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Design of Circular Stud Antenna and Parametric Analysis

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Abstract: *This paper presents the use of stud (Cup link), a part of daily wears as antenna. The studs are available in various shapes and designs. Circular stud is main consideration of this paper, to investigate the electromagnetic behavior of circular stud and its use as antenna. The analysis shows that bends and truncation in the structure of circular studs causes the acceleration and deceleration of charge carriers along its structure and set condition for electromagnetic radiation in free space. The circular stud antenna is analyzed to calculate different antenna parameters e.g. resonant frequency, directivity, radiation efficiency and half power beam width. The effects on resonant frequency, directivity, radiation efficiency of dimensions, i.e. radius, width and thickness of conductor and substrate, is also analyzed. It has been observed that these parameters can be modified by changing the dimensions of circular stud antenna.*

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

1. INTRODUCTION

An antenna is a device which transmits energy from guided media to free space in the form of electromagnetic signals. The antenna is an important component of wireless communication system to connect transmitting and receiving parties (Singh *et al.* 2013). The way in which radio frequency (RF) signals is distributed into and collected from the free space has a significant effect on the efficient use of RF spectrum.

The recent trend in the mobile systems is to develop pervasive computing networks, communicating directly with other worn devices and access points off the body (Salonen *et al.* 2005). Microstrip antennas mounted on textile substrates have been proposed to serve these mobile distributed systems (Sanz-Izquierdo *et al*. 2006, Visvanathan *et al*. 2012). For user's convenience the wearable antennas need to be hidden and of low profile and can be made conformal for integration into clothing (Nagar *et al.* 2014, Pandey *et al*. 2006, Ávila-Navarro *et al.* 2010). The Microstrip patch antennas have been of great interest of researchers and communication industry due to its low profile structure, light weight and low cost (Lockhart *et al.* 2010, Marroncelli *et al*. 2011, Salonen & Hurme, 2003).

Wearable antennas have applications in the areas like monitoring of high risk activities for elderly in hospitals and residential care facilities (Pattichis *et al*. 2002, Locher *et al*. 2006), Telemedicine in sensing, medical imaging and wireless data communications. The wearable antennas are allowing telemedicine to provide healthcare at a distance with much lower cost, enabling the development of new widespread remote medicine initiatives (Ranasinghe *et al.* 2012, Visvanathan *et al.* 2012), Body Area Networks (BAN) (Locher *et al.* 2006, Calhoun, *et al*. 2012), GSM (Nagar *et al.* 2014), RFID tag antennas (Marroncelli *et al.* 2011) and others.

Wearable antennas need to be hidden so as not to disturb the look of the dressing, however if it is apparent its look should be decent. Another problem with wearable antenna is the wrinkle effect that affects the antenna performance (Sahib *et al.* 2015). The practical way out is to use our daily wears as antenna that add to the beauty of our dressing and don't have the wrinkle effect. Stud is one such part of our daily wear which can fulfills these requirements.

This paper investigates the use of stud as an antenna and analyses the radiation characteristics of a circular stud antenna.

2. MATERIAL AND METHODS

Stud Antenna

A shirt stud made from alloys, precious metals, and gemstones is an attractive part of formal dress. The formal dresses have particular buttonholes for shirt studs. The stud may have engrave, such as of pearl or onyx (Eckstein *et al*. 2000). Studs designed for the shirt front are used as a part of party dress and are used extensively in modern full dress shirts worn with tie.

An antenna is an interface between the guided and unguided media to radiate energy from transmission lines into the free space and vice versa. Any conducting material can be used as antenna if there is an acceleration or deceleration of charge carriers along its

