MICROSTRIP PATCH ANTENNA + SHAPED LOADED WITH GEO TEXTILE METAMATERIAL

Manish Kumar Gupta[1], Manish Singh[2], Sanjay Sharma[3]

[1] *PG Student, Department of Electronic and communication, KIET (India)*
[2] *Asst. Prof., Department of Electronic and communication, KIET (India)*
[3] *Prof., Department of Electronic and communication, KIET (India)*

ABSTRACT

The Metamaterial based antenna is designed for some improvement in the performance of directivity gain, return loss and size of circuit area. A patch antenna has been designed and fabricated to operate at 3.19 GHz. In this paper, a geo-textile material that is polypropylene based metamaterial loaded wearable + shaped microstrip patch antenna for radio astronomy, microwave devices, radar, communication, satellite television broadcasting, DBS ,public safety band and amateur radio is presented. Under unloaded condition of + shaped microstrip patch antenna, poor matching is observed in the radar, satellite TV. Further, this antenna is loaded with metamaterial split ring resonators (SRRs). This loading provides better matched condition in the above applications. In loading condition, the antenna resonates at 3.19 GHz with the bandwidth and gain of 50 MHz and 3.8 dBi respectively. The electrical dimension of the proposed wearable antenna is 0.239 λ x 0.244 λ. The antenna is tested, and the measured results are presented in the paper. Desired Patch antenna design is initially simulated by using IE3D simulator and Patch antenna is realized as per design requirements.

Keywords: Geo-Textile, Polypropylene, Metamaterial, Split Ring Resonator, Patch Antenna, Public Safety Band

I. INTRODUCTION

The introduction of intelligent textile systems to increase the wearer's level of protection has exposed the necessity of wearable communication tools and has led to research in textile antennas. Portable electronic devices have become part and parcel of everyday human life. The International Telecommunications Union (ITU) allotted a separate frequency spectrum of 3 GHz to 30 GHz band for radio astronomy, microwave devices, radar, communication, wireless LAN, satellite television broadcasting, DBS and amateur radio. It also covers the applications such as public safety purpose ,fire fighter, police vehicles, offsite workers and rescue teams, private ambulance services, military services, airport and seaport surveillances so that the interior and sensitive locations can be monitored round the clock for the protection of human life and property. The compact, light weight, efficient, and easily installable antennas are essential. The limitations of conventional microstrip patch antennas are more deposition of electromagnetic signals in the human body that is high specific absorption rate (SAR) though their physical size is large. Secondly, due to size it is difficult to integrate and make them hidden inside the clothing of wearer [3-9]. Hence, a wearable antenna that is the textile based antenna is one of the better alternatives for such type of applications. The wearable antenna should be light weight, flexible, compact, hidden and should be easily integrated within the clothing and it should not affect the health of wearer.

In practice, different natural as well as synthetic textile materials such as nylon, cotton, Jean, polyester, Teflon, Nomex, liquid crystal polymer (LCP), fleece fabric etc. are used as a substrate to manufacture the wearable antennas for industrial scientific and medical (ISM) band applications [3- 9]. In the literature, different wearable antennas are fabricated on various textile substrates for body centric communication systems are reported that covers Wi-Fi, Wi-Max, WLAN, HYPER LAN, Body Area Networks (BAN), Bluetooth applications. Hall P. S. and Hao Y. presented a study on the necessity of wearable antennas for personal area networks (PAN), S. Sankaralingam and B. Gupta presented development of textile antennas for body wearable applications and investigation on their performance under bent conditions [3].Recently, the authors reported a metamaterial embedded wearable rectangular microstrip patch antenna for IEEE 802.11a WLAN applications [4]. C. Hertleer *et al.* presented ISM band microstrip patch antenna on flexible pad foam substrate for protective clothing of fire fighter [5].

