Micro Strip Wearable O-shaped Reconfigurable Antenna for Medical Applications

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Abstract: *Now a day, the wearable textile materials of the antenna seems to be a great extent in the miniaturization of wireless devices. The demand of the wearable antennas in rise because of their use in smart clothes in wireless communications. Basic requirements for wearable antennas are a planar structure and flexible construction materials. A novel wearable reconfigurable antenna is designed to provide optimal on-body performance at 2.4 GHz and 5.8 GHz in Industrial, Scientific and Medical bands (ISM). This wearable antenna is constructed in the area of 11mm × 11mm and it is based on the micro strip feeding connection that depends on switch for providing two frequency bands. The copper and flexible polyurethane foam respectively makes the conductive and ground planes. Here, copper acts as a conductor and polyurethane foam provides isolation between the human body and the antenna. Here micro strip feeding is provided for enhancing the reliability of the O-shaped antenna. The O-shaped antenna has two kinds of steps, those are, step 1 (OFF mode) and step 2 (On mode). In ON mode the O-shaped antenna gives the frequency of 2.38 - 2.52 GHz and OFF mode gives 5 - 5.5 GHz. Additionally, the performance of the O-shaped antenna is analysed by reflection coefficient and radiation pattern. The step 1 and step 2 antennas achieved the reflection coefficient of -26.9 dB and -19.96 dB respectively.*

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Index Terms: *Copper, Flexible polyurethane foam, Microstrip feeding, Reflection coefficient, Wearable reconfigurable antenna.*

I. INTRODUCTION

Now a day, the development and integration of wearable antennas and RF devices are receiving massive attention from the users. These wearable antennas are integrated into cloth for modern applications like satellite communications and telemedicine [1-2]. The wearable antenna provides an efficient and reliable wireless communication link between body worn electronic devices and the environment [3]. There are many applications like user safety, awareness, operability and convenience increased by integrating the wireless electronic devices into cloths [4-5] and also these used for fire-fighting [6], rescue work [7] and etc.

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Additionally, the wearable antennas should be lightweight, flexible substrate, garment integratable and low cost [8-9]. The flexible electronics often require a specific frequency to provide wireless connectivity through the antennas [10]. The recent developments in the wearable antenna are miniaturization in their size [11-12]. A compact band-notched Ultra Wide Band (UWB) antenna is introduced and this antenna occupies only a lesser area. This antenna provides a reliable performance even in high temperature and moisture and this UWB used in a 3D localization system [13-14]. The UWB antenna introduced with a full ground plane to operate in critical conditions and the ground plane used for reducing the back radiation and antenna loading from the biological tissues [15]. The dual band textile wearable antenna constructed by using brass eyelets with the combination of conducting and non-conducting textile materials [16]. Besides, the suspended plate antenna provides dual band frequency operated in both ISM and High Performance Radio Local Area Networks [17]. Here [18], a reconfigurable antenna introduced by turning a PIN diode into ON and OFF condition, that changes the radiation characteristics of stub that is folded in slot antenna. The Specific Absorption Rate (SAR) reduced by using polarization dependent AMC surface. Then the single and double-layered AMC was combined with a conventional planar Yagi antenna for changing the radiation direction from bidirectional-endfire to near-endfire [19]. The performance of the antenna degraded because power absorbed by the human tissue and detuning of antenna occurred because of the loading of the human tissue with high permittivity and high loss [20-21]. However, the wearable antennas need to be washed, because the antennas get dirt from dust, sweat. Therefore, the wearable and washable antenna requires breathable coating [22]. In this paper, the wearable reconfigurable band antenna is introduced to monitor the human's day to day activities and in medical instruments. This O-shaped antenna made with lesser size for user's compatibility. Additionally, the reflection coefficient of the antenna is measured for analysing performance of the antenna.

II. LITERATURE SURVEY

Shankar Bhattacharjee et al. [23] presented the dual band antenna based on the metallic micro-electro mechanical switch (MEMS) with a differential feeding technique for wearable applications. The feed was inserted near to the centre of the meander structure on both sides for achieving the constant impedance matching.

