Designing and Empirical Realization of Horn antennas and Waveguides in a 60 GHz Wireless System

A Thesis

Submitted to the Department of Electrical and Electronic Engineering

of

BRAC University

By

Sk. Laila Ayesha-07110059

Synthia Aman-07110100

Sumaiya Akhter-07110067

In Partial Fulfillment of the

Requirements for the Degree

of

Bachelor of Science in Electronics and Communication Engineering

April 2010

BRAC University, Dhaka, Bangladesh

DECLARATION

We hereby declare that this thesis is based on the results established by us. Materials of work found by other researchers are mentioned in the reference. This thesis, neither in whole nor in part, has been previously submitted by any degree.

A. F. [signature]

Signature of Supervisor

Sk. Laila Ayesha
Symaiya Akhter
Synthia Aman

Signature of Students

ACKNOWLEDGMENTS

Special thanks to honorable supervisor Dr. Ahmed Kamal, Professor, Department of Electrical and Electronic Engineering, Brac University, Dhaka for accepting the difficult task of overseeing this work to completion. The authors would specially express their most sincere gratitude to Mr. Apurba Saha, Lecturer, BRAC University for taking time out of their busy schedules to consider this work.

ABSTRACT

Wireless Communications in the unlicensed 60GHz band are becoming increasingly commercially attractive and popular. This paper focuses on to design and empirical realization of building a pyramidal horn antenna and waveguides for such a high frequency system. Antenna is an integral part of receiving and transmitting information at a much faster rate at this high frequency.

Therefore, a pioneer step is taken in order to design a 60GHz antenna with waveguide structures. The antenna system will be tested for data transmission and polarization diversity can also be verified for vertical, horizontal, slant, left circular, right circular and elliptical polarization in the future development of the thesis work.

Table of Contents

CHAPTER 2
Design and Calculations

CHAPTER 3
Conclusion and Further work

LIST OF FIGURES

Figure Page

CHAPTER 1

INTRODUCTION

1.1 Introduction to Wireless Communication System

In today's technological society, wireless communication has become an increasingly important part of daily life. We have come to depend on our pagers, cellular phones, satellite dishes, radios, etc., usually without understanding how they work. The common element to all of these wireless systems, whether they transmit or receive, is the antenna. Wireless communications involves the transfer of information between two points without direct communication. This can be accomplished using sound, infrared, and optical or radio frequency energy but most modern wireless systems rely on RF or microwave signals. Because of spectrum crowding, and the need for higher data rates, the trend is to higher frequencies. Recently, frequency range of 60GHz is unlicensed and if implemented properly can put the communication level to a much higher level in terms of speed and data transfer.

1.2 60 GHz Frequency System

1.2.1 Unlicensed bandwidth

There is a general trend in wireless communications to move towards higher frequencies. Due to wider bandwidths, and ability to penetrate fog, dust, foliage, even buildings and vehicles to some extent make higher frequencies more suitable. [1]Now the recent researches are on 60 GHz as there are several benefits in this frequency.

A major factor in this allocation with commercial benefits is that the spectrum is "unlicensed" – in other words, an operator does not have to buy a license from the FCC before operating equipment in that spectrum.

The licensing process typically is very expensive and time consuming. Point-to-point wireless systems operating at 60 GHz have been used for many years by the intelligence community for high security communications and by the military for satellite -to satellite communications.

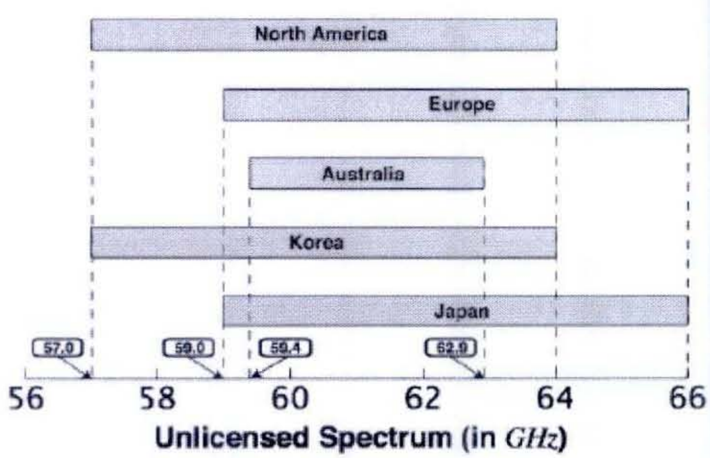


Figure 1 International unlicensed spectrum around 60 GHz

Figure 1.1 Unlicensed spectrums

While contemporary unlicensed systems support light and moderate levels of wireless data traffic, as seen in Bluetooth and wireless local area networks (WLANs), current technology is unable to supply data rates comparable to wired standards like gigabit Ethernet and high-definition multimedia interface

(HDMI). Fortunately, as illustrated in Figure 1, an abundance of widely available spectrum surrounding the 60 GHz (60G) operating frequency has the ability to support these high-rate, unlicensed wireless communications. [3]

1.2.2 Reasons of using 60 GHz frequency

One of the special characteristics is the oxygen molecule (O2) absorbs electromagnetic energy at 60 GHz most (Figure 2). This absorption occurs to a much higher degree at 60 GHz than at lower frequencies typically used for wireless communications. This absorption weakens (attenuates) 60 GHz signals over distance, so that signals cannot travel far beyond their intended recipient. For this reason, 60 GHz is an excellent choice for covert satellite-to-satellite communications because the earth's atmosphere acts like a shield preventing earth-based eavesdropping. However, this frequency can also be used in office environment.[6]

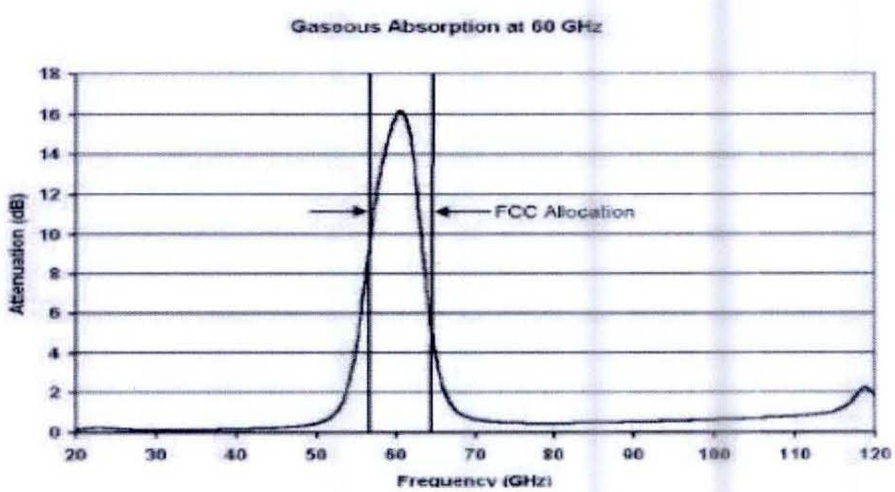


Figure 1.2 Attenuation versus frequency

In addition to the high-data rates that can be accomplished in this spectrum, energy propagation in the 60 GHz band has unique characteristics that make

possible many other benefits such as excellent immunity to interference, high security, and frequency re-use.

Another consequence of oxygen absorption is that radiation from one particular 60 GHz radio link is quickly reduced to a level that will not interfere with other 60 GHz links operating in the same geographic vicinity. This reduction enables higher "frequency reuse" – the ability for more 60 GHz links to operate in the same geographic area than links with longer ranges. As an example, two different links can be compared, one operating near 60 GHz and the other at a frequency that is less affected by O2 absorption. The second link could be operating at another unlicensed frequency such as 2.4 GHz or 24 GHz. Consider a typical operating scenario where both links are operating over a distance of one kilometer with the transmitter's power output adjusted such that the signal level at the receiver is 30 decibels (dB) above the background noise. Figure 3 shows how the signal level drops with distance beyond the receiver in the two cases. For the link unaffected by O2 absorption, it takes 32 kilometers (km) for the transmitted signal to drop down to the background noise level. In other words, that signal would interfere with any other signal at that same frequency for more than 30 kilometers beyond its original recipient. That reduces the number of links at that frequency that can be installed in a fairly large area. Also, this means that the lower-frequency signal could be intercepted up to more than 30 kilometers beyond its intended recipient. In contrast, the transmitted signal at 60 GHz drops down to the noise level in a mere 2.5 km. Consequently, more 60 GHz links can be used in the same area without worrying about interference. Also, the 60 GHz links are far more secure given their limited range.[6]