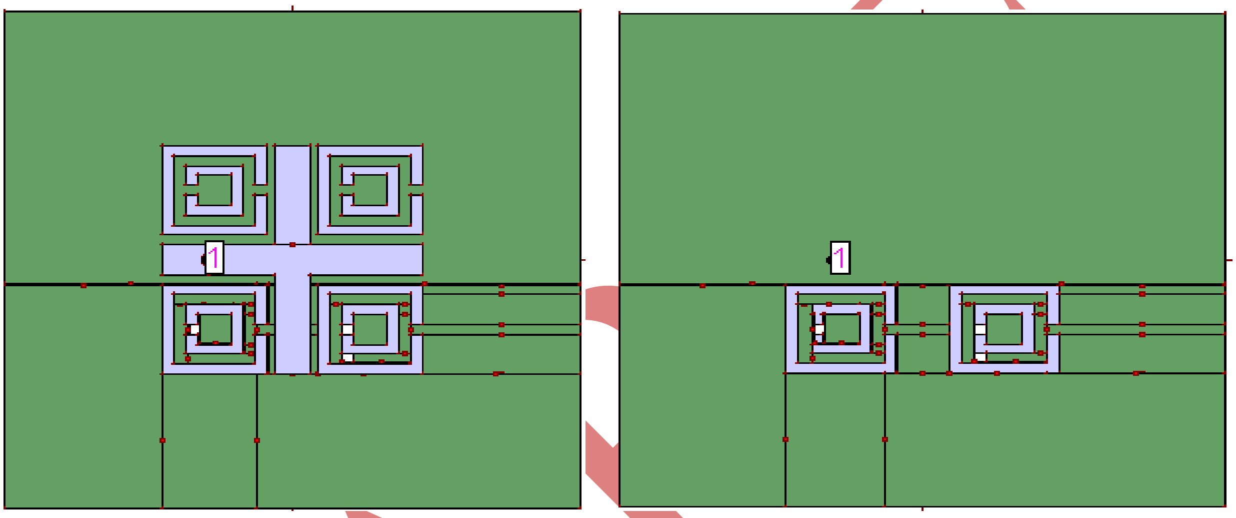
Metamaterial inclusions are directly used as loading element for size reduction, enhancement of gain, bandwidth, directivity and efficiency of microstrip patch antennas. In the literature, different metamaterial loaded microstrip patch antennas are reported [2], [4], [11-18]. These inclusions match the impedance at frequency which is lower than the initial resonant frequency of the unloaded microstrip patch antenna. Under loading condition, the microstrip patch antenna produces sub-wavelength resonances due to modifications of the resonant modes. In 1968, Veselago theoretically predicted that metamaterial possesses negative values of magnetic permeability (μ) and electric permittivity (ε) [19]. Some metamaterial structure consists of SRRs to produce negative permeability and thin wire elements to generate negative permittivity [11-23]. Authors have reported the effect of mutual inductance on the resonant frequency, bandwidth, gain, and size of metamaterial loaded electrically small microstrip patch antenna when the loading distance between the metamaterial element and the antenna gets varied [14]. This concept is used by the authors to design the polypropylene based metamaterial loaded + shaped microstrip patch antenna for various applications.

The polypropylene is a non-woven type of geo-textile which is used as a substrate because of its features such as light weight, the polypropylene sheets are available in different thickness which avoids the processes like sewing to obtain the substrate of desired thickness. The objective of this paper is to design and test the metamaterial loaded polypropylene based wearable antenna. In this antenna, a + shaped microstrip patch is loaded with four metamaterial square SRRs of equal dimensions by placing them around the patch. The proposed antenna is designed, tested, and the measured results are presented in the paper. An equivalent circuit model of the + shaped microstrip patch antenna under loading condition is also prepared and analyzed in this paper.

The paper is organized into following sections. In Section II, the geometrical sketch and design of the proposed wearable antenna is presented. Section III presents the results of + shaped microstrip patch antenna under unloaded and loaded conditions. The metamaterial characteristics of the square SRR are also studied and presented in this section. In Section IV, the equivalent circuit analysis of the designed antenna is presented. The paper is concluded in Section V.

II. ANTENNA DESIGN

Fig.1 (a) and (b) shows the top view and bottom view of geometrical structure of metamaterial loaded wearable + shaped microstrip patch antenna designed on the geotextile polypropylene substrate respectively.



(a) Top view **(b) Bottom view**

Fig.1.Geometrical sketch of metamaterial loaded wearable + shaped microstrip patch antenna on geotextile polypropylene substrate