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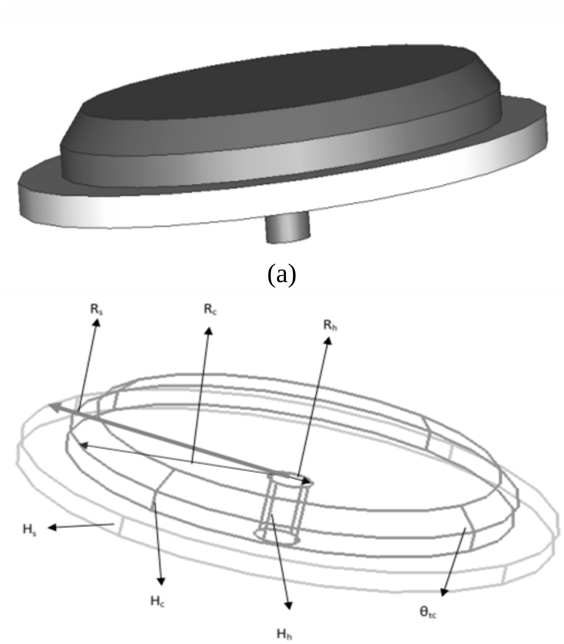
structure. The structure of conductor should be bent, truncated or terminated (Balanis. 2012).

As studs are mostly made of conductors e.g. gold, silver, platinum and its' structure has bents and truncation so charge carriers will change its velocity along its structure and hence the basic condition of acceleration and deceleration of charges is satisfied. As studs meet the basic needs of radiating structure so it can be used as antenna. The studs' antenna is an electrical-mechanical device that can support the antenna and act as a bridge between the antenna and the guided transmission line.

The importance of the stud mount cannot be over stressed! Accordingly, it needs to transmit and receive signal from a transceiver efficiently. If the signal is not radiated efficiently it will result in unnecessary loss (Sahib *et al.* 2015, Sahu and Choudri. 2012). And the stud mount must be strong enough to withstand all of the stress placed upon it.

Circular Stud Antenna

As discussed earlier stud antenna satisfy the basic conditions of radiation and it can be used as antenna. In this paper a circular stud antenna is designed with substrate of radius "R_s" and height "H_s", conducting copper of radius "R_c" and height "H_c", tapered circular copper section of height "H_{tc}" and taper angle of θ_{tc} degrees and a cylindrical hook of height "H_h" and radius "R_r" as shown in **(Fig. 1).**



(b)

Fig. 1.Circular stud antenna (a) Solid Structure (b) Wireframe Structure with dimensions

The cylindrical hook placed at the center of stud antenna is used to feed the antenna to radiate energy in free space in the form of electromagnetic waves. To calculate different antenna parameters the designed antenna is simulated and antenna resonant frequency "f_r", directivity "D" and radiation pattern both 2D and 3D are obtained.

The antenna is also analyzed to calculate various antenna parameters for different values of radius and heights of the conductor and substrate. The experimental results obtained are explained in the results section.

3. RESULTS AND DISCUSSION

Experimental Results

The A circular stud antenna is designed and presented in this paper as shown in Fig.1 (a) & (b). The circular stud antenna is designed with substrate of radius "R_s" 6mm and height "H_s"0.5mm, conducting copper of radius "R_c" 5mm and height "H_c"0.5mm, tapered circular copper section of height "H_{tc}" 0.5mm and taper angle of θ_{tc} -45^o and a cylindrical hook of height "H_h" 1.5mm and radius "R_r" 0.5mm as listed in **(Table 1)**.

Table 1. Dimensions Circular Stud Antenna

Label	Dimension
Substrate Radius (R_s)	6mm
Substrate Height (H_s)	0.5mm
Conductor Radius (R_c)	5mm
Conductor Height (H_c)	0.5mm
Taper Copper Height (H_{tc})	0.5mm
Taper Angle (θ_{tc})	-45^o

The antenna is simulated to find out various antenna parameters e.g. resonant frequency "f_r", directivity "D", radiation efficiency "e", half power beam width (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. 2).**

