International Journal of Scientific Research in Computer Science, Engineering and Information Technology
ISSN : 2456-3307 (www.ijsrcseit.com)
doi : https://doi.org/10.32628/CSEIT22837

Design and Analysis of Microstrip Patch Antenna properties with Split-Ring Resonator Metamaterial as Superstrate at mmWave Frequency

Priyadarshini. K. Desai, Bindu. S
Department of Electronics and Communication Engineering, B.N.M Institute of Technology, Bangalore, Karnataka, India

Article Info
Volume 8, Issue 3
Page Number : 217-224

Publication Issue :
May-June-2022

Article History
Accepted: 10 May 2022
Published: 30 May 2022

ABSTRACT

The Microstrip Patch antenna which is considered as low profile and easy to fabricate antenna incorporates drawbacks that include low gain and bandwidth. Using Metamaterials superstrate both bandwidth and the gain of patch antenna can be enhanced. This paper basically includes the study characteristics of rectangular patch antenna that is fed by microstrip line, with metamaterial as the two layers of superstrate is carried out at mmWave frequency ie 24GHz. The rectangular patch antenna is designed, that resonate at 24GHz, with copper as the radiating material put on Rogger 5880 substrate of 0.5mm thickness. The substrate dimension is taken to be 15mmx 15mm. The metamaterial structure exhibits negative permittivity and permeability at the same frequency as that of rectangular patch antenna ie at 24GHz. The substrate used for SRR structure design is Rogger 5880 of thickness 0.2mm. The unit cell dimension is 1.6mm x 1.6mm and the superstrate layer consists of a 9x9 SRR structure. Rectangular Patch characteristics are studied by placing the single layer and double layer of the superstrate at various distances (in mm). It is observed that placing a double superstrate layer with a gap of 1mm between them was placed at a distance of 1mm from the resonating rectangular patch antenna, making the antenna exhibit a multi-band feature along with an increase in the antenna gain. The Rectangular Patch antenna, SRR structure simulation is carried out in the CST simulation tool. Simulation results show that SRR characteristics are satisfied at 24GHz ie it behaves like a double negative structure and was verified using Matlab. The antenna shows multi-band resonance behavior at 24.033GHz, 25.36GHz, 25.285 GHz, 26.27 GHz when a double layer of 9x9 Split Ring Resonator is added above the radiating element. The gain offered by a single patch was 7.57dB and with the superstrate layer, the gain obtained was 9.01dB. The polarization component along the main lobe direction shows the cross-polarization component is found to be -85dB. The analysis of antenna with and without superstrate shows that there is improvement in gain and the multiband resonance can be achieved.

Keywords: mmWave, Microstrip Patch Antenna, Metamaterial, Superstrate.

I. INTRODUCTION

In recent years of wireless communication, the bandwidth, data rate, and connectivity requirement have increased. To cope with these requirements, the design of a smart, low-cost, flexible communication block becomes necessary. As the current frequency band, ie GSM band is heavily occupied, researchers are looking into the next frequency band or say higher frequency band, mmWave band. Designing the electronics components or devices to operate satisfactorily in this frequency range becomes important. Among many elements, the antenna is considered one of the important elements in any wireless communication system. The design of an antenna operating at mmWave frequency has received a lot of importance over the last few year years especially low profile and easy to fabricate microstrip patch antenna. The literature related to the analysis of microstrip patch antenna characteristics says that it offers low gain and low bandwidth. When communication has to be established at a high frequency ie at microwave frequency (ranging from 3GHz-300GHz), there is a need to design a high gain, multiband antenna to combat fading and achieve long-range communication.

In recent years, several methods and concepts have been used to increase the gain of the antenna thereby reducing the size and keeping other characteristics of the antenna such as radiation pattern, polarization, etc as constant, which is very well described in [1]. The very basic way to scale down the antenna size is to use the substrate having a high dielectric constant. But the use of high dielectric material offers more loss when being operated at mmWave frequency that is high frequency as the field are concentrated near high permittivity region. Also, the issue of impedance matching arises when high permittivity material is used described in The ordinary way to deal with scaling down an antenna is to put the radiator on a substrate with a high dielectric constant [2].

