10, 11, 15, 21, 23, 31
- BER detection: 0.5 to <1E-15

3.2.1.2 Bias Tee

Bias-tee is a three-port passive component that injects direct current (DC) into RF circuit without distorting the RF signal as depicted in figure 3.6.



Figure 3.6 Bias Tee.

The bias tee used in this system is the PSPL5575A where, this is a broadband coaxial bias insertion tee and DC blocking capacitor designed to pass fast rise pulses with minimum waveform distortion. The – 3dB bandwidth extending from 10 kHz to 12 kHz. Bias in our system serves as DC level shifter where, a DC voltage is applied to the DC port of the component in order to offset (shift) the DC level of the data signal that is connected to the alternating current (AC) port of the component. The usage of bias tee for this system will be explained in chapter 4.

3.2.1.3 Local Oscillator

Local oscillator (LO) is an electronic component that is used to generate frequency. In this system Yttrium Iron Garnet (YIG) serves as our LO as depicted in figure 3.7. YIG is a synthetic crystal that provide very high quality (Q) factor characteristic. The high Q offers lower phase noise in oscillators.



Figure 3.7 Yttrium Iron Garnet.

YIG resonates at certain frequencies when submerged in a DC magnetic field. The resonance is proportional to the strength of applied magnetic field. The DC magnetic field is generated using an electromagnet. The magnetic field of the electromagnet can be changed by applying a variable current [36].

3.2.1.4 Mixer

RF mixer is a non-linear passive component that creates new frequency as a result of two signals applied to its ports. It is a three port device where its used in transmitter and receiver side of a communication system. If it is used in the transmitter side of the system, it serves as an up-conversion device on the other hand it serves as down-conversion device in the receiving side of a system. The mixer in the transmitter side of our system is used to modulate the incoming data signal where, the data signal is coming from intermediate frequency (IF) port and it is mixed with LO. The output frequency from RF port of the mixer is the result of mixing data and LO. The photo of the mixer used in our system is depicted in figure 3.8.

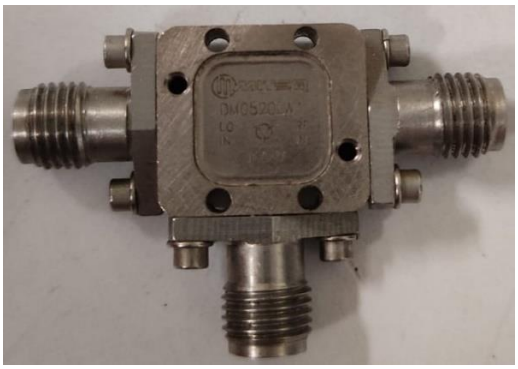


Figure 3.8 RF mixer.

3.2.1.4 Power Amplifier

Power amplifier is a device that increase the magnitude of power for a given input signal. Power amplifiers are used in varies types of products. It is used to increase the level of power in order to derive loads of output devices such as RF transmitters, headphones and etc. There are many different types of power amplifiers such as audio, DC and RF power amplifier. In our system we use an RF power amplifier where, it increases the strength of the modulated signal. Generally, wireless communications systems require to send modulated signal via long distances therefore, the strength of the signal need to be boosted hence to send it to the desired distance. We use a Miteq RF power amplifier that amplifies the signal by 34 dB. The amplifier is depicted in figure 3.9.



Figure 3.9 RF Power Amplifier.

3.2.1.5 Vivaldi Antenna

A Vivaldi or tapered slot is kind of exponential antenna that is made out of printed circuit board (PCB). For both the receiving and transmitting side of the system a Vivaldi antenna is drawn and fabricated as depicted in figure 3.10.

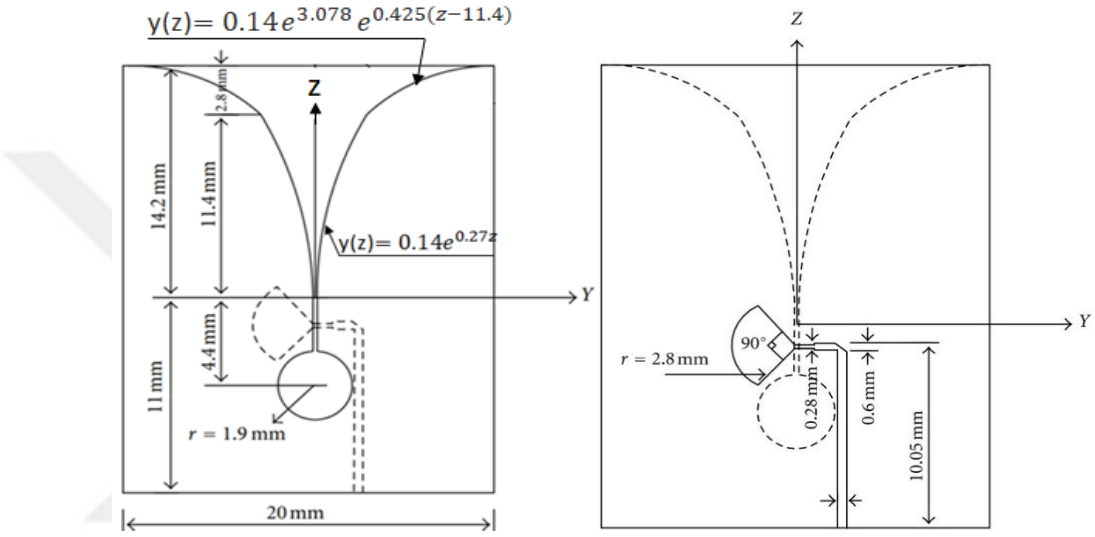


Figure 3.10 Vivaldi antenna front and back side view [38].

