Next-Gen Wearable Antenna: Harnessing Metamaterial for 5G Connectivity and SAR Evaluation

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***Abstract*: This article presents a 5G wearable wide band antenna designed on regular zeen cloth (Poly dimethylsiloxane) with electrical permittivity of 2.7 and loss tangent value of 0.134 at 3.4GHz central frequency which operates from 3GHz to 7GHz band. The proposed 5G antenna is of size 28X24X1.5 mm^3 and is microstrip patch antenna type with line feeding technique. The basic antenna is resonating at 3.8GHz and having low gain, to obtain the frequency shift and required gain values various slots on patch and on ground along with partial ground is introduced, further metamaterial concept based periodic split ring resonators are placed on the antenna. The basic antenna has the return loss of -29.62dB, voltage standing wave ratio of 1.09, 2.1dB Gain and 2.4w/kg SAR at 3.8GHz frequency. The introduction of slots and spilt ring resonators shifted the resonating frequency to 3.4GHz, further the return loss of -21.4dB, VSWR of 1.18 and Gain of 4.1dB which reasonably permissible 1.3W/kg SAR value. The unit cell tissue is designed in High Frequency Structural Simulator for SAR analysis in far field mode. The maximum SAR value observed is 1.3W/kg which is of below the SAR recommendation value which is 1.6w/kg. The proposed antenna is operating from 3GHz to 7GHz which is wide band range in lower 5G sub-band range. The modeled antenna is suitable for the next-generation wearable antenna for Internet of things and machine learning application.**

Keywords—Wearable Antenna, Split Ring Resonator, Slot, Specific Absorption Rate, HFSS.

I. INTRODUCTION

The modern human lives entirely encircled by wireless technology. Cell phones, GPS units, and other wireless gadgets that improve our lives are commonplace in modern society and are used for both work and daily activities. It implies that electromagnetic fields are always interacting with us. The specific absorption rate, or SAR, is introduced as a metric to quantify the amount of RF radiation that humans are exposed to. To guarantee safety, regulatory bodies have standards that cap the maximum SAR. Because these various electromagnetic fields may have negative effects on human health, it is crucial to research how electromagnetic fields, such as SAR Analysis, affect the human body.

$$SAR = \frac{\sigma_{eff} \times E_{rms}^2}{\rho} w/kg \quad (1)$$

Where, σeff is Conductivity of tissue in unit (Siemens per meter), E_{rms} is RMS value of the induced Electric field (Volts per meter) and ρ is mass density tissue in unit (Kilogram per Cubic meter)

When measuring the intensity and effects of RF exposure, the most widely used dosimetric quantities are the specific absorption rate (SAR) and the plane-wave equivalent power density (PD). SAR is a straight forward or direct process to measure exposure properties of the RF of cell phones so that the mobile phones produced are according to the set guidelines

The specific absorption rate (SAR) analysis of 5G technology has been studied in several papers. One paper presents the design and SAR analysis of a 37 GHz antenna for 5G applications, showing that the antenna meets the international recommendations for SAR values [1]. Another paper proposes a 5G network security analysis approach that includes SAR evaluation, identifying and quantifying network vulnerabilities under various attacks [2]. Additionally, a paper presents the design of a 5G flexible antenna using Polyvinyl alcohol (PVA) material for body-worn applications, with SAR values below the maximum limits [3]. Another study focuses on SAR reduction of MIMO antennas for 5G devices, demonstrating the cancellation of inverted phase currents and improved isolation [4-6]. Overall, these papers provide insights into the SAR analysis and reduction techniques for 5G technology.

