

SAR Reduction Using Array of SRR MTM Based Antenna for 5G Applications

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Abstract

Electromagnetic radiation is becoming a major concern worldwide as the use of portable communication devices increases. So, it is essential to utilize safe communication devices. A compact wide-band antenna of size $12 \times 8.5 \times 0.33$ mm³ and a metamaterial array contribution for Specific Absorption Rate (SAR) reduction are proposed in this paper. In this paper, an array structure of split ring resonators, SRR, which have a negative refractive index, is attached to the proposed MSPA to achieve SAR reduction by 89.88% in the 28 GHz range. Furthermore, the proposed antenna maintains other performance characteristics like high gain (7.7 dBi), radiation efficiency (82%), wide bandwidth (0.8 GHz), and fewer losses (-23 dB). However, this consequential antenna has been built on a low-loss Rogers RT 5880 substrate and a full ground-plane structure using CST microwave software.

Keywords

Human Body, Metamaterial MTM, Microstrip Patch Antenna MSPA, Specific Absorption Rate SAR.

I. INTRODUCTION

The core of any communication equipment is the antenna, which is preferred to be small, straightforward, and capable of supporting many operating bands. The ideal solution to address the aforementioned needs is always Microstrip Patch Antenna MSPA [1].

Since the use of portable communication devices is growing annually, electromagnetic (EM) radiation is becoming a serious problem globally [2]. In the 20th century, there was an increase in radiation emission, and this has several significant short and long-term effects on human health. The World Health Organization (WHO) examines how electromagnetic radiation affects several human health conditions, including headache, brain tumor, sleep difficulties, irregular blood pressure, and heart problems [3]. Radio waves are typically emitted by wireless mobile phones and part of those waves is absorbed by human heads.

SAR is an expression that used to describe the electro-

magnetic absorption in the entire human body of W/kg. IEEE C95.1:2005 and International Commission on Non-Ionizing Radiation Protection (ICNIRP) specified the maximum allowable electromagnetic absorption as 1.6 W/kg per 1 g of tissue in the form of a cube, and 2.0 W/kg per any 10 g of tissue [4].

Hence, in this paper, a negative refractive index of split ring resonators, which are arranged in an array structure attached to the proposed MSPA, has effectively contributed to achieving admirable SAR reduction in the 5G frequency range. Furthermore, the proposed antenna maintains other performance characteristics like high gain, radiation efficiency, wide bandwidth, and less losses. Because of this, the proposed antenna is a reliable option for designing 5G applications.

This paper has been organized into the following sections: Section II will discuss the materials and methods, including the design of the proposed MSPA and SRR unit cell structures, SAR reduction analysis, and the technique of utilizing an array of proposed SRR's to achieve SAR reduction. Section



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III will state the results of applying the proposed SRR-MTM to MSPA, the calculation of the SAR value of the resultant antenna, and the comparison between using MTM and without MTM. Finally, the conclusion and references are listed at the end of the paper.

II. LITERATURE REVIEW

In the last several years, a lot of research efforts have been made on the subject of handheld SAR reduction [5]. To forecast the SAR of an antenna, numerous detailed studies have been carried out in the past, for example, in [6] and [7]. These researches placed greater emphasis on determining the SAR than on reducing it. Additionally, SAR estimation is often done as a post-processing step after the antenna has been developed rather than making SAR minimization as a design objective [8], [9].

In [10], a metamaterial split ring resonator in the ground plane is used to achieve a multiband antenna for wireless and portable applications. It has greatly increased the multi-band antenna's realized gain and 10 dB impedance bandwidths. Applications for the proposed antenna include WLAN, 5G, RADAR, and ISM bands. An artificial magnetic conductor (AMC) is one type of MTM that is used in the low profile planar inverted-F antenna (PIFA), which has low SAR and high gain.

This antenna operates at 5.75 GHz, a resonance frequency that is appropriate for sub-6 5G, satellite uplink C-band, and wireless local area network (WLAN) applications [11]. In [12], a slotted circular MTM loaded multiband antenna with a SAR reduction has been reported for wireless applications. The ground plane was a laying T-shaped slot and an etched rectangular single complementary split-ring resonator (CSRR) in order to maximize the front lobe and reduce SAR.

The impact of metamaterial MTM in antenna design like meta-surface is absorbing or in another term restricting the back radiation of the antenna [13]. Hence, controlling SAR value towards human body will be achieved. The assistance of MTM significantly eliminates the SAR without affecting other antenna performance metrics [14]. The calculation of reduction percent can be found from the difference between original and new SAR values.

