Parametric Study of Sinc Shaped Monopole Antenna for Wireless Devices

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Abstract **—** In this work, a Sinc shaped printed monopole antenna is proposed for wireless devices. The radiating element is a strip monopole configuration folded in the shape of a Sinc function where the radiating element is an extension of 50 Ω microstrip line. The proposed antenna not only represents a compact configuration but is easier to design and feed. Several configurations of truncated Sinc($2x$) monopole geometry are taken into consideration to show the resonance behavior at single, two or more than two frequencies for multifrequency operation. The detailed parametric study has been carried out in terms of several truncated Sinc configurations, ground plane size, feed gap and Sinc strip length to achieve the desired band of operation. The design formula is also presented for the proposed monopole antenna. Finally, a prototype model is developed and the simulated results are validated experimentally for a particular configuration. It is seen that the proposed antenna occupies small area, depicts good radiation characteristics and is suitable for wireless devices operating at DCS/PCS/IMT-2000/UMTS frequencies.

Index Terms **—** Monopole antenna, multiband antenna, multifrequency antenna, patch antenna, Sinc antenna.

I. INTRODUCTION

Monopole antennas are widely used as efficient radiators in a variety of applications such as communication, navigation, mobile telephones, radio receivers, etc. It is due to its salient features in terms of light weight, planar conformal construction, low cost, ease of fabrication and integration with RF devices, etc. Recent demand of wireless devices requires a single, dual or multiband/multifrequency [1] compact monopole patch antennas.

Several techniques have been reported in the literature to realize multifrequency characteristics of printed monopole antennas such as use of bevels, slots and shorting pins [2,3], use of fractal structure [4], and mounting of slots like E-shaped slot on ground plane [5], etc. In most of the cases, by controlling the current flow on the patch and changing the resonant length, multifrequency characteristics are obtained.

Many compact printed monopole antennas have been designed for the wireless applications. Some of the monopole antenna structures among them are folded monopole antennas with shorting pins to achieve DCS, PCS, 3G and WLAN band [6], meandered patch antenna with modified ground structure for UMTS and WLAN application [7], CPW-fed strip monopole antenna with slant edge ground plane for DCS, PCS, 3G, and Bluetooth bands [8], CPW-fed dual inverted-L shaped monopole antenna for DCS, PCS and IMT 2000 [9], Y-shaped monopole antenna for PCS/WLAN application [10], dual band antenna for DCS/PCS/UMTS/WLAN/WiMAX using omega shaped structure [11], CPW-fed dual frequency monopole antenna [12], dual band CPW-fed strip-sleeve monopole antenna [13], compact dual band

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antenna for DCS/2.4 GHz WLAN application [14], a compact dual band planar branched monopole antenna for DCS/2.4 GHz WLAN application [15], etc. Various interesting dual or multiband structures with large ground plane size are reported in the literature for DCS/PCS/UMTS/IMT2000 bands such as DSPSL fed and coupled line broadband antenna [16], inverted-F antenna [17] and double inverted-L branched antenna with open stub [18], etc. Most of them have a complex shape involving difficult design steps. In the present work, a simple monopole antenna is proposed where the shape of the monopole is derived from the Sinc function in order to realize a compact and simple configuration, where just by changing the Sinc geometrical parameters, the antenna may be made to operate at the desired band of operation.

The Sinc shaped microstrip configuration was first proposed by Yang, et al. [19], and then Gupta, et al. [20] also used a similar configuration to realize multi-frequency antenna. However, in both these configurations the shape of the antenna was only Sinc like and not derived from the Sinc function. In [21-23], monopole antenna configurations based on the sinusoidal geometrical function is presented for wireless sensor node applications. In proposed work, a truncated Sinc shaped printed monopole antenna geometry obtained from the Sinc(*2x*) function for use as an efficient monopole radiator has been studied. The monopole geometry under consideration is a truncated Sinc giving rise to one of the compact monopole configurations. The simulation is performed for several truncated Sinc shaped monopole geometries printed on a glass epoxy substrate. Finally, a prototype is developed and the results are compared with the simulation results.

