Millimeter-Wave High-Gain SIW End-Fire Bow-Tie Antenna

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***Abstract*—The proposed antenna consists of a pair of bow-tie radiators, where each radiator is etched on the opposite side of the common dielectric substrate and fed through substrate integrated waveguide (SIW) feed-line. The bow-tie radiators are arranged to cross each other symmetrically by tilting the feed-lines by 30◦ to enhance the antenna gain and to obtain the required radiation pattern. This communication presents a high-gain bow-tie antenna that operates across 57–64 GHz for application in high data rate point-to-point communication systems. . The antenna is loaded with a pair of double G-shaped resonators (DGRs) that are located in a region between the radiators and SIW to suppress the back-lobe level in the H-plane. Embedded in the E-plane of the antenna is an array of zero index meta-material (ZIM) unit-cells whose purpose is to effectively confine the electromagnetic waves in the end-fire direction to enhance its gain performance. The proposed structure exhibits a gain of 11.8–12.5 dBi over the frequency range of 57–64 GHz with reflection coefficient less than − 11 dB. In addition, the proposed antenna exhibits good cross-polarization, which is less than − 17 dB in both E- and H-planes at 60 GHz.**

***Index Terms*—Bow-tie antenna, end-fire antenna, millimeter-wave antenna, Zero-index meta-material (ZIM), Double G-shaped Resonators (DGRs).**

I. INTRODUCTION

In order to operate the Unlicensed ISM band centered at 60 GHz(57-64GHz),High data rate (in the order of multiple of Gbps) and For the application to Transmit uncompressed HD video streaming in Wireless point to multipoint connections this type of end fire antenna can be used.

High propagation loss at these frequencies makes the design of high-gain antennas crucial. For such antennas to be commercially viable, they need to be compatible with low-cost technologies. Numerous antenna designs at 60 GHz have been previously proposed and implemented using multilayer technology including low-temperature co fired ceramic (LTCC), liquid crystal polymer (LCP), and high-end hydrocarbon ceramic printed circuit boards (PCB)

In this communication, a planar bow-tie antenna that uses an amalgamation of different techniques to realize a high-gain structure for operation over 57–64 GHz is presented.

Each radiator is etched on the opposite sides of the substrate and arranged to cross each other symmetrically. The radiators are tilted by 30◦ with respect to the end-fire direction (+ y) to increase the antenna gain and determine its radiation pattern. The antenna is loaded with double G-shaped resonators (DGRs) that have a band-stop property. The two DGR structures are located in the vicinity of the bow-tie radiators and substrate integrated waveguide (SIW) to suppress the back-lobe level (BLL) in the H-plane. An array of zero-index meta-material (ZIM) unit-cells is embedded laterally in the E-plane above the bow-tie radiators to convert the spherical waves into uniform field distribution. The fabricated bow-tie antenna provides a gain of 11.5–12 dBi over 57–64 GHz, and a reflection coefficient of less than − 11 dB

II. ANTENNA DESIGN

The lower end of the SIW structure is tapered to a microstrip feed-line, and the upper end tapered to a bow-tie radiating element.SIW structure resembling a rectangular tunnel created between the top and bottom copper foils of the dielectric substrate.

The SIW structure was fabricated on FR-4 Epoxy/Glass dielectric substrate with relative permittivity of 2.2, thickness of 0.5 mm, and loss tangent of 0.0009. The feed-line to the SIW structure has a tapered transition to provide a good impedance match over the required frequency range of 57–64 GHz.

In order to reduce the back-lobe radiation in the H-plane (yz), DGR.DGR is used to analyze the microwave and millimeter wave frequency circuits and by using this kind of resonator it provides high quality factor and high sensitivity level. The DGR behaves equivalently to an LC resonant circuit which is excited by an EM-wave source. The DGR structure is constructed on both layers of the substrate in the vicinity of the bow-tie radiating elements. This is necessary to couple the DGR with the electromagnetic field emanating from the radiating elements to induce current along the perimeter of DGR structure.

This resonator is based on the broadside coupled split-ring resonator structure. The S-parameter response of the DGR structure in exhibits a wide bandstop response over 55.4–65 GHz for a rejection level greater than − 10 dB.