Furthermore, using a ferrite substrate as a method of SAR minimization approach considerably reduces both the antenna gain and the SAR [15]. On the other hand, using an electromagnetic band gap EBG can extremely contribute for SAR reduction in ISM bands [16, 17]. Nano-material based antennas, like those made of graphene, multi-walled carbon nano-tubes, and single walled carbon nano-tubes, are taking the role of copper-based antennas. By adopting a nano-material based antenna, SAR is reduced by up to 66% when using single walled carbon nano-tubes [18].

The Finite Integration Technique (FIT) in Computer Simulation Technology (CST) was used to numerically simulate the electromagnetic characteristics of the proposed construction.

III. MATERIALS AND METHODS

A. Proposed MSPA and SRR unit cell structure

The MSPA comprises a rectangular patch of copper, feed line, substrate layer of Rogers RT5880 (with relative permittivity=2.2, and loss tangent=0.0009), and waveguide port for excitation as illustrated in Fig. 1. The dimensions of MSPA are illustrated in Table I. These dimensions are obtained from the sequential formulas of microstrip patch antenna design [19], and they have software optimized to achieve impedance matching between the feed line with characteristic impedance (50 ohm) [20]. The MSPA operates at 28 GHz with -21 dB return loss, and SAR value calculated on human tissues is 1.68 W/kg as shown in Fig. 2 and Fig. 3 respectively. Metamaterial MTM is an artificial material that gains its properties from its structure, so it is not available in nature [21]. The split ring resonator SRR has been used as MTM unit cell structure. The SRR structure published in [22], which is shown in Fig. 4, is dependent on this paper. The substrate used in SRR design is also Rogers RT5880. The real part of permittivity is negative (-0.31) at 28 GHz as shown in Fig. 5. The real part of permeability is negative also (-0.33) at 28 GHz as in Fig. 6. Hence, Fig. 5 and Fig. 6 present the properties of the used SRR structure which is clearly behave double negative metamaterial DNG-MTM. Split gaps are used in the design as a capacitive effect known as C. Meanwhile, the inductive effect is given as the value L, making it evident greatly dependent on the strip line in the design structure [23].

B. Specific Absorption Rate SAR:

SAR is a measurement of the amount of electromagnetic radiation that a mass of human tissue will absorb. An antenna's SAR over a unit volume of human tissue can be expressed mathematically as,

$$SAR = \sigma E / \rho \quad (1)$$

where σ denotes the conductivity of the human tissue, E denotes the electric field resulting from antenna radiation, and ρ denotes the density of the human body tissue [24]. As a result, it is clear that for a given amount of electromagnetic radiation, this absorption becomes a characteristic of the tissue in consideration. Nevertheless, the decreased value must be lower than FCC (Federal Communication Commission) permitted limit of the SAR. To attain that, firstly, a common technique is used to minimize the antenna's input power [15,

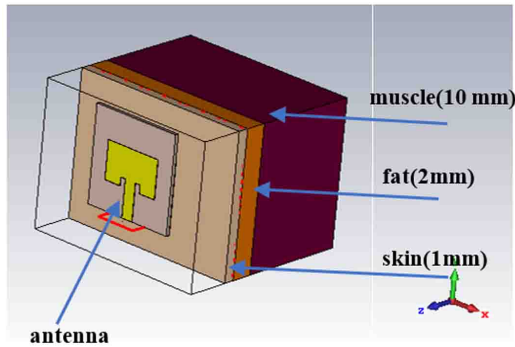
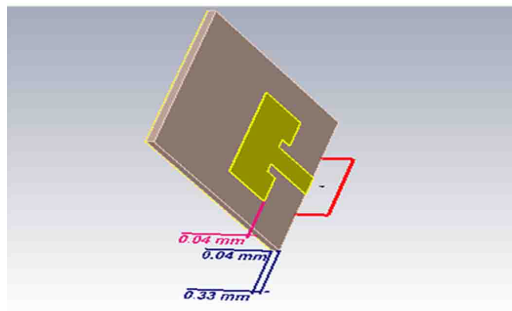
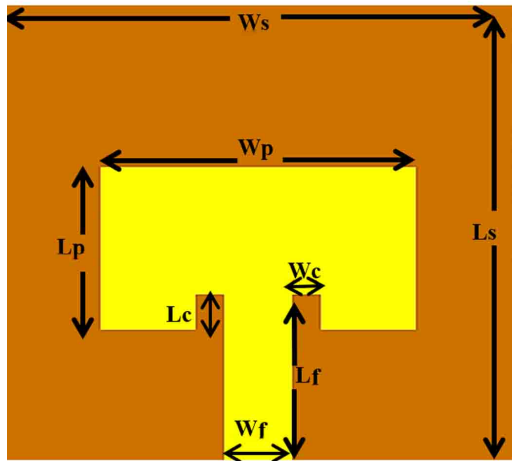