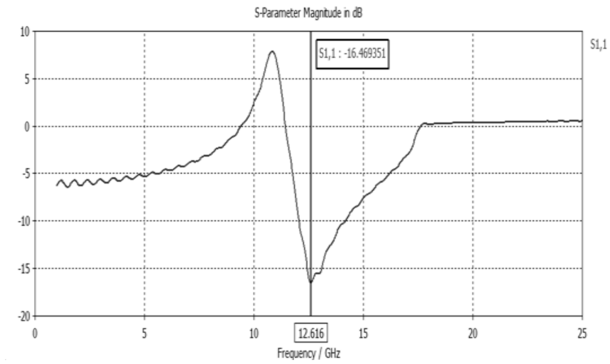
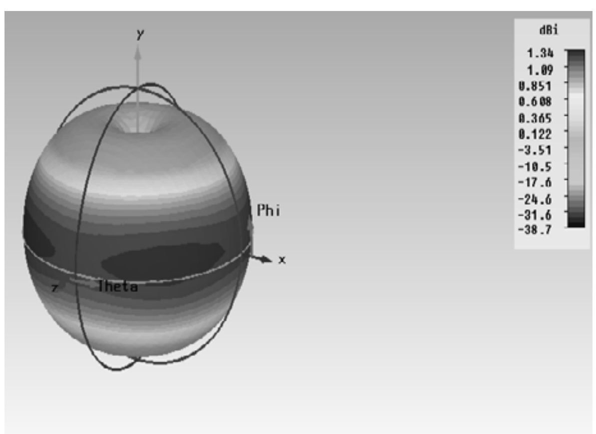
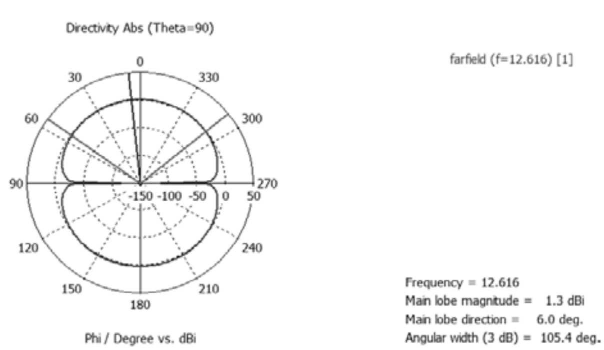


Fig. 2. Return Loss verses frequency

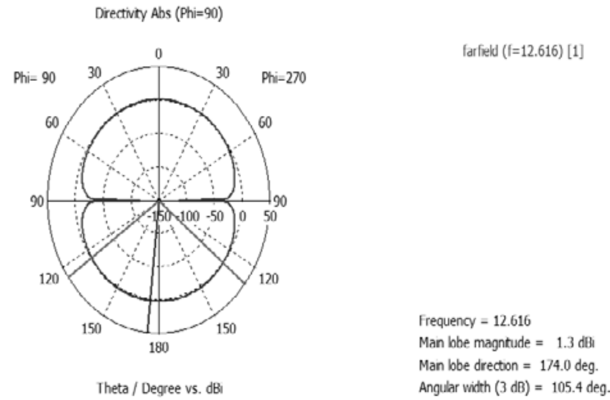
A clear depth of -16.469dB has been observed at 12.616 GHz frequency meaning that the resonant frequency for stud antenna is 12.616 GHz. It is also observed that the designed stud antenna gives a return loss of less than -10 dB over range frequencies from 12.051GHz to 14.202GHz, results in -10dB bandwidth of 2.1505GHz. **(Fig. 3 (a, b & c)).**



(a)



(b)



(c)

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

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

The results obtained shows that the circular stud antenna with given dimension in Table 1. has a directivity of 1.33 dBi as apparent from the 3D radiation pattern shown in Fig. 3(a). The azimuth plan 2D radiation pattern given in Fig. 3(b) shows that main beam in directed 6° with a magnitude of 1.3dBi and HPBW of 105.4°. The elevation plan 2D pattern observed shows that the main lobe is directed in direction of 174° with magnitude 1.3dBi and HPBW 105.4° as shown in Fig. 3(c).

Effect of Dimensions

To analyze the effect of dimension variation on antenna parameters, the Circular stud antenna is simulated for different values of radius 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 calculated different values.