The S-parameters of the DGR structure in were established by applying the ports on both sides of the resonator along the xy-plane. Application of a plane wave along the y-axis results in the electric and magnetic field polarized in the x- and z-axes, respectively.

With DGR loading, the antenna gain varies from 9.57 to 8.14 dB over 57–64 GHz, as shown in Fig. 9. Gain enhancement of 2.14– 0.28 dB is observed across 57–62 GHz compared with the bow-tie antenna without DGR loading. However, above 62.5 GHz, the gain begins to decline and reduces by 0.7 dB at 64 GHz.

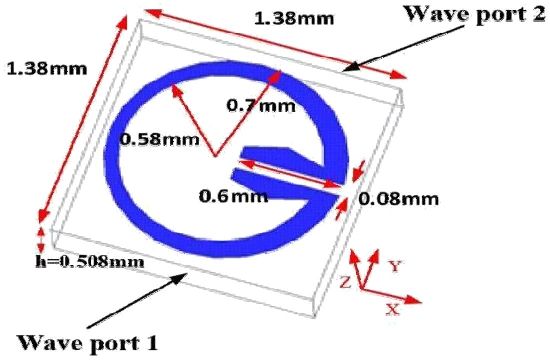


Fig.1 Structure of DGR

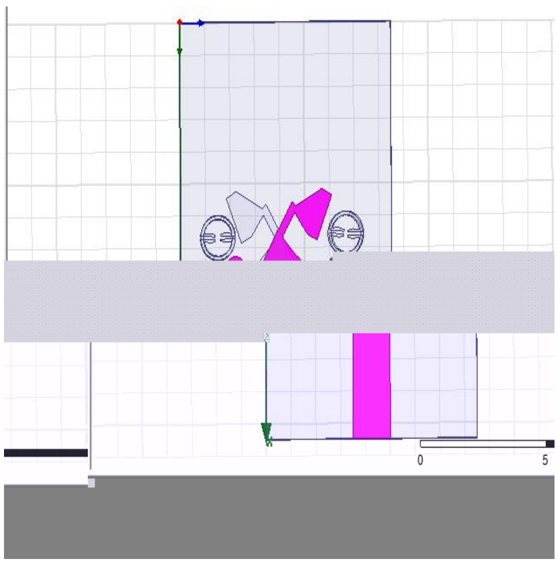


Fig.2. Configuration of the proposed tilted bow-tie antenna with DGR

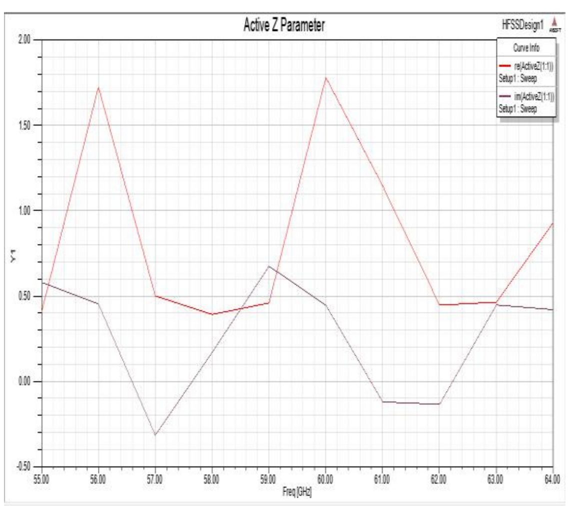
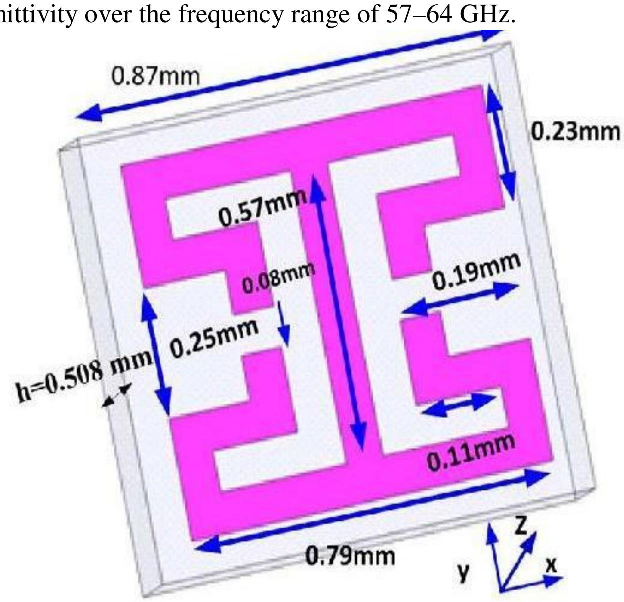