The proposed antennas in this paper are useful for several wireless applications such as DCS (1710-1880 MHz), PCS (1850-1990 MHz), IMT 2000 (1885-2070 MHz), UMTS (2120-2170 MHz), fixed mobile communication and fixed satellite communication (space to earth) (4500-4800 MHz), etc.

II. ANTENNA DESIGN

The Sinc shaped antenna of any dimension along the length or width can be visualized as one of the Sinc functions printed in the form of a strip on a substrate. The antenna dimension can be increased or decreased along the length as much needed, by taking the suitable value of the coefficient ‘b’ of the argument x; and along the height by taking appropriate factor ‘a’ of the function. Actually, the Sinc function extends up to infinity. Therefore in practice, the Sinc antenna refers to a ‘truncated’ Sinc function, the range of the function determining the length of the monopole strip.

The advantage of using Sinc shaped monopole antenna is in many folds. First of all, larger length can be accommodated in smaller space, thus realizing a compact structure. Secondly, the shape can be generated by a simple mathematical function. Thirdly, single, dual or multi band operation can be realized, simply by selecting a specific length of the Sinc strip. The strip width of the Sinc can be easily maintained for standard 50 Ω matching with the feed. The proposed Sinc shaped monopole antenna considers truncated Sinc(*2x*) function for strip geometry and may be considered as one form of meander line. However, the proposed Sinc shaped strip monopole antennas are superior to the meandered line strip monopole antenna. Unlike the meander line strip where there is more opposition of current vectors in the parallel section of strips leading to diminishing self-inductance, in the proposed Sinc(*2x*) strip configuration, the current vectors reinforce along the total strip length; thus, adding to more self-inductance as shown in Fig. 1. This is due to the fact that for proposed Sinc(*2x*) geometry, least coupling is evident between the adjacent strips which in turn is more effective in realizing a compact antenna configuration. This property of the Sinc(*2x*) function also facilitates the use of design formula available for simple monopole strip, conveniently for the proposed monopole strip with little modifications.

The normalized Sinc function Sinc(*2x*) for the proposed antenna configurations is shown in the Fig. 2. The Sinc(*2x*) configuration is considered because it shows a uniform current distribution along the strip. In higher order functions (Sinc(*3x*), Sinc(*4x*) etc.), the current distribution tends to become non uniform due to overlapping geometry of the radiating strip arising because of finite thickness of the strip. The simulation has been performed using a full-wave Method of Moments (MoM) software package IE3D from Zeland [24]. The geometry of the Sinc is obtained from the Sinc function using MATLAB and then imported to the

IE3D. The desired strip thickness is then set by setting the thickness of the line. The radiation characteristic of this antenna is examined with respect to several design parameters. The parametric analysis of the Sinc strip is performed both on finite and infinite substrate size, and for different set of design parameters. The strip width as equal to the 50 Ω microstrip line width and simple microstrip feeding mechanism to the monopole are selected as different set of parameters.

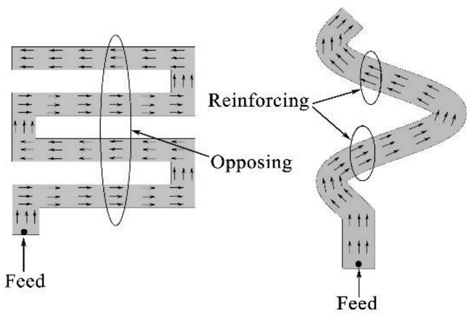


Fig. 1. Current flow in meander strip and Sinc shaped strip.

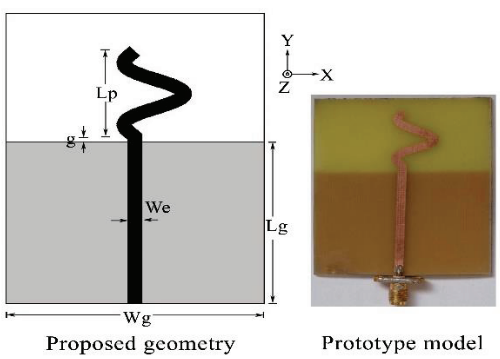


Fig. 2. Proposed Sinc shaped monopole antenna.

