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**Wideband Circular Patch Antenna with Parallel Slits Loading for Wireless Body Area Network**

By

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**ABSTRACT**

*A wideband circular patch antenna for WBAN is presented in this paper. It is miniaturized and loaded with three parallel slits to obtain the desired performance. The antenna has a compact size of  $0.37\lambda \times 0.37\lambda$ . It was tested in the vicinity of human body and measured impedance bandwidth are observed to be 2.75GHz-6.25GHz and 8.6GHz-9.9GHz Bands. Measurements in the vicinity of arm and shoulder agrees with each other while measurement in the chest varies slightly to account for the variation of tissues around the area. The antenna can be used for ISM/ WLAN/WiMAX and X-band.*

**Index Terms-** Antenna loading, wide-band, miniaturizations, body communication.

**INTRODUCTION**

The recent integration of wireless systems into medical care, security system, sports, entertainments and luxuries [1]-[4], creates the basis for growing demand of compact and efficient antenna that can be used for both on and off body communication. Articles [5]-[6] proposed the use of wearable antenna for energy harvesting. The authors in [1] proposed the design of wearable antenna that can be integrated into military beret for positioning system, the prototype was fabricated and tested using an equivalent human tissue phantom to observe the effect of human head in the performance of the antenna and it was observed to have negligible effect.

A wearable logo-antenna is designed in [7], the design covered GPS and GSM bands. However, this antenna was designed and customized to fit a logo of a certain brand of hand bag, this constrain is capable of compromising the performance of the antenna. In another approach by [8] a wearable tri-band SIW based antenna on leather substrate was presented, the tri bands cover 2.4GHz ISM band, 3.51GHz WiMAX-band and 4.69GHz for military applications. The overall size of the prototype covered an area of 80mm x 80mm for the length and the width respectively, this is actually too large, and the prototype was tested in a free space thereby neglecting the effect of human body. S. Kang and C. W. Jung in [9] presents reconfigurable wearable fabric antenna, the reconfigurable feature was achieved by the use of two artificial

switches, the antenna was manufactured on fabric substrate and the prototyped was measured on skin mimicking model. The skin mimicking model consists of certain percentage of sugar, NaCl and de-ionized water, this composition cannot adequately mimic the real arm that consists of skin, fat, muscle and so on.

Numerous challenges confront antenna designers for on and off body communication, but the most common challenge is having consensus between user's comfort and efficiency. In most of the literatures presented so far, the real consensus that ensures comfort of the users and at the same time maximizes the antenna efficiency is still in contention. Some literatures ensured the comfortableness of the wearer (by using flexible substrates and conducting materials) at the expense of the antenna efficiency while others compromised the comfortableness over the efficiency. In [10], the design of all-textile antenna for on-body to on-body communication is presented, the authors focused more on flexibility.

The consensus established in this approach is to sufficiently optimize the antenna to occupy the smallest possible space. The optimized antenna is then loaded with slits to achieve desired radiation characteristics.

**Table 1:** Comparison of the proposed antenna with some reported in literatures

S/N	Ref.	Technique	Bandwidth (GHz)	Volume (mm <sup>3</sup> )
1	[12]	Arc projection	2.33 – 2.35	3,920
2	[14]	Center fed	3.99 – 4.03	8,316
3	[15]	Annular rings	4.25 – 6.15	5,747.4
5	This work	3 open slits	2.75 – 6.25 8.50 – 10.00	2240

Several techniques of improving the performance of circular patch antenna have been reported in literatures, in [12], the authors proposed the use of semi-circle arc projection to miniaturize the patch and improve radiation characteristics. In another approach by [13] four curve patches were added around the circular radiating patch which resulted in broadening of the bandwidth. In [14], dual-band microstrip circular patch antenna with monopole radiation pattern is obtained by combining the circular patch with center-fed and circularly periodic mushroom unit. In another attempt by [15] two circular slot were introduced into the circular radiating patch in order to achieve wideband monopole-like radiation pattern with high gain and low cross polarization. The authors of [16] proposed V slit, stub and slot in circularly patch antenna to achieve compact size and dual polarizations. Polarizations reconfigurable circular patch antenna with C shape is proposed by [17], the reconfigurable C shaped slot on the circular patch controls the polarization of the antenna. In [18], a dual-polarized dual-band, omni-directional antenna is achieved by introducing eight open slots to the circular radiating patch.

