I.J. Wireless and Microwave Technologies, 2021, 1, 22-27
Published Online February 2021 in MECS (http://www.mecs-press.org/)
DOI: 10.5815/ijwmt.2021.01.03

Compact MIMO Shorted Microstrip Antenna for 5G Applications

S.Murugan[1*]
[1] Department of Electronics and Communication Engineering, Sri Vasavi Engineering College, Tadepalligudem, India
Email: murugans1976@gmail.com

Received: 25 December 2020; Revised: 06 January 2021; Accepted: 12 January 2021; Published: 08 February 2021

Abstract: The objective of the work is to design a compact MIMO antenna at 3.5 GHz suitable for 5G applications. MIMO antenna is suitable choice for increasing the signal to noise ratio of mobile communication systems. The channel capacity can be increased by improving signal to noise ratio. At the same time, high isolation between the elements should be maintained. Planar inverted F antenna (PIFA) is used as a unit element for MIMO antenna in this work. The unit element dimensions are 9.5 x 7 mm^2. Two shorting pins are used for getting better impedance matching. Four elements are arranged in the FR4 substrate with dielectric constant 4.4 and thickness of 1.6 mm. The performance of 4 element Multiple Input Multiple Output (MIMO) antenna is optimized using HFSS software. The results show that the better impedance matching at desired frequency band and a gain of 4.2 dB in the bore-sight axis is obtained for the four elements. The gain of four element antenna is improved from - 0.52 dB to 4.2 dB than two element antenna. The isolation between the elements is obtained below -15 dB. The overall volume of the antenna is 25.3 x 26.8 x 1.6 mm^3, which ensures compactness suitable for mobiles.

Index Terms: Shorting pin, Coaxial feed, 5G application, MIMO

1. Introduction

The future mobile communication requires high data rate and more bandwidth to accommodate more number of users. In multipath environment, the signal gets attenuated rapidly, hence achieving better Signal to Noise ratio (SNR) is difficult job. The gain of the antenna could be increased further for getting better SNR value. The gain of the antenna is directly proportional to effective aperture area of the antenna. So, a single antenna with larger aperture area is required for realizing more gain. To overcome this limitation, a Multiple Input Multiple Output (MIMO) antenna can be used for increasing gain and SNR in multipath environment. The space diversity scheme employed in MIMO antenna significantly increases the received power and gain, even in multipath environment. At the same time, the isolation between the antennas should be high in case of MIMO antenna. The 5G communication has the features like high data rate, low latency and enormous bandwidth. The frequency bands in 5G are divided into two types, (i) below 6 GHz band and, (ii) above 20 GHz and upto 80 GHz at several bands. The sub 6 GHz can be utilized immediately due to utilization of existing infrastructure of wireless communication. The sub 6 GHz frequency band is from 3.4 to 3.6 GHz for 5G communication.

Planar inverted F antenna is the most popular antenna in mobile handsets. Loading of shorting pin and slot in the conventional MSA decreases/increases its electrical length respectively. This change in the electrical length changes the resonant frequency of MSA, useful in designing compact MSA, dual frequency MSA and multi-frequency MSA. The length of rectangular MSA is approximately equal to $\lambda/2$, hence, voltage at the radiating edges of the patch are 180 degree out of phase with each other. The current is maximum at the centre of the patch, implies impedance is zero exactly at the centre of the patch. When the shorting pin is inserted at the centre of the patch, there is no change in the performance of antenna but at the same time, electrical length of the patch is reduced to half ie., $\lambda/4$ compared to conventional rectangular MSA. Hence, Planar Inverted F antenna is used for mobile handsets. The frequency bands used in 2G mobile communication are 900MHz and 1800 MHz GSM band. As the frequency increases, the length of the patch is reduced. The length of patch for 3500 MHz band is small than 900 MHz patch antenna. So, MIMO antenna with PIFA as unit element can be accommodated in small space. It is the main objective and motivation of proposed antenna design in this paper.

