Extremely Low Profile Flexible Antenna for Medical Body Area Networks

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***Abstract*— Medical Body Area Networks (MBAN) are widely used in healthcare systems employing in- and on-body applications. An extremely low profile patch antenna for the MBANs is presented in this paper. The antenna consists of two flexible printed circuit boards (FPCB) separated by an air gap and uses a rectangular radiating patch with four slots. Two variants of the antenna having single and dual band operation are discussed. The single band antenna operates at 2.4 GHz while the dual band antenna works at frequencies of 2.4 GHz and 4.3 GHz. Both versions of the proposed antenna offer good bandwidth, high gain and radiation coverage for the MBAN applications.**

***Keywords*— Medical BAN, Low profile antenna, Flexible PCB, Wearable applications.**

I. Introduction

Medical Body Area Networks (MBANs) are fast becoming one of the important technologies in wearable electronics. They have numerous applications in healthcare and telemetry systems [1]. MBANs are used to monitor the health of patients in hospitals and at homes. Vital health parameters are observed and measured using implanted and wearable devices employing in- and on-body scenarios. They provide continuous and unobtrusive examining of health conditions of patients including acidity in stomach, blood pressure, heart rate, EEG and ECG to name a few [2]-[3]. Performance of MBANs depends on the efficiency of the wireless communication device. These devices are required to be miniaturized, flexible, conformal to the body shape, lightweight, low profile, efficient and should be able to provide continuous monitoring. They should also maintain a reliable communication link between the networks [4]. The antenna is an integral part of such wireless communication systems and dictates their working. Design of a reliable antenna while maintaining form factor and performance specifications is a challenging task [5]-[6].

The performance of an antenna is diminished when it is placed in a lossy medium like in the close proximity to the human body. As the antenna and human body undergo capacitive coupling, the input impedance and the operating frequency of the antenna is affected. The body tissues absorb some of the power making the radiation efficiency of the antenna to be reduced. The reduced radiation efficiency causes the radiation pattern to be degraded resulting in the transmission errors [4]-[6]. To have a good performing antenna in the MBANs, it should be resistible to human body effects and have very low radiation towards the human body fulfilling the Specific Absorption Rate (SAR) limits. A number of antenna types are discussed in literature to accomplice these requirements including textile, planar inverted F, patch and monopole antennas [6]-[14].

For on body applications it is required that the polarization of the antenna should be normal to the human body so that it could not harm the body tissues. The monopole or dipole antennas are the best choice for these kinds of applications, but when such antennas are placed in close proximity to human body, their efficiency gets reduced. Antennas with unidirectional radiation patterns are also a preferred choice so that the effects of the human body on antenna performance can be reduced and the human body has less exposure to the electromagnetic radiations [11]-[12].

Patch antennas successfully meet these criterions and therefore, are the best possible choice for the MBAN applications. They are least sensitive to the human body effects and have very low SAR [13]. Various studies have been carried out to investigate the merits and demerits of the patch antennas when they are used in the MBAN [13]-[15]. Continuous growth of the MBANS necessitates novel antenna designs to improve the MBAN applications. In this paper, a novel patch antenna with slotted patch radiator and flexible PCB substrate is proposed for MBAN applications.

Following the introduction, the paper consists of three sections. In Section II, the single band antenna performance is studied while Section III discusses the design and performance of the dual band antenna. Conclusion and future work is given in Section IV.

II. Single Band Antenna

A. Antenna Geometry

The proposed single band antenna design consists of a ground plane, two flexible printed circuit boards (FPCB), an air substrate and a radiating patch. The top view of the modeled antenna structure is shown in the Figure 1. A microstrip feed having an impedance of 100 ohm is used to excite the antenna. The current is induced in the middle patch by electromagnetic coupling. The FPCB substrtae has a permittivity value of 3.4 and loss tangent of 0.005.

The FPCB has a thickness of 0.15 mm and the air substrate has a thickness of 1 mm. The slots are introduced in the patch to realize smaller size and improved matching. The antenna is modeled and simulated using CST Microwave Studio. Structural dimensions of this single band antenna are given in the Table 1.