In [3] metamaterial structure was loaded on the top of the radiating element, basically used as a superstrate layer to improve antenna properties such as gain, bandwidth and to achieve better impedance matching. The use of metamaterial as superstrate is a technique in which the basic structure or dimension of radiating patch remains unchanged, but of course, the addition of superstrate layer has a great impact on the antenna properties and thus, can be considered a good technique to improve some of the antenna properties. In [4,5] study of compact patch antenna loaded with metamaterial has been reported. The metamaterials are not available naturally but they are designed to be artificial as discussed in [7]. As described in [6] metamaterials are basically a group of microwave structures designed to exhibit double and single negative permittivity and permeability conditions. With these conditions of μ and ε metamaterials can be used to alter or improve the properties of microwave devices such as an antenna.

From the survey and work carried out in [8], it can be seen that the use of metamaterial as superstrate layers over the antenna has shown an improvement gain and bandwidth of the radiating patch. Superstrate layer when used, there is a reduction in the reflectance value(S11), creation the in-phase electric field, and by adding artificial property in superstrate layer results in gain improvement due to suppression in surface waves.

A layer of superstrate consisting of SRR as metamaterial is used in [9], and has shown improvement in gain and efficiency of the patch antenna. With the use of metamaterial, the size of the antenna can be reduced as well as the antenna can be made to resonate at different frequency bands ie multiband features can be achieved. In [10] microstrip patch antenna with a Split ring resonator as a superstrate layer resulted in the enhancement of antenna gain and efficiency with near-zero permeability.

In [11] multiple split-ring resonators were used with antenna substrate and as well as superstrate to increase the bandwidth and to achieve compactness in the design. The impact of the superstrate layer on the microstrip patch antenna properties is less when the layer is placed at a large distance. There is always a trade-off between the layers of superstrate used and antenna properties such as gain bandwidth enhancement, to be achieved.

In this paper, antenna characteristics mainly the gain of patch antenna with SRR metamaterial as superstrate is simulated and analyzed. Results show that there is a good improvement in gain and the multi-band feature is exhibited by the microstrip patch antenna.

A Microstrip Patch Antenna design that resonates at 24GHz is presented in Section 2. In section 3 design of the metamaterial structure that SRR is presented. In Section 4. A Microstrip Patch Antenna loaded with metamaterial layers is discussed. In Section 5 the comparison of antenna characteristics such as gain and reflection coefficient is provided. The conclusion and future work is discussed in Section 6 and 7.

II. DESIGN OF 24 GHz MICROSTRIP PATCH ANTENNA (MSA)

For the analysis of MSA with superstrate, the first step is to design an MSA. Microstrip Patch Antenna is constructed on the Rogger 5880 substrate having a height of 0.5mm. The Rogger 5880 having a dielectric constant of 2.2 was used as a substrate as it offers less attenuation at higher frequencies. The patch antenna width and length are calculated using the equation from[1-5]

$$Wp = \frac{c}{2f_0\sqrt{\frac{\epsilon_r+1}{2}}} \quad (1)$$

$$L = L_{eff} - 2\Delta L \quad (2)$$

$$\Delta L = 0.412h\,\frac{(\epsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{eff}-0.258)(\frac{W}{h}+0.8)} \quad (3)$$

$$L_{eff} = \frac{c}{2f_0\sqrt{\epsilon_{eff}}} \quad (4)$$

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (5)$$

Obtained dimension of the Microstrip Patch Antenna is Wp= 4.2mm and Lp =4.1mm. The length and width of the antenna are optimized, so that antenna resonates at the required frequency which is 24GHz. Table 1 shows the dimension of the patch antenna and feed line used for excitation.

TABLE 1.

ANTENNA PARAMETER SPECIFICATIONS.

Structure	Parameter (Symbol)	Value (mm)
Ground Plane	Width (Wg)	15
	Length (Lg)	15
	Thickness (t)	0.017
Substrate	Width (Ws)	15
	Length (Ls)	15
	Height (h)	0.5
Patch	Width (W)	4.98
	Length (L)	3.9
	Thickness (t)	0.017

Figure 1 shows the designed microstrip patch antenna with microstrip line as a feed structure.