The paper is organized as follows: section 2 discusses about the literature review, sections 3 discuss about design methodology, followed by results and discussion in section 4 and section 5 concludes the paper.

2. Literature Review

A few literature papers are discussed here related to 5G antennas. A shorted patch and a modified U slot is used for designing a dual band antenna for 5G application at 28 GHz and 38 GHz. The size of the antenna is 1.3 mm x 1.2 mm [2]. H shaped slots with shorting pins are used for the design. It consists of three metal layers and stacked substrates. It is designed to operate at 28 & 38 GHz band in [3]. In [4], PIFA with a meandered slot is used for getting multi-frequency band operation at 2.4GHz and 5.7GHz. The basics of MIMO-OFDM techniques used in 5G technology is discussed in [5]. A shorting pin loaded microstrip antenna operating at 3.4 - 3.6 GHz for 5G communication is designed in [6]. In this antenna, FR4 substrate with 1 mm thickness is used. A shorting pin of 4 mm height is used to achieve compact size. The overall size of the antenna is 85 x 55 x 4 mm^3 of which 14.2 x 13 mm^2 is used as radiating element. An inverted L Monopole 4 x 4 MIMO antenna with semi elliptical radiating patch operating at 3.5 GHz is proposed in [7]. The impedance bandwidth of the antenna is 320 MHz, however the radiation efficiency is 52%. In [8], a 4 x 4 MIMO base station antenna is designed by stacking 2 x 2 MIMO antennas vertically and array size may be increased by increasing the number of rows and columns, operating at 3.3 GHz- 3.8 GHz. In [9], a 2x2 MIMO antenna, capable of transmit-receive at different directions in the frequency range of 2 GHz-7 GHz including Wi-Fi, Wi-Max , LTE bands, IEEE WLAN standards including ISM band. In [10], four element PIFA antenna is designed to operate at 2.45 GHz. Two configurations of antenna which gives pattern diversity and polarization diversity is discussed. Each element occupies a volume of 0.455cm^3. A compact square slot microstrip antenna operating at 3.5 GHz is discussed in [11] in which the bandwidth of the antenna is improved by increasing the thickness of the substrate. In [12], a MIMO antenna operating at multiple frequencies such as 2.46, 3.72, 5.67 and 6.4 GHz is designed and fabricated. High isolation of 18 dB is achieved and return loss of 15 dB is achieved at each port. The size of the antenna is 52 x 40 x 1. 6 mm^3. A H shaped MIMO antenna is developed in [13] for WLAN 5.8 GHz applications and a high isolation of 35dB between the elements is achieved by introducing a dumb bell shaped slot in the ground plane.

3. Design Methodology

Figure 1 shows the proposed antenna design. It consists of four PIFA elements printed on top of FR4 material with ε_r= 4.4 and ground plane in the bottom of the substrate. Two shorting pins are placed at center of the radiating edges of each unit element. For the operating frequency of 3.5 GHz, dielectric constant of substrate ε_r= 4.4 and thickness of the substrate 1.6 mm, the length of conventional rectangular patch is estimated as 20 mm by using the equations available in [14]. The resonant frequency of shorting pin loaded PIFA is given below [15].

$$fr = \frac{c}{4\left(L+\frac{W}{2}\right)\sqrt{\varepsilon e}} \tag{1}$$

Where, c is the velocity of light in air $3x10^8$ m/s. W is the width of the patch, L is the length of the patch. ε_e is the effective dielectric constant of the substrate. The length of the shorted patch is estimated using (1) , as 7 mm length, assuming L=W. Using this value as initial patch length, the dimensions of single element shorting pin loaded patch is optimized for desired frequency 3.5 GHz using HFSS. Table 1 shows dimensions after optimization of the performance at 3.5 GHz for the single antenna.