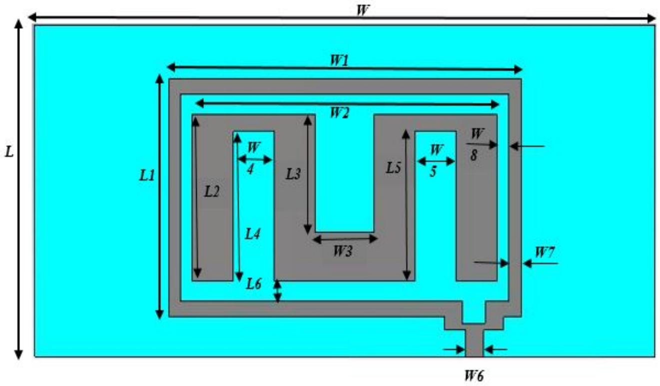

Figure 1. Top view of the antenna model.

TABLE I. SINGLE BAND ANTENNA DIMENSIONS (IN MM).

L	22	L6	1.5	W5	3.5
L1	18	W	52.9	W6	1.54
L2	12.6	W1	30	W7	1.2
L3	8.4	W2	26	W8	1
L4	9.8	W3	3		
L5	9.8	W4	3.5		

B. *Current Distribution*

Current distribution on the patch is studied in order to understand the role of different patch elements in the resonance generation and radiation. The current distribution of the single band antenna is shown in Figure 2. It can be seen that most of the current is at the center of the patch and in between and at the edges of the slots making the antenna to resonate at 2.4 GHz.

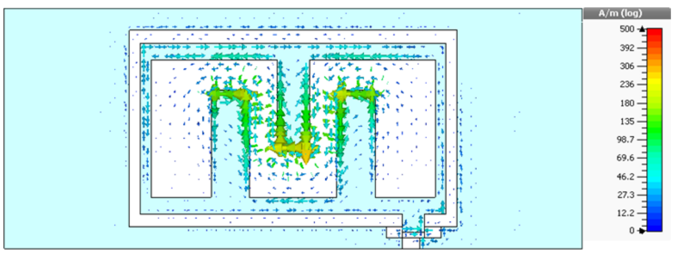

Figure 2. Current distribution of single band antenna at $f = 2.4$ GHz.

C. *Antenna Performance*

The antenna performance is analyzed in terms of reflection coefficient, impedance matching, radiation pattern and gain.

The reflection coefficient (S_{11}) plot of the proposed single band antenna is shown in Figure 3. The result shows that the proposed antenna operates at a frequency of 2.4 GHz that can be used for MBAN. The return loss at this frequency is -31.5 dB, meeting -10 dB threshold effectively to make it radiate maximum amount of power. The antenna has a -10 dB impedance bandwidth of 15 MHz covering the MBAN range specified by the Federal Communications Commission (FCC).

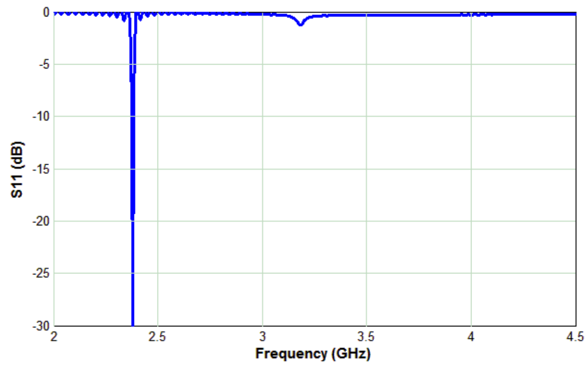

Figure 3. Reflection coefficient response of single band antenna.

The 3D radiation pattern of the antenna is shown in Figure 4. The result shows that the direction of radiation is perpendicular to the plane of the antenna. The radiation is more in the y-z plane. The 3 dB angular width is noted to be 111.5 degree. The antenna has a gain of 4.3 dBi. Backside radiation level is also low.