The Sinc shaped configuration accommodates larger electrical length in small area; therefore, the current on the strip takes a longer path compared to the unfolded strip. The Sinc strip is simply an extension of the 50 Ω transmission line which reduces the mismatch between feeding line and strip, thus shows good impedance matching behaviour. The desired band of operation can be achieved by selecting the optimized length of Sinc strip, feed gap between the ground plane and Sinc strip, ground plane size and off center position of feeding line as discussed in the next section.

The simulation is performed for Sinc(*2x*) strip configuration having two zero crossing points, considering the parameters like length of Sinc (*Lp*)=20 mm, dielectric constant (ε_r)=4.4, loss tangent (*tanδ*)=0.018, dielectric thickness (*h*)=1.57 mm, width of the 50 Ω microstrip line (*We*)=3.0 mm, feed gap (*g*)=0.3 mm and ground plane size *Wg*=52 mm, *Lg*=38 mm.

The design formula for first three resonant frequencies of proposed Sinc(*2x*) monopole antenna is given by:

$$f_n = a^{n-1}\frac{(2n-1)c}{2\sqrt{\varepsilon_r}\,Le}, \qquad (1)$$

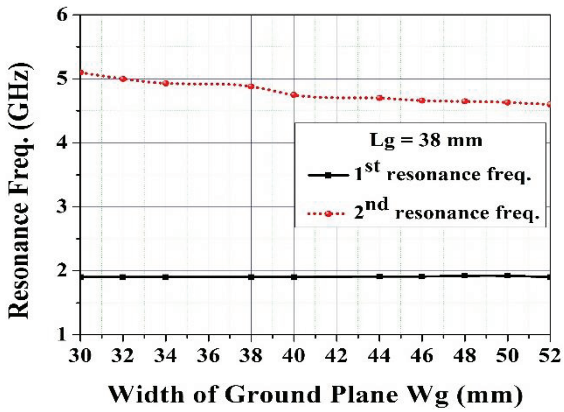
where *n*=1,2,3, *a*=0.82, *c*=speed of light in free space, ε_r=relative permittivity and *Le*: physical length (unfolded length) of Sinc strip=36.6 mm.

III. PARAMETRIC STUDY

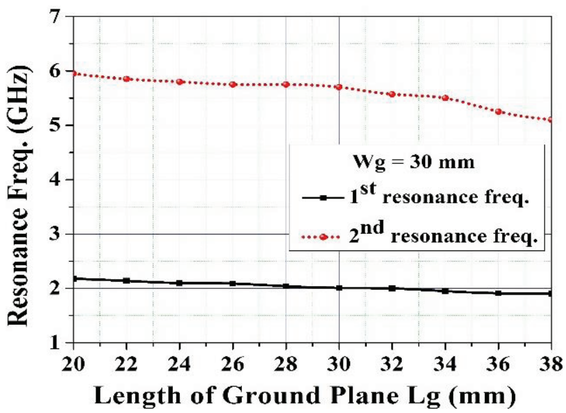
A. Effect of the ground plane

The ground plane dimensions are very important parameters in the design of a monopole antenna because of the strong dependence of gain, bandwidth and antenna efficiency on ground plane size. Simulation is performed for various ground plane parameters and the effect of ground plane size on resonant frequency is shown in Figs. 3 (a) and 3 (b). As evident from the figure, the ground plane width (*Wg*) has very little impact on the first resonant frequency. However, the second resonant frequency is influenced and decreases up to 500 MHz by increasing *Wg*. The ground plane length (*Lg*) affects both the resonant frequencies with more variation for the second resonant frequency and a decrease in second resonant frequency up to 900 MHz is obtained. The results for the other antenna parameters are tabulated in Table 1. As seen, with an increase in the ground plane size, both the gain and antenna efficiency increase. The ground plane size of 52 mm (~λ_0/3) width and 38 mm (~λ_0/4) length is selected to achieve larger gain and antenna efficiency for the proposed monopole configuration.

Figure 4 shows the reflection coefficient of Sinc(*2x*) monopole antenna for the case of finite and infinite substrate size. The parameters taken into consideration are: *Wg*=0.33λ_0 (~=λ_0/3), *Lg*=0.24λ_0 (~=λ_0/4), *Lp*=0.125λ_0 (~=λ_0/8) and the physical length of the patch (*Le*)=0.23λ_0. It is observed that there is a small shift in the resonant frequencies towards the lower side with finite substrate size.