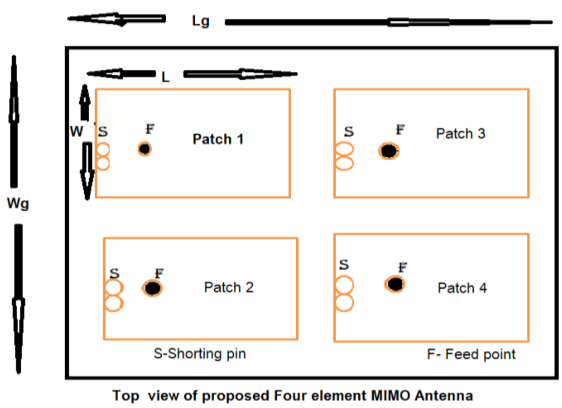

Fig. 1. Top view of Proposed Antenna .

Table 1. Dimensions of Proposed MSA at 3.5 GHz

Dimensions	Size (mm)
Unit element patch length(L)	9.5
Unit element patch width(W)	7
Substrate thickness	1.6
FR4 Substrate dielectric constant	4.4
Loss tangent of substrate	0.02
Length of ground plane (Lg)	25.3
Width of ground plane (Wg)	26.8

For improving the gain of the antenna and to make the antenna suitable for MIMO, four elements are incorporated on the same substrate with each element having same dimension as in Table 1, keeping the spacing between the elements 2.3 mm. The spacing between the shorting pin and coaxial feed position is adjusted for getting better impedance matching. The overall volume of the antenna is 25.3 x 26.8 x1.6 mm^3, which is suitable for mobile applications. Another advantage of the design is that the channel capacity is increased by increasing the number of elements. The channel capacity is directly proportional to Signal to Noise Ratio (SNR). The performance of four element MIMO antenna is analysed using HFSS. The results of proposed MSA are discussed in Section 4.

4. Results and Discussion

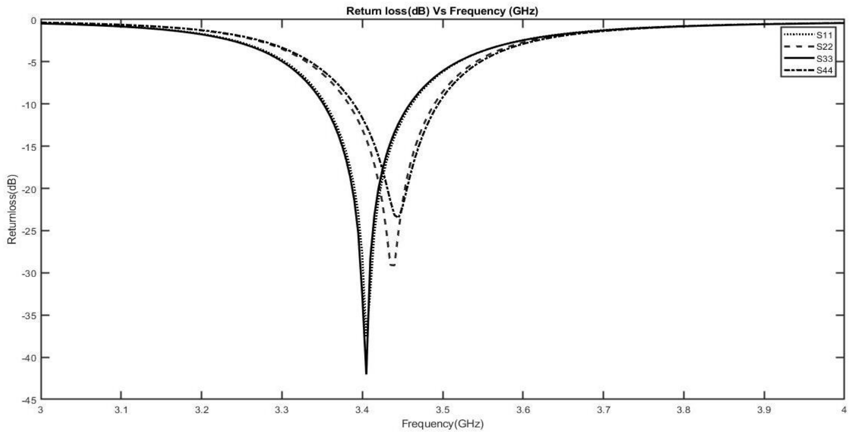

Fig.2 Return loss S_{11} (dB) at each port Vs frequency (GHz)