The antenna consists of two rectangular microstrips which are overlapped on each other to form a + shaped microstrip patch. The purpose to select the + shape is to increase the resonant length of the antenna so as to reduce the size of antenna and to accommodate the metamaterial SRRs to achieve the further size reduction. The dimensions of the + shaped microstrip patch are; length of horizontal and vertical microstrips L_h = 22.5 mm and L_v = 23 mm respectively. The width of both micostrips is W_r = 3 mm. The geometrical dimensions of a square SSR are; length of outer split ring is L_s = 9 mm, gap at the split of both rings (g), width of the rings (w) are set to; g = w = 1 mm, and separation between the inner and outer split rings (s) is 0.5 mm. The electrical size of the square SRR is 0.239 λ × 0.244 λ (λ is the free space wavelength at resonance frequency of square SRR 8.45 GHz). The + shaped microstrip patch antenna is loaded with such a four square SRRs that are placed at the distances g_1 = 1 mm, g_2 = 0.75 mm, g_3 = 4.5 mm, and g_4 = 0.6 mm to obtain the resonance frequency of public safety band. The aspect ratio of horizontal rectangular microstrip that is length (L_h) to width (W_r) is fixed to 7.5 similarly, the ratio of the gaps between upper square SRRs (g3) to (g4) is also set to 7.5. The ratio of the gaps of lower square SRRs (g_1) to (g_2) is set to 1.33.The length of vertical rectangular microstrip (L_v) is fixed to 1.33 times the aspect ratio of horizontal microstrip. According to the designed dimensions and shapes the radiating patch, square SRR, and ground plane of the antenna are cut from the self adhesive copper tape of thickness 0.1 mm and tightly adhered on the polypropylene substrate. The size of this antenna at resonance frequency 3.19 GHz is 0.239 λ × 0.244 λ. The finely cut microstrip patch and the SRRs are tightly adhered on the polypropylene substrate. This antenna is designed and simulated on polypropylene (PR 30) substrate of thickness h = 1.9 mm and dielectric constant $\varepsilon_r = 2.2$ supplied by TECHFAB India, Mumbai, India. The antenna is co-axially fed at $x = -7.2$ mm and $y = 0$ mm. Method of moment based IE3D electromagnetic simulator is used to simulate this antenna.

III. RESULTS & DISCUSSION

Fig. 2 shows the reflection (S_{11}) and transmission (S_{21}) coefficient characteristics of the square SRR that resonates at 8.48 GHz. The effective medium theory is used to verify the permeability (μ_r) and permittivity (ε_r) from the reflection and transmission coefficients (S-parameters).The Nicolson-Ross-Weir (NRW) approach is used to obtain the effective medium parameters. The expressions of equations (1) and (2) are used to determine these effective parameters.

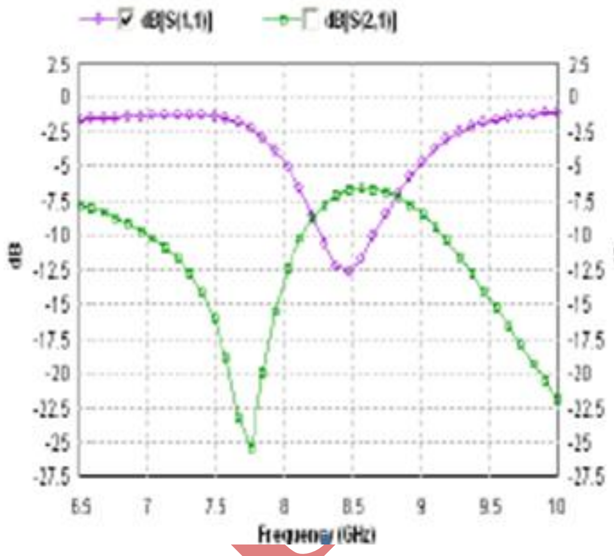


Fig.2.

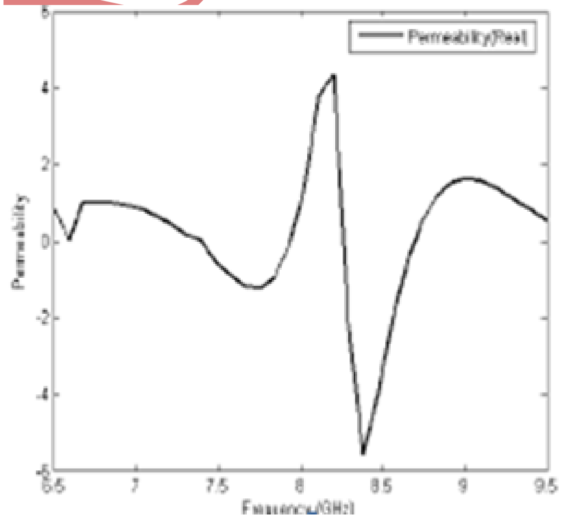


Fig. 3

Fig.2. Reflection (S_{11}) and Transmission (S_{21}) coefficient characteristics of square SRR

Fig. 3. Relative permeability (μr) characteristics of the square SRR

The metamaterial characteristics of the SRR are verified using the *S*-parameters obtained from IE3D electromagnetic simulator and MATLAB code with mathematical equations (1) and (2) [13- 18],[21-23].

