Design of a Funnel-Shaped MIMO Antenna for RADAR Applications

Srinu Budumuru
Department of Electronics and Communication Engineering, GITAM University, Visakhapatnam, India
sbudumur@gitam.edu (corresponding author)

Gayatri Allu
Department of Electronics and Communication Engineering, GITAM University, Visakhapatnam, India
gallu@gitam.edu

Durgarao Jenjeti
Department of Electronics and Communication Engineering, GITAM University, Visakhapatnam, India
djenjeti@gitam.edu

Venkata Suri Apparao Tanakala
Department of Electronics and Communication Engineering, GITAM University, Visakhapatnam, India
vtanakal@gitam.edu

Srinivasa Rao Sankranti
Department of Electronics and Communication Engineering, GITAM University, Visakhapatnam, India
ssankran@gitam.edu

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ABSTRACT

Achieving a compact-size, high-performance antenna covering the K-Ka bands is not an easy task. A Multi-Input Multi-Ooutput (MIMO) funnel-shaped wideband antenna for RADAR applications is introduced in this paper. One of the flaws of the MIMO antenna is its size. In modern communications, the space given for an antenna is minimal due to the compact size of the communication devices. In the present work, by keeping space occupancy in mind, two element compact antennas, with 76×34×1.6 mm3 size, operating bandwidth of 24.7 GHz, isolation greater than 18.9 dB, and gain of 9.26 dB, were designed. The designed funnel shape patches and defective ground structure provide better gain and isolation, therefore allowing for larger bandwidth. Furthermore, the simulated and measured results are in good agreement.

Keywords-MIMO antenna; isolation; wide bandwidth; defected ground structure; 5G applications

I. INTRODUCTION

Shortly, IoT, requiring high data transfer rates and extreme channel capacity, will become crucial for all communication systems, whereas 5G mm networks are fast-growing systems that support high data transfers. Some countries already introduced 5G mm networks for their communication networks in the frequency range of 24.25 to 29.5G Hz [1]. For high data rates, a new technology, a Multiple-Input Multiple-Output (MIMO) system, has been developed for 5G applications [2-4]. Serially fed transmitters and receivers in the transmitting and receiving portion broadcast massive amounts of data at once utilizing techniques such as spatial diversity, resulting in high data rates without the need for increased bandwidth and power [5, 6]. The present LTE system will not be able to support the fast-growing demands of high data rates and low latency in the future. The development of MIMO antennas is required for further 5G network applications to improve spectral efficiency and channel capacity. The 5G network implemented a new radio frequency range to accommodate all the above requirements, which is almost 100 times faster with a latency less than 1 ms [7]. This NR takes into account two frequency bands: FR1 and FR2, which encompass mm waves and frequencies lower than 6 GHz, respectively [8]. The space occupied by the antennas is more significant because of the multiple antennas used in the MIMO system, so implementing the system for limited space is tricky. If the space between the elements is reduced, the interference between the elements increases, causing data loss [9]. Isolation techniques have been introduced to improve the system's performance [10]. For 5G

IoT applications, authors in [11] presented a 4-port MIMO antenna with dimensions of 56 mm × 56 mm × 35.3 mm. They employed a shaped construction to ensure isolation. Authors in [12] proposed a compact 3-port orthogonally polarized MIMO antenna with good diverse gain and channel capacity with a coupling efficiency of about -18 dB. Placing a large count of MIMO antennas enhances the interference between the antenna elements, proving that the isolation between the elements is also an essential parameter [13, 14]. Mutual coupling between MIMO elements can be avoided via a defective ground structure, resulting in increased bandwidth [15, 16]. Series-fed antenna elements are capable of producing multiple broadband characteristics. MIMO antennas' operating frequency and return loss may be modified by altering the size and spacing between the antenna components. Authors in [17] worked on a MIMO antenna operated at 2.6 GHz. Authors in [18] worked on a 4-port MIMO antenna and obtained less mutual coupling between the antenna elements.

The present work concentrated on a funnel-shaped MIMO antenna to obtain better gain and isolation between the antenna elements while keeping the size compact. Designing a compact size antenna with more than one elelment is influenced by the interference between the elements. In the proposed design, the bottom shape of each element is arranged in such a way that precents the interference. The proposed compact size antenna can be ued for the different RADAR applications.

II. DESIGN PROCESS

Figure 1 shows the flowchart of the design and implementation process.

