Transparent and Flexible Coplanar Antenna for 5G Mobile Communication

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DISCLAIMER

This thesis work is submitted as a part of partial requirement for the degrees of BSc in Electrical and Electronic Engineering and BSc in Electronic and Communication Engineering at BRAC University. We hereby declare that this work is the product of our own labor except where indicated in the paper. This paper has not been previously submitted anywhere.

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ABSTRACT

Over the few decades wireless mobile communication technology has developed tremendously although the inception of this is not so ancient. Recently the electronic device fabrication technologies are moving towards transparency and flexibility. That's why for accelerating the journey towards communication technical revolution, researchers are now mostly focused on designing transparent and flexible antenna. As we are moving to 5th generation (5G) wireless mobile communication, we suppose transparent and flexible antenna would enhance its possibility. Now we are proposing an antenna that would be visibly transparent using AgHT-8 as conductive material. We mostly focused on studying the characteristics of different materials to reach our goal and used CST microwave studio for simulating possible antenna design and analyzing return loss, radiation pattern, efficiency and directivity of them. Then we looked for the perfect material like transparent conductive oxide (TCO) like Indium Tin Oxide (ITO). We became successful in designing an antenna using AgHT-8 material over Polyethylene Terephthalate (PET) substrate operating in 28GHz with maximum transparency and flexibility possible enabling 5G mobile communication. Performance tuning of the Y- shaped antenna changing the angle between two arms of Y-shaped antenna and effect of adding lumped element (resistor) is discussed thoroughly.

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CHAPTER 1

1. Introduction:

Over the few decades wireless mobile communication technology has developed tremendously although the inception of this is not so ancient. Fifth generation mobile communication is about to be launched in 2020 whereas the word '5G' itself became the topic of discussion apart from the researchers from the second half of the year 2014 [1]. Obviously it is supposed to have better coverage than others and possess high bit rate with the lowest battery consumption [2]. As per the requirement of 5G mobile communication technology, proposed antenna can be operable with desired performance at 28GHz frequency. The frequency can be tuned by changing the angle between two arms of 'Y' shaped antenna. Wireless signals might be shifted to higher frequency range for 5G communications with lower range of wavelength which could be up to centimeter and millimeter wave. Consequently, it will require a large bandwidth which will enable wireless traffic congestion properly and will generate a few challenges for designer [3]. Deprivation of line of sight communication can be a challenge for the researchers which can be avoided by using microcell technology [4]. The proposed antenna is about to provide tremendous facilities like transparency and flexibility. The idea of transparent electronics implemented in reality during the verge of last Millennium. In this paper to design transparent and flexible antenna we needed to consider the transparency and flexibility as well. Generally we comprehend by the word of transparent material is transparent conductive oxides or TCOs. As AgHT-8 material is used over polyethylene terephthalate (PET) which sheet resistance can be tuned to be the desired one, it would have better conductivity as well as better traded transparency compared to Indium Tin Oxide (ITO) which is fragile and can not achieve the best flexibility. The antenna will provide maximum aesthetic value as it can be usable in transparent glass windows, car windows, windshield and future generation transparent mobile phone. Another challenge in using transparent antenna is that human body can be affected by the high dielectric constant of the chosen materials [5]

CHAPTER 2

2. Background Study

2.1 Antenna:

Antenna is a very vital structure for radio wave communication. Antenna is necessary for two principal reasons which are efficient radiation and matching wave impedance for minimal reflection [6]. A generalized definition of antenna would be a metallic device for transmitting and catching radio waves [7]. It can also be defined as a device associated with transformation of free space wave into guided wave and guided wave into free space wave [7]. Antennas are supposed to convert electron into photons and vice versa. In terms of commencing wireless communication system antenna is required to optimize or strengthen the electromagnetic energy in multiple directions and inhibit in others. This is how antenna acts as a directional device in addition to a probing device [7]. For improvised system performance a good antenna design can play a very important role. The purpose of antenna in communication system is similar kind of purpose that served by eyes to human [7]. Over the past five decades antenna came hand in hand with the progression of communication technology used in aircrafts, ships, automobiles etc. There are various types of antenna like wire antenna, aperture antenna, microstrip antenna, array antenna, reflector antenna, lens antenna. In accordance of needs various antennas are utilized for various applications.

2.2 Radiation Pattern:

Antennas don't radiate uniformly in all directions. The graph that describes the relative far zone field strength versus direction at a fixed distance from an antenna is called radiation pattern of the antenna or simply the antenna pattern. According to Balanis, radiation pattern is defined as a mathematical function or graphical representation of the radiation properties of the antenna as a function of space coordinates. Radiation pattern is inclusive of radiation intensity, field strength, power flux density, polarization or directivity phase [7]. Two dimensional and three dimensional spatial distribution of radiated energy is represented as a function of observer's location along a path or surface of fixed radius which is the main concern of radiation property [7]. It is defined in terms of θ and ϕ in spherical coordinate system. Field strength vesus θ is actually the Electric field or E-field pattern where field strength versus ϕ shows magnetic or H-field pattern.

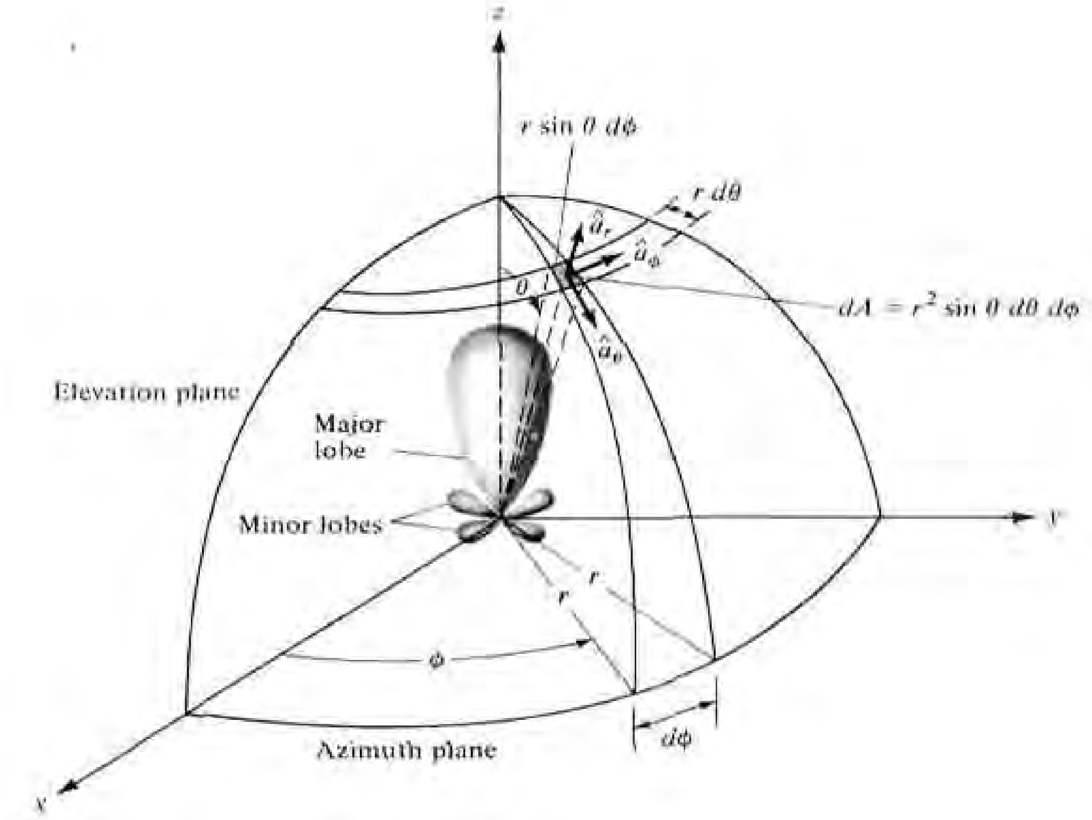


Fig 2.1: Coordinate system for antenna analysis

E-plane: E- plane pattern is actually the representation of electric field in terms of direction of maximum radiation energy [8]. For two dimensional calculation it is measured by keeping ϕ constant.

H-plane: H-plane pattern is actually the representation of magnetic field in terms of direction of maximum radiation energy [8]. For two dimensional calculation it is measured by keeping $\theta = \frac{\pi}{2}$constant.

2.3 Radiation pattern lobe:

Radiation pattern lobe can be defined as a region of strong radiation intensity bounded by weak one. Various parts of radiation pattern are referred to as lobes. They are classified as major, minor, side and back lobes [7].

2.4 Bandwidth:

Bandwidth is defined as the particular range of frequency [9]. It's definition can also be given by the ratio of the higher to lower frequency of acceptable operation [10]. For narrowband antenna bandwidth is the percentage of the difference of frequency over the center frequency. The expression for bandwidth can be such as:

$$BW= \frac{f_H - f_L}{f_c} \times 100\%$$

Where, f_H= Upper Frequency

f_L= Lower Frequency

f_C= Centre Frequency

2.5 Polarization:

Polarization of an antenna in a certain direction can be stated as the polarization associated with radiation or reception of transmitted wave of an antenna. When the direction is not properly defined the polarization in the direction of maximum gain is taken into account. Moreover polarization of transmitted energy varies according to the direction of the centre of antenna. It is the characteristics of an electromagnetic wave describing the time-varying direction and relative magnitude of the electric-field vector [8]. If the receiving antenna polarization does not match with the polarization of the received electromagnetic wave then there would be power loss. Types of polarization like linear, circular and elliptical must be matched.

Linear Polarization: If the electric field vector at a point is oriented along the same straight line at every instant of time then that wave is considered to be polarized linearly at that point. A linearly polarized wave would be horizontally polarized electric field is parallel to the earth and vertically polarized if the electric field is perpendicular to the earth surface [7].

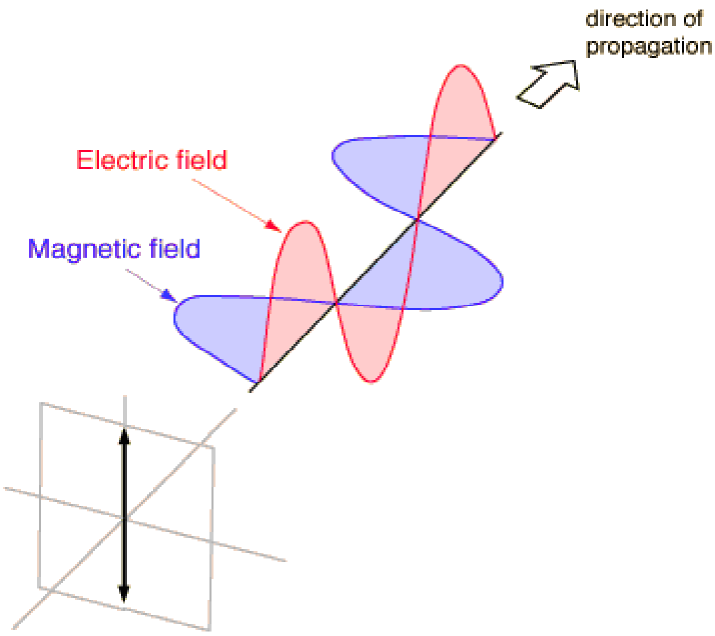


Fig. 2.2 : Linear Polarization[10]

Circulation Polarization: The receive wave would be recognized as circularly polarized at a certain point in space if the electric field vector remains constant in length but rotate around a circular path. In circular polarization two field component has phase difference of 90°.

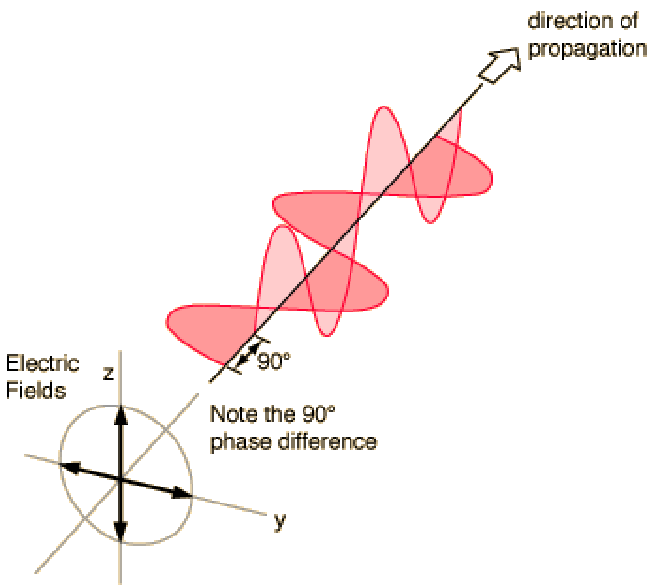


Fig 2.3: Circular Polarization [10]

Elliptical Polarization: This is similar to the circular polarization except the phase difference between two wave components is less than 90°.

2.6 Return Loss:

Return loss is a parameter of importance during the connection of an antenna. The signal source output and input can be sorted by return loss. The return loss is closely connected with the impedance matching and the maximum transfer of power theory. It actually quantify the effectiveness of the antenna. It execute the intensity of reflected signal over the incident signal in dB. It can be measured by the ratio of incident power P_{in} to reflected power P_{ref}. The mathematical

expression for return loss can be stated as:

$$RL = -20 log_{10}|\Gamma|$$

Where, Γ is the reflection coefficient.

$$|\Gamma| = \frac{P_{in}}{P_{ref}} = \frac{Z_{.} \quad Z_o}{Z_L + Z_o}$$

Here z_L = Load impedance, z_o = Initial Impedance.

For proper transmission of power, the P_{in} must be higher than P_{ref} thus the ratio becomes higher. Unless the resonance might occur which will have impact on efficiency. In most practical cases the value of return loss less than -10 dB is considered good enough.

2.7 Radiation Intensity:

Radiation intensity of an antenna in a particular direction is actually the power that transmitted from the antenna per solid angle. It is a far-field parameter. If we multiply the power density with the distance squared, radiation intensity is obtained [7]. As the time average power per unit solid angle is radiation intensity, the expression can be written as follows

$$\mathbf{U} = \boldsymbol{r^2 W_{rad}}$$

Where, U = Radiation intensity or Power per unit solid angle (Watt/Unit Solid angle) [7]
$and\ W_{rad}$= Radiation Density (Watt/$Meter^2$) [7].