The introduction of 5G technology, there are concerns about potential health impacts in addition to anticipation about its revolutionary potential, particularly with regard to Specific Absorption Rate (SAR). SAR calculates the rate at which radio-frequency electromagnetic fields (RF-EMF) are absorbed by electromagnetic radiation from wireless devices and how quickly they reach the human body. This paper offers a comprehensive analysis of 5G SAR, including crucial subjects required to understand and minimize potential health risks. It examines the fundamentals of SAR, measurement techniques, safety evaluation protocols, adherence to regulations, and variables affecting SAR values. Understanding SAR factors, such as exposure period, exposure frequency, radiation power level, and proximity to the radiation source, is necessary to abide by regulatory requirements established by organizations such as the FCC and ICNIRP to protect public health.

The purpose of SAR testing is to evaluate any possible health risks related to RF energy exposure. Because it measures the amount of radiofrequency energy absorbed by biological tissue when using a wireless device over time, specific absorption rate (SAR) testing is becoming increasingly important. Through this testing, you can prove that your product meets the SAR limits for RF exposure that have been set globally. It matters because we cannot guarantee that radiofrequency energy will not have an impact on human health. Therefore, we will conduct a SAR test in relation to human health concerns.

SAR Measurement:

1. The liquid used to simulate is used to measure SAR. It is crucial that the tissue-equivalent liquid's dielectric characteristics resemble those of bodily or brain tissue.
2. The permittivity and conductivity must match those found in bodily tissue, such as the brain.
3. Due to varying standards and the use of distinct frequency areas, SAR measurement procedures differ between nations.
4. Compared to 2G and 3G, 4G devices need more testing because the radio access technology is more complex. SAR testing for 5G devices also presents new difficulties.
5. We regularly perform system checks and liquid checks before SAR testing to make sure all measurements are made accurately.

Table.1 International SAR Limitations

S. No	Country	Certification Body	SAR value in W/kg
1	United States	FCC	1.6
2	Canada	ISED	1.6
3	Europian Union	CE	2.0

A study by researchers at the National Institute of Health, revealed radiation emitted after just 50 minutes on a mobile phone increases the activity in brain cells. The penetration of electromagnetic radiations into the human brain is based on the age and it is proved that children are most vulnerable for its ill-effects. The SAR values of smart phones which are available in present society of India are represented in a table shown below. J. Behari [7] analyzed the bio-logical effects of mobile phone frequency exposure in 2008. In this he discussed about possible health effects of radiofrequency emissions with an increasing number of mobile communication base stations. Prof Girish kumar[8] stated Temperature of ear lobes increases by one degree centigrade when cell phone is used for approximately 20 minutes. Rajagopal B[9] proved that children head absorbs more power than adult, using Hand held device model (with and without resistive sheet) having dipole antenna enclosed by plastic cover for human interaction.

Table.2 SAR Values of the Smart phones in India

Product name	**At head (W/Kg)**	**At Body(W/Kg)**
XIOMI MI4I	1.29	NA
MOTO G2	1.52	0.894
SONY XPERIA	1.11	1.17
MOTO G(XT1033)	1.35	1.06
LENOVO(A7000)	1.260	0.999
IPHONE	1.12	1.14
REDMI NOTE	1.256	NA
MICROSOFT	0.88	NA
INFOCUS	0.479	0.593
MOTO E	1.5	1.36
HTC	0.995	0.693
I PHONE	0.98	0.97
LG MAGNA	0.743	0.826
CELKON	0.559	0.481
MOTO G	1.53	0.894

Introduction of 5G technology, body-worn antennas are becoming more and more important in the development of wireless communication systems. Dynamic, mobile solutions are being added to the conventional strategy of depending only on fixed infrastructure as the need for seamless connectivity increases. Wearable or integrated into apparel and accessories, body wearable antennas are essential for enabling ubiquitous connectivity while maintaining user comfort and convenience [10-13].

In addition, body wearable antennas open up new applications beyond traditional communication, like gesture recognition, augmented reality, and health monitoring. Through the seamless integration of antennas into daily clothing and accessories, users can maintain constant connectivity without compromising their comfort or mobility. The role of body wearable antennas will only grow in importance as 5G networks spread and develop, spurring advancements in wearable computing and antenna technology[14-15].