The design complexities reduced by using the differential feeding and the device was also operated in the differential circuits. It works in both the ISM and Medical Implant Communication Service (MICS) by optimizing the MEMS switch position. The MEMS based switch operates the antenna in reconfigurable manner.

Z. Hamouda et al. [24] developed the wideband flexible antenna by covering a kapton substrate with flexible magneto dielectric polymer based on the carbon-coated cobalt (CCO). The conjugated polymer and polyaniline (PANI) were used to coat the magneto dielectric polymer. The Nano composite material (i.e., Combination of CCo and PANI) has the conductivity at 7500 S/m which realizes a monopole dual band frequency antenna in Wi-Fi and wireless networks. The open-ended coaxial probe method and Nicholson–Ross–Weir (NRW) technique were used for calculating the relative permeability and dielectric permittivity. Here, the first method depends on the capacitive model and the second method is used for performing material characterization.

Vivek Kumar and Bharat Gupta [25] has introduced the Swastika Slot-UWB (SS-UWB) patch antenna for on-body applications i.e., Wireless Body Area Networks (WBAN). This antenna is placed in, on or around the human body to monitor the health condition and the impedance bandwidth of the antenna is improved by partial ground plane, slot and feed. In this antenna, the modified slotted radiating patch with partial ground plane is used and it is act as an impedance matching element. The swastika slot of SS-UWB gives better current rotational symmetry over the curved slot. An appropriate selection of feed gap, notches and slot are required for this SS-UWB.

Andrea Ruaro et al [26] have developed the wearable shell type antenna to use over an on-body Hearing Instrument (HI) with a target of 2.4 GHz ISM band. A cavity backed design was adopted in-the-ear (ITE) hearing instrument and it needs only a 40% of volume through the sphere with the radius of 12 mm. Selective Heat Synthering (SHS) 3D-printed plastics made the frame of the antenna. The antennas are not affected by the electronic environment that is the benefit of cavity backed antenna. Then the antenna was constructed over a realistic 3D printed lossy substrate. It increased the available volume and decreased the losses that is caused by the human body. It is important to make the antenna with the large ground plane.

Lingnan Song and Yahya Rahmat-Samii [27] analysed the effects of bending over the rectangular patch antenna. The resonant frequency and radiation pattern variations were analysed at various bending angles and the antenna was simulated in a full wave bending model. Here a generalized circuit model was introduced for E plane bending and the parameter of this circuit was optimized by PSO. This E plane bending in different angles was used for analysing the bending behaviours of patch antenna. The length and width of the patch antenna substrate is 100mm and it has the dielectric constant of 2.1.

Hamidreza Memarzadeh-Tehran et al [28] presented the high gain antenna (cavity-backed antenna) which has a unidirectional radiation pattern. This antenna comprises of concentric complementary split ring resonators (CSRRs) which radiate at various frequencies, were calculated by the area of each ring slot. In the design of antenna feed, the miniaturization was made by replacing the monopole with 29 mm length and 0.98 mm diameter to a capped monopole. Then the effect of the monopole was analysed by simulating the antenna in solid ground plane. The performance of antenna was optimized at 2.4 GHz, which is in ISM band and this cavity-backed antenna is suitable for on-body to off-body conditions.

Farooq A. Tahir and Ambreen Javed [29] has developed the compact dual band frequency reconfigurable textile antenna and it works on the ISM, 2.45 GHz and wireless local area network (WLAN), 5GHz bands. Here an indigo blue jean material is used for fabricating the substrate and the flexible copper tape is used for the printing radiating patch. The size of the Denim substrate was 50 × 23.5 mm2, its thickness was 1 mm, and the copper tape size was 0.05 mm. This antenna radiates unidirectional and the radiation coupling over the human's body that was avoided by using ground plane that is made by copper tape. The tuning of antenna was made by enabling a single PIN diode with simple biasing circuitry. The achieved simulation frequency for ON state is 2.39–2.52 GHz and for OFF state is 5.20–5.35 GHz.

