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DIELECTRIC LOADED EXPONENTIALLY TAPERED SLOT ANTENNA FOR WIRELESS COMMUNICATIONS AT 60 GHz

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Abstract—This paper deals with the dielectric loaded Exponentially Tapered Slot (ETS) antenna needed for ultra-high-speed, high-capacity wireless communication systems which work at 60 GHz and illustrates its specifications and requirements. The antenna in such system requires high gain, high-efficient and high performance design specifications. The ETS antenna and the loaded dielectric are integrated using the same single substrate resulting in easy fabrication and low cost. The ETS antenna with rectangular and elliptical shaped loaded dielectrics were designed and fabricated. These antennas have high gain and wider beamwidth in both E-plane and H-plane. The proposed antenna design is simulated using 3D electromagnetic software CST Microwave Studio and the comparison is made with Ansys HFSS to validate the design procedure. The results obtained from the simulations and the measurements are in good agreement.

1. INTRODUCTION

The ever-increasing demand for mobile and wireless communication and the development of new generation wireless technologies require an efficient design of antenna in smaller size for wide range of variety of applications with style and performance [1, 2]. Wireless applications such as online video streaming, online games, medical data collection and health care applications etc., desires some special requirements, such as high data rate, larger capacity, limited communication area, and high angular resolution [3].

Recently, emerging systems of Gigabit (GiFi) wireless communications [3] are pushed into regimes of higher frequencies at 60 GHz with

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capabilities of gigabit data rates. Corresponding to these ultra-high data rates, the operating bandwidth is also stretched to millimeter (Mm) waves at 60 GHz. The radio systems at Mm wave frequencies including its antennas are required to enable these wide bandwidth transmissions for high-speed broadband wireless local area networks (WLAN) and wireless personal area networks (WPAN) communication systems which are expected to proliferate across very wide variety of consumer devices over the next years. Within these Mm wave radio technologies, various kinds of wireless data transmissions and advanced information services are expected to develop with and without license. Strong attenuation over the free space due to the smaller wavelengths, oxygen absorption and severe attenuation by walls allow frequency reuse and user privacy [4–6] makes Mm waves based wireless technologies an attractive proposition for ultra-high-speed new generation WLAN and WPANs [7].

Therefore, the proposed work addressing the challenges in dielectric loaded ETS antenna designed for the realization of Mm wave based wireless communication networks [8], particularly at 60 GHz. This work utilizing 3D electromagnetic software CST MW Studio and comparison with Ansys HFSS validates the design procedure. The paper is organized as follows; Section 2 deals with technical challenges, especially on antenna design and development. Section 3 deals with results obtained in our proposed work and discussions. Finally, Section 4 gives conclusions.

2. TECHNICAL CHALLENGES AND ISSUES

Antennas with excellent design can improve the communication performances. Due to the short wavelength of Mm waves, it is easy to obtain an electrically larger antenna aperture. It means that high gain and angular resolution are easily obtained. However, it is also difficult to develop an Mm wave antenna because of the rigorous manufacturing requirement and large metal and dielectric loss. Despite many advantages offered and high potential applications envisaged in 60 GHz, there are number of technical challenges and open issues that must be solved prior to the successful deployment of this technology. These challenges can be broadly classified into channel propagation, antenna technology, RF section, and choice of modulation. Many types of antenna structures are not suitable for 60 GHz WPAN and WLAN applications due to the requirements of low cost, small size, light weight, and high gain. In addition, 60 GHz antennas require to be operated with approximately constant gain and high efficiency over the broad frequency range (57–64 GHz) [8, 9].