$$\mu_r = \frac{2}{jk_o h}\frac{1-V_2}{1+V_2} \quad (1)$$

$$\varepsilon_r = \frac{2}{jk_o h}\frac{1-V_1}{1+V_1} \quad (2)$$

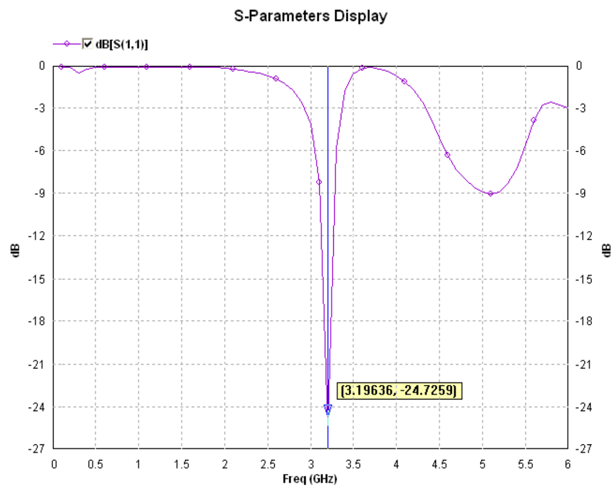
where k_0 is wave number, *h* is substrate thickness; V_1 and V_2 are composite terms to represent addition and subtraction of *S*-parameters. The factor $k_0h = 0.336$ which is <<1 [21-22]. The values of V_1 and V_2 are calculated using equations (3) and (4) [13- 18], [21-23].

$$V_1 = S_{21} + S_{11} \quad (3)$$

$$V_2 = S_{21} - S_{11} \quad (4)$$

From Fig. 2 good matching is observed near the resonant frequency of SRR that is at 8.48 GHz in the range of 8.35 GHz to 8.7 GHz. Fig. 3 depicts the relative permeability (μ_r) characteristics of the SRR which indicates that the SRR structure is single negative that is mu negative (MNG) metamaterial. The value of permeability (μ_r) is negative in the frequency range of 8.35 GHz to 8.7 GHz. Such four square shaped SRRs are used to load the T-shaped microstrip patch as shown in Fig.1

Fig 4 shows the simulated return loss (S_{11}) characteristics of the metamaterial loaded polypropylene based wearable microstrip patch antenna. This antenna resonates at 3.19 GHz (in the frequency band of 3.16 GHz to 3.22 GHz) with the bandwidth and gain of 400 MHz and 3.85 dBi respectively. Numerical calculations of the Return loss is performed using the method of moments (mom) based electromagnetic solver IE3D commercial software. From the obtained curve, return loss value is -24.7259 dB.This antenna will find its applications in different public safety band applications.



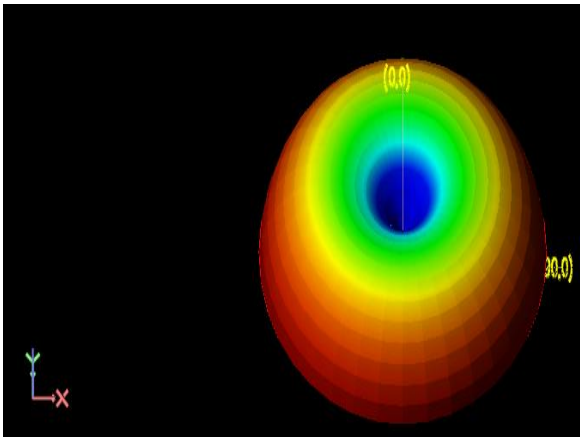
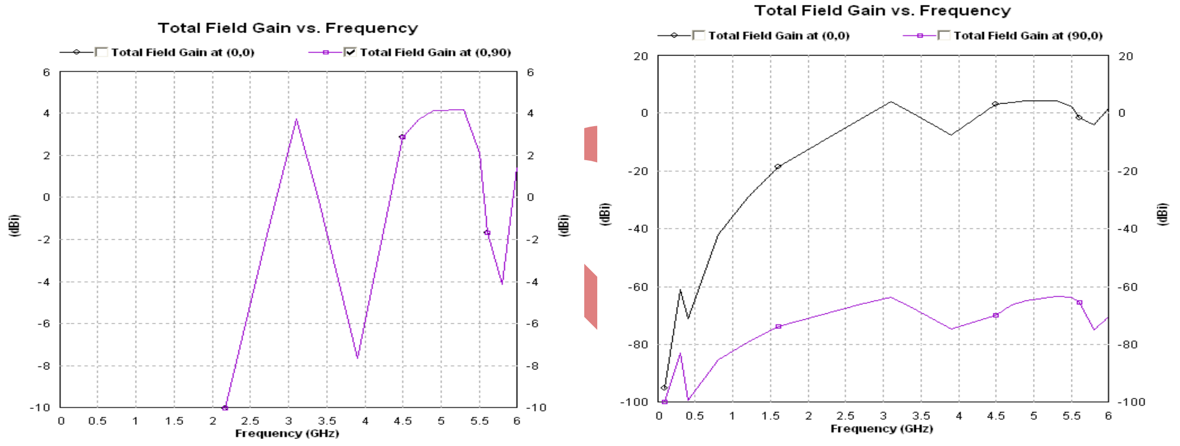