Vivaldi antennas are planner that work via broad frequency range. Because of the tapered slot devise Vivaldi antennas have high gain. In contrast to horn antenna, Vivaldi antenna can be fitted into smaller spaces which they can be made out of flat laminate. Due to their easy impedance matching, makes communication more feasible between two points. The Vivaldi antenna deliberated for the present study engages use at X-band frequencies generally from 8 to 12 GHz however, the antenna is modeled with CST microwave studio. Traveling-wave propagation diffusion takes place along a Vivaldi antenna's architecture by virtue of the phase pace of its electromagnetic waves is smaller than the pace of light in free space. As conclusion, a Vivaldi antenna is defined by radiation in the end-fire direction. Vivaldi antenna has an end-fire radiation pattern which continuously scaled, gradually curved and slow leaky end-fire traveling waves are the main criteria of this antenna. The Vivaldi can be designed with a range of taper profiles. A slot line is said to be feeding antenna and radiation slot behaves as the ground plane for the antenna. Studies

have been made to research the effect of the curvature of the mounting structure on a verity numbers of Vivaldi antennas. The experiment showed that the curvature of tapered profile has a significant impact on the gain, beam width and bandwidth of Vivaldi antennas [39]. The antenna printed on PCB has thinness of 0.035 mm which used in our system as depicted in figure 3.11.

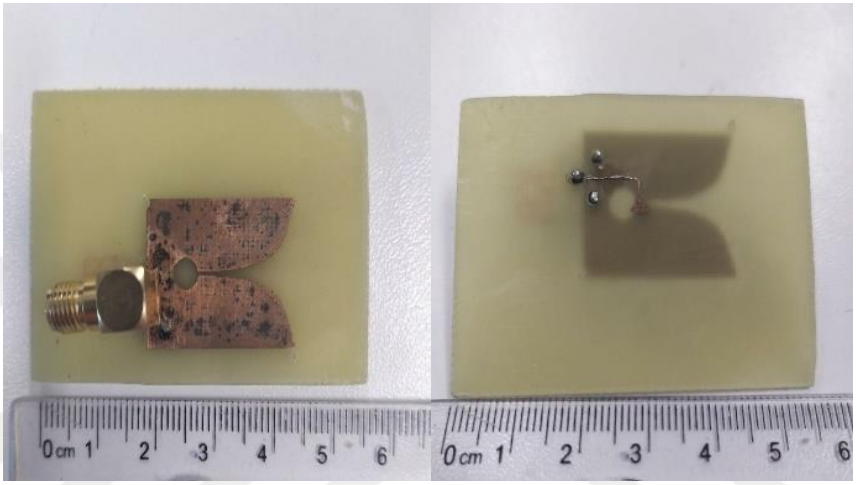


Figure 3.11 Printed circuit board Vivaldi antenna.

A matching impedance Vivaldi antenna with similar characteristics is placed at the receiver in order to compensate the end-fire radiation transmitted by the transmitter [37].

The scattering parameters of the Vivaldi antenna s11 and s21 which are reflection and transmission respectively measured in order to observe effective transmission or resonant frequency of the antennas. Therefore, reflection and transmission tests are accomplished using R&S ZNB Vector Network Analyzer (VNA), whose results are illustrated in figure 3.12, and figure 3.13. It is clearly seen that s11 and s21 parameters demonstrate that these antennas can be used effectively between 8 GHz to 12 GHz. For the sake of effective transmission some tests have been utilized at this interval [40].

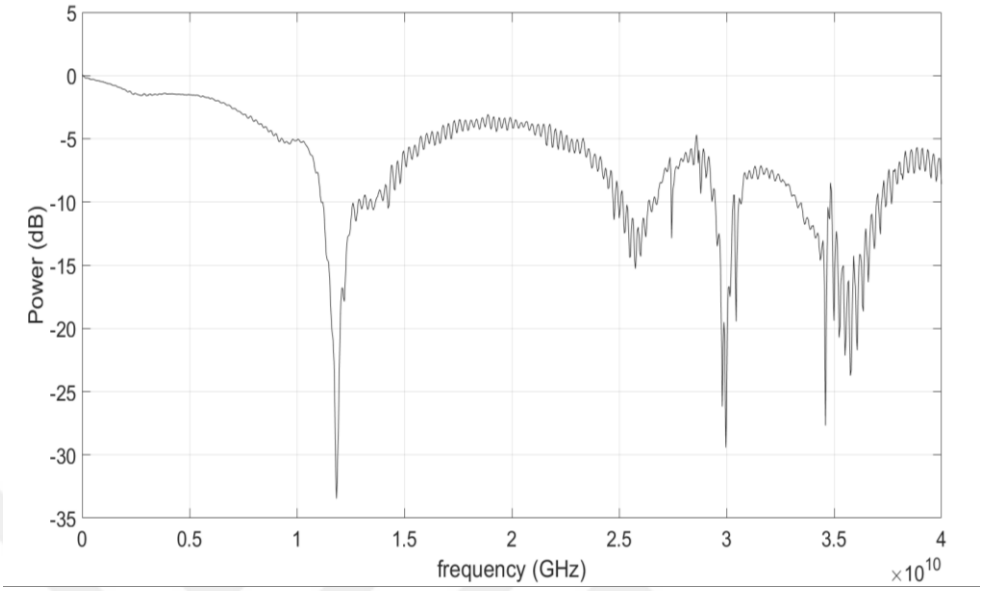


Figure 3.12 VNA measurement S11 parameters for the Vivaldi antenna.

