Performance Enhancement of Patch Antenna Using Meta Surface and Dielectric Superstrate for 5GHz Wi-Fi Applications

Swapna Kumari Budarapu(✉) and M. Shyam Sunder

University College of Engineering, Osmania University, Hyderabad, India
swapnakumaribudarapu@gmail.com, shyamsunder@osmania.ac.in

Abstract. In this paper, a fabry-perot resonator (FPR) antenna for 5 GHz Wi-Fi applications with high gain and high impedance bandwidth (IBW) is proposed. For improving the performance of circularly polarised antennas, a 6 × 6 reactive impedance surface (RIS) based meta surface and a dielectric superstrate are used. The cavity created between superstrate and ground plane of a patch antenna acts as an FPR, improves the gain. RIS is used to make the antenna's IBW better. The proposed antenna has an IBW of 18.7% (5.19 GHz–6.26 GHz), a 3 dB axial ratio bandwidth (ARBW) of 4.7% (5.39 GHz–5.65 GHz), and a gain of 10.3 dB.

Keywords: Slot-loaded patch · circular polarization · dielectric superstrate · reactive impedance surface · fabry perot resonator · wide band · high gain · single feed

1 Introduction

The bandwidth of 5 GHz Wi-Fi frequency band is 12.7% (5.150–5.850 GHz), broadband antennas are necessary to cover the whole frequency range. The antennas should have a high gain so that it can broadcast over long distances while using low power. Furthermore, circularly polarized antennas are necessary in wireless communication systems to limit the Faraday rotating effect, multipath interference, and immunity to mismatch of polarization. CP antennas are used in a number of wireless applications, including Wi-Fi networks, wireless local area networks (WLAN), and satellite navigation systems. Microstrip patch antennas (MPA) often meet the standards of light weight and compactness; however, their use in many systems is limited due to narrow bandwidth, low gain, and low efficiency. For 5 GHz Wi-Fi applications, a high gain, broadband, and circularly polarized antennas are required.

Due to its unique ability to affect electromagnetic waves, the metasurface (MS) has been used in numerous applications in recent years. Metasurfaces are planar or two-dimensional metamaterial structures [1]. They are often used on antennas because of their attractive properties such as small weight and a easy fabrication process. Because MS structures can alter the properties of electromagnetic waves at microwave frequencies, the performance of MPA can be improved. Metasurfaces can be employed in a variety

B. Raj et al. (Eds.): ICETE 2023, AER 223, pp. 952–959, 2023.
https://doi.org/10.2991/978-94-6463-252-1_96

of ways, including as RIS [2], which increased the performance of a patch antenna by increasing IBW, gain and ARBW. MPA on an Artificial Magnetic Conductor (AMC) surface [3] improved the radiation characteristics of the antenna. Electromagnetic Band Gap structure (EBG) based metasurfaces [4] used in antennas to improve their performance. Polarization Metasurfaces have been frequently used in MPA to convert linear polarization to circular polarization [5].

Antenna gain can be increased using a variety of techniques such as antenna arrays, surface-mounted horn antennas, antenna hybridization. Array antenna elements are a cost-effective way to boost antenna gain [6, 7]. The disadvantage of this method is the coupling of each element and the use of a power source for each antenna. Several options have been proposed, such as using substrates with high permittivity or permeability [8, 9] presents the gain improvement of a rectangular patch by a surface mounted horn antenna. In [10], a lens antenna is used to improve gain. The technologies described above are bulky and expensive, and they suffer from surface waves, which affect the antenna's main features such as emission pattern. FPR antennas are the best alternative for overcoming the difficulties and increasing antenna gain. FPR antennas create a cavity between the superstrate and antenna ground plane. Many different forms of superstrates are employed, including frequency selective surfaces (FSS), partially reflecting surfaces (PRS), metamaterials, and so on. [11] describes a high gain slotted MPA with a Meta surface. The antenna gain is improved by using FPR, PRS is used to create the cavity between radiator and superstrate is proposed in [12].