Fig.4 Simulated return loss (S_{11}) characteristics of loaded wearable + shaped microstrip patch antenna on polypropylene substrate

Fig.5 Radiation Pattern

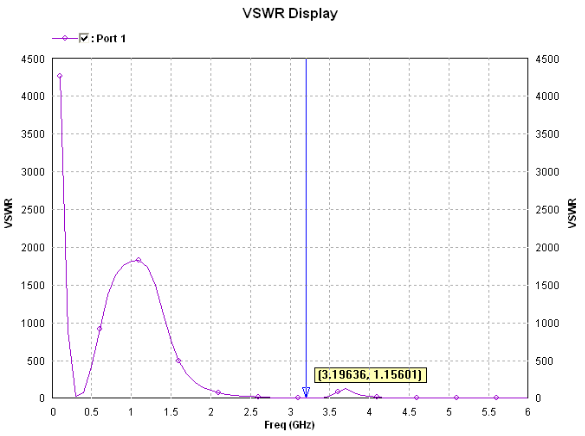
The far-field radiation patterns of the designed microstrip patch antenna at 3.19 GHz, are shown in the fig.5. Nearly dipole-like radiation patterns in the ***xz*** plane and omni-directional radiation patterns in the ***yz*** plane are obtained at these frequencies.

Fig. 6 (a) and (b) shows the gains in the maximum directions of required frequency point i.e. 3.19 GHz. The antenna gain has a peak value of 3.8 dBi (0,90)at 3.19 GHz,2.3 dBi (0,0) at 3.19GHz, and -62.1 dBi (90,0)at 3.19 GHz, respectively. There should be a maximum power transfer between the transmitter and the antenna for the antenna to perform efficiently. This happens only when the impedance Z_{in} is matched to the transmitter impedance, Z_s. In the process of achieving this particular configuration for an antenna to perform efficiently there is always a reflection of the power which leads to the standing waves, which is characterized by the Voltage Standing Wave Ratio (VSWR). Fig 7 shows the VSWR vs frequency curve .the value of VSWR for this antenna is 1.156 at 3.19 GHz.



(a) (b)

Fig.6 Gain Vs Frequency Curve



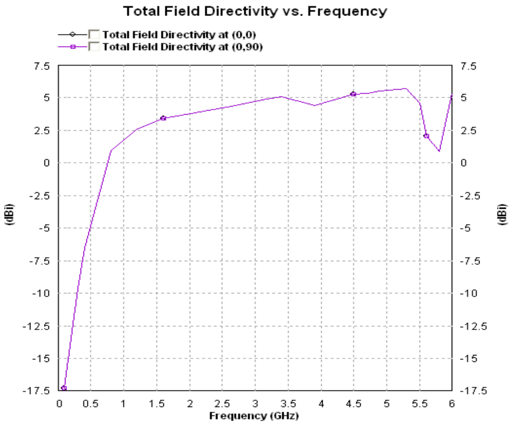


Fig.7 VSWR Vs Frequency Curve **Fig.8(a) Directivity Vs Frequency Curve**

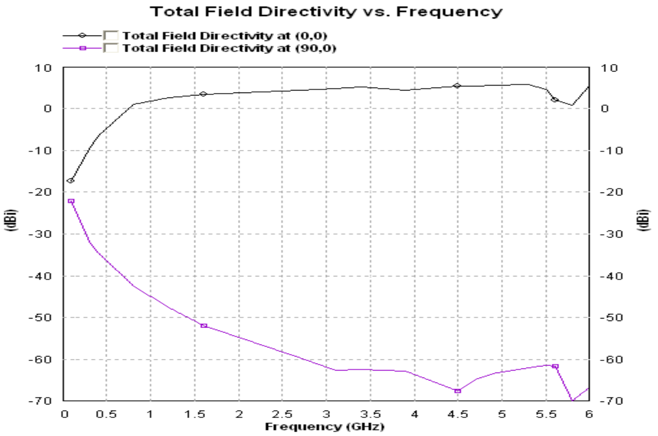


Fig.8 (B) Directivity Vs Frequency Curve

Fig 8 (a) and (b) shows the directivity curve of the proposed antenna against frequency. The directivity value is 4.9 dBi (0,90) at 3.19 GHz,3.3 dBi (0,0) at 3.19 GHz and -63 dBi (90,0) at 3.19 GHz.