This research work presents design of a 5G flexibly wearable wide band antenna on zeen cloth that is Polydimethylsiloxane Substrate with electrical permittivity of 2.7 and loss tangent value of 0.134. The application of metamaterial concept is introduced for the frequency shifting and gain improvement purpose along with different slots in over the patch and ground plane. Various antenna parameters are studied for the antenna operation and SAR analysis is done for unit cell equivalent tissue case in far field mode.

II.ANTENNA DESIGN PROCEDURE

Antennas are devices that are used for radio and television signal transmission and reception. Antenna's size and form are determined by its intended use and frequency range. They come in directional and omni-directional varieties, and they can be mounted on a tower, a building, or an automobile. Antennas convert electrical impulses into electromagnetic waves, which can either be picked up from the surroundings or sent into space Though there are various antenna designs are available it is challenging for the antenna engineers to introduce new optimise design to meet the day to day technological requirements of 5G.

Microstrip patch antennas are used in mobile and satellite communication systems, RFID systems, GPS, and wireless local area networks (WLANs). They are also used in the defense industry for projects like radar electronic warfare and mobile industry. There are few antenna designs available in literature for the SAR analysis by using Patch antennas. The basic antenna design equations are mentioned in Eq. (2) to Eq. (6). The dimensions are optimized in such a way that to match the port impedance of 50Ω. Dimensions of the proposed antenna are mentioned in the following chapters. The proposed antenna is designed in full wave electromagnetic solver High Frequency Structural simulator (HFSS) which uses the Finite Element Method and requires less memory space on computer [16-17].

$$w = \frac{C}{2 f_0 \sqrt{\varepsilon_r}} \tag{2}$$

$$l_{eff} = \frac{c}{2 f_0 \sqrt{\varepsilon_{reff}}} \tag{3}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2} \tag{4}$$

$$\Delta l = \frac{\varepsilon_{reff} + 0.300}{\varepsilon_{reff} - 0.258}\left[\frac{l/h + 0.262}{l/h + 0.813}\right] \tag{5}$$

$$l = l_{eff} - 2\Delta l \tag{6}$$

III. PROPOSED DESIGN

The fifth generation of wireless communication technology, or 5G, is anticipated to completely change how we access information and communicate. Thoughts have been raised concerning possible health dangers related to electromagnetic radiation released by 5G antennas as a result of the rollout of 5G networks. One of the potential problems with 5G antenna is abnormal SAR values. The design model of the antenna in communication devices plays vital role in reducing the SAR value. The intended antenna performance is significantly influenced by the substrate material's thickness, permittivity, and loss tangent. To obtain the appropriate antenna size and performance, these elements need to be selected with care. In modern Internet of things and Machine Learning applications, wearable antenna design is crucial.

Taking this into account as a design challenge, a smaller, lower permittivity antenna that still maintains performance characteristics is created. The suggested antenna has an overall size of 28x24x1.5 mm3, is built on a flexible dielectric material, has a low dielectric constant of 2.7, and a loss tangent of 0.134. A basic microstrip patch antenna is first designed using standard equations [2-6]. The proposed antenna is resonating at 3.8GHz. Later, a number of techniques were added to the design in order to improve the antenna's performance characteristics. After the antenna is designed, the patch is altered to have a trapezoid shape by cutting the lower edge corners of the rectangular patch. Originally intended to be a rectangular patch antenna, the patch is later changed to a trapezium structure by truncating the lower edge corners of rectangular patch, which further increases the antenna slots' bandwidth. Spirals are etched into the patch, creating multiple resonant modes that further increase the bandwidth. A 50 microstrip line that is 12 mm long and 7.5 mm wide feeds the antenna. The dimensions of its partial ground are 24 x 9.5mm^2.The dimension of the final proposed antenna are mentioned in Table.3 below.

