Design and Comparison of the effect of SRR Metamaterial on the performance of Microstrip Patch Antenna of various shapes at millimetre-wave band Useful for 5G enabled Internet of Things Applications

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Abstract. 5G is the creation of apprehending the total potential IoT. Since the request for 5G and Web of things, applications such as e-health, keen homes, e-learning, work from domestic, virtual conferences, and another gushing of online high-quality video substance is exponentially expanding day by day. The authors in this research have designed, compared and examined the execution of different Microstrip Antenna geometrical patches with and without metamaterial such as Circular Shape, Rhombus Shape, Square shape, Elliptical shape, and Triangular shape for 5G enabled IoT systems at 27 GHz, millimeter-Wave Band. In this research, authors have utilized Rogers RT/Duroid 5880 substrate with 50-ohm Microstrip Transmission line nourish. After Comparing and Examining the performance, authors have found square Patch Microstrip Antenna appears way better execution and exceedingly proficient than other shapes.

Keywords: Metamaterial, SRR, Microstrip antenna, 5G, IoT, Millimetre-wave band

1. Introduction

The 5G wireless communication innovation at millimetre-wave band empowered to IoT devices will revolutionize the electronic communication framework and remote sensor systems in this cutting-edge computerized world due to its capacity in giving enormous web connectivity, exceedingly productive transmission of sensor information, and low latency as compared to existing 3G/4G wireless communication. Therefore, a compact design of microstrip antennas plays a major part in the wireless communication of data. These antennas are the metallic devices utilized for emanating and accepting radio waves [1]. The transmission line in microstrip antenna also plays an important role in transferring high electromagnetic energy from the source (transmitting) to antenna or from the antenna to the receiver [1]. There are various types of Antennas such as wire antennas, microstrip antenna, aperture antenna, array antennas, reflector antennas, and lens antennas. Microstrip antennas are one of the most popular and widely used antennas because of their use in advanced mobile communication
network technology like 5G. In the modern era of digital life, 5G wireless communication has a great impact on the Internet of Things based electronic devices because of its tremendous ability to generate a high data rates and speed useful for various 5G and IoT application. 5G is the advanced wireless fifth-generation communication network technology that uses a millimetre-wave band and provides excellent bandwidth and high data rates [2]. This millimetre-wave band has a massive frequency band from 30 GHz to 300 GHz with a wavelength from 1 millimetre to 100 millimetres [3]. The microstrip antennas consist of a copper patch, which is a highly conductive material mounted on a dielectric substrate. The metallic patch is available in a variety of geometric shapes such as rectangular, triangular, elliptical, square, circular, etc. [1]. Within the proposed design, the authors examined the productivity of elliptical, circular, triangular and rhombus-shaped patch antennas due to their compact surface zone, fabulous radiation characteristics, tall request, ease of make and investigation. The proposed design has Rogers RT/Duroid dielectric substrate which could be a low cost conjointly gives fewer dielectric losses and reasonable substrate for 5G Wireless communication. This substrate encompasses a dielectric consistent of 2.2 and a loss tangent of 0.009. The design is mimicked utilizing FEKO software at the Resonance frequency of 27 GHz. The different Characteristics of Microstrip Patch Antenna such as return loss, transmission capacity, and antenna gain is analysed and compared for its execution. In this proposed design, the authors have used unit cell of circular SRR at the millimetre-wave band of 27 GHz and the same is loaded on the various shapes of Microstrip patch antenna and compared for its performance.

The metamaterial is a copper-based material that was engineered artificially through varying its permittivity and permeability in the negative quadrant as $\mu<0$ and $\varepsilon<0$. This was done by manipulating the flow of electromagnetic waves thereby alternating its direction to propagate backwards and thus attaining the negative refractive index which is given by $n=-\sqrt{\mu\varepsilon}$, where $\mu$ is the permeability in free space and $\varepsilon$ is the permittivity. This negative refractive index hence suggests the name for the material as Left-handed material or double-negative metamaterial (DNG) where the propagation of electromagnetic waves exhibit group velocities and antiparallel phase. This DNG medium was simulated using magnetization and lossy Drude polarization models where the permittivity and permeability were defined in the frequency domain as [4]. So, when a plane wave is incident on DNG medium the equations of transmission and reflections coefficient were modified by using the transverse impedance and wavenumber. This transverse wave impedance has opposite signs in terms of capacitive reactance and inductive reactance in [4]. The concept of metamaterial provides with a lot of potentials for applying and decoding its physical properties from laboratories to innovative antenna designs in practical engineering applications. Thus, improving the performance of antenna by giving rise in enormous bandwidth, return loss, charge densities etc.