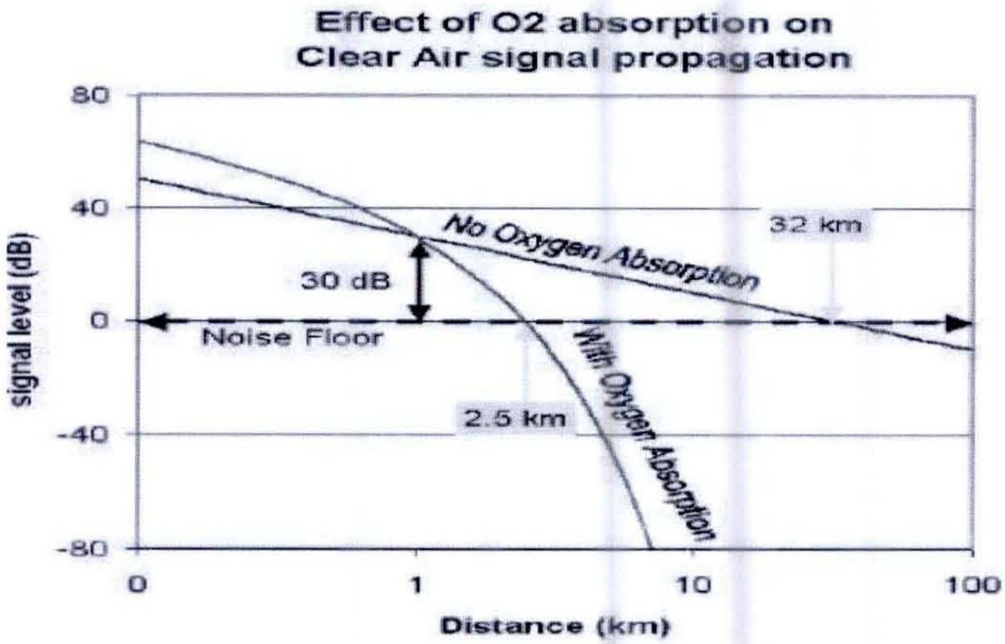


Figure 1.3 Radiations Limiting by O2 Absorption

The combined effects of oxygen absorption and narrow beam spread result in high security, high frequency re-use, and low interference for 60 GHz links. Figure 4 shows two buildings that are 1 km apart. The wedges show the radiation pattern from 2.4, 24 and 60 GHz links operating with the same performance at 1 km. The links have equivalent 1-foot diameter antennas. The three wedges show the locations where the radiation at each frequency remains high. The largest wedge represents the radiation pattern from a 2.4 GHz link. The 60 GHz link has the narrowest and shortest wedge and can be barely be seen except in the blow-up. The wedges for 2.4 and 24 GHz links are substantially larger than the 60 GHz link, even though their operational link distance is the same (1 km).

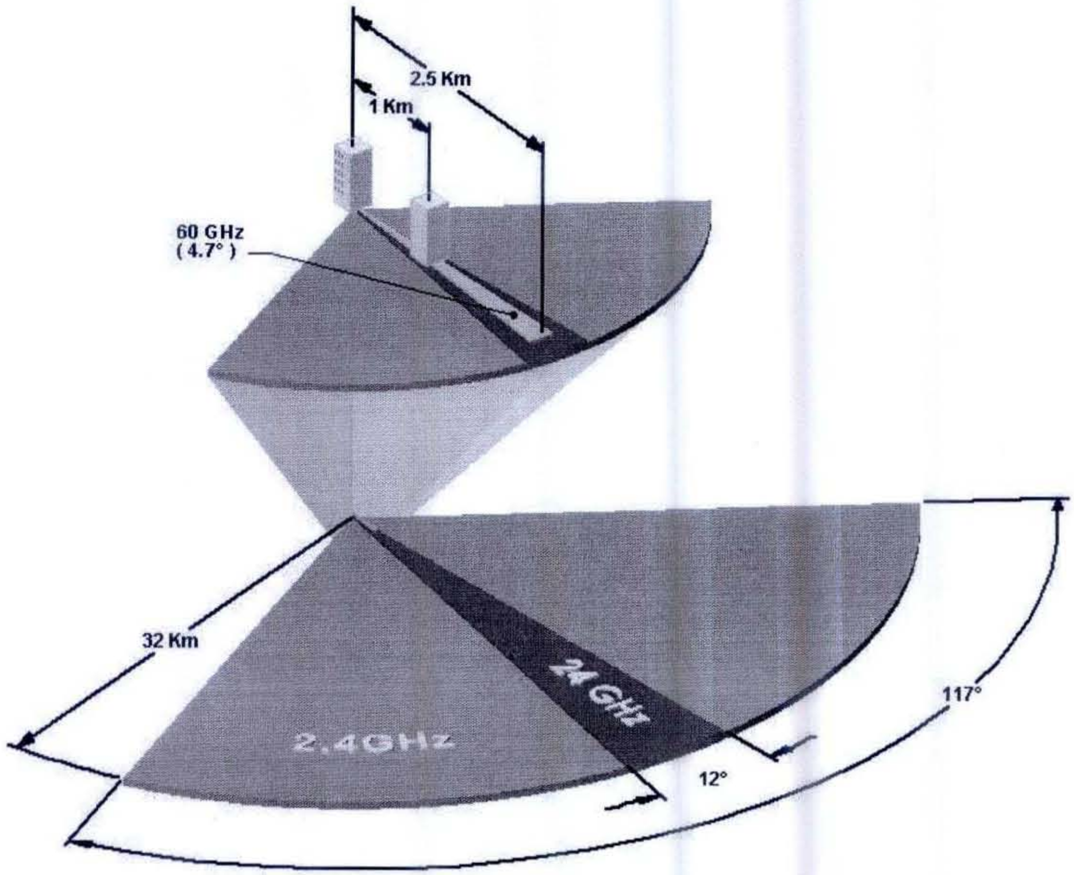


Figure 1.4 Area covered by 2.4GHz and 60GHz frequency

The practical implications of these graphics are obvious. A 60 GHz link can only be intercepted in the tiny wedge and will only interfere with another 60 GHz link in that wedge. A 24 GHz link has interference and interception risks over a much longer and somewhat broader wedge, while a 2.4 GHz link has interference and interception risks over a very large area, both in distance and in breadth.[6]

The 60 GHz band is an excellent choice for high-speed Internet, data, and voice communications offering the following key benefits:

-Unlicensed operation – no need to spend significant time and money to obtain a license from FCC

-Highly secure operation – resulting from short transmission distances due to oxygen absorption and narrow antenna beam width

-Virtually interference-free operation – resulting from short transmission distances due to oxygen absorption, narrow antenna beam width, and limited use of 60 GHz spectrum

-High level of frequency re-use enabled – communication needs of multiple customers within a small geographic region can be satisfied

-Mature technology – long history of this spectrum being used for secure communications.[6]

1.3 Electromagnetic energy

The definition of electromagnetic energy can be given as, the energy source required to transmit information (in the form of waves) from one place (material) to another. This information can be in the form of light, heat, or in any other form. However, the very basic terms in order to know the exact meaning are discussed below.

1.3.1 Electric Charge - It is an attribute of subatomic particles, that determines their interactions when placed in electric and magnetic field. Electrically charged matter has as well as gets affected by electromagnetic field.

1.3.2 Electric Current - It is the movement or flow of electrically charged particles. There are two types of charged particles namely, positively charged particles i.e. protons and negatively charged particles i.e. electrons.

1.3.3.Magnetism - Magnetism is a force that affects the interaction of materials or moving charged particles, by developing attractive or repulsive forces between them.

1.3.4 Electromagnetic Wave Energy - It is a wave created by the acceleration of charged particles that are placed in magnetic and electric field; both the fields acting at right angles to each other. The oscillation of the particles in the wave emits energy called as electromagnetic wave energy.

1.3.5 Electromagnetic Spectrum Energy - A range of electromagnetic waves of all possible frequencies and wavelengths forms an electromagnetic spectrum. The total energy of the spectrum is called electromagnetic spectrum energy.

1.3.6Electromagnetic Radiation Energy - Electromagnetic radiation is a collection of electromagnetic waves traveling in vacuum or in matter. The energy radiated by the electromagnetic waves is called electromagnetic radiation energy.

1.3.7Electromagnetic Field Energy - Electromagnetic field is caused by electrically charged objects, that influences the behavior of materials or charged particles around the field. The total amount of energy of the field and the materials it affects is called electromagnetic field energy.

