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Investigation into Low SAR PIFA Antenna and Design a Very Low SAR U-slot Antenna using Frequency Selective Surface for cell-phones and Wearable Applications

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Abstract

There are very important questions. “Do Electromagnetic waves have irreparable effects on human or not?” “Are there any relation between cancer and waves?” and finally “what should we do to be safe?”. In the present article, these questions will be answered simply and professionally. First of all, Specific Absorption rate (SAR) is define then L-Slot and U-slot antenna is designed and simulated using cell-phones and wearable applications, operating at 900 and 1800 Mhz consist of GSM900 and GSM1800. Standard frequency band width for the first and second band is 30 and 75 MHz for uplink and downlink and in the present research these numbers are obtained. The SAR of each antenna is measured and is compared with each other. Thanks to design of antenna, The SAR of U-Slot antenna is very low and it is almost stimulated 0.2783 W/kg and this sentence means this antenna is anti-cancer. Finally, Some SRR unit-cells are designed and when they are used in structure, SAR will be more decrease. Last SAR value is 0.16 and 0.12 for each bands .In the last table, There are some comparison between different creditable references and present article SAR reduction is acceptable and it is near to 30 percentage.

Keywords:

PIFA Antenna;
U-Slot Antenna;
L-Slot Antenna;
Meta-Materials;
SRR Surfaces;
SAR (Specific Absorption Rate).

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1- Introduction

PIFA antenna was invented many years ago and it has been using since times ago. This type of antenna has many advantages like: small size, low cost, simple structure and also this antenna is low SAR (the rate of energy deposited per unit mass of tissue) antenna and this sentence means this antenna is very low noisome, but there are some disadvantages for PIFA antenna like: low B.W. and mono-band antenna. In this paper, first there are some information about electromagnetic waves and cancer and there are some useful methods to reduce the probability of cancer. Then, two type of PIFA antenna are designed and stimulated. The SAR of each antenna is measured and compared with each other. Finally, a very low SAR U-slot antenna is designed then some SRR unit-cells are design and if these unit-cells will use between antenna and human head, The SAR of U-slot antenna will be more decrease and because of this reason we called this paper anti-cancer.

In 1997, a group of scientists announced that experiment had shown cell-phone waves increase the percentage of lymphoma between mice. In 2002 other group of scientists invited to national T.V. in Australia and declared that there is no lymphoma effect on mice when they are remained at 900MHz electromagnetic wave for a long time and the second group of scientist publishes lots of article about this subject [1]. This program were accosted with lots of protests.

Finally, Professor LEE wrote a protest against that scientist in IEEE magazine and showed with simple examples their papers were fault. One of the most simple examples was about mice health ,in that paper reported that mice were death in 20th mouth but in different table their growth quantity were measured till 26th mouth [1]. Nowadays, the fourth generation of mobile communications, the Long Term Evolution (LTE), is expected to deliver multimedia services anywhere, anytime. The LTE standard is scheduled to operate in different frequency bands [2]. So mobile antenna have been more complicated.

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The mutual effects of the human head and the antenna have been introduced by many research works. Through the last years, different methods to reduce the SAR produced by a handset antenna were used-specifically, auxiliary antenna elements, ferrite loading, the electromagnetic band-gap (EBG)/ artificial magnetic conductors (AMCs) surfaces, and meta-materials. The Specific Absorption Rate (SAR) is generally accepted as the most appropriate dosimetric measure, and compliance with international guidelines is assessed. For example, the IEEE C95.1-1999 standard restricts the SAR averaged over any 1g of tissue in the shape of a cube to less than 1.6 W/kg ($SAR_{1,gmax} \leq 1.6$ W/kg) [3]. The ICNIRP basic restrictions limit the SAR averaged over 10g of contiguous tissue to less than 2 W/kg. [4] To harmonize with the ICNIRP guidelines, the IEEE C95.1-2005 standard restricts the SAR averaged over any 10g of tissue in the shape of a cube to less than 2 W/kg ($SAR_{10,gmax} \leq 2$ W/kg) [5].

The power absorbed by the human body in the presence of an incident electromagnetic field is given by equation (1);

$$P_{abs} = \frac{1}{2}\int \sigma |E|^2 \, dV \qquad (1)$$

Where σ is the conductivity of the human tissues, and E is the intensity of the electric field inside the body. Equation (1) indicates that the absorbed power is related to the electric field, so that maximum SAR values are recorded in the areas where maximum electric-field intensities occur. Based on the deduction that peak averaged SAR values are generated from high near fields [6].

SAR mathematical definition is as follows: The time derivative of the absorbed energy boost for increase in crime. ρ is the density increased and the volume is dv.

$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right) = \frac{d}{dt}\left(\frac{dW}{\rho dV}\right) \qquad (2)$$

According to this definition, SAR unit watt per kilogram SAR calculation formula can be stated as follows:

$$SAR = \frac{\sigma}{2\rho} E^2 \qquad (3)$$

In this formula E (v/m) electric field and σ (s/m) conductivity and ρ (kg/m^3) is density of the object

2- The Effects of Electromagnetic Waves on Human

These waves have dangerous effects on humans. Some of them are summarized in Table 1. If the central antenna waves as much as 400 meters away, there will be no danger. The number of articles is 400 meters. The most important effects of electromagnetic waves could be mentioned: Increased rate of brain cancer and lymphatic, increased rate of seizures in patients with epilepsy, Effects on Children.

Table 1. Biological effects

Reference	Biological effects	Power density
Altpeter 1997	Weakness, fatigue, pain in the hands and feet, learning disorders	20 μW/m²
Eger 2004	Tripling of cancer, at a distance less than 400 meters from phone masts	1 mW/m²
Navaro, Oberfeld, Santini 2004	At a distance less than 350 meters from the mast Phone: cognitive dysfunction, muscle aches, headache, dizziness	<2.7 mW/m²
Pyrpasopoulo	Changes cell activity in students	40 m W/m²
Adey 1982	Increasing infertility in men	66 mW/m²
Elekes	Changes in the function of the immune system	1000 mW/m²

This content is only a small part of the impact of the waves. With increasing frequency and amplitude of the electric field effects will also be more and more dangerous.

3- Theoretical analysis

Analysis rectangular patch and mono-band PIFA antenna analysis are so well-known, which can be seen in different references.

