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Research paper

Performance Characteristics of Head-Worn Antenna based on Dielectric Substrate Over WBAN Application

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Abstract

Performance characteristics of head-worn antenna based on dielectric substrate for WBAN application with various dielectric constant for square slot patch antenna are demonstrated in this paper. The impact of Electromagnetic (EM) energy from antenna towards human head and on antenna performance changes due to human head proximity are explored in this paper. The human head exposed to 5.8 GHz on ISM frequency band and radiation pattern, return loss, efficiency, and bandwidth and SAR distribution value performance have been thoroughly explored. However, decreasing the antenna size is a great topic of antenna development, which differentiates antenna performance for a small antenna. Multilayered human head phantom having five layers are constructed based on different tissues and these tissues represent human head parts such as (Skin, fat, Cerebrospinal fluid (CSF), bone and brain), all of each tissues are based on their electromagnetic properties and set at 5.8GHz.The proposed antenna with human head model simulated through (FDTD) using CST and variation of parameters of antenna with MATLAB. Antenna with FR4 substrate produces the highest SAR values while antenna with RT5880 substrate has the lowest SAR value 0.206 W/kg and 0.0784 W/kg at 5.8 GHz frequency exposed for 10g tissue respectively. It can be observed that the radiation pattern shows that the antenna gain with substrate of Rogers RT5880 is increased from front –to-back from 7.1 to 7.29 dB in the free space and on human head respectively. A good agreement between simulation and measurements in free space are obtained. The presented prototype has a potential to work for ISM applications.

Keywords: *Body Area Networks; Dielectric Constant; ISM; Multilayered Human Head Phantom; Specific Absorption Rate Square Slot Patch Antenna*

1. Introduction

Potential wellbeing risk of wireless body area network system(WBANs) which are caused by the electromagnetic(EM) interface with human head and how the effects of this interface can be reduced, have become a common issue and many factors can affect the EM interaction while using communication is used in close proximity to head. The growing international technology development, especially, in the field of Wireless body area network (BANs), wireless personal area network (WPANs) and telecommunications has increased interest in usable antenna designed for human body [1-3]. The challenge with this type of antenna design is the presence of a human body with losses that can absorb radiation, resulting in some increase in the absorption rate (SAR), as this can reduce gain and efficiency of antenna .Antennas is a major component of wireless communication and it's also integrated in electronics and telecommunication devices that enable the introduction of new solution, in medical services, national defense and sports activity [4]. A more recent approach is to use body-worn wireless networks, knows Wireless Body Area network (WBANs). Therefore, the design of the portable antenna has great interest, because it can be used in the same way on body the application .Although, keeping appropriate radiation characteristics with the lowest of specific absorption rate (SAR) value is a challenge task. Also, antennas are favored to be adaptable and conformal to the human body [5-9].Certain resonates frequency have been chosen to WBAN system, such as medical implant communication system (MICS: 400MHz) band, industrial scientific medical (ISM: 2.45GHz) and the ultra-wide band. In the optimization the antenna used for portable devices and it is significant to reduce the negative effects of electromagnetic interference (EM) between the biological and dissipative tissues [10]. The effect of the human body as lossy tissue on radiation efficiency is challenging task. The antenna is needed to act near to body or head, which has a very high dielectric constant, the effect of this high dielectric surface leads to frequency detuning. Finally, the radiation from the back lobe of the antenna affects the human body. Therefore, it is suggested to use unidirectional antenna, such microstrips, or other insulator material in order to decrease the effect radiation to the human body on its performance and reduce SAR levels [11].Therefore, in order to research usable antennas and integrated portable devices systems, it is important to analysis the interaction between the human body and the electromagnetic (EM) emitted from the antenna. The influence of the human head on the performance of the antenna and the affects of electromagnetic waves on the human body are investigated. In order to investigate the performance of antenna and the effect of EM, it must be utilized a human head phantom as validation tool before the antenna is applied to the human body. From the literature, it has been observed that most of the researchers considered microstrip patch antenna as one of the most suitable candidates for portable applications due to low profile, easy to integrate and cost-effectiveness. Therefore, various antennas have been studied including inverted-

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F based on microstrip [12-18]. The specific absorption rate is the number of merits to evaluate the SAR value per biological tissue. Therefore, the maximum average specific absorption rate (SAR) limit is considered 1.6 W/Kg and 2W/kg averaged 1 and 10 gram both FCC and ICNIRP respectively [19].

In this work, as square slot antennas are designed at (5.725-5.857 GHZ) for ISM band application. To assess the impact of EM radiation to human head with varieties in the dielectric properties of human head which exposed at 5.8 GHz and also comparisons of the two different substrates with different permittivity (εr) are used and the performance and characteristics of the designed antennas at both the on/off head-worn antenna in terms of radiation properties, return loss and SAR due to the proximity of the body have been examined in this paper. Five significant layers of human head which includes skin, fat, bone, CSF and brain have been developed. The structures are designed and analyzed using CST microwave software and MATLAB.

2. Research Method and Materials

In this section will be clarified sequential of the research , including research configuration, investigate process is discussed, it is organized into a few sub-sections. Tables and Figures are introduced, as demonstrated as follow.

2.1. Antenna design

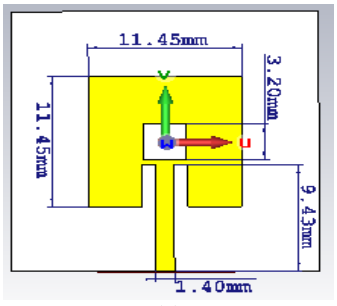
The geometry of square ring patch antennas for ON and OFF WBAN application is shown in Fig1(a)-1(b). These antennas were fabricated on FR4 substrate and Roger RT5880 which has a relative dielectric constant of 4.3 and 2.2 respectively. The radiating part of antenna and ground were positioned on front and back of the substrate. The both antennas were designed and simulated using CST Microwave studio based on finite different time domain and variation of parameters of antenna is computed MATLAB. Table 1, Table 2 and Figure 1 are shown a correlation between size value and design configuration of the antenna.