Fig.3. Z-parameter (|Z12 | and |Z11 |) response of the DGR configuration

III. ZIM UNIT-CELL

In order to enhance the gain of the antenna, a ZIM unit-cell structure was embedded in the antenna. The transmission and reflection coefficient response of the ZIM unitcell in that the signal is uninhibited to pass through the structure over the required operating frequency range of 57–64 GHz.

The ZIM unit-cell structure is a modified version of the electric LC resonator. Here, we have increased the effective inductance and capacitance of the structure, so that its resonant frequency is lower and it exhibits near-zero permittivity over the frequency range of 57–64 GHz.



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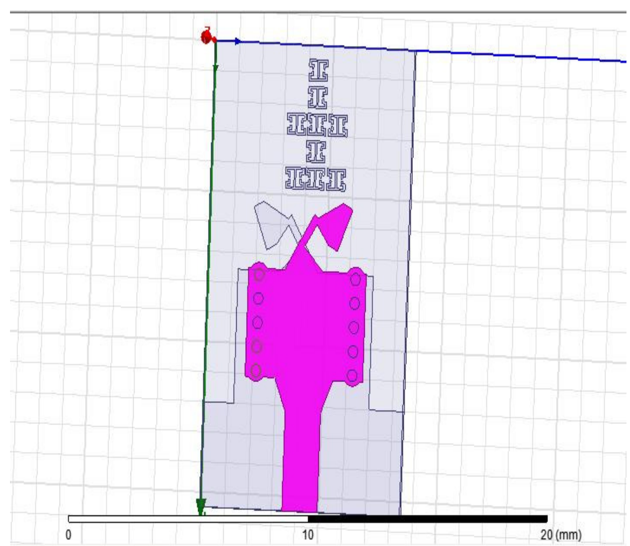
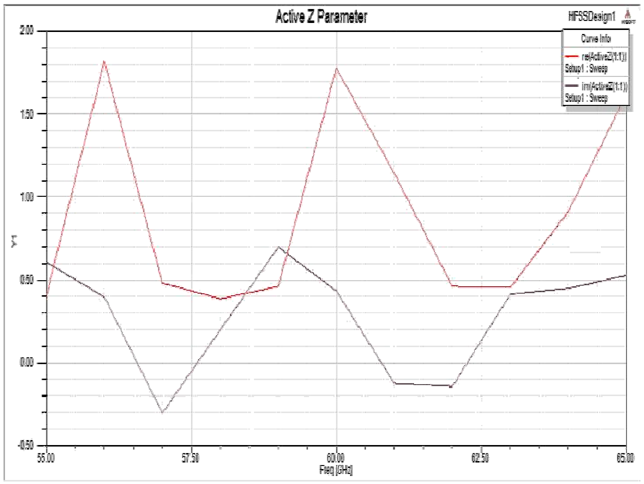
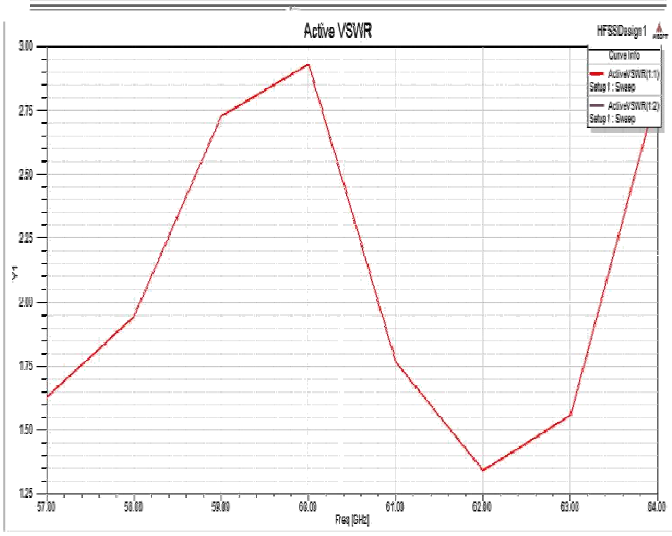


