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Design and Characterization of Rectangular Stud Antenna

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Abstract- This paper refers to the investigation and design of Stud (Cup link) Antenna. Studs are part of daily wears. Studs are available in various shapes and designs. To investigate the electromagnetic behavior of studs and its use as antenna, the analysis shows that studs can be used as antenna and it radiates electromagnetic energy from guided medium to free space. A rectangular stud antenna is considered and it parameters e.g. resonant frequency, directivity, radiation efficiency, half power beam width etc are calculated. The effects of dimensions e.g. length, width and thickness of conductor and substrate on resonant frequency, directivity and radiation efficiency are analyzed and it has been observed that these parameters can been modified by changing the dimensions of stud antenna.

Keywords: Electromagnetic Radiation, Wearable Antenna, Stud Antenna, Patch Antenna

1. INTRODUCTION

Electromagnetic spectrum is one of the utmost gifts of nature and antennas are the tools to harness this precious resource. An antenna finds an important role by establishing link between two parties in modern communication industry nowadays. In the competition to become a popular science, all compact and portable communication equipments are in need of an antenna of good shape and design to let them connect to the everywhere available wireless connections (Sahu and Choudri 2012, Singh *et al.* 2011).

Antenna engineering has a history of over 80 years (Eckstein *et al.*, 2000). In early days Antennas have been the most neglected of all components of wireless communication systems. But later on it became an area of great interest for researchers and designers of communication systems. The way in which RF signal is distributed into and collected from free space has a significant effect on the efficient use of RF spectrum, the cost and the service quality provided by communication systems and networks. Depending upon the applications, the properties of an antenna including physical structure varies. Due to low profile structure light weight and low cost Microstrip Antenna (MSA) got a great interest of communication industry (Breed 2009, Lockhart *et al.* 2010, Ali *et al.* 2011, Balanis 2012, Hamadamin *et al.* 2014) after Deschamps proposed the concept of the MSA for the first time in 1953. But still the Size reduction, gain and narrow bandwidth from printed micro strip patches is one of the most significant factors limiting the widespread applications couldn't fulfilled by the conventional MSA (Marroncelli *et al.*, 2011).

The trends of antenna design in today's wireless applications are toward compactness, robustness, and ease of integration with RF circuit components (Ranasinghe, *et al.* 2012). In future, a person is likely to carry a range of devices and sensors, including medical sensors, communicating each other and outside world all the time. A key technology to achieve this goal is wearable electronics and antennas (Salonen and Hurme 2003, Calhoun, *et al.* 2012). For the convenience of the user, wearable antennas need to be hidden and of low profile and can be made conformal for integration into clothing (Wong and Lin 2005, Saznz-Izquierdo *et al*. 2006).

Wearable antennas have been deployed in various applications such as monitoring of high risk patients/elderly people in hospitals and residential care facilities (Ranasinghe *et al.* 2012, Visvanathan *et al.* 2012), telemedicine, and wireless data communications, Body Sensor Networks (BSN) (Locher *et al.* 2006, Calhoun, *et al.* 2012), GSM (Nagar *et al.* 2014) and RFID tag antennas (Marroncelli *et al.* 2011). The wearable textile antennas are allowing telemedicine to provide healthcare at a distance with much lower costs, enabling the development of new widespread remote medicine initiatives (Pattichis *et al.* 2002).

There are few problems with wearable antennas. As mentioned earlier wearable need to be hidden so that it doesn't disturb the dressing look or if it is apparent then it should look decent. Another problem with wearable antenna is wrinkle effect that affects the antenna performance. So to use our daily wears as antenna that add to the beauty of our dressing and

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doesn't have wrinkle effect. Stud is one such part of our daily wear that fulfills the requirement.

This paper introduces the use of stud as an antenna. It presents the design of a rectangular stud antenna and analyzes its different parameters and radiation characteristics.

2. MATERIAL AND METHODS

Stud Antenna

Shirt studs are decorative pieces used on the pleated and stiff-front shirts, fitting into the buttonholes specifically made for the shirt studs, shown in **(Fig.. 1)**. The shirt studs are made of alloys, precious metals or gemstones. The stud may have engrave, such as of pearl or onyx.

Fig. 1: Stud/Cufflink

Antenna is an electro mechanical device that radiate electromagnetic signal into free space. To radiate energy into free space some basic conditions for radiation need to be satisfied. For a conductor to radiate its' structure should be bent, truncated or terminated. As studs are mostly made of conductors with bents and truncations, so it meets the basic conditions for radiation by a conductor and can be used as antennas. The studs' antenna is an electrical-mechanical device that can support and act as a bridge between the unguided media i.e. free space and guided media i.e. transmission line.

