Distinguishing Performance of 60-GHz Microstrip Patch Antenna for Different Dielectric Materials

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***Abstract*— With the increased need for high speed (> 1 Gbps) wireless communication systems, the 60 GHz free spectrum has received a lot of attention during these days for the advancement and development of short-range, high data rate wireless links. 60 GHz patch antennas using an array of materials providing minimumreturnloss, higher gain; overall better efficiency was developed and simulated. Low dielectric constant substrates are generally preferred for maximum radiation, higher bandwidth and low power loss. In this paper, materials for patch antenna pondering higher efficiency, maximum directivity or gain, higher bandwidth and minimumreturn loss were considered.**

Keywords-60GHz; Microstrip; UWB; Substrate; Return Loss; Patch antenna.

I. INTRODUCTION

With the rapid development in the field of communication technology, Ultra-Wide Band (UWB) antennas have been an important branch of the antenna technology. UWB technology is based on the use of very narrow pulses on the order of nanoseconds, which covers a very wide bandwidth in the frequency domain [1]. Due to ability in sharing large frequency spectrum with higher capacity thus rise in bandwidth, low signal-to-noise ratio as well as lower power loss, low probability of jamming; intercept UWB antennas are popular now. Even today this is considered to be the only elucidation to meet the future need certifying high speed data communications. It has a potential of providing wireless communication of multi-Gbps over typical indoor distance of up to 10 meters [2]. Moreover, low-cost wireless communication systems that operate in the 60-GHz frequency band supporting gigabit-per-second (Gbps) data rates are in demand [3]. This frequency can be used in Wireless Personal Area Network (WPAN) and Wireless Local Area Network (WLAN) with a data rate of 1.5 Gbps which would enable to transfer uncompressed video signal between two devices. Again Millimeter Wave Identification (MMID) that enables developing new applications (i.e. wireless mass memory) is an interesting possible application [4]. This system however has challenges like low cost Monolithic Microwave Integrated Circuit (MMIC) and efficient antenna technology.

Microstrip patch antennas are currently widely used particularly since they are lightweight, compact and cost effective; however, their main disadvantage is their narrow bandwidth. Therefore, various designs have been proposed in the literature to improve their band- width, including the use of thicker substrates, different shape patches and probes, addition of parasitic patches and cutting of slots [5].

II. WHY 60 GHz AS OPERATING FREQUENCY

The interest of using spectrum around 60 GHz is leaded by many argument and comparison among the entire free frequency spectrum. The principal reason for focusing on the 60 GHz band is the huge amount of allocated free spectrum by Federal Communication Commission (FCC) around 60 GHz, which can be used to accommodate all kinds of short-range (< 1 km) wireless communication [14]. It is important to take into account the problems that rise due to high frequency. According to the Friss formula, the free-space path loss is proportional to the square of the frequency.

The link budget at 60 GHz is around 21 dB less than the link budget at 5 GHz under the same conditions (same antenna patterns, separation distances etc.)[14]. But this higher free space loss can be compensated by using antennas with more pattern directivity with small antenna dimensions. However for this spectrum Doppler effects are relatively severe because they are also proportional to frequency.

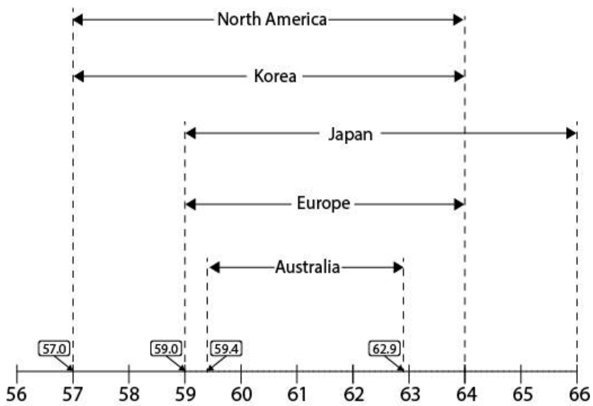

Fig.1. Unlicensed Frequency Spectrum around 60 GHz for different countries (Reproduce from [2])

At first sight there seems to be a substantial disadvantage of 60 GHz transmission, but considering all the possible solutions above and the fact that this frequency is used by most of the countries, this is the finest solution to ensure low cost communication medium as well as high speed data rate.