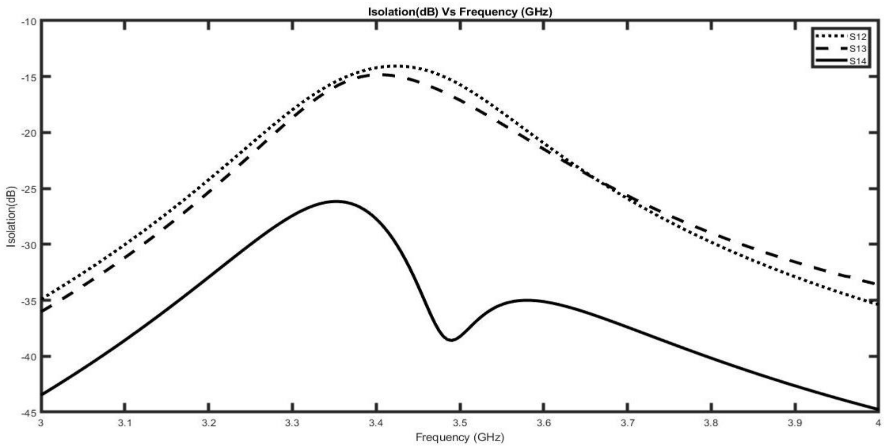

Fig 3.Isolation (dB) Vs Frequency (GHz)

The performance results of different parameters such as Return loss (dB), Gain(dB), Bandwidth and Radiation efficiency are analyzed in this section. Figure 2 shows the combined plot of Return loss at each port of the antenna Vs. Frequency (GHz) . The antenna is resonating at frequency of 3.41 GHz with return loss S_{11} of -37.65 dB at port 1, S_{22} of -29.12 dB at 3.44 GHz, S_{33} of -42dB at 3.405 GHz, and S_{44} of -23 dB at 3.445 GHz with impedance bandwidth (return loss < -10dB) of approximately 100 MHz at center frequency. Figure 3 shows the isolation (dB) between port 1 and remaining ports 2, 3 and 4. From the above graph, it is inferred that the isolation between the ports is well below -15 dB, which is essential for multiple input antenna. Hence, mutual coupling between the elements is very low

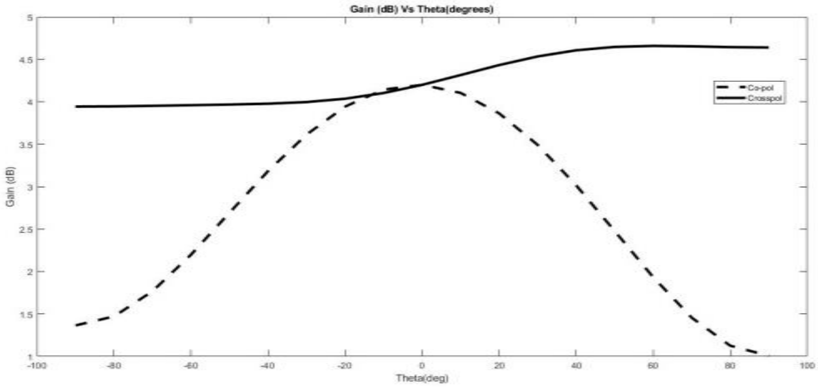

Fig.4. Gain (dB) Vs Elevation angle (deg)

The gain (dB) of the four element antenna is shown in Fig.4 in both co-polarisation and cross-polarisation ie., φ =0° and φ =90° at desired frequency. At φ =0°, the gain plot is symmetrical and at bore-sight maximum gain of 4.2 dB is obtained. At φ =90°, the gain curve is flat between the angle -90 ° to +90 ° and 4 dB is maintained constant. The radiation efficiency of the antenna is obtained as 70%.

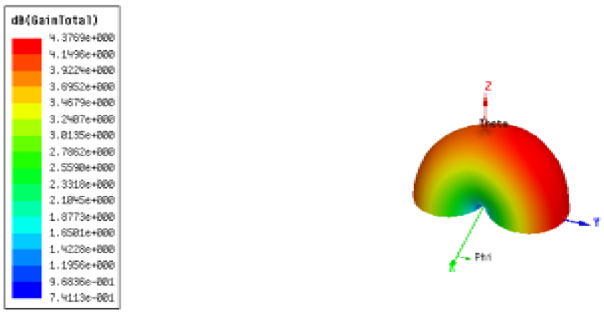

Fig 5(a) 3D Polar plot for two element antenna.