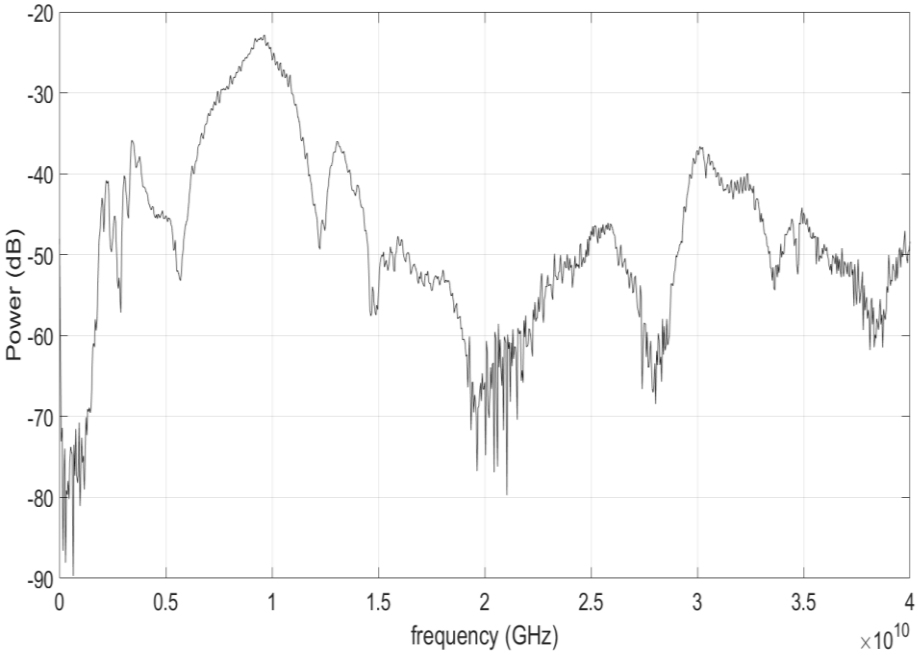


Figure 3.13 VNA measurement S21 parameter for the Vivaldi antenna.

3.2.2 Receiver of the System

The receiving unit of the system is consisting of a Vivaldi antenna, same as used in the transmitting unit, a local oscillator, an RF mixer, a low noise amplifier (LNA) and a bit error rate calculating unit. The receiving unit is depicted in figure 3.14.

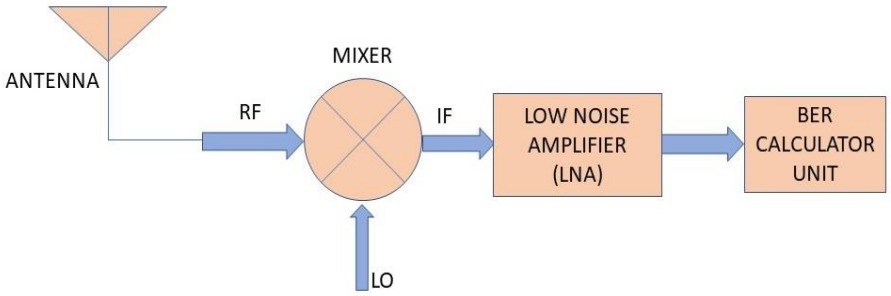


Figure 3.14 Receiving unit of the system.

The Vivaldi antenna utilized in the receiving side of the system fabricated with the same parameters and size as in the transmitting side of the system. The impedance mismatch is one of the major issues between two communication points. If the antennas are not well matched it will result in less power transfer between the transmitting and receiving units of the system. both of the antennas used in the system are tested under the same conditions hence, to facilitate the communication more effective and efficient.

Phase mismatch is another crucial issue between transmitter and receiver because the transmitted wave arrives at the receiver with a very small time delay therefore, phase mismatch occurs. In order to avoid phase mismatch transmitter and receiver units shares the same LO through a splitter.

3.2.2.1 RF Splitter

An RF power splitter is a component that splits an incoming signal into two identical signals. The RF splitter can be used as an RF combiner as well where, it combines incoming two signals into one signal. For our system, we use model 5331 6 dB power

splitter which is a very broadband resistive tee as depicted in figure 3.15. This splitter operates up to 20 GHz.