Several useful techniques of achieving wideband and improving radiation characteristic are reported in [19]-[22].

In this approach, a wideband circular patch antenna with multiple band is proposed. The antenna is sufficiently miniaturized and then loaded with three parallel slits and partial ground plane. It's the simplest but robust, having the largest bandwidth and occupied smallest space compared to those reported in table 1.

**ANTENNA DESIGN AND SIMULATION RESULTS**

Circular patch antenna shown in figure 1 is considered to be the best candidate for a conformal structure. The resonating frequency depend mainly on the radius of the patch. However, the patch behaves electrically larger than its physical dimension, this is due to the infringing fields around the circular radiating patch. The effective radius  $r_e$  for antenna with  $r \gg h$  can be determined using (1) [11]

$$a_e = a \left[ 1 + \frac{2h}{f r \sqrt{\epsilon_r}} \left\{ \ln \left( \frac{f r}{2h} \right) + 1.7726 \right\} \right]^{\frac{1}{2}} \tag{1}$$

where  $r$  is the radius of the patch,  $h$  is height and  $\epsilon_r$  is dielectric constant.

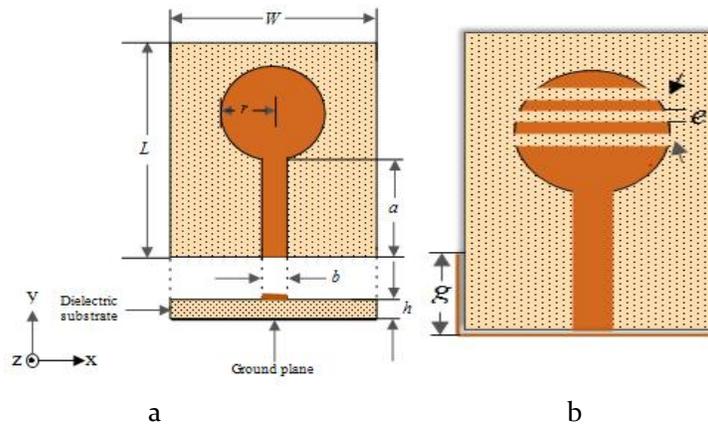


Fig. 1, (a) Circular patch antenna, (b) Slits loaded antenna.

**Table 2:** Optimized dimension of the proposed antenna

Parameter	L	W	a	b	h	r	e	g
Size (mm)	40	40	13	4.2	1.6	11	2	15

The geometry of the proposed slits loaded circular patch antenna and the defected ground plane are depicted in figure 1b. The circular radiating patch along with three open slits on the horizontal plane are printed on FR4 substrate material with dielectric constant of 4.4. The distance between successive slits is 2mm, all the three slits have the same width  $e$  and the length of each slit terminates at the corresponding points on the circumference of the circular

radiating patch. The antenna is fed using microstrip feed line with length  $a$  and width  $b$ . The ground plane is defected along its length and the new length is  $g$ . The optimized parameters are given in table 2. The basic circular patch (without slits) depicted in fig.1a has been used to generate the resonant modes and then three successive slits shown in fig. 1b were been used to enhance the performance of the antenna. The three parallel slits increase the bandwidth by shifting the lower band to the left and incorporate more frequencies. The partial ground plane not only helped in further broadening the bandwidths but also stabilizes the position of the central frequencies. The antenna was simulated on human body model using high frequency structure simulation software and the results are presented by fig. 2 and fig. 3a, b, c. The human body model consists of skin, fat, muscle and bone.