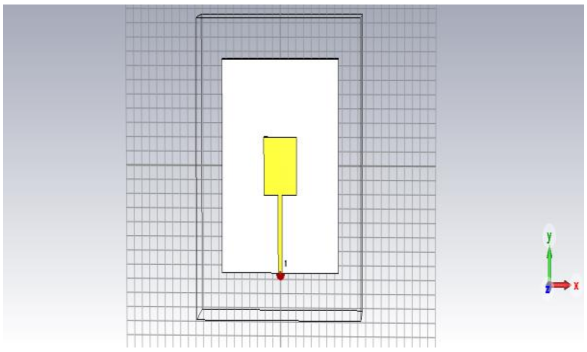

Figure 1 Designed MSA with Microstrip Feed Line

The length and width are along the y- axis, and x-axis of the coordinates. The radiation was along the z-coordinate. The port used is a discrete port. The power fed to the antenna was 0.5W. The feed line used is a 50-ohm transmission line of width equal to 0.5mm. Copper material with an electrical conductivity of 5.8x107 S/m was used to design the patch antenna and ground plane. The thickness of the copper used is 0.017mm.

III. DESIGN OF SPLIT-RING RESONATOR

A pair of concentric metallic rings etched on the dielectric substrate, with the slits etched on the opposite side form an SRR. The SRR unit cell was constructed on an RT5880 substrate of thickness 0.2mm. The size of the unit cell to exhibit metamaterial property was 1.6mm x 1.6mm. the dimension of SRR is listed in table-2.

TABLE 2.

SRR PARAMETER SPECIFICATIONS

Structure	Parameter (Symbol)	Value (mm)
Outer Ring	Width (W1)	0.11
	Length (L1)	1.2
	Thickness (t)	0.017
Substrate	Width (Ws)	1.6
	Length (Ls)	1.6
	Height (h)	0.2
Inner Ring	Width (W2)	0.11
	Length (L2)	1.2
	Thickness (t)	0.017

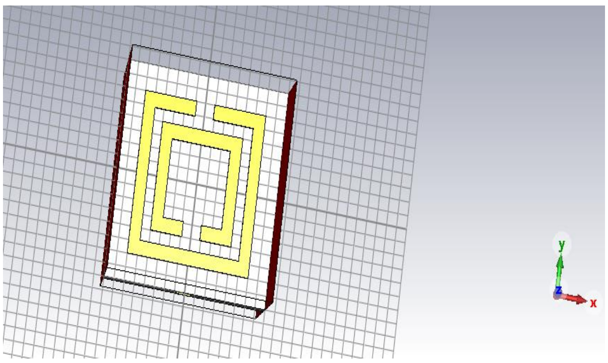

Figure 2 Designed Split Ring Resonator

Figure 2 shows the structure of the SRR metamaterial. As given in [10, 11] the resonance frequency of SRR metamaterial can be obtained by equation:

$$f = \frac{1}{2\pi\sqrt{LC}} \qquad (6)$$

S-parameters are used to analyze metamaterial properties The equation (7-10) are used to obtain the Refractive index (n), impedance permittivity, and permeability of SRR through s-parameters.

$$n = \frac{1}{kd}\cos^{-1}\left[\frac{1}{2S_{11}}\left(1 - S_{11}^2 + S_{21}^2\right)\right] \qquad (7)$$

$$z = \sqrt{\frac{(1+S_{11}^2)-S_{21}^2}{(1-S_{11}^2)-S_{21}^2}} \qquad (8)$$

$$\varepsilon = \frac{n}{z} \qquad (9)$$

$$\mu = \frac{n}{z} \qquad (10)$$

The metamaterial layer acts as a good resonator with a high Q-factor. The use of metamaterial superstrate above the antenna makes the antenna resonate at multi-band.