Sen Yan and A. E. Vandenbosch [30] have designed the wearable pattern reconfigurable antenna based on the metamaterial structure. This patch antenna is resonated either in the zeroth order mode or in +1 mode, by reconfiguring the dispersion curve as well as these two modes achieving broadside or an omnidirectional pattern respectively. The resonant frequency of ZOR mode depends on the inductance caused by the capacitance among the patch and ground.

The above-mentioned methods have some problems like high area, high reflection loss. These problems overcome by developing the antenna with less area and high effective performances.

III. O-SHAPED DESIGN

A. Antenna design specifications

A tiny, high performance, on body antenna is constructed and operated over the 2.4 and 5.8 GHz ISM bands. The impedance of the O-shaped wearable antenna is 50 Ω at the frequency bands of 2.38-2.52GHz and 5-5.5 GHz and additionally the radiation efficiency that better than 50% are imposed. The major consideration of the wearable antenna is less weight and flexibility in an all dimensions. Then SAR guidelines for electromagnetic radiation also considered, because an average region of 1g of human tissue absorbs 1.6 W/kg of power. The stable radiation performance and stable reflection coefficient are achieved by minimizing variations through the body morphology, movement and location of the antenna.

B. Antenna topology

To achieve this robust on-body requirement, an O-shaped tiny antenna is developed with two circular patches. Here, the micro strip line feeding is placed between the outer conductor and bottom plane for providing the supply voltage to the wearable antenna.

This type of O-shaped antenna is linearly polarized and it has a two kinds of steps, those are, OFF and ON. The OFF and ON step of the antenna provides the ISM bands of frequency 5-5.5 GHz and 2.38-2.52GHz respectively. The following Fig. 1.a and Fig. 1.b shows how the single frequency antenna is tuned into reconfigurable antenna by placing the switch between two circular patches.

(a) (b)

Fig. 1. O-shaped antenna in different configurations: a) Step 1 (OFF state), b) Step 2 (ON state)

C. Design process

The design procedure for the O-shaped antenna is developed from the textile materials and the design requirement is mentioned above in this section. Here a flexible polyurethane foam is chosen as a substrate with the thickness $h1 = 1.67$ mm, $\varepsilon r = 1.28$ and tan $\delta = 0.016$. The electromagnetic properties of all materials and the effects of textile materials are obtained by characterization techniques [31]. The conductive planes of the O-shaped antenna are made using copper with the thickness of 1mm and the surface resistivity is 0.0171 Ω-mm2/m [32]. The layout of the O-shaped reconfigurable band antenna, top view and geometrical dimensions of this antenna are given in Fig. 2, Fig. 3 and Table 1 respectively.

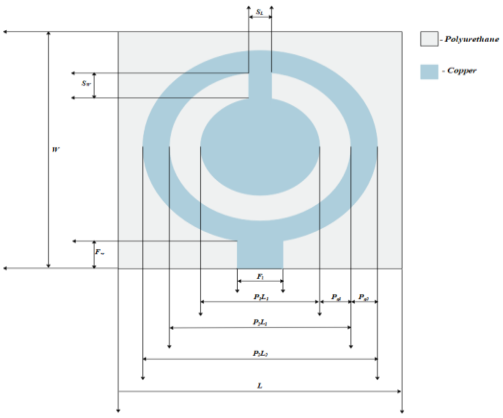


Fig. 2. O-shaped geometry of the textile antenna (Front view)

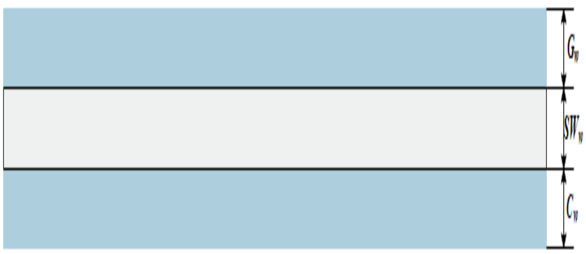


Fig. 3. O-shaped geometry of the textile antenna (Top view)