Table.3 Proposed Antenna Design Dimensions

Parameter	value in mm	Parameter	Value in mm
Substrate length	28	Circular slot outer radius	4.75
Substrate width	24	Circular slot inner radius	2
Substrate thickness	1.5	Outer circular slot thickness	1
Feed line width	7.75	Inner circle thickness	0.75
Rectangular slot length	6	Ground length	9.5
Rectangular slot width	1	Ground slot outer radius	2.5
Metasurface length	27.2	Ground slot thickness	0.75
Metasurface width	22.2	CSRR outer radius	4
CSRR inner radius	2.5	CSRR Slit gap	0.5

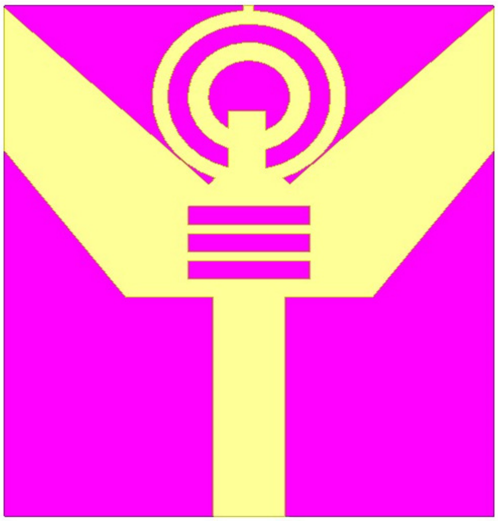

Figure.1 Proposed antenna top view

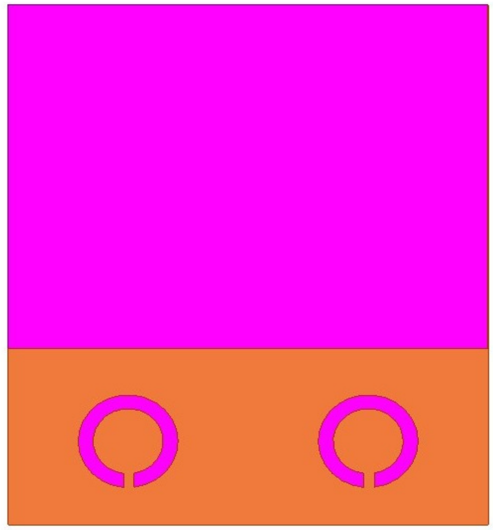

Figure.2 Proposed antenna bottom view

The basic proposed antenna has three symmetric rectangular slots and two concentric circles on the top and on the bottom surface departure ground model is applied along with two semi circular slots such that it resonates in 5G sub band and 6G frequency bands. Manufacturers of 5G antennas utilise shielding and other methods to lessen the electromagnetic radiation that the antennas emit in order to reduce electromagnetic radiation. The amount of electromagnetic radiation that 5G antennas can release is also strictly regulated by regulatory bodies like the Federal Communications Commission (FCC). The return loss, vswr and gain curves are mentioned in Fig3, 4&5, further Fig.6 represents the axial ratio values which gives the polarization of the designed antenna.