Fig. 1. Geometrical representation of MSPA. (a) Front view. (b) Side view. (c) Proposed conventional MSPA on human body tissues (skin, fat, muscle)

TABLE I. SUMMERY OF MSPA DIMENSIONS

Parameter	Description	Calculated Values (mm)	Optimized Values (mm)
L_p	Length of patch	3.40435	3.36
W_p	Width of patch	4.23519	5.18
L_s	Length of substrate	5.635	10
W_s	Width of substrate	6.3058	8.5
h	Thickness of substrate	0.3451	0.33
t	Thickness of patch	0.0345	0.04
W_c	Width of cut	0.41	0.5
L_c	Depth of cut	1.259	0.74
W_f	Width of feeder	0.8219	1.1
L_f	Length of feeder	1.8059	2.7

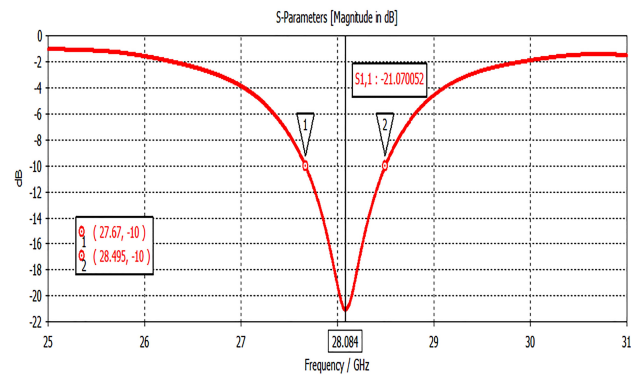


Fig. 2. Return loss S11 at input power=15dBm (antenna with human body)

25]. According to IEEE C95, the SAR limit for any 10 g of human tissues is 2 W/kg. The SAR limit for 1 g of human tissues has been set at 1.6 W/kg by the FCC [26]. Due to all of the preceding, the decrease in SAR is an indicator of the decrease in the body's absorption of electromagnetic radiation, and thus, the potential health risks to humans will be reduced [14]. The SAR value can be calculated using CST as a post-processing step after the antenna has been designed [27].

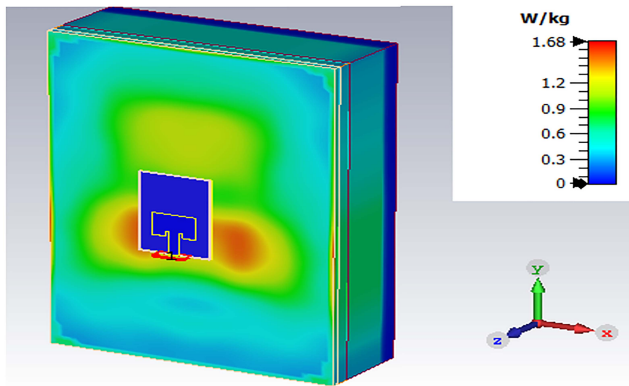


Fig. 3. SAR simulation per 1g of tissue when input power=15dBm

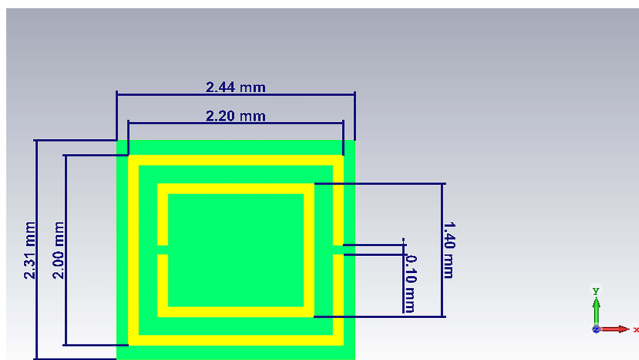


Fig. 4. SRR as MTM unit cell

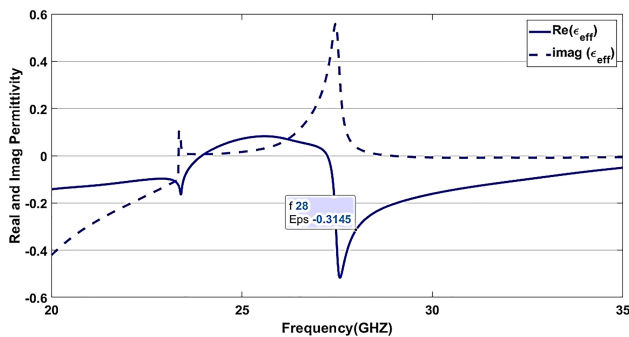


Fig. 5. Permittivity of proposed MTM unit cell

C. SRR array technique

In this section, an extended demonstration will be presented to give a good idea of the collaboration of MTM with conventional MSPA. Utilizing array of SRR elements instead of one element will enhance the gain, directivity, and radiation efficiency. Furthermore, the array can reduce the SAR value more than one SRR element can do. Fig. 7 shows an array of