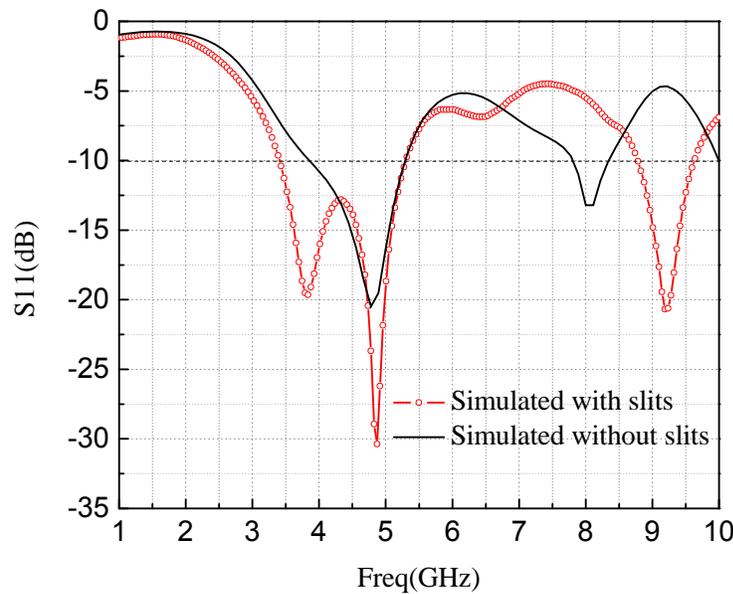
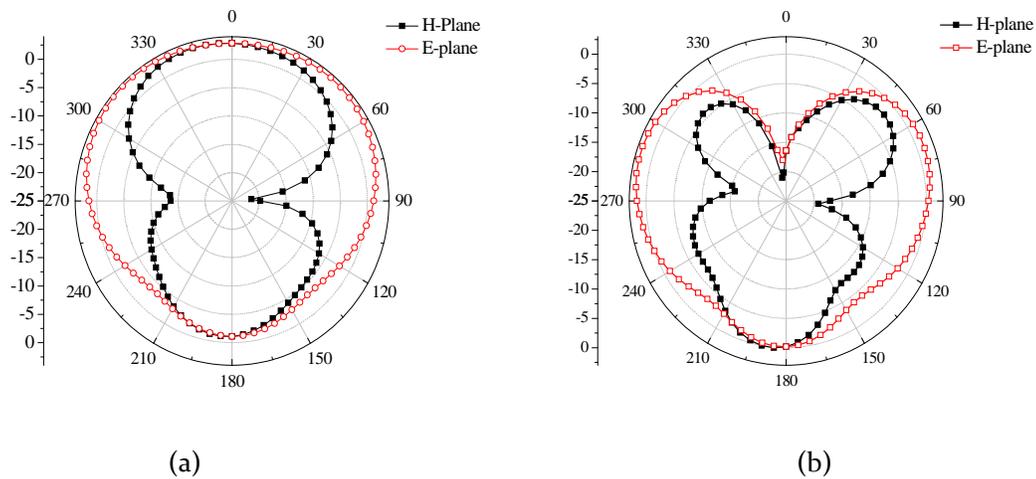
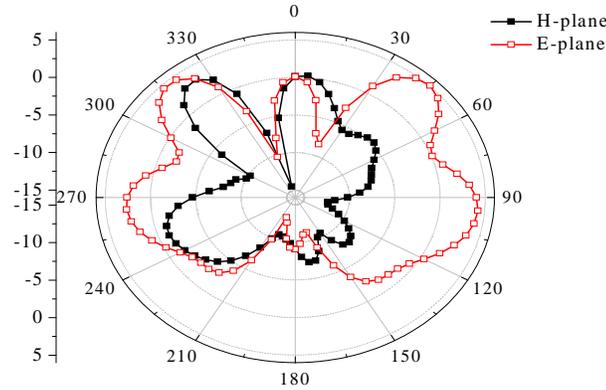


Fig. 2. Simulated  $S_{11}$ .





(c)

Fig. 3. Radiation pattern at (a) 3.5GHz, (b) 5GHz and (c) 9.2GHz.