Table 1. Dimensions of the O-shaped antenna

Parameter	Description	Value
L	Length of antenna	11mm
W	Width of antenna	11mm
P1L1	Length of Patch 1	5.4mm
P2L1	Length of inner conductor of patch 2	7.1mm
P2L2	Length of outer conductor of patch 2	9.7mm
Pg1	Gap between the patch 1 to the inner conductor of patch 2	0.85mm
Pg2	Gap between the inner conductor of patch 2 to the outer conductor of patch 2	1.3mm
Fl	Length of feed	1mm
Fw	Width of feed	1.53mm
SW	Width of switch	1.75mm
SL	Length of switch	0.8mm
Gw	Height of the ground plane	0.5mm
Cw	Height of the copper	1mm
SWw	Height of substrate plane	1.67mm

In O-shaped antenna, the copper is used as a ground plane with the thickness of 0.5mm and flexible polyurethane foam is used as a substrate over the ground plane. The wearable antenna is made based on the dimensions of the antenna that is given in the Table 1 and this antenna is shown in Fig. 2. This antenna provides two ISM frequency bands by enabling the switch between two patches. The power supply to the antenna is given by providing micro strip line feeding between the outer conductors and the bottom plane. The detailed explanation about this micro strip line feeding is given in the following section The antenna gives 5-5.5 GHz of frequency when the switch is OFF as well as it gives 2.38-2.52GHz when the switch is ON. The switch enabled in this O-shaped antenna is IN4001, which is a power blocking diode.

D. Microstrip line feeding

In this microstrip line feeding, the conducting strip is directly connected to the edge of the microstrip patch that is shown in Fig. 1 and 2. The width of the conducting strip (0.1mm) is smaller than the width of the patch (0.97mm).

The merits over this feeding technique is that the feed is etched on the same substrate for providing the planar structure and it gives better reliability. The better impendence matching is achieved in O-shaped antenna by incorporating an inset cut to the patch and this is achieved by controlling the inset position.

IV. EXPERIMENTAL SETUP

The O-shaped wearable antenna was designed and simulated by using CST STUDIO SUITE 2017. The materials for creating the antenna design was taken from the library file of CST software and the simulation of this antenna was taken the free space as references. The selected model of a diode (i.e., switch) is IN4001. The simulation model of the O-shaped antenna is shown in Fig. 4.

Besides, this software analysed the S11 parameter, return loss, VSWR and mismatch loss when the O-shaped wearable antenna is in OFF and ON state.

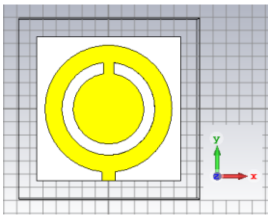


Fig. 4.a. Front view

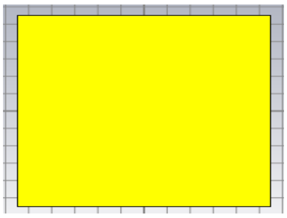


Fig. 4.b. Back view

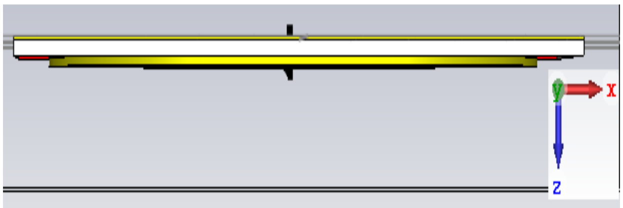


Fig. **4.c.** Top view

Fig. 4. Simulation model of the O-shaped antenna

A. Performance measures

The performance measures that were obtained from this simulation are given as follows:

a. Reflection loss (R_L)