2.8 Directivity:

Directivity of an antenna is referred to a ratio of radiation intensity in a particular direction over the average radiation intensity in all directions. If the direction is not defined then the maximum radiation intensity in any direction is taken into account, whereas the average radiation intensity is equal to whole radiation power over all direction divided by 4π [7]. Actually directivity of an antenna is measured by dividing the radiation intensity at a particular direction by radiation intensity of isotropic source.

Which implies that,

$$\mathbf{D} = \frac{U}{U_0} = \frac{U}{\frac{P_{rad}}{4\pi}} = \frac{4\pi U}{P_{rad}} \ \ldots\ldots \ [7]$$

Here, D = Directivity

U = Radiation Intensity for given direction

U_0= Radiation intensity of an isotropic source

P_{rad}= total radiated power varying over θ and ϕ.

Again if want to measure the maximum directivity instead of using radiation intensity for a particular direction over radiation intensity for isotropic source we need to use maximum radiation intensity over radiation intensity for isotropic source. That would be denoted as D_{max}

2.9 Gain:

Gain is one of the most important parameter in terms of measuring antenna efficiency. It can be defined as the ratio of the radiation intensity in a particular direction over the radiation intensity of antenna power received which radiated isotropically [7]. Directivity and gain is closely related but where direction is the main concern of directivity, in gain whole antenna efficiency along with directional capability is taken into account [7]. The gain we already defined is also known as the absolute gain where the radiation intensity related to the isotropically radiated power is equal to the input power by the antenna and divided by 4π. Here, gain is denoted by G.

$$\mathbf{G} = 4\pi \frac{radiation intensity}{total input power} = 4\pi \frac{U(\theta\phi)}{P_{in}} \ldots\ldots \ [7]$$

There is another term called relative gain which measured by the ratio of power gain in a particular direction over the power gain of a reference antenna in reference direction. Gain is also an actual or realized quantity of lower value than the directivity D due to the ohmic loss and polarization loss. These losses occur power fed to the antenna which is not radiated. A mismatch in feeding the antenna can reduce the gain [12]. A relationship with antenna gain efficiency factor can be taken into consideration.

Thus,

$$\mathbf{G = k \times D} \ldots\ldots [12]$$

Here, k = efficiency factor for dimensionless and it can vary from 0 up to 1.
If the antenna is fully efficient that means 100% efficient then there would be no loss at all hence the directivity and gain will be equal. In decibels as follows $G_{db} = 10log(G)$[13]

2.10 Antenna Efficiency:

Antenna efficiency is one of the major parameter that needs to be taken in consideration while judging overall antenna performance. The total antenna efficiency is denoted by $\boldsymbol{e}_0$. It is responsible for the losses at the input terminal and between the whole structure of the antenna which is caused for reflection because of mismatch between the transmission line and due to conductive and dielectric losses [7]. Actually antenna efficiency presents the power transmitted to antenna and the radiated or dissipated power within the antenna structure. Unfortunately an antenna can not be fully efficient that means 100% efficient. This is why and antenna is said to be the low efficiency antenna which would have the most power delivered to its input terminal but absorbed within the whole antenna structure [8]. Omni-directional patterns are the key components. They will provide superior radiation coverage and will avoid polarization [14]. The formula for measuring antenna efficiency is written as:

$$\boldsymbol{e_0 = e_r e_c e_d} \quad [1]$$

Where ,

e_0 = total efficiency (dimensionless)
e_r = reflection (mismatch) efficiency = (1- $|\Gamma|^2$) (dimensionless)
e_c = conduction efficiency (dimensionless)
e_d = dielectric efficiency (dimensionless)

CHAPTER 3

3. Transparent and Flexible Antenna:

3.1 Transparent Electronics:

The idea of transparent electronics implemented in reality during the verge of last Millennium. Transparent electronic are neither very well conductive nor perfectly transparent [15]. So a fine trade off occurs in between these two characteristics. In this paper to design transparent and flexible antenna we needed to consider the transparency and flexibility as well. Generally we comprehend by the word of transparent material is transparent conductive oxides or TCOs. Moreover, TCOs constitute an unusual class of materials possessing two physical properties combined. One of them is high transparency and another one is high electrical conductivity compared to other transparent materials which are considered mutually exclusive [16].

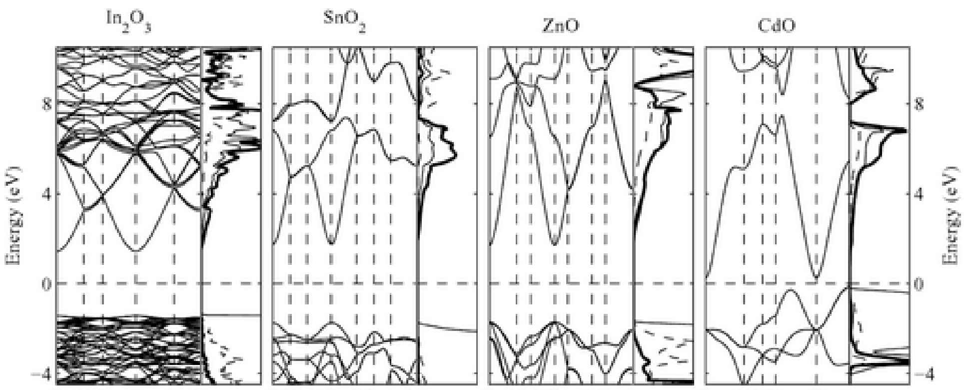


Fig 3.1 : Electronic band structure and partial density states of TCO hosts [15]

Conventional n-type TCO hosts like Indium Oxide, Cadmium Oxide and Zinc Oxide share almost similar kind of chemical, structural and electronic properties [15]. They have densely packed structure with four or six coordinate metal ions. They have general electronic configuration of (n-1)$d^{10}ns^2$. Strong interactions between the oxygen 2p and metal ns orbitals give rise to electronic band structures qualitatively similar for all these oxides [15]. The bonding and nonbonding oxygen, 2p states form the valence band while the conduction band arises from the antibonding Ms-Op interactions. Ms-Op interaction result in a gap between the valence and the conduction bands [15]. TCOs are also used in ovens. Oven windows employ TCOs which is responsible for conserving energy and for maintaining an outside temperature that makes them safe to touch [17]. These TCOs also can be used in rear view glass of automobiles [17]. Another use could be in the touch screen panels of ATMs and PC monitors or mobile phones. It can be used as magnetic shield which is invisible in nature [17]. Transparent antenna have been widely used in various applications, such as vehicle communication and navigation, as well as integration with satellite solar cell panels [18] and with glass for security concerns [19], [20]. For our desired antenna designing we have studied immensely Indium TIn Oxide shortly known as ITO and AgHT-8.

3.1.1 Indium Tin Oxide:

Indium tin oxide is a well known transparent semiconducting oxide thin film [21]. As it has high optical transmittance in the visible and near infrared regions, high reflectance in the infrared region, it has been widely applied in various opto-electronic devices, infrared reflectors and display devices [22]. Along with these applications ITO is also can be used as patches on the antennas according to the recent studies. There are various methods to grow semiconducting and conducting thin films. The specific techniques for the growth of thin ITO film includes chemical vapor deposition (CVD), magnetron sputtering, vacuum evaporation, spray pyrolysis, electron beam evaporation and ion-beam sputtering, etc. Each of the processes has its own advantages and disadvantages [23]. Indium tin oxide has the film thickness of 1000 nanometer with the sheet resistance of $\frac{86\Omega}{m^2}$. ITO has a high band gap of 3.75eV.

Table of comparison between different materials [21]:

Film	Film thickness, nm	Sheet resistance, $\Omega/\square$	Global conductivity, S/m	Transmittance in visible spectrum
Cu_1	1000	0.01	59.59×10^6	reflecting film
Cu_2	10	8.3	12.05×10^6	$45\% < T < 64\%$
ITO	1000	8.6	0.12×10^6	$69\% < T < 86\%$
ITO/Cu/ITO	85/13/85	4.7	1.16×10^6	$28\% < T < 61\%$

ITO is a fragile material, which is why it can not be applied in display [24]. It is a hindrance for designing a flexible antenna. Another problem with ITO is it has low conductivity [24].

3.1.2 AgHT:

AgHT is a 3- layered film made of a silver (Ag) layer sandwiched between two-layers of tin oxide. AgHT is fabricated of a 3- layered conductive coating on a polymer base. This 3 layered coating on a transparent polyethylene terephthalate (PET) or polymer, comprises of a silver layer sandwiched between 2 layers of tin oxide. The coating is electrically conductive and transparent with a visible light transmittance or VLT of 75-82%. The AgHT film has an approximate thickness of 0.175mm. 40% of this thickness is the coating and the balance PET [25].

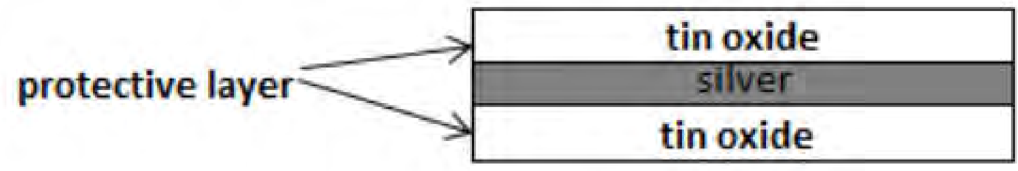


Fig. 3.2: Structure of AgHT [21]

AgHT was the TCO used to demonstrate the feasibility of the first transparent narrowband antenna in 1997 [26]. It was also used for demonstrating first ultra wide band antenna [27]. AgHT is used noticeably in buildings, cars for EMI (Electromagnetic Interference) or RFI (Radio frequency Interference) shielding and infrared reflection applications [25]. There are two types of AgHT available in the market. One is AgHT-8 and AgHT-4 where we used AgHT-8 for better light transmittance for our desired transparent antenna designing. The number 4 or 8 indicates the surface resistance $4\Omega m$ and 8Ωm respectively [25]. The electrical conductivity of AgHT-4 and AgHT-8 are 250000 S/m and 125000 S/m respectively [21].

Properties of Standard AgHT™ Products

	AgHT-4	AgHT-8
Visible Transmittance	Min. 75%	Min. 82%
Infrared Reflectance	Min. 80%	Min. 75%
Surface Resistance (ohms per square)	4.5 ± 1.0	8.0 ± 2.0
Shielding Effectiveness*	24 – 44 dB	20 – 40 dB

Fig. 3.3: Comparison between AgHT-4 & AgHT-8 [25]

Hence the topography has to be as thin as possible which is only possible with thin as possible TCO, the AgHT's conductive layer is as thin as 0.0525 mm where the conductivity have to taken in consideration [25].

The conductivity σ increases actually with the products of the concentration of free electrons and the mobility of the electrons. Where the metal electronic concentration is fixed, the concentration of semiconducting layer can be tuned by depending on the maximum number of electronically active dopant atoms in the lattice structure [25].

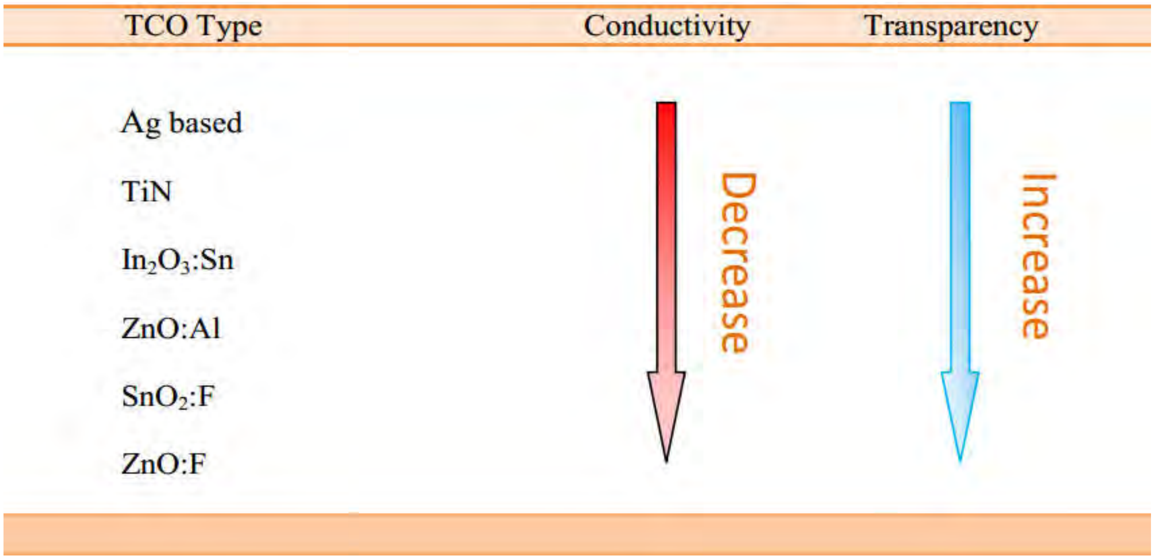


Fig. 3.4: Order of Conductivity and Transparency of TCO [25]

Another beneficiary fact or AgHT-8 is it required less deposition temperature compared to other TCOs.