1.3.8 Electromagnetic Energy Facts

- The different types of electromagnetic waves are light, microwaves, x-rays, and TV and radio transmissions[4].
- Here is a list of the electromagnetic waves in the decreasing order of their frequencies that constitute the electromagnetic spectrum:
    1. Gamma rays
    2. X-rays
    3. Ultraviolet rays
    4. Visible light rays
    5. Infrared rays
    6. Microwaves
    7. Radio waves (FM)

8. Radio waves (AM)
9. Long radio waves

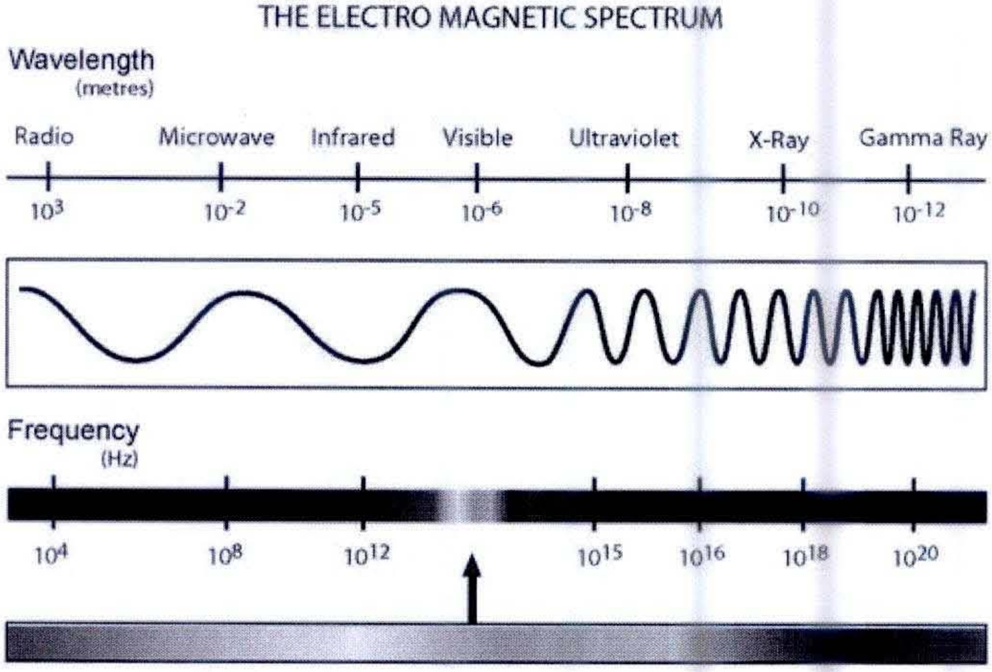


Figure 1.5 Electromagnetic spectrum

- Higher the energy of the particles of electromagnetic wave, shorter is the wavelength.
- Electromagnetic waves travel through any material as well as through vacuum.
- The velocity of electromagnetic waves in vacuum is same as that of light, i.e. approximately 1,86,000 miles per second or 3,00,000 kilometers per second.
- When electromagnetic waves enter matter, they slow down i.e. their energy decreases, hence wavelength increases.
- When any object is heated, its particles are accelerated that causes change in their electric and magnetic fields, thus forming an electromagnetic wave. Whereas when an electromagnetic wave hits an

object, it generates heat at the surface that in turn causes the particles of that object to vibrate. The heat and vibration of the particles depends on the wavelength and energy of the electromagnetic wave.

We utilize electromagnetic energy in our day-to-day life without being aware of its existence.

1.4 Radio Frequency (RF) communication

Radio frequency (RF) radiation is a subset of electromagnetic radiation with a wavelength of 100 km to 1 mm, which is a frequency of 3 kHz to 300 GHz, respectively. This range of electromagnetic radiation constitutes the radio spectrum and corresponds to the frequency of alternating current electrical signals used to produce and detect radio waves. RF can refer to electromagnetic oscillations in either electrical circuits or radiation through air and space. Like other subsets of electromagnetic radiation, RF travels at the speed of light.

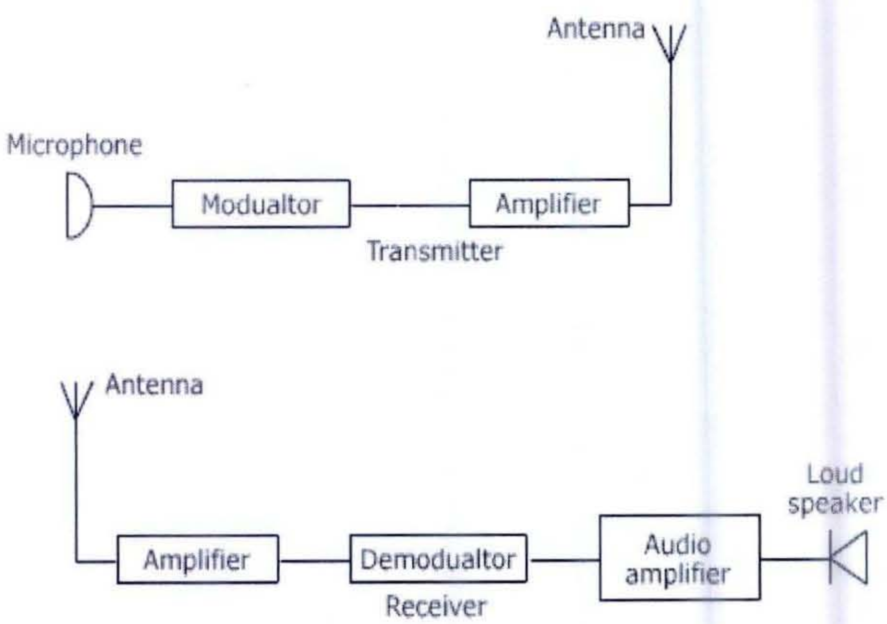


Figure1.6: Block diagram of Radio Frequency communication

1.4.1 Microwave frequency

Our thesis deals with the microwave range of frequency.
Microwaves are electromagnetic waves with wavelengths ranging from as long as one meter to as short as one millimeter, or equivalently, with frequencies between 300 MHz (0.3 GHz) and 300 GHz.

This range is situated between radio waves and infrared radiation. They are the principal carriers of television, telephone, and data transmissions between stations on Earth and between the Earth and satellites.
Microwave frequency bands, as defined by the Radio Society of Great Britain (RSGB), are shown in the table below:

Table: Microwave frequency bands

Letter Designation	Frequency range
L band	1 to 2 GHz
S band	2 to 4 GHz
C band	4 to 8 GHz
X band	8 to 12 GHz
K_u band	12 to 18 GHz
K band	18 to 26.5 GHz
K_a band	26.5 to 40 GHz
Q band	30 to 50 GHz
U band	40 to 60 GHz
V band	50 to 75 GHz
E band	60 to 90 GHz
W band	75 to 110 GHz
F band	90 to 140 GHz
D band	110 to 170 GHz

Microwave frequencies present special problems in transmission, generation, and circuit design that are not encountered at lower frequencies. Conventional circuit theory is based on voltages and currents while microwave theory is based on electromagnetic fields.

Now the according to the range of frequency, there are different frequency bands as shown in the chart above. [2]

1.5 Transferring of electromagnetic waves

1.5.1 The two-wire transmission line: used in conventional circuits is inefficient for transferring electromagnetic energy at microwave frequencies. At these frequencies, energy escapes by radiation because the fields are not confined in all directions (Fig-1.7)

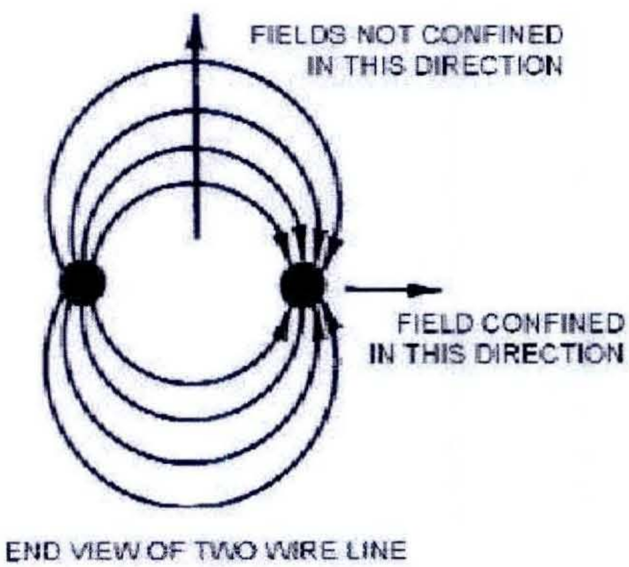
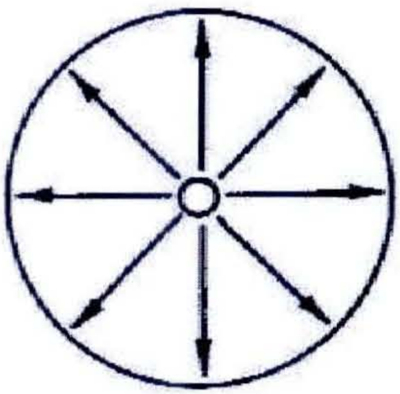


Figure 1.7.:Fields confined in two directions only

1.5.2Coaxial lines: More efficient than two-wire lines for transferring electromagnetic energy because the fields are completely confined by the conductors, as illustrated in figure 1-2



END VIEW OF COAXIAL CABLE

Figure 1.8.—Fields confined in all directions.

1.5.3 Waveguides are the most efficient way to transfer electromagnetic energy. WAVEGUIDES are essentially coaxial lines without center conductors

A hollow conductive metal pipe used to carry high frequency radio waves, particularly microwaves. In other words, it is used to guide electromagnetic waves at microwave frequency regions. They are constructed from conductive material and may be rectangular, circular, or elliptical in shape, as shown in figure 1-3.