These antennas are entirely theoretical analysis is very time consuming why should the computer be used to analyse the antennas. Such antennas easiest method to analyse the theory of antenna is using segmentation and de-segmentation theories. With this method, any complex shape can be divided into simple shapes known.

a) Segmentation

The original form should be divided into several parts. Then different parts should be joined together two by two. The important thing is that the impedance matrix of small parts should be well known because of this reason Created the small rectangular patch must be selected. For example, for the analysis of a U- slot antenna, should be divided into five rectangular patches. Small parts will be combined two by two by following Equation.

$$[Z_{AB}] = \begin{bmatrix} Z_{pa} & 0 \\ 0 & Z_{pb} \end{bmatrix} + \begin{bmatrix} Z_{paq} \\ -Z_{pbr} \end{bmatrix} . [Z_{qq} + Z_{rr}]^{-1} . [-Z_{qpa}, Z_{rpb}] \quad (4)$$

The new boot is fortunately no longer need to use these Equations.

b) De-segmentation

This method is similar to the previous method. With the difference that must first be considered a general form which is well-known like a rectangular patch antenna then small parts should be reduced from original shape. For example, for the analysis of a U-slot antenna, first a main rectangular patch should be considered and then three rectangular patches should be reduce from original shape [7]. In this case, Smalls parts should be combined two by two by following Equation.

$$Z_a = Z_{ppb} - Z_{pd} . [Z_{ddb} - Z_{ddB}]^{-1} . Z_{dp} \quad (5)$$

4- Design and Simulation L-slot Antenna

A Dual band antenna can be created by using A L-slot in patch plane in mono-band PIFA antenna. This antenna should be resonated at cell-phone frequency 800 and 1800 MHz so the length and width of antenna should be selected according to these frequencies. Theoretical analysis can be seen of L-slot antenna in Reference number 8. After some simulation, L-shape antenna is designed and simulated, Overview of Antenna in Figure 1 can be seen and in this antenna three shorting pin are used (Figure 2). All parameters are shown in these figures and the exact values of these parameters are shown in Table 2. Ground antenna is much larger than usual and we have a specific purpose from this designing. Simulated antenna can be seen in Figure 4 which is simulated in CST studio 2015 software.

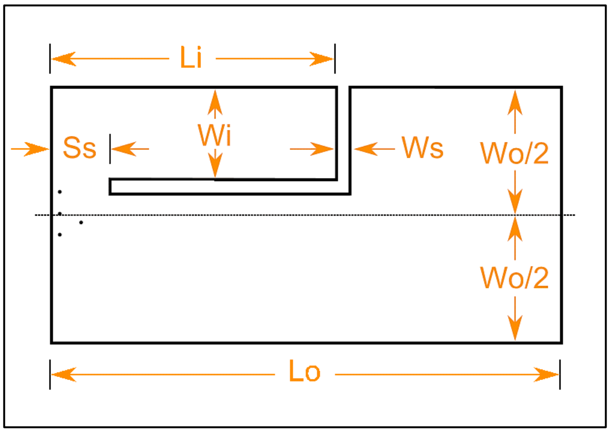

Figure 2. overview of antenna

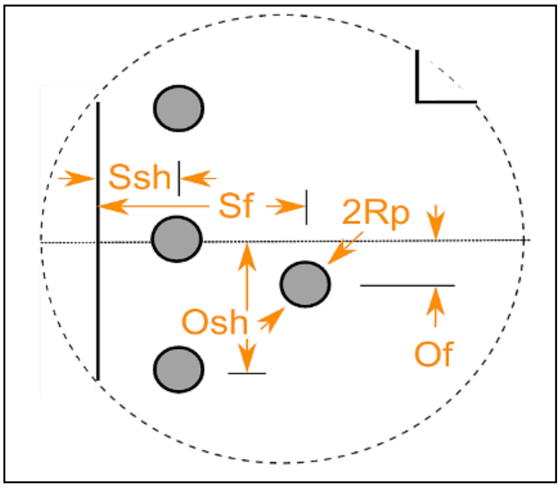

Figure 3. Shorting pins and feeding ports

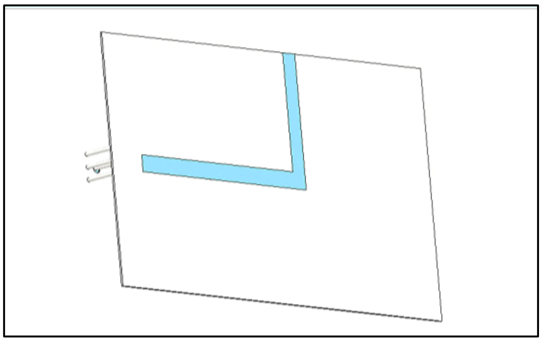

Figure 4. Simulated Antenna in CST software

Table 2. Exact value of antenna parameters

Name	Description	Value
Wo	Outer element width	30 mm
Lo	Outer element length	53.28 mm
Wi	Inner element width	14.11 mm
Li	Inner element length	30.2 mm
H	Element height	4.5 mm
Ws	Slot width	2 mm
Ss	Slot inset from element edge	5 mm
Sf	Feed-pin inset	2.25 mm
Of	Feed-pin offset (from the patch centre-line)	0 mm
Rp	Feed-pin radius	250 µm
Ssh	Inset of the shorting pins	750 µm
Osh	Offset of the shorting pins (from the patch centre-line)	1.5 mm

In Figure 5. the return loss of antenna and everything at these frequencies is acceptable. The antenna has a relatively large back loops and side loops As a result expected, SAR will be plenty. There is a trade-off here between big ground and antenna pattern and it will be seen that pattern antenna is much more effective on SAR. In this antenna, SAR is focused on a point and it will be more explained later.

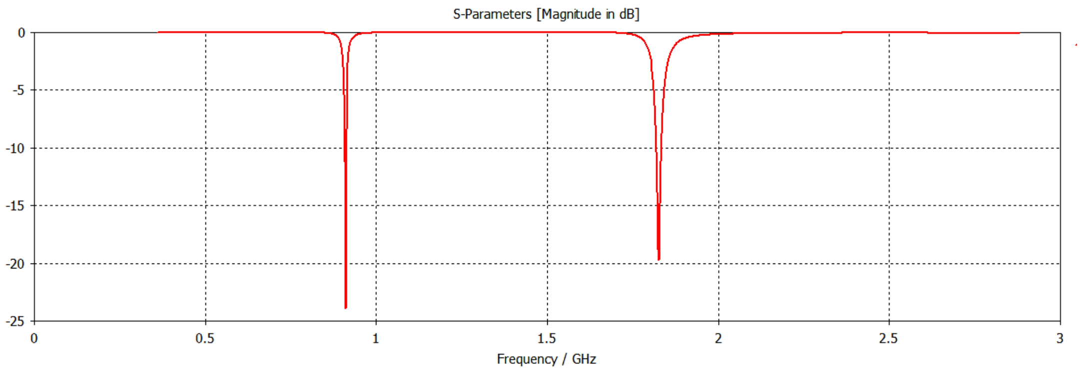

Figure 5. Return Loss (L-slot antenna)

One of the basic parameters for SAR is antenna gain. In Figure 6 to 9. antenna patterns and also their gain. As it can be seen at first frequency gain is low and at second frequency gain is higher. With the increase antenna gain, SAR will be also goes up.