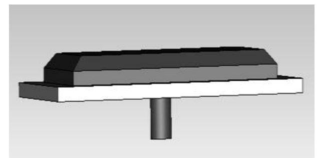
The stud mount just needs to transmit and receive signal from a transceiver efficiently. If the signal is not radiated efficiently it will result in unnecessary loss. And the stud mount must be strong enough to withstand all of the stress placed upon it.

Rectangular Stud Antenna

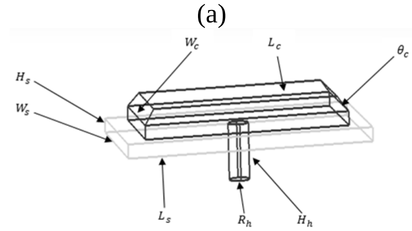
A rectangular stud antenna is presented in this paper as shown in the **(Fig.. 2(a, b)** consists of substrate of length "L_s", width "W_s" and height "H_s", rectangular copper of length "L_c", width "W_c" and height "H_c", tapered copper section of same length "L_c" , width "W_c" and height "H_c" as that of rectangular copper but tapered with angle of θ_c degrees and a cylindrical hook of height "H_h" and radius "R_r".

The antenna is centre feed via hook to radiate electromagnetic signal is free space. The antenna is simulated to find its different parameters e.g. antenna gain, directivity, resonant frequency and radiation pattern.

The antenna is also analyzed for different values of length and width of the conductor and the results obtained are explained in the results section.



(a)



(b)

Fig.2: Stud Antenna (a) Solid structure (b) Wireframe structure with dimensions

3. RESULTS AND DISCUSSION

Experimental Results

The designed rectangular stud antenna has the substrate of length "L_s" 12mm, width "W_s" 8mm and height "H_s" 0.5mm, rectangular copper of length "L_c" 10mm, width "W_c" 6mm and height "H_c" 0.5mm, tapered copper section of same length, width and height that of rectangular copper but tapered with angle of θ_c - 45^o and a cylindrical hook of height "H_h" 1.5mm and radius "R_r" 0.5mm as shown in the Fig. 2. The antenna is simulated to find out various antenna parameters e.g. resonant frequency f_r "", directivity "D", radiation efficiency "e", HPBW and bandwidth "BW".

To find out resonance frequency "f_r ", the most commonly used parameter in case of antenna is S11 showing the power reflected from the antenna and hence is known as the reflection coefficient "Γ" or return loss. Smaller the value of S11, more power is radiated and if S11=0 dB, then all the power is reflected from the antenna and nothing is radiated.

The return loss "S11" behavior of the designed stud antenna is analyzed over a range of frequency from 1GHz to 25GHz and the results obtained is shown in **(Fig. 3)**. A clear depth of -16.172dB has been observed at 12.472 GHz frequency meaning that the resonant frequency for stud antenna is 12.472GHz. It is also observed that the designed stud antenna gives a return loss of less than -10 dB over range frequencies from 11.868GHz to 13.829GHz, results in -10dB bandwidth of 1.9611GHz.

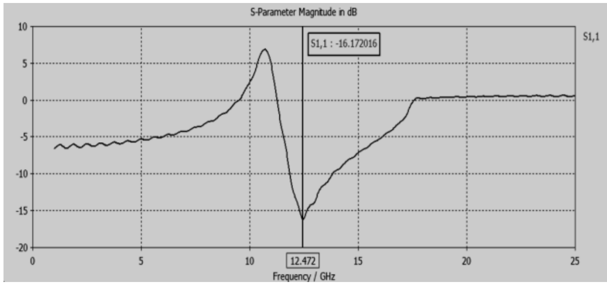
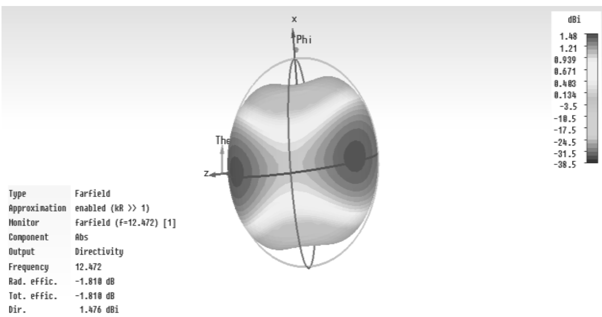
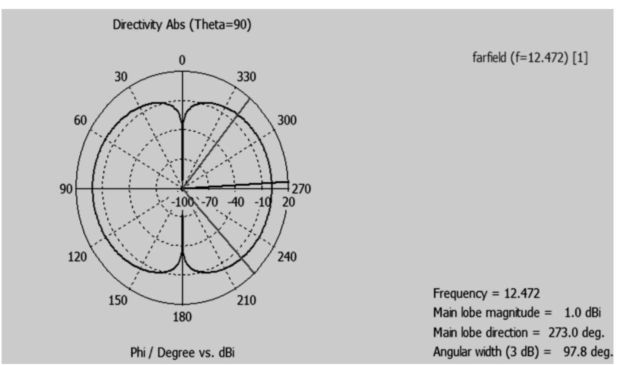