Table 1: Summary of antenna Parameters for FR4

Parameters	Symbols	Value unit (mm^2)
Patch	(L_1×W_1)	11.45*11.45
Feed length	Lf	9.43
Height	h	1.6
Permittivity	$\mathcal{E}r$	4.3
Tan δ	δ	0.025
Gap	x	1
Ring Slot	Wr	3.20*3.20

Table 2: Summary of antenna Parameters for RT5880

Parameters	Symbols	Value unit (mm^2)
Patch	(L_1×W_1)	16.15*16.15
Feed length	Lf	13.38
Height	h	1.57
Permittivity	$\mathcal{E}r$	2.2
Tan δ	δ	0.009
Gap	x	1
Ring Slot	Wr	3.20*3.20



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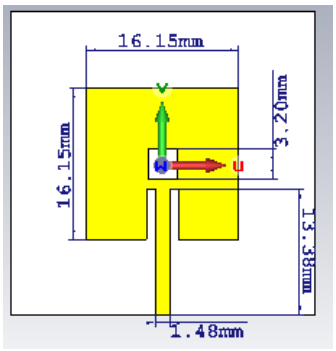


(b)

Fig. 1: Layout of the two antennas for various substrates (a) FR4 substrate (b) Rogers RT5880

Three parameters are fundamental of the proposed design, such as frequency, dielectric substrate constant ε_r, and thickness of the substrate. To realize the preferred resonant frequency, the following mathematical approach is used [20]:

$$\mathrm{Wo} = \frac{\mathrm{C}}{2\mathrm{fr}}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{2.1}$$

Where Wo, is the width of the patch while c, and εr are the speed of light and dielectric constant permittivity of the substrate, and fr is resonant frequency respectively.

$$\varepsilon_{\mathrm{ref\ f}} = \frac{\varepsilon_{\mathrm{r}} + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + \frac{12h}{w}}}\right) \tag{2.2}$$

Where, ($\varepsilon reff$) is the effective permittivity where (h) is variable of the substrate thickness.

$$L_{eff} = \frac{C}{2\,fr\sqrt{\varepsilon_{reff}}} \tag{2.3}$$

$Leff$ is the effective length of the patch while εreff is the effective of the permittivity.

$$\Delta L = 0.412h\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{w}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{w}{h} + 0.8\right)} \tag{2.4}$$

ΔL and Lo are the length extension and the actual length of the patch respectively.

$$L_o = L_{eff} - 2\Delta l \tag{2.5}$$

$$Z_o = Z_{in}\cos^2\left(\frac{\pi d}{L_o}\right) \tag{2.6}$$

Zo and Zin are characteristics impedance, Zin is the input impedance while d is inset depth. The complete ground planes, as well as the substrate, is six times larger than the substrate thickness in addition to the length or width used. The following equation can be used to calculate the ground plane:

$$Wg = 6h + w \tag{2.7}$$

$$Lg = 6h + L \tag{2.8}$$

2.2. Specific Absorption Rate (SAR)

The value of the specific absorption rate (SAR) is determined the rate at which power is absorbed by biological tissue when is exposed to electromagnetic field. SAR value is normally estimated for 1 g or 10 g of simulation biological tissue in the shape of a cube and as far as possible set by the FCC and European Union is 2.0 W/Kg and 1.6 W/Kg averaged over 1 gram averaged over 10 g of actual tissue respectively. It is significant to characterize the dielectric properties of the each tissue, so as to do theoretically calculation for the SAR. The conductivity and relative permittivity are the most critical dielectric properties of the human tissue in the body. Theoretically calculation for the SAR, the following mathematical approach is applied.

$$SAR = \frac{\mathrm{d}}{\mathrm{dt}}\left[\frac{dw}{dm}\right] = \frac{d}{dt}\left[\frac{dw}{\rho dv}\right] \tag{2.9}$$

Where *dw, dv and* ρ and h are incremental energy (dw), in volume element and density.

$$SAR = \frac{\sigma \mathrm{E}^2}{\rho} \tag{2.10}$$

Where ρ, σ, *and* E and are the density, electrical conductivity and electrical conductivity tissue. The power density farmed by antenna can be determined by utilizing the following question.

$$S = \frac{PtGt}{4\pi d^2} \tag{2.11}$$

Pt and Gt are the radiated power (W) and the Gain of transmitter antenna while d is the distance from antenna in meters. The impedance of human head tissues can be determined by formula.

$$\eta = \eta_o = \sqrt{\frac{\mu_r}{\varepsilon_r}} \tag{2.12}$$

3. Result and Analysis

In this section, it is clarified that the results of outcome and it the meantime is given at the complete discussion. Results can be represented in figures, graphs, tables, and others. The discussion can be made a few sub-topics.

3.1. Simulation and measurement of antennas results

In this section, the antennas performance for free space is analysed and compared the simulated and measured results which is obtained in using CST Microwave studio based on finite different time domain and variation of parameters of antenna is computed MATLAB. The simulated and measured return loss of the presented antenna configuration based on FR4 substrate has showing in Figure 2. The simulated and measured the reflection coefficient (S11) exhibit the outcome is significant as it covers the total ISM band (5.725-5.875) GHz. Both the simulated and the measured return loss is compared, the (S11) are all below -10 dB. The simulated and measured parameters are observed those reflection coefficients of -42.821 dB and -20.46 dB, while bandwidths are 263.3 MHz and 280 MHz respectively. The measured return loss (S11) is shifted to towards the right side of 5.8 GHz resonance frequency as shown in Figure. 2 which is attributed the factors such as the impact of SMA plug, fabricating errors and dielectric losses of the materials.