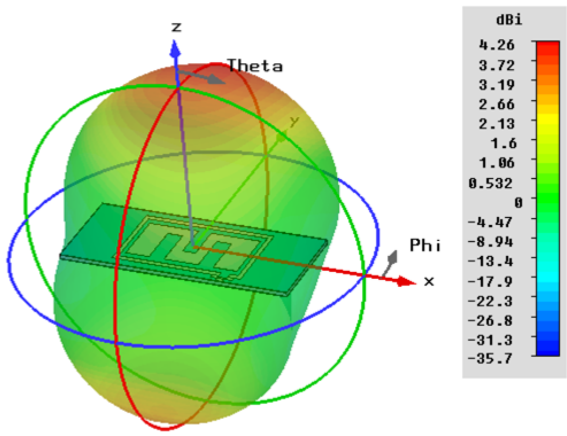

Figure 4. Radiation pattern of the antenna single band antenna at $f = 2.4$ GHz.

III. DUAL BAND ANTENNA

A. *Antenna Geometry*

A dual band operation can be achieved using the proposed structure by introducing small changes in the geometry. For this purpose, the dimensions of the antenna are changed and the permittivity of the FPCB is used to be 3.5. Optimized dimensions of the dual band antenna are given in Table 2.

B. *Current Distribution*

The dual band antenna operates at MBAN frequency of 2.4 GHz and WiMAX frequency of 4.3 GHz. There are three slots that make this antenna to resonate on two frequencies. Figures 5(a) and 5(b) show the current distribution of dual band antenna. Concentration of the current on the middle patch at the edges of the slots makes the antenna to resonate at 2.4 GHz, similar as observed for the single band antenna. The outer feeding loop plays a more important role with longer current path to have the resonance at 4.3 GHz.

TABLE II. DUAL BAND ANTENNA DIMENSIONS (IN MM).

L	25	L6	1.5	W5	3.5
L1	18	W	52.9	W6	1.54
L2	12.6	W1	30	W7	1.2
L3	8.9	W2	26	W8	1
L4	11.3	W3	5		
L5	11.3	W4	3.5		

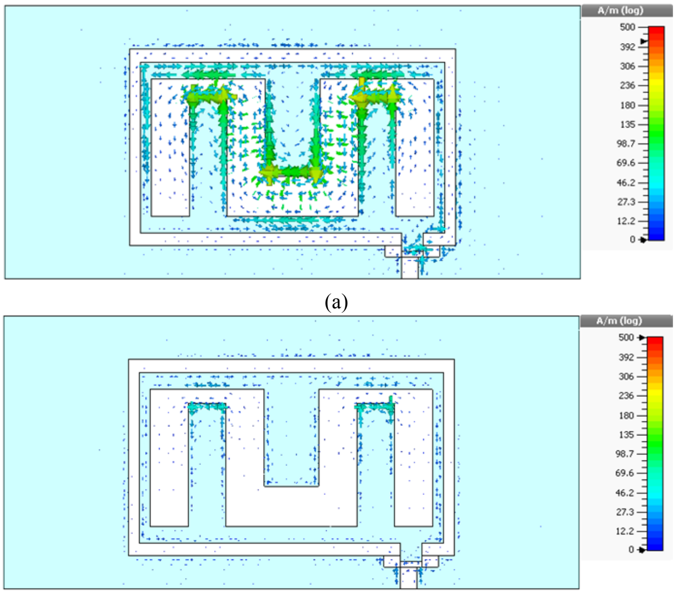

Figure 5. Current distribution of dual band antenna at (a) $f = 2.4$ GHz (b) $f = 4.3$ GHz.

The current distribution results show that the gap between feeding loop and radiating patch has little impact on the matching of both the single and dual band designs. Slots' position and dimensions play a more important role in the antenna performance. The antenna bandwidth and resonant frequency can be adjusted by changing the length, position and width of slots and length and width of patch.

C. *Antenna Performance*

The reflection coefficient response for the dual band antenna is shown in Figure 6. It is evident that the dual band antenna is operating at 2.4 GHz and 4.3 GHz with good impedance matching. The reflection coefficient is noted to be -14.3 dB and -17.4 dB at 2.4 GHz and 4.3 GHz, respectively. The bandwidth of dual band antenna at 2.4 GHz is 12 MHz and at 4.3 GHz is 13 MHz.