From the configuration standpoint, most of the antennas in Mm waves are similar to those in microwaves. However, the choice of antennas for Mm wave depends on the applications and the propagation environment. Recently, the technology of planar integrated antenna [10] has been developed for Mm wave applications due to the trend of the integration in radio frequency front-end circuits and systems. As the operating frequency of wireless systems move into Mm wave range in order to provide gigabits per second service, there is an increasing demand of high gain antennas used for consumer devices. The desired antenna has to be compatible with integrated circuits, and possess high gain and small side lobes. The antenna, when integrated into consumer devices, should also have the benefits of small size and low production cost. Rectangular waveguide components have widely been used in millimeter-wave systems. Relatively high cost and difficult integration prevent them from being used in low-cost, high-volume applications. The proposed dielectric scheme provides an interesting alternative. This antenna is integrated by using a single substrate. It is easy to fabricate and the structure is compact. To eliminate the higher order modes in the waveguide, the thickness of the substrate is restricted. The loaded dielectric slab in front of the exponential taper can be considered as a dielectric guiding structure excited by the exponential flare resulting in a wider beamwidth in both plane and maximum gain. The compact millimeter wave ETS antenna with dielectric loading can achieve a broadband performance and offer several advantages over other counterparts such as relatively low insertion loss, better VSWR, good design tolerance and circuit size compactness [11].

3. ANTENNA DESIGN

The ETS antenna is also known as flared notch or Vivaldi antenna, is one of the most promising antenna satisfying all requirements described in the technical challenges [12, 13]. It is basically a planar traveling wave antenna with end-fire radiation. The ETS antenna is the preferred candidate for Mm Wave applications due to its wide bandwidth, low cross polarization and high directive patterns [14]. A major advantage of this antenna type is that the ultra-wide bandwidth and high gain can be achieved using exponentially tapered profiles with dielectric loading [15].

The Figures 1, 2 and 3 illustrate structure of an ETS antenna without dielectric loading and with dielectric loading simulated by using CST. The ETS antenna is fabricated on Rogers RT/Duroid 5880 substrate with a thickness of 0.787 mm, relative permittivity of 2.2,

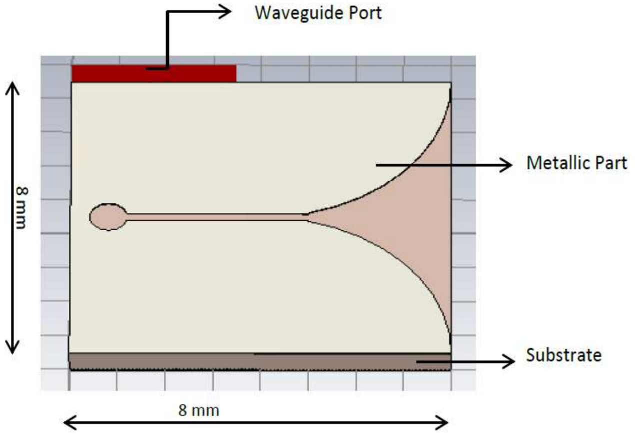

Figure 1. ETS antenna without dielectric loading.

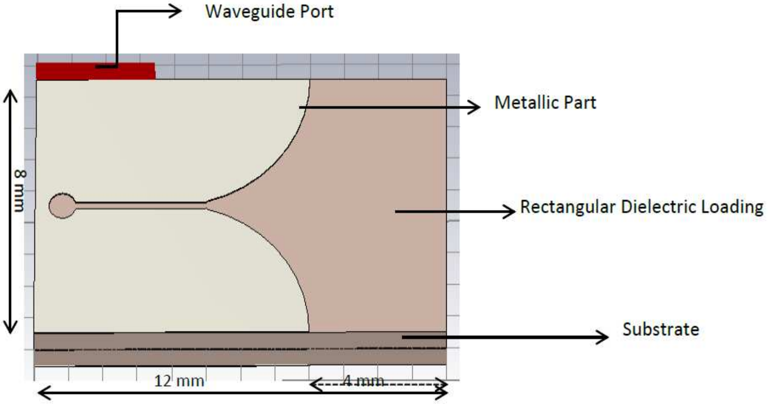

Figure 2. ETS antenna with rectangular dielectric loading.

and relative permeability of 1 and loss tangent of 0.0009.