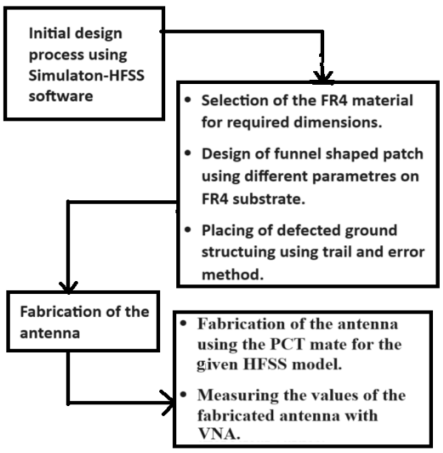

Fig. 1. Flowchart of the design process.

Figure 2 depicts a schematic of the 2-port MIMO antenna design process, which includes two antennas on the same plane. The two antenna components are of the same form and are symmetric around the axis. The design consists of two funnel-shaped components mounted on an FR4 substrate with a dielectric constant of 4.4 and a loss tangent of 0.02. The substrate dimensions are 76×34×1.6 mm^3, with 28×22 mm^2 patches and a 3×9 mm^2 feed line. The antenna design and analysis were completed with the HFSS software. Figure 2(a) displays the top view of the funnel-shaped antenna design, while Figure 2(b) shows the defective ground structure perspective. Figure 3 illustrates the current distribution of individual and combined patch components. The comparison of the current distributions in the separate patch antennas reveals that the bulk of the current directions are diverse. Figure 4 depicts the MIMO antenna's gain plot, which yielded a maximum gain of 9.26 dB, which is suitable for real-time applications. The provided antenna's design specifications are listed in Table I.

(a)

(b)

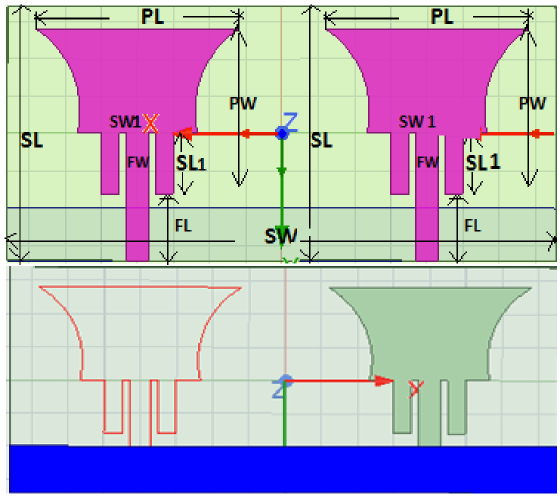

Fig. 2. (a) Top view of the funnel-shaped MIMO antenna, (b) bottom view of the defective ground structure.

(a)

(b)

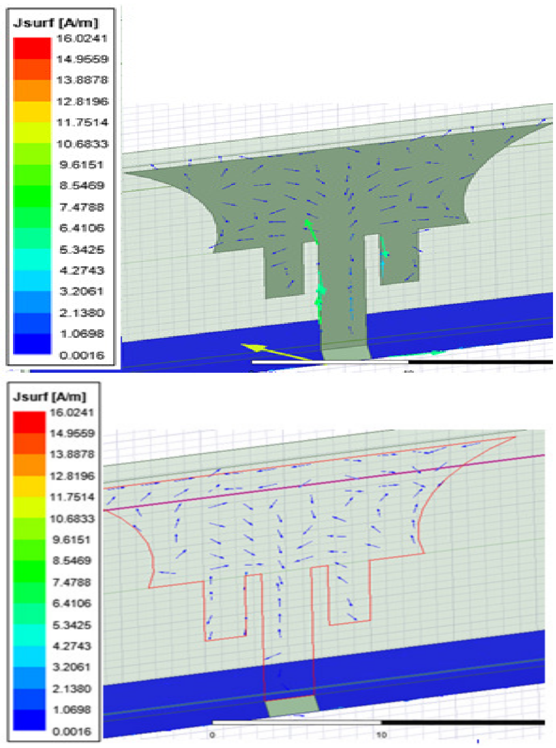

Fig. 3. Current distribution in the individual antenna elements.

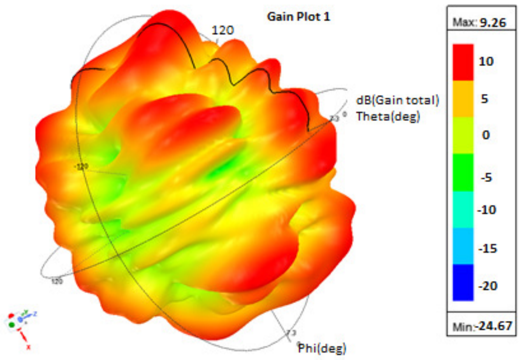

Fig. 4. Gain plot of the MIMO antenna with a maximum gain of 9.26 dB.

