Design of a Circularly Polarized Implantable Monopole Antenna for Biomedical Application

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***Abstract* — A circularly polarized monopole antenna has been proposed in this paper for implantable biomedical application. The monopole antenna is designed as an inverted 'Y' structure with unequal arm lengths (L_1 and L_2). The inverted 'Y' structure helps to achieve compactness and the difference in length between two arms causes the circular polarization (CP). This proposed antenna has been fed with co-planar waveguide (CPW) and it shows the near omnidirectional radiation pattern with gain of -6 dB at 2.45 GHz operating frequency. 4.41% axial ratio bandwidth defines the circular polarization property of the antenna. Specific absorption rate for a single layered human skin model is also obtained.**

Keywords — Biomedical antenna; Circular polarization; Implantable antenna Monopole antenna

1. INTRODUCTION

In recent times Implantable Medical Devices (IMD) have increased the life quality by modifying the entire healthcare system with their numerous benefits. In these IMDs, implantable antenna is one of the most important part of the transceiver system, which receives external signals and also transmit signals from the implant to an external device.

It is desirable that an implantable antenna should have higher mobility, so that, the efficient reception of the implantable antenna remains unaffected by the orientation of external transmitting antenna. Hence the Circular Polarization (CP) can be a solution for it. Moreover by achieving CP, multipath loss reduction, polarization mismatch and improved bit error rate can also be obtained [1]. Over the time researchers obtain CP by various techniques. A 'Y' shaped printed monopole antenna with a micro-strip feed, proposed in [2], obtain the CP by varying both the arms of the monopole. In [3], CP is obtained in biomedical antenna by structural modification of the patch as well as by inserting a cross shaped slot on the ground plane, where the arm lengths of the cross are different. In another biomedical, implantable antenna paper [4], CP has been obtained using reactive elements and asymmetric structure with respect to its coplanar waveguide (CPW) feed. It complicates the design though.

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In this paper we proposed a circularly polarized implantable antenna for bio-telemetry applications. To obtain CP in our proposed monopole antenna an inverted 'Y' structure has been designed with unequal arm lengths. Unlike the structure in paper [2], to design a biomedical, implantable antenna direction of both the arms are revered. It reduces the total size of the antenna and makes it compact enough to be implanted inside a human tissue. Also we have designed a CPW feed instead of micro-strip feed for better insulation from the human tissue environment. In addition to it, a superstrate layer has been introduced to the proposed antenna for better insulation. Reflection coefficient, impedance bandwidth (31.85%) and axial ratio bandwidth (4.41%) have been measured in Industrial, Scientific and Medical (ISM) band to check the desired antenna operation and CP. Specific absorption rate (SAR) has been calculated as 37.5 W/Kg for the proposed antenna.

2. ANTENNA DESIGN

A. *Proposed Antenna Geometry*

The proposed antenna has been designed and simulated in High Frequency Structure Simulator (HFSS). The basic design is shown in Fig.1.

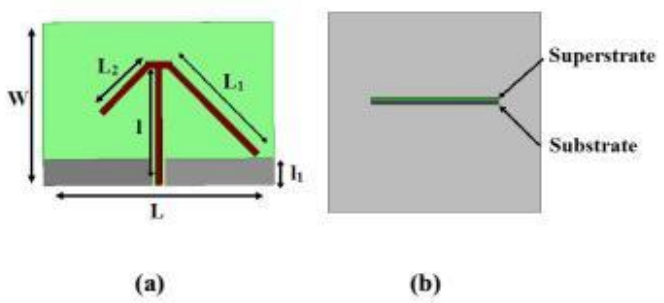

Figure 1. (a) Proposed antenna top view, (b) Antenna side view, placed inside a single layer human skin model

A CPW fed monopole antenna of inverted 'Y' shape is designed. Difference in the length of two arms L_1 and L_2, causes circular polarization. A flexible material Kapton (ε_r = 2.91, tan δ = 0.005) [5] has been used as the substrate of the antenna. A 12.5 mm X 18 mm slab of Kapton with thickness

(h) of 0.2 mm and metal layer on one side, is taken as substrate. The printed monopole along with the CPW feed is designed on the metal layer. The width of the ground and spacing between feed and the ground is denoted by w and s respectively. A superstrate layer of high dielectric constant (ε_r = 10.2, tan δ = 0.035) and thickness (h) 0.2mm is placed over it. Superstrate material has been chosen with high dielectric constant, keeping in mind both the surrounding absorbing medium and loss due to the introduction of superstrate layer. The material choice should be based on impedance matching and minimum reflection [6]. The proposed antenna is of compact size (90 mm^3) so that it can be easily implemented inside a human tissue. Antenna dimensions are given in the Table 1.

TABLE 1.
Design Parameters (in mm)

L	W	S	w	l	l_1	L_1	L_2	h
12.5	18	0.05	0.5	9	2	9.8	5.3	0.2

B. Antenna Analysis

The antenna is simulated inside a single layer human skin model (ε_r = 42.92, σ = 1.562 at 2.4 GHz). Return loss has been calculated and shown in the Fig 2. The impedance bandwidth of the proposed antenna is 31.85% (2.39 – 3.26 GHz). Circular polarization has been analyzed by plotting the axial ratio vs frequency graph in Fig 3. 3-dB axial ratio bandwidth of the proposed antenna is 4.41%, which lies within the operating frequency band.

