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Study on Metamaterial-based Bio-inspired Microstrip Antenna Array for 5G Enabled Mobile Health Technology

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***Abstract*—5G is a fifth-generation wireless technology that enables extremely fast data transfers and massive connection capacity. Existing Mobile health technology requires more reliable connection power and data transfer rates. The purpose of this research is to design, analyse, and compare the performance of a bio-inspired lotus-shaped microstrip patch antenna array with two to three radiating elements. The proposed antenna utilizes proximity coupled indirect microstrip transmission line feeding technique operating in the 24 GHz-30 GHz frequency band. The results indicate that performance continues to improve as the number of radiating elements increases. Moreover, each radiating element is loaded with complementary and non-complementary split-ring resonators (SRRs). The performance of the proposed microstrip antenna array is then analysed and compared with and without split-ring resonators. The findings validate that the proposed bio-inspired metamaterial-based microstrip patch array antenna is more reliable and performs better than an antenna without SRRs.**

***Keywords*—microstrip; antenna; bio-inspired; array; split-ring resonators; metamaterial; 5G**

I. INTRODUCTION

THE microstrip patch antennas have become increasingly important in 5G wireless communication technology owing to their simplicity and extensiveness of application. 5G will be phased in overtime to address primary objectives such as enhanced mobile broadband, massive machine-type communication and low-latency and ultra-reliable communication for remote sensing and control in medical and autonomous car applications [1]. With exponential growth in user demand, 4G will quickly be surpassed by 5G, which will employ sophisticated access technologies such as beam division multiple access (BDMA), orthogonal and non-orthogonal or filter bank multiple carriers (FBMC) [2]. The fundamental advantage of millimetre-wave communication systems is that the physical size of radiating components decreases proportionally to the wavelength, allowing antennas and RF electronics to be integrated into small form-factor devices [3]. A 5G antenna array should be capable of multi-beam transmission, wide azimuthal coverage, and high strength [4]. In 5G technology, each endpoint receives a composite beam composed of signals from an array of numerous antenna elements. This creates an excellent communications environment. The cutting-edge technology utilizing an "analogue-digital hybrid configuration" is capable of meeting the requirement for extreme downsizing, as well as highly integrated RF circuitry [5].

The use of small and compact antennas, such as bio-inspired antennas derived from biological concepts, is a continuing trend in the development of antennas for modern wireless systems. Numerous institutions worldwide, including the Massachusetts Institute of Technology, London College, and Harvard University, have invested in and established research institutes keen on biologically inspired engineering [6]. Due to the positive outcomes, researchers are interested in studying microstrip antennas with models inspired by leaves or flowers (leaf-shaped antennas). The leaves exhibit fractal-like characteristics, such as a decrease in overall dimensions as the periphery increases. The leaves also contain a light-harvesting reaction centre complex, which is made up of an antenna array designed to work in the visible light spectrum (400–700 nm) and look like satellite dishes. [6].

Three distinct configurations of patch array antennas are investigated in this article to determine their radiation patterns at 28 GHz for 5G applications with varying orientation and excitation phases. Each antenna is supplied by an inset feed line [7]. The authors in this research work propose a microstrip patch antenna operating at 23.9 GHz, 35.5 GHz, and 70.9 GHz and analysed it for its various characteristics. The obtained results are verified to suit the requirements and are discussed for 5G and space applications [8]. Using the Wilkinson power divider concept, an innovative two-element patch antenna array for 5G and IoT communications applications with 4 distinct frequency bands spanning from 30 GHz to 50 GHz has been presented [9]. For future 4G/5G multiple-input multiple-output (MIMO) applications, a hybrid antenna is recommended. It consists of two antenna modules: a covering for the 4G antenna module and a 5G antenna module. 4G based antenna module comprises a two-antenna array capable of covering the LTE2300/2500, UMTS2100, and GSM850/900/1800/1900, operating bands, while the 5G based antenna module comprises an eight-antenna array functional in the 3.5 GHz frequency range and accomplished of covering the C-band (3400-3600 MHz) [10]. The authors propose a microstrip patch antenna

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array composed of graphene material mounted on three distinct substrates operating in the frequency range 13 GHz-17 GHz, which is suitable for 5G communication [11].