Reflection loss is defined as the amount of power loss due to reflection of power at a line discontinuity. It is expressed in terms of decibels (dB) and the return loss is expressed in Eq. (1).

$$R_L(dB) = -20\log 10(\Gamma) \qquad (1)$$

Where, Γ is a reflection coefficient (i.e., S parameter) from the simulated antenna.

b. Mismatch loss (MM_L)

Mismatch loss is nothing but the amount of power obtained from output. The power loss occurs due to the impedance mismatches and signal reflections and this mismatch loss denotes the amount of power wasted in the system. This is also expressed in decibels (dB) which is shown in Eq. (2).

$$MM_L(dB) = -10\log 10\left(1-|\Gamma|^2\right) \qquad (2)$$

c. Voltage Standing Wave Ratio (VSWR)

VSWR is the amount of mismatch between antennas and the feeding line. It is calculated for knowing the amount of reflected power and the mathematical expression for VSWR is given in Eq. (3).

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \qquad (3)$$

V. RESULTS AND DISCUSSION

The simulated and measured results of ON and OFF states of O-shaped wearable reconfigurable band antenna is discussed here. The S-parameter, radiation pattern of the two steps of an O-shaped antenna is clearly explained below.

A. Step 1 (OFF)

In this step, the switch is not placed between the patches and this antenna provides the frequency in the range of 5-5.5 GHz. The total efficiency and radiation efficiency of the antenna are 16.8 dB and 16.6 dB respectively. There are two types of losses occur during the transmission. Those are dielectric, material (i.e., copper) losses. The losses that occurred in the O-shaped antenna depends on the characteristics of material and medium (air). The dielectric and material losses are in the range of 0.375 and 0.0076 watts as well as the radiated power is 0.104 watts. The simulation results of the step 1 (OFF mode) are described below.

a. S-parameter of Step 1

The S-parameter (S11) for simulated and measured setup of step 1 is shown in the Fig. 5. From the Fig. 5, it can be concluded that the simulated value of S-parameter is somewhat near to the measured setup. Here the air is taken as the medium for analysing this wearable antenna. The S-parameter is named as reflection coefficient (Γ).

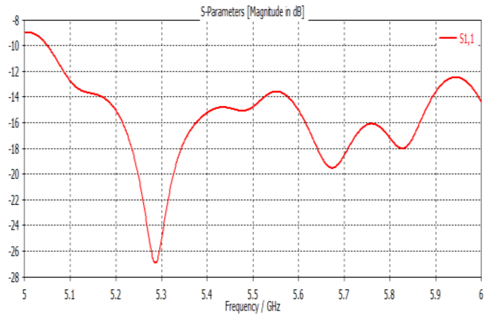
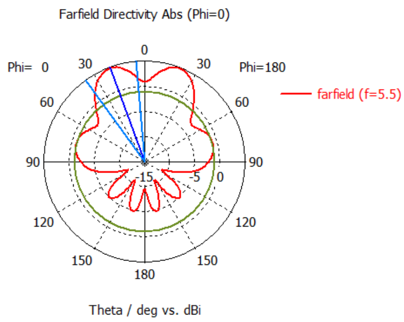