III. PROPERTIES OF DIELECTRIC SUBSTRATES

Normally high frequency circuit materials which have low loss tangent, good chemical resistance, product uniformity, dimension stability, low dissipation factor and are efficient in high reliability, aerospace and defense applications, Millimeter Wave Applications are chosen as substrates for antenna. In this section the characteristics of six substrates, which were used for the patch are discussed.

A. RT Duroid

RT Duroid 5880 (Rogers RT 5880) is filled Polytetrafluoroethylene (PTFE) composite laminates having low electrical loss, low moisture absorption and stable performance over frequency [7].

B. Arlon Diclad 522

ArlonDiclad 522, a popular composite of DiClad family uses a higher fiberglass/PTFE ratio to provide mechanical properties approaching conventional substrates. It has excellent performance in every aspects of antenna technology.In addition to applications like military radar feed networks, commercial phased array networks, low loss base station antennas it is used in missile guidance systems, digital radio antennas, filters, couplers, low noise amplifiers also [9].

C. Taconic RF-35P

RF-35P is an organic-ceramic laminate in the ORCER family of Taconic products based on woven glassreinforcement, having expertise in both ceramic fill technology and coated PTFE fiberglass [10]. It is the best choice for low cost, high volume, high frequency applications.

D. Dupont 951

Dupont 951 is a low-temperature cofired ceramic tape, comprising a complete cofireable family of Au and Ag metallization, buried passives, and encapsulants. 951 is available in multiple thicknesses and is designed for use as an insulating layer in multichip modules, single chip packages, ceramic printed wiring boards, RF modules and so on. Under proper circumstances 951offers the benefits like hermetic packaging, low temperature brazing, cavities, high density interconnections, cofire processing and refire stability, component integration–buried resistors, capacitors, and inductors [11].

E. Teflon

Polytetrafluoroethylene (PTFE), mostly known as teflon is a Dupont corp. product. It is a tough, waxy, nonflammable, colorless, odorless powder, a fluoroplastic with many properties which give an increasingly wide range of uses [12].

F. Bakelite

Bakelite or polyoxybenzylmethylenglycolanhydride, is an early plastic. It is a thermosetting phenol formaldehyde resin, formed from an elimination reaction of phenol with formaldehyde. It is most commonly used as an electrical insulator possessing considerable mechanical strength.Bakelite can be molded, and in this regard was better than celluloid and also less expensive to make.

IV. ANTENNA DESIGN

A. Theoretical Design

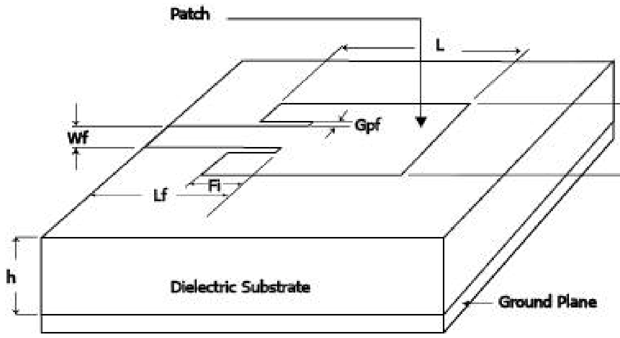

Fig.2. Microstrip patch antenna

Designing of a patch antenna includes consideration about the width (W), effective dielectric constant ($\boldsymbol{\mathcal{E}_{eff}}$), effective length ($\boldsymbol{L_{eff}}$), length extension ($\Delta L$), actual length of patch (L).In order to find the value of effective length, effective dielectric constant can be found by (1) [13].

$$\mathcal{E}_{eff} = \frac{\mathcal{E}_r+1}{2} + \frac{\mathcal{E}_r-1}{2}\left[1 + 12\,\frac{h}{W}\right]^{-\frac{1}{2}} \tag{1}$$

To design an antenna that works on 60 GHz, ($f_r = 60\ GHz$) width (W) was found by (2) [13].