This research work involves two studies firstly, designing, analyzing and comparing the performance microstrip patch antenna array of radiating elements 2 to 3 respectively placed circularly and secondly, analyzing and comparing the performance microstrip patch antenna array by loading designed metamaterial-based complementary and non-complementary split-ring resonators on each radiating element. The substrate proposed is RT Duroid 5880. The width and length of the proposed microstrip feed line are 0.5mm and 2.0 mm respectively. The approximate size of each radiating element is 5mm× 4mm.

According to the experimental results, the microstrip patch antenna performance feed with a proximity-coupled feeding approach may increase the bandwidth by at least 13 % [12]. The word mobile HEALTH refers to the combination of communications technology, smart sensing, and medical technologies for the aim of delivering healthcare [13]. In other words, it is used to refer to the practice of e-Health aided by 5G enabled smart electronics devices [14]. Furthermore, SARS-COVID 19 has hastened health professionals' development of telehealth services, and Mobile health technology equipped with 5G is likely to revolutionise the way healthcare is provided. 5G wearables, for example, that constantly monitor sensory processing devices [14]. Therefore, the authors of this paper have proposed a detailed comparative study in the performance of microstrip patch antenna with and without split-ring resonators-based metamaterial.

II. DESIGN AND ANALYSIS OF MICROSTRIP PATCH ANTENNA ARRAY WITHOUT SPLIT-RING RESONATORS

A. *Design using 2 radiating elements*

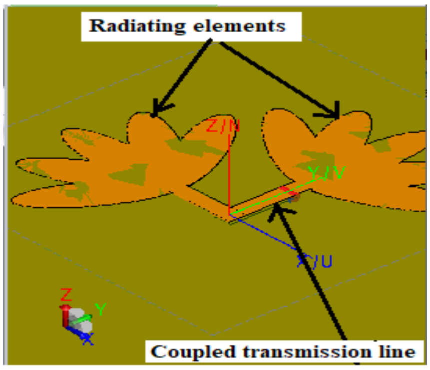

Fig. 1. 3D geometrical view

The top view of the proposed design of a microstrip antenna array with two radiating elements using the proximity coupled feeding technique is depicted in Figure 1. This method of feeding is also known as indirect feeding. The feeding line is electromagnetically coupled into the patch but does not touch the patch's edge, thereby maintaining a gap of half the substrate's thickness. Capacitance is provided by the gap that is maintained.

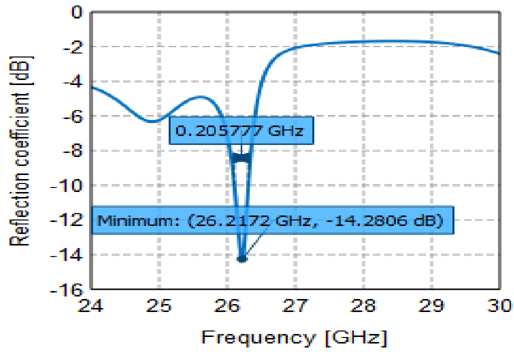

Fig. 2. Return loss and bandwidth. Impedance matching characteristic

The return loss and bandwidth characteristics of a microstrip patch antenna array with two radiating elements are depicted in Figure 2. The gain and half-power beamwidth variations at various theta and phi angles are shown in Figure 3, while the total radiated power is shown in Figure 4. The results of the proposed microstrip patch antenna array with two radiating elements is shown in Table II. The gain is greatest at theta=0 degrees and lowest at theta=45 degrees. At phi=30 degrees, the beamwidth is narrower; at phi=0 degrees, it is wider.