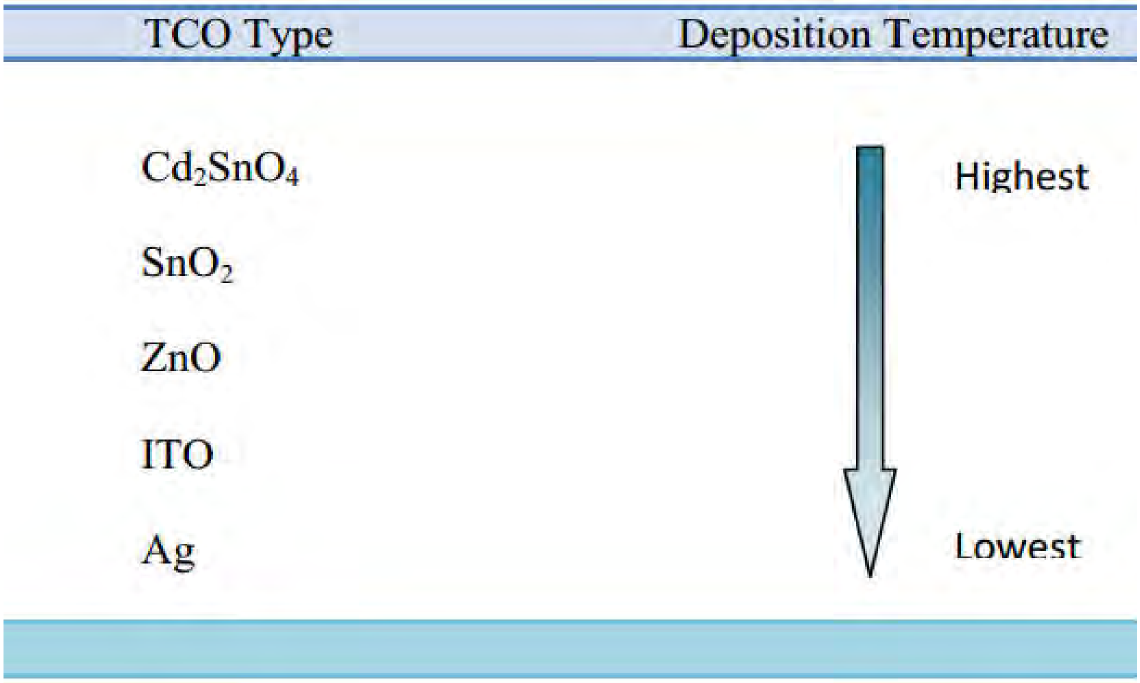


Fig. 3.5: Deposition temperature of TCOs [25]

There are some problem associated with designing AgHT-8 based antenna like low gain [28]. It is so tough to improve the gain of these type of antennas which are made from this transparent conductive material [28]. One of the main reason could be alluded to the 3 layered material composition of AgHT-8; the primary conducting layer, that is the central silver layer which is overlayed with tin oxide and that makes it lossy in nature. Another factor affecting the efficiencies of AgHT-8 material is the surface resistivity which is inversely proportional to conductivity [17]. Gain improvement which is why needs to be additionally explored to make transparent antenna a good commercial option [28].

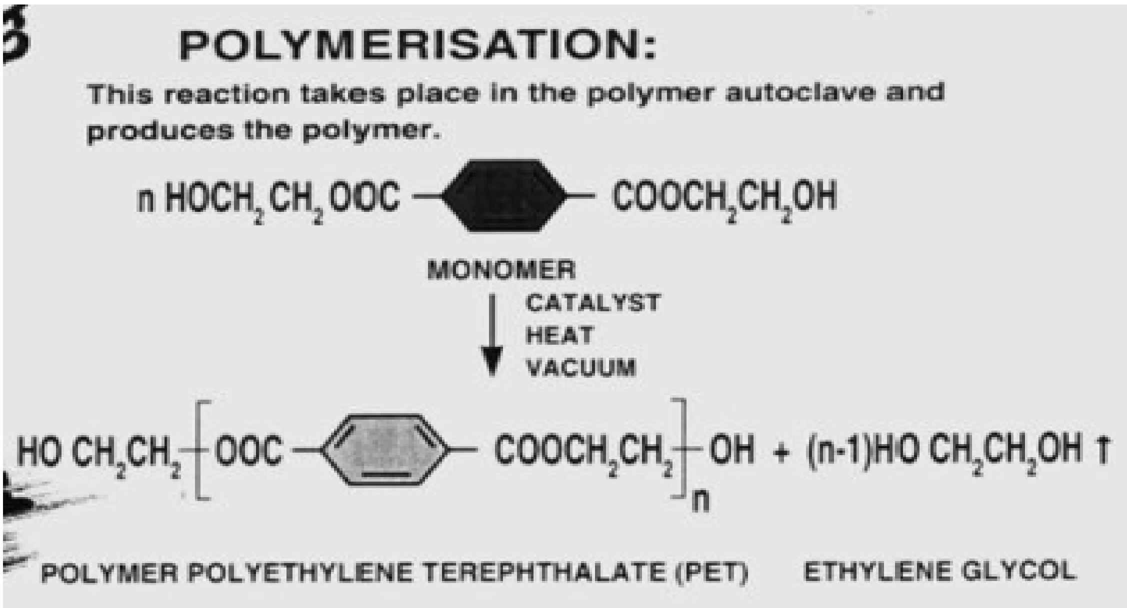
3.2 Flexible Antenna Design:

Wearable and flexible electronics are considered as the hottest trend of modern times. The number of flexible electronics like helmets, smart clothing, smart watch seems to grow in the market exponentially [29]. So the need to operate these devices the need of flexible antenna is obligatory. Moreover, the functionality and effectiveness of such devices are primarily dependent on the properties of antenna used [29]. The deterioration in the resonant frequency and return loss of flexible antennas need to be accounted as they are prone to shift or decrease due to impedance mismatch and change in effective capacitance when the antenna is bent or rolled while using [29]. Along with the conductive flexible material for antenna designing we also need to ensure the flexibility of the substrate material. That is why we are using PET as substrate of AgHT-8 material for better transparency as well as better flexibility.

3.2.1 PET (Polyethylene Terephthalate):

Polyethylene Terephthalate also known as PET is used as the substrate of the proposed transparent and flexible antenna. PET is the main substance which is mainly responsible for the flexibility of the proposed antenna. It is a plastic like substance and has glass like transparency. The optical transparency and mechanical flexibility and seamless integration process will indicate antenna’s promising potential in a variety of transparent antenna applications for future wireless networks [30]

3.2.2 The Production Process of PET:



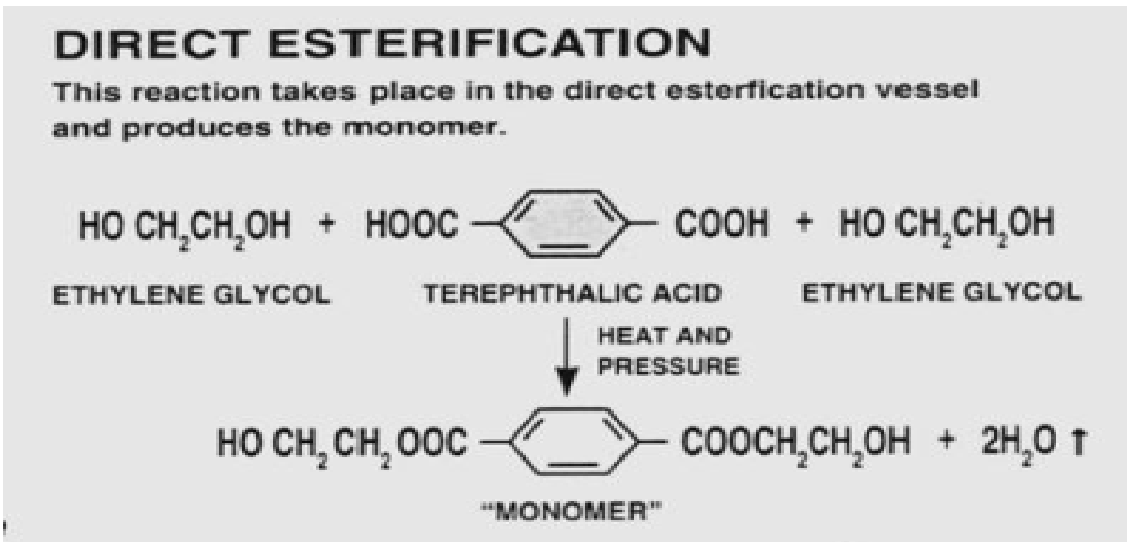


Fig. 3.6: Chemical process of forming PET [17]

Properties of PET (Mylar)

Physical Properties			
Properties	**Typical Value**	**Units**	**Test Method**
Tensile Strength (MD)	28,000	psi	ASTM-D882
Tensile Strength (TD)	34,000	psi	ASTM-D882
Strength Elongation MD	15,000	psi	ASTM-D882
Strength F-5 TD	14,000	psi	ASTM-D882
Modulus MD	710,000	psi	ASTM-D882
Modulus TD	740,000	psi	ASTM-D882
Elongation MD	115	%	ASTM-D882
Elongation TD	92	%	ASTM-D882
Surface Roughness	38	nm	Optical Profilometer
Density	1.39	g/cc	ASTM-D1505
Viscosity	0.56	dL/g	ASTM-D4603
Yield	21,000	in2/lb	n/a

Electrical Properties				
Properties		**Typical Value**	**Units**	**Test Method**
Dielectric Strength	AC, 20º C, .00092"	7,000	volts/mil	ASTM-D149-64
Dielectric Constant	25º C, 1kHz	3.2	n/a	ASTM-D150-81
Dissipation Factor	25º C, 1kHz	0.005	n/a	ASTM-D150-65
Volume Resistivity	25º C	1.00E+19	ohm-cm	ASTM-D257-78
Corona Threshold		V-AC	V-AC	ASTM-D2275-80

Thermal Properties			
Properties	**Typical Value**	**Units**	**Test Method**
Melting Point	254	º C	n/a
Dimensional Stability	n/a	n/a	n/a
at 105º C MD	0.6	%	n/a
at 105º C TD	0.3	%	n/a
at 150º C MD	1.8	%	n/a
at 150º C TD	1.0	%	n/a
Specific Heat	0.28	cal/g/º C	n/a
Thermal Expansion	1.7 x 10-5	in/in/º C	ASTM-D696
UL94 Flame Class	94VTM-2	n/a	Slow to self extinguishing

Fig, 3.7: Properties of PET [17]

CHAPTER 4

4. 5G:

Over the few decades wireless mobile communication technology has developed tremendously although the inception of this is not so ancient. Significant momentum has started to build around the fifth generation wireless communication technologies [31]. Analog signal modulation technology is mostly progressing towards digital data transmission. In 1980 first generation (1G) communication was introduced which was mainly based on transmission of modulated voice signal which had a very poor noise immunity. Gradually technology has provided the opportunity to communicate highest possible noise immunity with code division multiplexing (CDMA) and high speed internet enabling multimedia data transfer in minimal time. It availed fourth generation (4G) technology which introduced in 2011. Now we are looking forward to fifth generation (5G) communication which is expected to be launched in 2020 [32, 33, 34, 35]. The term 5G itself came into matter of discussion beyond the researchers during the second half of the year 2014 [1].

As 5G is the latest technology, it has got the paramount importance which should grab all attention. Device to device communication of 5G will bring significant improvements in system capacity, spectral efficiency, communication range and channel reliability as a consequence of its advantages for realizing spatial diversity [36]. Being the fastest communication media, it would have enormous amount of security risk which needs to be taken care of. However, 5G is providing large data bandwidth, immeasurable capacity of networking and excellent signal coverage to support high range of high quality individualistic service to the final users [37]. Mobile data trafficking now carries higher value as because of the demand for commencing multi-media applications such as High definition and three dimensional video as well as augmented reality. Recent statistics show that 50% of mobile data transfer is of video transfer which is supposed to be higher like two-third of recent users. According to International Mobile Telecommunications (IMT) requirements the peak value of internet users must be up to 10Gbps where it should provide 1Gbps blanket coverage for highly motile user (speed> 300 kilometer/hour) [37]. 5G network is about to require excellent flexibility and intelligence in the aspects like sharing of spectrum, communication by millimeter wave, integrated access of “internet of things(IoT)”, massive multiple input and multiple output system, smart antennas, big data transferring, cloud computing and so on [38]. Again advances in silicon manufacturing have reduced the cost of mm-Wave electronics

and enabled consumer use [39]. A set of frequencies are beginning though to emerge as candidates for 5G 28GHz, 38GHz and 73GHz [40].
Consequently, it will require a large bandwidth which will enable wireless traffic congestion properly and will generate a few challenges for designer [3].

4.1 Different Generation Communication technology:

1G: First generation mobile communication technology was introduced in 1983 as the consequence of the decision taken by Bell labs in 1966 of adopting the analog system into high capacity mobile system. For this an analogue system with FM radio was chosen. Thus AMPS or Advanced Mobile Phone System was introduced in United States of America which was later known as first generation or 1G mobile communication.

2G: During the inception of wireless communication it was only voice centric. Second generation communication system was introduced in 1990. As North American communication system was using Time Division Multiplexing shortly known as TDMA was abandoned due to its being back dated in 1980's and devastation of AT&T. However, before launching 3G, Europe was using GSM network and US was using IS-54 based on TDMA [37]. It provides data rate up to 144Kbps [41].

3G: 3G was introduced in 1999 where it used WCDMA which means Wideband Code Division Multiple Access with the availability of 5MHz bandwidth. Another salient feature of third generation communication system is, it was operated both in frequency division duplexing (FDD) and time division duplexing (TDD) mode [37].

4G: Fourth generation or 4G communication was introduced in 2013. There were two 4G system. One is WiMAX (Worldwide Interoperability for Microwave Access) which was developed in United States using orthogonal frequency division multiplexing (OFDM) and another was LTE or Long Term Evaluation. Both are pretty much similar using 20MHz bandwidth [37]. 4G offers downloading speed upto 100Mbps [41]

4.2 Expected Salient Features of 5G:

>> 1-10 Gbps connection to end users

>> 1 millisecond time latency.

>> 1000 times bandwidth per area than 4G network. [42]

>> 10-100 times number of connected devices than 4G communication system.

>> About 100% availability.

>> Around 90% reduction in energy usage.[43].