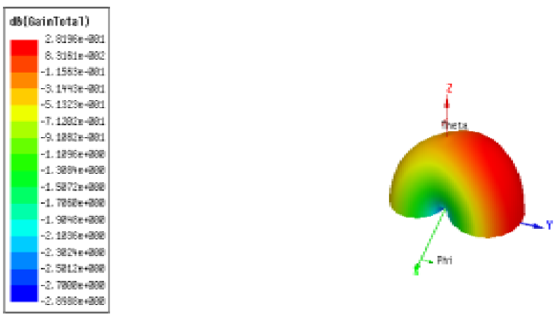

Fig 5(b) 3D polar plot of four element antenna.

Fig. 5(a) and 5(b) shows the 3D polar gain plot of four element and two element MIMO antenna at 3.4 GHz respectively. It is inferred that the radiation covers the upper hemisphere with a gain of 4.2 dB in bore-sight axis in the case of four element and -0.59dB in bore-sight axis in the case of two elements.

Table 2 .Summary of the performance of proposed antenna at 3.4 GHz

Parameters	Return loss S_{11}(dB)	Gain (dB)	Impedance bandwidth (MHz)	Radiation efficiency
Proposed Four element	S_{11}= -37.65 S_{22}= -29.12 S_{33}= -42 S_{44}= -23	4.2 at bore-sight axis	100	70%
Two element	S_{11}= -25 S_{22}= -24	-0.59 at boresight axis	100	61%
Single element	S_{11}= -13	-4.5dB at bore-sight	100	40%

Table 3. Comparison of the performance of proposed antenna with some reference papers

Ref no [ ]	Resonant frequency (GHz)	Gain (dB)	Impedance Bandwidth (MHz)	Size of the antenna
[6]	3.4	5.9	350	85x55x4 mm^3
[7]	3.5	-	320	0.64λx0.64λ at 3.5 GHz ie., (55 x 55 mm^2)
Proposed antenna	3.41	4.2	100	25.3 x25.3x 1.6 mm^3

Table 2 shows the summary of the comparison of the performance of the proposed 4 element MIMO antenna with two element and single element shorting pin loaded MSA . It is inferred from Table 2 that the impedance matching is well improved in the case of 4 element MIMO antenna compared to two element and single element antenna. The gain is also significantly increased from -0.52 dB to 4.2 dB for 4 element antenna. Also, the radiation efficiency of the antenna is increased from 61% to 70 %. Table 3 shows the comparison of the proposed antenna with existing literatures. It is clear that the size of the proposed antenna is smaller compared to antennas designed in [6] and [7] at same operating frequency 3.4 GHz. Though the gain of the antenna is low compared to [6], a gain of 4.2 dB is adequate for personnel mobile handset applications. The bandwidth of the antenna is also lower compared to [6] , which is due to low substrate thickness. The substrate thickness is directly proportional to bandwidth of MSA.

5. Conclusion and Future Scope

Hence, a four element shorting pin loaded patch antenna is designed at sub 6 GHz 5G band which covers the frequency range from 3.4 GHz to 3.5 GHz and reasonable gain of 4 dB is obtained. The gain and radiation efficiency of the proposed 4 element antenna is increased compared to two element and unit element antennas. The volume of the proposed antenna is 1084 mm^3, which is suitable for mobile handsets. From the above results, it is clear that the proposed antenna exhibits adequate gain and compactness, suitable for personnel mobile devices. The configuration can be extended for base station antenna by increasing the number of elements. Also, antenna configuration can be integrated with RFIC to design system in package for 5G communication.

References

[1] Rishi, Rahul & Sharma, S. (2017). Impedance Matching Techniques for Microstrip Patch Antenna. Indian Journal of Science and Technology, 10, 1-16.

[2] W. Ahmad & W. T. Khan, (2017).Small form factor dual band (28/38 GHz) PIFA antenna for 5G applications. 2017 IEEE MTT-S International Conference on Microwaves for Intelligent Mobility (ICMIM), Nagoya, (pp.21-24).