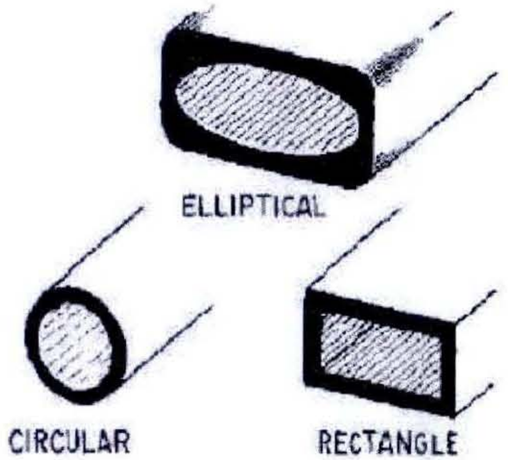


Figure 1.9.—Waveguide shapes.

1.5.3.1Waveguide Advantages

Waveguides have several advantages over two-wire and coaxial transmission lines. For example, the large surface area of waveguides greatly reduces COPPER (I^2R) LOSSES. Two-wire transmission lines have large copper losses because they have a relatively small surface area. The surface area of the outer conductor of a coaxial cable is large, but the surface area of the inner conductor is relatively small. At microwave frequencies, the current-carrying area of the inner conductor is restricted to a very small layer at the surface of the conductor by an action called SKIN EFFECT.[7]

Power-handling capability is another advantage of waveguides. Waveguides can handle more power than coaxial lines of the same size because power-handling capability is directly related to the distance between conductors [5].

However, waveguides have certain disadvantages that make them practical for use only at microwave frequencies.

1.5.3.2Waveguide Disadvantages

Physical size is the primary lower-frequency limitation of waveguides. The width of a waveguide must be approximately a half wavelength at the frequency of the wave to be transported. For example, a waveguide for use at 1 megahertz would be about 500 feet wide. This makes the use of waveguides at frequencies below 1000 megahertz increasingly impractical. The lower frequency range of any system using waveguides is limited by the physical dimensions of the waveguides. Waveguides are difficult to install because of their rigid, hollow-pipe shape. Special couplings at the joints are required to assure proper operation. Also, the inside surfaces of waveguides are often plated with silver or gold to reduce skin effect losses. These requirements increase the costs and decrease the practicality of waveguide systems at any other than microwave frequencies.

1.6 Waveguide design

1.6.1Dimensions

As shown in figure 1-9, the widest dimension of a waveguide is called the "a" dimension and determines the range of operating frequencies. The narrowest dimension determines the power-handling capability of the waveguide and is called the "b" dimension.

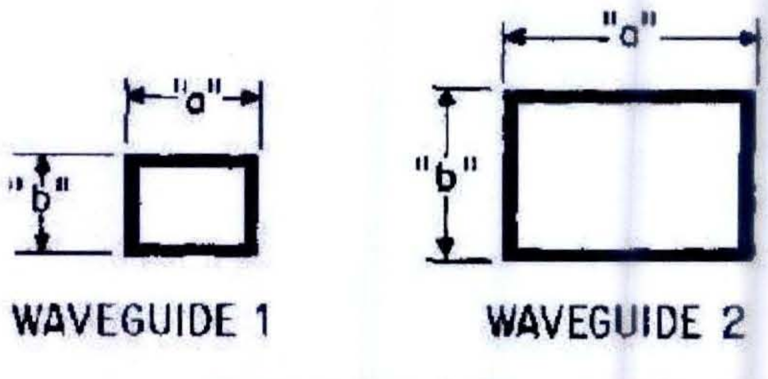


Figure 1.10.:Labeling waveguide dimensions.

In practical applications, the wide dimension of a waveguide is usually 0.7 wavelength at the operating frequency. This allows the waveguide to handle a small range of frequencies both above and below the operating frequency. The "b" dimension is governed by the breakdown potential of the dielectric, which is usually air. Dimensions ranging from 0.2 to 0.5 wavelength are common for the "b" sides of a waveguide.[7]

In our making of antenna we used the standard USA and European Waveguide sizes with their Pertinent Mechanical and Electrical Parameters[8] which is attached at the end of the report.

Since energy is transferred through waveguides by electromagnetic fields, it is important to have a basic understanding of field theory. Both magnetic (H FIELD) and electric field (E FIELD) are present in waveguides, and the interaction of these fields causes energy to travel through the waveguide. This action is best understood by first looking at the properties of the two individual fields. E FIELD.—An electric field exists when a difference of potential causes a stress in the dielectric between two points. The simplest electric field is one that forms between the plates of a capacitor when one plate is made positive compared to the other, as shown in figure 1-11A. The stress created in the dielectric is an electric field. Electric fields are represented by arrows that point from the positive toward the negative potential. The number of arrows shows the relative strength of the field. In figure 1-11A, for example, evenly spaced arrows indicate the field is evenly distributed. For ease of explanation, the electric field is abbreviated E field, and the lines of stress are called E lines.

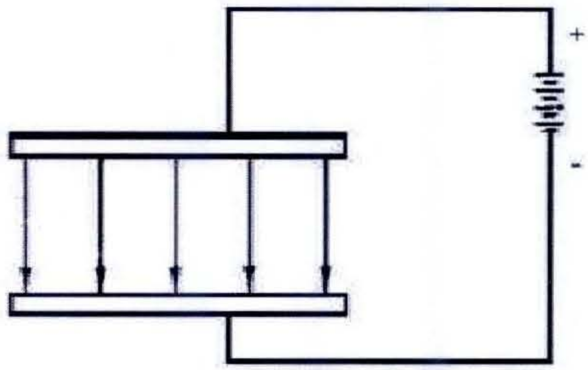


Figure 1.11: Simple electric fields. CAPACITOR.

Figure 1.12, view (A), shows the E-field pattern created by a voltage sine wave applied to a one-wavelength section of waveguide shorted at one end. The electric fields are represented by the arrows shown in views (B) and (C). In the top view of view (A), the tip of each arrow is represented by a dot and the tail of each arrow is represented by an X. The E field varies in density at the same sine-wave rate as the applied voltage. This illustration represents the instant that the applied voltage wave is at its peak. At other times, the voltage and the E field in the waveguide vary continuously from zero to the peak value. Voltage and E-field polarity reverse with every reversal of the input. Note that the end view shown in view (B) shows the E field is maximum at the center and minimum near the walls of the waveguide. View (C) shows the arrangement of electromagnetic fields within a three-dimensional waveguide.

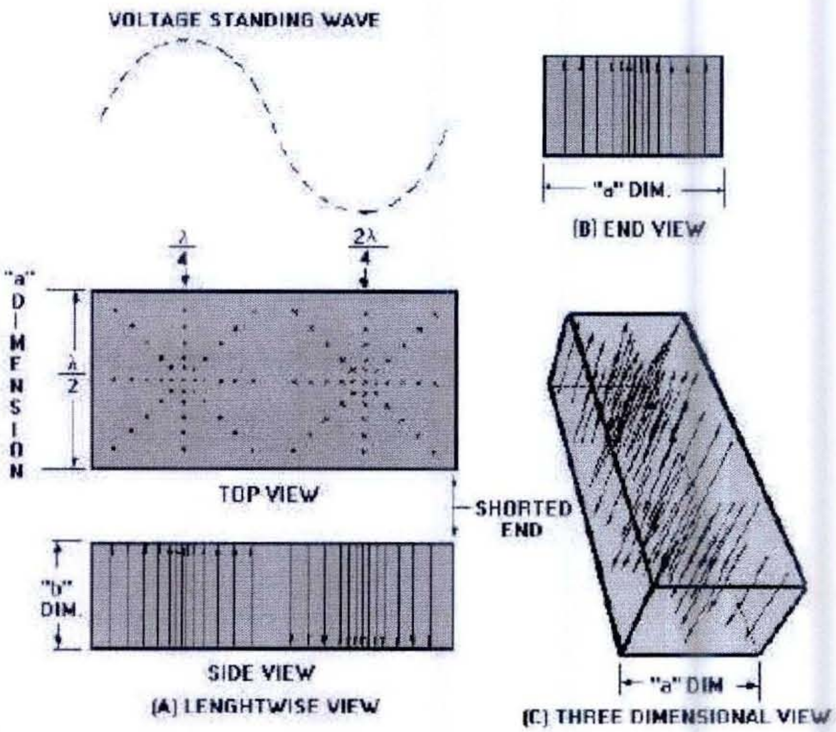


Figure 1.12:_E field of a voltage standing wave across a 1-wavelength section of a waveguide

Two conditions, known as BOUNDARY CONDITIONS, must be satisfied for energy to travel through a waveguide.