>> Ten times battery life [42]

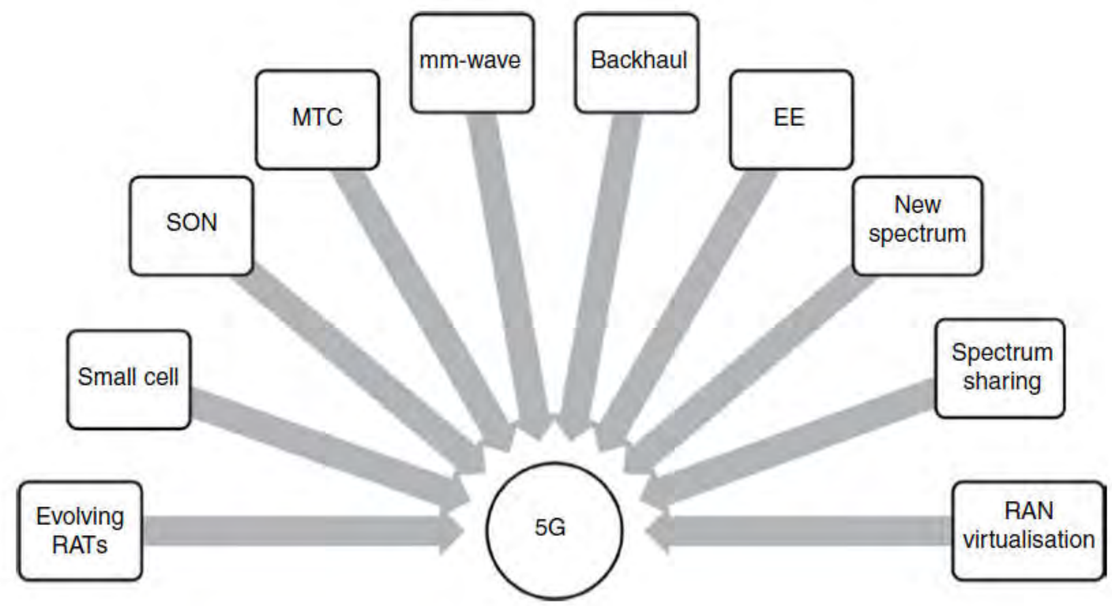


Fig. 4.1: Pillars of 5G

4.3 10 pillars of 5G:

I) Evolution of Existing Radio Access Technology: In 5G there will be no particular RAT rather than it will be the collection of RATs along with more improvised existing RAT. WiFi technology will also be evolved for better exploitation of available unlicensed spectrum which will use wider bandwidth up to 160MHz employing 256 Quadrature Amplitude Modulation [37].

II) Hyperdense Small Cell Deployment: The capacity get increased by increasing the cell number that is hyperdense small cell deployment. Reducing the cell size increases the possibility of inter cell interference. Intercell interference removal technique is needed to avoid such consequences [37].

III) Self Organising Network: As there is about to be more users in hyperdense small cell deployed strategy and most of the users will be on indoor, to facilitate this huge traffic there needs to self organising network capability to ensure low interference and intelligent adaptation [37].

IV) Machine Type Communication: Another major aspect of 5G communication is machine type communication or MTC. It is the implementation of using machine either from one end user or both end users. One of the major challenge is that there need a very low almost zero time latency for connecting the devices [37].

V) Developing the Millimeter wave RATs: There are three main impediments for mmWave mobile communications. First, the path loss is relatively higher at these bands, compared to the conventional sub□3GHz bands. Second, electromagnetic waves tend to propagate in the Line□Of□Sight (LOS) direction, rendering the radio links vulnerable to being blocked by moving objects or people. Last but not least, the penetration loss through the buildings is substantially higher at these bands, blocking the outdoor RATs for the indoor users [37].

VI) Redesigning Backhaul Links: Redesigning the backhaul links is the next critical issue of 5G. In parallel to improving the RAN, backhaul links also need to be reengineered to carry the tremendous amount of user traffic generated in the cells. Otherwise, the backhaul links will soon become bottlenecks, threatening the proper operation of the whole system [37].

VII) Energy Efficiency: Today, Information and Communication Technology (ICT) consumes as much as 5% of the electricity produced around the globe and is responsible for approximately 2% of global greenhouse gas emissions roughly equivalent to the emissions created by the aviation industry. What concerns more is the fact that if we do not take any measure to reduce the carbon emissions, the contribution is projected to double by 2020. The main concern is to reduce it [37].

VIII) Allocation of New Spectrum for 5G: Another critical issue of 5G is the allocation of new spectrum to fuel wireless communications in the next decade.In fact, the leading telecom companies such as Qualcomm and NSN believe that apart from technology innovations, 10 times more spectrum is needed to meet the demand. The allocation of around 100 MHz bandwidth at the 700 MHz band and another 400 MHz bandwidth at around 3.6 GHz, as well as the potential allocation of several GHz bandwidths in cm□ or mm Wave bands to 5G will be the focal point of discussion [37].

IX) Spectrum Sharing: Regulatory process for new spectrum allocation is often very time consuming, so the efficient use of available spectrum is always of critical importance. Innovative spectrum allocation models (different from the traditional licensed or unlicensed allocation) can be adopted to overcome the existing regulatory limitations. Plenty of radio spectrum has traditionally been allocated for military radars where the spectrum is not fully utilized all the time (24/7) or in the entire geographic region [37].

X) RAN Virtualization: The last but not least critical enabler of 5G is the virtualization of the RAN or Radio Access Network, allowing sharing of wireless infrastructure among multiple operators. Network virtualization needs to be pushed from the wired core network (e.g. switches and routers) towards the RAN. For network virtualization, the intelligence needs to be taken out of the RAN hardware and controlled in a centralized manner using a software brain, which can be done in different network layers [37].

4.4 5G antenna designing challenges: As per the requirement of 5G network communication technology antenna should be operable in 28GHz frequency with desired performance which in terms of designing is one of the major challenges. As experimental results have proved that the 28 GHz frequency band is suitable for such 5G mm-Wave cellular system [4]. As per the requirement of mobile antenna is supposed to be omni-directional which was another challenge of designing the proposed antenna. As we moving toward high frequency the antenna size will become smaller correspondingly [3]. However the frequency range increases there will be noticeable amount of reduction in terms of wavelength up to millimeter wave [3]. Again our mobile antenna is designed based on mobile communication which is about to be omni-directional whereas the to achieve high SNR or signal to noise ration uniformly on the whole cell mm wave network requires high gain directional antenna which is pretty tough to consider while designing [41]. Gain value of antenna operable at 28GHz can be increased by increased size of ground [44]. In this new arena, the demand for flexible, transparent and robust antenna that are able to fit with devices of various shapes and sizes, as well as being environmentally friendly, is expected to rise exponentially [30].

CHAPTER 5

5. Design Analysis

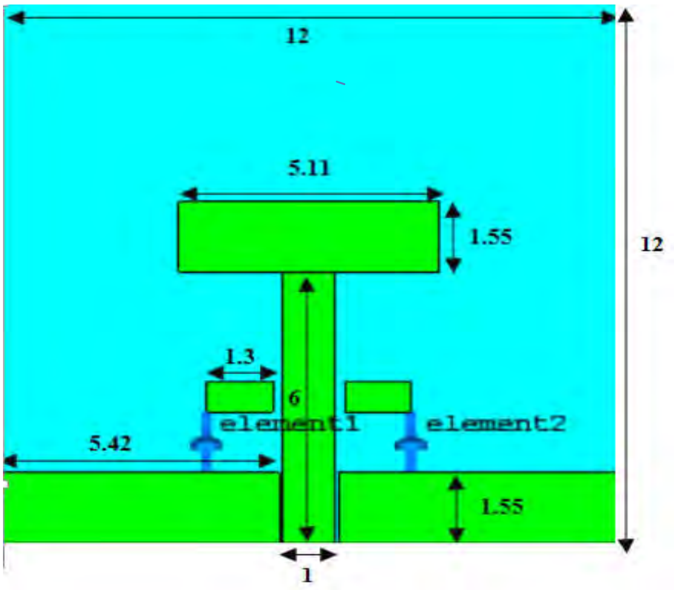


Fig. 5.1: Designed antenna

Parts	Width(mm)	Length(mm)
Substrate	12	12
Ground plane (both side)	5.42	1.55
Feed-line	1	6
Radiating element	5.11	1.55

In our thesis work, we used 1.3 mm long stub which has 0.2mm gap from the feed-line. For frequency reconfiguration two variable resistors used that is connected with stub and ground at both side. We changed the lumped element by 1k, 1.5k ,0.5k for changing the frequency in this issue. Here, 0.0525mm thick Aght-8 films used on 0.1225mm thick PET substrate (=3.228) which provides flexibility and transparency of our proposed antenna. Radiating element is fed by 6mm long and 1mm width feed-line with 0.08mm space gap with the ground.

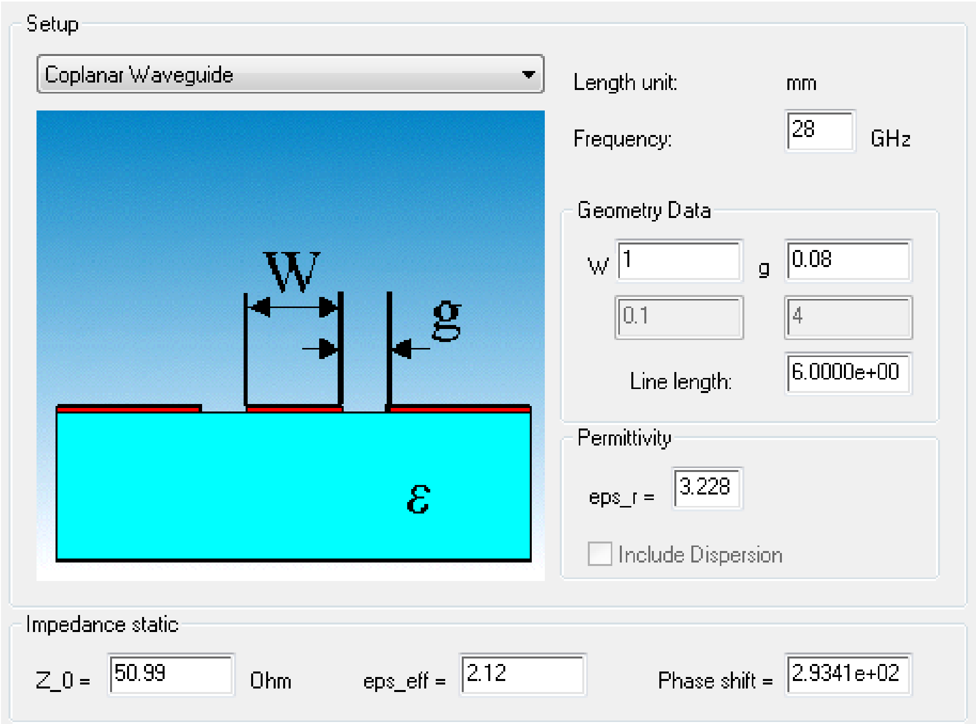


Fig. 5.2: CST Microwave Studio data input

5.1 Software design and simulation:

We designed our proposed antenna in Computer simulation microwave studio or CST Studio to get the required result and compare it within different angles. At first we created a new template which is referred to as MW & RF & OPTICAL >> Antennas >>Planar (Patch, slot e.t.c)>>Time domain solver. We selected the units mm and GHz according to our proposed antenna model. Our main focus is to getting the result at 23-29 GHz, that`s why we selected the range of frequency from 0 GHz to 30 GHz. We also have to select E-field, H-field, Far-field to see the S-parameter, radiation pattern, current distribution e.t.c.

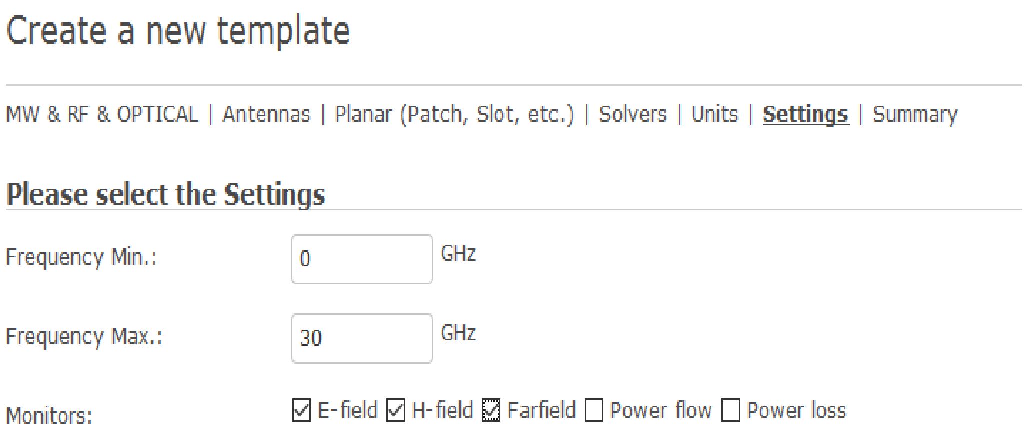


Fig. 5.3: CST Microwave Studio data input

Now we got a working plane created on the software. We designed our antenna on that plane according to the dimension of the geometric diagram of the antenna. For radiating element, we kept the angle at 0-degree that gives us a T-shaped antenna. Electrical conductivity of AGHT-8 material is 125000 S/m and we selected it as a lossy metal type. For PET substrate, value is 3.228 and it`s normal type. Material properties of both Aght-8 and PET are showed in the following.