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}} \tag{2}$$

Using value of ϵ_{eff} found from (1), effective length is then found by (3) [13].

$$L_{eff} = \frac{c}{2f_0\,\sqrt{\mathcal{E}_{eff}}} \tag{3}$$

Extension length (ΔL), which is required to determine actual length of antenna is found by (4) [8].

$$\Delta L = 0.412h\,\frac{(\mathcal{E}_{eff}+0.3)(\frac{W}{h}+0.264)}{(\mathcal{E}_{eff}-0.258)(\frac{W}{h}+0.8)} \tag{4}$$

From the equations it is noted that the width and length of the antenna depends on the appropriate resonant frequency and effective dielectric constant. The input impedance and radiation pattern both are controlled by the width of the micro -strippatch antenna. Larger widths reduce the impedance and increase the bandwidth. Smaller permittivity for the substrate is used forbetter radiation. The frequency of operation of the patch antenna is determined by the length, using the value of ΔL actual length is found by (5) [13].

$$L = L_{eff} - 2\Delta L \tag{5}$$

V. ANTENNA CHARACTERISTICS

The entire analysis of this research is based on Computer Simulation Technology (CST) software. And Transient Solver was used for simulation. To design the antenna Waveguide Port was used as it has lower dielectric loss and higher transmitting power. Input impedance of the patch antenna is 50 ohms. Gaussian signal was used as port signal of the antenna.

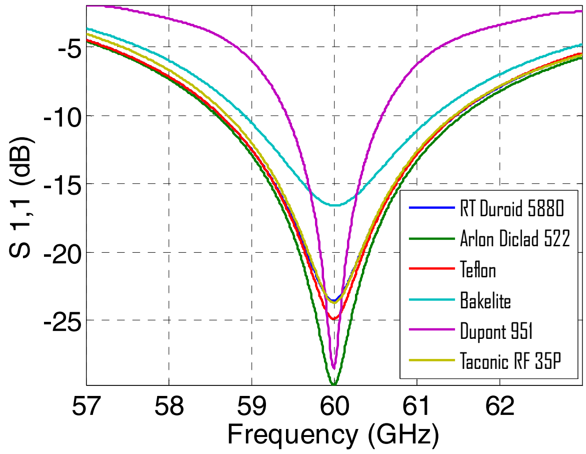

Fig.3. Simulatedreturn loss of patch antenna of different materials

Simulated results for patch antenna with patches of different materials (different dielectric strength) were determined and plotted in fig.3 for return loss and radiation pattern. The analysis shows that, all these materials give resonant in 60 GHz which as desired. S11 parameter also known as reflection co-efficient shows how much power is radiated or reflected from the antenna. Again Bandwidth is a strong catalyst while choosing materials for antenna design. Observing the -10dB crossing points and return loss of the graph it can be concluded that 'ArlonDiclad 522' gave the best performance in both aspects, whereas material like 'Bakelite' showed a poor performance in terms of return loss and 'Dupont 951' gave the worst bandwidth coverage.

In fig. 4, this is the far field 3D view for 'ArlonDiclad 522'lossy materials. The far field region determines the antenna radiation pattern.

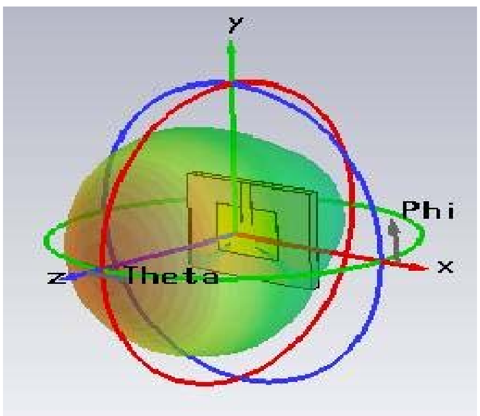

Fig.4. Far Field Region for 'Arlon Di 522'

Here, from fig. 4 the maximum directivity is on the xz plane at theta zero degree. It is a measure of how "directional" an antenna radiation pattern is. From the simulation of patch antenna for 'ArlonDiclad 522', total radiation efficiency has found to be -0.82 dB and directivity is 8 dBi. From fig.4, it is found that the bottom green color indicated the reactive near field region; hence, in this region the directivity is low. The directivity increased from green to yellow in the radiation near field (Fresnel) region. Top red color indicated the far field region because in this region the directivityis higher [13].