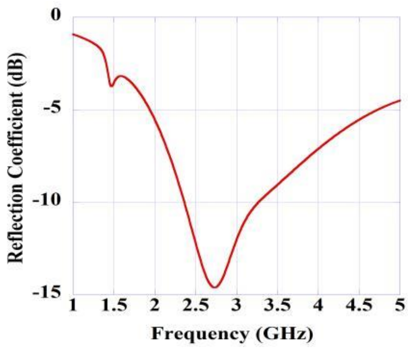

Figure 2. Simulated return loss (S_{11}) value of the proposed CP monopole antenna.

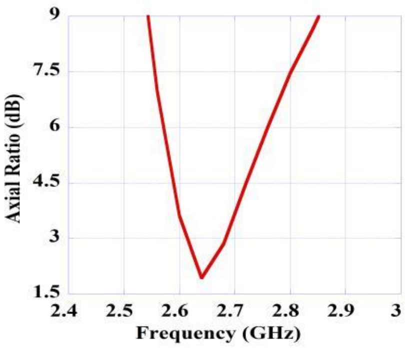

Figure 3. Axial ratio plot for the CP monopole antenna

3. RESULT

Along with the impedance bandwidth and axial ratio bandwidth we obtain a maximum gain of around -6 dB at 2.45GHz. For the entire bandwidth the total gain is approximately in the range of -5 dBi to -25dBi. Radiation pattern, given in Fig 4 (a) and (b), is almost omnidirectional as required.

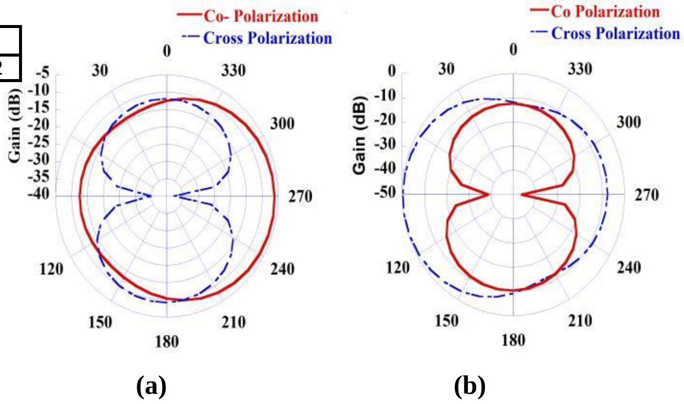

Figure 4. Radiation pattern of the proposed antenna (a) H-field, (b) E-field

Circular polarization has been achieved by varying the difference of the length (L_1 - L_2) between the two arms. The shorter arm was varied keeping the other arm fixed. Arm length L_2 has been varied from 4.5 mm to 5.5 mm. CP was achieved in each case with different axial ratio bandwidth. Fig 5. shows the variation of axial ratio with respect to length of the shorter arm. Optimization has been done between axial ratio bandwidth and the frequency at which the CP was obtained.

Table 2. represents the performance comparisons for similar kind of antenna.

TABLE 2.
Performance Comparison for the flexible antennas

Antenna Structure	Reference	Volume (mm^3)	S_{11} (% BW)	Axial Ratio (% BW)
Planar	H. Li, et al., Elec. Lett. ,2016 [3]	127	16.15	6.09
Planar	This proposed work	90	31.85	4.41

The Specific Absorption Rate (SAR) is important for biomedical implantable antennas. It gives the measure of absorbed power within a unit mass of biological tissue. SAR distribution for the proposed antenna is given in Fig 6.

The SAR value should be within the range set by IEEE C95.1-1999 standard. For safety the average SAR should be less than 1.6 W/Kg for a 1g- body model. Here we have obtained a relatively low SAR of 37.5 W/Kg. We need to reduce input power to meet the safety level.

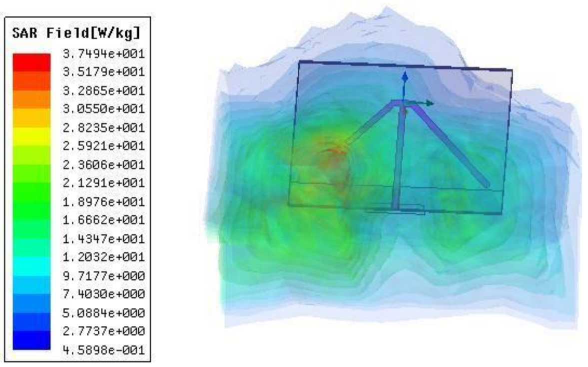

Figure 6. Average SAR distribution for the proposed monopole antenna.

4. CONCLUSION

In this paper a circularly polarized monopole antenna has been designed for biomedical application. This implantable antenna is consists of thin layers of both substrate and superstrate. Low thickness has made this antenna flexible. Also it is compact in size and the impedance bandwidth is high (31.85%). CP with 4.41% axial ratio bandwidth has been achieved within the operating frequency band. Difference in length of the two arms decides the axial ratio and hence the CP. Low SAR value of 37.5 W/Kg has been obtained for 1-g human skin model.

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