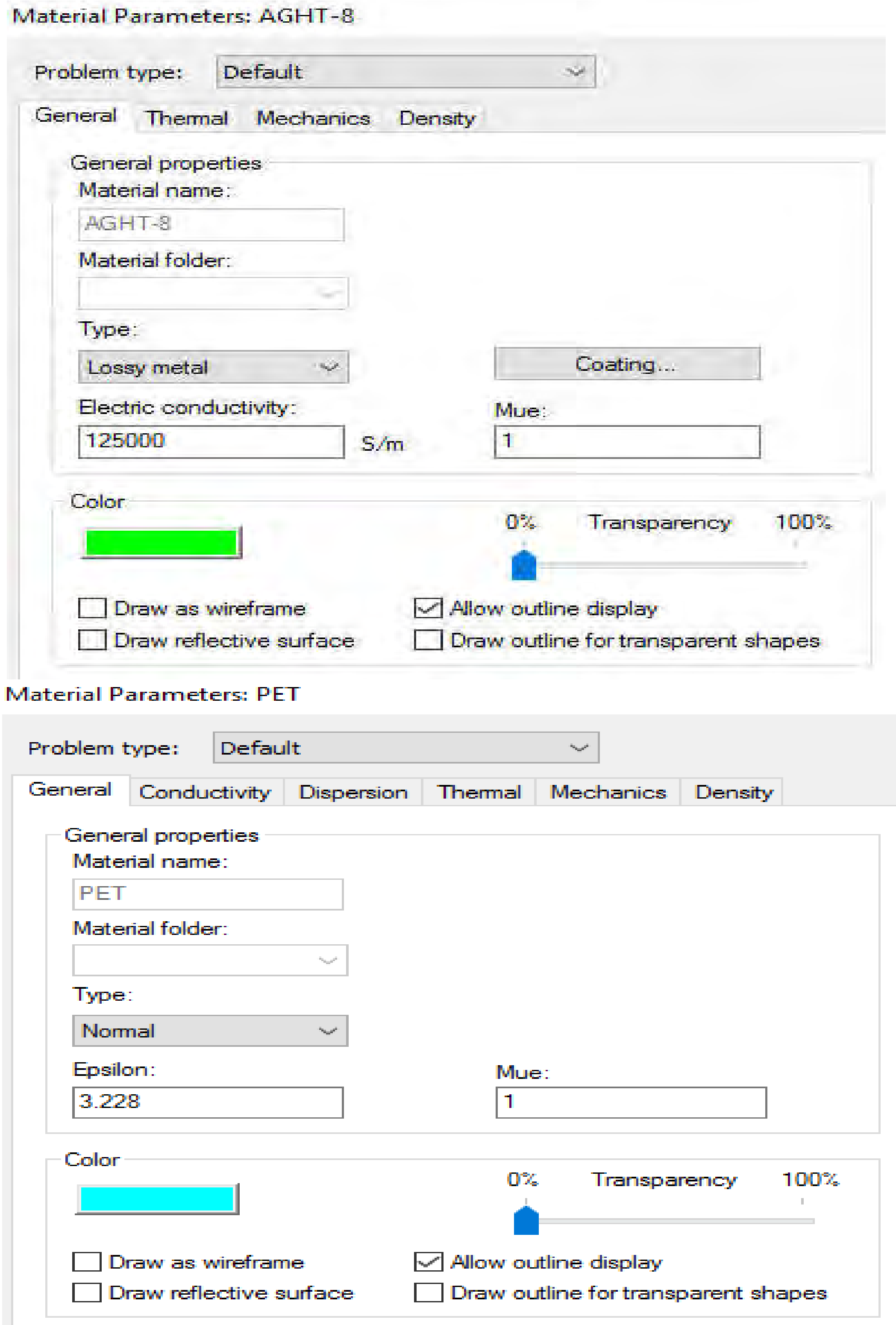


Fig. 5.4: CST Microwave Studio data input

We are considering 1K lumped element on the both side for 0-degree initially and we will see the result by changing the resistance later.

5.2 Effect of feed-gap:

Different feed gaps =0.3, 0.2, 0.1, 0.08, 0.06 used to simulate the antenna and compared the return loss curves for those. Of-course we changed the feed line width for different feed gaps for making the input impedance 50 ohm. We see from the following figure that changing a very little amount of gap brings a drastic change to the curve. The best result we found from 0.06 to 0.1 which covers the higher frequency range 25 to 30 GHz that is required for 5G mobile application. If we analysis the following curve then we can understand that the more the feed gap is decreasing and that`s why feed line width decreasing also to make input impedance 50Ω, the more the lowest value frequency(dB) or resonant frequency is shifting to left-ward. With this decreasing of feed gap of the antenna, the directivity is also decreasing.

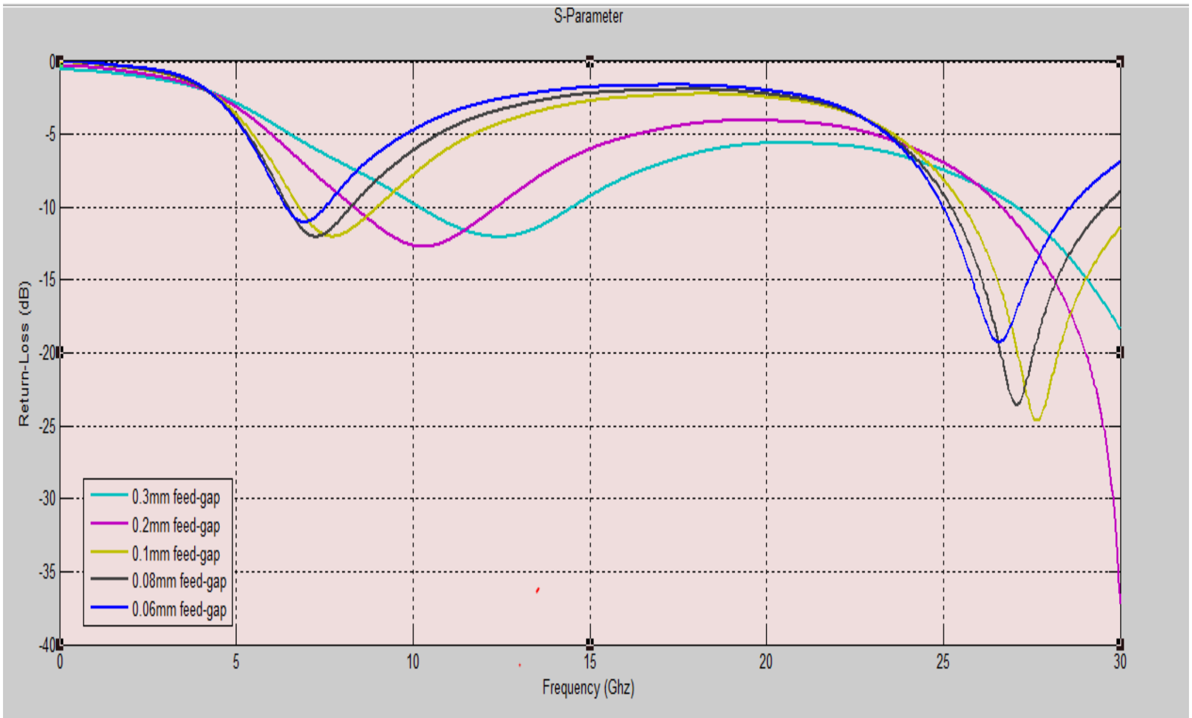


Fig 5.5: S-Parameter in different feed gaps

Feed-gap	Feed-line width	Directivity
0.3mm	4mm	2.37 dBi
0.2mm	2.7mm	2.24dBi

0.1mm	1.3mm	1.89dBi
0.08mm	1mm	1.78 dBi
0.06mm	0.8mm	1.72 dBi

5.3 Effect of Ground-plane:

In the previous figure, we can see the variations of return loss curves which is actually the reason of changing feed-gap and that time we also had to change ground plane width to make the input impedance 50Ω. As a result, ground plane also contributes to the resonant frequency and so bring noticeable changes in return loss curves.

5.4 Effect of the lumped element:

In our thesis, we are using different resistors to get frequency variation and it also important to work the proposed antenna at higher frequency. Voltage and current distribution of stubs also get changed with varying the resistors. We have analyzed our proposed antenna at 0-degree when it becomes T-type shape with varying the resistance 500Ω, 1k, 1.5k, 2k. The return loss curve of using these resistors is shown I the following figure.

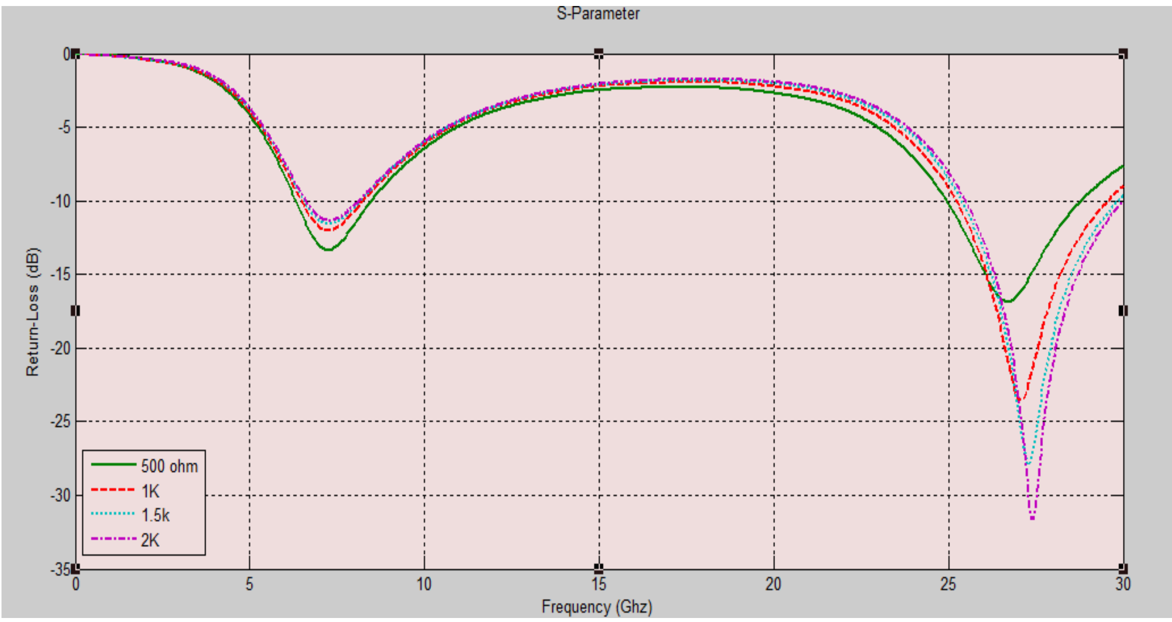


Fig. 5.6: S-Parameter for different lumped elements

From the last figure, we can see that by using 500Ω, 1k, 1.5k, 2k we are getting sharp deep under -10dB at higher frequency range 25 GHz to 30 GHz which is required for 5G application. It`s a great advantage and also adds a reconfigurable feature to or proposed antenna model, because we can use our proposed antenna in different frequencies by only changing the resistance. However, higher value resistance contributes to the resonant frequency more efficiently rather than lower value resistance. And also with increasing the value of the resistance the resonant frequency shifts to the downward or get deeper under -10dB and it shifts to the leftward very little. So using 2k resistance connected between stub and ground-plane gives better performance for higher frequency application rather than 500Ω, 1k, 1.5k resistance. In this way, we can increase the value of the resistance and up to 5k it will be efficient as reconfiguration of frequency but after 5k if we add higher value resistance as lumped element we can`t see any drastic change in resonant frequency.

5.5 Antenna structure:

Our proposed antenna model structure is actually a coplanar structure in which ground, feed line and radiating element are mounted on the substrate films. We have learnt from our research that coplanar antenna model provides better results at higher frequency rather than other types of antenna model. At 0 degree this antenna looks like T-shaped and it`s shape becomes changed with changing the angles and this mechanism will be explained later. In this antenna, coplanar waveguide (CPW) has been used to feed the radiating element. We have used PET substrate and AgHT-8 as conductor to design our proposed antenna model .

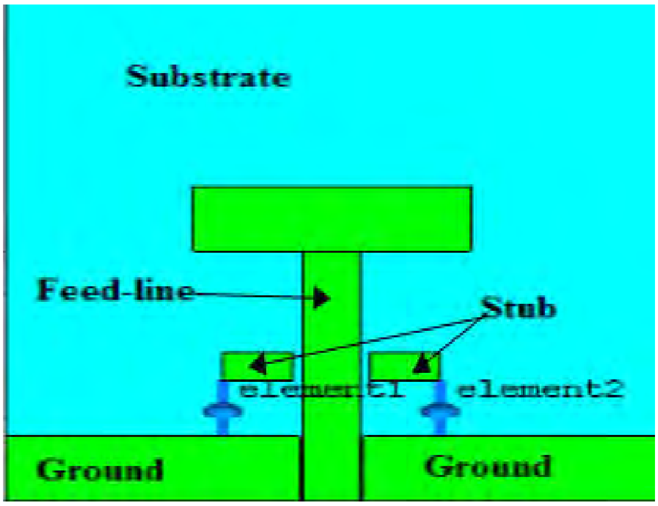


Fig. 5.7: Antenna Structure

5.6 Return loss:

The following figure is the return loss curve of our proposed antenna at 0-degree angle which looks like T-shaped antenna and we used 1k resistor as lumped element.

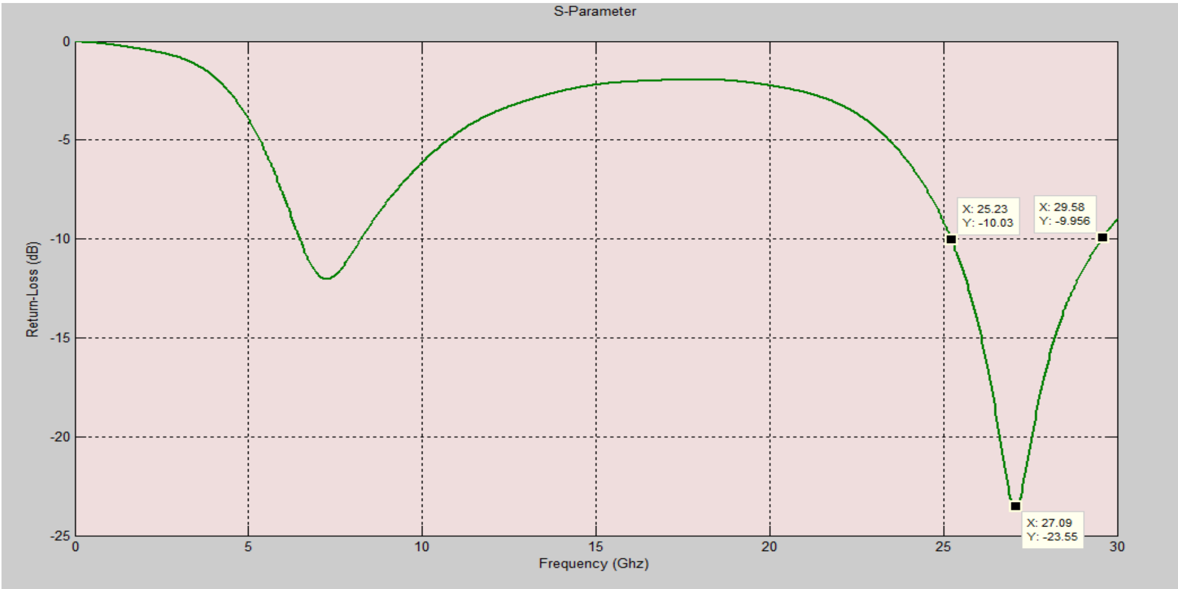


Fig. 5.8: S- Parameter of 28GHz

From the previous figure, we can see that the bandwidth for our 0-degree antenna model with 1k resistor is 25.23GHz to 29.58GHz which fulfill the requirement for 5G mobile application. This time we are getting resonant frequency at 27.09GHz which refers to -23.55 dB return loss.