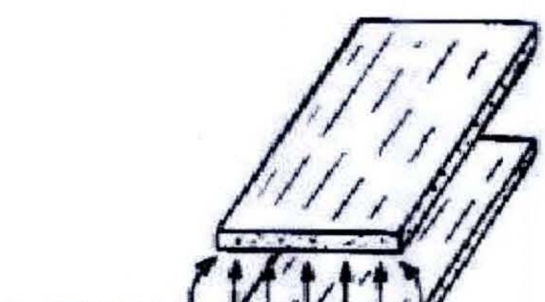


Fig. 1.13Direction of Electric Field of a waveguide(First Boundary condition)

In order for the energy to travel through waveguide and for the electric field to exist at the surface of a conductor it must be perpendicular to the conductor as shown in the above diagram.

H FIELD.—The magnetic field in a waveguide is made up of magnetic lines of force that are caused by current flow through the conductive material of the waveguide. Magnetic lines of force, called H lines, are continuous closed loops. All of the H lines associated with current are collectively called a magnetic field or H field. The strength of the H field, indicated by the number of H lines in a given area, varies directly with the amount of current.

No H lines can form outside the waveguide as long as it is completely enclosed. Figure 1-13 shows a cross-sectional view of the magnetic field pattern .It must be noted in view (A) that the field is strongest at the edges of the waveguide where the current is highest. The minimum field strength occurs at the zero-current points. View (B) shows the field pattern as it appears 1/4 from the end view of the waveguide.

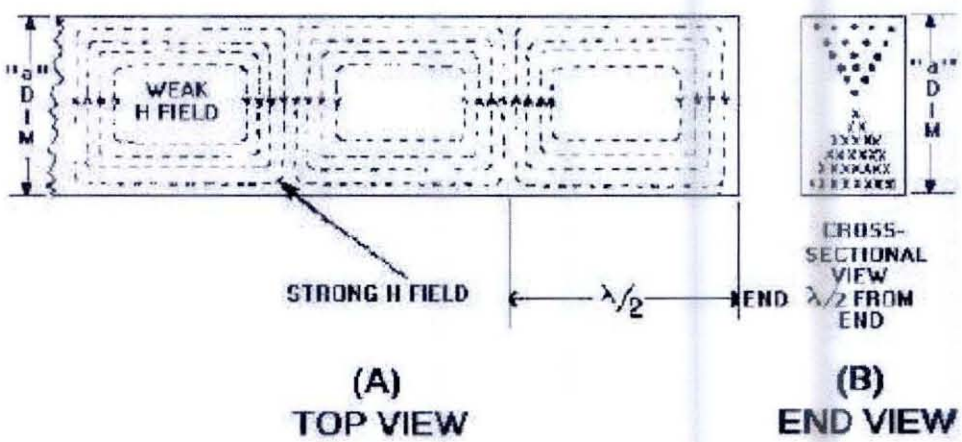


Figure 1.14—Magnetic field in a waveguide three half-wavelengths long.

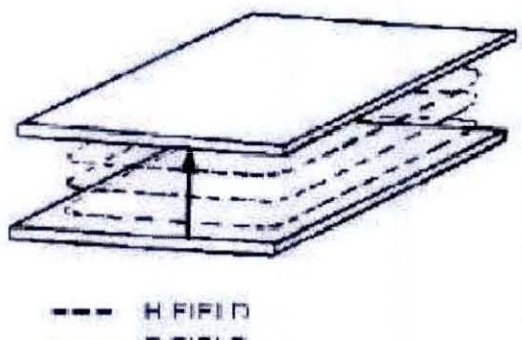


Fig.1.15_H field boundary condition.

The second boundary condition states that , for a varying magnetic field to exist, it must form closed loops in parallel with the conductors and be perpendicular to the electric field.Since an E field causes a current flow that in turn produces an H field, both fields always exist at the same time in a waveguide. If a system satisfies one of these boundary conditions, it must also satisfy the other since neither field can exist alone.

Electromagnetic energy transmitted into space consists of electric and magnetic fields that are at right angles (90 degrees) to each other and at right angles to the direction of propagation[7].

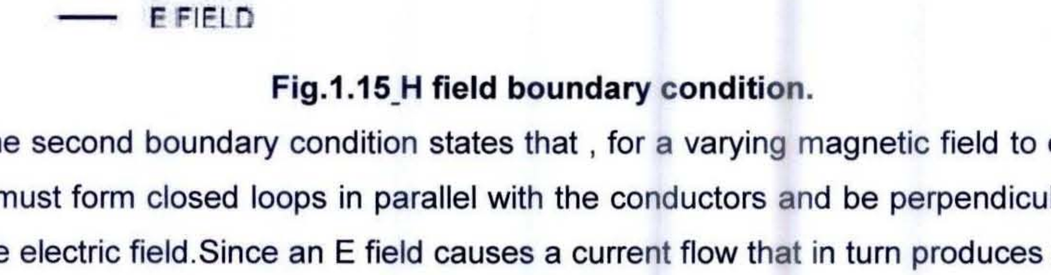


Fig.1.16 Waves traveling through a waveguide

1.7 Horn antenna

Horn antennas are very popular at UHF (300 MHz-3 GHz) and higher frequencies .They often have a directional radiation pattern with a high gain , which can range up to 25 dB in some cases, with 10-20 dB being typical. Horns have a wide impedance bandwidth, implying that the input impedance is slowly varying over a wide frequency range (which also implies low values for S11 or VSWR). The bandwidth for practical horn antennas can be on the order of 20:1 (for instance, operating from 1 GHz-20 GHz), with a 10:1 bandwidth not being uncommon.

The gain often increases (and the beamwidth decreases) as the frequency of operation is increased. Horns have very little loss, so the directivity of a horn is roughly equal to its gain.

Horn antennas are somewhat intuitive and not relatively simple to manufacture. In addition, acoustic horns also used in transmitting sound waves (for example, with a megaphone). Horn antennas are also often used to feed a dish antenna, or as a "standard gain" antenna in measurements.

1.7.1 Why Horn Antenna

As we are dealing with a very high frequency of 60 GHz, a horn antenna is more suitable over other antennas for this project, as wired antennas are used at very low frequency.
However the main advantage of the horn antenna is that it provides a significant level of directivity and gain. For greater levels of gain the horn antenna should have a large aperture. Also to achieve the maximum gain for a given aperture size, the taper should be long so that the phase of the wave-front is as nearly constant as possible across the aperture.
Another reason to choose horn antenna is- it is easy to build as fabrication not needed unlike microstrip patch antenna. A microstrip patch antenna is a

narrowband, wide-beam antenna fabricated by etching the antenna element pattern in metal trace bonded to an insulating dielectric substrate with a continuous metal layer bonded to the opposite side of the substrate which forms a groundplane. This process is expensive and time consuming.[8]

1.7.2 Classification of horn antenna

1.7.1 Pyramidal horn

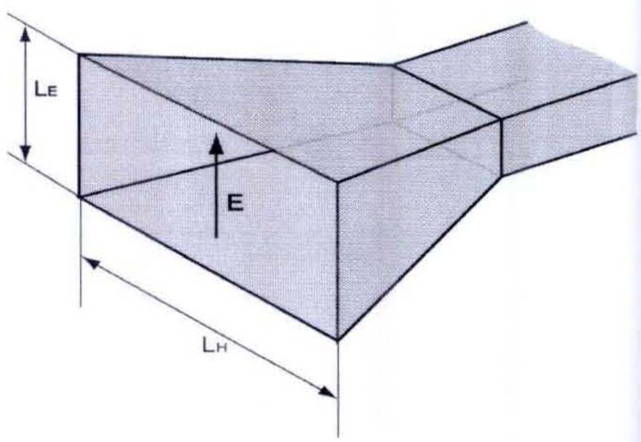


Fig.1.17 Pyramidal horn

1.7.2 Conical horn

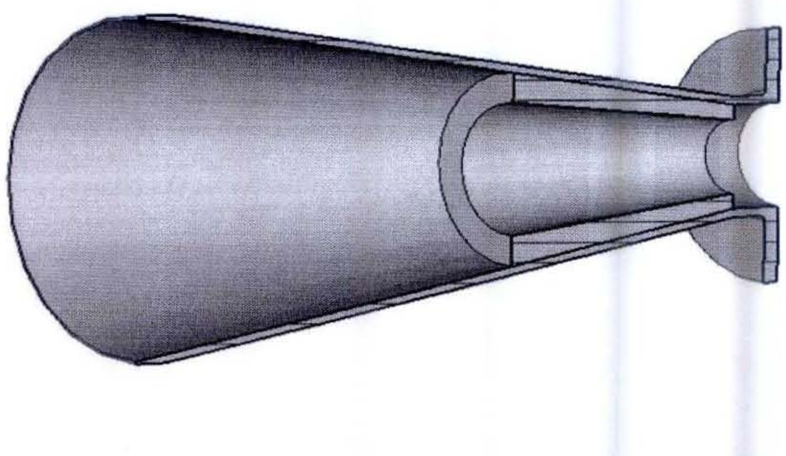


Fig.1.18 Conical Horn

1.8 Dipole

A dipole is a very basic antenna structure consisting of two straight collinear wires as depicted in Figure 1. The first thing to notice about a dipole is that it has two parts, hence the term "di" in its name.

