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A High Gain SIW Elliptically Polarized Antenna for Millimeter-Wave Applications

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***Abstract*—A high-gain SIW elliptically polarized antenna combination of a dipole and loop antenna based on substrate-integrated waveguide (SIW) is proposed for millimeter-wave (mm-wave) applications. The dipole and loop antenna are differentially excited by a longitudinal slot etched on the top layer of SIW. The proposed combination of dipole and loop antenna forms a parallel electric dipole and magnetic dipole, which radiates two orthogonal electric field components and 90° phase difference in the far-field radiation when they are excited with the same phased signal. The proposed antenna achieves a realized gain of 8.346 dBi, with a radiation efficiency of 89.40% at 60 GHz.**

I. Introduction

Since the increase in the huge amount of information or data exchange raised the demand for extremely high data rates and large capacities, mm-wave band communication assures to fulfill all the requirements for wideband systems and devices. Due to the increase in the possibility to achieve working on the unlicensed spectrum of the 60 GHz band and including the range from 57 GHz to 71 GHz, the public has endorsed using this band more compared to the lower frequency bands that are being used by conventional dynamic receivers such as UAVs [1], [2]. Compared to the elliptically polarized (EP) antenna as opposed to the linear polarized antenna, EP better diminishes polarization mismatch and eliminates multi-path interference, which makes it preferable for satellite, and wireless communications, systems for UAVs (Unmanned Aerial Vehicles). However, mm-wave has a shorter wavelength ranging from 1 mm to 10 mm, which causes a high propagation attenuation and suffers from atmospheric absorption, which limits the communication distance [3]. Therefore, the resolution to minimize the effect of propagation attenuation is to achieve a higher gain. Another issue needed to resolve while designing a high-gain antenna is, it is very important to select proper antenna elements. There are many antennas reported at 60 GHz, such as dipole antennas, cylindrical dielectric antennas, helical antennas, patch antennas, complementary antennas, and so on. Since, in the previous research works, microstrip patch antennas were widely used due to their simple structure, but they suffer from high insertion loss at high frequencies.

In this paper, a novel bow tie-shaped complementary dipole, and a loop antenna are used for elliptical polarization, introducing high gain at 60 GHz. The proposed design has the novelty of achieving a high gain of 8.346 dBi with a radiation efficiency of 89.40% compared to the previous research works. The design of the combination of dipole and loop antenna in the second layer achieves a -10 dB fractional bandwidth of 22.98% ranging from 48.15 GHz to 62.30 GHz. This paper is organized as follows. The antenna elements are discussed in Section II. The simulation results for a single antenna are analyzed in Section III, where Section IV provides the conclusion.

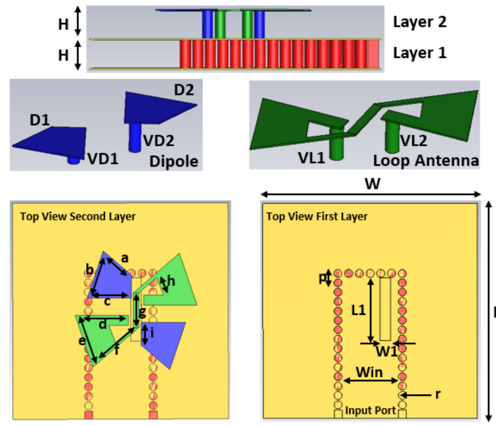

Fig. 1. Geometry of proposed antenna element

II. Antenna Element

A. Antenna Configuration

The configuration of the proposed antenna element is shown in Fig, 1. The single antenna element is a two-layer structure. Layer 1 uses substrate integrated waveguide (SIW), with a longitudinal slot etched on the top layer (Copper) of SIW. The combination of antenna is integrated into Layer 2. The combination of antennas includes a bow tie-shaped dipole (in blue) and a loop antenna (in Green). Both antennas are excited differentially through the etched slot on the top conductor layer of SIW. The dipole antenna is designed in a bow tie-shaped, with two patches (D_1 and D_2) in opposite directions of the slot fed using metalized Vias (VD_1 and VD_2). The loop antenna (in green) is designed in a shape forming the number 8 (eight) with straight edges, making the shape analogous to a bow tie shape. The loop antenna is also energized using metalized Vias (VL_1 and VL_2) at the opposite sides of the etched slot. The radius of all the antenna feeding vias are same R_1. The VL_1 and VL_2 are fed differentially using a single slot and are connected to each other through eight shaped loop antenna. The loop antenna is designed with a combination of different widths and lengths. The combination of different lengths and widths is used for tuning impedance matching. The proposed antenna is designed using CST Studio Suite 2022. The substrate used for layer 1 and layer 2 is Rogers 5880 with a relative dielectric constant of 2.2 and thickness of 0.787 mm, where copper is used as the conducting material with a thickness of 0.035 mm. The final dimensions of the various designed parameters of the proposed antenna element are listed in Table I.