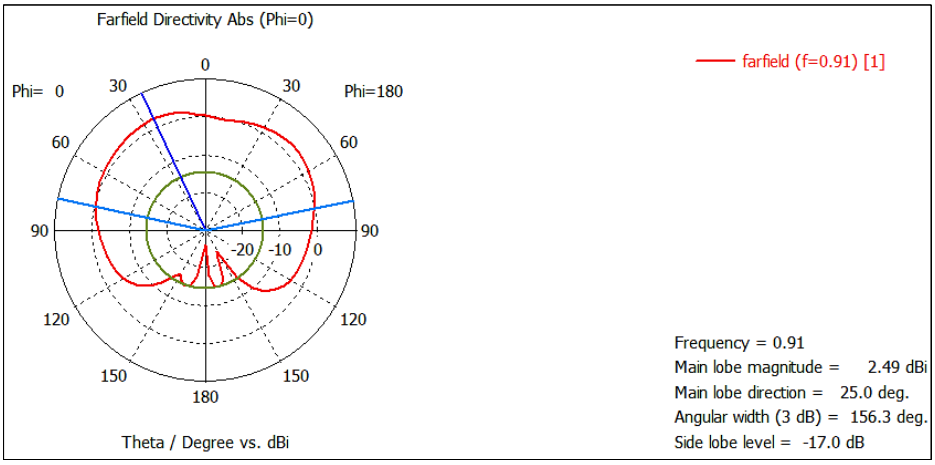

Figure 6. Antenna pattern at first frequency ($Phi = 0$)

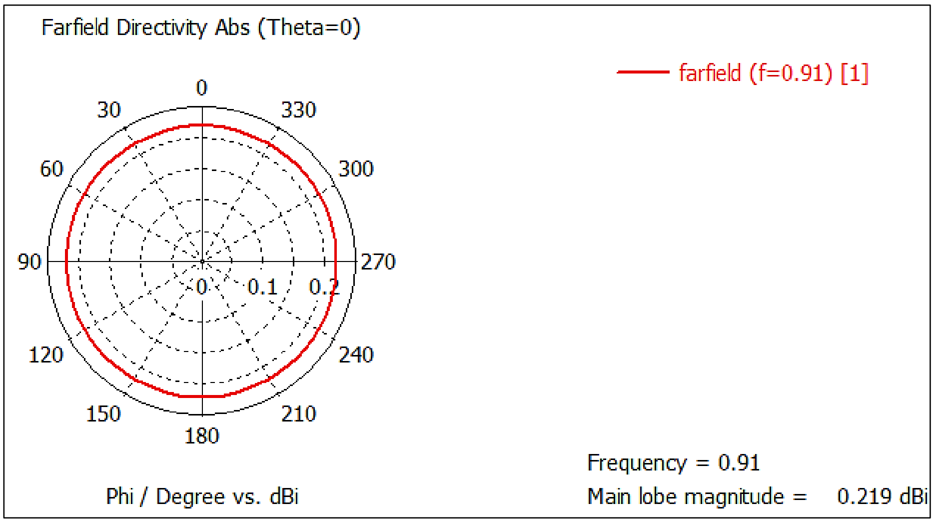

Figure 7. Antenna pattern at first frequency ($Theta = 0$)

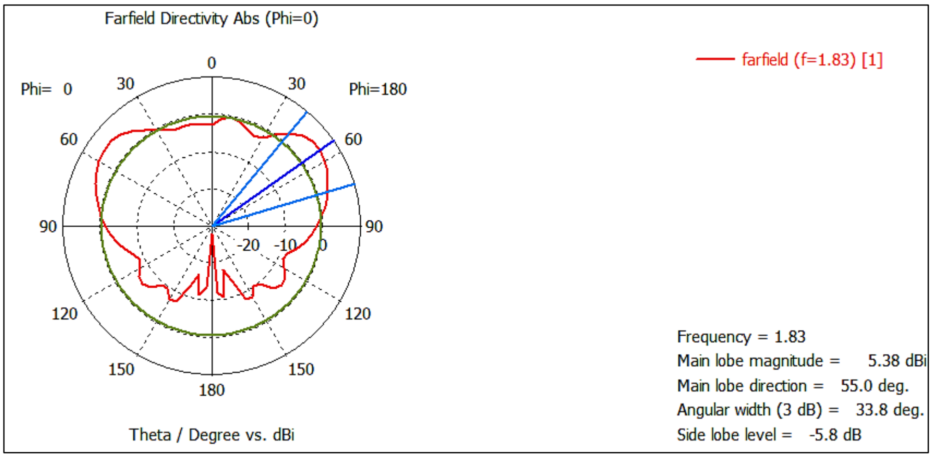

Figure 8. Antenna pattern at second frequency ($Phi = 0$)

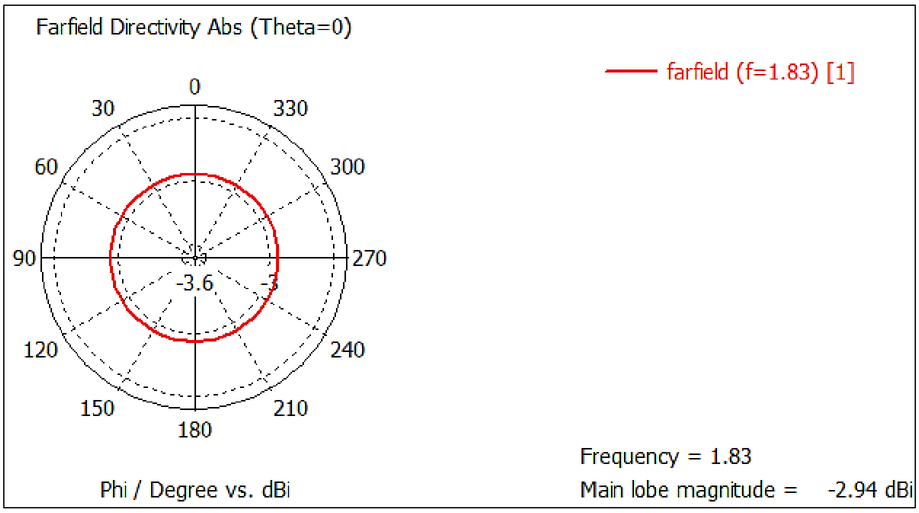

Figure 9. Antenna pattern at second frequency ($Theta = 0$)