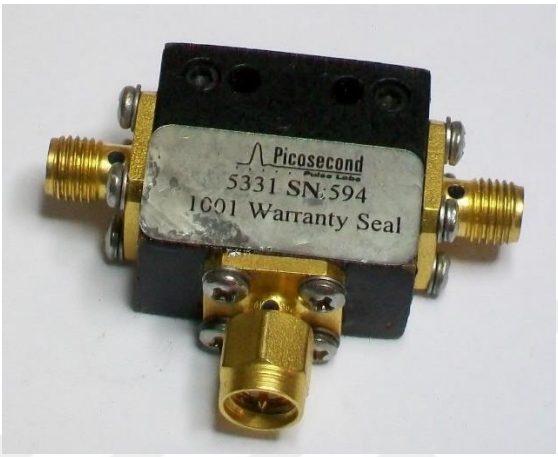


Figure 3.15 RF splitter.

The RF mixer used in the receiving unit is the same as used in the transmitting unit of the system.

3.2.2.2 Low Noise Amplifier

RF LNA is an active component that increases the amplitude of weak RF signals. Amplifiers are generally used in communication systems in order to strengthen the signal to be sent for a long distance. Such amplifiers increase the noise level as well where, they cannot be used in the receiving unit of a communication system. LNA comes into the picture for the low noise solution in the receiving unit of the system. LNA amplifiers are designed to increase the level of the required signal and degrades the level of unrequired signals which is unwanted noise. The LNA that is used in the system is depicted in figure 3.16.

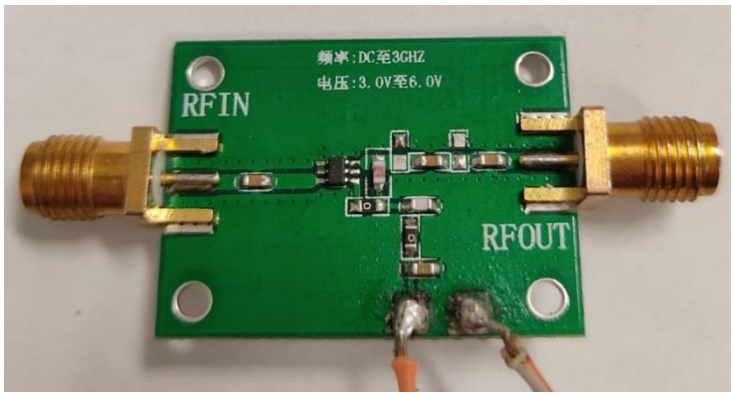


Figure 3.16 Low noise amplifier.

3.2.2.3 BER Calculating Unit and Setup

For the BER calculation an Error Detection the module namely PN L-6001-EED10-6 of LUCEO technologies is used which is explained in section 3.2.1.1.

The experimental setup is designed to achieve a high data rate between two points at different distances through our self-fabricated Vivaldi antenna. This experimental setup aims to achieve a comparison between two different modulation techniques which we will talk in chapter 4 of the thesis. The experimental setup as a whole is depicted in figure 3.17.

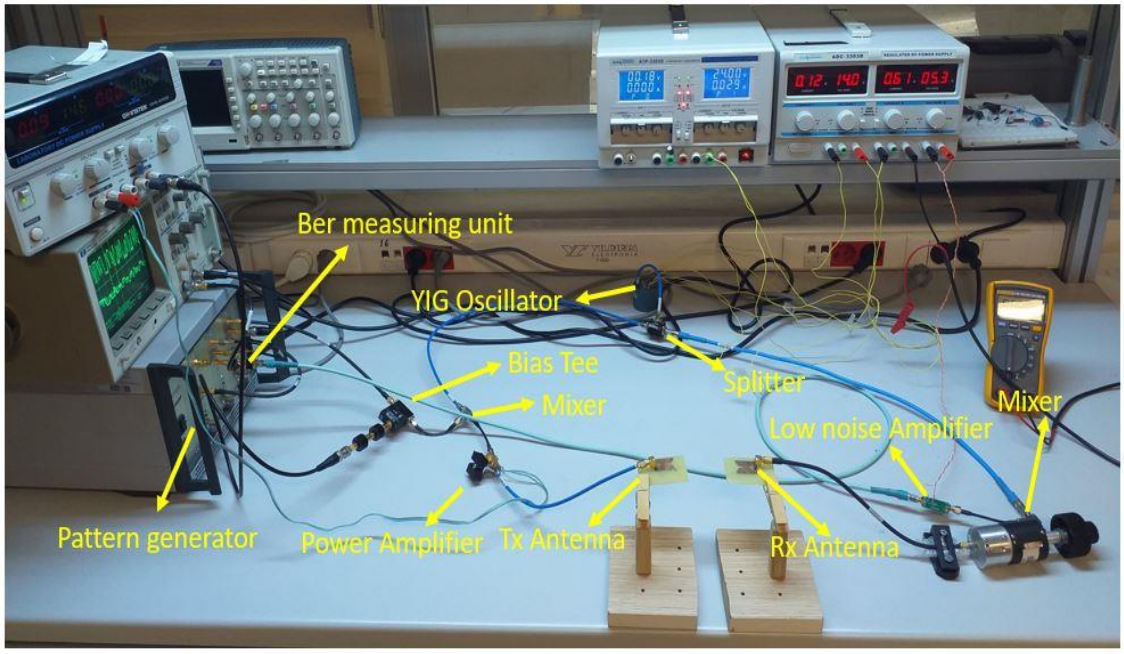


Figure 3.17 Experimental setup of the system.