The fabry perot cavity concept is used in this paper to propose a novel method for enhancing IBW and gain. The combination of a circular RIS structure with a dielectric superstrate improves the gain and bandwidth of a conventional slot loaded microstrip patch antenna simultaneously.

2 Geometry and Design of Proposed Antenna

Figure 1(a) depicts the suggested antenna structure, which consists of a slot loaded square patch, a circular RIS metasurface, and a dielectric superstrate. Figure 1(b) depicts a top view of substrate 2, whereas Fig. 1(c) depicts a top view of substrate 1. The substrate 1 is built of FR4 ($\epsilon_r = 4.4$) materialand has a height of h1. On top of the substrate 1 circular RIS metasuface is placed that is 6 × 6 in size. Fig. 1(c) depicts the RIS-based metasurface, which is made up of 36 circular metal plates of radius rc; d represents the distance between RIS unit cells. Substrate 2 is also built of FR4 ($\epsilon_r = 4.4$) and is placed above Substrate 1. As shown in Fig. 1(b), a slot loaded patch antenna with dimensions Lp × Lp is placed on substrate 2 and excited by coaxial feed. The slot dimensions are $S_l * S_w$. The antenna's feed position is optimised to produce two orthogonal fields, resulting in circular polarisation. To enhance performance of the conventional slot loaded patch by improving IBW, gain, and AR bandwidth, Ansys High.

Frequency Structure Simulator (HFSS) simulation software was used to perform a parametric analysis. The proposed antenna dimensions are optimized and listed in Table 1.

Figure 2 depicts the evolution phases of proposed antenna, which involve the analysis of three different design configurations named Antenna 1, Antenna 2, and the Proposed

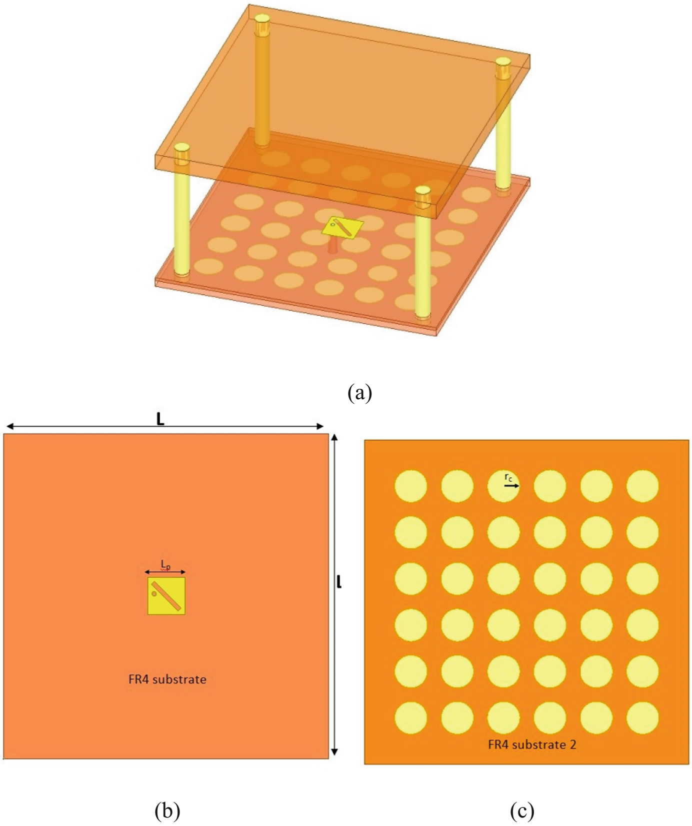

Fig. 1. (a) Proposed antenna geometry (b) Top view of substrate 1 (c) Top view of substrate 2