The ETS antenna tapered profile is described by an exponential function. The ETS antenna is excited via the microstrip to stripline transition. The transition construction exploits wideband features of a microstrip radial stub used as a virtual wideband short. The microstrip is virtually shunted to the second half of the strip line metallization while the first half serves as a ground metallization for the microstrip line. It is necessary to transform the impedance of the input feeding microstrip line to the input impedance of the transition. Therefore, the

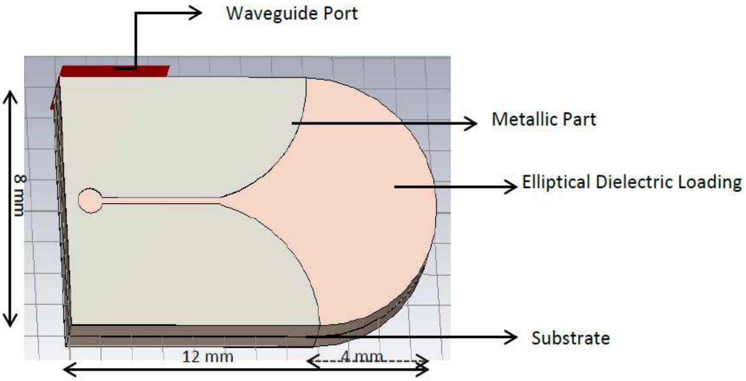

Figure 3. ETS antenna with elliptical dielectric loading.

linear microstrip taper is used as the input impedance transformer [16].

Antenna tapers are defined as exponential curves in the x-y plane. To comply with the antenna board dimensions and slot line parameters, following exponential taper curve definition equation is used [17],

$$y = C_1 e^{ax} + C_2 \tag{1}$$

where 'a' is the rate of opening the exponential taper, and C_1 and C_2 can be calculated by the starting and ending points of the taper $P_1(x_1, y_1)$ and $P_2(x_2, y_2)$,

$$C_1 = (y_2 - y_1)/\left(e^{ax_2} - e^{ax_1}\right) \tag{2}$$

$$C_2 = \left(y_1 e^{ax_2} - y_2 e^{ax_1}\right)/\left(e^{ax_2} - e^{ax_1}\right) \tag{3}$$

The Table 1 shows the dimensions of the ETS antenna used in the simulation. The shape of the curvature influences the traveling wave in two main areas. First is the beginning of the taper and the second is the wide end of the taper [18]. On both places, a reflection of the

Table 1. Dimensions of ETS antenna.

Parameters	Specifications (mm)
Slot Width	0.4
Tapper width	8
Tapper length	4
Strip length	3.7
Total length	8
Total width	8

traveling wave is likely to occur. Therefore, the smoother taper in the neck minimizes the reflection at that place. This can be achieved with higher value of 'a'. The designed antenna is simulated without feeding section, using lumped port as the source of excitation [19].

The beamwidth in the H-plane can be controlled through the flare in the H-plane. The beamwidth in the E-plane is determined by the flare in the E-plane that is limited [20]. In some indoor applications, a wider beamwidth in the E-plane is also desired. For this purpose, a dielectric slab is placed in front of the flare of the ETS antenna. This slab serves as the dielectric guiding structure in the E-plane. In the H-plane, for an ETS antenna with maximum gain, the flare phase distribution along the H-plane is nearly uniform without the dielectric loading. If the length of the slab is not properly chosen the beamwidth in the H-plane will even be broadened.

4. RESULTS AND DISCUSSIONS

The simulated ETS antenna without dielectric loading is shown in Figure 1, the gain is 3.8 dBi, main lobe direction is 74 degree, S_{11} parameter is -8.9 dB, VSWR is 2.12 and side lobe level is -3.7 dB. The 4 mm length of rectangle and elliptical dielectric loading is placed in front of the ETS antenna flare. The respective structures are shown in Figures 2 and 3. The lengths of the dielectric loading versus gains of the antenna are shown in Figure 4.

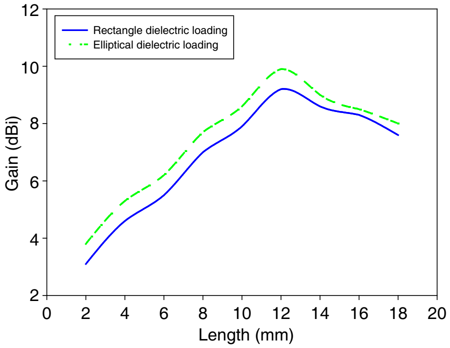

Figure 4. Length of dielectric loading versus gain.