IV. RECTANGULAR PATCH ANTENNA WITH SRR METAMATERIAL AS SUPERSTRATE.

SRR metamaterial layer was placed above the patch antenna. There was an improvement in the S11 parameter and better gain when two-layer of the superstrate were used. The two layers were placed at different distances from the radiating patch. The distance between the two-layer was varied from 0.5mm -4mm. The first layer distance from the radiating patch was varied from 0.2mm to 1mm. There was variation in the distance that led to different results but the better results were obtained when layer-1 was at the distance of 0.5mm from radiating patch and layer-2 was at a distance of 0.85mm. The MSA with the two-layer of superstrate is depicted in figure 3

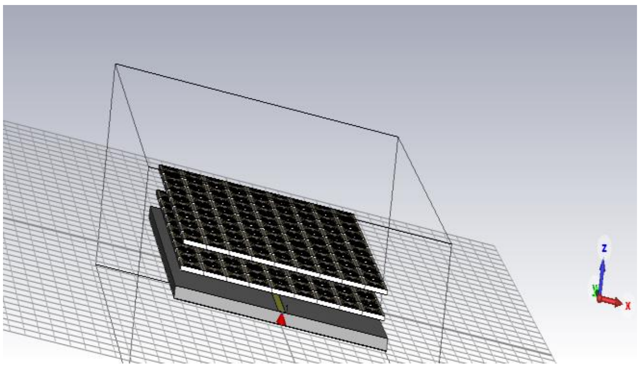

Figure 3 MSA with a two-layer of Superstrate

V. RESULTS AND DISCUSSION

A. Designed Microstrip Patch Antenna Characteristics

The Patch antenna designed offers good impedance matching at 24GHz which is realized through the S11(dB) plot shown in figure 4

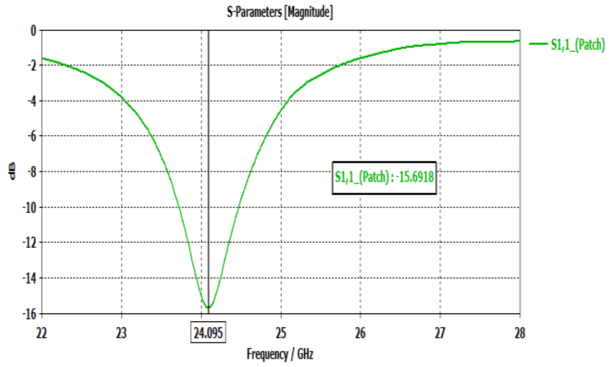

Figure 4 S11 Plot of the Single Rectangular Patch

The radiation pattern of the designed MSA is shown in figure 5. The directivity of the antenna is 7.687dB as can be observed in figure 5. The radiation pattern in the Cartesian plot is shown in figure 6. It can be observed that the main lobe direction is along 00 . The Cross-pol and Co-pol component magnitude plot shows that the cross-polarization component is -57.66dB along the main lobe direction.

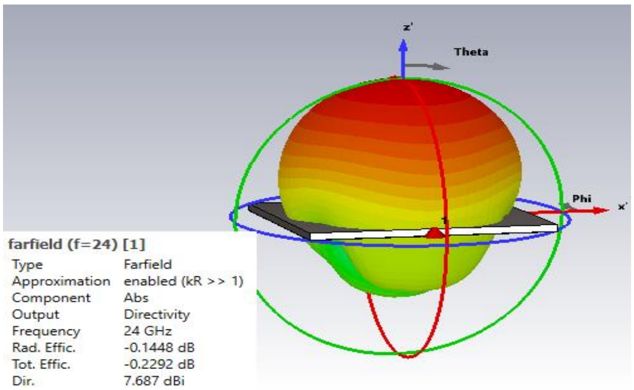

Figure 5 The Pattern of Rectangular Patch Antenna

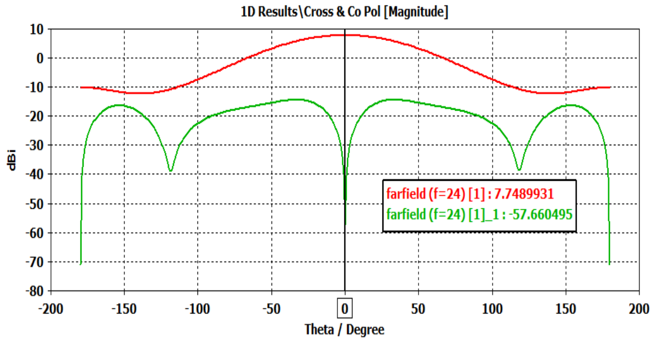

Figure 6 Cross- and Co- Polarization Plot along the Main Lobe direction

From the S11 and Radiation Plot, it can be seen that the single patch antenna resonates at a single frequency that is 24GHz with a gain of 7.74dB.