The working principle and modulation techniques will be explained in the next chapter where, a comprehensive detail about the system will be given.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Modulation

The EPG10 module that is explained in chapter 3 generates a PRBS pattern that is a sequence of 1's and 0's. This pattern is generated between -0.5V to 0.5V where, it comes to IF port of the RF mixer. The YIG oscillator generates a sinusoidal signal at 11.2 GHz which serves as our carrier signal in the system. The incoming PRBS pattern modulates the phase of the carrier signal that is coming to the LO port of the mixer. This process is called binary phase shift keying (BPSK). The carrier wave is modulated correspond to the IF signal with two phase reversal such as 0^0 and 180^0. For BPSK, each symbol includes a single bit, therefore two different values of θ(t) should be chosen in order to represent 0's and 1's [37].

For the sake of comparison on-off keying (OOK) modulation technique, is also done in the transmitting unit. The same is mixer is used for OOK modulation. This modulation is provided with the help of bias-tee connected to the IF port of the mixer which allows to adjust the DC offset of the data signal without disturbing other components. Hence, this device has been used to make an offset for the 1's and 0's sequence. This device provides approximately 0.5V offset for the PRBS sequence, the bits of the incoming stream change the amplitude of carrier signal, if it is 1, the mixer is ON and vice-verse and the carrier signal is modulated with OOK [40]. In the transmitting end, the sending information is handed as oscillating voltage to the antenna. The surface current is then raised by the given voltage which increment the oscillating electric and magnetic field accordingly, the energy produced is radiated as electromagnetic waves into space.

4.2 Demodulation

For the BPSK demodulation, a coherent detection has been made at the receiver. Coherent detection, mixes LO with the received RF signal to produce a product term therefore, received RF signal can be demodulated or translated to IF. The product of LO and RF signal would result in generating the sum and the differences between the RF signal and LO. By tuning the frequency of LO much better frequency selection has been accomplished in coherent detection. A typical coherent demodulation specifies the phase of the input RF signal to retrieve the data bit. This needs the demodulator to have exemplary signal in rem with frequency and phase to the inventive carrier. The IF signal is received as a result of coherent detection at the receiver.

For the OOK demodulation scheme a mixer has been used in order to retrieve the data from the modulated carrier signal. Since our transmitter and receiver are not very far away from each other hence, it is feasible for them to share the same LO. For the perfect demodulation the incoming RF signal should be multiplied with a replica of the carrier signal that should be in phase with incoming RF signal. As a result of this multiplication a baseband signal with lower frequency than the modulated signal is obtained.

As a result of both demodulation schemes an IF signal is individually obtained at different time. The acquired IF signal is then forwarded to the LNA, that is adopted to raise signals of very nominal strength thus, LNAs are generally used at the receiver to let increment the amplitude of weak RF signal and recover the received signal whereby the received signal is treated and turned into information (data signal). In receivers generally noise is expected to be reduced to minimum for this reason, LNAs are utilized for minimal loss due to interference. Although signals are distorted by amplifiers howsoever, RF LNAs are constructed to lower the noise without distorting the desired signal consequently this is the main reason LNAs are used in receivers [37].

The amplified signal is then process in the error detection module in order to check if the system is reliable for communication or not.

4.3 Numerical Results

In telecommunication systems total number of errors have quite an important role. Because it is crucial to characterize the channel whether it is reliable for the data transmission. The quality of a transmission channel depends on SNR if SNR is increased the better performance is observed. In a typical communication system one of the main objectives is to transmitted bits without being flipped. Namely the received bits are undesired to change over the transmission period the data bits are flipped due to obstacles, multipath and etc. in the transmission path which is unwanted situation. In order to prevent this issue, input power of the transmitting bits should be increased for the transmitting bits. On the other hand, input power can be increased to a certain level otherwise, it requires much expensive RF front-end components which is not practical [40].

4.3.1 Bit Error Rate vs Signal to Noise Ratio

In this system we compare two different modulation schemes namely, BPSK and OOK for its experimental and analytical results. As shown in figure 4.1 the BPSK modulation technique performs better than the OOK modulation technique. Where, 3 dB gain is observed at 10^{-4} compared to OOK modulation technique. However, in the analytical and experimental results the bit energy of BPSK is double of OOK.