5- Design and Simulation of U-slot Antenna

U-slot antenna is similar to L-slot antenna with more band width. Actually U-slot antenna consists of two L-slot antenna. Each L-slot antenna has two frequency bands and if both of L-antennas are same with each other, there will be antenna with higher band width and this is U-slot antenna. More bands can be created by using more U-slot antenna at the same one on patch or it can be designed H-slot antenna with 7 bands as presented by Yeh (2002) [9] but be careful about band width frequency. is A acceptable U-slot antenna designed and simulated in CST studio 2015 software that operate at cell-phone frequencies GSM800 and GSM1800. Overview of Antenna can be seen in Figure 10. The exact values of U-slot antenna are calculated in Table 3. In Figure 11. the return loss of antenna and everything at these frequencies is acceptable. More band width can be seen in Figure 11. in comparison with L-slot antenna. Figures 12 to 15. show antenna patterns and also their gain.

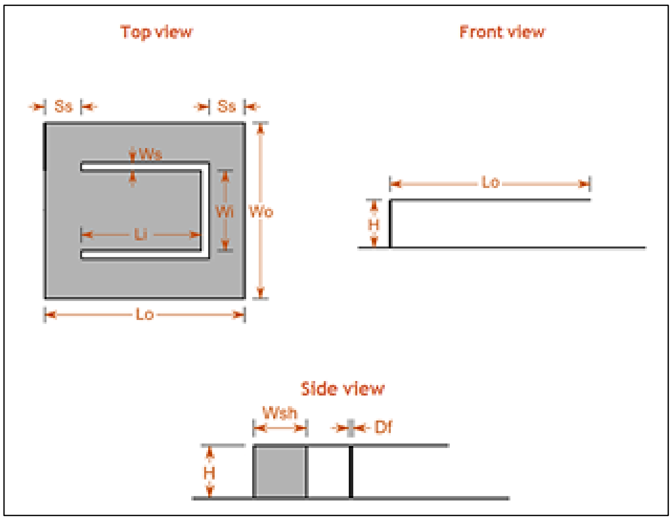

Figure 10. U-slot antenna's Overview

Table 2. U-slot antenna parameters

Name	Description	Value
Df	Diameter of feed pin	1.186 mm
H	Plate height	11.86 mm
Li	Inner element length	28.46 mm
Wi	Inner element width	20.16 mm
Lo	Outer element length	53.61 mm
Wo	Outer element width	44.67 mm
Wsh	Width of shorting plate	17.59 mm
Ws	Slot width	2.372 mm

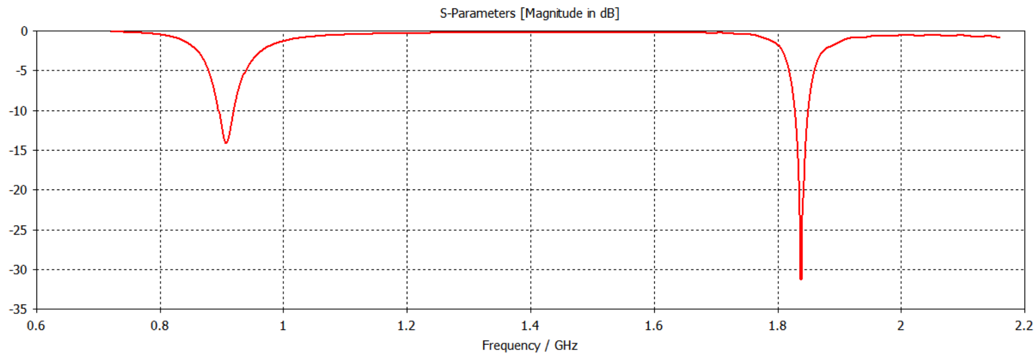

Figure 11. Return Loss (U-slot antenna)

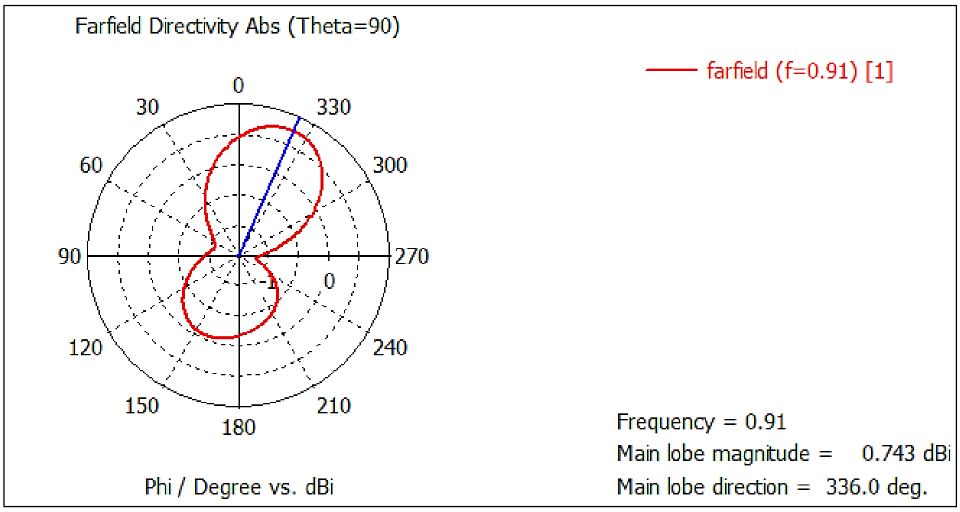

Figure 12. Antenna pattern at first frequency ($Theta = 90$)