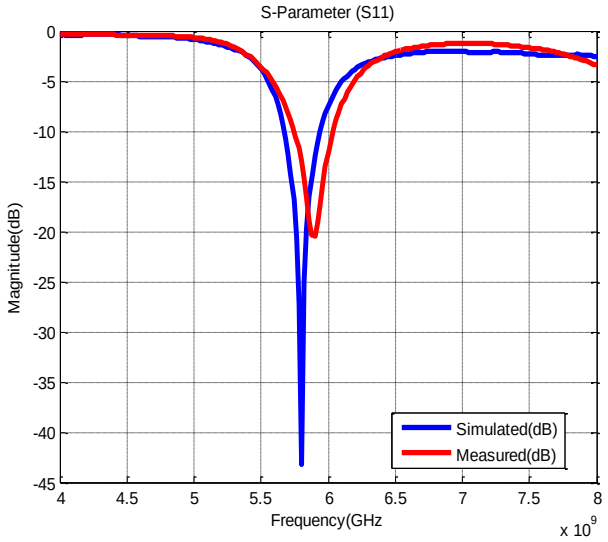


Fig. 2: Comparison simulated and measured S-parameter of the proposed antenna with FR4 substrate material

Figure 3 shows the return loss results of the proposed antenna using Roger RT5880 substrate.The achieved simulated and measured the return loss bandwidths of proposed antenna are around 128.4 MHz and 125.2 MHz with relating return loss of -24.5 dB and -27.2 dB respectively, Both the simulated and the measured return loss is compared, the (S11) are all below -10 dB. The measured return loss (S11) is exactly same as the simulated result at 5.8 GHz.

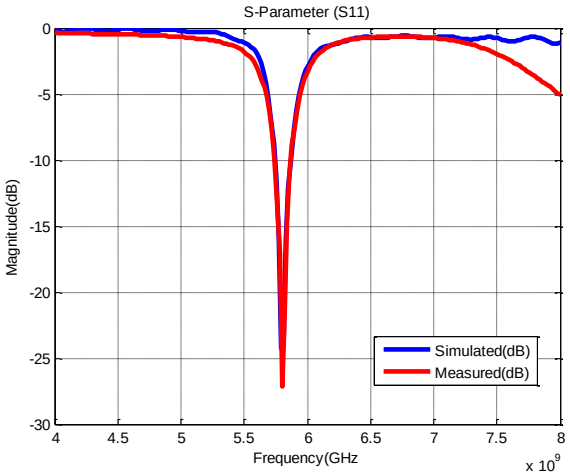
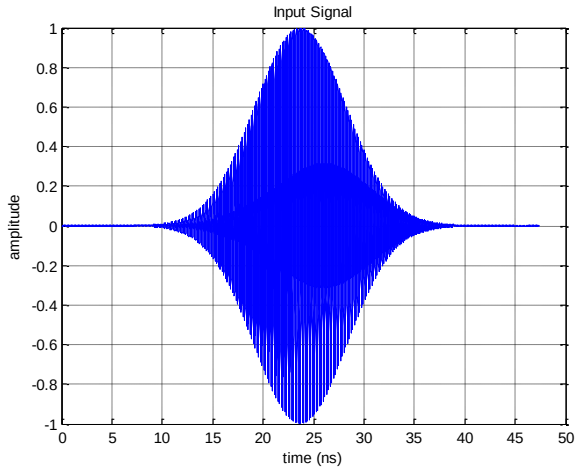


Fig. 3: Comparison simulated and measured S-parameter of the proposed antenna with Rogers RT5880 substrate material

In Figure 4 demonstrates modulated Gaussian pulse input signal where the frequency mode is chosen 5.8 GHz with bandwidth (5.725-5.857 GHz). It can be observe that two pulses are used in order to excite the antenna and it can be noticed that amplitude output signal is interval between (0.2 -0.2 amplitude) when is applied the FR4 material while the interval between (0.4 -0.4 amplitude) when is applied the Rogers RT5880 material.



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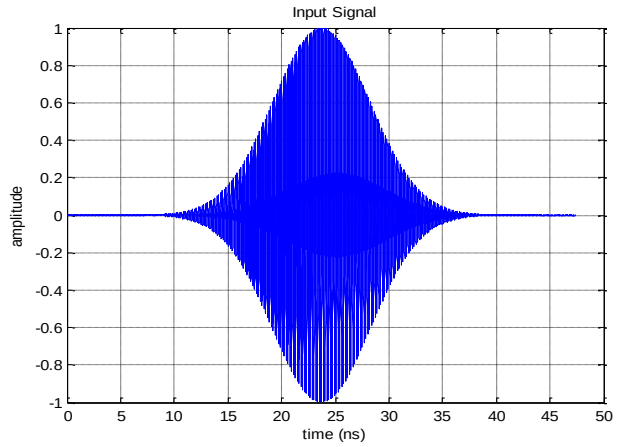


(b)

Fig. 4: Generated Gaussian signal time (ns) vs amplitude (V) for various substrates (a) FR4 substrate (b) Rogers RT5880

In Figure 5 shows the comparison of VSWR of the proposed antennas which all cases are lower than 2.Therefore, the outcome of simulation and measurement of VSWR indicates a good agreement.