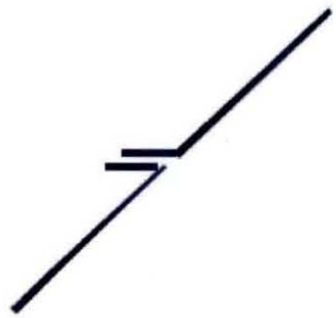


Fig.1.19 Dipole

It is widely used on its own, and it is also incorporated into many other RF antenna designs where it forms the radiating or driven element for the antenna.

Adipole is an antenna that is a resonant 1/2 wave in length. It has 2 electric poles (at the ends) of opposite polarity at any given instance. A dipole can be fed with RF energy anywhere along its length although center feed is the most common followed by end feed[9].

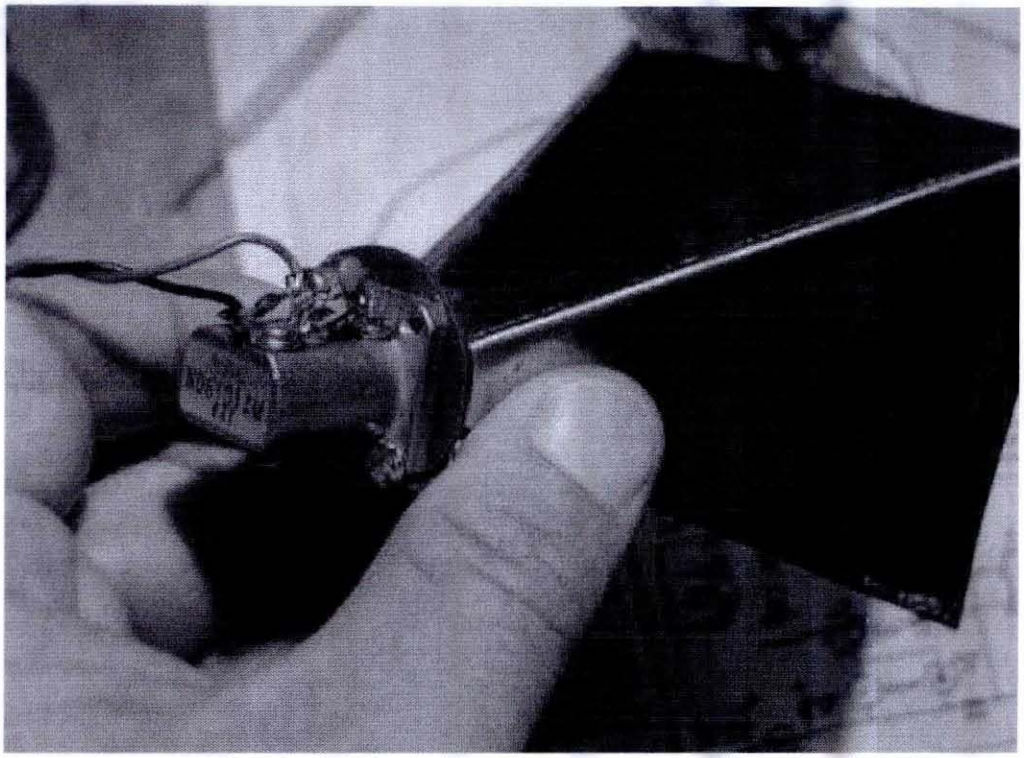


Fig.1.20 Connection of dipole with waveguide of horn antenna

The open ended waveguide attached with the horn antenna must be added with the dipole. The waveguide end must be closed with a metal part so the waves generating from the dipole can reflect from the closed end. The above diagram shows the connection of dipole with waveguide of horn antenna.

1.9 Oscillator

In order to make 60GHz voltage source generator it is important to know the operations of simple oscillator and Crystal oscillator.

1.9 Oscillator

Oscillators are active devices that generate power at a frequency determined by circuit parameters. The circuit forms a harmonic oscillator for current and will resonate

An important property of RLC circuit is its ability to resonate at a specific frequency, Resonance occurs because energy is stored in two different ways: in an electric field as the capacitor is charged and in a magnetic field as current flows through the inductor. Energy can be transferred from one to the other within the circuit and this can be oscillatory. The resonance frequency in a series or parallel resonant circuit has the value[10]

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

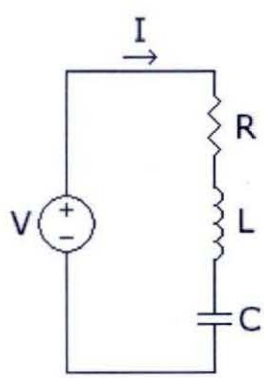


Figure.1.21 RLC series circuit

V - the voltage of the power source

I - the current in the circuit

R - the resistance of the resistor

L - the inductance of the inductor

C - the capacitance of the capacitor

1.9.1 Crystal Oscillator

A crystal is a solid material that vibrates at a specific frequency when energy is supplied.
When a crystal of quartz is properly cut and mounted, it can be made to distort in an electric field by applying a voltage to an electrode near or on the crystal. This property is known as piezoelectricity. When the field is removed, the quartz will generate an electric field as it returns to its previous shape, and this can generate a voltage. The result is that a quartz crystal behaves like a circuit composed of an inductor, capacitor and resistor, with a precise resonant frequency.

Quartz has the further advantage that its elastic constants and its size change in such a way that the frequency dependence on temperature can be very low. The specific characteristics will depend on the mode of vibration and the angle at which the quartz is cut (relative to its crystallographic axes) Therefore, the resonant frequency of the plate, which depends on its size, will not change much, either. This means that a quartz clock, filter or oscillator will remain accurate.

A quartz crystal can be modeled as an electrical network with a low impedance (series) and a high impedance (parallel) resonance point spaced closely together

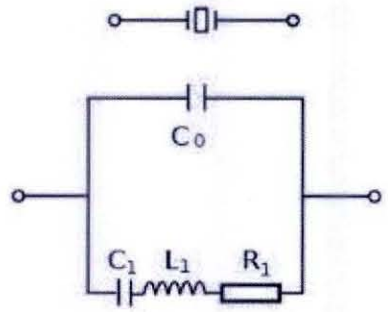


Figure1.22 : Crystal oscillator

$$\Rightarrow \omega_s = \frac{1}{\sqrt{L_1 \cdot C_1}}, \quad \omega_p = \sqrt{\frac{C_1 + C_0}{L_1 \cdot C_1 \cdot C_0}} = \omega_s \sqrt{1 + \frac{C_1}{C_0}} \approx \omega_s \left(1 + \frac{C_1}{2C_0}\right) \quad (C_0 \gg C_1)$$

where s is the complex frequency ($s = j\omega$), ω_s is the series resonant frequency in radians per second and ω_p is the parallel resonant frequency in radians per second.

However, for this project crystal is required but unfortunately it is not available in our country. It is not possible to build a source without the crystal for such a high frequency range of 60GHz.

Chapter 2

Design and Calculations

2.1 Waveguide

WAVEGUIDE SIZE CHART

USA WR-(size)	Europe WG-(size)	START Frequency, (Ghz)	STOP Frequency (Ghz)	*TE10 CUTOFF* Frequency, (GHz)	*TE20 CUTOFF* Frequency, (GHz)	Inside Dimension "a"	Inside Dimension "b"	Inside Tol: (±)	Wall Thickness (in)
2300		.32	.49	0.256	0.51	23.000	11.500	0.02	.15
2100		.35	.53	0.28	0.56	21.000	10.500	.02	.125
1800		.41	.62	0.32	0.65	18.000	9.000	0.02	.125
1500		.490	.750	0.39	0.78	15.000	7.500	.015	0.125
1150		0.64	0.96	0.51	1.02	11.500	5.750	.015	.125
975		.750	1.12	0.60	1.21	9.750	4.875	.010	.125
770		.960	1.46	0.76	1.53	7.700	3.850	.010	.125
650	6	1.120	1.70	0.908	1.82	6.500	3.250	.010	.080
510		1.45	2.20	1.157	2.31	5.100	2.550	.010	.080
430	8	1.70	2.60	1.372	2.74	4.300	2.150	.008	.080
340	9A	2.20	3.30	1.736	3.47	3.400	1.700	.005	.080
284	10	2.60	3.95	2.078	4.15	2.840	1.340	.005	.080
229	11A	3.30	4.90	2.577	5.15	2.290	1.145	.005	.064
187	12	3.95	5.85	3.152	6.3	1.872	0.872	.005	.064
159	13	4.90	7.05	3.711	7.42	1.590	0.795	.004	.064
137	14	5.85	8.20	4.301	8.60	1.372	0.622	.004	.064
112	15	7.05	10.00	5.259	10.51	1.122	0.497	.004	.064
102		7.00	11.00	5.785	11.57	1.020	0.510	.003	.064
90	16	8.20	12.40	6.557	13.11	.900	.400	.003	.050
75	17	10.00	15.00	7.868	15.73	.750	.375	.003	.050
62	18	12.40	18.00	9.486	18.97	.622	.311	.002	.040
51	19	15.00	22.00	11.574	23.14	.510	.255	.002	.040
42	20	18.00	26.50	14.047	28.1	.420	.170	.002	.040
34	21	22.00	33.00	17.328	34.71	.340	.170	.002	.040
28	22	26.50	40.00	21.08	42.15	.280	.140	.002	.040
22	23	33.00	50.00	26.34	52.69	.224	.112	.001	.040
19	24	40.00	60.00	31.36	62.78	.188	.094	.001	.040
15	25	50.00	75.00	39.86	79.74	.148	.074	.001	.040
12	26	60.00	90.00	48.35	96.74	.122	.061	.0005	.040
10	27	75.00	110.00	59.01	118.0	.100	.050	.0005	.040
8	28	90.00	140.00	73.60	147.53	.0800	.0400	.0003	.020
7	29	110.00	170.00	90.90	181.5	.0650	.0325	.0002	.020
5	30	140.00	220.00	115.7	231.42	.0510	.0255	.0002	.020