TABLE I. PROPOSED FUNNEL-SHAPED ANTENNA DESIGN PARAMETERS

Parameter	Value (mm)
Substrate Length (SL)	76
Substrate Width (SW)	34
Substrate Height (SH)	1.6
Ground Length (GL)	76
Ground Width (GW)	7
Patch Pength (PL)	28
Patch Width (PW)	22
Slot Length (SL1)	1
Slot Width (SW1)	8
Feed line Lenth (FL)	9
Feed line Width (FW)	3

Figure 5 illustrates the radiation pattern between the two components. Figure 6 shows the current density representations in single and multi-input antennas. Figure 7 depicts the top and bottom views of the constructed funnel-shaped antenna that was tested in an anechoic laboratory. Figure 8 shows the practical results, which assess return loss and are compared to theoretical values.

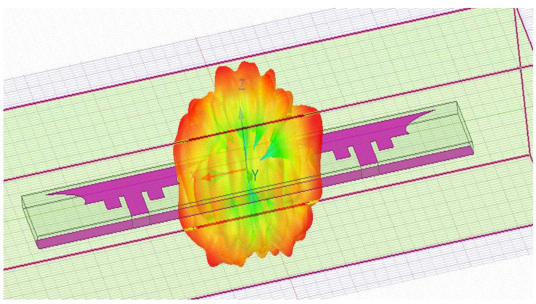

Fig. 5. Radiation pattern representation of the funnel-shaped proposed MIMO antenna.

III. RESULTS

Isolation is a critical metric to consider when assessing the interference between individual elements. If the interference between the two aspects exceeds -15 dB, it can be utilized in real scenarios. Figure 9 depicts the isolation parameter S_{12}, with most values more significant than 20 dB, resulting in a uniformly polarized pattern, a gain of 9.26 dB, and a bandwidth ranging from 1.7114 to 2.6651 Ghz. Thereafter, the size of the arm SL1 varied at different levels, i.e at 1, 1.5, and 2 mm and the isolation between the individual elements was monitored. As the size of the arm increases, the interference between the individual elements increases and isolation decreases. At 1 mm arm length, an isolation value of -27 dB was obtained and which is well suitable for realtime applications. Table II shows the comparison of the theoretical and measured gain of the proposed antenna and the ones in [19, 20].

(a)

(b)

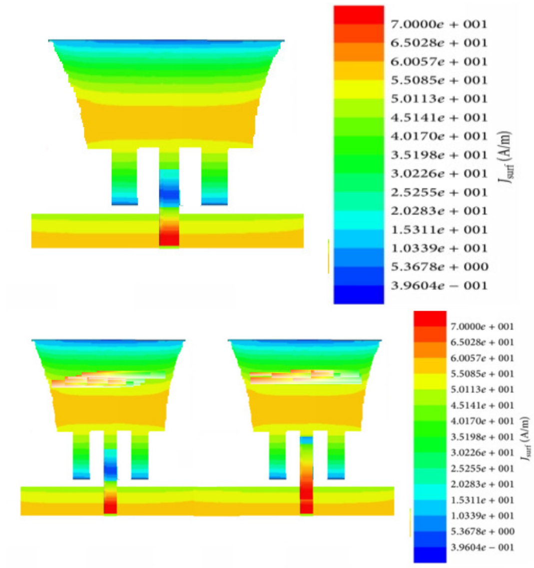

Fig. 6. Current distribution in (a) single and (b) double funnel-shaped antennas.

(a)

(b)

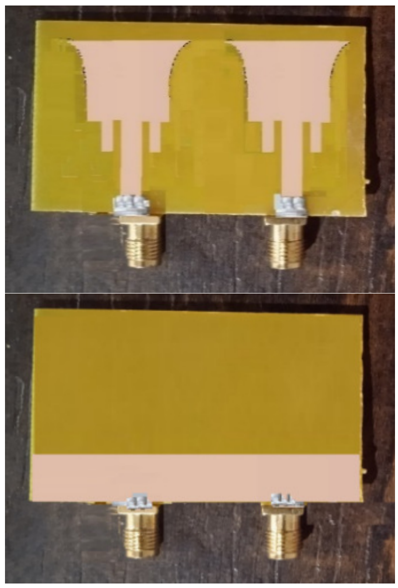

Fig. 7. (a) Top view of the funnel-shaped MIMO antenna, (b) Bottom view of defective ground structure of the antenna.