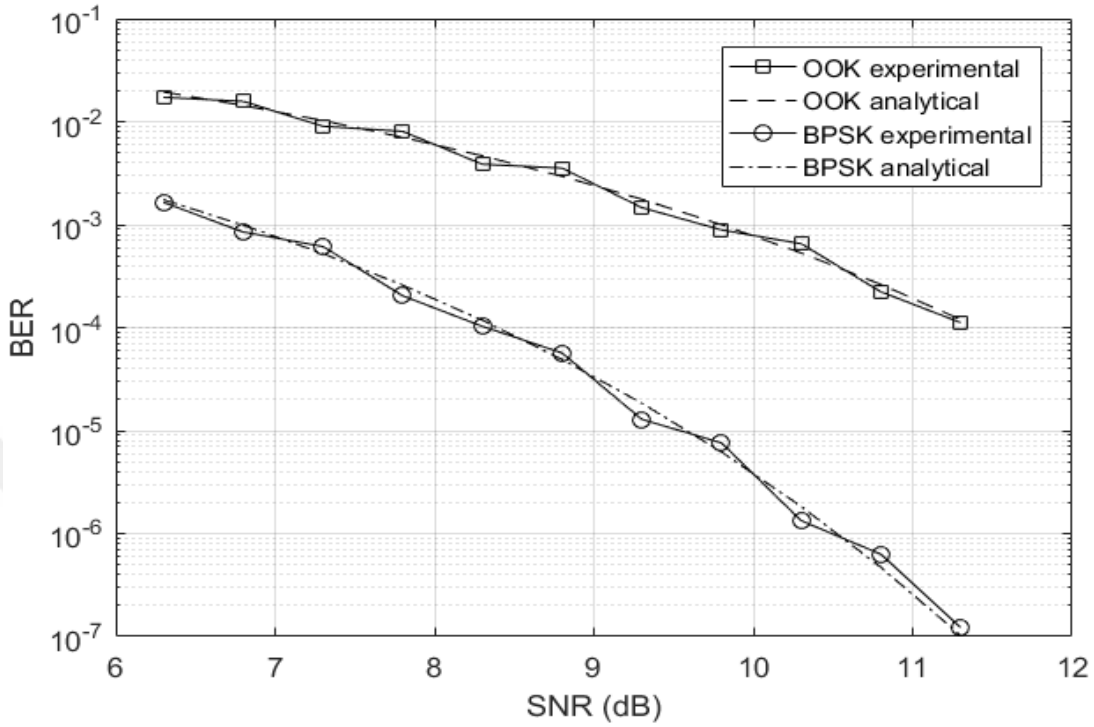


Figure 4.1 Bit error rate vs signal to noise ratio for BPSK and OOK.

4.3.2 Bit Error Rate vs Data Rate

Errors are caused due to ambient obstacles while signals are transmitted wirelessly that can make any bit flipped. Without changing the bandwidth and power of the system increasing data rate results in higher BER. The space between constellation points becomes shorter due to data rate increase therefore, the likelihood that the receiver makes mistakes rises as the distance between the constellation points decrease. As a result, 3.7 Gbps data rate has been achieved as depicted in figure 4.2.

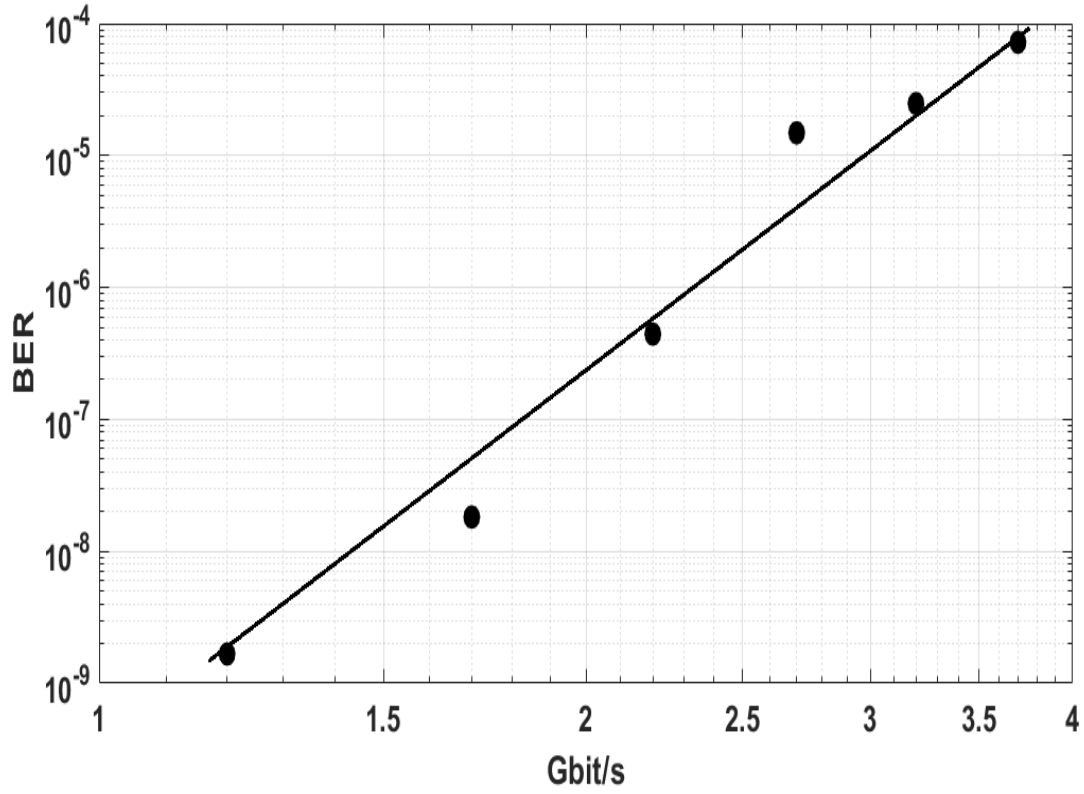


Figure 4.2 Bit error rate vs data rate.

In today's digital world data plays an important rule because the need for remotely controlled devices is increasing day by day. Where, factories, homes, and cars are remotely controlled. For the fulfillment of this requirement a high data rate is needed to fetch information in real time from remotely located server.