B. SRR Structure and its Characteristics

The Split Ring Resonator unit cell of 1.6mm x 1.6mm was designed on Rogger 5880 substrate of 0.2mm thickness. figure 7 shows the magnitude plot of the S-parameter. From figure 8 it can be depicted that the designed SRR exhibits the phase change around 24GHz.

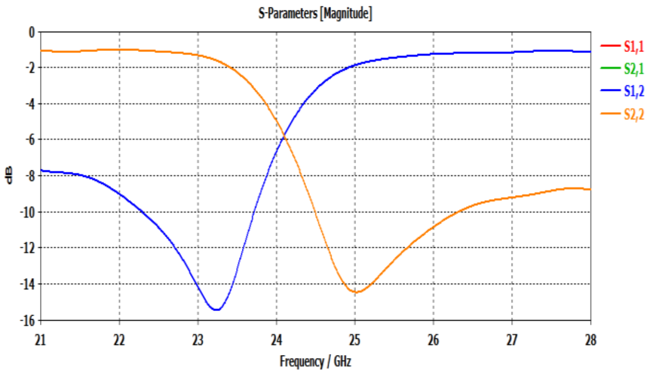

Figure 7 S-parameter magnitude plot of designed SRR metamaterial

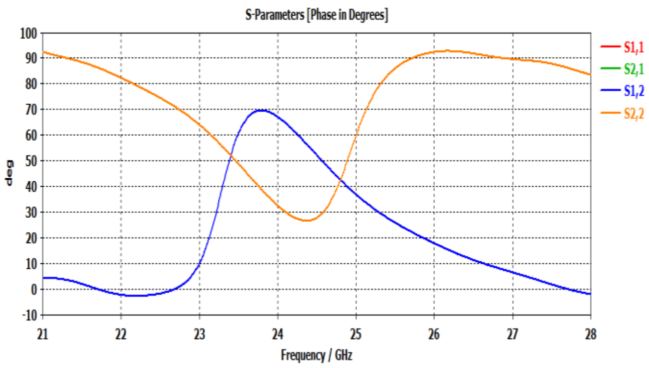

Figure 8 S-parameter Phase-Plot of Designed SRR metamaterial

Verification of double negative nature is verified using Matlab. The obtained results are depicted in figure 9 showing that both permittivity and permeability are negative around 24GHz.

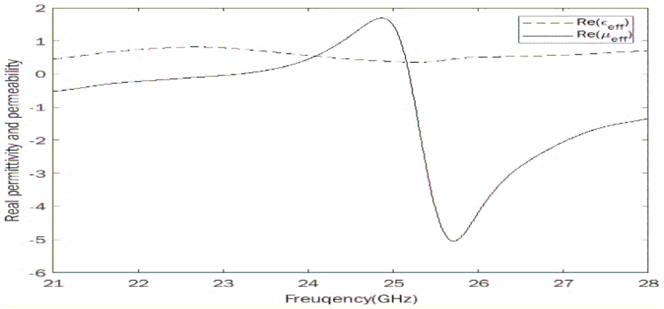

Figure 9 Plot of Real permittivity and permeability v/s frequency of designed SRR Structure

C. Rectangular Patch with SRR as Superstrate

The rectangular patch antenna performance analysis was carried out for the following cases

1. Rectangular Patch Antenna with Single Layer of Superstrate
2. Rectangular Patch Antenna with Double Layer Of Superstrate

Case 1: The Rectangular Patch antenna was loaded with a single layer of 9x9 SRR metamaterial Layer The distance between the radiating material and superstrate was varied from 0.2mm to 1mm. Figure 9 indicates the gain of the antenna with the introduction of a single layer of superstrate with a distance between layer-1 and patch being 1mm observed in figure 10.