TABLE II. GAIN COMPARISION

Parameter	Theoritical	Measured
Gain (proposed)	9.26 dB	9.16dB
Gain [19, 20]	Max (5.94 dB), 8.12 dB	--

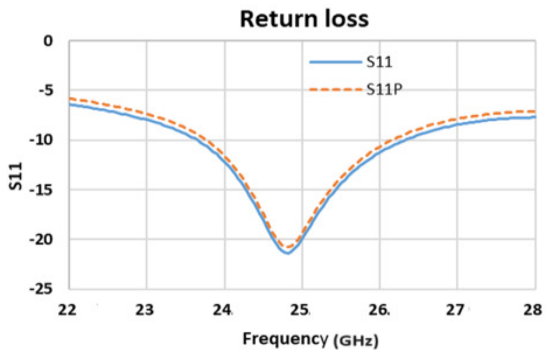

Fig. 8. Return loss of the funnel-shaped MIMO antenna in the frequency range of 22 GHz to 28 GHz.

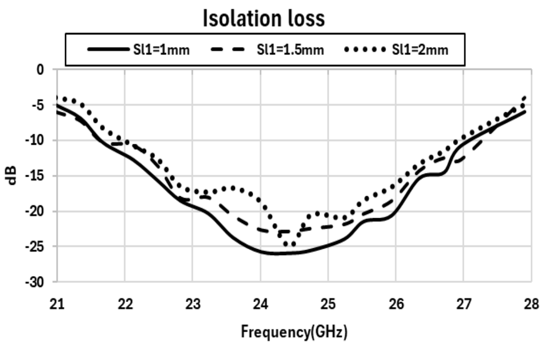

Fig. 9. Isolation loss of the funnel-shaped MIMO antenna in the frequency range of 22 GHz to 28 GHz.

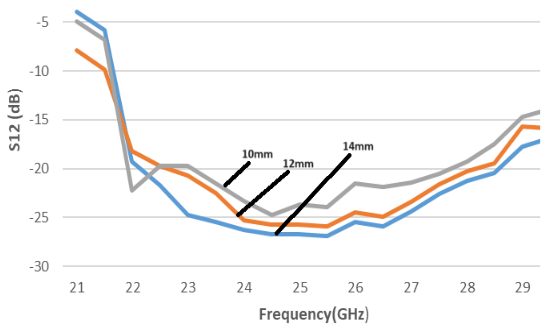

Fig. 10. Isolation loss representation of the funnel-shaped MIMO antenna for different separations.

The isolation between the different antenna elements was examined by varying the distance between them from 10 mm to 12 mm and 14 mm. The isolation reduces as the distance between the patch elements decreases, which may increase the interference that exists between the patch's components. The isolation loss for various element separations is displayed in Figure 10. A separation of 14 mm produced an isolation of 23 dB, whereas a separation of 12 mm produced a separation of 26 dB.

The comparison of the gain plots for the simulated and measured antenna is shown in Figure 11. The plots are almost identical, with an estimated value of -22 dB and a practical value of -21 dB. These values prove that the antenna is appropriate for real-world uses.

TABLE III. RETURN LOSS OF THE PROPOSED FUNNEL-SHAPED MIMO ANTENNA

Parameter	Theoretical (S11)	Measured (S11P)
Return loss	-22dB	-21dB

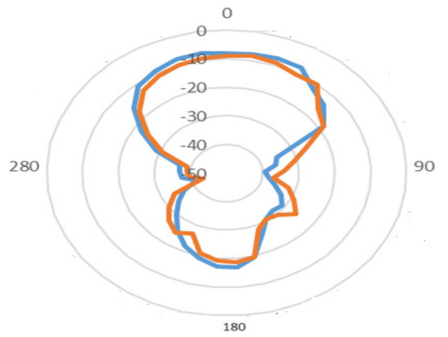

Fig. 11. Simulated (blue) and measured (orange) gain plots of the proposed funnel-shaped antenna.

IV. CONCLUSION

In this paper, a 2-port funnel-shaped MIMO antenna of compact size was designed, simulated, fabricated, and tested. The maximum acquired gain was 9.26 dB, the return loss was 22 dB, the isolation was above 18 dB, and the bandwidth ranged between 23.6 and 26.3 GHz. i.e. a bandwidth of 2.7 GHz was obtained, which can be practically used for various 5G applications. The measurements on the fabricated antenna obtained almost 9.16 dB gain and return loss of 21 dB. Isolation loss was also considered. A value of 27 dB isolation loss was acquired for 10 mm gap between the patch elements. The proposed compact-size broadband MIMO antenna can be used for many real-time applications.

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