Design Of Planar Monople Antenna For Wireless and Energy Harvesting Applications

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Abstract— A planar circular monopole antenna with slots in the patch as well as in the ground plane is presented. Slots of different shapes and sizes are etched in patch and ground plane to bring down the resonant frequency of proposed antenna and increase its bandwidth. The antenna operates over a wide frequency range, covering some of wireless standards/protocols at the same time, such as Wi-Fi, WiMAX, Bluetooth, RFID and GPS (L1). The antenna is simulated in HFSS and measured using pocket VNA. The simulated result shows S11 parameter less than -10dB from 0.72GHz to 1.24GHz and again from 1.52GHz to 2.65GHz. The measured result shows S11 parameter of around -10dB and less from 0.628GHz to 1.28GHz and again from 1.466GHz to 2.72GHz. Without using any slot in the ground plane and patch, the simulated result shows S_{11} parameter less than -10dB from 0.85GHz to 2.18GHz. The simulated gain obtained is around 4dBi at almost all the frequencies. Therefore simulated and measured results are in close agreement. Without using slots in the patch and ground plane, the simulated S-parameter shows S11 less than -10dB from 0.84GHz to 2.25GHz. The overall dimension of the fabricated antenna is 160mm by 76mm. The antenna is fabricated on FR4 epoxy substrate having $\varepsilon_r = 4.4$ and loss tangent 0.02. The proposed antenna, besides its use in wireless communication, finds application in energy harvesting where low frequencies are abundantly present in the environment.

Keywords—circular monopole, energy harvesting, slots.

I. Introduction

Owing to the emergence of several wireless standards and protocols it has become necessary to design an antenna that can operate in multiple frequencies. This calls for broadbanding an antenna. A planar monopole antenna is inherently broadband because it is evolved from microstrip patch antenna by increasing the substrate height and decreasing the permittivity of substrate since both height and permittivity of the substrate have direct affect on the bandwidth [1, 2]. For planar monopole antenna ground plane can be thought to be at infinity and permittivity close to 1 (air substrate) [3]. Increasing the thickness of the monopole further increases the bandwidth [3]. At the design frequency, the monopole antennas should be a quarter of a wavelength long. If the radius of the cylinder is made thicker, the bandwidth of the antennas can be increased. The same approach applies to planar monopole antennas: instead of utilizing a 50 ohm metal strip for the monopole, a wider strip (rectangular shape) or any other shape (triangular, circular, ellipse, etc.) can be used to achieve broadband characteristics. Further optimization of the broadband characteristics can be performed by introducing defects in the ground plane (by etching slots or slits) and/or etching slots/slits in the monopole. This is the guiding premise for this type of research. Different authors in the past have reported modification in the basic structure of planar microstrip and monopole antennas in order to improve the bandwidth and also to provide miniaturization. In one such paper [4], the author has reported an array of two U shaped planar monopole antennas and a slit in the ground plane to achieve 80% fractional bandwidth. Authors in [5] have designed annular ring shaped microstrip patch antenna with ground plane of hexagonal shaped to achieve 151% of fractional bandwidth due to the excitation of closely spaced multimodes [5]. The multimodes may be from same antenna or from two closely spaced antennas [6-7]. In [8], authors have reported that cutting U shaped slot in the microstrip patch/ground plane enhances bandwidth due to alteration of current path [8]. In [9] authors have reported two-element multiple-input multiple-output (MIMO) antenna for ultra wideband applications with tapered feed instead of standard feed. In this work, the two antennas are orthogonally fed which resulted in good isolation between antennas. In [10], the authors have reported three radiating strips and a back coupling pad to improve impedance matching. This structure achieves a wide bandwidth of 2.972GHz from 2.315GHz to 5.285GHz. In [11], the authors have reported U shaped microstrip patch with circular slots in the ground plane achieving 81% fractional bandwidth. In [12], the authors have reported an eye shaped slot in dipole antenna. This slot improves the gain and return loss bandwidth of antenna. The frequency of this antenna is from 3.1 to 12 GHz. The authors in [13] have reported etching complementary split ring resonator on the radiating patch of the planar monopole antenna. By this technique, a fractional bandwidth of upto 76% has been achieved.