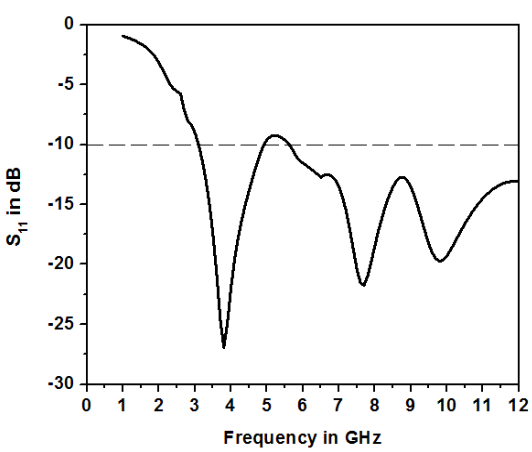

Fig.3 Return loss of the Basic antenna

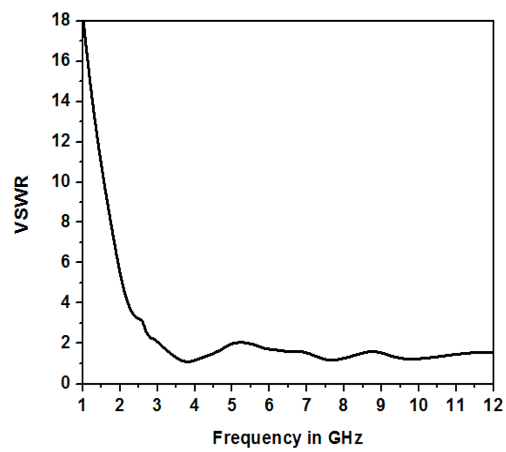

Fig.4 VSWR of the basic antenna

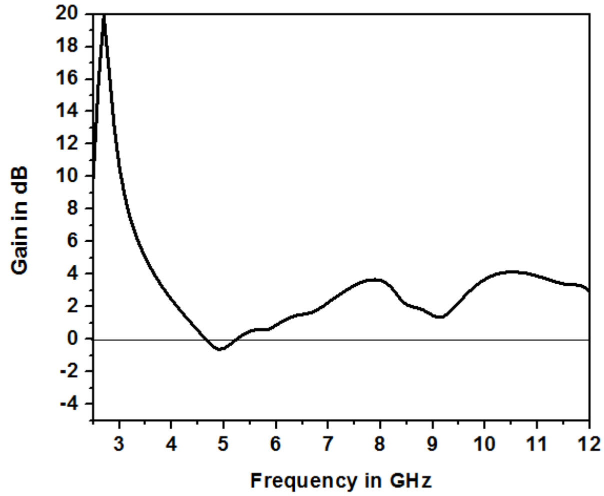

Fig.4 Gain of the proposed antenna

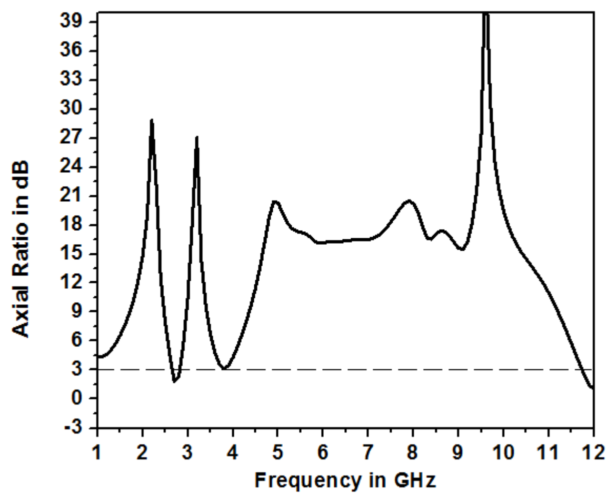

Fig.5 Axial of the proposed antenna

5G antennas must go through testing and certification procedures to obtain EMC compliance. The above mentioned 5G antenna is resonating at 3.8GHz frequency but the operating frequency of the antenna is 3.4GHz and the SAR value observed is 2.4W/Kg and gain is also very small. To overcome the above problem metamaterial based split ring resonators are placed on proposed antenna as explained in the next chapter. The dimensions of the periodic split ring resonators are as mentioned in table.3. The 3.4GHz resonance is observed at reduced meta surface area than the basic antenna substrate. The meta surface substrate area is 27.2X 22.2 mm^2. The design model and antenna performance parameters are mentioned in Fig 6 to 12.

