Design of a 3D Cross-fed Antenna for Microwave-based Head Imaging Applications

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***Abstract*— A compact microstrip slot-loaded antenna with three-dimensional geometry is presented in this article. The antenna achieves an operational bandwidth from 1.23 GHz-2.56 GHz. The low frequency enables the high penetration into the human head. It shows 70.18% of impedance bandwidth centered at 1.9 GHz with a peak gain of 3.82 dB at the center frequency. The antenna has the front-to-back ratio around 2.4 dB-6.48 dB and efficiency more than 93%. The dimension of the antenna is $0.58 \times 0.12 \times 0.05\,\lambda^3$, where λ represents the effective wavelength of the smallest frequency in the required band of operation. This antenna can be suitable for head imaging applications.**

Keywords- Microstrip antenna; cross-fed; biomedical; slot-loaded.

I. Introduction

In the last few decades, microwave-based imaging is one of the favorable methods employed in designing of diagnostic systems. The features such as low-cost, non-ionizing property, small size makes the technique attractive in medical applications. Some of the promising applications are the detection of the breast cancer, brain tumor, heart failure, and brain stroke [1] etc. The microwave imaging systems analyze the scattered signal due to the variation of dielectric constant between affected and healthy tissues for detection of diseases. The antenna is the important element in any microwave-based imaging system. Low-frequency operational band of the antenna is very much essential in order to have the reasonable penetration of signal into the human head. For obtaining low operating frequency band of interest, different varieties of antennas have been suggested [1]-[2].

The objective of this article is to design a 3D compact antenna with wide operating bandwidth. Here the folded antenna mainly consists of a basic dipole antenna structure along with a folded-parasitic element. The dipole antenna is a symmetrical structure with properly arranged feed line and ground components. It is crucial for obtaining the higher resonant frequency. The slotted section is responsible for enhancing the overall electrical length of the excited signal without changing the dimension of the antenna. Along with this, it induces required capacitances in order to obtain proper impedance matching. The cross feeding helps in providing balanced radiation patterns and also decreases the input resistance and enhances the capacitive reactance by shrinking the distance of feed line and the meandering process respectively. The addition of the parasitic elements in the proposed structure is basically to dominate the low operating frequency band. The proposed design achieves an operating bandwidth of 1.23 GHz-2.56 GHz which satisfies the low-frequency requirement of the antenna to be used in microwave based head imaging systems.

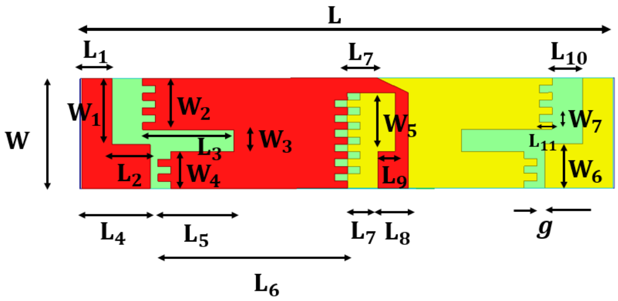

Fig. 1. Structure of the proposed antenna (Top view)

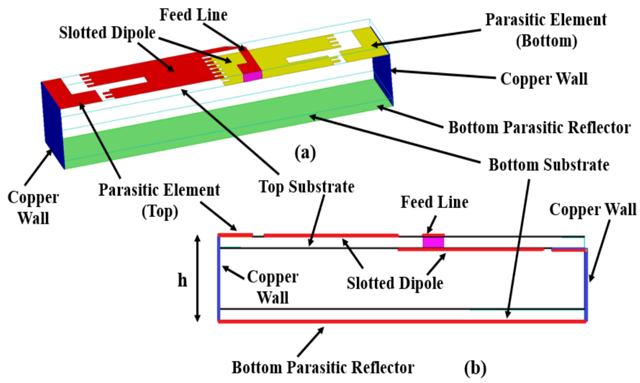

Fig. 2. Structure of the proposed antenna (a) 3D Side view (b) Side view

II. Antenna Design

The geometry of the proposed design is shown in Fig. 1. The antenna is designed on two FR4 substrates having a relative permittivity (ϵ_r) = 4.4, and thickness (h_s) = 1.6 mm. The top-substrate is printed on both the sides and the feeding of the structure is provided at the top layer with the 50Ω microstrip line. The bottom-substrate is printed on one side and connected to the two opposite sides using 0.2 mm thick parasitic copper walls with the height of 7 mm. Two parasitic patches are also printed on the top substrate at both the sides as shown in Fig. 2 (a). Both the substrates are having the same dimension covering the area of $L \times W$. The parasitic elements at the top and bottom side of the top substrate couples with feed and ground components of the antenna. Thus, it helps in driving currents to the folded parasitic element and enhances the effective current path to lower the operating frequency. Fig. 2 (b) indicates the side view of the proposed antenna.

The initial values of the design are selected based on the half wavelength assumption of the dipole for the center frequency value of 1.9 GHz. The following formulas are used in order to calculate the initial dimensions [3].