Antennas also find applications in harnessing RF energy from environment. For better harnessing the RF energy from ambient environment, it is desired to have the antenna radiation pattern almost equal in all the directions. Monopole antennas are a very good choice for such applications. Antennas for energy harvesting applications do not require to be compact. However planar antennas are preferred as these can be integrated with microwave circuitry required with antenna for RF energy harvesting like rectifiers etc. [14] Authors in [14] have designed and optimized a rectifier combined with a broadband planar monopole antenna (called rectina) which can be used for RF energy harvesting.

The advancement of current world technology, as well as customer demand for multiple services offered by a single wireless device, has influenced the need for an antenna capable of transmitting and receiving electromagnetic waves across multiple frequency bands. A distinct frequency band is associated with each wireless service. The most prevalent wireless services are listed, along with their respective frequency ranges.

Frequency ranges	wireless service
860-960MHz	RFID
2.51-2.55GHz	WiMAX band
2100MHz	UMTS(3G of GSM)
824-890MHz	CDMA
1575+-10MHz	GPS
890-915MHz and 935-960MHz	GSM(900)
1710-1780MHz and 1810-1880MHz	GSM(1800)
1920-1980MHz and 2110-2170MHz	3G
2300-2400MHz	4G
2400-2483MHz	Wi-Fi

In this paper the authors have proposed a novel broadband planar monopole antenna that will cover simultaneously a number wireless standards and protocols (especially the standards at low frequencies) so that the proposed antenna can be used in wireless as well as energy harvesting applications.

II. Design of the proposed monopole antenna

A simple circular monopole antenna is designed and simulated in simulation software as shown in Fig. 1. One side of the substrate consists of circular monopole with microstrip line (top side) and the other side (bottom side) consists of only ground plane. The substrate used is FR4 epoxy having relative permittivity ε_r=4.4 and thickness h=1.6mm. The dimensions are optimized for better impedance matching. The initial length of monopole is obtained using the available analytical formulation available in literature [3]. The length of the wire monopole antenna is quarter-wave long at the design frequency with some correction factor. With increase in the thickness of the radius of the wire, the bandwidth increases. So for broadband monopole antenna the lower frequency corresponding to VSWR=2 or S_{11}=-10dB can be calculated by equating the area of the radiating structure with the equivalent cylindrical monopole antenna having the same height as that of original antenna. Let us consider the case of a circular monopole antenna of radius 'a'. The equivalent length of the cylindrical monopole antenna is $L=2a$. Now area of circle is πa^2. Area of cylinder of length L and radius r is $2\pi r L$. Equating the two areas we obtain $r = a/4$.

For a cylindrical wire monopole antenna having length L and radius r, the following relation holds [3]

$$L + r = 0.24\lambda$$

(1)

$$L + r = 0.24 \frac{c}{f_L \sqrt{\varepsilon_{reff}}}$$

(2)

where f_L is the lower cutoff frequency

Here $\varepsilon_{reff} \approx 1$ (since we are considering air dielectric)
This simplifies to

$$f_L = \frac{7.2}{L + r} \text{ GHz}$$

(3)