4.3.3 Bit Error Rate vs Distance

The distance effect has also been studied in this research. The distance has got a direct impact on a wireless communication system for multiple reasons firstly, as the distance increases the air volume between the transmitter unit and receiver unit increases. Therefore, it more likely to attenuate the wirelessly transmitted signal and results in less power transferred to receiver. Secondly, as the electromagnetic wave travels from transmitter to the receiver unit, the air creates a molecular friction between the wave and

molecule. Hence, results in data bits been flipped that causes the receiver to receive false data bits thus, results in higher BER. Lastly, the ambient also effects wireless communication where obstacles decrease and makes data bits been flipped. In figure 4.3, it is seen that as the distance increased the BER increased.

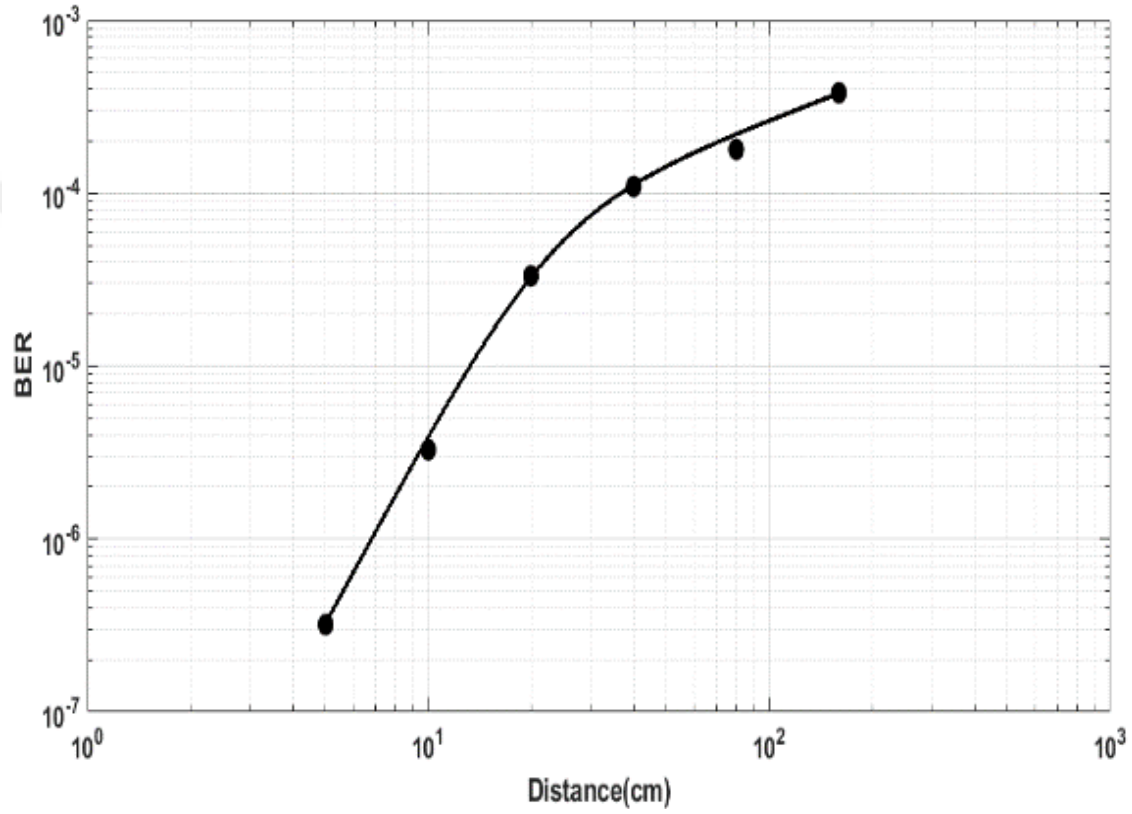


Figure 4.3 Bit error rate vs distance.

4.3.4 Eye Diagram

A digital signal can maintain impairments between transmitter and receiver. Each component in the system cause an interference that not only degrade the amplitude of the signal but also lead to phase delay to the system. Hence, eye diagrams are used to detect the effects of inter-symbol interference and amount of mitigation of the signal due to the ambient around the transmitter and receiver. This only cause degradation in signal power as depicted in figure 4.4.