From this figure it is seen that the gain increases with the increase of dielectric length. For example, when the length of elliptical dielectric loaded antenna is 12 mm, the gain is 9.9 dBi, main lobe direction is 70 degree, S_{11} parameter is -14.6 dB, VSWR is 1.7 and side lobe level is

Table 2. Performance comparison of the dielectric loading at 60 GHz.

	Gain (dBi)	Main Lobe (Degree)	S_{11} (dB)	VSWR	Side Lobe (dB)
Without dielectric	3.8	74	−8.9	2.12	−3.7
Rectangle	9.2	72	−12.5	2.01	−2.0
Elliptical	9.89	73	−14.6	1.70	−1.7

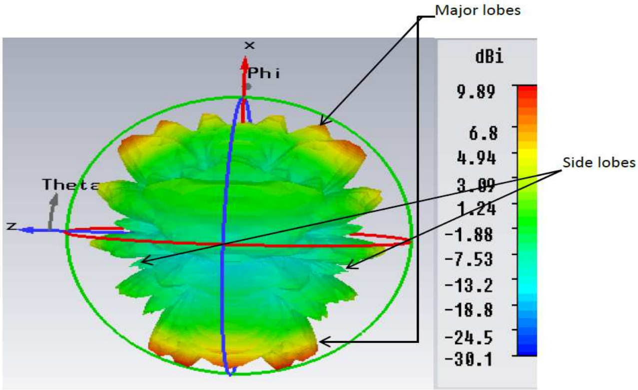

Figure 5. Simulated 3D radiation pattern.

−1.7 dB. When comparing elliptical dielectric loaded antenna without dielectric loading the gain is increased by 6.1 dBi and S_{11} parameter has decreased by −5.7 dB.

Further, the rectangle and elliptical dielectric loading are investigated. The Table 2 shows the performance comparison of the dielectric loading at 60 GHz. From these results it is seen that elliptical dielectric loading with the ETS antenna gives more gain at 60 GHz with slightly lesser main lobe direction. The ETS antenna provides gain depending on the length of the taper and the shape of the curvature.

The simulated results of 3D radiation pattern, S_{11} parameter, VSWR, total and radiation efficiency for the ETS antenna with elliptical dielectric loading is shown in Figures 5, 6, 7 and 8.

The Table 3 shows the performance comparison of ETS antenna with elliptical dielectric loading using 3D electromagnetic software CST and comparisons with HFSS validate the design procedure based on antenna gain, S_{11} and VSWR. It is observed that there is good

Table 3. Performance comparison of ETS antenna with elliptical dielectric using CST and HFSS.

Parameters	CST	HFSS
Gain (dBi)	9.89	9.87
S_{11} (dB)	-14.6	-14.56
VSWR	1.70	1.68

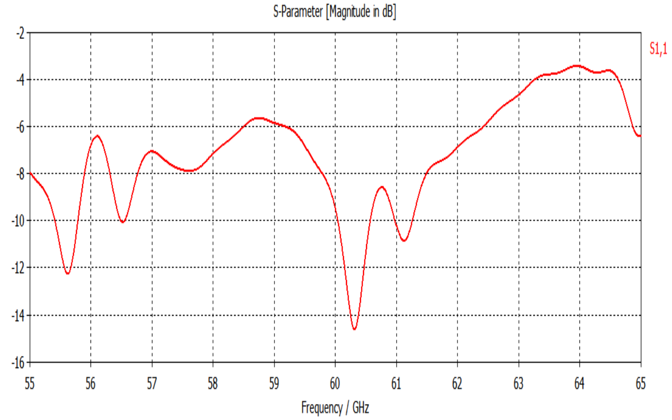

Figure 6. Simulated S_{11} parameter.