Fig.4.(a) Configuration of ZIM unit cell (b) Proposed tilted bow-tie antenna with ZIM unit cell





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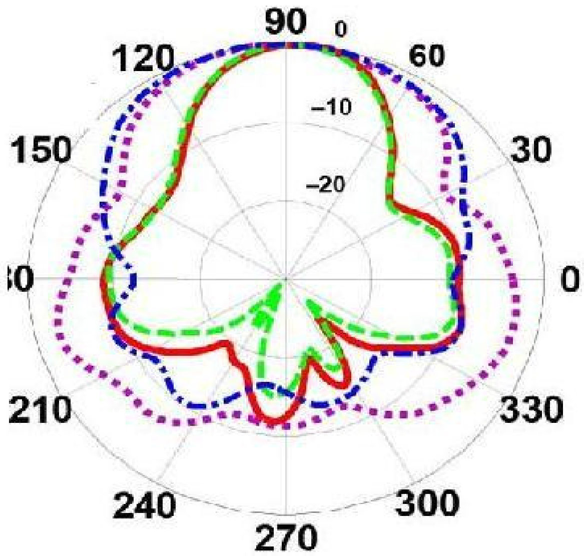

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Fig.5.(a) Z-parameter (|Z12 | and |Z11 |) response of the ZIM unit cell configuration (b) VSWR parameter response of Bow-Tie Radiator (c) Radiaton pattern

ZIM may have paved a new way for designing novel high-gain antennas due to its unique properties. Based on Snell's law, it is considered an incident ray on an interface of the ZIM with grazing incidence that comes from a source inside ZIM. A near-zero index ray in the media will be refracted in a direction that is very close to the normal.

ZIM unit-cells provides a gain variation of 11.8–12.5 dB between 57 and 64 GHz, which corresponds to an average gain enhancement of 3.95 dB compared with the tilted bow-tie antenna without ZIM unit-cells. Based on the effective medium theory, electromagnetic metamaterials can be characterized by electric permittivity and magnetic permeability.

The zero-index metamaterials (ZIM) are such kinds of metamaterials whose value of permittivity or permeability approximates to zero. With such a unique property, ZIM can be used for gain enhancement of antennas. As illustrated in the the ZIM unit cell is a two-layer structure with meander lines etched on both sides of the dielectric substrate. Each tail of the two meander lines is connected by a metallic stick through the substrate, which enlarges the current loop thus minimizes the overall dimension of the unit cell. when the antenna is implemented with the ZIM structure, the −10 dB return loss frequency band splits into two.

IV. EFFECT OF BOW-TIE RADIATOR TILT ANGLE

Bow-tie antenna is featured by its wide impedance bandwidth in the microwave band, thus can be versatile for various needs as an ideal radiator. Such type of antenna, which has been extensively used in the UWB system, is the planarization of bi-conical antenna. In consideration of the commercial aspects, the antenna should be compact, low-cost and easy to fabricate. Bow Tie antenna is also known as "Butterfly antenna or Biconical antenna". Its radiation pattern is similar to dipole antenna and it undergoes a cross polarization which is less than -17 dB. The radiation patterns of the antenna with the bow-tie radiators tilted by 30◦.

The dielectric substrate is chosen as FR-4 with the permittivity of 4.3 and the loss tangent is 0.025. The length of the antenna (Lb) is 53 mm, and the angle of the wing of the antenna is 60◦. As a result of study that increasing the tilt angle from 5◦ to 30◦ has a direct effect on the antenna gain. Certain tilt angles improve the antenna gain over the frequency range of 56– 64 GHz, which is equivalent to enlargement of the antenna aperture. A tilt angle of 30◦ is observed to provide an optimum gain performance. At a tilt angle of 30◦ , the gain varies between 7 and 8.8 dB, which corresponds to a gain enhancement of 1.5–2.0 dB over frequency band of 57–64 GHz compared with the antenna with 0◦ tilt angle.It can be made with a 2x4, some coat hangers, aluminium foil and few other common parts. While very inexpensive to build, this design is able to pull in stations from 45 and 50 miles away.