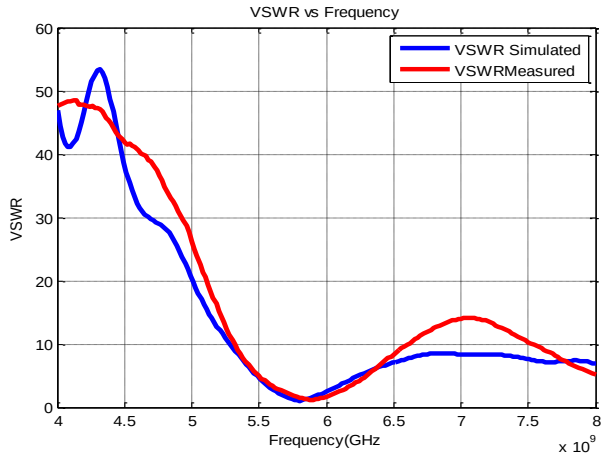


Fig. 5: VSWR of the Proposed Simulated and Measured Result at 5.8 GHz

The difference between the Simulated radiated efficiency in the case of an antenna with constructed different dielectric constant whose permittivity are $\varepsilon r = 4.3$ and, $\varepsilon_r = 2.2$ at 5.8 GHz is 54% and 93% in free space respectively in free space. It can be observed that the simulated efficiency is higher when is applied lower dielectric constant $\varepsilon_r = 2.2$ at 5.8 GHz as shown in Figure 6.

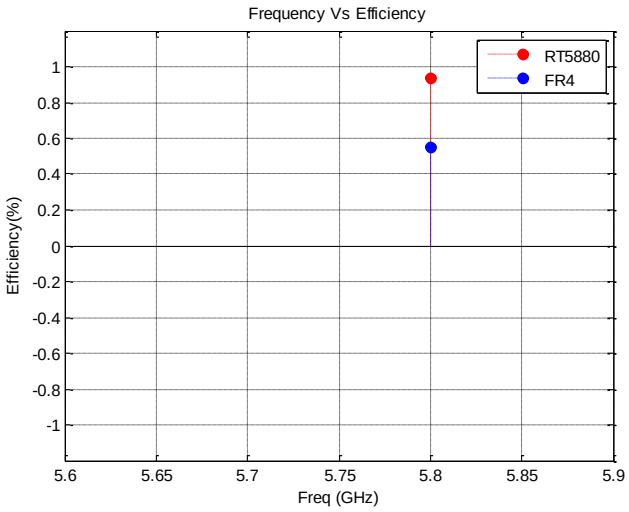
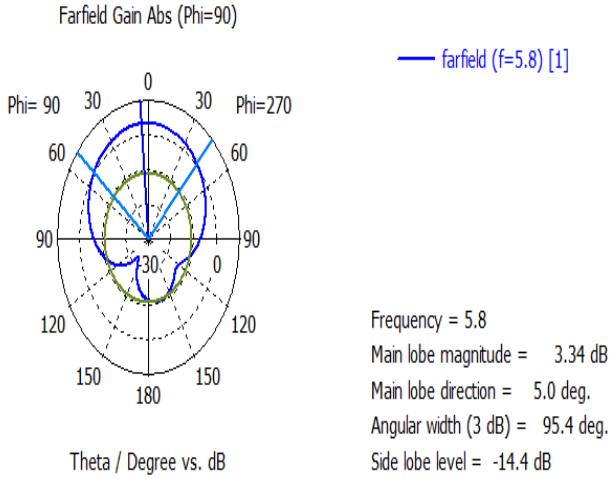


Fig. 6: Simulated radiation efficiency comparison between Rogers RT5880 and FR4 substrates

Figure 7 shows that the gain of the proposed antenna constructed with $\varepsilon_r = 4.3$ and, $\varepsilon_r = 2.2$ at 5.8 GHz is 3.34 dB and 7.1 dB respectively in free space. It can be observed that the polar plot Indicates when Phi=90° and 270°. The main beam lobe direction is 5.0°with beam width 95.4° and side lobe level is -14.4 dB respectively when is applied FR4 as substrate while The main beam lobe direction is 0°with beam width 79.5° and side lobe level is -23.4 dB.



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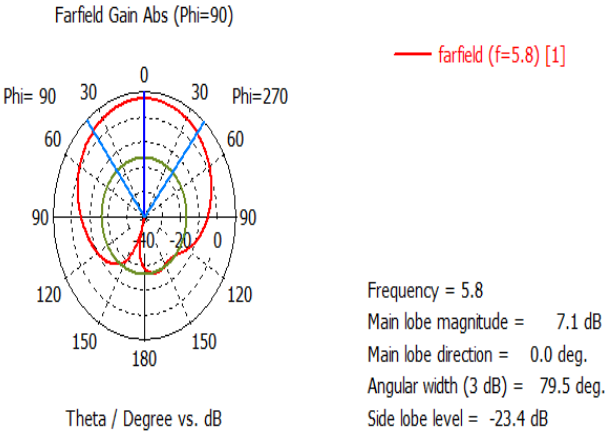


(b)

Fig. 7: Simulated 2D Radiation Pattern comparison between (a) FR4 substrate and (b) Rogers RT5880at 5.8 GHz

Table 3: Comparison of Simulated and Measured Result of with various substrates

Parameters	Symbol	Simulated	Measured
FR4	Return loss(dB)	-42.82 dB	-20.46 dB
	Bandwidth(MHz)	263.3MHz	280MHz
Rogers	Return loss(dB)	-24.5 dB	-27.2 dB
RT5880	Bandwidth(MHz)	128.4MHz	125.2 MHz

3.2. Proposed Phantom model of human head and SAR analysis

In this section, the performance of patch antenna on the human head and the SAR value due to square ring antenna with two different substrates whose permittivity are $\varepsilon r = 4.3$ and, $\varepsilon_r = 2.2$ at 5.8 GHz with human head phantom are investigated. The proposed antennas along with its geometry are indicated in Figure 1.There are different ways for SAR assessment; in general, numerical modelling and experimental test are the two standards in SAR examines.