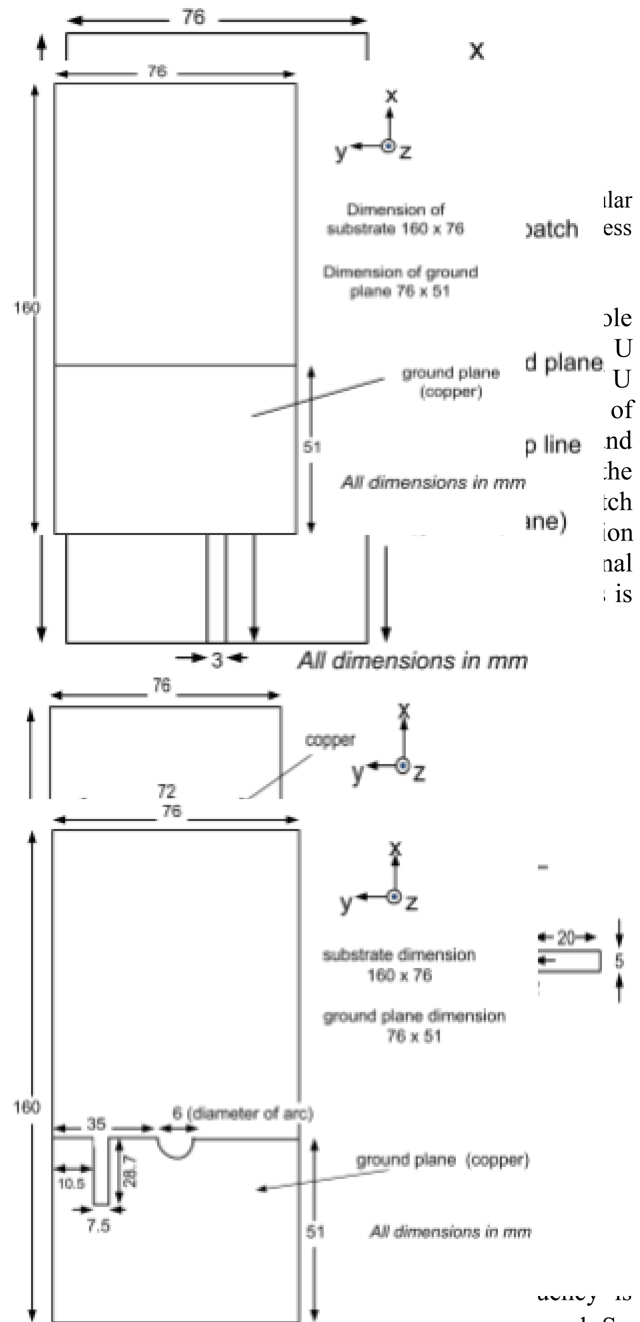
where L and r to be considered in cm.

In order to account for the gap 'p' (3) modifies to

$$f_L = \frac{7.2}{L+r+p} \text{ GHz} \tag{4}$$

This is the basic design equation.

In the present optimized design, a=36mm. Hence r=9mm, L=72mm, p=5.3mm. Putting these values in (4) we obtain f_L=834.298MHz.



reduced and the upper cutoff frequency is increased, S_{11} parameter is slightly more than -10dB around 1.3GHz. The simulated 3D radiation pattern (plot of gain in dBi) of the slotted monopole antenna at 0.9GHz is shown in Fig.4. The E-plane and H-plane radiation pattern of the proposed antenna is shown in Fig. 5. The proposed antenna is then fabricated and its S-parameter measured using pocket VNA. The fabricated antenna is shown in Fig. 6 and the pocket VNA with the antenna connected is shown in Fig. 7. The measured S-parameter shows S_{11} less than -10dB from 0.628GHz to 1.28GHz and again from 1.466GHz to 2.72GHz. The measured and simulated S-parameter S_{11} are compared in Fig. 8. The results show good agreement between measured and simulated S-parameter S_{11}.

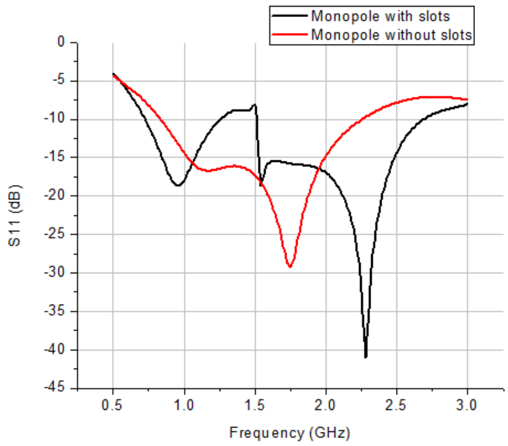


Fig. 3. Simulated S_{11} parameter (magnitude only) of simple circular monopole antenna with and without slots.