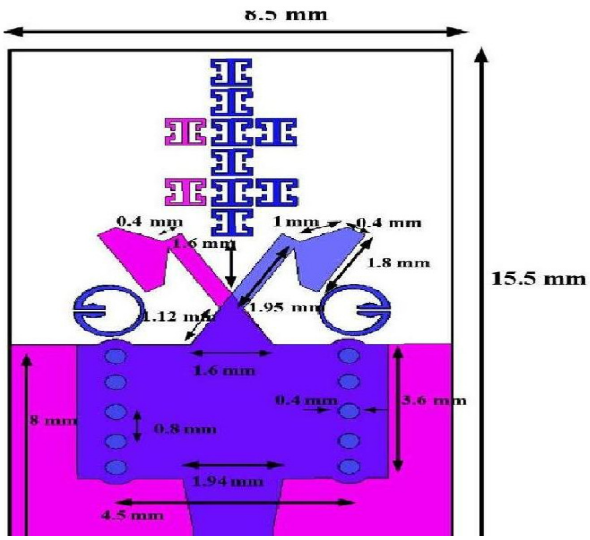
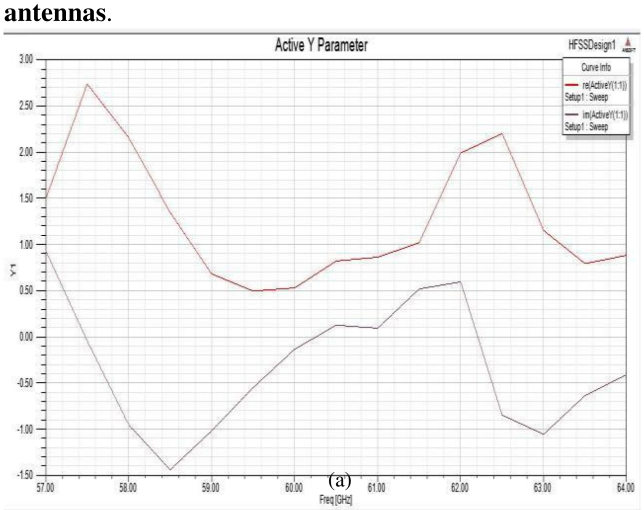


Fig.5. Proposed structure of our work

The biconical antenna has a broad bandwidth because it is an example of a travelling wave structure; the analysis for a theoretical infinite antenna resembles that of a transmission line. For an infinite antenna, the characteristic impedance at the point of connection is a function of the cone angle only and is independent of the frequency. Practical antennas have finite length and a definite resonant frequency. A simple conical monopole antenna is a wire approximation of the solid biconical antenna and has increased bandwidth.

In radio systems, a biconical antenna is a broad- bandwidth antenna made of two roughly conical conductive objects, nearly touching at their points. Biconical antennas are broadband dipole antennas, typically exhibiting a bandwidth of three octaves or more. A common subtype is the **bowtie antenna**, essentially a two-dimensional version of the biconial design which is often used for short-range UHF television reception. These are also sometimes referred to as **butterfly antennas**.



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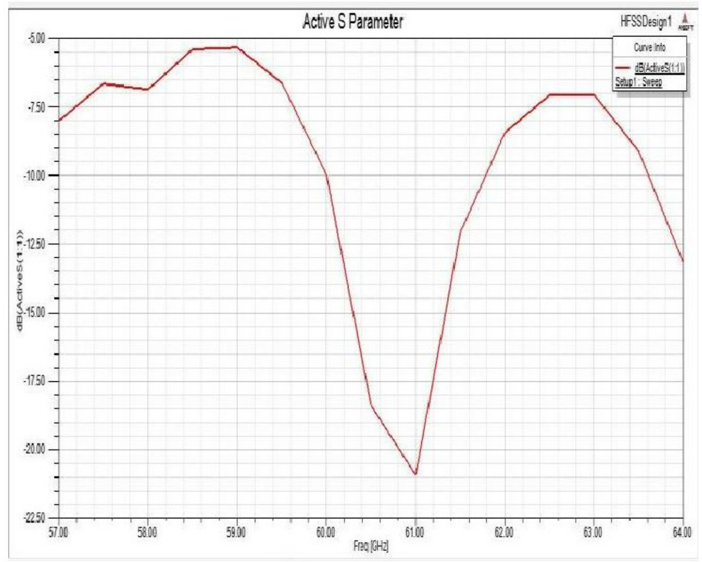