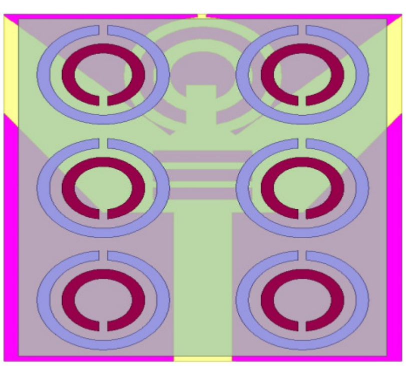

Fig.6 Proposed antenna with SRRs

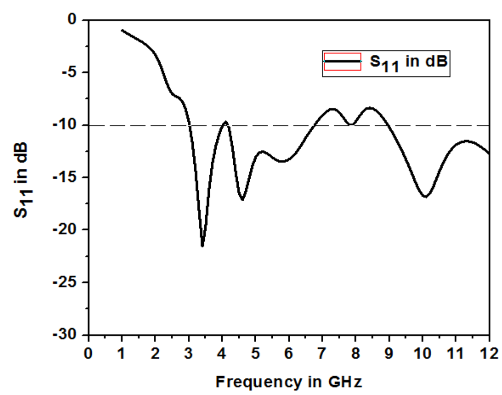

Fig.7 Return loss of the meta surfaced antenna

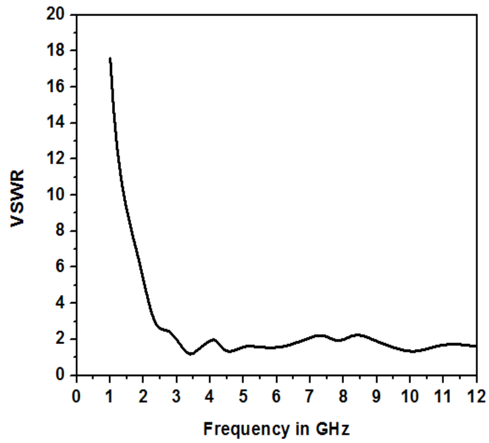

Fig.8 VSWR of the Meta antenna

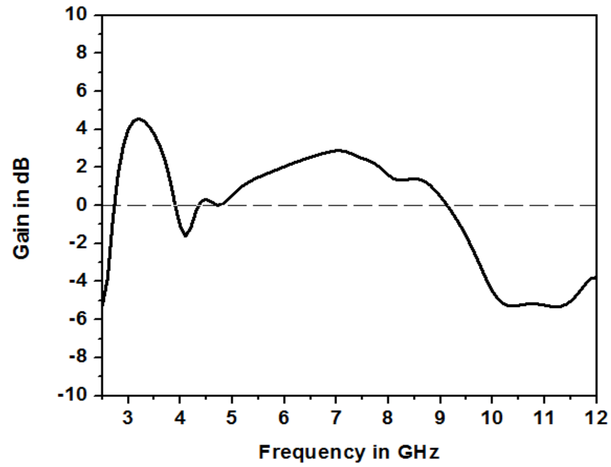

Fig.9 Meta antenna Gain

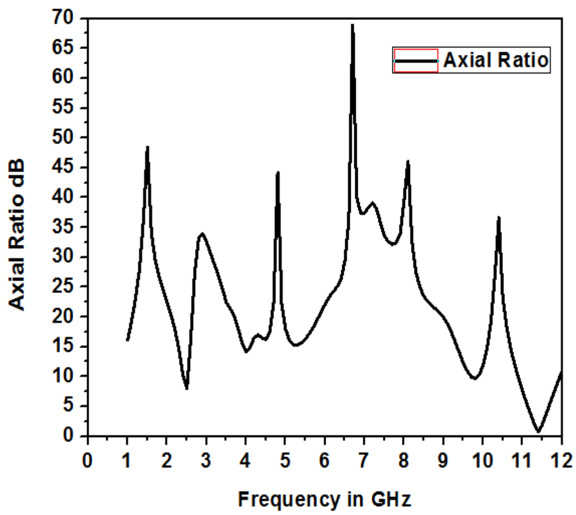

Fig.10 Axial Ratio of the Meta antenna

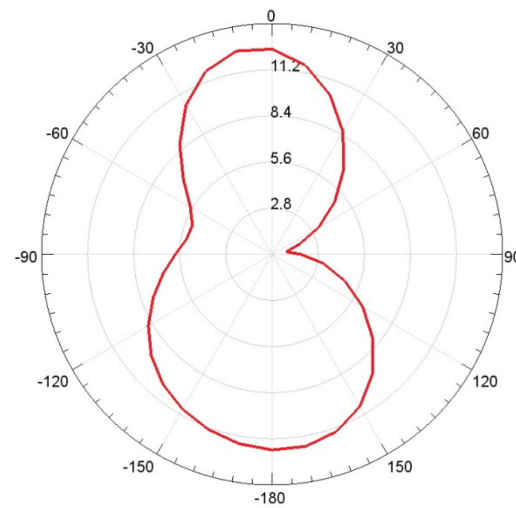

Fig.11 Radiation Pattern of the Meta antenna

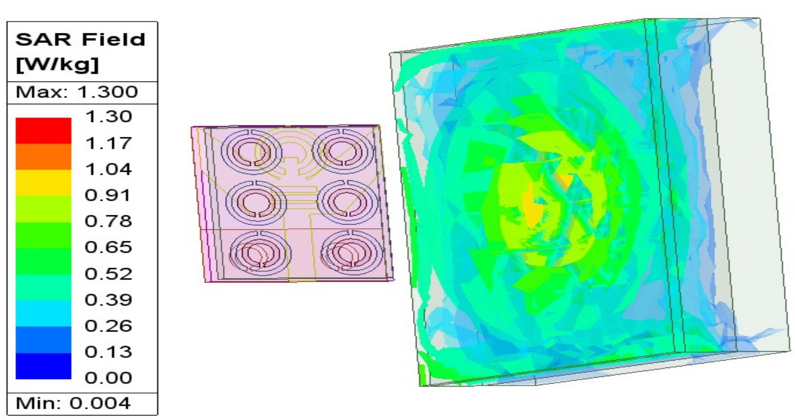

Fig.12 SAR Analysis of the Proposed Meta antenna

IV. Discussion of results

The proposed antennas mentioned in Fig. 6 with metamaterial based split ring resonators arranged in periodically as mentioned in previous chapter operates over a wide band range starting from 3GHz to 7Ghz. The shift in resonating frequency from 3.8GHz to 3.4 GHz is observed and gain improvement of 2.1 db to 4.2db is also observed in figure mentioned above. Clearly the SAR value observed in normal design is 2.4W/kg which is quit high value and hazardous to human health. The SRRs on meta surface helped to achieve the SAR value of 1.3W/kg which is under permissible level that is 1.6W/kg. In both cases normal design and meta surfaced antenna single unit equivalent tissue is used for SAR analysis that is creating skin, fat and skull electrical properties in the simulator. The single unit tissue is located at far field for the analysis purpose. Based on the observation from axial ratio graph which is mentioned in Fig.10 the designed antenna is linearly polarized one. The radiation pattern also improved after the application of SRRS to the basic design. The performance comparison in both cases i.e normal design and SRR based design is mentioned below in Table.4.

Table.4 Antenna Performance Parameters

	Freq(GHz)	S11(dB)	VSWR(dB)	Gain(dB)	SAR Value in W/kg
With Out Meta-surface	3.8	-29.62	1.09	2.1	2.4
With Meta-surface	3.4	-21.42	1.18	4.1	1.3