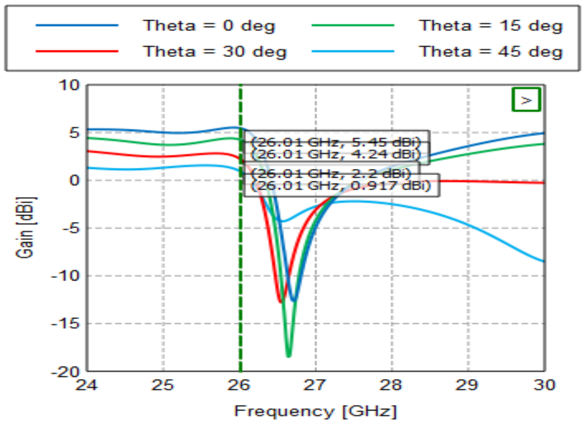

Fig. 3. Gain. Radiation capacity characteristic at various angles of theta

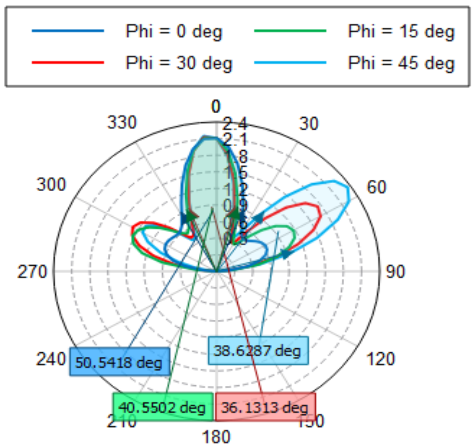

Fig. 4. Half-power Beamwidth. Angular coverage of radiation of the main lobe at various angles of phi

TABLE I
FINDINGS OF PROPOSED MICROSTRIP PATCH ANTENNA ARRAY OF 2 RADIATING ELEMENTS

Frequency (GHz) (24 GHz-30 GHz)	Return Loss (dB)	Bandwidth (MHz)	Gain (dBi)	Half-power beamwidth (deg)	Radiated power (mW)
26	-14.26	205	5.45 (theta=0 deg) 4.24 (theta=15 deg) 2.20 (theta=30 deg) 0.97 theta=45 deg)	50.54 (phi=0 deg) 40.55 (phi=15 deg) 36.13 (phi=30 deg) 38.62 (phi=45 deg)	572

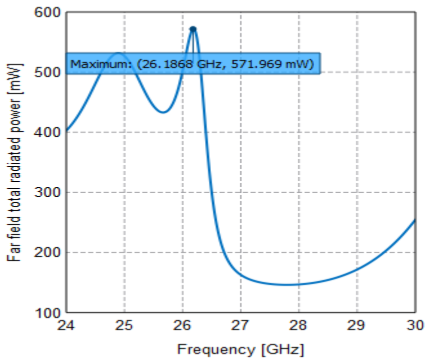

Fig. 5. Radiated power. Signal strength directional capability characteristic

B. *Design using 3 radiating elements*

This design results in an increase in return loss and bandwidth. The top view of the proposed design of a microstrip antenna array with three radiating elements is shown in Figure 6. Figure 8 illustrates the improved return loss and bandwidth characteristics of a three-element microstrip patch antenna array over a two-element array. Figure 7 illustrates the variations in gain at various theta angles, while figures 10 and 11 illustrate the variations in half-power beamwidth at various phi angles. The increased total radiated power is depicted in Figure 9.

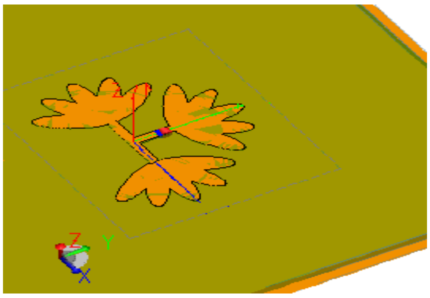

Fig. 6. 3D geometrical view

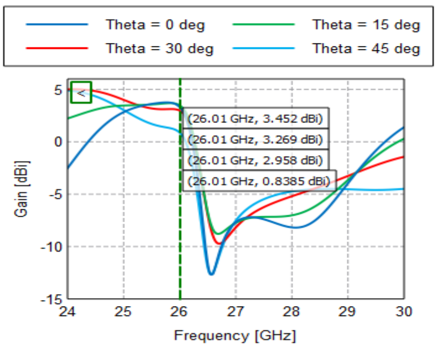

Fig. 7. Gain. Radiation capacity characteristic at various angles of theta in an isotropic direction