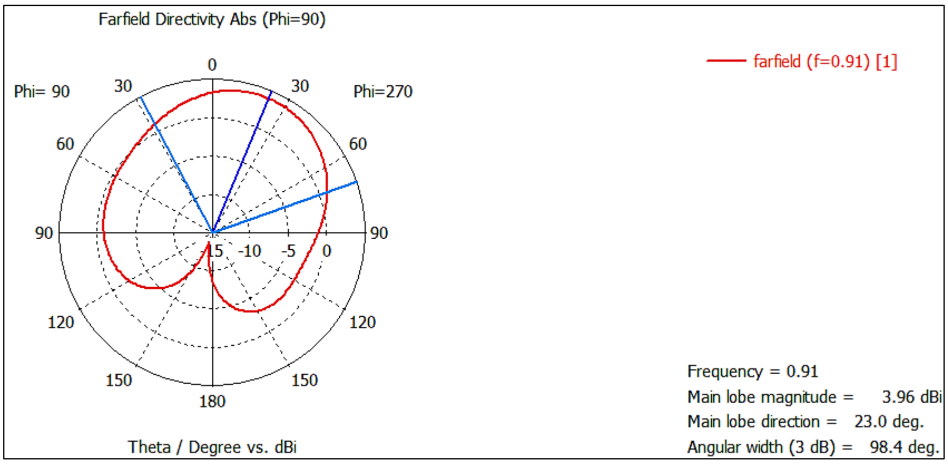

Figure 13. Antenna pattern at first frequency ($Phi = 90$)

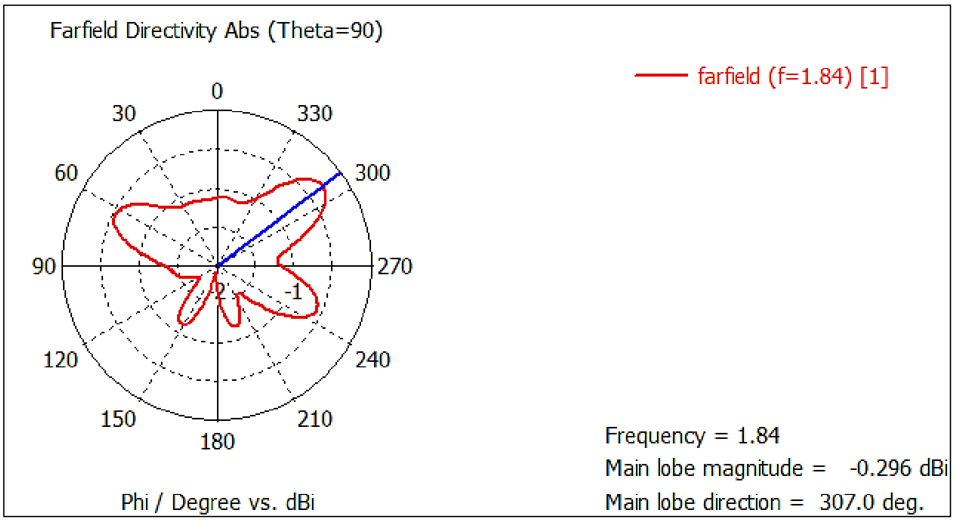

Figure 14. Antenna pattern at second frequency ($Theta$ = 90)

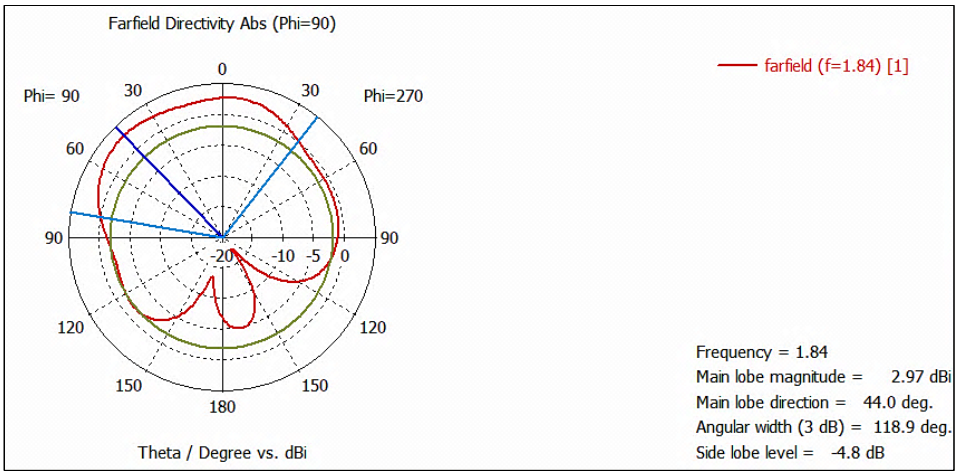

Figure 15. Antenna pattern at second frequency (Phi = 90)

As it can be seen at first frequency gain is high and at second frequency gain is lower. In U-slot antenna, there are less back loops and side loops, so we expect SAR will be calculated less.

6- Use Meta-Material Structure

FSS (frequency selective surface) and meta-materials can be used to reduce SAR in multi-band antennas. In these structures, Microscopic view is important. For example, the activity of strong inhomogeneous fields cause Increase the force field at critical points. This increase is to strengthen the non-linear properties of matter ultimately power is to be reduced. It is the general view.

Generally, materials in nature are divided into 4 categories according to electromagnetic properties:

1. Usual materials, they are called DPS (Double positive materials) or RHM (Right hand materials)
Re (μ)>0 && Re (ε)>0.
2. Metals and plasma, they are called ENG (Epsilon Negative materials)
Re (μ)>0 && Re (ε) <0.
3. Ferro magnetic and ferrite, they are called MNG (Mu Negative Materials) like SRRs
Re (μ) <0 && Re (ε)>0.
4. Left hand materials, they are not found in nature and called DNG (Double Negative materials
Re (μ) <0 && Re (ε) <0.

DNS and DNS electromagnetic radiation in the environment can be published but MNG and ENG electromagnetic radiation in the environment cannot be published because ε beat μ and their negative.(μ*ε <0) In such an environment, wave will be damped. In this case, the diffusion coefficient will be just imaginary and As a result, a phrase is added damping in wave amplitude. The tide after the passage of such an environment is extremely weak. This property can be used to reduce SAR. Epsilon Negative materials have a problem for making, they are very big in this frequency and they cannot be used in these dimensions.

As a result, the material will be used to negative μ. One of the easiest ways to build these Materials is using SRRs unit cell. To simplify the analysis of the structure, can be said that if An electromagnetic wave with a vertical H vector shine to SRRs cell, Circular currents will be induced on the inner and outer rings. And electric charge will be gathered on both sides of the gap between the inner and outer rings. So this structure is like a RLC circuit where L is Inductance between the loops and C is Capacitance between the two rings.