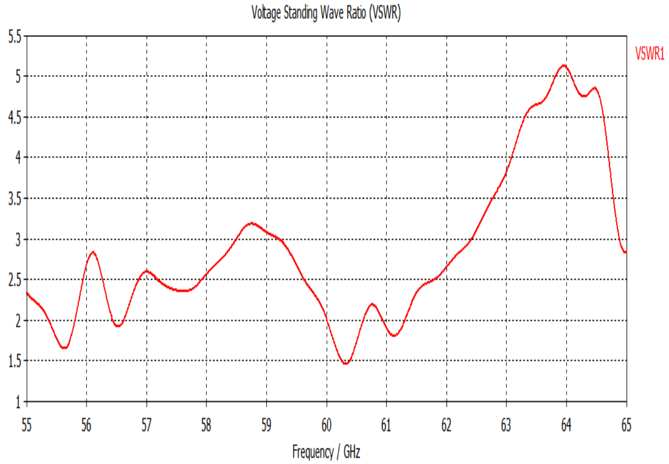

Figure 7. Simulated VSWR.

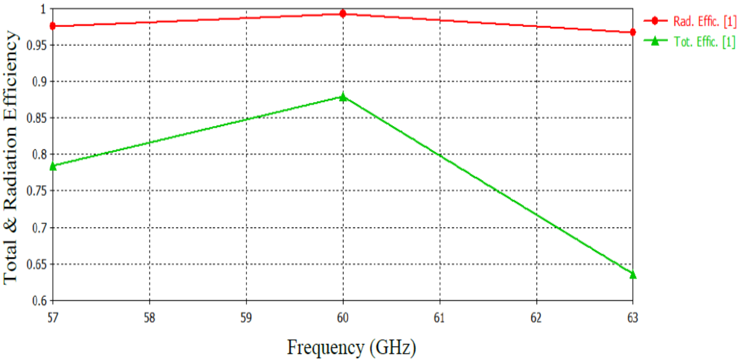

Figure 8. Simulated total and radiation efficiency.

Figure 9. Elliptical dielectric loaded ETS antenna.

agreement between the gain, S_{11} and VSWR. A slight difference in the two simulated values is basically because of the two different numerical methods employed in CST and HFSS.

The ETS antenna with elliptical dielectric loading is fabricated with optimized dimensions and measured. The photograph of fabricated elliptical dielectric loaded antenna is shown in Figure 9. The antenna is fabricated on RT Duroid 5880 high frequency laminates with thickness of 0.031 inch. The antenna is having two substrates such as top and bottom consisting of radiating flare geometries on the two opposite faces. One of the substrate is etched completely on the opposite side of the flare and the other substrate consists of stripline feed being printed and sandwiched between the two substrates containing the fares. The top, bottom and middle layers are forming the complete antenna. It is fabricated using printed circuit processing techniques. The two substrates were bonded together with the glue them together without any air gaps.

The simulated and measured results of S_{11} parameter and gain are shown in Figures 10 and 11. A slight difference is observed between the measurement value and simulated value. The results from simulation and measurement are in good agreement.

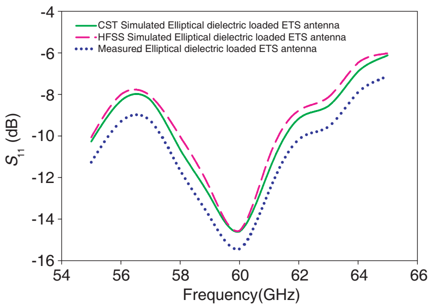

Figure 10. Simulated and measured S_{11} parameter.

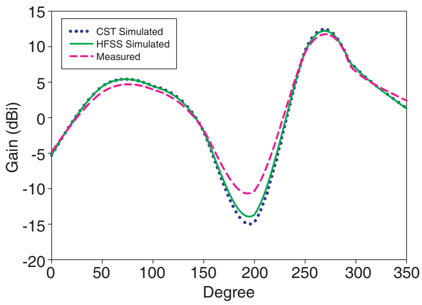

Figure 11. Simulated and measured gain.

5. CONCLUSIONS

Broadband Mm wave transmissions in the 60 GHz range enable WLAN/WPAN systems with regard to increasing data rates and faster performance. The use of Mm wave techniques offers many advantages for short-range wireless systems compared to radio techniques at lower frequencies. This work targets design and development of a dielectrically loaded ETS antenna and presents measured/simulated results. The proposed ETS antenna results showed a high gain of 9.46 dBi and a return loss of -15.43 dB at 60 GHz. It is also observed that with proper selection of dielectric structures and its parameters, maximum gain for the given antenna can be achieved. The reasonable agreement between the simulated and measured results shows that the designed ETS antenna with elliptical dielectric loading fulfills the requirements of GiFi wireless communications at Mm waves.