The geometry of the phantom heads such as cubical and spherical phantom are usually used for analysis the SAR values. In this case, configuration of the phantom heads, like the spherical is modelled using in CST for analysing the SAR and this multilayered human head phantom constructed five layers such as skin, fat, bone, CSF and brain. For the spherical phantom with a radius of 47 mm is based on the shape of a typical adult human heads shown in Figure 8; therefore, these phantoms are used for the evaluating SAR values. Thickness and dielectric properties of the layers which is considered in human head are listed in table2.

Table 4: Dielectric properties of biological tissue used in the head Model at 5.8 GHz with 100mW power [19]

Tissue	Relative permittivity	Tan δ	Thickness (mm)
Skin	35.11	0.33	2
Fat	9.86	0.26	2
Bone	9.67	0.37	7
CSF	60.47	0.40	1
brain	44.00	0.35	35

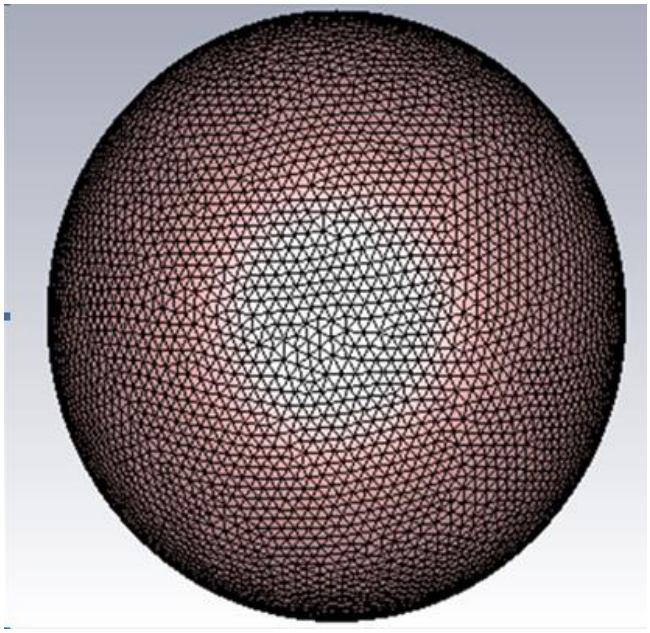
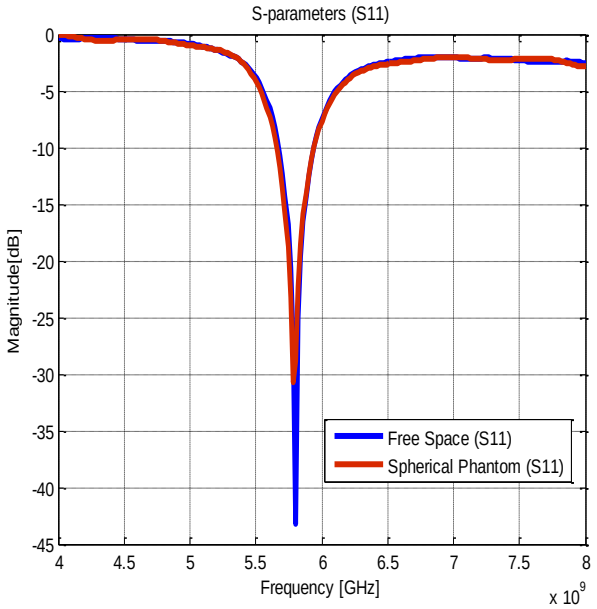


Fig. 8: Proposed Phantom Models of Human Head Spherical phantom

The proposed antennas are designed and placed on human head, in order to operate proximity of human head, therefore, the human head model affects the antenna performance such as detuning, and radiation pattern and efficiency due to mounting of the antenna on human body have been countered in number of ways. The evaluation of the simulated return loss of the presented antenna in free space and mountain on the human head phantom is shown in Figure 9 , and all magnitudes of the (S11) are under -10 dB and (VSWR< 2) at a resonant frequency of the proposed antenna. Figure 9 (b) shows the return loss results of the proposed antenna using Roger RT5880 substrate is shifted of the resonant frequency of 5.8 GHz from 5.8 to 5.88 with same bandwidth of the application due to body which is considered as lossy tissue and it also depends on the shape of the phantom head model.



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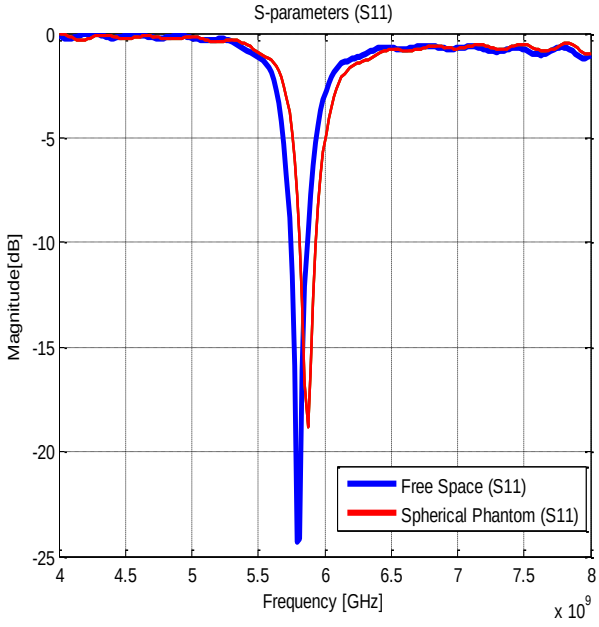