V. Conclusion

Design of a 5G wearable wide band antenna on regular zeen cloth (Poly dimethylsiloxane) with electrical permittivity of 2.7 and loss tangent value of 0.134 at 3.4GHz central frequency which operates from 3GHz to 7GHz band. The line fed antenna has two modes of operation in normal design and metamaterial based design. Both modes observed for the 5G wide band frequency of operation and SAR analysis. Basic design is resonating at 3.8GHz instead of the 3.4GHz which is operating frequency. Application of meta surface based split ring resonators shifts the operating frequency to 3.4GHz with enhanced antenna parameters in terms of Gain & SAR value which is 1.3 W/kg. The proposed antenna is suitable for the optimal for the 5G applications over the wide range from 3GHz to 7GHz. The proposed antenna is 5G wearable antenna; hence it is high time for the fabrication such that the SAR value can be measured in anechoic chamber. The real time fabrication and measurement of SAR for IOT application is subjected to future scope of study.

References

[1] CA Balanis, “Antenna Theory: Analysis and Design”, John Willey & Sons, New York -1989.

[2] Lin JC,“Popularity, funding for health-effect research and cell-phone addiction”, Antennas Propagation Magazine IEEE52(2):164–166, 2010

[3] Lin JC, “The blood-brain barrier, cancer, cell phones, and microwave radiation”, Antennas Propagation Magazine IEEE43(3):141–143, 2001

[4] Lin JC, “Risk of human exposure to cellular mobile communication radiation”, MicrowaveMagazine IEEE 2(2):36–40, 2001

[5] Lin JC, “Are cell phones or radio-frequency electromagnetic fields possibly carcinogenic to humans?” [Telecommunications health and safety]. Antennas Propagation Magazine IEEE 54(1):210–212, 2012

[6] Relova JL, Pértega S, Vilar JA, López-Martin E, Peleteiro M, Ares-Pena F,"Effects of cell-phone radiation on theelectroencephalographic spectra of epileptic patients", [telecommunications health and safety]. Antennas Propagation Magazine IEEE 52(6):173–179, 2010

[7] V A Sankar et al.., "A Study on Scilab Free and Open Source Programming for Antenna Array Design", IEMTRONICS-2020.

[8] J. Zhang, X. Yang, and Y. Liu ,"Design and EMC analysis of a dual-polarized microstrip antenna for LTE applications" Radioengineering, 21(3)-875-880-2012.

[9] "Mobile phone frequency exposure and human health" Behari, J.; Recent Advances in Microwave Theory and Applications, 2008. MICROWAVE 2008. International Conference on Digital Object Identifier: 10.1109/AMTA.2008.4763247 Publication Year: 2008 , Page(s): 275

[10] "Mobile tower/mobile phone radiation hazards" Prof Girish Kumar, Electrical Engineering Department, IIT Bombay,

[11] Rajagopal B, Rajasekaran L (2014) SAR assessment on three layered spherical human head model irradiated by mobile phone antenna. Hum-Centric Comput Inform Sci 4:10

[12] J. Chen, C. Liang, and K. Pan, "Radiation Efficiency and EMC of Antennas for Wireless Communication Systems" , IEEE Transactions on Electromagnetic Compatibility, vol. 56, no. 5, pp. 1125-1132, Oct. 2014.

[13] International Non-Ionizing Radiation Committee of the International Radiation (1988) Protection Association,"Guidelines on limits of exposure to radio frequency electromagnetic fields in the frequency range from 100 kHz to300 GHz". Health Physics 54(1):115–123

[14] Islam MT, Faruque MRI, Misran N (2009) Design analysis of ferrite sheet attachment for SAR reduction in human head. Progress in Electromagnetic Research PIER 98:191–205

[15] Hanafi NHM, Islam MT, Misran N, Faruque1 MRI (2011), "Numerical analysis of aluminum sheet for SAR reduction", Proceeding of the 2011 IEEE International conference on space science and communication (Icon Space), Penang.

[16] G. Garg, P. Bhartia, I. Bahl and A. Ittipiboon, "Microstrip Antenna Design Handbook," Artech House, Canton, 2001.

[17] Ansys HFSS simulator v.22-2022.