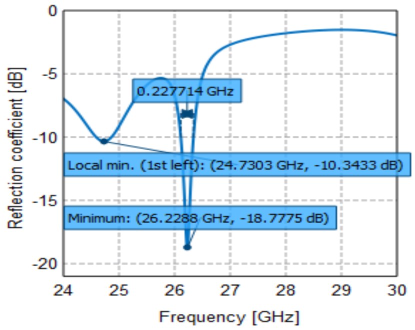

Fig. 8. Return loss and bandwidth. Impedance matching characteristic

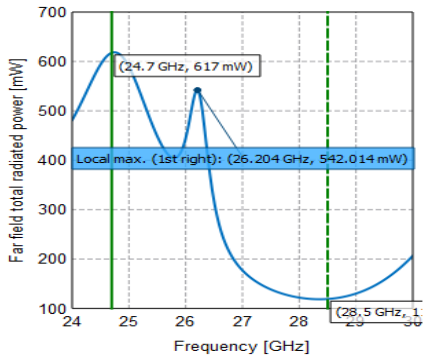

Fig. 9. Radiated power. Signal strength or directional capability

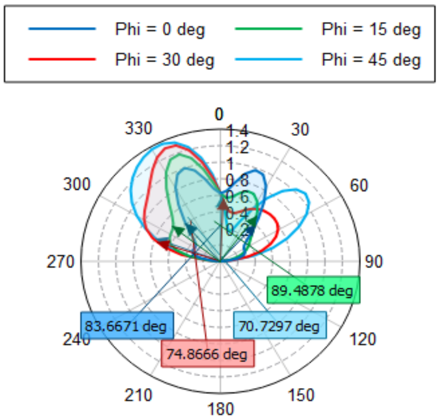

Fig. 10. Half-power Beamwidth at 26 GHz. Angular coverage area

Table II illustrates the proposed microstrip patch antenna array with three radiating elements. Dual frequency band operation is achieved, with excellent performance in both bands. At 26 GHz, the gain is greatest at theta=0 degrees and lowest at theta=45 degrees; however, the gain is greatest at theta=30 degrees at 24.7 GHz. At 26 GHz, the beamwidth is narrower, while at 24.7 GHz, it is wider.

TABLE II
FINDINGS OF MICROSTRIP PATCH ANTENNA ARRAY WITH THREE RADIATING ELEMENTS

Frequency (GHz) (24 GHz-30 GHz)	Return Loss (dB)	Bandwidth (MHz)	Gain (dBi)	Half-power beamwidth (deg)	Radiated power (mW)
24.7	-10.34	263	1.78 (theta=0 deg)	50.54 (phi=0 deg)	617
			3.31 (theta=15 deg)	40.55 (phi=15 deg)	
			4.58 (theta=30 deg)	36.13 (phi=30 deg)	
			3.9 (theta=45 deg)	38.62 (phi=45 deg)	542
26	-18.77	227	3.45 (theta=0 deg)	83.6 (phi=0 deg)	
			3.3 (theta=15 deg)	89.48 (phi=15 deg)	
			3.0 theta=30 deg)	74.86 (phi=30 deg)	

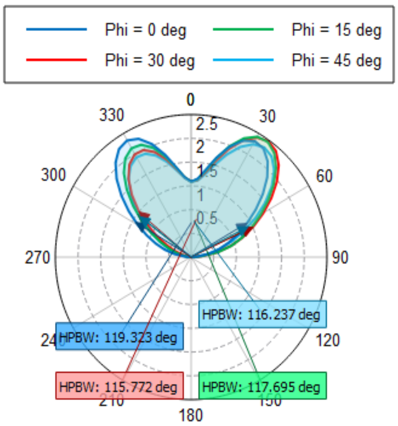

Fig. 11. Half-power Beamwidth at 24.7 GHz. Angular coverage of radiation of the main lobe at various angles of phi

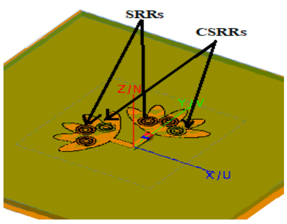

Fig. 12. 3D geometrical view with SRRs

III. DESIGN AND ANALYSIS OF A TWO-ELEMENT MICROSTRIP PATCH ANTENNA ARRAY WITH SPLIT-RING RESONATORS

A. Design using 2 radiating elements

Figure 12 depicts the top view of the proposed design of microstrip antenna array of 2 radiating elements loaded with complementary and non-complementary split-ring resonators