The directive gain of an antenna system towards a given direction (θ,ϕ) is the radiation intensity normalized by the corresponding isotropic intensity. The directive gain measures the ability of the antenna to direct its power towards a given direction. The maximum value of the directive gain, $D_{\max}$, is called the directivity of the antenna and will be realized towards some particular direction, say (θ_o,ϕ_o).

IV. EQUIVALENT CIRCUIT ANALYSIS & THEORETICAL DISCUSSION

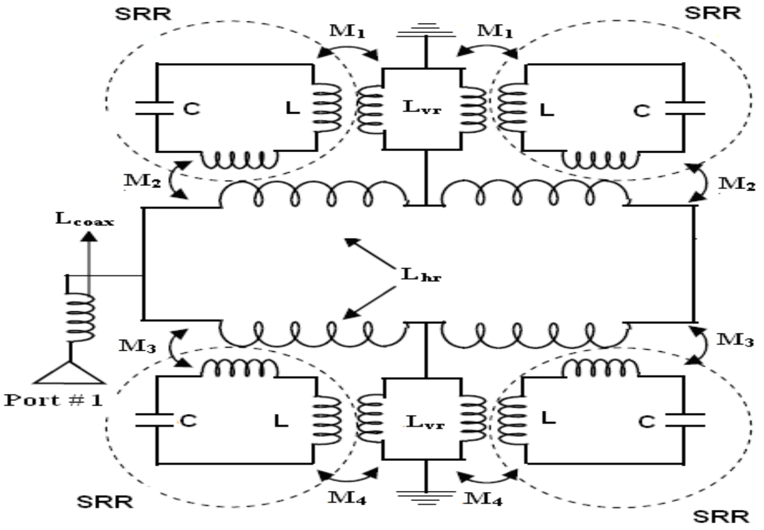


Fig. 9 Equivalent circuit diagram of metamaterial loaded wearable + shaped microstrip patch antenna on polypropylene substrate

Fig. 9 shows the equivalent circuit diagram of metamaterial square SRR loaded polypropylene based wearable T-shaped microstrip patch antenna. Basically, SRR is a *LC* resonant circuit where *L* and *C* are the equivalent inductance and capacitance respectively. *Lcoax* represents the probe inductance.

The inductance (*L*) of the square SRR is calculated using equation (5) [14], [16-18], [23-24].

$$L = \frac{\mu_0}{2}\frac{L_{savg}}{4} 4.86\left[\ln\left(\frac{0.98}{\rho}\right) + 1.84\rho\right] \qquad (5)$$

Where μ_0 is the permeability of free space (4π x 10^{-7} H/m).

ρ is the filling ratio expressed a

$$\rho = \frac{(N-1)(w+s)}{[L_s-(N-1)(w+s)]} \qquad (6)$$

L_{savg} is the average length of square SRR and calculated as $L_{savg} = 4[L_s - (N-1)(w+s)]$and N is the number of split rings .The equivalent capacitance (*C*) that is capacitance per unit length of the square SRR is calculated using equation (7) [14], [16-18], [23]

$$C = \varepsilon_0 \frac{N-1}{2}[2L_s - (2N-1)(w+s)]\frac{K\sqrt{1-k_1^2}}{K(k_1)} \qquad (7)$$

Where ε_0 is the permittivity of free space (8.85 x 10^{-12} F/m) ,K is the complete elliptic integral of first kind and k_1 is the arguement of integral expressed as $k_1 = \frac{\frac{s}{2}}{w+\frac{s}{2}}$.

By using the principles of equivalent circuit theory and mathematical equations, the calculated values of equivalent circuit elements are; inductance *L* = 30 *nH* and capacitance *C* = 0.0119 *pF*. Theoretically, using the values of *L* and *C* the resonant frequency of square SRR is calculated to 8.43 GHz.In loading condition, the four SRR inclusions are inductively coupled with the + shaped microstrip patch. The LC resonant circuit of the corresponding square SRR gets mutually coupled with the + shaped microstrip patch through the mutual inductance 'M' which is modeled as the magnetic coupling between these two elements. Let, M_1 is mutual inductance between the vertical arm of +shaped microstrip structure and upper SRR..