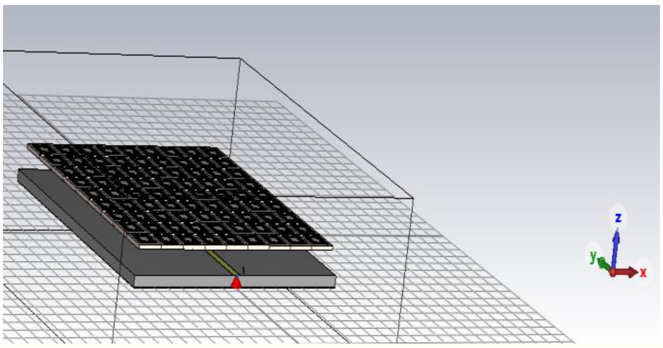

Figure 10 Rectangular Patch Antenna with Single Layer of Superstrate.

Case 2: Rectangular Patch Antenna with Double Layer Of Superstrate.

Since there was a satisfactory improvement in the gain of the radiating patch with a single superstrate, a second layer of the superstrate of the same dimension was added above the first layer at a distance of 1mm initially. The distance between both the layers was varied from 0.5mm-3mm. To obtain better gain and proper impedance matching. The gain of the antenna with the introduction of a double layer of superstrate with the distance between two layers of 0.85mm and distance between layer-1 and patch being 0.65mm observed in figure 11 and figure 12 shows the 3D radiation plot.

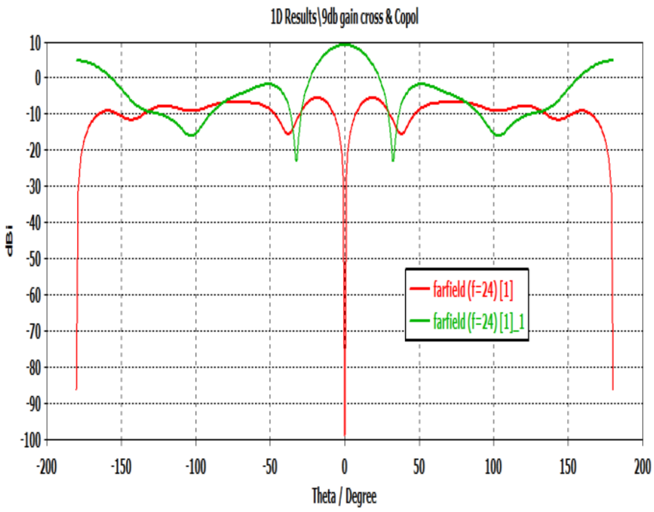

Figure 11 1-D Radiation Pattern Plot of Patch Antenna with the two-layer of Superstrate.

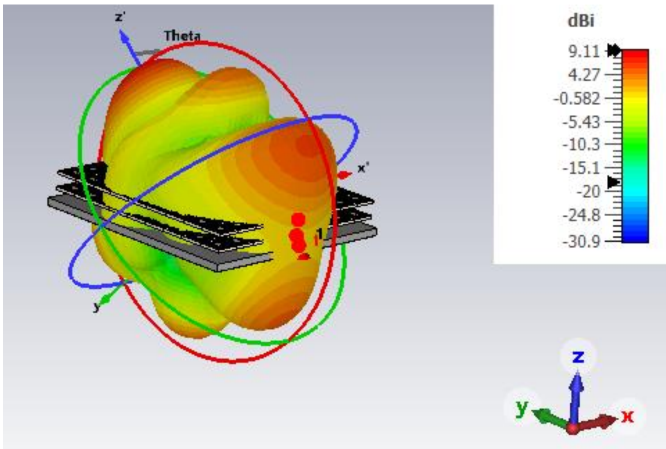

Figure 12 3D Radiation Plot of Patch antenna with two layers of superstrate.

Figure 13 and figure 14 show the comparison of the S-parameter and gain plot of the single patch antenna and patch antenna loaded with single- and double-layers of superstrate above it. It can be depicted that the antenna shows multi-band resonance when loaded with a double layer of superstrate.