TABLE I
PARAMETERS OF PROPOSED ANTENNA (UNIT: MM)

Para	Value	Para	Value	Para	Value	Para	Value
a	1.38	e	2.02	i	0.83	W1	0.4
b	1.83	f	2.24	p	0.35	Win	2.4
c	1.63	g	1.28	r	0.15	L	8
d	1.97	h	0.69	L1	2.34	W	8

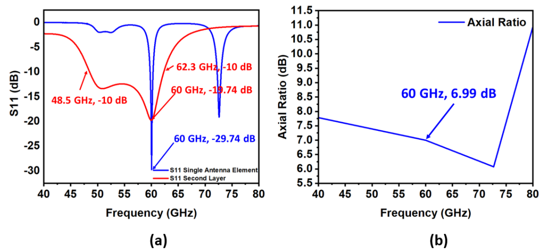

Fig. 2. (a) S11 for Single antenna Element and Second Layer and (b) Axial Ratio

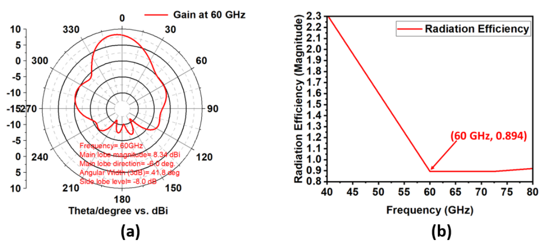

Fig. 3. (a) Gain vs. Theta and (b) Radiation Efficiency

B. Substrate Integrated Waveguide

For high-frequency applications where the wavelengths are pretty small, ranging from 1-10 mm, the microstrip-based feeding network is not efficient, and it requires very tight tolerance during manufacturing. Substrate Integrated Waveguide is a rectangular waveguide created using two rows of metallic vias and slots embedded in a dielectric substrate that connects two parallel metal plates. SIW is the transition between microstrip and dielectric-filled waveguide (DFW). Vias at the side wall for SIW eliminate the transverse magnetic (TM) modes, which makes TE_{10} the dominant mode. For TE_{10} mode, the width (a) of the rectangular waveguide is given as:

$$a = \frac{c}{2f_c} \quad (1)$$

For DFW with the same cut-off frequency (f_c), the width can be obtained as follows:

$$a_d = \frac{a}{\sqrt{\epsilon_r}} \quad (2)$$

Now the width of the SIW is determined using the equ. 3.

$$a_s = ad + \frac{d^2}{0.95p} \quad (3)$$

Where c is the speed of light propagation in air, ϵ_r is the relative dielectric constant, d and p are the diameter of vias and spacing between each via, respectively. Following the condition that the radius should be less than $\frac{\lambda_g}{5}$ and the spacing should be less than 2d, where λ_g is guided wavelength, and the longitudinal slot etched on the top layer of the SIW is at a distance of $\lambda/4$ from horizontal via [4].

III. SIMULATION RESULTS

The simulation is carried out individually, once for the full antenna and then separately for the second layer. The reflection coefficient for both simulations are shown in Fig. 2(a). The S_{11} for the whole antenna element is -29.74 dB and that for the second antenna layer antenna is -19.74 dB. The achieved bandwidth for the proposed second layer antenna is 22.98% from 48.15 GHz to 62.3 GHz. The obtained axial ratio at 60 GHz is 6.99 dB, which makes it an elliptically polarized antenna, as shown in Fig. 2(b). At 60 GHz, the realized gain is 8.346 dBi at an elevation angle of -6.0° and side lobe level at -8.0 dB shown in Fig. 3(a) and radiation efficiency is plotted in Fig. 3(b). The Comparison among the proposed antenna and the prior published works are presented is given in Table II.

TABLE II
COMPARISON TABLE

Ref.	Structure	Polarization	Peak Gain (dBi)
[5]	Planar	CP	4
[6]	Non-Planar	CP	7.15
[7]	Planar	CP	5
Prop.	Non-Planar	EP	8.34

IV. CONCLUSION

For mm-wave applications, a design of a SIW-based double-layer single antenna element is proposed for a high gain of 8.34 dBi. The antenna is matched to demonstrate elliptical polarization by showing an axial ratio equal to 6.99 dB at 60 GHz.

ACKNOWLEDGEMENT

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