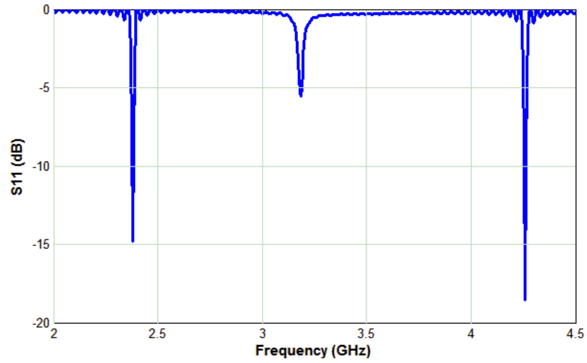

Figure 6. Reflection coefficient response of dual band antenna.

The radiation patterns of the proposed dual band antenna at the two operating frequencies are shown in Figure 7.

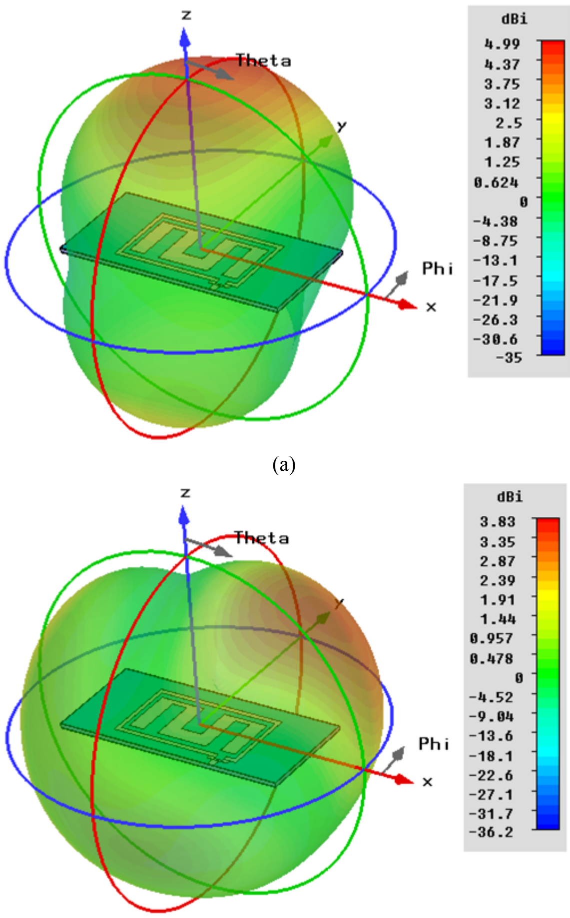

Figure 7. Radiation pattern of the antenna (a) at $f = 2.4$ GHz (b) at $f = 4.3$ GHz.

It can be seen from the Figure 7(a) and 7(b) that the dual band antenna has a unidirectional radiation pattern at the two frequencies. At 2.4 GHz the main lobe direction is approximately 90 degree while the main lobe direction is 177 degrees at 4.3 GHz. The 3 dB angular width of main lobe is observed to be 110 degrees at 2.4 GHz while it is 67 degrees at 4.3 GHz. The antenna offers a gain of 5 dBi at the lower frequency while it is 3.8 dBi at 4.3 GHz.

The presented results show that both the single band and dual band antenna designs offers good bandwidth, high gain and good radiation coverage on top of a miniaturized and flexible structure. These characteristics make this design a suitable contender for the MBAN applications.

IV. Conclusion

A low profile antenna for the MBAN is discussed and evaluated. The antenna is modified to operate at two frequencies making it dual band. The antenna employs an FPCB substrate with a slotted patch structure. It operates at 2.4 GHz in single band version while works at 2.4 GHz and 4.3 GHz at dual band frequency. The peak gain of the single band antenna is 4.3 dBi and the peak gain of the dual band antenna is 5 dBi. The antenna has good impedance matching, bandwidth, gain and radiation pattern over desired range of frequencies. It can be effectively used for remote health monitoring systems. Further work would be carried out to reduce the size and evaluate the performance in body conformal scenarios.

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