Fig. 3: Return loss verses frequency

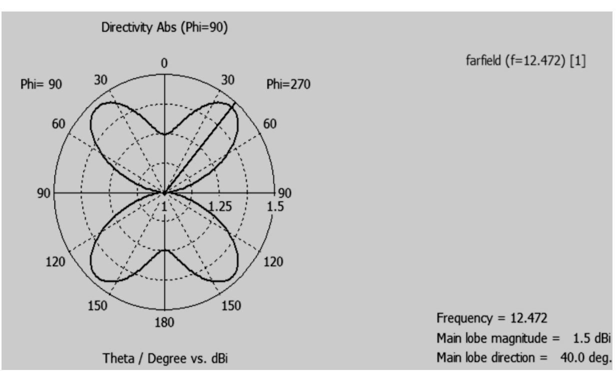
The 3D radiation pattern, Azimuth plane pattern and Elevation plan pattern of the Stud antenna at resonant frequency is shown in **Fig..4 (a, b, c, d).**



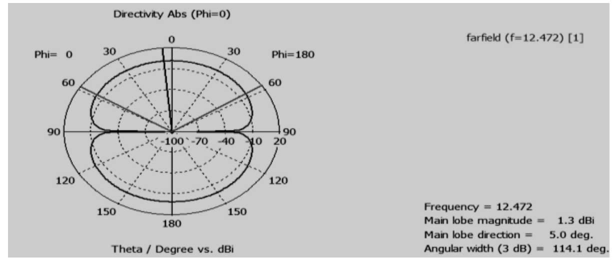
(a)



(b)



(c)



(d)

Fig. 4: (a) 3D radiation Pattern (b) Azimuth plane radiation pattern (c) Elevation plane radiation pattern (Phi=90°) (d) Elevation plane radiation pattern (Phi=0°)

The results obtained shows that the design stud antenna has a directivity of 1.48 dBi as apparent from the 3D radiation pattern shown in Figure 4(a). The azimuth plan 2D radiation pattern given in Fig. 4(b) shows that main beam in directed 273° with a magnitude of 1dBi and HPBW of 29.8°. The elevation plan 2D pattern is observed with azimuth angle 0° and 90° the elevation plan pattern with azimuth angle 90°, the main lobe is directed at 40° with magnitude 1.5dBi as shown in Fig. 4(c) with the elevation plan pattern observed with azimuth angle 0° show that the main lobe is directed in direction of 5° with magnitude of 1.3dBi and HPBW of 114.1° as shown in Fig. 4(d).

Effect of Dimensions

The stud antenna is analyzed for varying lengths, width and thickness of conductor and Substrate and taper angle of tapered section. The antenna resonant frequency "f_r", directivity "D" and radiation efficiency "e_r" are find out each case.

Table 1: The effect of Conductor Length on Antenna Parameters

SNO	L_c (mm)	f_r (GHz)	D (dBi)	e_r (dB)
1	8	12.928	1.51	0.1189
2	9	12.688	1.502	-0.7264
3	10	12.472	1.476	-1.810
4	11	12.400	1.462	-2.227
5	12	12.328	1.456	-2.427

To find out the resonant frequency "f_r", directivity "D" and radiation efficiency "e_r" for different values of length of conductor "L_c" all other lengths, widths, thickness and taper angle are kept constant and conductor length "L_c" is varied from 8mm to 12mm with increment of 1mm per results and the results obtained are listed in Table 1 above. The results show that the resonant frequency "f_r" and directivity "D" of stud antenna increase with increase in length of conductor "L_c" while the radiation efficiency "e_r" decreases.

To find out the resonant frequency "f_r", directivity "D" and radiation efficiency "e_r" for different values of length of substrate "L_s" all other lengths, widths, thickness and taper angle are kept constant and substrate length "L_s" is varied from 11mm to 15mm with increment of 1mm per results and the results obtained are listed in **(Table 2)** below.