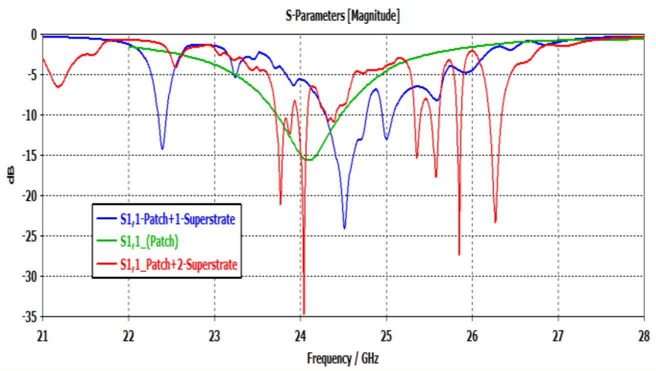

Figure 13 Comparison of S-parameters of Single Patch, Patch with Single Layer, Patch with two-layer Superstrate.

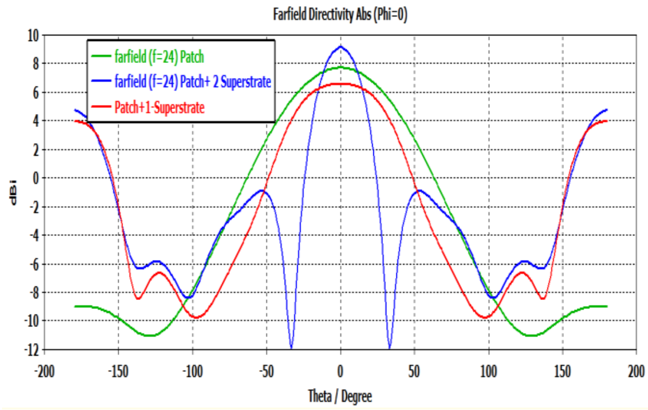

Figure 14 Comparison of Far-field Plot of Single Patch, Patch with Single Layer, Patch with two-layer Superstrate.

Voltage Standing Wave Ratio Comparison for Rectangular Patch with both single-layer and double-layer superstrate is shown in figure 15. As depicted in figure 14 the VSWR is nearing 1 with a double layer of superstrate in comparison with a single layer of superstrate.

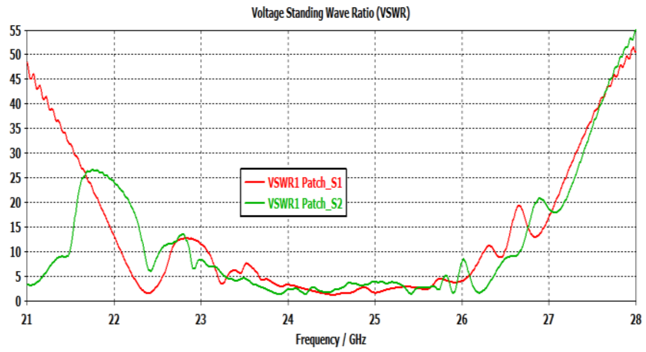

Figure 15 Comparison of VSWR of Rectangular Patch Antenna with Single- and Double–Layers of Superstrate.

VI. CONCLUSION

The antenna with the high gain and multiband resonance is one of the major requirements of the mmWave wireless communication system. In this work, MSA is designed to resonate at mmWave frequency that is 24GHz. The gain offered by the MSA is 7.67 dB and the frequency of resonance is 24GHz. To improve the gain and to achieve multi-band resonance Rectangular Patch Antenna is loaded with Superstrate. The Analysis of Antenna characteristics is carried with a single layer and double layer superstrate. The superstrate used SRR as a basic element. 9x9 SRR was used to create one layer of superstrate. From the results, it can be observed that the addition of double-layer superstrate gain is increased to 9.01dB and the antenna offers multi-band resonance apart from resonating at 24GHz. The distance between the individual layer and radiating element was varied in order to achieve better gain and directivity. The addition of a further layer did not sever the purpose of increasing the gain. Trade of has to be in terms of a number of layers to be used and bandwidth and gain enhancement. In the simulation carried out there was not much change in the gain and bandwidth when layer-3 is added. The Rectangular Patch Antenna loaded with superstrate offers a better gain in comparison with the rectangular patch antenna alone. The structure can be used in a wireless communication system operating at mmWave frequency.