Table 1. Antenna parameter values

Parameters	Values (mm)
L	70
H1	1.6
H2	0.8
P	10
H	31.5
Lp	8
Sl	4
Sw	0.45
Rc	3

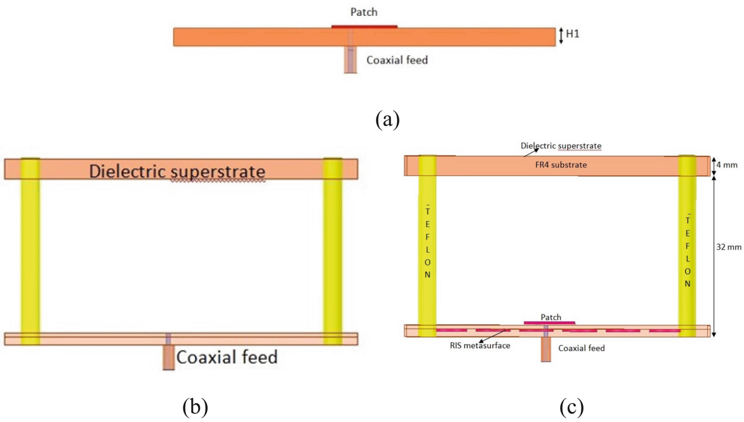

Fig. 2. (a) Antenna 1 (b) Antenna 2 (c) Proposed Antenna

antenna. Right-handed Circular Polarization (RHCP) waves are produced by Antenna 1, which is a slot-loaded square patch fabricated on FR4 substrate 1 with a height of h1. The RHCP waves are produced as a result of this antenna's generation of two orthogonal modes, each of which has the same amplitude but a phase difference of 90 degrees.

A dielectric superstrate is placed at a distance approximately equivalent to $\lambda/2$ to improve the performance of Antenna 2. The cavity is created by ground plane of antenna and dielectric superstrate in the proposed antenna. The dielectric superstrate reflects the waves radiated by the antenna, the reflected waves again reflected by the ground plane. The position and thickness of the superstrate is important to attain a resonance condition. At resonance the trapped waves in the cavity bounce back and forth, coherent addition of waves takes place in the broadside direction. So, the antenna gain in the broadside direction is improved.

To improve the performance of antenna1, we construct a 6×6 circular RIS based metasurface on FR4 substrate, with a periodicity (P) of 10 mm, and placed between ground plane and radiating element of antenna. To achieve a high impedance bandwidth and antenna gain similar to a Fabry Perot resonator antenna, the radius (r_c) and periodicity (P) of the circular RIS structure are optimized.

RIS as the substrate for planar antennas, can considerably reduces the size of the antenna, improves the bandwidth and radiation characteristics of the antenna. RIS has ability to store electric or magnetic energy, which is used to compensate the magnetic or electric energy stored below the antenna, resulting antenna miniaturization and bandwidth enhancement. The magnetic energy stored in the RIS below the resonance frequency cancels the stored electric energy in the near field (inner dielectric) of the microstrip patch when the RIS is employed as the ground plane of a microstrip antenna. This results in antenna miniaturization since the microstrip patch resonates at a lower frequency than its theoretical resonance [13].