For SRR unit cells:

$$\mu = 1 - \frac{A\omega}{\omega^2 - \omega_m^2 + j\omega\lambda_m} \tag{6}$$

Where:

$$\omega_m = \frac{3ac^2}{\pi r^3 \ln\left(\frac{2w}{d}\right)} \tag{7}$$

$$\lambda_m = \frac{2a\sigma}{r\mu_0} \tag{8}$$

The relationship is clear that ω_p and λ_p depends on Geometric dimensions like w, r, a, d and σ.

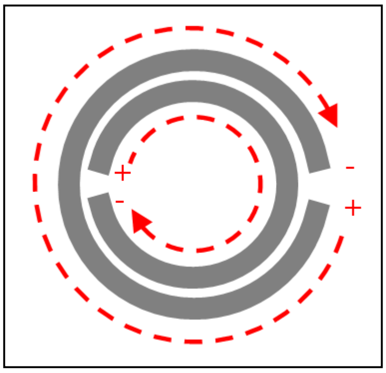

Figure 16. Electric current in SRR unit cell

The Figure (17) shows the effective magnetic permeability in terms of the frequency effective factor. From this figure, it is clear that the coefficient of magnetic permittivity is negative only in a narrow range around resonance point but the point is enough for our design. The structure can be selected according to the LC and also as presented by Yeh (2002) [9], there are lots of structure like SRRs and other structure but it should select structure which can make it and the surface should be realizable.

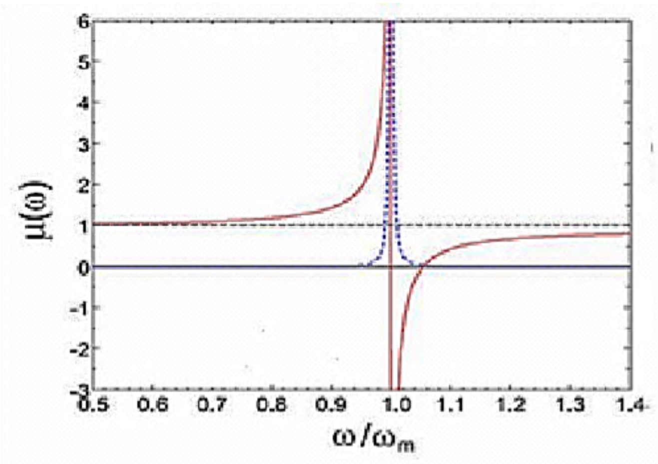

Figure17. Effective magnetic permeability in terms of the frequency

For design a SRR unit cell, first the exact value of L and C in ADS software should find so the SRR will resonate at cell phone frequencies. After that SRR's dimensions should find, Then a surface between antenna and human can be put and finally SAR should calculate, SRRs are designed and simulated. A single unit cell can be seen in Figure 18. and also the designing parameters can be seen in Table 3.

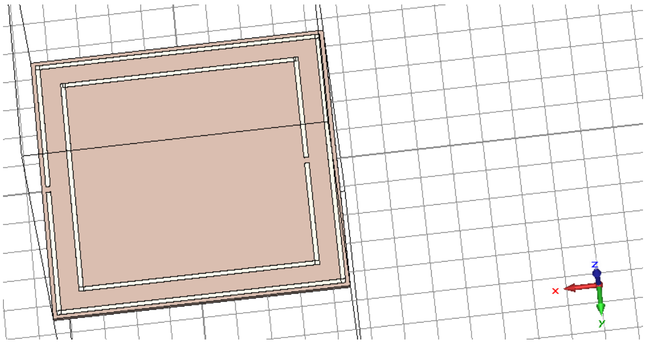

Figure 18. **Simulated SRR Unit cell**

Table 3. **Designing SRR parameters**

Value	Description	parameters
44 mm	Length of outer ring	**L1**
36 mm	Length of inner ring	**L2**
0.7 mm	Thickness of outer ring	**S1**
0.7 mm	Thickness of inner ring	**S2**
1 mm	The gap between outer ring	**G1**
1 mm	The gap between inner ring	**G2**
1.25 mm	Distance between cells	**G**
0.5 mm	Thickness of Di-electric (FR4)	**H**

SRR structure should prevent from electromagnetic wave pass because if electric field cannot pass the surface, SAR will be zero. It means surface should have very low S_{21}. This surface has very low S_{21} at resonate frequencies and it is less than -20 dB. This attenuation is perfect so we expect that SAR will be very low. Additionally, FR4 Di-electric is used in this surface for economic reason and this structure can build by very low cost and if better di-electric with higher ε will use, it will take much more result.

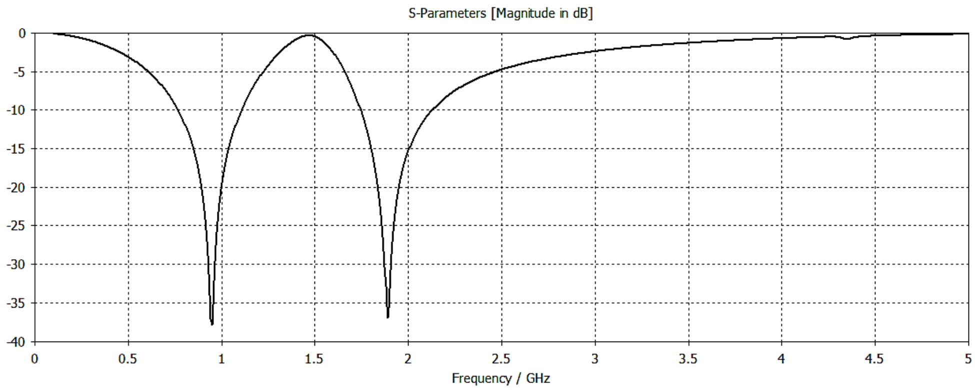

Figure 19. **The S_{21} chart for SRRs unit cells**

7- SAR Measurement

SAM model is used in CST studio for modeling human head. This type of modeling is a modeling perfectly acceptable and approved. All simulations should be done in two stages. In the first case without SRRs unit cells and then simulation should be done with SRRs. Also more complex models can be used but results will not change much and more will be spent on simulation.