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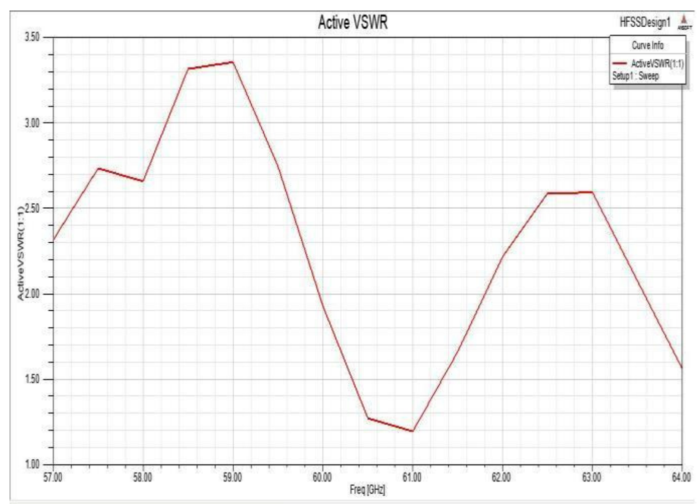

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Fig.6. Output of our work (a) Y-parameter (b) S-parameter (c) VSWR

Biconical (or "bicon") antennas are often used in electromagnetic interference (EMI) testing either for immunity testing, or emissions testing. While the bicon is very broadband, it exhibits poor efficiency at low frequencies, resulting in low field strengths when compared to the input power. Log periodic dipole arrays, Yagi-Uda antennas, and reverberation chambers have shown to achieve much higher field strengths for the power input than a simple biconical antenna in an anechoic chamber. However, reverberation chambers, especially, are poor choices when the goal is to fully characterize a modulated or impulse signal rather than merely measuring peak and average spectrum energy content.

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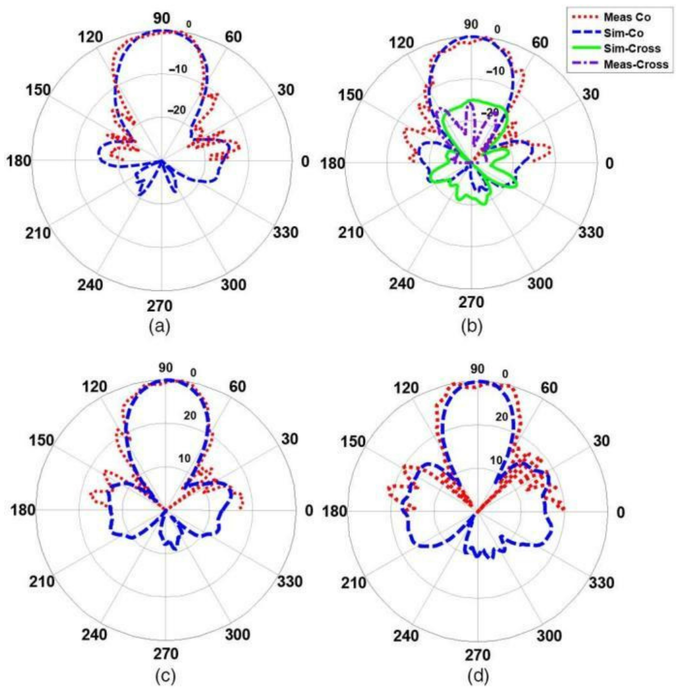
V. EXPERIMENTAL RESULTS

The proposed tilted bow-tie antenna incorporating an array of ZIM unit-cells and a pair of DGR structures was fabricated and its performance was measured. The magnitude of S11 was measured using an Anritsu 3739C Vector Network Analyzer connector was utilized to measure the reflection coefficient. The measured reflection coefficient of the antenna is less than – 15 dB over 59–64 GH.

The measured radiation patterns of the ZIM bow-tie antenna in the E-plane (xy) and H-plane (yz) at 58, 60, 62, and 64 GHz are plotted in Correlation between the simulated and measured results is good. The results indicate that the SLL of the antenna in the H-plane is less than – 11.5 dB at 60 GHz and less than – 9.7 dB at 64 GHz, which is better than that of Yagi-Uda design in that has SLL of – 5 dB, and the front to back radiation in both planes is better than – 20 dB.