5.7 Radiation pattern at 0 degree:

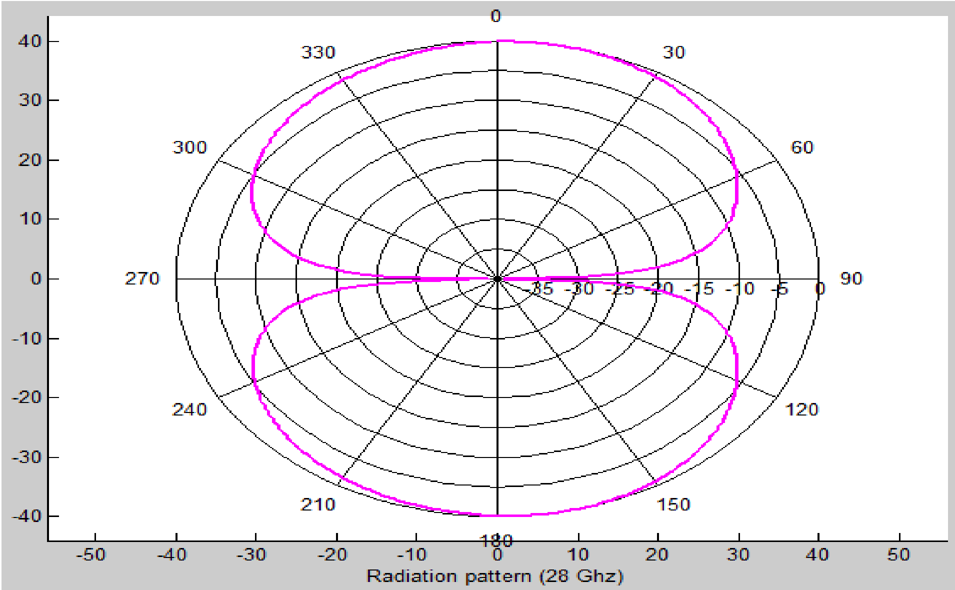


Fig. 5.9: Radiation Pattern at 0 degree angle of 28GHz antenna

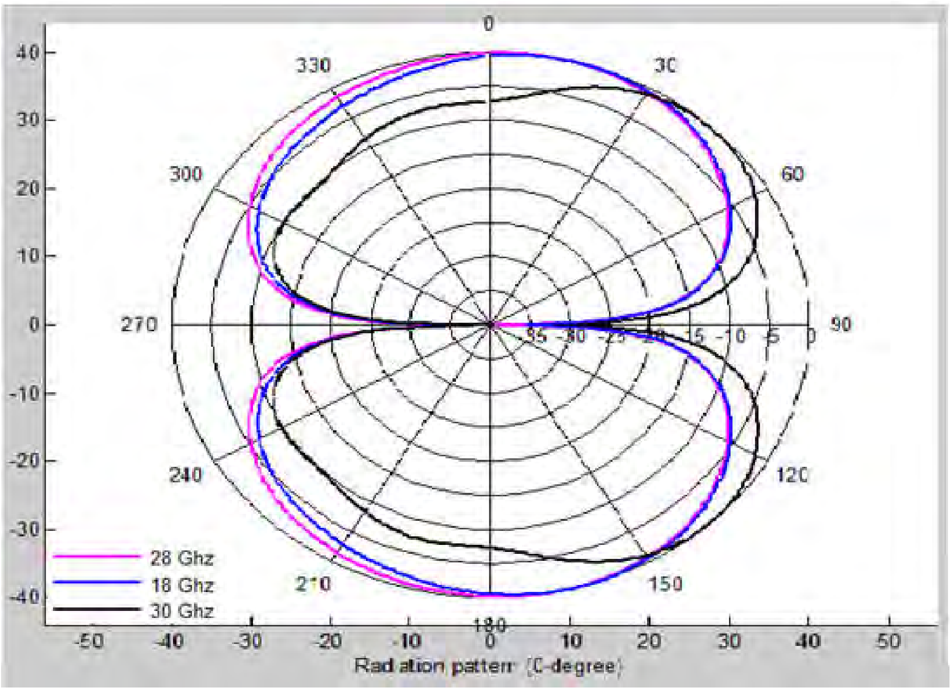


Fig. 5.10: : Radiation Pattern at 0 degree angle of multiple frequency antenna

5.8 Radiation pattern (3D view):

The following figures are indicates the 3D view from the top side and we can clearly understand from that the proposed antenna gives us the omni-directional pattern which is necessary for mobile application.

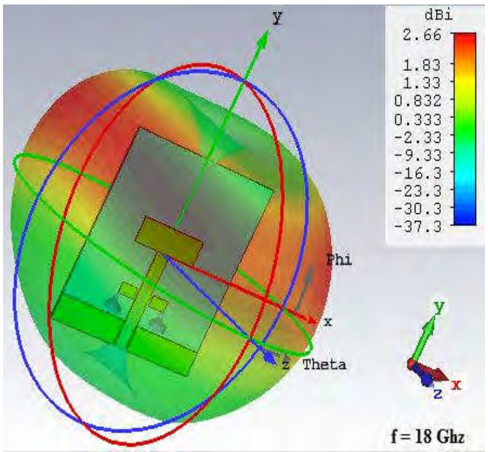


Fig. 5.11:Farfield f=18GHz

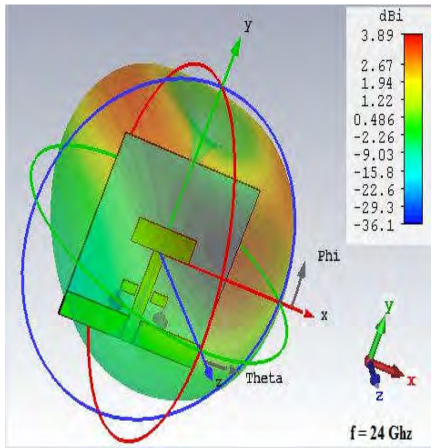


Fig. 5.12:Farfield f=24GHz

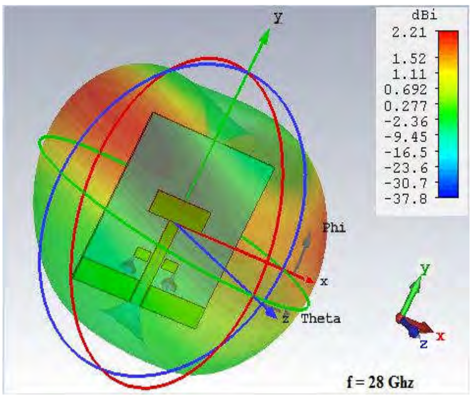


Fig. 5.13:Farfield f= 28GHz

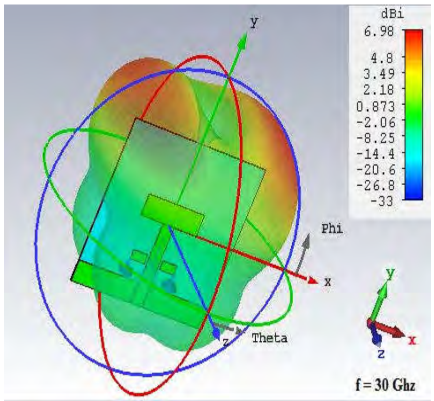


Fig. 5.14:Farfield f=30GHz

5.9 Current flow through antenna:

Antenna radiation pattern and return loss can be changed drastically depending on the current flow through it. In the following three figures for current distribution has been shown in three different frequencies which are 18GHz, 24GHz and 30GHz. The deepest pink color indicates the highest current flow portion of the antenna. The current distribution will be changed if we change the figure and following this mechanism we have researched to get our expected antenna model.

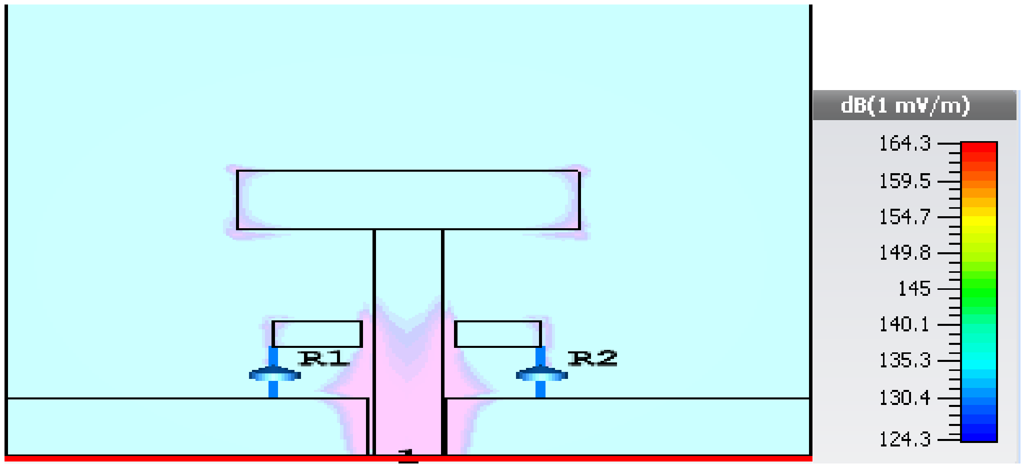


Fig. 5.15:E-field(f=18GHz)

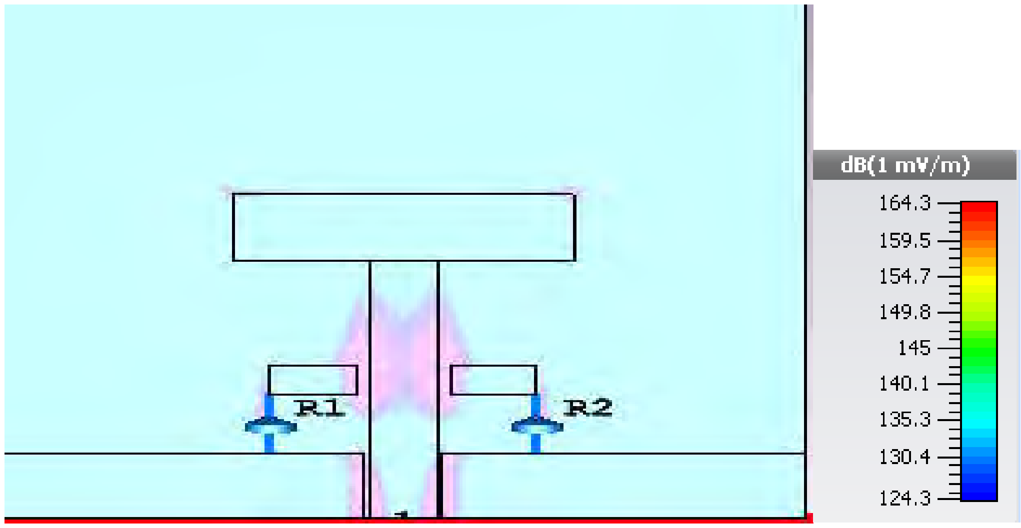


Fig. 5.16: E-field(f=24GHz)

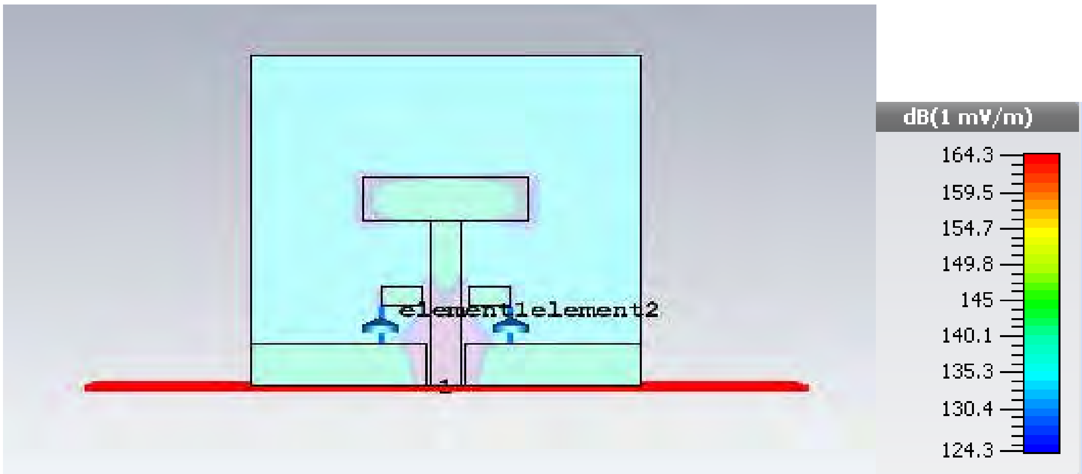


Fig. 5.17: E-field(f=28GHz)

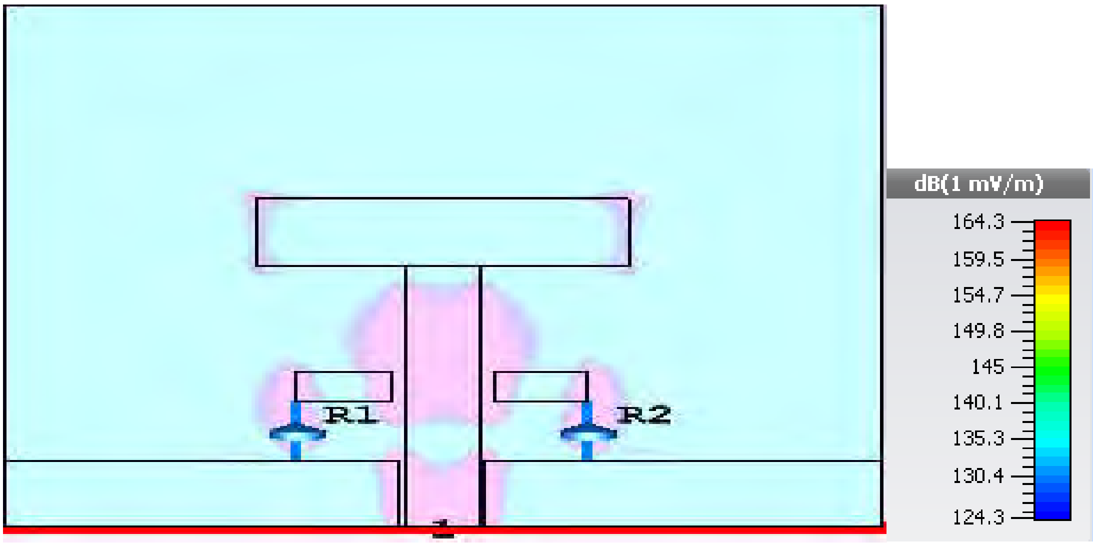


Fig. 5.19: E-field(f=30GHz)

Table:- E-field

Frequency	3D Maximum(v/m)
18	103.3dB

24	106.6dB
30	106.6 dB

5.10 Different angles

Mechanism of varying angle: The most interesting feature of our antenna is to vary the angle of radiating element and so it can be applicable for different application. In this issue, we are proposing a mechanism of changing the angle. The following figure indicates the dimension of the radiating element of our proposed antenna in terms of x and y co-ordinates. The following figure indicates our proposed model. Here (X1,Y1), (X2,Y2), (X3,Y3), (X4,Y4) indicates the four points of radiating element and the values has been shown in the following table. So we are following the mechanism of angle variation is to change theta(θ) value only and with changing Ө value the antenna diagram will be changed also which will be applicable for different frequencies. Here, Wr and Lr are the width and length of the radiating element respectively. If we fix he angle θ= 0 degree then the diagram looks like T-shaped antenna and if we increase the angle then the diagram turns to Y-shaped with increasing the value of the theta.