All the condition should be same in all experiments like: the distance between head and antenna and head model. First, The SAR of U-slot antenna is simulated and measured then the SAR of L-slot antenna is simulated and measured. In the previous section was told that the ground of L-slot antenna is much larger than U-slot. As a result, it may feel L-slot antenna has less SAR but this thinking is totally wrong. Antenna design and shape is much more important than the size of ground plane See the results of this study can be found in Table 4. In U-slot antenna, Waves spread all over the head. In L-slot antenna, Waves focus on a point of head. As a result U-slot antenna is much better and because of this reason, SAR Reduction surface have been used for the U-slot antenna. So finally we have an excellent antenna with very low SAR.

Antenna return loss should not change (Figure 20). In Figure 20. it can be seen the return loss of antenna and SAM model and Figure 21. shows the return loss of model and surface and SAM model and in all figures return loss is totally acceptable.

Table 4. Comparison between L and U antenna

Antenna	U-slot antenna	L-slot antenna
Distance between head & antenna	7 mm	7 mm
SAR (1gr) [W/kg] F1	0.2783	7.645
SAR (10gr) [W/kg] F1	0.2103	2.72
Ground size	134*160 mm^2	≈500*300
SAR (1gr) [W/kg] F2	0.2467	3.988
SAR (10gr) [W/kg] F1	0.1726	1.501

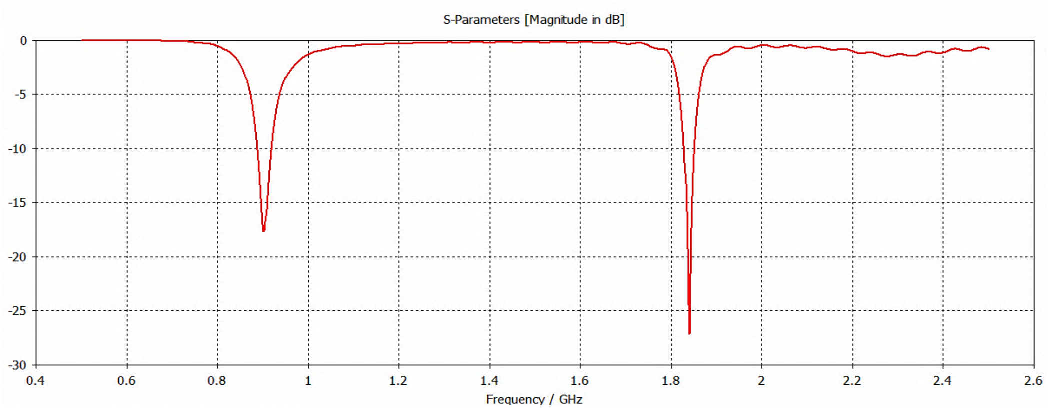

Figure 20. The return loss of antenna with head

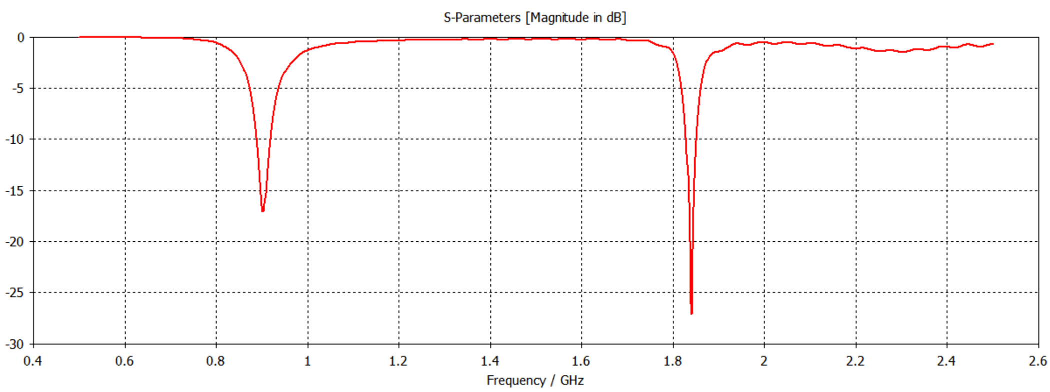

Figure 21. The return loss of antenna with head and SRRs

Figure 22, shows the power distribution on head. In this figure, SRRs are not added. Figure 23. Shows the power distribution on head after adding SRRs unit cells.

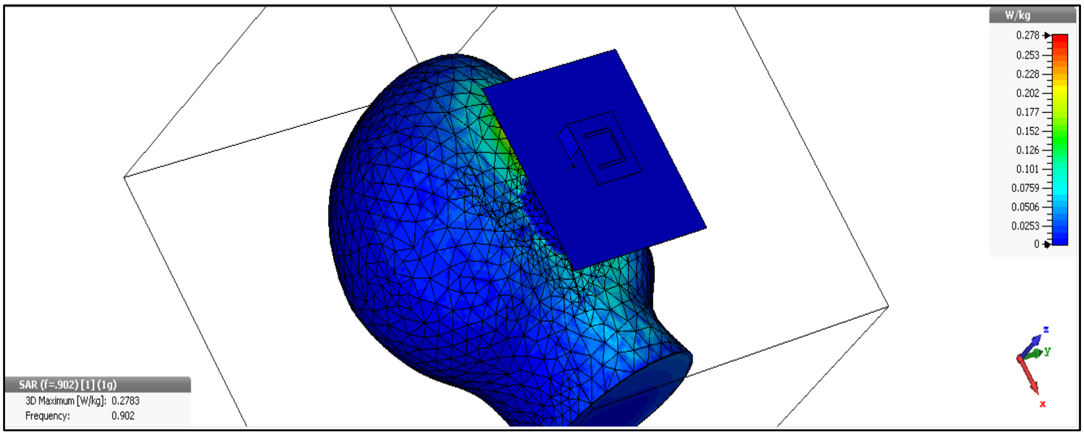

Figure 22. Power distribution before without SRRs

The antenna pattern diagrams have also not changed so, bringing these charts are eliminated.