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}} \quad (1)$$

$$\epsilon_{r_{eff}} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1+12\frac{h_s}{W}\right]^{-\frac{1}{2}} \quad (2)$$

$$\lambda_{eff} = \frac{c}{f_r\sqrt{\epsilon_{r_{eff}}}} \quad (3)$$

Here $f_r, \epsilon_{r_{eff}}, \lambda_{eff}$ represents the resonant frequency, effective permittivity and the effective wavelength respectively. The overall length of the antenna is assumed to be half of the effective length corresponding to the lower resonant frequency. The optimized dimensions of the design are obtained by using ANSYS HFSS electromagnetic simulation tool. After optimization, the final dimension of the antenna is as shown in Table 1.

TABLE 1. Design Parameters (in mm)

L	W	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9
70	15	4	5	12	9	17	25	4	4	2.3
L_{10}	L_{11}	W_1	W_2	W_3	W_4	W_5	W_6	W_7	g	h
4	1.7	9	7	3	5	8	6	1	1	7

III. SIMULATION RESULTS

The proposed antenna has been simulated using EM software ANSYS HFSS version 15. Fig. 3 demonstrates the variation of S_{11} and gain of the structure.

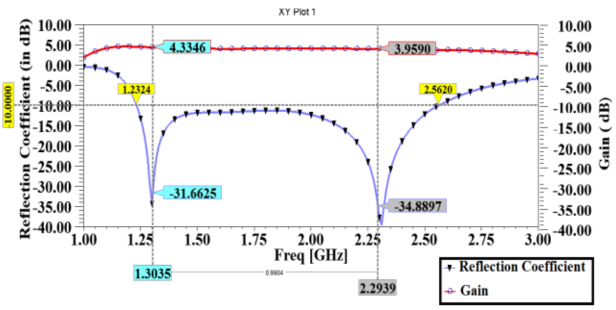

Fig 3. Variation of the Reflection coefficient and gain for the proposed antenna.

It shows -10 dB bandwidth in the range of 1.23 GHz-2.56 GHz. The plot represents an impedance bandwidth of 70.18% for the center frequency at 1.9 GHz. The peak gain of the design is observed to be 4.33 dB and 3.95 dB at the resonant frequencies of 1.3 GHz and 2.29 GHz respectively. Fig. 4 represents the surface current distribution at two different resonant frequencies for the proposed design. The antenna operates at 2.29 GHz with the folded dipole structure as shown in Fig 4 (a) whereas, due to enhanced length the antenna operates at 1.3 GHz as presented in Fig. 4 (b). This provides a wider bandwidth to the proposed design. Fig. 5 shows the radiation patterns obtained at three different frequencies i.e. 1.23 GHz, 1.9 GHz, and 2.56 GHz respectively. The results indicate that cross polarization level is below -25 dB at 1.9 GHz in both XZ-plane and YZ-plane.

IV. CONCLUSION

A compact folded cross-fed three-dimensional microstrip antenna has been presented and analyzed. The antenna is designed using the slotted dipole and the parasitic elements. The compact antenna with dimension $0.58\lambda \times 0.12\lambda \times 0.05\lambda$ shows -10dB impedance bandwidth of 70.18 %, peak gain more than 3.66 dB, and efficiency greater than 93% over the frequency band of 1.23 GHz-2.56 GHz. The low operating frequency criteria make the antenna suitable to be used in head imaging applications. Measurement results of this design will be submitted during the presentation.

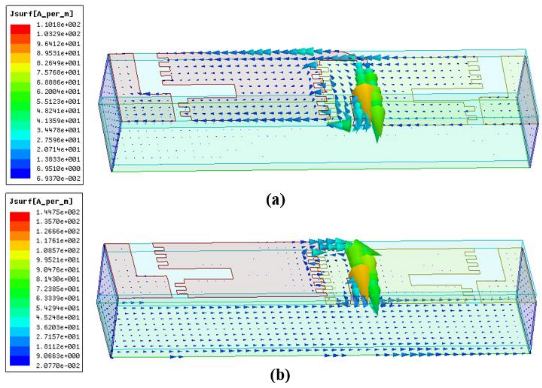

Fig. 4. Surface current distribution (a) at 2.29 GHz (b) at 1.3 GHz

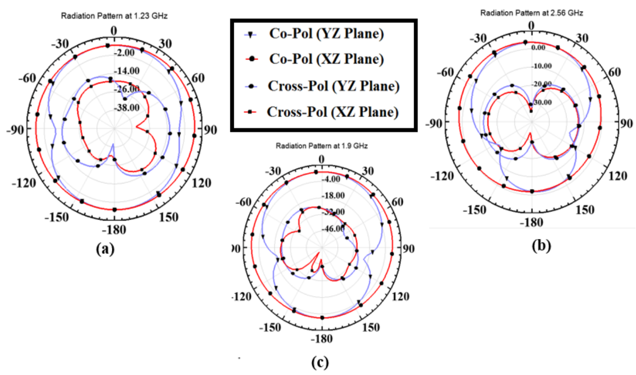

Fig. 5. Radiation pattern (a) 1.23 GHz (b) 1.9 GHz (c) 2.56 GHz

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