(b)

Fig. 9: Comparison simulated in free space and on human head model S-parameter for with (a) FR4 and (b) RT5880 substrates

Table 5. Comparison of Simulated in free space and human head phantom with various substrates

Materials	Parameters	Free spaces	Model
FR4	Return loss(dB)	-42.82 dB	-30.441 dB
	Bandwidth(MHz)	263.3MHz	281.5MHz
RT5880	Return loss(dB)	-24.5 dB	-19.512 dB
	Bandwidth(MHz)	128.4MHz	124.4 MHz

The efficiency of the antenna which is printed FR4 is also reduced from 54% to 42% when brought in close proximity to the human head phantom, due to high value of human tissue's dielectric constant , while the efficiency of the antenna which is fabricated Rogers RT5880 is less decreased from 93% to 91 % as shown in Figure10.

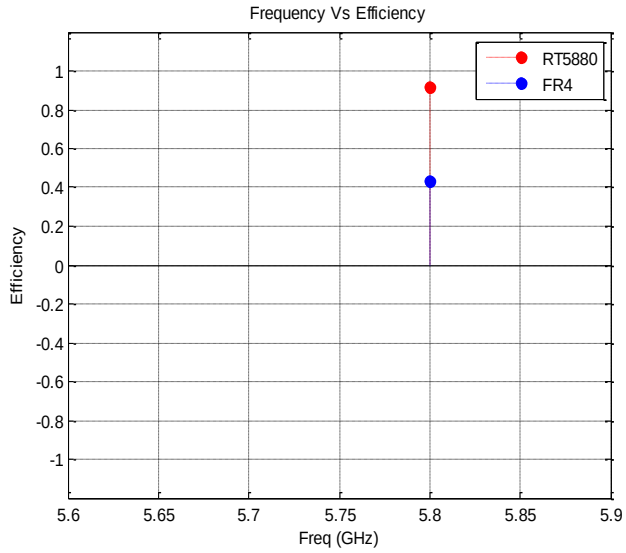
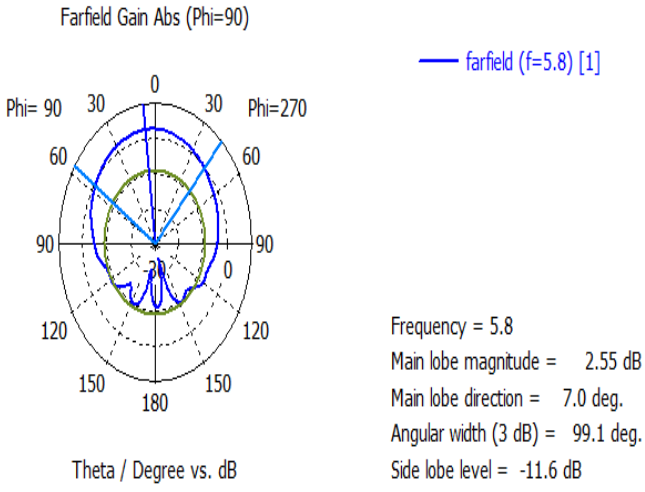


Fig. 10: Comparison Simulated radiation efficiency in close proximity to the human between Rogers RT5880 FR4 substrates

The proposed antenna radiation pattern is defective by the presence of human heads. Figure 11 show the proposed radiation pattern, which is parallel to the human head at different distances from the surface of the head. It can be seen that some changes occur as the approach of the human head and the different placement positions affect the direction of main beam due to the shadowing effect of the human head. There is a significant increase in gain and this indicates that the lower permittivity has the higher the antennas gain comparing FR4 material. It can be observed that the radiation characteristics show that the gain of the antenna which is fabricated Rogers RT5880 is increased from front –to-back from 7.1 to 7.29 dB in the free space and on human head respectively.



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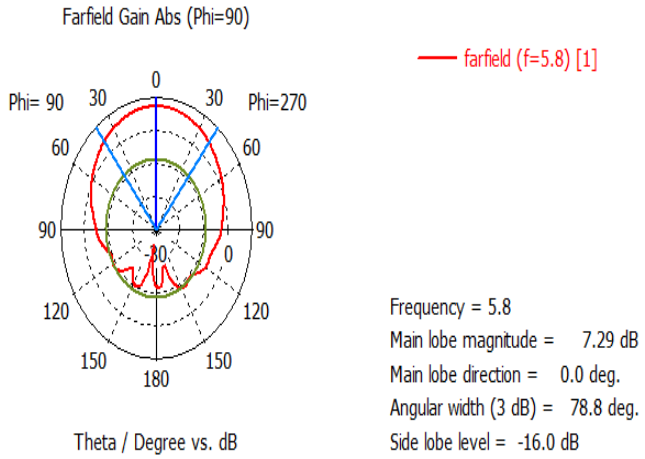

(b)

Fig. 11: Comparison simulated 2D Radiation Pattern in close proximity to the human between (a) FR4 & (b) RT5880 substrates

The Figure 12 shows variation of the SAR and simulated SAR distribution at 5.8 GHz against separation distance between head and antenna.It can be seen that the antenna with substrate of FR4 produces the highest SAR values gradually while the antenna with Rogers RT5880 substrate contributes low SAR value at 5.8 GHz for 10g tissue. In Figure 13.