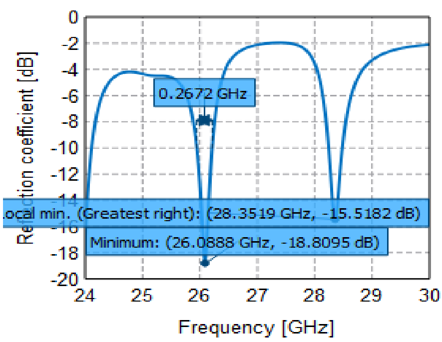

Fig. 13. Return loss and bandwidth of 2 radiating elements with SRR

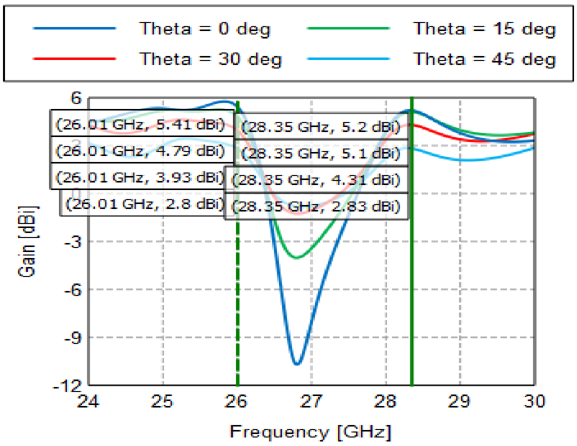

Fig. 14. Gain of 2 radiating elements with SRR

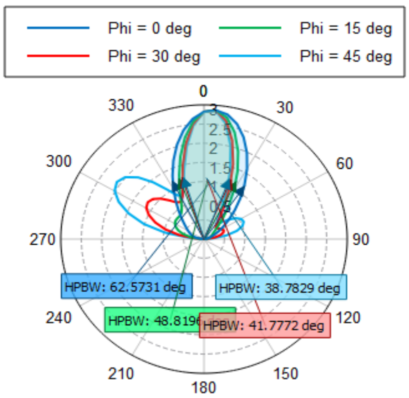

Fig. 15. Half-power Beamwidth at 26 GHz of 2 radiating elements

The improved return loss and bandwidth achieved with loaded Split-ring resonators are depicted in Figure 13. Moreover, figure 14 illustrates the variations in gain at various theta angles, while figures 15 and 16 illustrate the variations in half-power beamwidth at various phi angles. The increased total radiated power is depicted in Figure 17. The results of a proposed microstrip patch antenna array with two radiating elements loaded with metamaterial-based split-ring resonators are shown in Table III. The performance of a two-element microstrip patch antenna array with split-ring resonators is improved as compared to a two-element array without split-ring resonators. Here the gain is maximum at theta=0 deg and minimum at theta=45 deg under both the frequency bands. The beamwidth is narrower at 26 GHz and wider at 28.3 GHz.