From the above chart[8], the frequency range of 10GHz to 15GHz is chosen to calculate the horn antenna design parameters. This frequency range has a size of WR-75(USA) and WG-17(Europe). The waveguide dimensions found from this range are wider dimension 'a' of 0.75 inches and narrower dimension 'b' of 0.375 inches.

In general, 'a' dimension as suggested in the previous chapter must be 0.7 of the wavelength and 'b' dimension between 0.2 to 0.5 wavelength.

Now calculating whether the value obtained from the chart matches the criteria mentioned above.

Calculating waveguide dimensions

For 10 GHz

$$f := 10 \cdot 10^{9} s^{-1}$$

$$\lambda := \frac{c}{f}$$

$$\lambda = 0.03\,m$$

$$a := 0.7 \cdot \lambda$$

$$a = 0.021\,m$$

$$b1 := 0.2 \cdot \lambda \qquad b2 := 0.5 \cdot \lambda$$

$$b1 = 5.996 \times 10^{-3}\,m \qquad b2 = 0.015\,m$$

$$b := \frac{(b1 + b2)}{2}$$

$$b = 0.01\,m$$

Comparison between standard and calculated values

- 10 GHz

	Standard Values (cm)	Calculated values (cm)	% difference
a	1.905	2.1	0.102
b	0.952	1	0.05

As it is seen from the above table, the percentage difference came to be less so our calculated values came to be correct.

2.2 Horn antenna

In order for accurate design of an optimum gain horn antenna all the design parameters and formulas are taken from an electronic letter[12].

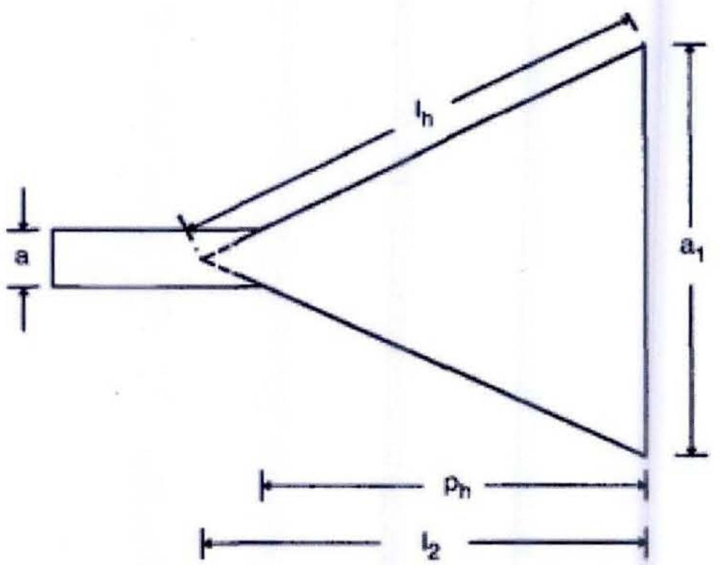


Fig.1.23 H-plane dimensions of a pyramidal horn antenna

$$u_1 = \left[\sqrt{q^3 + r^2} + r\right]^{1/3} - \left[\sqrt{q^3 + r^2} - r\right]^{1/3}$$

$$q = \frac{2}{9}g(4g - ab)$$

$$r = \frac{1}{3}g^2\left(\frac{2}{3}a^2 - b^2\right)$$

$$g = \frac{G\lambda^2}{6.464}$$

$$b_1 = \frac{-z + \sqrt{z_1^2 + 4z_2}}{2}$$

$$z_1 = -\frac{b}{2} + \sqrt{\frac{b^2}{4} + u_1}$$

$$z_2 = \sqrt{\frac{u_1^2}{4} + \frac{2}{3}g^2} - \frac{u_1}{2}$$

$$a_1 = g/b_1$$

$$l_e = \frac{b_1}{2}\sqrt{1 + \left(\frac{b_1}{\lambda}\right)^2}$$

$$l_h = a_1\sqrt{\frac{1}{4} + \left(\frac{a_1}{3\lambda}\right)^2}$$

$$p_e = \frac{l_1(b_1 - b)}{b_1} \qquad p_h = \frac{l_2(a_1 - a)}{a_1}$$

2.2.1 60 GHz horn antenna calculations

Different antenna parameters for 10 GHz frequency

For frequency range 60 - 90 GHz waveguide dimensions are :

$a1 := .122\ cm$

$b1 := .061\ cm$

where waveguide size is WG-17(Europe) and WR-75(USA)
considering a gain of 20 dB

$Gi := 100$

Our purpose is to deal with 60GHz range so taking the above dimensions to calculate different parameters.

frequency $fi := 60 \cdot 10^9 s^{-1}$

speed of light $c = 2.998 \times 10^8 \frac{m}{s}$

wavelength $\lambda := \frac{c}{fi}$

$\lambda = 4.997 \times 10^{-3} m$

$\lambda 1 := .5\ cm$

Now we need to calculate the dimensions of the antenna and for that we need to calculate few parameters which are found out below.

$$g1 := \frac{Gi \cdot \lambda 1^2}{6.464}$$

$g1 = 3.868$ cm

$$r := \frac{1}{3}(g1)^2 \cdot \left[\left(\frac{2}{3}a1^2\right) - b1^2\right]$$

$r = 0.031$ cm

$$q := \frac{2}{9}g1 \cdot (4 \cdot g1 - a1 \cdot b1)$$

$q = 13.29$ cm

+

$$u1 := \sqrt[3]{\left(\sqrt{q^3 + r^2} + r\right)} - \sqrt[3]{\left(\sqrt{q^3 + r^2} - r\right)}$$

$u1 = 1.551 \times cm^3$

$$Z2 := \sqrt{\frac{u1^2}{4} + \left(\frac{2}{3}g1^2\right)} - \frac{u1}{2}$$

$Z2 = 3.157$ cm

$$Z1 := \left[\frac{-b1}{2} + \sqrt{\left(\frac{b1^2}{4}\right) + u1}\right]$$

$Z1 = 0.019$

$$B1 := \frac{\sqrt{Z1^2 + 4 \cdot Z2}}{2}$$

$B1 = 1.777$ cm

$$A1 := \frac{g1}{B1}$$

$A1 = 2.177$ cm

$$Le := \frac{B1 \cdot \sqrt{1 + \left(\frac{B1}{\lambda 1}\right)^2}}{2} \qquad Lh := A1 \cdot \sqrt{\left(\frac{1}{4}\right) + \left(\frac{A1}{3 \cdot \lambda 1}\right)^2}$$

$Le = 3.28$ cm $\qquad Lh = 3.341$ cm

$$L1 := \sqrt{Le^2 - \left(\frac{B1}{2}\right)^2} \qquad L2 := \sqrt{Lh^2 - \left(\frac{A1}{2}\right)^2}$$

$L1 = 3.157$ cm $\qquad L2 = 3.159$ cm

$$Ph := L2 \cdot \frac{(A1 - a1)}{A1} \qquad Pe := L1 \cdot \frac{(B1 - b1)}{B1}$$

$Ph = 2.982$ cm $\qquad Pe = 3.049$ cm

Now , calculating the gain using this above values :

$$G2 := 6.464 \cdot A1 \cdot \frac{B1}{\lambda 1^2}$$

$G2 = 100$

So , the above diameters are correct to build the horn antenna of 20 dB gain.