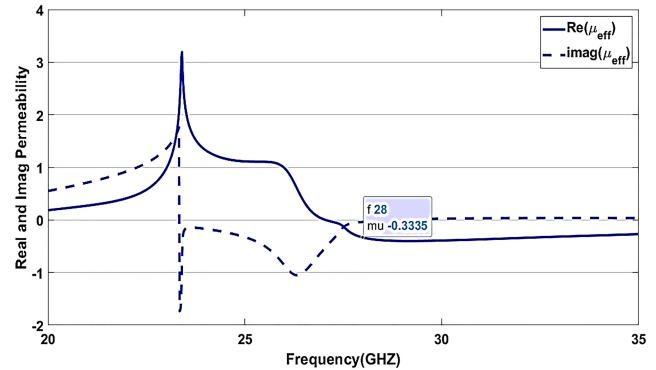


Fig. 6. Permeability of proposed MTM unit cell

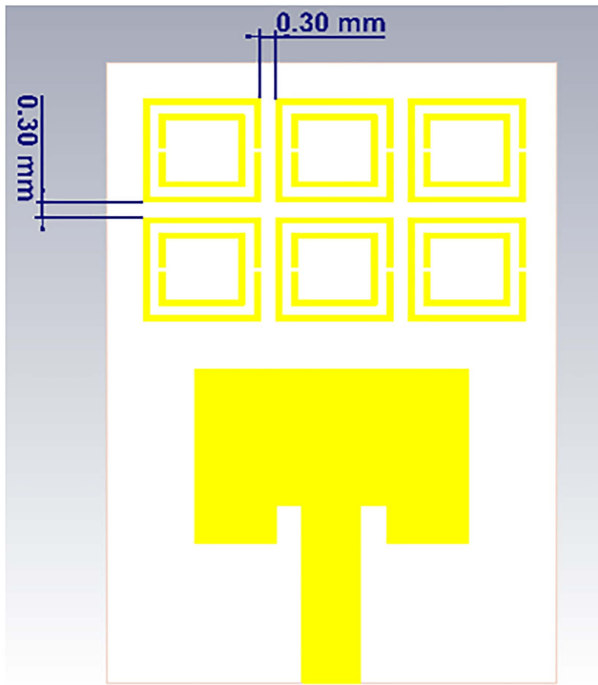
SRR elements arranged in 2 rows and 3 columns, along with conventional MSPA, which was designed and analyzed earlier in this paper. This SRR array located up to the MSPA and with the same material and thickness. The single element has exactly the same dimensions and properties of the MTM unit cell which analyzed before. It has taken 0.3 mm to separate two SRR elements. The periodicity of the elements in one row (the distance between centers of 2 SRR elements) is 2.5 mm, but the periodicity in one column is 2.3 mm.

IV. RESULTS AND DISCUSSION

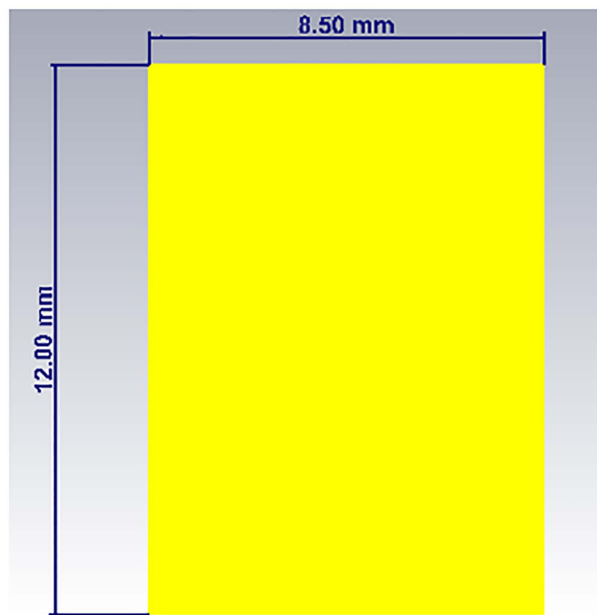
The gain of the antenna is impacted by SRR insertion, mostly at the resonant frequency. Higher resonating modes increase gain because the patch dimensions increase relative to the corresponding antenna wavelength at these higher frequencies. This phenomenon explains the improvement in peak gain. Additionally, it is noted that resonant wireless communication frequency bands show improved gain.