1.1. Related work
In the proposed work, the execution of three diverse shapes such as circular, rectangular and triangular shapes of microstrip patch antenna at 2.4 GHz utilizing FR-4 Substrate has compared and analyzed [5]. Utilizing ground plane procedures for WLAN application the proposed rectangular patch Antenna design has compared and analyzed the execution of microstrip patch antenna [6]. High-performance square patch microstrip antenna design has proposed utilizing RT Duroid 5880 substrates at 28 GHz for 5G applications [7]. A compact inset-fed microstrip patch antenna design has proposed at 28 GHz resonance frequency for 5G systems [8]. The Circular shape Microstrip patch Antenna design is Proposed utilizing RT Duroid 5880 substrate at 28.5 GHz for 5G applications [9]. The Circular shape Microstrip patch Antenna design with different coaxial feed is Proposed and compared by using RT Duroid 5880 substrate at 28 GHz for 5G applications [3]. Using HFSS software, the comparison of various shapes of microstrip patch antenna applicable for X-band application is being investigated [10]. The unit cell of SRR metamaterial is designed and analysed at X-band using HFSS software [11]. A microstrip printed dipole antenna loaded with SRR metamaterial for 5G applications is presented [12].

2. Design and investigation of Metamaterial Split ring resonator unit cell
Figure 1 is showing the representation of the 3D view design of proposed SRR unit cell, figure 2 is showing the representation of transmission and reflection coefficient, figure 3 is showing the representation of the corresponding effect of permittivity and permeability and figure 4 is showing the representation of magnetic and electric field effect of SRR metamaterial. The parameters obtained for the design is shown in Table 1.

Table 1. Design parameters.

| Symbols | Description                              | value (mm) |
|---------|------------------------------------------|------------|
| d       | Gap between two concentric rings         | 0.1        |
| r₁      | Radius of the outer concentric ring      | 0.65       |
| r₂      | Radius of the inner concentric ring      | 0.45       |
| w       | Width of the concentric rings            | 0.2        |
| g       | Gap for each of the concentric ring       | 0.53       |
| h       | Substrate thickness                      | 0.65       |

Figure 1. 3D view design of the proposed SRR unit cell

Figure 2. Effect of transmission and reflection coefficient of the proposed SRR unit cell

Figure 3. Effect of permittivity and permeability of proposed SRR unit cell

Figure 4. Effect of magnetic and electric field on SRR unit cell
Figure 2 describe the behaviour of electromagnetic plane wave when incident on the DNG medium slab, figure 3 describes the effect of unusual behaviour of electromagnetic wave moving in reverse direction giving the negative effect of the material which is usually not found in any other material in nature, figure 4 describes the magnetic and electric strength of the material which signifies the power associated with an electromagnetic wave.

3. Design and investigation of various shapes of microstrip patch antenna with and without metamaterial

3.1. Circular shape

Figure 5 is showing the representation of the top 3D view design of circular patch with SRR loaded microstrip Antenna and figure 6 is showing the representation of corresponding return loss and bandwidth. The parameters obtained for the design is shown in Table 2. The expression used for calculating the radius of the circular patch antenna is taken from [1].

| Symbols | Description       | value (mm) |
|---------|-------------------|------------|
| $W_s$   | Substrate width   | 12.00      |
| $L_s$   | Substrate length  | 12.00      |
| $h$     | Substrate thickness | 0.65      |
| $L_F$   | Microstrip line-feed length | 1.90 |
| $W_F$   | Microstrip line-feed width | 0.53 |
| $a$     | Circular patch radius | 1.94 |

Figure 5. Top 3D view design of microstrip circular patch antenna loaded with SRR

Figure 6. The return loss of microstrip circular patch antenna
3.2. Square shape

Figure 7 is showing the representation of the 3D top view design of proposed SRR loaded square patch microstrip Antenna and figure 8 is showing the representation of return loss and bandwidth. The parameters obtained for the design is shown in Table 3. The geometrical width and length of the square patch antenna is determined using the expression given as [6],

| Symbols | Description                               | value (mm) |
|---------|-------------------------------------------|------------|
| \( W_s \) | Substrate width                           | 12.00      |
| \( L_s \) | Substrate length                          | 12.00      |
| \( h \) | Substrate thickness                       | 0.65       |
| \( L_F \) | Microstrip line-feed length               | 1.90       |
| \( W_F \) | Microstrip line-feed width                | 0.53       |
| \( L \) | Patch length                              | 3.3        |
| \( W \) | Patch width                               | 3.3        |

![Figure 7](image-url)  
**Figure 7.** Top 3D view design of microstrip square patch antenna

![Figure 8](image-url)  
**Figure 8.** The return loss of microstrip square patch antenna

3.3. Triangular shape

Figure 9 is showing the representation of the top 3D view design of SRR loaded proposed square patch microstrip Antenna and figure 10 is showing the representation of corresponding return loss and bandwidth. The parameters obtained for the design is shown in Table 4. The geometrical length and height of the triangular patch antenna is determined using the expression given as [9],
3.4 Elliptical shape

Figure 11 is showing the representation of the top 3D view design of proposed SRR loaded elliptical patch microstrip Antenna and figure 12 is showing the representation of corresponding return loss and bandwidth. The parameters obtained for the design is shown in Table 5. The geometrical length and height of the triangular patch antenna is determined using the expression given as [10].