[3] P. Liu, X. Zhu, Y. Zhang, X. Wang, C. Yang & Z. H. Jiang (2020). Patch Antenna Loaded With Paired Shorting Pins and H-Shaped Slot for 28/38 GHz Dual-Band MIMO Applications. IEEE Access, 8, 23705-23712.

[4] R.Tiwari & H.V.Kumaraswamy (2016). Multiband PIFA for Wi-Fi and 5G mobile communication application. International journal of Engineering and Technology, 3(6).781-785.

[5] A.Khare, M.Sexana, & Rishobh Dubey (2011). MIMO-OFDM wireless system: Basics, perspectives and challenges. International journal of Engineering and advanced technology, 1(2), 50-55.

[6] N. Sharma & D. Khosla (2018). A Compact two element U shaped MIMO Planar Inverted-F Antenna (PIFA) for 4G LTE Mobile Devices. 2018 Fifth International Conference on Parallel, Distributed and Grid Computing (PDGC), Solan Himachal Pradesh, India, (pp.838-841).

[7] M. Singh & M. S. Parihar (2019). A Compact 4×4 MIMO Antenna with High Isolation for 5G Application. 2019 IEEE Asia-Pacific Microwave Conference (APMC), Singapore, Singapore, (pp. 688-690).

[8] L. Shen, H. Wang, W. Lotz & H. Jamali (2019). Dual Polarization 4x4 MIMO Sub-6GHz Multi-Beam Base Station Antennas. 2019 International Symposium on Antennas and Propagation (ISAP),Xi'an, China, (pp. 1-3).

[9] R.K. Machavaram & Kartikeyan (2016). A multi-standard, wide-band 2×2 compact MIMO antenna with ground modification techniques. International journal of Microwave and Optical Technology, 11(4), 259-268.

[10] S. Ghosh, T. Tran & T. Le-Ngoc (2013). Miniaturized Four-Element Diversity PIFA. IEEE Antennas and Wireless Propagation Letters, 12, 396-400.

[11] S. Murugan (2020). Compact Square patch antenna for 5G Communication. 2nd International Conference on Data, Engineering and Applications (IDEA), Bhopal, India, (pp. 1-3), doi: 10.1109/IDEA49133.2020.9170695.

[12] Sachin.S.Khade, S.L.Badjate, (2016). A Compact Multiband U shape MIMO antenna for wireless applications. International Journal of Wireless and Microwave Technologies, 5, 61-71.

[13] Pratima C.Nirmal, Anil Nandgaonkar & Sanjay Nalbawar, (2017). Mutual coupling reduction between H shaped Compact MIMO antenna for WLAN applications. International Journal of Wireless and Microwave Technologies, 6, 46-57.

[14] C.A.Balanis (2016). Antenna Theory, Analysis and Design. John Wiley 4th Edition .

[15] G.Kumar & K.P.Ray (2002) . Broadband Microstrip antennas. Artech House publishers.

Author’s Profile

S.Murugan received his B.E. in Electronics and Communication Engineering from Madurai Kamaraj University, Madurai, India in 1997 and M.E. in Microwave and Optical Engineering from Madurai Kamaraj University, Madurai, India in the year 2001and PhD degree under the faculty of Information and Communication Engineering from Anna University, Chennai in the year 2014.. He is currently working as Professor at Sri Vasavi Engineering College, Tadepalligudem, Andhrapradesh, India. He has published more than 20 international journals and conference papers in the antenna domain. His main research interests includes Microstrip antenna design, MIMO antenna, 5G communications, Microwave devices and circuits etc.

How to cite this paper: S.Murugan, " Compact MIMO Shorted Microstrip Antenna for 5G Applications", International Journal of Wireless and Microwave Technologies(IJWMT), Vol.11, No.1, pp. 22-27, 2021.DOI: 10.5815/ijwmt.2021.01.03