Table 2: The Effect Of Substrate Length On Antenna Parameters

SNO	L_s (mm)	f_r (GHz)	D (dBi)	e_r (dB)
1	11	12.496	1.466	-1.687
2	12	12.472	1.476	-1.810
3	13	12.488	1.478	-1.872
4	14	12.448	1.482	-1.904
5	15	12.448	1.483	-1.922

The results listed in Table 2 show that the resonant frequency "f_r" and the radiation efficiency "e_r" are showing decreasing trends with increasing length of substrate "L_s" while directivity "D" of stud antenna increase with increases with increasing length of substrate "L_s".

The resonant frequency "f_r", directivity "D" and radiation efficiency "e_r" are obtained for different conductor thicknesses "H_c" while all other lengths, widths, thickness and taper angle are kept constant. The conductor thickness "H_c" is varied from 0.5mm to 0.9mm with increment of 0.1mm per results and the results obtained are listed in **(Table 3).**

Table 3: The effect of conductor thickness on Antenna Parameters

SNO	H_c (mm)	f_r (GHz)	D (dBi)	e_r (dB)
1	0.5	12.472	1.476	-1.810
2	0.6	12.472	1.479	-1.654
3	0.7	12.568	1.49	-1.339
4	0.8	12.568	1.504	-1.324
5	0.9	12.616	1.514	-1.084

Table 4: The Effect of Substrate Thickness on Antenna Parameters

SNO	H_s (mm)	f_r (GHz)	D (dBi)	e_r (dB)
1	0.5	12.472	1.476	-1.810
2	0.6	12.544	1.488	-1.959
3	0.7	12.76	1.532	-3.075
4	0.8	12.88	1.553	-3.178
5	0.9	13.312	1.58	-3.212

The increasing trend of the resonant frequency "f_r" and directivity "D" and decreasing trend of radiation efficiency "e_r" with increase in conductor thickness "H_c" is apparent from the data listed in Table 3. While same behavior is observed for different values of substrate thickness "H_s" given in **(Table 4).**

The resonant frequency "f_r", directivity "D" and radiation efficiency "e_r" are obtained for different values of conductor width "W_c", substrate width "W_s" and taper angle "θ_c" each, while all other lengths, widths, thickness and taper angle are kept constant and the results obtained are listed in Table 5, 7 respectively.

The resonant frequency "f_r" changes in a nonlinear manner with the changes in conductor width "W_c", substrate width "W_s" and taper angle "θ_c", while the directivity "D" and radiation efficiency "e_r" of stud antenna increases and decreases in regular manner with changes in conductor width "W_c", substrate width "W_s" and taper angle "θ_c" as shown in **(Table 5 to 7)** respectively.

Table 5: The Effect of Conductor Width on Antenna Parameters

SNO	W_c (mm)	f_r (GHz)	D (dBi)	e_r (dB)
1	4	12.328	1.659	-1.851
2	5	12.424	1.560	-1.840
3	6	12.472	1.476	-1.810
4	7	12.424	1.405	-2.181
5	8	12.304	1.36	-2.615

Table 6: The Effect of Substrate Width on Antenna Parameters

SNO	W_s (mm)	f_r (GHz)	D (dBi)	e_r (dB)
1	6	12.616	1.523	-1.207
2	7	12.472	1.481	-1.779
3	8	12.472	1.476	-1.810
4	9	12.448	1.470	-1.928
5	10	13.472	1.472	-1.880

Table 7: The Effect of Taper Angle on Antenna Parameters

SNO	θ_c (°)	f_r (GHz)	D (dBi)	e_r (dB)
1	-15	12.496	1.462	-1.670
2	-30	12.424	1.466	-1.955
3	-45	12.472	1.476	-1.810
4	-60	12.52	1.482	-1.458
5	-75	12.712	1.491	-0.742

4. CONCLUSION

Stud antennas are new types of antenna which utilizes daily wears for communication. Stud antenna is wrinkle free, which make it more attractive. The designed Stud antenna is useful for communication in frequency range of 11.868GHz to 13.829GHz with resonant frequency of 1.9611GHz. This antenna is resulting in a very small reflection coefficient/ returns loss of -16.17dB and directivity of 1.47dB at 12.472GHz frequency. The antenna parameters can be changed by varying antenna dimensions e.g. length, width etc. The stud antenna can be designed for desired bands of frequencies. The stud antenna will find it application in communication industry to be used for telemedicine, body area network (BAN) and others.

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