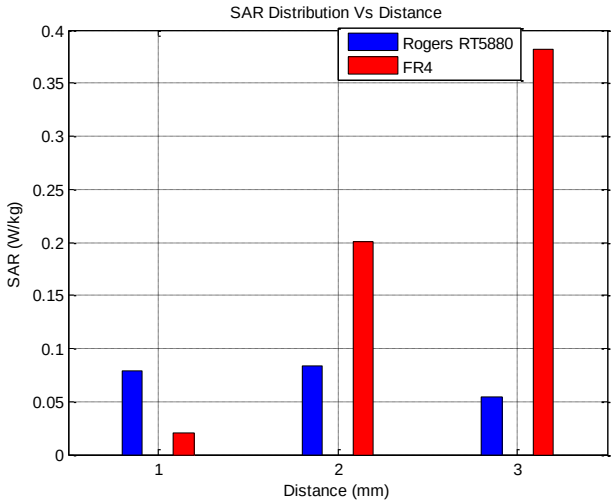

Fig. 12: Comparison of SAR Variation Vs Distance in close proximity to the human between Rogers RT5880 FR4 substrates

The SAR calculations were performed with the microwave CST studio 2015. Finite Difference Time Domain (FDTD) method is used for this section, corresponding mesh properties were set for all simulation, separation distance between head and antennais about 0 mm. Thus, the antenna with FR4 substrate demonstrated the highest SAR values compared with other substrates used. Various SAR values were detected due to the various substrates with various dielectric properties. Figure 13 indicates the simulated SAR values with human head phantom were 0.0784 W/Kg and 0.206 W/Kg for 10 g respectively. Moreover, SAR rises when the conductivity has increased. It can be seen the head tissues which has high conductivity is easier to absorb the emitted electrometric waves from antenna, this more radiation has penetrated human head. In general, the results show the return loss of both materials slightly shifted due to presence of spherical human head modeling. The spherical human head phantom consists of various tissues and each tissue is based on their electromagnetic properties at 5.8 GHz. Therefore, the loss tangent value of substrate inversely proportional at the SAR Value. As a result, the values Roger RT5880 are much lower than the SAR values of FR4. The returning, pattern

structural changes and degreased efficiency have been counted as results mounting of the antenna on the human head model. The maximum absorption rate (SAR) is simulated by considering average limits of 2 W/kg of the ICNIRP on 10 gram of tissue.

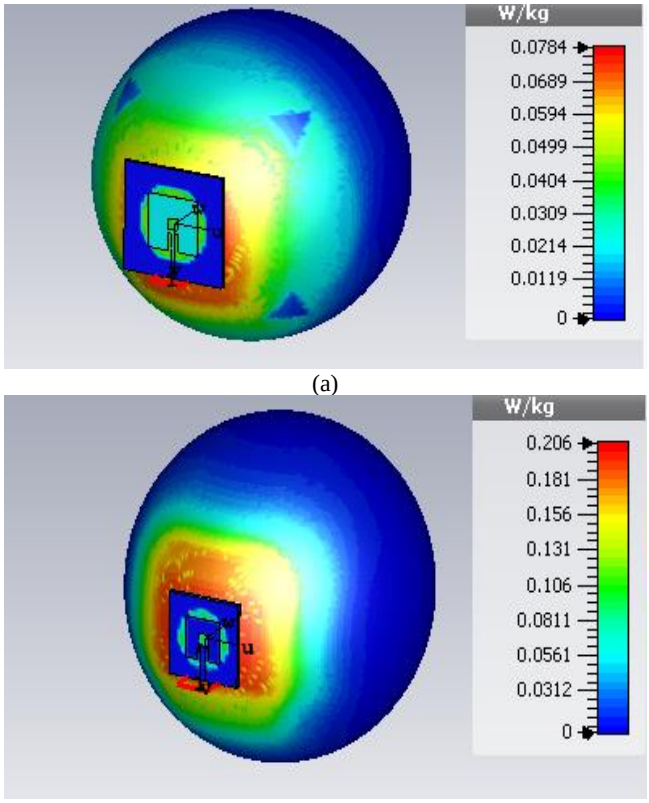

Fig. 13: Simulated SAR distribution at 5.8GHz for (a) RT5880 and (b) FR4

Figure 14 indicates the measurement set up on the fabricated on FR4 and Rogers RT5880 with a relative permittivity of 4.3 and 2.2 respectively. The simulated and measured reflection coefficient has a good agreement in terms obtained results at 5.8 GHz.

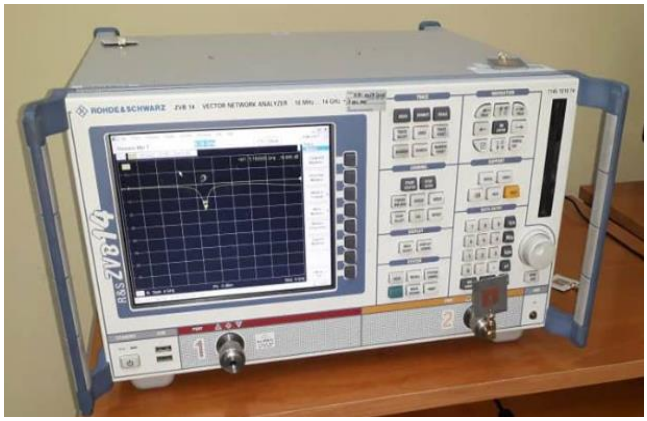

Fig. 14: Proposed Antenna Prototype and Measurement Set-up for Square Ring Antenna