Consider M_2 is mutual inductance between the upper SRRs and the horizontal microstrip of the + shaped patch. Let M_3 is mutual inductance between the two lower SRRs and horizontal microstrip of the patch. M_4 is mutual inductance between the two lower SRRs and vertical microstrip of the patch. The mutual inductance M_1 to M_4 are respectively calculated to 0.861 nH [14],[17-18] and [24].

$$M_1 = M_2 = M_3 = M_4 = \frac{\mu_0 L_s}{2\pi}\left[0.467 + \frac{0.059(W_r+w)^2}{L_s^2}\right] \qquad (8)$$

The inductance of horizontal (L_{hr}) and vertical (L_{vr}) rectangular microstrips of the + shaped patch is calculated to 14.6 nH and 5 nH respectively [14],[17-18] and [24].

$$L_{hr} = L_{vr} = \frac{\mu_o L_r}{2\pi}\left[\ln\left(\frac{2L_r}{W_r}\right) + 0.5 + \left(\frac{W_r}{3L_r}\right) - \left(\frac{W_r^2}{24L_r^2}\right)\right] \quad (9)$$

The values of L_{hr} and L_{vr} are calculated at the lengths $L_r = L_h = 22.5$ mm and $L_r = L_v = 23$ mm respectively. In loading condition, the SRRs are positioned proximity to the horizontal and vertical microstrips of the + shaped patch. The microstrip patch is coaxially excited hence, due to electromagnetic induction the time varying flux induces the current on each of the square SRR used for loading the patch. Thus, the electric field is induced across the gap capacitance of the splits and mutual capacitance (capacitance per unit length) between the inner and outer splits rings of the SRRs. Ground of + shaped antenna is also loaded with same SRR structure. The inductance of rectangular microstrip patch antenna with the capacitance of SRRs and the mutual inductances forms the *LC* resonant circuit of the loaded antenna. This capacitance compensates inductance of + shaped microstrip patch and the good matching is obtained at the lower resonant frequency 3.19 GHz. Thus, the capacitance of SRRs and the mutual inductance are sufficiently large to match with inductance of the + shaped microstrip patch. Therefore, the negative permeability SRRs acts as matching elements at the lower resonant frequency 3.19 GHz. In loading condition, the gain of antenna is enhanced because the SRRs acts as matching elements and accepts maximum power from the source for the radiation. Thus, the SRR loading reduces the resonant frequency of the proposed antenna by better impedance matching at 3.19GHz by reducing the antenna size.

V. CONCLUSION

In this paper, a geo-textile material polypropylene based metamaterial SRR loaded + shaped microstrip patch wearable antenna for various applications is presented. Thus, metamaterial loading is an advantageous approach for size reduction with considerable gain and bandwidth. The SRR loading introduces the inductance, capacitance and mutual inductance to match the impedance at desired resonance frequency. The software used to model and simulate the Microstrip patch antenna is Zealand Inc's IE3D. IE3D is an integrated full-wave electromagnetic simulation and optimization package for the analysis and design of antennas. It can be used to calculate and plot the S_{11} parameters, VSWR, directivity, gain as well as the radiation patterns. The advantages of proposed antenna are small size, inexpensive, light weight, and easy integration within the clothing.

ACKNOWLEDGEMENT

I would like to express my sincere thanks to my esteemed and worthy supervisor, Mr. Manish Singh Assistant Professor, Department of Electronics and Communication Engineering, KIET Ghaziabad for his valuable guidance in carrying out this paper. I would like to express sincere thanks to Dr. Sanjay Sharma, Head, Department of Electronics and Communication Engineering, KIET Ghaziabad, for his moral support, effective supervision and encouragement.

REFERENCES

[1] "Point-to-Point Connectivity in the 4.9 GHz public safety band," *Solutions Paper, Motorola*, pp. 1-8, 2007.

[2] J.G. Joshi, Shyam S. Pattnaik, S. Devi, and M.R. Lohokare, "Microstrip patch antenna loaded with magneto-inductive waveguide," *Proceedings of Twelfth National Symposium on Antennas and Propagation* (APSYM 2010), Department of Electronics, Cochin University of Science and Technology (CUSAT), (Cochin, India), pp.101-105, 2010. This antenna structure has been published in the *IEEE Antennas and Propag. Magazine*, Vol.53, No.1, pp.123-126, 2011 under "Report on APSYM'2010: National Symposium on Antennas and Propagation".

[3] Sankaralingam, S. and B. Gupta,\A textile antenna for WLAN applications,"*Proc. of ELECTRO*, 397{400,Varanasi, India, December 2009.

[4] J. G. Joshi, Shyam S. Pattnaik, and S. Devi, "Metamaterial embedded wearable rectangular microstrip patch antenna," *International Journal of Antennas and Propaga*, *Special issue on Wearable Antennas and Systems*, Hindwai Publication Corporation, ID. 974315, pp.1-9, doi: 10:1155/2012/974315, 2012.

[5] C. Hertleer, H. Rogier, L. Vallozzi, and L.Van Langenhove,"A textile antenna for off-body communication integrated into protective clothing for firefighters," *IEEE Trans. Antennas and Propag;* Vol.57, No.4, pp. 919-925, 2009.

[6] S.H. Choi, T.J. Jung, and S. Lim, "Flexible antenna based on compact right/left-handed transmission line," *Electronic Letters*, Vol. 46, No.17, pp.1181-1182, 2010.