To find out the effect changing radius of conductor on the resonant frequency "f_r", directivity "D" and radiation efficiency "e_r" the circular stud antenna is simulated for different radiuses of conductor "R_c" while all other dimensions are kept constant. The radius of conductor length "R_c" is varied from 5mm to 6mm with increment of 0.25mm per results and the results obtained are listed in **(Table 2)**. The results show that the resonant frequency "f_r" and directivity "D" of stud antenna decrease with increase in radius of conductor "R_c" while the radiation efficiency "e_r" varies in an irregular fashion.

Table 2: The Effect of conductor radius on Antenna Parameters

R_c (mm)	f_r (GHz)	D (dBi)	e_r (dB)
5	12.616	1.33	-2.397
5.25	12.568	1.308	-2.772
5.5	12.496	1.258	-3.064
5.75	12.448	1.231	-3.215
6	12.424	1.184	-3.152

To find out the resonant frequency "f_r", directivity "D" and radiation efficiency "e_r" for different values of radius of substrate "R_s" all other dimensions are kept constant and substrate length "R_s" is varied from 6mm to 7mm with increment of 0.25 mm per results and the results obtained are listed in **(Table 3)** as given below.

Table 3: The effect of substrate radius on Antenna Parameters

R_S (mm)	f_r (GHz)	D (dBi)	e_r (dB)
6	12.616	1.33	-2.397
6.25	12.592	1.335	-2.466
6.5	12.592	1.331	-2.503
6.75	12.592	1.325	-2.558
7	12.592	1.321	-2.591

The results listed in (Table 3) show that the resonant frequency "f_r" remains constant except for radius of substrate equal to 6mm and the radiation efficiency "e_r" and directivity "D" of circular stud antenna decreases with increasing radius of substrate"R_s".

The resonant frequency "f_r", directivity "D" and radiation efficiency "e_r" are obtained for different values of conductor thickness "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 4).**

Table 4: The effect of conductor thickness on Antenna Parameters

H_c (mm)	f_r (GHz)	D (dBi)	e_r (dB)
0.5	12.616	1.33	-2.397
0.6	12.616	1.35	-2.328
0.7	12.688	1.371	-2.022
0.8	12.688	1.384	-1.993
0.9	12.712	1.413	-1.844

The increasing tendency is observed for the resonant frequency "f_r" and directivity "D" and radiation efficiency "e_r" with increase in conductor thickness "H_c" as apparent from the results presented in **(Table 4)**.

Table 5: The effect of substrate thickness on Antenna Parameters

H_S (mm)	f_r (GHz)	D (dBi)	e_r (dB)
0.5	12.616	1.33	-2.397
0.6	13.072	1.34	-2.516
0.7	12.832	1.36	-3.519
0.8	13.264	1.376	-3.604
0.9	13.408	1.386	-3.765

While calculating the resonant frequency "f_r" and directivity "D" and radiation efficiency "e_r" for different values of substrate thickness "H_s", it has been observed that resonant frequency "f_r" and directivity "D" increases with increase in thickness and radiation efficiency "e_r" decreases as mentioned in **(Table 5).**

Table 6: The effect of Taper angle on Antenna Parameters

θ_c (°)	f_r (GHz)	D (dBi)	e_r (dB)
-15	12.592	1.333	-2.439
-30	12.616	1.340	-2.329
-45	12.616	1.33	-2.397
-60	12.616	1.347	-2.419
-75	12.640	1.342	-2.222

The resonant frequency "f_r", directivity "D" and radiation efficiency "e_r" are obtained for different taper angle "θ_{tc}" and the results are given in (Table 6).

4. CONCLUSION

Stud, part of our daily wear, can be used in communication systems as antenna to interface guided and unguided media. The circular stud antenna is wrinkle free and much immune to compression. The designed circular stud antenna is useful for communication in frequency range of 12.051GHz to 14.202GHz with bandwidth of 2.1502GHz. This antenna is resulting in a very small reflection coefficient/ returns loss of -16.469dB and directivity of 1.33dBi at 12.616GHz frequency. The antenna parameters can be changed by varying antenna radius, thickness and taper angle of substrate and conductor. The circular stud antenna can be designed for any desired bands of frequencies by using suitable dimensions. The stud antenna will find it application in wireless communication industry to be used for telemedicine, body area network (BAN) and others.

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