VII. FUTURE WORK

As the work involved a design and analysis of MSA characteristics loaded with two layers of superstrate, further work can be taken as deigning patch antenna array fed with serial feed structure and corporate feed structure. As antenna array is one of the solutions to enhance the gain of the antenna system, thus antenna array with layers of superstrate can be carried out and the design can be used for wireless communication system at mmWave frequency.

Acknowledgment

The work is carried out in the research center of Department of ECE, BNMIT Bengaluru affiliated with Visvesvaraya Technological University. The support provided by the college and the university is gratefully acknowledged.

VIII. REFERENCES

[1]. Zhong, S.S.; and Cui, J.H. (2002). Compact circularly polarized microstrip antenna with magnetic substrate. IEEE Antennas and Propagation Society International Symposium(IEEE Cat. No. 02CH37313), San Antonio, USA, 793-796

[2]. Psychoudakis, D.; Koh, Y.H.; Volakis, J.L.; and Halloran, J.H. (2004). Design method for aperture-coupled microstrip patch antennas on textured dielectric substrates. IEEE Transactions on Antennas and Propagation, 52(10), 2763-2766.

[3]. Lim, J.S.; Kim, C.B.; Jang, J.S.; Lee, H.S.; Jung, Y.H.; Kim, J.H.; and Lee, M.S. (2008). Design of a subwavelength patch antenna using metamaterials. 2008 38th European Microwave Conference. Amsterdam, Netherlands, 1246-1249.

[4]. Bantwal, M. (2013). Design of rectangular microstrip antenna with metamaterial for increased bandwidth. International Journal of Innovation and Applied Studies, 3(4), 1094-1100

[5]. Bagri, R.K.; and Meena, S. (2015). Design and analysis of rectangular microstrip patch antenna using metamaterial for WIMAX application at 2.5 GHz. 2015 International Conference on Applied and Theoretical Computing and Communication Technology (ICATCCT), Davangere, India, 697-700.

[6]. Ruvio, G.; and Leone, G. (2014). State-of-the-art of metamaterials: characterization, realization and applications. Studies in Engineering and Technology, 1(2), 38-47.

[7]. Veselago, V.G. (1968). The electrodynamics of substances with simultaneously negative values of ε and μ. Soviet Physics Uspekhi, 10(4), 509-514

[8]. Singh, A. K., Abegaonkar, M. P., & Koul, S. K. (2017). Highgain and high-aperture-efficiency cavity resonator antenna using metamaterial superstrate. IEEE Antennas and Wireless Propagation Letters, 16, 2388–2391.

[9]. Attia, H., Yousefi, L., Bait-Suwailam, M. M., Boybay, M. S., & Ramahi, O. M. (2009). Enhanced-gain microstrip antenna using engineered magnetic superstrates. IEEE Antennas and Wireless Propagation Letters, 8, 1198–1201

[10]. Gangwar, D., Das, S., & Yadava, R. L. (2017). Gain enhancement of microstrip patch antenna loaded with split ring resonator based relative permeability near zero as superstrate. Wireless Personal Communications, 96(2), 2389–2399.

[11]. Gangwar, D., Das, S., & Yadava, R. L. (2017). Gain enhancement of microstrip patch antenna loaded with split ring resonator based relative permeability near zero as superstrate. Wireless Personal Communications, 96(2), 2389–2399.

[12]. Patel, S. K., Argyropoulos, C., & Kosta, Y. P. (2017). Broadband compact microstrip patch antenna design loaded by multiple split ring resonator superstrate and substrate. Waves in Random and Complex Media, 27(1), 92–102.

Cite this article as :

Priyadarshini. K. Desai, Bindu. S, "Design and Analysis of Microstrip Patch Antenna properties with Split-Ring Resonator Metamaterial as Superstrate at mmWave Frequency", International Journal of Scientific Research in Computer Science, Engineering and Information Technology (IJSRCSEIT), ISSN : 2456-3307, Volume 8 Issue 3, pp. 217-224, May-June 2022. Available at doi : https://doi.org/10.32628/CSEIT22837

Journal URL : https://ijsrcseit.com/CSEIT22837