Radiating Element diamension	Values
(X1,Y1)	[{(-Wr/2)*Cosθ}, {(Wr/2)*Sinθ}]
(X2,Y2)	[{(-Wr/2)*Cosθ}, {(Wr/2)*Sinθ}+Lr]
(X3,Y3)	[{(Wr/2)*Cosθ}, {(Wr/2)*Sinθ}+Lr]
(X4,Y4)	[{(Wr/2)*Cosθ}, {(Wr/2)*Sinθ}]

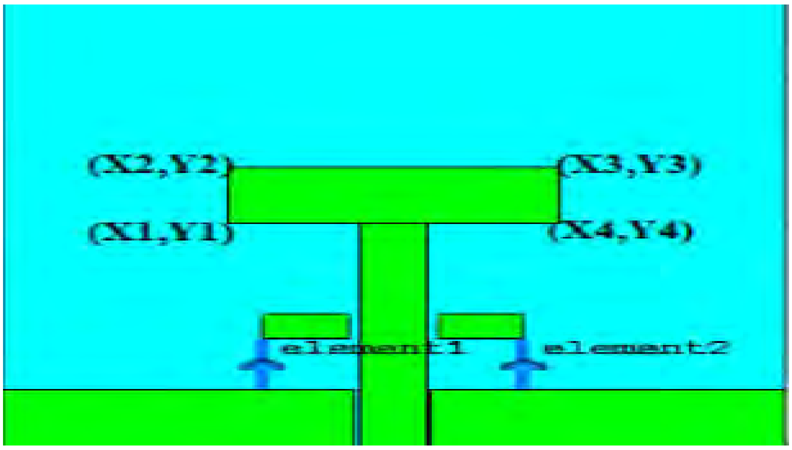


Fig. 5.20: Y-shaped antenna 0 degree

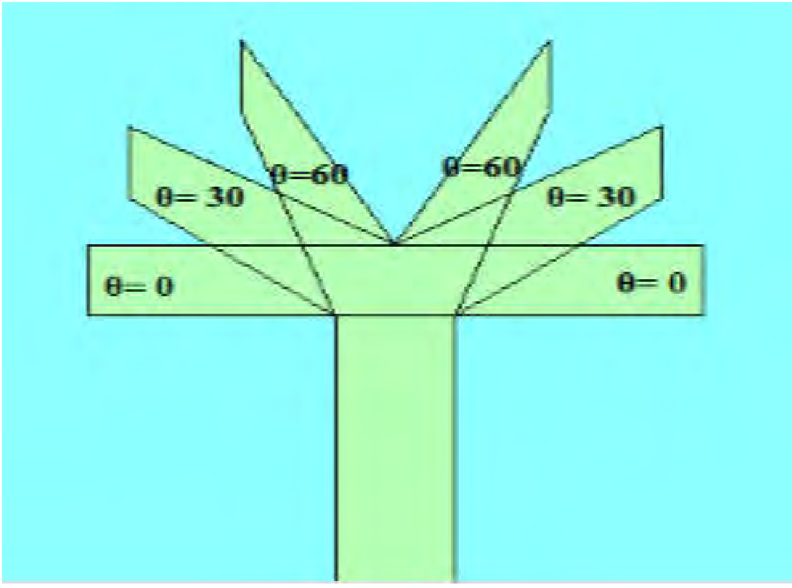


Fig. 5.21: Different angle for Y-shaped antenna

5.11 Return loss (Different angles): The following figure indicates the return loss curve of different angles antenna. Here, we have simulated our proposed antenna at 7 different angles which are 0, 10, 20, 30, 40, 50 & 60 degrees to compare the result so that we can understand the changes of return loss curve because of changing the angles. From this graph we can see that when the antenna radiation element angle is 0-degree then it provides the best result at higher frequency which can be applicable for 5g mobile communication. At 0 degree, the resonant frequency is 27.09 GHz and the return loss is -23.552dB . If we increase the angle just 10 degree then the resonant frequency is 26.55GHz and the return loss is -20.39dB and it`s clear that the resonant frequency has been decreased due to increasing the antenna angle.

In this way if we gradually increase the angle then the resonant frequency will be decreased also and we get 23.211 GHz as resonant frequency at 60 degree antenna angle which is the lowest frequency among the 7 different angles. From this curve it`s also clear to us that the bandwidth of the antenna is shifting towards left with increasing the angles. At 0 degree angle the bandwidth is 25.239 GHz to 29.506 GHz and it has been shifted to 21.837GHz—24.947GHz which indicates that the bandwidth is shifted almost 4GHz for changing the angle from 0-degree to 60-degree. The following return loss curve also indicates that we get narrowband antenna at lower angle rather than higher angle as we see that the 0-degree antenna provides the most narrowband curve. So, we can use our proposed antenna at different bandwidth by changing the angle which adds more advantage to our proposed model.

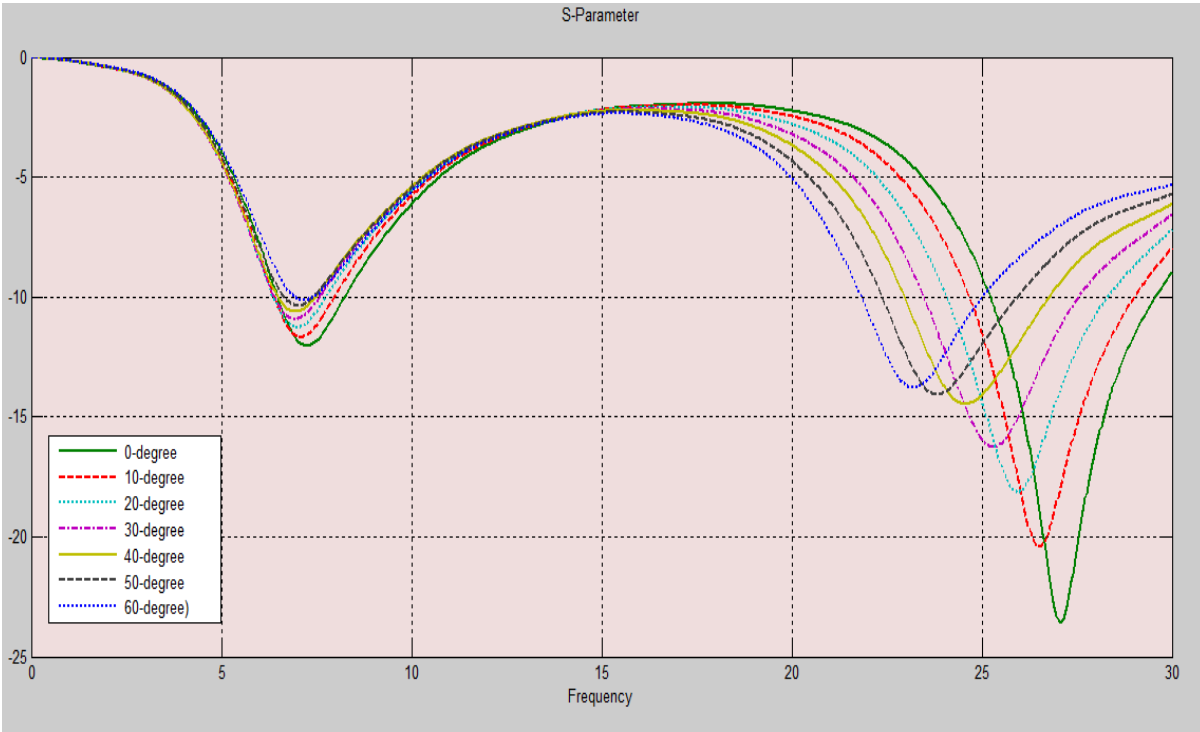


Fig. 5.22: S-parameter for different angle between two arms of Y-shaped antenna(I)

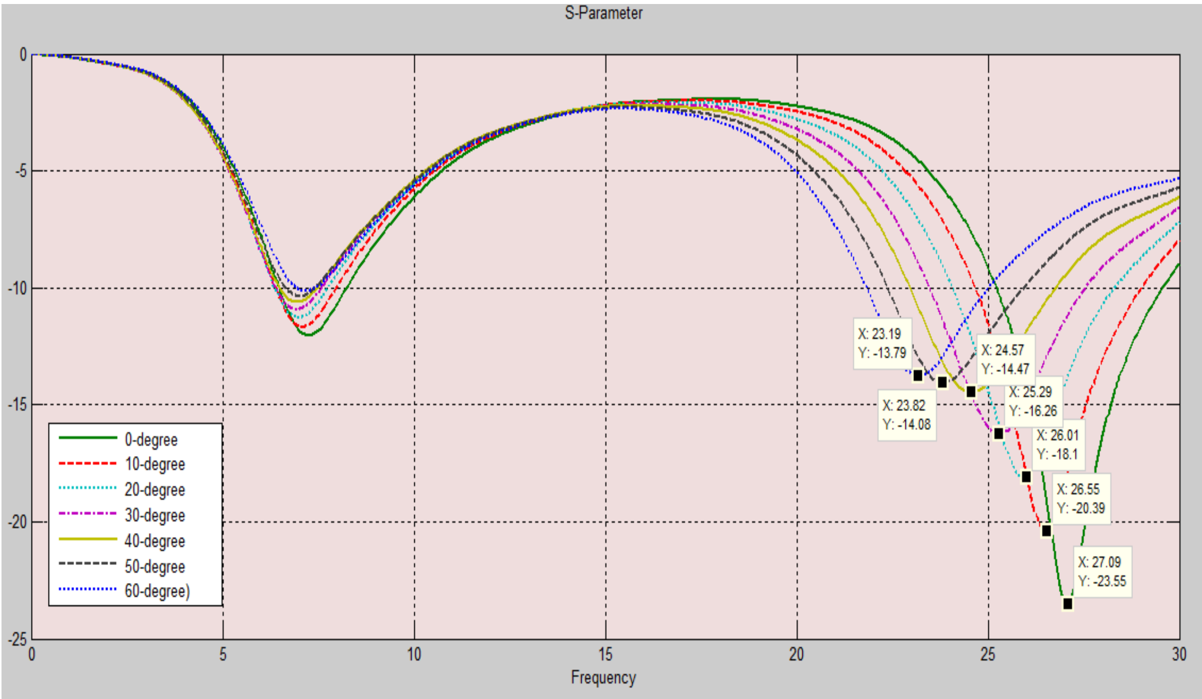


Fig. 5.23: Fig: S-parameter for different angle between two arms of Y-shaped antenna(II)

Angle (Degree)	Bandwidth(GHz)	Return loss(dB)	Resonant frequency (GHz)	Directivity (dBi)	Directivity angle(Degree)
0	25.239 --- 29.506	-23.552	27.09	1.78	170
10	24.645 --- 29	-20.39	26.55	1.97	171
20	24.074 --- 28.284	-18.104	26.01	2.08	170
30	23.486 --- 27.522	-16.261	25.297	2.19	170
40	22.968---26.77	-14.465	24.6	2.27	170
50	22.395 --- 25.908	-14.074	23.88	2.34	169
60	21.837 --- 24.947	-13.793	23.211	2.38	169

5.12 Generalized equation for Resonant frequency:

Code for general equation: We have used Matlab software to find out the relation between angle and resonant frequency. Using the following code we got three approximated coefficients and using that we have got a polynomial equation which is y=ax^2 + bx +c.

Here, y = Resonant frequency.

x = Angle.

a = 1^{st} co-efficient, b = 2^{nd} co-efficient, c = 3^{rd} co-efficient.

From the Matlab code we got the values of coefficients which is shown in table.

Approximate co-efficient	Values
a	-0.0002
b	-0.0548
c	27.1109

So, our approximate equation of finding resonant frequency in terms of angle for our proposed model is

Y= (-0.0002)x^2-0.0548x+27.1109.

Justification of equation: show 3 justification like justification-1,2,3

Justification-1:

Assuming any angle 20 degree which is the value of x. then the resonant frequency will be

Y= (-0.0002)(20)^2-0.0548(20)+27.1109.

= 26.0149.

Now, from the previous table we can see that we got resonant frequency 26.01 for 20 degree angle and so our equation is valid.

Justification-2:

$Y= (-0.0002)(30)^2-0.0548(30)+27.1109$

$=25.28$

Justification-3:

$Y= (-0.0002)(40)^2-0.0548(40)+27.1109$

$=24.59$

Again, we plot the curve in Matlab using all the real values and approximate values for different angles and found that both the curves are almost similar and from this similarity it`s also justified that our approximated equation to find out radiation pattern is correct.