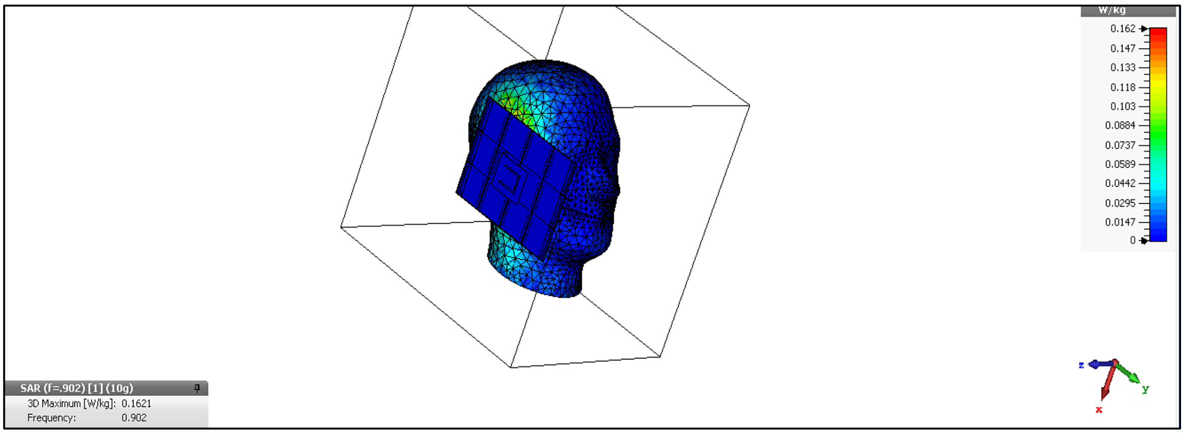

Figure 23. Power distribution after adding SRRs

The antenna pattern diagrams have also not changed so, bringing these charts are eliminated. In Table 5, shows the influence of surface and SSRs unit cells have reduced SAR 30.96% in first frequency band and 30.80% in second frequency band for 1gr's tissue and for 10gr's tissue SAR reduction is 29.73 and 37.20 for first and second frequencies. (12 unit-cells are used under the U-slot antenna) Perhaps, the percentage of SAR reduction is so much but the value of SAR is too low because of well designing and also SRRs surface. At the end of the present research, there is a comparison between the present article with other references and it can be seen the present article is totally acceptable. Not only the SAR of this U-slot is very low but Antenna gain is high.

Table 5. SAR reduction using SRRs surface

SAR [1gr] (f1)	SAR [10gr] (f1)	SAR [1gr] (f2)	SAR [10gr] (f2)	U Slot Ant.
278.3mW/kg	210.3mW/kg	246.7mW/kg	172.6mW/kg	With surface
212.5mW/kg	162.1mW/kg	188.6mW/kg	125.8mW/kg	With 12 SRRs

Table 6. Comparison between literatures

	[12]	[13]	[14]	[15]	[16]	[17]	Present research
SAR GSM900 [10gr] (W/kg)	1.61	2	0.68	0.26	0.88	2.17	0.16
SAR GSM1800 [10gr] (W/kg)	1.03	1.68	0.54	0.47	2.65	2.38	0.12
SAR GSM 900 [1gr](W/kg)	2.42	2.86	1.13	0.38	1.44	-	0.21
SAR GSM 1800 [1gr] (W/kg)	2.14	2.25	0.9	0.8	4.35	-	0.18
Gain GSM900 dBi	-	-0.7	0.32	-	2.37	-	2.92
Gain GSM1800 dBi	-	1.24	2.03	-	5.93	-	4.65

8- References

[1] Lin, James C. "Health effects-effects of cell-phone radiation on lymphoma-prone mice." IEEE microwave magazine 4, no. 2 (2003): 22-28.

[2] Sultan, K. S., H. H. Abdullah, E. A. Abdallah, and E. A. Hashish. "Low-SAR, miniaturized printed antenna for mobile, ISM, and WLAN services." IEEE antennas and wireless propagation letters 12 (2013): 1106-1109.

[3] IEEE Standard for safety levels with respect to human exposure to radiofrequency electromagnetic fields, 3 KHz to 300GHz, IEEE Standard C95.1, 1999.

[4] International commission on Non-lonizing radiation protection, “guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz),” Health Physics, 74, 1998,pp. 494-522.

[5] IEEE Standard for Safety Levels with Respect to Human Exposure to Radiofrequency Electromagnetic Fields, 3 kHz to300 GHz, IEEE Standard C95.1, 2005.

[6] Kiourti, Asimina, and Konstantina S. Nikita. "A review of implantable patch antennas for biomedical telemetry: Challenges and solutions [wireless corner]." IEEE Antennas and Propagation Magazine 54, no. 3 (2012): 210-228.

[7] M.H.Repacholi,A.basten,V.Gebski,D.Noonan,J.Finnie,andW.Harris,”Lymphom-asin E mu – Pim1 transgenic mice exposed to pulsed 900 MHz electromagnetic fields”,Radiat.Res.,vol.147, pp.631-640,1997.

[8] Yeh, Shih‐Huang, Shyh‐Tirng Fang, and Kin‐Lu Wong. "Dual‐band shorted patch antenna for dual ISM‐band application." Microwave and Optical Technology Letters 32, no. 1 (2002): 79-80.

[9] D. Singh1, *, A. Kumar2, S. Meena1, and V. Agarwala2”ANALYSIS OF FREQUENCY SELECTIVE SURFACES FOR RADAR ABSORBING MATERIALS” Progress In Electromagnetic Research B, Vol. 38, 297–314, 2012.

[10] A. Cabedo,J. Anguera, C. Picher, M. Ribó, and C. Puente. "Multiband handset antenna combining a PIFA, slots, and ground plane modes." Antennas and Propagation, IEEE Transactions on 57,no.9: 2526-2533, 2009.

[11] A. H. Kusuma , A.-F. Sheta I. M. Elshafiey, M. A. S. Alkanhal , S. Aldosari , and S. A. Alshebeili,. "Low SAR antenna design for modern wireless mobile terminals." In STS International Conference. 2010.

[12] A. H. Kusuma , A.-F. Sheta, I. M. Elshafiey, Z. Siddiqui, M. A. S. Alkanhal, S. Aldosari, S. A. Alshebeili, and S. F. Mahmoud, "A new low SAR antenna structure for wireless handset applications," Progress In Electromagnetics Research, Vol. 112, 23-40, 2011.

[13]S.Y. Lin, Y.C. Lin, Y.R. Cheng, and J.R. Wu. "Folded wire antenna with low SAR." In Microwave Conference Proceedings (APMC), 2011 AsiaPacific, pp. 638-641. IEEE, 2011.

[14] Jegadeesam.S , Zahra Mansouri “Ultra Wideband PIFA Antenna with supporting GSM and Wimax Mobile Phone Applications “ 2015 Fifth International Conference on Advanced Computing , Communication Technologies.

[15] J. L. T. Garzon, A. A. de Salles, A. C. O. Pedra, S. Severo “T-Slot PIFA with excitation of the ground plane resonant modes and considerations of the interaction between antenna, mobile handset and user's head “2013 IEEE.