[7] A. Tronquo, H. Rogier, C Hertleer, and L. V. Langenhove, "Robust planar textile antenna for wireless body LANs operating in 2.45 GHz ISM band," *Electronic Letters*, Vol. 42, No.3, 2006.

[8] S. Sankaralingam, and B. Gupta, "Development of textile antennas for body wearable applications and investigations on their performance under bent conditions," *Progress In Electromagnetics Research B*, Vol. 22, pp.53-71, 2010.

[9] Salonen, P; and Y. Rahmat-Samii, "Textile antennas: Effects of antenna bending on input matching and impedance bandwidth," *IEEE Aerospace and Electronic Systems Magazine*, Vol. 22, No.3, pp. 10-14, 2007.

[10] Jiunn-Nan Hwang, and Fu-Chiarng Chen, "Study of SAR reduction with split ring resonators," *Proceedings of International Symposium on IEEE Antennas and Propagation Society*, Washington DC, USA, Vol.2B, pp.780-783, 2005.

[11] P. Y. Chen, and A. Alu, "Dual-band miniaturized elliptical patch antenna with μ–negative metamaterials," *IEEE Antennas and Propag. Letters*, Vol. 9, pp. 351-354, 2010.

[12] A. Alu, F. Bilotti, N. Engheta, and L. Vegni, "Subwavelength, compact, resonant patch antennas loaded with metamaterials," *IEEE Trans. Antennas and Propag;* Vol.55, No.1, pp.13-25, 2007.

[13] J. G. Joshi, Shyam S. Pattnaik, Swapna Devi, and M.R.Lohokare, "Electrically small patch antenna loaded with metamaterial," *IETE Journal of Research*, Vol. 56, No.6, pp.373-379, 2010.

[14] J.G. Joshi, S. S. Pattnaik, S. Devi, and M.R. Lohokare, "Frequency switching of electrically small patch antenna using metamaterial loading," *Indian Journal of Radio and Space Physics*, Vol.40, No.3, pp.159-165,2011.

[15] Montero-de-Paz, E. Ugarte-Munoz and F. J. Herraiz- Martnez, "Multifrequency self-diplexed single patch antennas loaded with split ring resonators," *Progress In Electromagnetics Research*, Vol.113, pp. 47-66, 2011.

[16] J. G. Joshi, Shyam S. Pattnaik, and S. Devi, "Partially metamaterial ground plane loaded rectangular slotted microstrip patch antenna," *International Journal of Microwave and Optical Technology*, Vol.7, No.1, pp. 1-10, 2012.

[17] J. G. Joshi, Shyam S. Pattnaik, S. Devi, and S. Raghavan, "Magneto-inductive waveguide loaded microstrip patch antenna," *International Journal of Microwave and Optical Technology*, Vol.7, No.1, pp. 11-20, 2012.

[18] J. G. Joshi, S. S. Pattnaik, S. Devi, and M. R. Lohokare, "Bandwidth enhancement and size reduction of microstrip patch antenna by magneto-inductive waveguide loading," *Journal of Wireless Engineering and Technology*, Vol. 2, No. 2, pp. 37-44, 2011.

[19] V.G. Veselago, "The electrodynamics of substances with simultaneously negative values of ε and μ," *Soviet Physics Uspekhi*, Vol.10, pp. 509-514, 1968.

[20] J.B. Pendry, A.J. Holden, D.J. Robbins, and W.J. Stewart, "Magnetism from conductors and enhanced nonlinear phenomena," *IEEE Trans. Microwave Theory Tech;* Vol. 47, No.11, pp.2075-2084, 1999.

[21] D.R. Smith, D.C. Vier, Th. Koschny, and C.M. Soukoulis, "Electromagnetic parameter retrieval from inhomogeneous metamaterials," *Physical Review*, Vol. E71, pp.036617-1- 10, Equivalent 2005.

[22] R. W Ziolkowski, "Design, fabrication, and testing of double negative metamaterials," *IEEE Trans. Antennas and Propag;* Vol. 51, No. 16, pp.1516-1529, 2003.

[23] F. Bilotti, A. Toscano, L. Vegni, K. Aydin, K.B. Alici, and E. Ozbay, "Equivalent-circuit models for the design of metamaterials based on artificial magnetic inclusions," *IEEE Trans. Microwave Theory and Tech;* Vol.55, No.12, pp.2865-2873,2007.

[24] S. S. Mohan, Design, modeling and optimization of onchip inductor and transformer circuits, A Ph.D.

Dissertation submitted to The Department of Electrical Engineering, and The Committee of Graduate Studies of Stanford University, December 1999.