Additionally, the cross-polarization of the antenna in the E-plane (xy) and H-plane (yz) is better than – 17 dB at 60 GHz, which is better than ZIM Vivaldi antenna in with – 10 dB cross-polarization. The measured radiation efficiency of the antenna is 91% at 60 GHz



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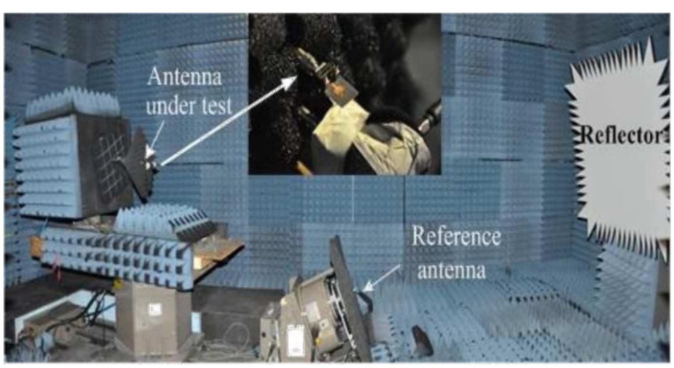

(b)

Fig.7.(a) Radiation pattern (b) Application of our proposed antenna

V.Conclusion

A modified bow-tie antenna structure is proposed for high-gain performance across 57–64 GHz. The antenna consists of a pair of tilted bow-tie radiators, where each radiator is etched on the opposite side of the common dielectric substrate and fed through SIW feed-line. The bow-tie radiators are arranged to cross each other symmetrically to enhance the antenna gain and to obtain the required radiation pattern. It is shown that the antenna gain can be significantly enhanced by loading the antenna with an array of ZIM unit-cells that are implemented laterally to the radiators. In addition, DGRs are employed to reduce the BLL of the antenna. The antenna exhibits a measured gain of 11.5–12 dBi over the frequency range of 57–64 GHz with reflection coefficient less than – 11 dB. The proposed antenna is simple to design and inexpensive to fabricate. The characteristics of the antenna make it suitable for application in 60 GHz indoor wireless communication system

REFERENCES

[1]. H.-L.Wang, Y.-X. Guo, andW.-X. Sheng, "Wideband high-gain 60-GHz LTCC L-probe patch antenna array with a soft surface," IEEE Trans.Antennas Propag., vol. 61, no. 1, pp. 153–161,Jan. 2013.

[2]. H. Chu, Y.-X. Guo, and Z. Wang, "60-GHz LTCC wideband vertical offcenter dipole antenna and arrays," IEEE Trans. Antennas Propag., vol. 61, no. 1, pp. 153–161, Jan. 2013.

[3]. K. Gong, Z. N. Chen, X. Qing, P. Chen, and W. Hong, "Substrate Intregated waveguide cavity-backed wide slot antenna for 60–GHz bands,"IEEE Trans. Antennas Propag., vol. 60, no. 12, pp. 6023–6026, Dec.2012.

[4]. WiGig white paper, defining the future Of multi-gigabit wireless communication Jul. 2010.

[5]. M. Ando, J. Hirokwa, T. Yamamoto,A. Akiyama, Y. Kimura, and N.Goto "Novel single-layer waveguides for high-efficiency millimeter-wave arrays," IEEE Trans. Microw. Theory Tech.,vol. 46, no. 6, pp.792–799, Jun. 1998.

[6]. J. Hirokawa and M. Ando, "Efficiency of 76 GHz postwall waveguide fed parallel plate slot arrays," IEEE Trans. Antennas Propag., vol. 48, no. 11, pp. 1742–1745, Nov. 2000.

[7]. J. Hirokawa and M. Ando, "Single-layer feed waveguide consisting of posts for plane TEM wave excitation in parallel plates," IEEE Trans. Antennas Propag., vol. 46, no. 5, pp. 625–630, May 1998.

[8]. S. Park, Y. Okajima, J. Hirokawa, and M. Ando, "A slotted post-wall waveguide array with interdigital structure for 45-degree linear and dual polarization," IEEE Trans. Antennas Propag., vol. 53, no. 9, pp. 2865–2871, Sep. 2005.