2.2.2 10GHz horn antenna calculations

<u>Different antenna parameters for 10 GHz frequency</u>

For frequency range 10 - 15 GHz waveguide dimensions are :

$a = .750$ inches

$b = .375$ inches

Converting into cm we get

$a1 := 1.9$ cm

$b1 := .95$ cm

where waveguide size is WG-17(Europe) and WR-75(USA)
considering a gain of 20 dB

$Gi := 100$

Our purpose is to deal with 10GHz range so taking the above dimensions to calculate different parameters.

frequency $fi := 10 \cdot 10^9 s^{-1}$

speed of light $c = 2.998 \times 10^8 \frac{m}{s}$

wavelength $\lambda := \frac{c}{fi}$

$\lambda = 0.03\,m$

$\lambda 1 := 3$ cm

Now we need to calculate the dimensions of the antenna and for that we need to calculate few parameters which are found out below.

$$g1 := \frac{Gi \cdot \lambda 1^2}{6.464}$$

$$g1 = 139.233 \quad cm$$

$$r := \frac{1}{3}(g1)^2 \cdot \left[\left(\frac{2}{3}a1^2\right) - b1^2\right]$$

$$r = 9.72 \times 10^3 \quad cm$$

$$q := \frac{2}{9}g1 \cdot (4 \cdot g1 - a1 \cdot b1)$$

$$q = 1.718 \times 10^4 \quad cm$$

$$u1 := \sqrt[3]{\left(\sqrt{q^3 + r^2} + r\right)} - \sqrt[3]{\left(\sqrt{q^3 + r^2} - r\right)}$$

$$u1 = 0.377 \quad cm$$

$$Z2 := \sqrt{\frac{u1^2}{4} + \left(\frac{2}{3}g1^2\right)} - \frac{u1}{2}$$

$$Z2 = 113.495 \quad cm$$

$$Z1 := \left[\frac{-b1}{2} + \sqrt{\left(\frac{b1^2}{4}\right) + u1}\right]$$

$$Z1 = 0.301$$

$$B1 := \frac{\sqrt{Z1^2 + 4 \cdot Z2}}{2}$$

$$B1 = 10.654 \quad cm$$

$$A1 := \frac{g1}{B1}$$

$$A1 = 13.068 \quad cm$$

$$Le := \frac{B1 \cdot \sqrt{1 + \left(\frac{B1}{\lambda 1}\right)^2}}{2}$$

$$Le = 19.655 \quad cm$$

$$Lh := A1 \cdot \sqrt{\left(\frac{1}{4}\right) + \left(\frac{A1}{3 \cdot \lambda 1}\right)^2}$$

$$Lh = 20.068 \quad cm$$

$$L1 := \sqrt{Le^2 - \left(\frac{B1}{2}\right)^2}$$

$$L1 = 18.92 \quad cm$$

$$L2 := \sqrt{Lh^2 - \left(\frac{A1}{2}\right)^2}$$

$$L2 = 18.975 \quad cm$$

$$Ph := L2 \cdot \frac{(A1 - a1)}{A1}$$

$$Ph = 16.216 \quad cm$$

$$Pe := L1 \cdot \frac{(B1 - b1)}{B1}$$

$$Pe = 17.233 \quad cm$$

Now , calculating the gain using this above values :

$$G2 := 6.464 \cdot A1 \cdot \frac{B1}{\lambda 1^2}$$

$$G2 = 100$$

So , the above diameters are correct to build the horn antenna of 20 dB gain.

2.3 Dipole design

First it is important to find some coaxial AWG wire. The thicker the wire the greater the operating bandwidth of the antenna. Often 12 AWG is used.

Next step is to cut the wire for the frequency at which it will operate. The formula shown below is used to calculate the dipole length, which is more accurate.

Length (feet) = 468 / Frequency (MHz)

or

Length (meters) = 144 / Frequency (MHz)

However, the dipole length is usually half of the wavelength calculated from the equation below. But the length of the dipole calculated this way gives comes much longer.

wavelength $\lambda := \frac{c}{fi}$

Dipole calculations

- Two formulas

Formula 1:

Length (meters) = 144 / Frequency (MHz)

Formula 2 :

Dipole length=wavelength/2

Frequency(GHz)	Wavelength(mm)	Formaula 1(mm)	Formaula 2(mm)
10	30	14	15
60	5	2.4	2.5

A wavelength (or fraction of) in coax cable is physically shorter than calculated from the formula for wavelength. As the formula used to calculate the wavelength was probably meant for calculating a "free space" (air) wavelength. In fact, RF energy moves more slowly in a transmission line than it does in air because the materials used in cable slow it down. Therefore, a wavelength in cable takes up less length.

Its important to add enough extra length to these dimensions calculated from the dipole formula for wrapping around the insulators. Its important to have two equal lengths of wire.

Insulators should support the weight of the wire, withstand ultraviolet radiation from the sun, and not absorb moisture. The center insulator will only have a small voltage across it

There should be a wire attached to each end of the center insulator and one insulator to the end of each free wire.

This version of the dipole will be fed with coax cable. Now the coaxial cable is separated as shown in the diagram.

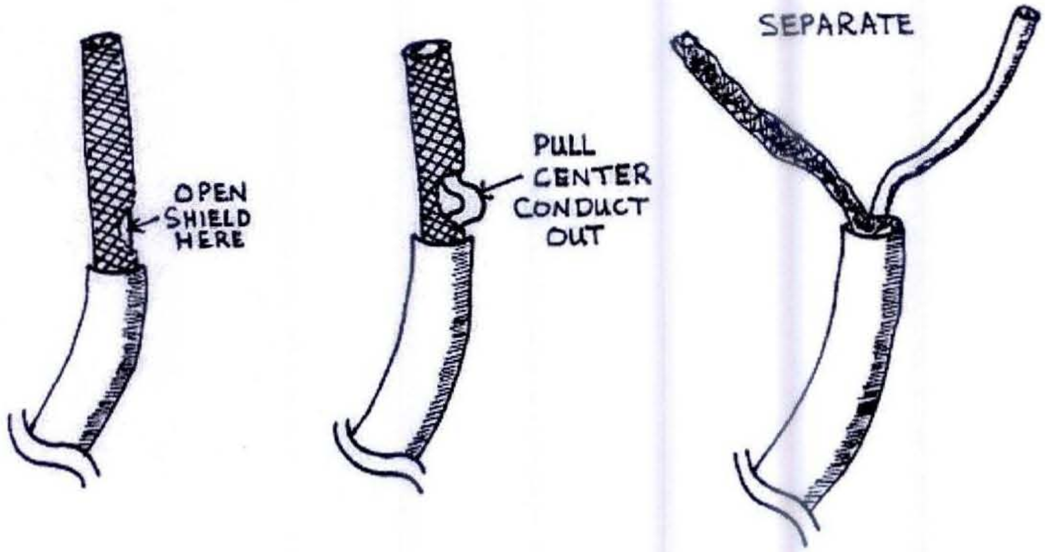


Fig.1.24 How to separate the coaxial cable in a dipole

Calculation of dipole length:

For 60 Ghz frequency dipole length

$$L1 := \frac{144}{60000}$$

$$L1 = 2.4 \times 10^{-3} \quad m$$

For 10 Ghz frequency

$$L2 := \frac{144}{10000}$$

$$L2 = 0.014 \quad m$$

For 100 MHz frequency dipole length

$$L3 := \frac{144}{100}$$

$$L3 = 1.44 \quad m$$

Chapter 3

3.1 Conclusions:

We calculated the parameters for different kinds of antenna and made a 10 GHZ transmittings antenna so that we can test this antenna with the receiving antenna which is available in the lab. But due to absence of source for 10GHZ as the source available in the lab had the output port is incorporated in to the antenna system so we could not test it. But when the source will be available we can make a 60GHz source and can test polarization diversity for 60 GHz.

As 60GHZ is a relatively new concept and we are the first group to research on it we had could not make more progress as it consumed a lot of time finding the design parameters for this frequency. Even the materials needed for testing a 60 GHZ antenna are not readily available in this country yet.

Further work:

We need 3-4 more weeks to get a voltage source and crystal oscillator to test 10 GHz antenna and to make 60 GHz voltage source in order that we can test different kinds of polarization diversity.

References

[1] http://www.mindstien.net

[2] http://www.tpub.com/content/neets/14182/css/14182_111.htm

[3] 60 GHz Wireless Communications: Emerging Requirements and Design Recommendations Robert C. Daniels and Robert W. Heath, Jr. The University of Texas at Austin

[4] http://www.khargoosh.ir/fa/images/electromagnetic-spectrum.jpg

[5]http://www.tudelft.nl/live/pagina.jsp?id=e25715a1-49e1-43a3-9e85-8576c9e2493f&lang=en

[6] Chris Koh, "The Benefits of 60 GHz Unlicensed Wireless Communications"http://wireless.fcc.gov/outreach/2004broadbandforum/comments/YDI_benefits60GHz.pdf

[7] http://www.tpub.com/content/neets/14183/css/14183_14.htm

[8] http://www.engineeringspecialties.net/waveguide.htm

[9] http://www.hottconsultants.com/pdf_files/dipoles-1.pdf

[10] http://en.wikipedia.org/wiki/RLC_circuit

[11] http://en.wikipedia.org/wiki/Crystal_oscillator

[12] Selvan K. T., "Accurate design method for optimum gain pyramidal horns" IEEE Electronic Letter 18th Feb 1999