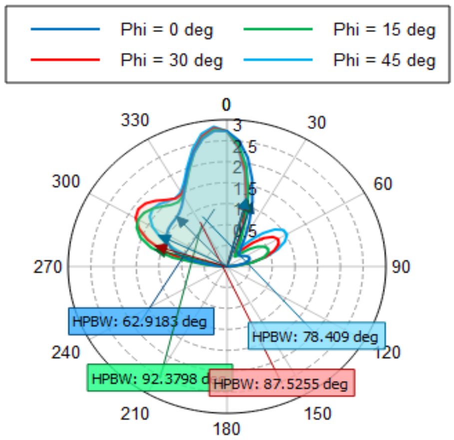

Fig. 16. . Half-power Beamwidth at 28.3 GHz of 2 radiating elements

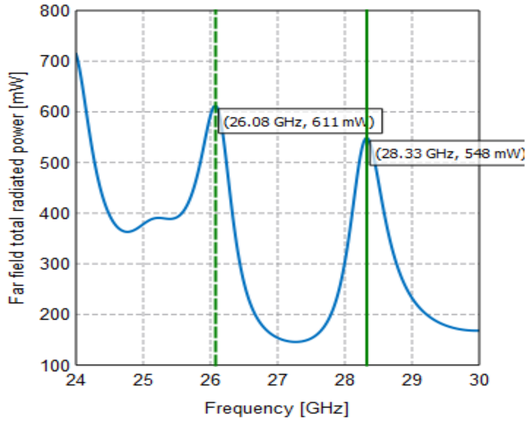

Fig. 17. Radiated power for 2 radiating elements with SRR

TABLE III
FINDINGS OF PROPOSED MICROSTRIP PATCH ANTENNA ARRAY OF 2 RADIATING ELEMENTS WITH SPLIT-RING RESONATORS

Frequency (GHz) (24 GHz-30 GHz)	Return Loss (dB)	Bandwidth (MHz)	Gain (dBi)	Half-power beamwidth (deg)	Radiated power (mW)
26	-18.80	267	5.4 (theta=0 deg)	62.9 (phi=0 deg)	617
			4.8 (theta=15 deg)	92.8 (phi=15 deg)	
			3.9 (theta=30 deg)	87.5 (phi=30 deg)	
			2.8 (theta=45 deg)	78.4 (phi=45 deg)	
28.3	-15.55	274	5.2 (theta=0 deg)	62.6 (phi=0 deg)	542
			5.1 (theta=15 deg)	48.9 (phi=15 deg)	
			4.3 theta=30 deg)	41.8 (phi=30 deg)	
			2.8 (theta= 45 deg)	38.8 (phi=45 deg)	

B. Design using 3 radiating elements

The top view of the proposed design of a three-element microstrip antenna array loaded with complementary and non-complementary metamaterial-based split-ring resonators is depicted in Figure 6.