A. SRR based MSPA with human body:

In this section we will apply the proposed antenna into the human body tissue, to evaluate the SAR value when collaborating MTM unit cells as array in proposed antenna. After designing the proposed antenna based SRR MTM, the simulation can be started using CST microwave studio with time domain solver. The mesh cell used is 18 cells/wavelength and total number of cells is 117,766 cells to get accurate simulation with acceptable time response. Fig. 8 shows the proposed antenna based on applying SRR-MTM on the human body tissue. The tissue layers consist of skin (1mm), fat (2mm), and muscle (10 mm). The boundary conditions illustrated in Fig. 9. The boundary conditions are open at front and back sides, and periodic at other sides of human body tissues. The radiation pattern of SRR_MTM based antenna is shown in Fig. 10, illustrating the gain (7.7 dBi) at operating frequency (28GHz) which is greater than the gain of the antenna in free



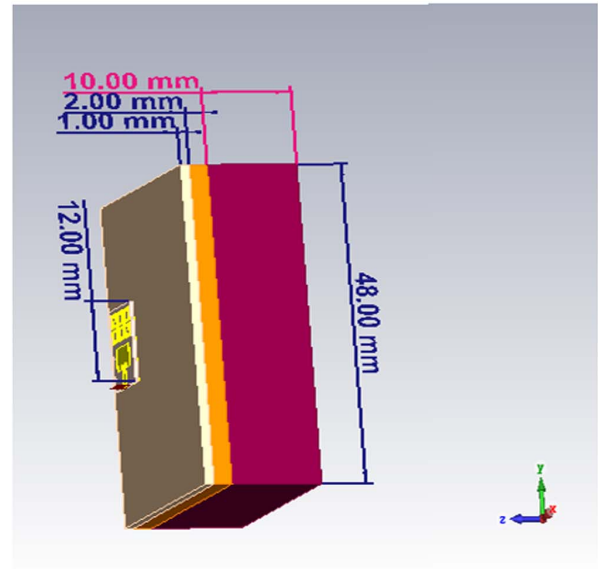
(a)



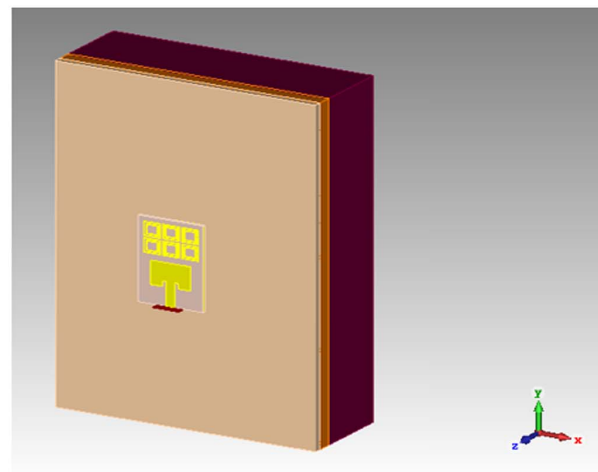
(b)

Fig. 7. Geometrical representation of SRR array technique with MSPA. (a) front view (b) back view

space (7.18dBi). The directivity is (8.44 dBi) as shown in Fig. 11.



(a)



(b)

Fig. 8. SRR array technique with MSPA applied on human body (a) illustrating dimensions (b) structure as in CST software

The reflection coefficient S_{11} resulted after applying the proposed antenna into the human body tissues is illustrated in Fig. 12. The minimum value of S_{11} at 28.03 GHz is -23.06 dB, and the -10 dB bandwidth, also called the impedance bandwidth, is 0.8 GHz centered on 28 GHz. The radiation efficacy at resonant frequency is 82%, and the voltage standing wave ratio (VSWR) is 1.15, which is very close to the