4. Conclusion

In this work presents the performance of various antennas in free space and at human head. The impact of Electromagnetic (EM) wave radiated from antenna to human head by measured SAR value. Specific absorption rate (SAR) induced human head model in the near-field with a low profile antenna for head-worn WBAN at 5.8 GHz is proposed. The multilayered human head phantom which consist of different tissues are used, with an aim to determine the maximum SAR value for 2 W/Kg averaged over 10g of tissue with 100mW. Therefore, the antenna parameters such as the reflection coefficient, gain and SAR of the presented antenna are investigated. The gain of the antenna with substrate of Rogers RT5880 has been increased from 7.1 to 7.29 dB when placed on human head.The antenna with substrate of FR4 Produces the highest SAR values 0.206 W/kg while the antenna with RT5880 substrate produces low SAR value 0.166 W/kg at 5.8 GHz for 10g tissue. Also, the results indicate that some pattern changes take place due to the presence of human head phantom as the antenna approaches to head. The periodic load analysis for body communication through the surface wave and integration of the isolated layer to prevent direct electrical contact to the antenna with the human body communication is recommended as a part of future study.A good agreement between simulation and measurements are obtained. The presented prototype has a potential to work for ISM applications.

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References

[1] Zheng YL, Ding XR, Poon CC, Lo BP, Zhang H, Zhou XL, Yang GZ, Zhao N, Zhang Y (2014), "Unobtrusive sensing and wearable devices for health informatics," *IEEE Trans. Biomed. Eng* 61(5), 1538–1554.

[2] Movassaghi S, Abolhasan M, Lipman J, Smith D & Jamalipour A (2014), "Wireless body area networks: A survey,". *IEEE Commun. Surveys Tuts* 16(3),1658–1686.

[3] Yoo HJ (2013), "Your heart on your sleeve: Advances in textile-based electronics are weaving computers right into the clothes we wear,". *IEEE Solid-State Circuits Mag*, 5(1), 59–70.

[4] Januszkiewicz Ł, Di Barba P, Hausman S (2016), "Field-based optimal placement of antennas for body-worn wireless sensors". *Sensors* 16(5), 713.

[5] Koski K, Sydnheimo L, Rahmat-Samii Y, & Ukkonen L (2014), "Fundamental characteristics of electro-textiles in wearable UHF RFID patch antennas for body-centric sensing systems". *IEEE Trans. Antennas Propag* 62(12), 6454–6462.

[6] Raad HR, Abbosh AI, Al-Rizzo HM & Rucker DG (2013), "Flexible and compact AMC based antenna for telemedicine applications". *IEEE Trans. Antennas Propag* 61(2), 524–531.

[7] Yan S, Soh PJ & Vandenbosch GAE (2014), "Low-profile dual-band textile antenna with artificial magnetic conductor plane". *IEEE Trans. Antennas Propag* 62(12), 6487–6490.

[8] Cook BS & Shamim A (2013), "Utilizing wideband AMC structures for highgain inkjet-printed antennas on lossy paper substrate," *IEEE Antennas Wireless Propag. Lett.* 12, 76–79.

[9] Saeed SM, Balanis CA & Birtcher CR (2016), "Inkjet-printed flexible reconfigurable antenna for conformal WLAN/WiMAX wireless devices". *IEEE Antennas Wireless Propag. Lett* 15, 1979–1982.

[10] Mäkinen RM & Kellomäki T (2014), "Body effects on thin single-layer slot, self-complementary, and wire antennas". *IEEE Trans. Antennas Propag.* 62 (1), 385–392.

[11] Velan S, Sundarsingh EF, Kanagasabai M, Sarma AK, Raviteja C, Sivasamy R, Pakkathillam JK (2015) "Dual-band EBG integrated monopole antenna deploying fractal geometry for wearable applications." *IEEE Antennas and Wireless Propagation Letters* 14,249-252.

[12] Samal PB, Soh PJ & Vandenbosch GAE (2014), "UWB all-textile antenna with full ground plane for off-body WBAN communication". *IEEE Trans. Antennas Propag.* 62(1), 102–108.

[13] El Hajj W, Person C & Wiart J (2014), "A novel investigation of a broadband integrated inverted-F antenna design; application for wearable antenna," *IEEE Trans. Antennas Propag*. 62(7), 3843–3846,

[14] Soh PJ, Vandenbosch GAE, Ooi SL & Husna MRN (2012), "Design of a broadband all-textile slotted PIFA*," IEEE Trans. Antennas Propag*. 60(1), 379–384.

[15] Raad HR, Abbosh AI, Al-Rizzo HM & Rucker DG (2013), "Flexible and compact AMC based antenna for telemedicine applications," IEEE Trans. Antennas Propag. 61(2), 524–531.
[16] Agneessens S, Lemey S, Vervust T & Rogier H (2015), "Wearable, small, and robust: The circular quarter-mode textile antenna*". IEEE Antennas Wireless Propag. Lett*. 14, 1482–1485.
[17] Scarpello ML, Vallozzi L, Rogier H, & Vande Ginste D (2012), "Highgain textile antenna array system for off-body communication," *Int. J. Antennas Propag.* 2012, 573438.
[18] Kang S & Jung CW (2015), "Wearable fabric reconfigurable beam-steering antenna for on/off-body communication system," *Int. J. Antennas Propag.* 2015, 539843.
[19] Bjorninen T, Yang F (2016), "Low-profile head-worn antenna with a monopole-like radiation pattern". *IEEE antennas and wireless propagation letters* 15, 794-797.
[20] Mumin AR, Alias R, Abdullah J, Dahlan SH, Abdulhasan RA, Ali J(2017), "Simulation of Square Ring Microstrip Patch Antenna Performance Based on Effects of Various Dielectric Substrates". *In Asian Simulation Conference*, Singapore 679-694. Springer,