The area ‘A’ of the elliptical Patch is given as the product of the area of the two circular patches with radii ‘a’ and ‘b’ respectively. Therefore,

\[ A = \pi ab \]  

(1)

The focal point of the ellipse ‘c’ is given by

\[ c = \sqrt{a^2 - b^2} \]  

(2)

The eccentricity of the ellipse ‘e’ is given by

\[ e = \frac{c}{a} \]  

(3)

where \(a\) is the length of the semi-major axis and \(b\) is the length of semi-minor axis with eccentricity.

The length of the semi-major axis is calculated by using the resonant frequency formula given by Damiano as [10].
Table 5. Design parameters.

| Symbols | Description                          | Value (mm) |
|---------|--------------------------------------|------------|
| $W_s$   | Substrate width                      | 12.00      |
| $L_s$   | Substrate length                     | 12.00      |
| $h$     | Substrate thickness                  | 0.65       |
| $L_F$   | Microstrip line-feed length          | 1.90       |
| $W_F$   | Microstrip line-feed width           | 0.53       |
| $a$     | Length of Semi-major axis of the Patch | 2.9        |
| $b$     | Length of Semi-minor axis of the Patch | 1.91      |

Figure 11. Top 3D view design of microstrip elliptical patch antenna

Figure 12. The return loss of microstrip elliptical patch antenna

3.5 Rhombus shape

Figure 13 is showing the representation of the top 3D view design of proposed SRR loaded rhombus patch microstrip Antenna and figure 14 is showing the representation of corresponding return loss and bandwidth. The parameters obtained for the design is shown in Table 6. The geometrical length and width of the triangular patch antenna is determined using the expression given as [1].
Table 6. Design parameters.

| Symbols | Description                | Value (mm) |
|---------|----------------------------|------------|
| $W_s$   | Substrate width            | 12.00      |
| $L_s$   | Substrate length           | 12.00      |
| $h$     | Substrate thickness        | 0.65       |
| $L_F$   | Microstrip line-feed length| 1.90       |
| $W_F$   | Microstrip line-feed width | 0.53       |
| $a$     | Length of patch            | 3.5        |
| $b$     | Length of Semi-minor       | 3.8        |

Figure 13. To view design of microstrip rhombus patch antenna

Figure 14. The return loss of microstrip rhombus patch antenna

4. Comparison and performance analysis of different shapes of microstrip patch antennas

Below table shows the comparison and performance analysis of three different shapes such as circular shape, square shape, triangular, elliptical, and rhombus shape. The findings of characteristics of microstrip patch antenna such as return loss, and bandwidth are highlighted in the table and compared their performance for the betterment of various 5G wireless communication and its applications and also, IoT applications. As seen from table 7, and table 8 square patch is showing better performance in terms of bandwidth and return loss. The bandwidth is important for providing high data rates and speed, return loss is important for good maximum power transfer to an antenna and good impedance matching.
Table 7. Comparative Analysis of different shapes without metamaterial

| Patch Geometry | Return loss (dB) | Bandwidth (GHz) |
|----------------|------------------|-----------------|
| Circular       | -26.62           | 1.61            |
| Square         | -28.88           | 4.56            |
| Triangular     | -28.5            | 4.42            |
| Elliptical     | -21.29           | 1.62            |
| Rhombus        | -21.12           | 1.56            |

Table 8. Comparative Analysis of different shapes with metamaterial

| Patch Geometry | Return loss (dB) | Bandwidth (GHz) |
|----------------|------------------|-----------------|
| Circular       | -26.76           | 1.62            |
| Square         | -33.9            | 4.65            |
| Triangular     | -31.48           | 4.54            |
| Elliptical     | -24.37           | 1.71            |
| Rhombus        | -20.7            | 1.58            |

5. Conclusion and future scope

The metamaterial-based Microstrip Patch Antenna of various geometrical shapes patches has been designed at resonance frequency 27 GHz. Their important characteristics such as return loss, and bandwidth, have been compared and analyzed for the performance of various 5G applications such as e-learning, smart city, e-governance, self-driving vehicles, e-health, etc. The same is implemented using FEKO software as this software provides an excellent platform for designing and analysing the electromagnetic solutions to an antenna. The future scope is to implement by using various sizes of array elements and then loading metamaterial on the patch array.

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