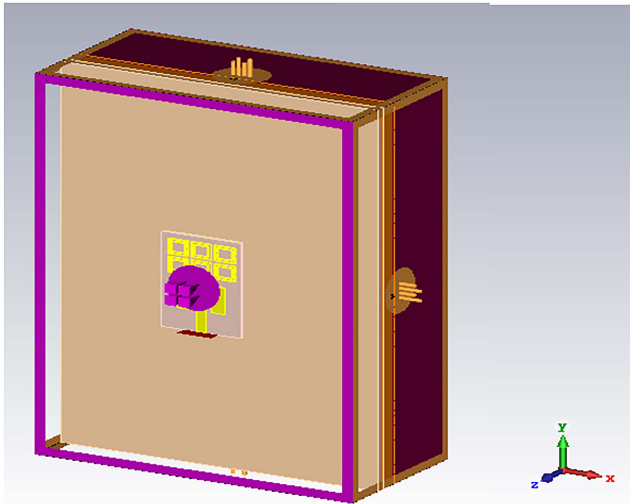


Fig. 9. Boundary conditions of SRR array technique with MSPA

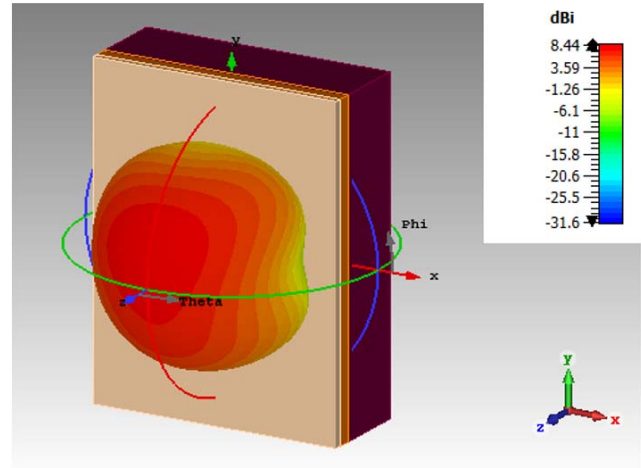


Fig. 11. Radiation Pattern illustrating the Directivity

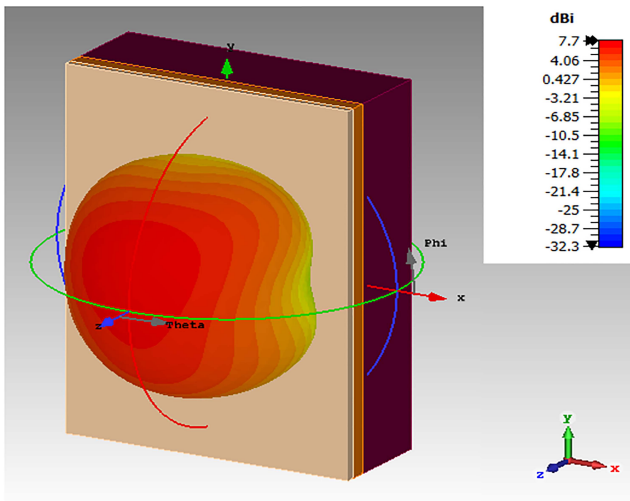


Fig. 10. Radiation Pattern illustrating the Gain

ideal unity value. The real and imaginary parts of impedance are 43.4 ohm and 0.4 ohm, respectively, as shown in Fig. 13. These values provide a good match to the characteristic impedance of the transmission line. The power flow, surface current (182 A/m), and power loss density (1.4 MW/m³) are illustrated in Fig. 14.

B. SAR calculation when using SRR based MSPA:

Now we can calculate the SAR value in the same condition of calculation SAR without MTM. The input power will be 15 dBm = 0.0316 W, to match the FCC standard of input power for 5G antennas. The input power should not exceed the

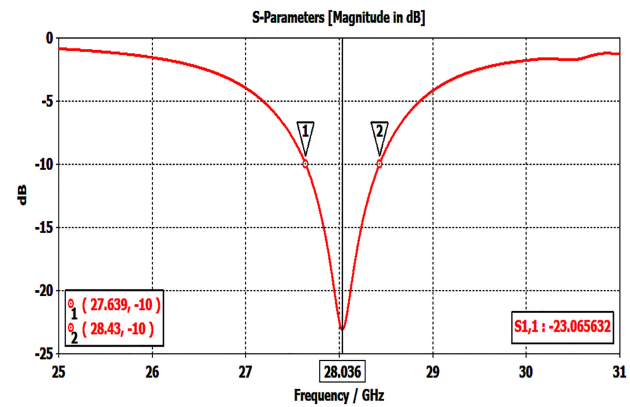


Fig. 12. Reflection Coefficient S11 of the proposed antenna applied on human body