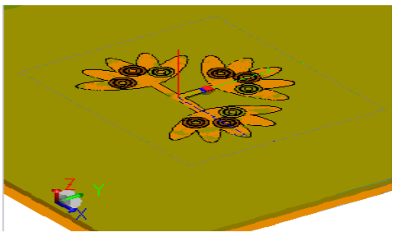

Fig. 18. Fig. 12. 3D geometrical view with SRRs

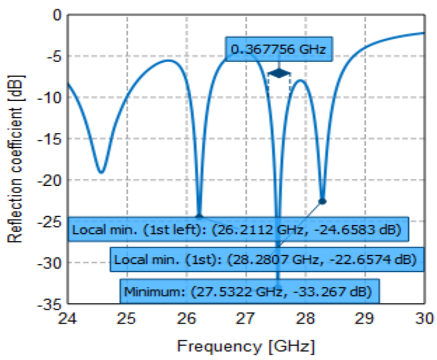

Fig. 19. Return loss and bandwidth for 3 radiating elements with SRR

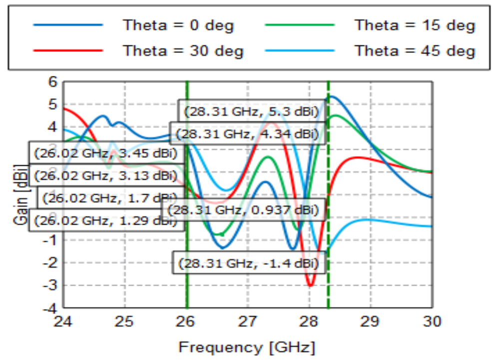

Fig. 20. Gain for 3 radiating elements with SRR

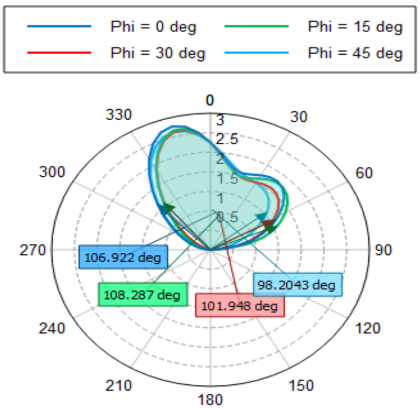

Fig. 21. Half-power Beamwidth at 24.5 GHz for 3 radiating elements

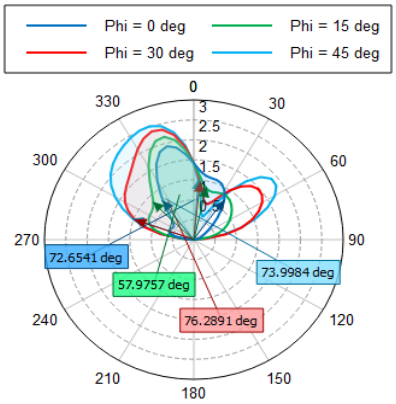

Fig.22. Half-power Beamwidth at 26 GHz GHz for 3 radiating elements

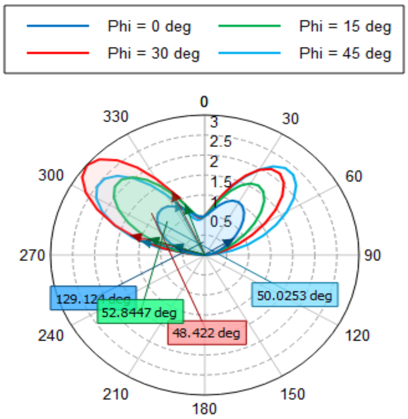

Fig. 23. Half-power Beamwidth at 27.5 GHz for 3 radiating elements

The additional improvement in return loss and bandwidth achieved with loaded Split-ring resonators is depicted in Figure 19. Moreover, figure 20 illustrates the variations in gain at various theta angles, while figures 21, 22, 23, and 24 illustrate the variations in half-power beamwidth at various phi angles resonating at 24.5 GHz, 26 GHz, 27.5 GHz, and 28.3 GHz frequencies, respectively. The results of a proposed microstrip patch antenna array with three radiating elements loaded with metamaterial-based split-ring resonators are shown in Table IV. Also, the proposed microstrip array antenna with three radiating elements loaded with split-ring resonators resonates at a quadruple frequency band with improved results across the entire resonating frequency range. Thus, it will be extremely reliable and efficient for various mobile health technologies enabled by 5G in the frequency range of 24 GHz to 30 GHz.

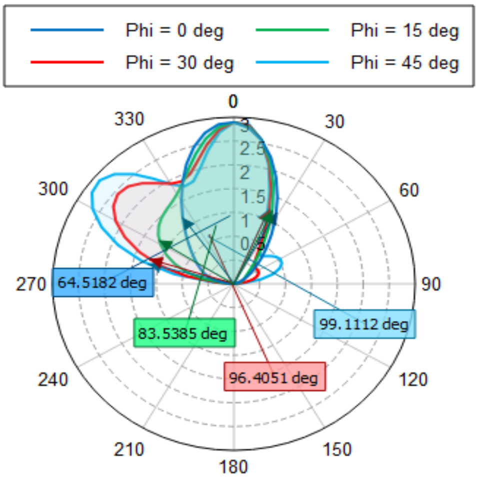

Fig. 24. Half-power Beamwidth at 28.3 GHz for 3 radiating elements

TABLE IV
FINDINGS OF PROPOSED MICROSTRIP PATCH ANTENNA ARRAY WITH THREE RADIATING ELEMENTS LOADED WITH SPLIT-RING RESONATORS

Frequency (GHz) (24 GHz-30 GHz)	Return Loss (dB)	Bandwidth (MHz)	Gain (dBi)	Half-power beamwidth (deg)	Radiated power (mW)
24.5	-18.80	847	4.2 (theta=0 deg) 3.3 (theta=15 deg) 3.5 (theta=30 deg) 2.9 (theta=45 deg)	106.9 (phi=0 deg) 108.9 (phi=15 deg) 101.9(phi=30 deg) 98.2 (phi=45 deg)	722
26	-24.66	322	3.1 (theta=0 deg) 1.71 (theta=15 deg) 1.3 theta=30 deg)	72.6 (phi=0 deg) 57.9 (phi=15 deg) 76.3 (phi=30 deg)	607
27.5	-33.26	368	1.4 (theta=0 deg) 1.9 (theta=15 deg) 3.8 theta=30 deg)	129.1 (phi=0 deg) 52.8 (phi=15 deg) 48.4 (phi=30 deg)	563
28.3	-22.6	401	5.3 (theta=0 deg) 4.3 (theta=15 deg) 0.8 (theta=30 deg)	64.5 (phi=0 deg) 83.5 (phi=15 deg) 96.4 (phi=30 deg)	535

CONCLUSION

A research study on a bio-inspired shape microstrip patch array antenna with two to three radiating elements that are suitable for various 5G enabled mobile health systems is conducted successfully using FEKO EM software. Moreover, the same was used to compare for better performance by loading metamaterial-based split-ring resonators on a radiating element (both complementary and non-complementary split-ring resonators). The return loss, bandwidth, beamwidth, and radiated power all increased when three radiating elements were loaded with metamaterial-based split-ring resonators, but the gain remained almost uniform between 3dBi to 5.5dBi throughout the research study. The multiple frequency bands were also obtained using three radiating elements loaded with split-ring resonators, making this proposed antenna with three radiating elements well suited for 5G-based mobile health technology. However, a disadvantage may be a lack of isolation between radiating elements, which can be overcome by employing electromagnetic bandgap structures. Further research can be conducted using a super-substrate to increase the bandwidth, gain, and radiation efficiency.

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