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REFERENCES

1. Smulders, P., "Exploiting the 60 GHz band for local wireless multimedia access: Prospects and future directions," *IEEE Communications Magazine*, Vol. 40, No. 1, 140–147, 2002.
2. Yong, S. K. and C.-C. Chong, "An overview of multi gigabit wireless through millimeter wave technology: Potentials and technical challenges," *EURASIP Journal on Wireless Communications and Networking*, Vol. 2007, Article ID 78907, 2007.
3. Daniels, R. C., J. N. Murdock, T. S. Rappaport, and R. W. Heath, "60 GHz wireless: Up close and personal," *IEEE Microwave Magazine*, Vol. 11, No. 7, 44–50, Dec. 2010.
4. Rappaport, T. S., J. N. Murdock, and F. Gutierrez, "State of the art in 60-GHz integrated circuits and systems for wireless communications," *Proceedings of the IEEE*, Vol. 99, No. 8, 1390–1436, Aug. 2011.
5. Yong, S. K., "Multi gigabit wireless through millimeter wave in 60 GHz band," *Proceedings of Wireless Conference Asia*, Singapore, Nov. 2005.
6. Teshirogi, T. and T. Yoneyama, Eds., *Modern Millimeter-wave Technologies*, Ohmsha Ltd., Tokyo, Japan, 2001.
7. Schantz, H., *The Art and Science of Ultra Wideband Antennas*, Artech House, Norwood, MA, USA, 2005.
8. "Next-generation broadband wireless access tech.," *NTT Technical Review*, Vol. 2, No. 1, 12–63, 2004.
9. Ihara, T. and K. Fujimura, "Research and development of millimeter-wave short-range application systems," *IEICE Trans. Commun.*, Vol. E79-B, No. 12, 1741–1753, Dec. 1996.
10. FCC, First Report and Order, Feb. 2001.
11. Xiao, S.-Q., M.-T. Zhou, and Y. Zhang, *Millimeter Wave Technology for Wireless LAN, PAN and MAN*, Auerbach Publications, 2008.
12. Yong, S.-K., P. Xia, and A. V. Garcia, *60 GHz Technology for GBPS WLAN and WPAN: From Theory to Practice*, John Wiley & Sons Ltd., 2011.
13. Deslandes, D. and K. Wu, "Design consideration and performance analysis of substrate integrated waveguide components," *IEEE 32nd European Microwave Conference*, 1–4, Sep. 2002.
14. Gibson, J. P., "The Vivaldi aerial," *Proc. 9th European Microwave Conference*, 1979.

15. Gazit, E., "Improved design of the vivaldi antenna," *IEE Proceedings H: Microwaves, Antennas and Propagation*, Vol. 135, No. 2, 89–92, Apr. 1988.
16. Langley, D., P. Hall, and P. Newham, "Balanced antipodal Vivaldi antenna for wide bandwidth phased arrays," *IEE Proc. Microwave Antennas Propag.*, Vol. 143, No. 2, 97–102, Apr. 1996.
17. Yang, Y., Y. Wang, and A. E. Fathy, "Design of compact Vivaldi antenna arrays for UWB see through wall applications," *Progress In Electromagnetics Research*, Vol. 82, 401–418, 2008.
18. Hood, A. Z., T. Karacolak, and E. Topsakal, "A small antipodal vivaldi antenna for ultrawide-band applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 7, 556–560, 2008.
19. Hamzah, N. and K. A. Othman, "Designing Vivaldi antenna with various sizes using CST software," *Proceedings of the World Congress on Engineering 2011*, Vol. II, WCE 2011, London, UK, Jul. 6–8, 2011.
20. Kedar, A. and K. S. Beenamole, "Wide beam tapered slot antenna for wide angle scanning phased array antenna," *Progress In Electromagnetics Research B*, Vol. 27, 235–251, 2011.