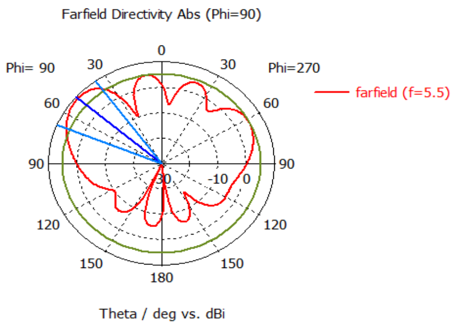
Fig. 5. S parameter for step 1

b. Radiation pattern of step 1

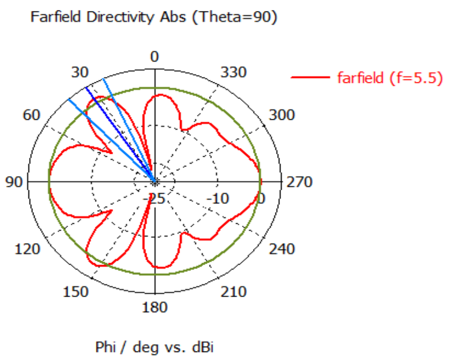
The performance of the O-shaped antenna is analysed in step 1 for different far field conditions. Here, three different far field conditions are utilized, those are phi=0, phi=90 and theta=90 and the illustrations for these conditions are shown in Fig. 6.a, 6.b and 6.c respectively.



(a)



(b)



(c)

Fig. 6. a, b and c are the radiation pattern of step 1 in phi=0, phi=90 and theta=90.

The O-shaped antenna performance in step 1 with different level of angles are known from the radiation pattern of Fig. 6. The performance of radiation pattern of step 1 (OFF mode) is given in Table 2 and the frequency level of these standards is 5.5 GHz.

Table 2. OFF mode radiation pattern for different angles

Parameter	Far field phi=0	Far field phi=90	Far field theta=0
Main lobe magnitude	4.74 dB	9.18 dB	1.3 dB
Main lobe direction	20.0 deg	49.0 deg	33.0 deg
Angular width (3dB)	30.8 deg	31.7 deg	18.7 deg
Side lobe	-5.7 dB	-4.1 dB	-1.3 dB

The return loss, mismatch loss and VSWR of step 1 are -28.60 dB, -28.5955 dB and -1.00772 respectively.

B. Step 2 (ON)

In this step, the antenna provides the frequency in the range of 2.38-2.52 GHz and this kind of antenna does not have the switch among the patches. The total efficiency and radiation efficiency of the antenna are 19.5 dB and 18.3 dB respectively. There are two types of losses occur during the transmission. Those are dielectric, material (i.e., copper) losses. The losses that occurred in the O-shaped antenna depend on the characteristics of material and medium (air). The dielectric and material losses are in the range of 0.29 and 0.009 watts as well as the radiated power is 0.026 watts. The simulation results of the step 2 (ON mode) are described below.

a. S-parameter of Step 2

The S-parameter (S11) for simulated and measured setup of step 2 are shown in the Fig. 7. From the Fig. 7, it is concluded that the simulated value of S-parameter is somewhat near to the measured setup. Here the air is taken as the medium for analysing the wearable antenna. The S-parameter also named as reflection coefficient (Γ).

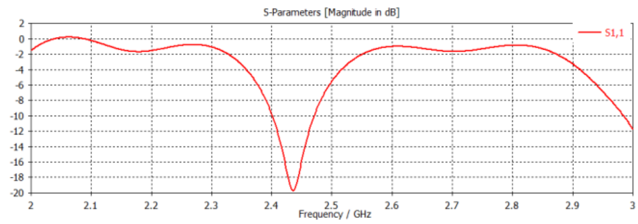
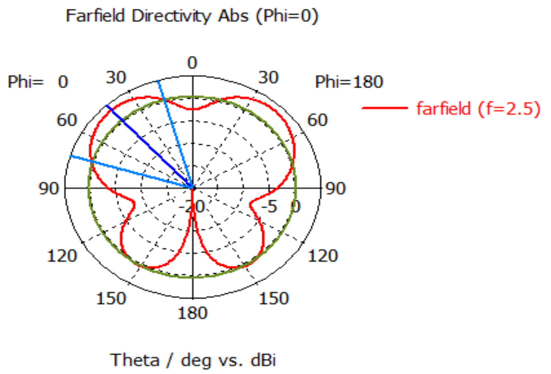