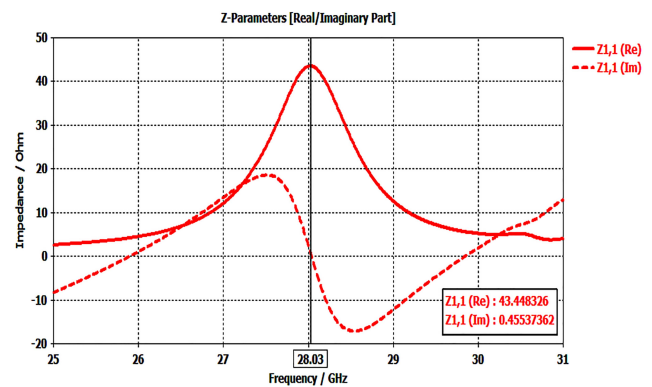
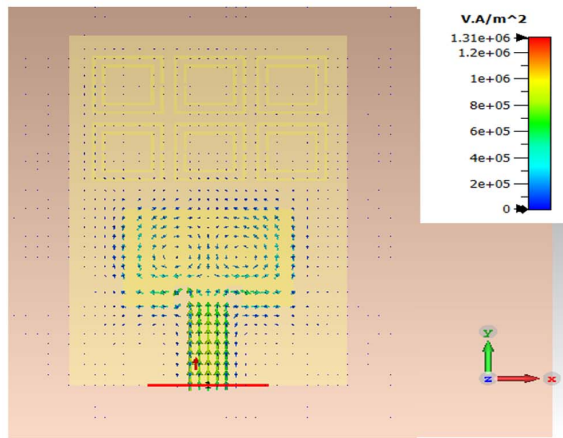
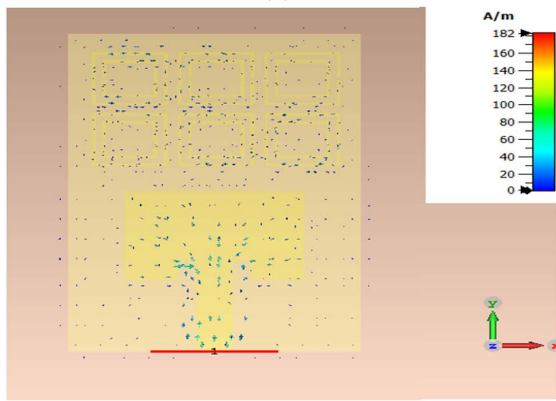


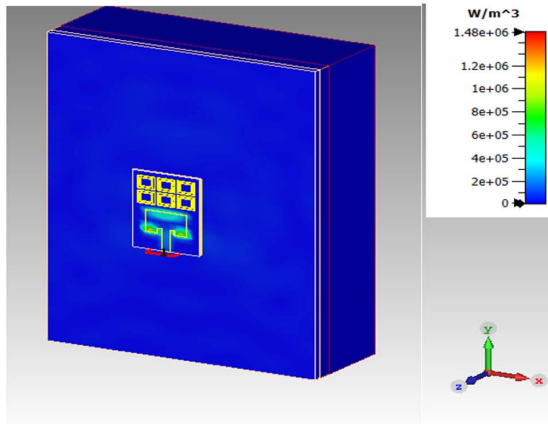
Fig. 13. Impedance (real and imaginary parts) of the proposed antenna applied on human body



(a)



(b)



(c)

Fig. 14. The proposed antenna in terms of (a) Power flow, (b) surface current, and (c) power loss density

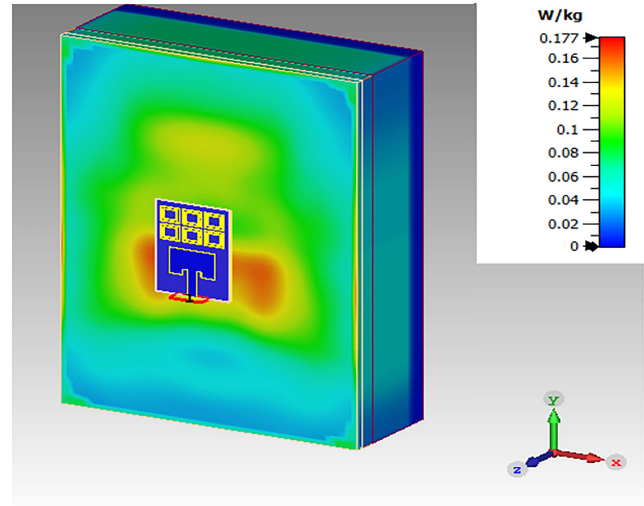


Fig. 15. SAR calculations at resonant frequency of the proposed antenna per 1g of human body

limit of incident power density which is 100mW/m^2 . The full ground plane is 12 mm length.