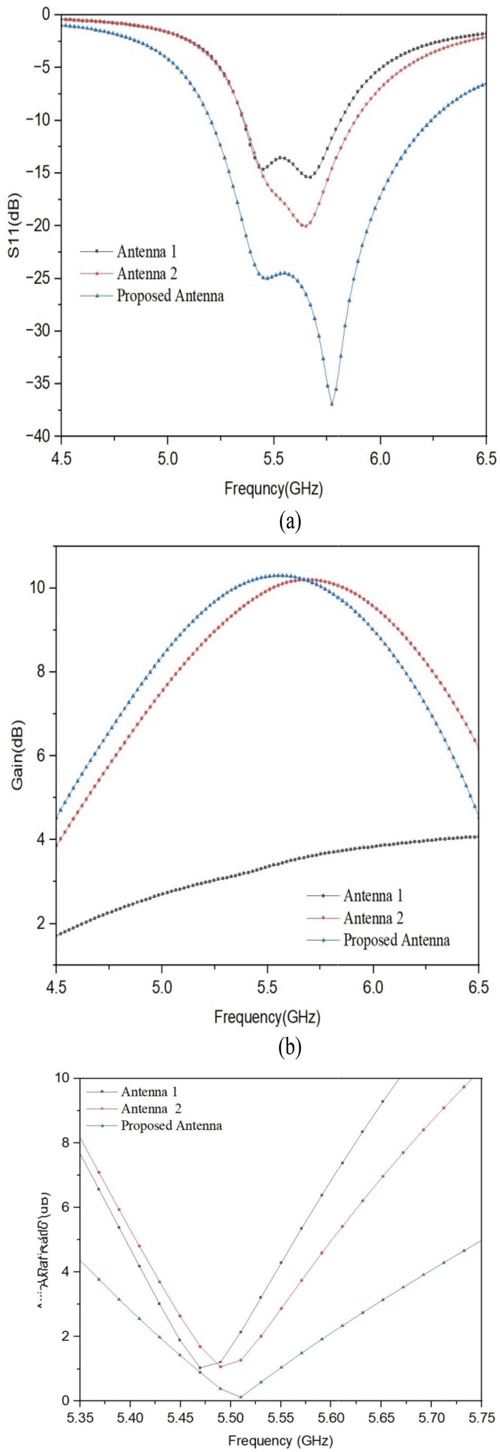

Fig. 3. Simulated results of Antenna 1, Antenna 2, Proposed antenna (a) Reflection coefficient (S11) (b) Gain (c) Axial ratio

3 Results

HFSS software is used to simulate the Antenna 1, and the simulation results are shown in Fig. 3. The antenna has a 8.23% (5.36–5.82 GHz) IBW, gain of 3.7 dB and 1.6% (5.43 GHz–5.52 GHz) ARBW. The FPR antenna with dielectric superstrate has IBW is 9.25% (5.36–5.88 GHz), gain is around 10.16 dB, and the ARBW is 5.51% (5.46–5.56 GHz). The conventional slot loaded antenna with FPR is increased, but there is no change in IBW is observed. The composite structure with slot loaded patch, RIS structure and a dielectric superstrate antenna has an IBW of 18.7% (5.19–6.26 GHz), a gain of 10.3 dB, and ARBW of 4.7% (5.39–5.65 GHz).

The RHCP (copolarization) and LHCP (crosspolarization) simulation results are shown in Fig. 4. In the resonance frequency range RHCP gain is high. Hence, the antenna exhibits right hand circularly polarized radiation (RHCP). LHCP gain in the resonant frequency range is less. At 5.5 GHz, proposed antenna's AR is less than 3 dB, showing an extremely poor LHCP gain (Table 2).

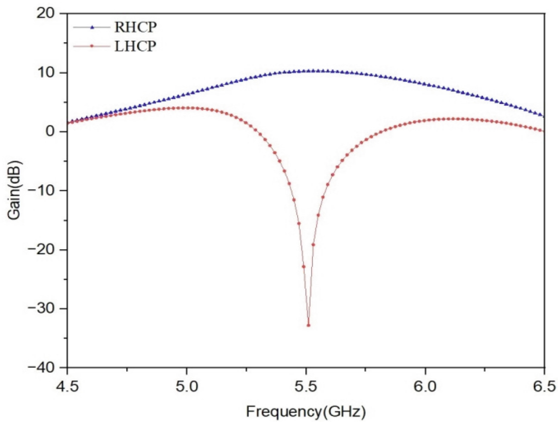

Fig. 4. Simulated LHCP and RHCP gain of proposed antenna

Table 2. Simulation results

S.No	Antenna	IBW	Gain (dB)	AR Bandwidth
1	Antenna 1	8.23% (5.36 GHz–5.82 GHz)	3.7	1.6% (5.43 GHz–5.52 GHz)
2	Antenna 2	9.25% (5.36 GHz–5.88 GHz)	10.16	1.8% (5.46 GHz– 5.56 GHz)
3	Proposed Antenna	18.7% (5.19 GHz–6.26 GHz)	10.3	4.7% (5.39 GHz–5.56 GHz)