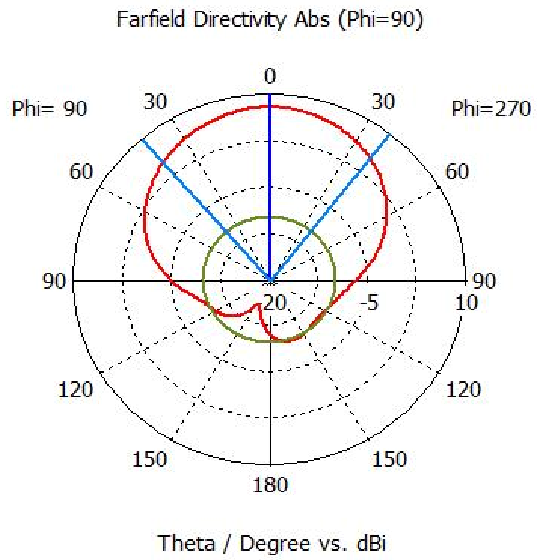

Fig.5. Far field polar view for 'Arlon Di 522' material

In fig.5 theta is at 45 degree and phi is at 90 degree. The two blue lines in fig.5 indicating the half power beam width denote the angular separation in which the magnitude of the radiation pattern decreases by 50% or -3dB from peak of the main beam.For 'ArlonDiclad 522' half power beam width is 76.6degrees,angular width is 78.5 degree and side lobe level is -17.6dB.

TABLE I. PERFORMANCE OF ANTENNA FORDIFFERENT SUBSTRATES

Parameters	**Substrates**					
	Teflon	***RTDur-oid 5880***	***Arlon Di 522***	***Taconi-c RF 35P***	***Bakeli-te***	***Dupont -951***
Dielectric Constant	2.1	2.2	2.5	3.5	4.8	7.8
Resonant Frequency (GHz)	60	60	60	60	60	60
Return Loss	-24.87	-23.74	-29.71	-23.69	-16.6	-28.52
Side Lobe (dB)	-17.5	-17.7	-17.6	-17.0	-3.0	-1.9
VSWR	1.28	1.14	1.07	1.14	1.35	1.076
Gain (dB)	7.68	7.56	7.21	5.66	4.84	3.1
Directivity (dBi)	8.32	8.26	8.02	7.16	5.67	4.6
Bandwidth (GHz)	58.66-61.47 (4.7%)	58.64-61.48 (4.7%)	58.59-61.56 (4.9 %)	58.72-61.46 (4.6%)	58.92-61.21 (3.8%)	59.44-60.58 (1.9%)

Different parameters for different materials were observed in the table-I. Here it is clearly showed that substrate with lower dielectric constant shows better performance. One important parameter to analyze the performance of antenna is return loss, which is a logarithmic ratio measured in dB comparing the power reflected by the antenna to the power that has fed into the antenna from the transmission line.

Another important parameter, directivity is the ability of an antenna to focus energy in a particular direction when transmitting and receiving energy better from a particular direction w. In static situation, it is possible to use the antenna directivity to concentrate the radiation beam in the wanted direction.

The gain of an antenna in a given direction is the amount of energy radiated in that direction compared to the energy [6]. Antenna Gain (G) can relate to directivity (D) by (6).

$$G = \varepsilon_R D \tag{6}$$

Voltage Standing Wave Ratio (VSWR) is also an important parameter and like both the directivity and gain, VSWR is better for substrate with lower dielectric constant.

One more important parameter, -10dB bandwidth can be described in terms of the percentage of the center frequency of the band as showed in (7) [15].

$$BW = 100 \times \frac{F_H - F_L}{F_C} \% \tag{7}$$

VI. CONCLUSION

This paper focused on the Ultra Wide band Patch antenna of different dielectric materials for 60 GHz considering higher efficiency, maximum radiation, higher bandwidth and minimum return loss. The patch antenna was designed for six different materials with different substrate permittivity height and length. It has implied the antenna more focused and directional. Amongst the experimented materials, ‘ArlonDiclad 522’ gave the best performance. Through the analysis, we got the Return loss is -29.71, Bandwidth 4.95 %, gain 7.205 dB, Directivity 8.024 dBi for patch antenna of ‘ArlonDiclad 522’ that indicated the better efficiency with no loss around them.

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