This section presents the very expensive result of maximum SAR value when adapting the MTM in designing antenna. Fig. 15 shows the maximum value of SAR about 0.177 W/kg which has a significant improvement compared to that SAR value of MSPA without MTM. As a result, this SAR value direct the spot to importance of adapting the proposed SRR-MTM unit cells as array configuration into the conventional MSPA.

C. Comparison between using MTM and without MTM:

Table II briefs the results of both antennas applied on human body; conventional MSPA and MSPA based on SRR MTM array.

Using an array of 6 elements of SRR MTM unit cells as 2×3 array dimension have decreased the SAR value from 1.68 W/kg in conventional MSPA into 0.177 W/kg . However, the gain and directivity were increased without compromising the radiation pattern or reflection losses when an array of SRR units rather than MSPA alone was used. This is illustrated in the Table II. The suggested antenna is appropriate for 5G networks and beyond due to the rapid decline in SAR reduction, and absolutely safe to human body when use it in portable or wearable devices. Table III illustrates the comparison of the proposed structure (MSPA+SRR's) characteristics in term of SAR reduction technique used, gain, antenna size, and the percentage of SAR reduction with those reported in recent antenna literature. For example, the proposed design is better than the design in [27] in terms of size (ours is compact and smaller), even though there is no big difference in SAR

TABLE II.
COMPARISON OF PROPOSED MSPA ALONE AND MSPA
WITH SRR-MTM ARRAY

Parameter	f_r (GHz)	S_{11} (dB)	Radiation efficiency	Gain (dBi)	Directivity (dBi)	Matching ($Z_{real,1}$ imag)	B.W (GHz)	SAR (W/kg)
MSPA alone	28.08	-21	83%	7.2	8.1	41 + 0.9	0.82	1.68
MSPA with SRR-MTM	28.03	-23	82%	7.7	8.4	43 + 0.4	0.8	0.177

reduction (ours is 89.8% and in [27] is 93%). Besides, the gain was not specified in [27], and the operating frequency is 3.25 GHz, which is less than 28 GHz.

V. CONCLUSION

Novel technique has been investigated to maintain the SAR values below the current level of International Standards. This technique can meet the demand for producing safe and effective antenna for mobile and wearable devices in 5G and beyond. The radiating structure consists of rectangular split ring resonators SRR's, which had confirmed MTM property existence, with conventional MSPA. Radiation properties of the proposed SAR reduction technique are achieved with satisfied impedance matching at the resonant frequency. The radiation efficiency, gain, losses, B.W, and compact size are reliable over the operating band making the suggested antenna design a superior option to current designs for wireless applications. The SAR has reduced by approximately 89.88% by adopting the SRR-MTM in 28 GHz antenna. Despite its advanced design, this proposed antenna is not suitable for multiband applications.

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CONFLICT OF INTEREST

The authors have no conflict of relevant interest to this article.

TABLE III.
COMPARISON OF PROPOSED STRUCTURE WITH THOSE IN
THE STATE-OF-ART LITERATURE

Ref.	Operating Frequency (GHz)	SAR reduction technique	Gain (dBi)	Size mm^3	SAR reduction percent
[10]	3 – 6	SRR in ground plane	5.24	$60 \times 60 \times 1.6$	Not specified
[11]	5	AMC under antenna	7.6	$30 \times 50 \times 3.4$	75%
[20]	28	Tuning ground plane and power density	7.2	$12 \times 8.5 \times 0.33$	54%
[28]	5.8	square ring patch antenna with AMC	8.69	$15.27 \times 15.27 \times 2.2$	93.7%
[12]	3-10.6	Single Rectangular SRR	3.11	$35 \times 34 \times 0.8$	13.3%
[29]	3.25	Single Circular SRR	Not Specified	$24.8 \times 24.8 \times 0.8$	93%
[1]	2.4 – 5	Polygonal split rings	3	$20 \times 13 \times 1.6$	84.50/57.2
[5]	1.8-3.8	Multi split square ring MTM	Not Specified	$22 \times 11 \times 1.6$	36.87% (L-band) 45.54% (S-band)
[9]	2.8-4.5	Multiport antenna cluster technique	5	$30 \times 3 \times 5$	50%
[30]	2.2-6.9	Wearable patched antenna Uniplanar compact EBG (UC-EBG)	11.8 – 13.6 dBi operating band of 4.5 – 6.5 GHz	$140 \times 27.3 \times 1.15$ EBG array	70% at 4 GHz 63% at 6 GHz
This work	28	2x3 SRR MTM+ MSPA	7.7	$12 \times 8.5 \times 0.33$	89.88 %

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