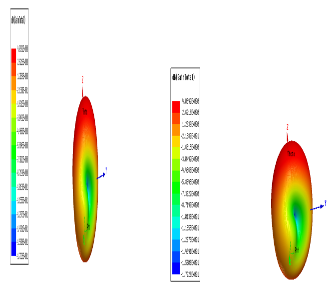
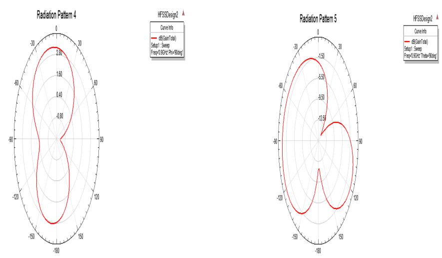


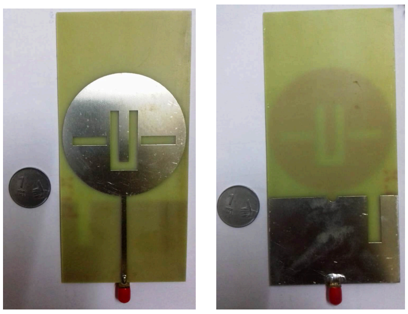
Fig. 4. Simulated 3D radiation pattern of slotted monopole antenna at 0.9GHz



(a) (b)

(b)

Fig. 5. Simulated 2D radiation pattern in y-z plane ($\varphi = 90^0$) (H-plane) (a) and in x-y plane ($\theta = 90^0$) (b) at 0.9GHz (E-plane)



(a) (b)

Fig. 6. Top side view (a) and bottom side view (b) of fabricated slotted monopole antenna

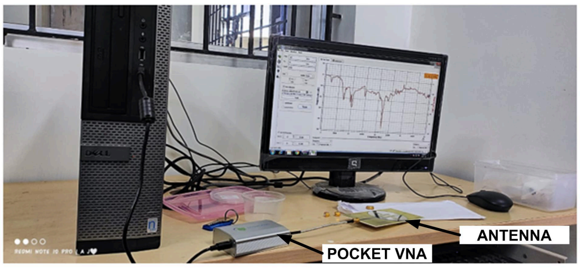


Fig. 7. Experimental set for the measurement of S_{11} parameter of the proposed antenna using pocket VNA.

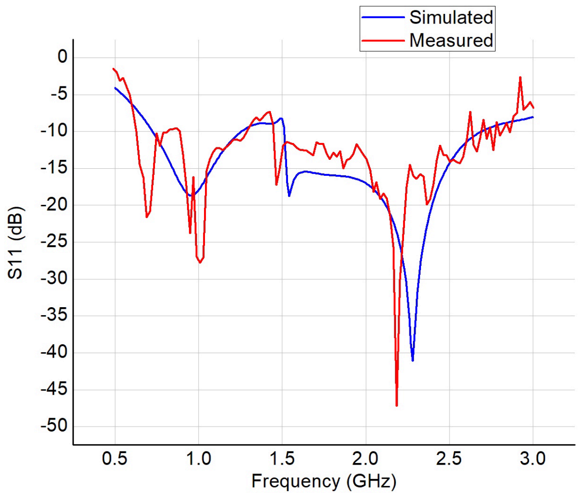


Fig. 8. Measured and simulated S11 parameter for the proposed slotted monopole antenna

IV. Conclusion

A simple circular monopole antenna provides high bandwidth. The lower cutoff frequency of the monopole antenna can be lowered by cutting lots in the radiating patch and/or ground plane, however doing such also introduces some band of frequencies where the S_{11} parameter deteriorates. The proposed antenna finds application in wireless standards like Wifi, WiMAX, Bluetooth, RFID, GPS etc. and also finds application in energy harvesting.

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