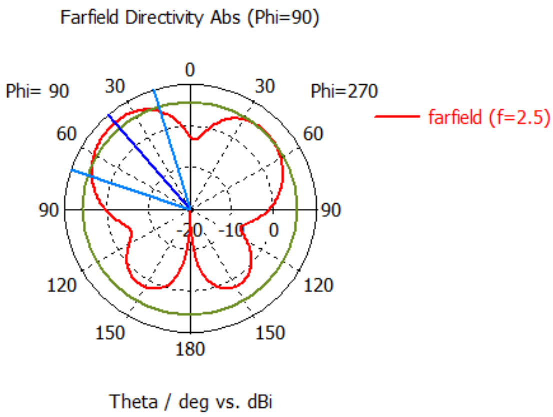
Fig. 7. S parameter for step 2

b. Radiation pattern of step 2

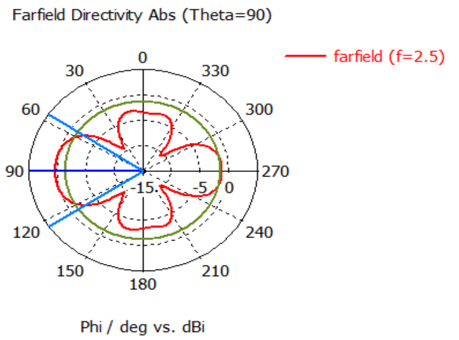
The performance study is completed when analysing the O-shaped antenna in step 2 for different far field conditions. Here, three different far field conditions are utilized, those are phi=0, phi=90 and theta=90 and the illustrations for these conditions are shown in Fig. 8.a, 8.b and 8.c respectively.



(a)



(b)



(c)

Fig. 8.a, b and c are the radiation pattern of step 2 in phi=0, phi=90 and theta=90

The performance of O- shaped antenna in step 2 with different level of angles are known from the radiation pattern of Fig. 8. The performance of radiation pattern of step 2 (ON mode) is given in Table 3 and the frequency level of these standards is 2.5 GHz.

Table 3. ON mode radiation pattern for different angles

Parameter	**Far field phi=0**	**Far field phi=90**	**Far field theta=0**
Main lobe magnitude	3.45 dB	7.51 dB	0.286 dB
Main lobe direction	42.0 deg	41.0 deg	90.0 deg
Angular width (3dB)	57.5 deg	54.8 deg	68.3 deg
Side lobe	-3.1 dB	-1.7 dB	-1.5 dB

The return loss, mismatch loss and VSWR of step 2 are -26.0032 dB, -25.9923 dB and -1.1055 respectively.

The size of the O-shaped antenna is compared with some conventional antennas and it is shown in the following Table 4.

Table 4. Size analysis of proposed O-shaped antenna with conventional antennas

Antenna	**Size (Length* Width)**
O-shaped antenna	11mm×11mm
Band-Notched Flexible Antenna [13]	16mm×26mm
Ultra Wideband Antenna [14]	16mm×27mm
Magneto dielectric nanocomposite polymer antenna [24]	40mm×58mm

From the above analysis, it can be concluded that the antenna has less area when compared to the conventional antennas. The compatibility over the O-shaped antenna is increased by reducing the size of the antenna. This leads to make an improvement in textile antennas.

VI. CONCLUSION

In this paper, a novel O-shaped reconfigurable antenna with microstrip feeding technique has been introduced for wearable applications. The microstrip feeding provides direct connection between the edge of the conducting plane and bottom plane and this feeding gives better reliability of the antenna design. Here the conducting plane (copper) is synthesized with flexible polyurethane foam. The O-shaped antenna with a simple slot structure only occupies 11 mm × 11 mm, which is acknowledged as a small antenna for on-body application. The efficiency of this antenna has been analysed in free space. The fabricated O-shaped antenna gives wider frequency in step 1 (OFF mode) is 5-5.5 GHz and step 2 (ON mode) is 2.38-2.52 GHz. The O-shaped antenna properties are reflection coefficient, radiation patterns, reflection loss, mismatch loss and VSWR have been simulated and measured in free space. The size of O shaped antenna is very compact compared to the conventional antennas like band-notched flexible antenna, ultra wideband antenna and magneto dielectric nanocomposite polymer antenna.

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