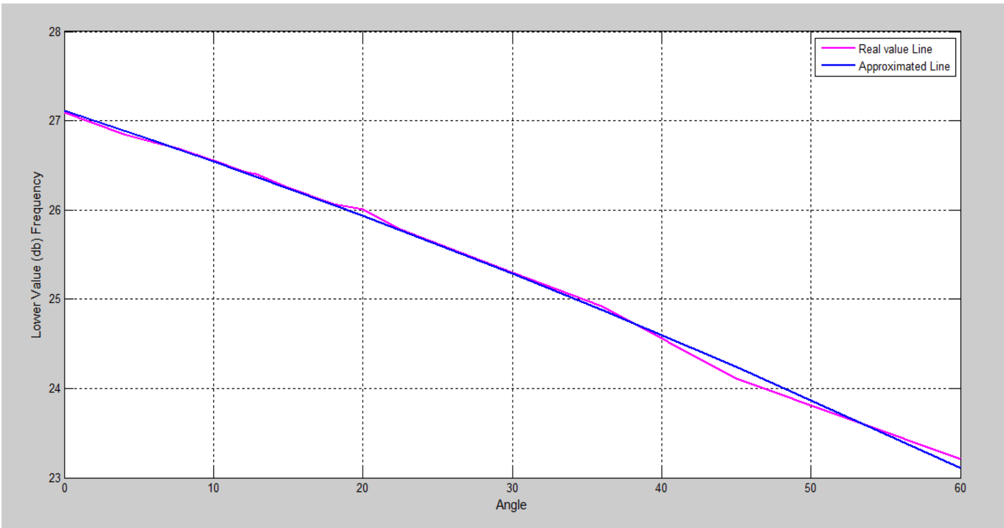


Fig. 5.24: Relation between angle and frequency of the antenna

5. 13 Radiation Pattern for different angle antennas:

In the following the radiation curves for 10, 30 and 60 degree has been sown. From those figures it`s clear that the curve is omnidirectional for all these 3 different angles which is required for mobile communication. In this regard, the interesting matter is that no major change in directionality is happening due to change the angle but the main lobe directivity and angle gets measurable changed. At 0 degree the main lobe directivity 1.78 is dBi and it increases with increasing the antenna angle. At 60 degree we get 2.38dBi as main lobe directivity. But the directivity angle is almost same for different angles. Following figure expresses the changes within these three angles and we can see that the different angles polar plot is almost overlapping.

Angle	Directivity (dBi)	Directivity angle (degree)
0-degree	1.78	170
30-degree	2.19	170
60-degree	2.38	169

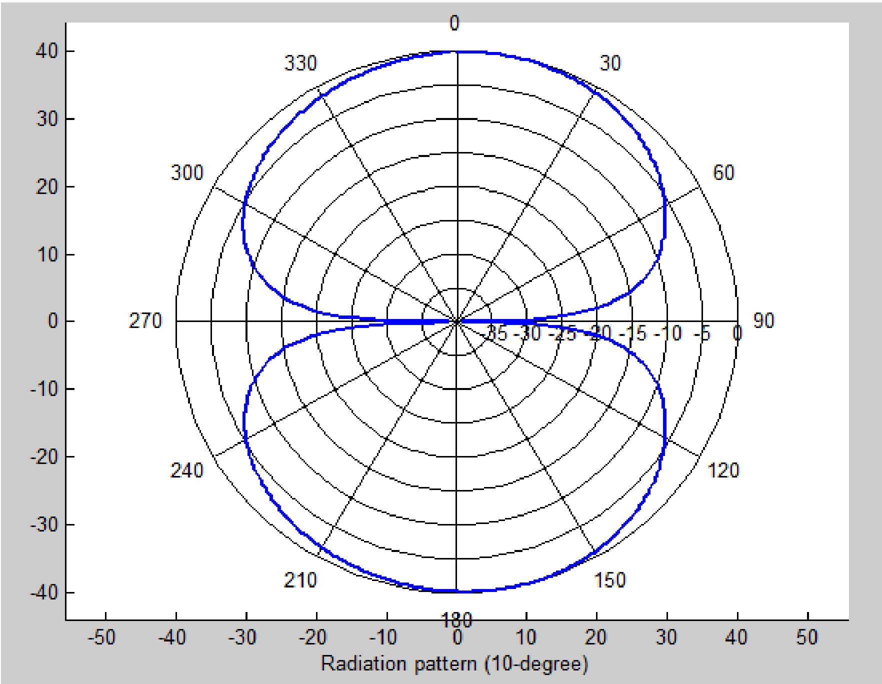


Fig. 5.25: Radiation pattern for 10 degree angle

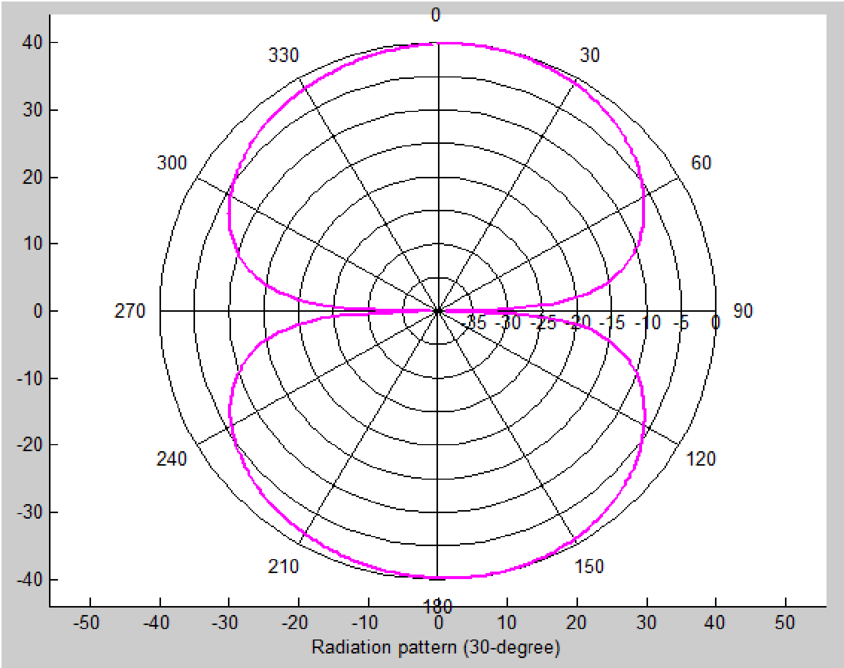


Fig. 5.26: Radiation pattern at 30 degree

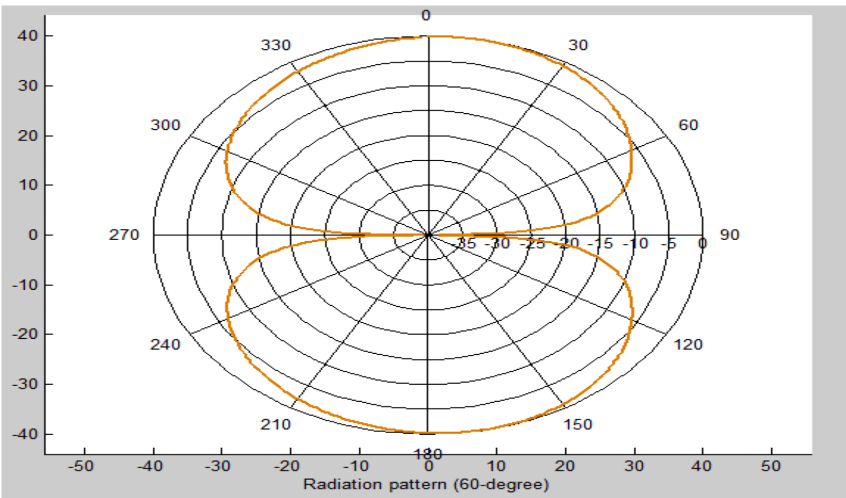


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Fig. 5.27: Radiation pattern for 60 degree

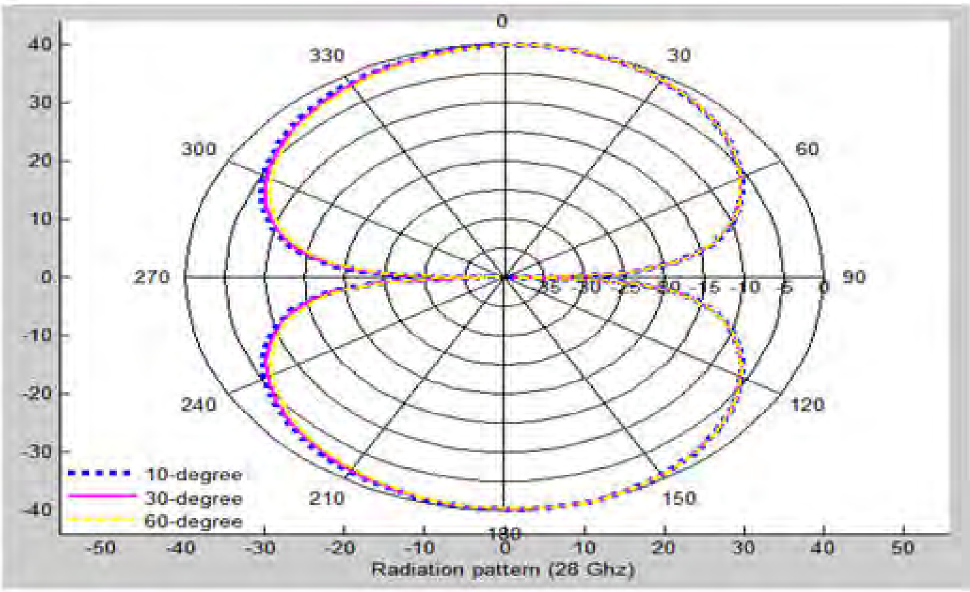

Fig. 5.28: Radiation pattern for multiple angles

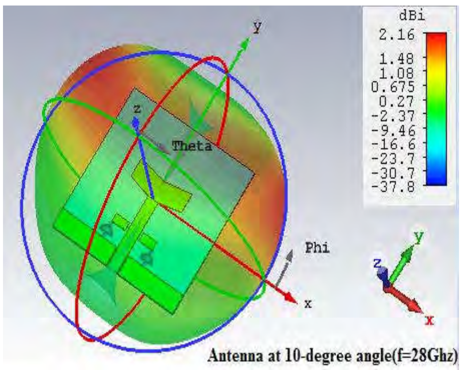

Fig. 5.29: 3D view RP(10-degree)

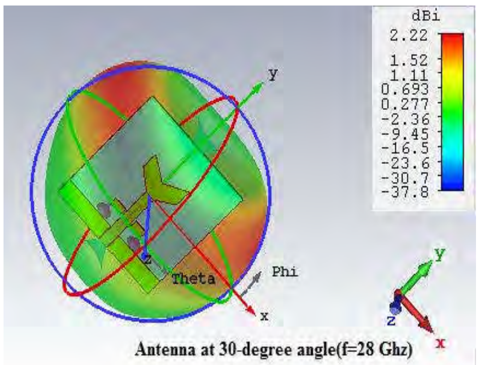

Fig. 5.30: 3D view RP(30-degree)

CHAPTER 6

6.1 Conclusion:

The main purpose of our thesis work was designing an antenna with capability of transparency and flexibility for 5G mobile communication. As we took a step ahead to accomodate the facility of 5G mobile communication which is about to be the hottest topic of recent times we needed to have such an antenna with better performance from all and operable at 28GHz. As mentioned before to avail 5G mobile communication facility 28GHz frequency is a must, although further research is still going on. When we started our thesis we wanted to use Indium Tin Oxide (ITO) for designing our antenna. As it is very rare material and unavailable we found very little research in this field. Although ITO had the better transparency compared to AgHT-8 material we couldn't configure it in CST Microwave Studio. We tried to communicate with many scholars nationally and internationally to configure ITO manually in the software by knowing the parameters, but we got very little help in this matter and finally we couldn't configure it. Then we moved toward the use of AgHT-8 material for designing antanna. When we came to conclusion we see that it is very much possible to fabricate a flexible antenna with almost 70-80% trasparency which is even operable at 28GHz. In this paper we have discussed the change in antenna performance by using lumped element (Resistor, Capacitor, Inductor) and changing the angle between two arms of Y-shaped antenna. We used AgHT-8 material over PET substrate to have the better trade off between transparency and conductivity. We faced challanges like designing the antenna at high frequency and 50Ω impedance matching. Finally we overcame all these to design our desired antenna. So, it depends on further research in the near future to reach maximum transparency and flexibility with better antenna performance. Living in a country like Bangladesh we are deprived of proper fabrication facilities. That is we couldn't go on fabrication of our designed antenna. We even tried to communicate with different companies in China, Taiwan and some European nations to fabricate. Still we are looking for opportunities and trying our best to fabricate our designed antenna. Another problem is the unavailability of AgHT-8.

6.2 Future work:

If we have a swift glance over our recent advancement of telecommunication technology we see a vast and lucrative change in a short span of time. Only a decade ago it was a fantasy to use a touch screen mobile phone, where this is now a reality. Modern commencing technology is like a mythical epic where it is unpredictable and thrilling all the time. We are eagerly waiting for what's coming next. As our proposed antenna is transparent and flexible one with facilitating 5G mobile communication with high frequency it has a huge possibility to open up the next door of commencement rather than just ending up here. In the near future mobile phone may be in a hologram technology and our antenna could be usable in fabric with 100% transparency and flexibility. Now we can avail only 70-80% of transparency where it can be maximized in near future. Our further research will be on searching for a material than can facilitate glass like transparency. We saw ITO avails up to 80% of transparency while we need an unwanted trade off for conductivity. As our thesis is totally new in genre, first we want see the implementation of such technology. We wanted to fabricate our designed antenna but we couldn't because of unavailability of the fabrication facility and the material itself. We hope to fabricate it in near future obviously before the launching 5G mobile communication in 2020. Our first and foremost target is to publish our work in a reputed journal. For this reason we must find a way to fabricate our designed antenna to match the measurement with the analyzed simulated data and also find out its economic viability as well as commercial production possibility.

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