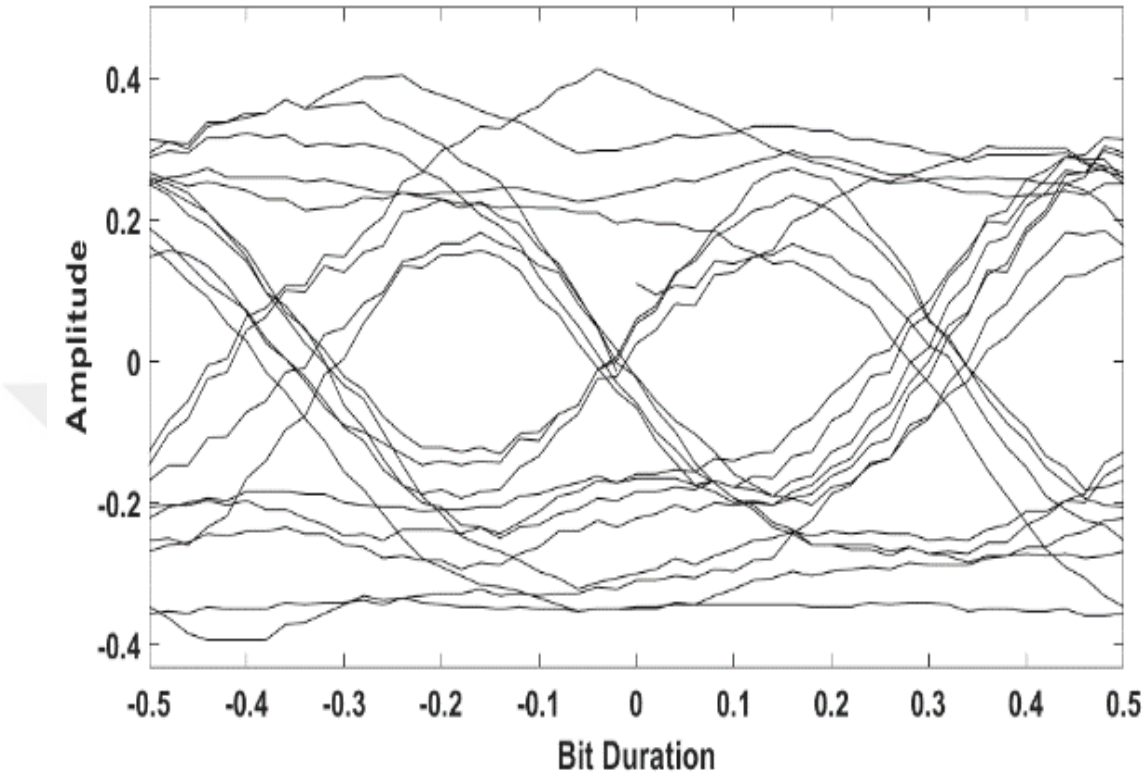


Figure 4.4 Eye diagram of the system.

Every component in the system from components to cables introduce interference that will degrade the signal both in amplitude and time thus, eye diagram is introduced which is a method of analyzing high speed digital signals to study inter symbol interference.

CHAPTER 5

CONCLUSION

In the era of technology and science human requirements for high data rates increase as new technologies come into market. Now a day's robots and autonomous cars take over the industry. For this reason, high data rates are required to control these components. In this research thesis, we have achieved to send data between two points by a distance of 1.6 m where, 3.7 Gbps data rate has been achieved where, the bit error rate is at 10^{-4}. A tremendous performance has been obtained in BER due to the distance and an appropriate antenna has been drawn and fabricated to increase the effectiveness and efficiency of the communication. The frequency which our system works the antennas work effectively. For the sake of accuracy, the S_{11} and S_{21} parameters of the antennas are tested by vector network analyzer hence, a 19.2 dB gain is obtained at 11.2 GHz.

The main purpose of this study, in offices, buildings and data centers that are all covered with cables running everywhere which carry data in a very high speed. This causes problem in many ways firstly, it occupies space. secondly, it is not feasible to extent cable everywhere in crowded spaces that people use. Lastly, cables in fancy office or building destroys the decoration of the place. Hence, it is more appropriate to design such places with wireless communication systems that carry data in a very high speed appropriate for today's needs. The digital data is sent in terms of Gigabits it needs to be reached within seconds to a required place. The system operates at 11.2 GHz, two different modulation schemes namely, BPSK and OOK are introduced and empirically tested on the system. The experimental results that are obtained from the system have been compared thus, the BPSK modulation scheme performance is better than OOK. Hence, a 3 dB performance has been observed in the BPSK modulation scheme. Every component in the system introduces errors some components attenuate the signal and some components distort the signal. Therefore, the eye diagram clearly shows that the system is appropriate for data transfer in a very high rate. Where, the inter symbol interference is to be considered

minimum because an almost perfect human eye is clearly observable through the eye diagram.

5.1 FUTURE WORK

Underwater communication is a challengeable issue for many sectors mainly submarine and autonomous underwater vehicles. The challenges are caused by multi-path propagation, time variation of the channel, small available bandwidth and strong signal attenuation. Above the water on terrestrial land electromagnetic wave made communication more feasible due to its directivity and huge bandwidth. Underwater communication uses acoustic waves instead of electromagnetic waves. The underwater acoustics is the diffusion of sound in water. The underwater acoustics are between 10 Hz and 1 MHz where 1 MHz is occasionally used due to quick underwater absorption. Therefore, the bandwidth, speed and long rages are limitations of the underwater communications that submarine and autonomous underwater vehicles are faced.

Future work concerns deeper analysis of particular mechanisms, new proposals to try different methods, or simply curiosity. For future work, the distance can be increased for couple of meters and this study can be adapted for underwater wireless communication.

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TOPICS OF INTEREST

High data rate wireless communications, digital signal processing, RF and THz technologies and applications, terahertz and millimeter wave imaging

PUBLICATIONS

[1] Z. Sediqi and A. Şahin, "Single Pixel Scanning Based Millimeter Wave Imaging," International Journal of Agriculture Environment and Food Sciences, 14, (18), 2020.

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PROJECT

High Resolution Capacitive Micro Machined Ultrasonic Transducer Ultrasound Imaging System. Research Scholar., TÜBİTAK 1003 Project No: 116E659. Nov.2018-Present.