**MEASUREMENT AND TESTING**

The antenna is fabricated using PCB technology and fed with 50Ω SMA connector. The photographs of the fabricated antenna are depicted in figure 4a and 4b. The reflection coefficient  $S_{11}$  in dB and the voltage standing wave ratio  $VSWR$  were measured on arm, on shoulder and on chest using PNA-X Network Analyzer, N5244A (Agilent technology), the results are compared in fig.5a and fig.5b. It can be observed that, there is good agreement between on arm and on shoulder measurements. A little variation with measurement on chest is observed which is attributable to the variation in surrounding tissues. The measured working frequency bands (at  $S_{11} \leq -10dB$ ) are 2.75GHz – 6.25GHz and 8.6GHz – 9.6GHz for on arm, 2.8GHz – 6.00GHz and 8.6GHz – 9.5GHz on shoulder and 2.8GHz – 4GHz, 4.75GHz – 6GHz and 8.6GHz – 9.9GHz on chest.

The simulated antenna has a bandwidth of 3.50GHz – 5.90GHz and 8.75GHz – 9.7GHz. The discrepancies between the simulated and the measured results are attributable to soldering effect and testing environment. In general, the simulated and the measured results agrees with one another.

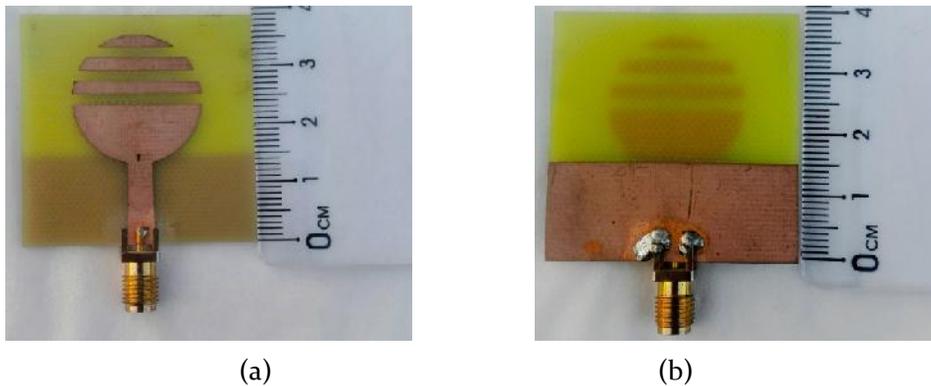


Fig. 4. Fabricated antenna: (a) Front side, (b) Partial ground plane.

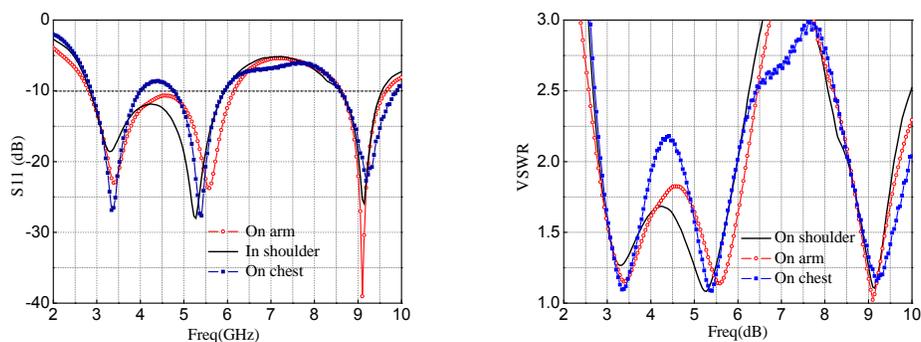


Fig. 5. Measured  $S_{11}$  and VSWR on FR-4 Substrate.

## CONCLUSION

A compact, optimized and loaded circular patch antenna with multi-band is presented. The antenna is sufficiently miniaturized and loaded with three open slits. It's very simple but robust, having the largest bandwidth and occupied smallest space, these are the essential features that make it attractive for both on and off body communication services. The wider bandwidths covered portions of WLAN, ISM WiMAX and X-Band.

## ACKNOWLEDGMENTS

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