4 Conclusion

In the design of a slot-loaded square patch antenna in order to enhance antenna gain by adding a dielectric superstrate on top of the antenna, which forms the fabry perot resonator. The impedance bandwidth of the antenna is improved by placing a circular RIS metasuface between radiating patch and ground plane. The circular RIS structure and the dielectric superstrate above the antenna were used to improve both gain and bandwidth at the same time. The results show that this proposed wideband, high gain antenna can be used in 5 GHz band for Wi-Fi and Wi-MAX applications.

References

1. C. Holloway, A. Dienstfrey, E. F. Kuester, J. F. O. Hara, A. K Azad, and A. J. Taylor, A discussion on the interpretation and characterization of metafilms/metasurfaces: The two-dimensional equivalent of metamaterials, Metamaterials, vol. 3, pp. 100–112, 2009.
2. L. Bernard, G. Chertier, and R. Sauleau, "Wideband circularly polarized patch antennas on reactive impedance substrates," IEEE Antennas Wireless Propag. Lett., vol. 10, pp. 1015–1018, 2011.
3. D. Sievenpiper, L. Zhang, R. Jimenez Broas, N. Alexopolous, and E. Yablonivitch, High-impedance electromagnetic surfaces with a forbidden frequency band, IEEE Trans. Microw. Theor. Tech., vol. 47, pp. 2059–2074, 1999.
4. F. Yang and Y. Rahmat-Samii, Reflection phase characterizations of the EBG ground plane for low profile wire antenna applications, IEEE Trans. Antennas Propag., vol. 51, no. 10, pp. 2691–2703, 2003.
5. H. Zhu, K. L. Chung, X. L Sun, S. W Cheung, and T. I Yuk, CP metasurfaced antennas excited by LP sources, Proc. of the 2012 IEEE Int. Symp. Antennas Propag., 2012, pp. 1–2.
6. Nasser Ghassemi and Ke Wu. High-efficient patch antenna array for e-band gigabyte point-to-point wireless services. IEEE Antennas and Wireless Propagation Letters, Vol. 11, 1261–1264, 2012.
7. Dong-yeon Kim, Youngjoon Lim, Hee-Sung Yoon, and Sangwook Nam. High efficiency w-band electroforming slot array antenna. IEEE Transactions on Antennas and Propagation, Vol. 63, No. 4, 1854–1857, 2015.
8. Karu Esselle, AK Verma, et al. Compact circularly polarized enhanced gain microstrip antenna on high permittivity substrate. In 2005 Asia-Pacific Microwave Conference Proceedings, IEEE, Vol. 4, 4, 2005.
9. Sebastian Methfessel and Lorenz-Peter Schmidt. Design of a balanced-fed patch excited horn antenna at millimeter-wave frequencies. In Proceedings of the Fourth European Conference on Antennas and Propagation, IEEE, pp. 1–4, 2010.
10. Hailiang Zhu, Sing Wai Cheung, and Tung Ip Yuk. Enhancing antenna boresight gain using a small metasurface lens: Reduction in half-power beamwidth. IEEE Antennas and Propagation Magazine, Vol. 58, No. 1, 35–44, 2016.
11. Diptiranjan Samantaray and Somak Bhattacharyya. A gain-enhanced slotted patch antenna using metasurface as superstrate configuration. IEEE Transactions on Antennas and Propagation, Vol. 68, No. 9, 6548–6556, 2020.
12. Meriche MA, Attia H, Messai A, Mitu SSI, Denidni TA (2019) Directive wideband cavity antenna with single-layer meta-superstrate. IEEE Antennas Wirel Propag Lett 18(9): 1771–1774.

13. Shyam Sundar Jash, Chiranjib Goswami, Rowdra Ghatak. A low profile broadband circularly polarized planar antenna with an embedded slot realized on a reactive impedance surface. AEU - International Journal of Electronics and Communications, 2019.