[9]. W. Hong, A. Goudelev, K. Baek, V. Arkhipenkov, and J. Lee, "24-element antenna-in-package for stationary 60-GHz communication scenarios," IEEE Antennas Wirel. Propag. Lett., vol. 10, pp. 738–741, Jun.2011.

[10]. S. B. Yeap, Z. N. Chen, and X. Qing, "Gain-enhanced 60-GHz LTCC antenna array with open air cavities," IEEE Trans. Antennas Propag.,vol. 59, no. 9, pp. 3470–3473, Sep. 2011.

[11]. P.Pursula, T. Karttaavi, M. Kantanen, A. Lamminen, J. Holmberg, M. Lahdes, I. Marttila, M. Lahti, uukanen, and T. V. Heikkila,"60-GHz millimeter-wave identification reader on 90-nm CMOS and LTCC," IEEE Trans. Microw. TheoryTech., vol. 59, no. 4, pp.1166–1173, Apr. 2011.

[12]. M. Sun, Y. Q. Zhang, Y. X. Guo, M. F. Karim, O. L. Chuen, and M.S. Leong, "Integration of circular polarized array and LAN in LTCC as a 60-GHz active receiving antenna," IEEE Trans. Antennas Propag.,vol. 59, no. 8, pp. 3083–3089, Aug. 2011.

[13]. J. F. Xu, Z. N. Chen, X. Qing, and W. Hong,"Bandwidth enhancement for a 60 GHz substrate integrated waveguide fed cavity array antenna on

[14]. LTCC," IEEE Trans. Antennas Propag., vol. 59, no. 3, pp. 826–832,Mar. 2011.

[15]. M. T. Sebastian and H. Jantunen, "Low loss dielectric materials for LTCC applications:A review," Int. Mater. Rev., vol. 52, no. 2, p.57–99, 2008.

[16]. Y. She, J. Hirokawa, M. Ando, D. Hanatani, and Fujimoto, "LTCC partially-filled post-wall rectangular-waveguide slot array antenna in the millimeter-wave band," IEICE Trans.Electron., vol. E95-C, no.10, pp.

1635–1642, Oct. 2012.

[17]. R. Fujino, Y. She, M. Zhang, J. Hirokawa, and Ando, “Loss reduction by air-region insertion to rectangular waveguide-fed oversized post-wall waveguide slot array antenna in the millimeter-wave band,”in Proc. APMC2012, Dec. 2012, vol. 4A4-03.

[18]. K. Hashimoto, J. Hirokawa, and M. Ando, “Design of post-wall feed waveguide for a parallel plate slot array by an analysis model with corrected solid-walls,” IEICE Trans. Commun., vol. E93-B, no. 6, pp.1566–1573, June 2010.

[19]. P. S. Kildal, “Definition of artificially soft and hard surfaces for electromagnetic wave,” Electron. Lett., vol. 24, no. 3, pp. 168–171, Feb.1988.

[20]. P. S. Kildal, “Artificially soft and hard surfaces in electromagnetics,”IEEE Trans. Antennas Propag., vol. AP38, no. 10, pp. 1537–1544, Oct.1990.

[21]. F. R. Yang, K. P. Ma, Y. Qian, and T. Itoh, “A novel TEM waveguide using uniplanar compact photonic-band (UC-PBG) structure,” IEEE Trans. Microw. Theory Tech., vol. 47, pp. 2092–2098, Nov. 1990.

[22]. M. Samardzija, J. Hirokawa, and M. Ando, “Design of narrow wall windows in a waveguide to feed partially-dielectric-filled oversized-rectangular waveguide based on 2-dimensional analysis of two orthogonal directions,” IEICE Trans. Comm., vol. E93-B, no. 4, pp. 871–878,Apr. 2010.

[23]. M.Samardzija, J. Hirokawa, and M. Ando, “Scattering analysis of H-plane T-junction between fully dielectric-filled parallel-plate,” in Proc. IEEE AP-S Int. Symp., Jul. 2008, vol. 511.4.

[24]. M.Samardzija, J. Hirokawa, and M. Ando, “Dominant quasi-TEM mode generator for thin oversized dielectric-coated rectangular waveguide,” in Proc. IEEE AP-S Int. Symp., Jun. 2007, vol.IF327.8.