(a)



(b)

Fig. 3. Effect of ground plane dimensions on resonant frequency.

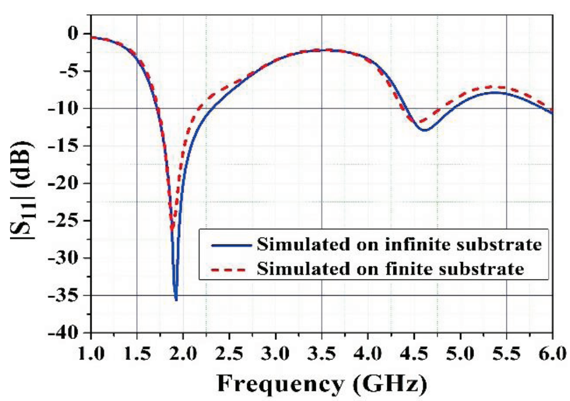
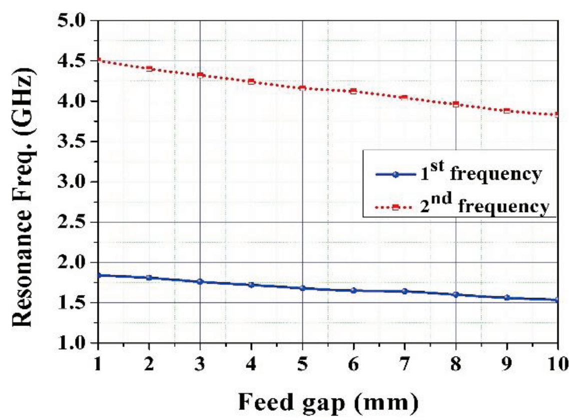


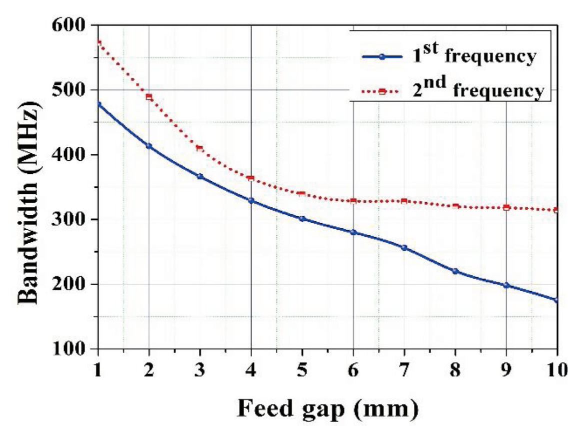
Fig. 4. Reflection coefficient ($|S_{11}|$) of Sinc(*2x*) monopole antenna for infinite and finite dielectric size.

B. Effect of feed gap

Next, the effect of the feed gap on the characteristics of the antenna is examined. For the different feed gap (*g*) between the patch and the ground plane, it is seen that the resonance frequency is reduced with increasing feed gap for both lower and higher resonance modes; however, the impedance bandwidth deteriorates for larger values of '*g*' for both the cases. On the other hand, the reflection coefficient deteriorates for larger feed gap at a lower resonant frequency, while at the second resonant frequency it improves. The effect of the feed gap between 1.0 to 10 mm is shown in Table 2. The effect of feed gap on resonant frequency and bandwidth is plotted and shown in Figs. 5 (a) and 5 (b). It is seen that for both the modes, the resonant frequencies decrease linearly with increase in feed gap, but the bandwidth reduction for both the cases is not linear. This is due to the fact that a larger feed gap offers extra inductance to the Sinc length, and deteriorates the matching.



(a)



(b)

Fig. 5. Effect of feed gap on: (a) resonant frequency, and (b) bandwidth.

C. Effect of off center position

For the different off center position of microstrip feed and Sinc strip, it is seen that the first resonance frequency is constant in a range of off center position as 1 mm to 5 mm, and then in the range of 7 mm to 23 mm it reduces monotonically with an increase in off center values. The second resonance frequency is reduced between 1 mm to 7 mm and increased between 9 mm to 23 mm with increasing off center values. The effect of off center position is presented in Table 3. Here, the feed gap (*g*) is considered as 2 mm.

The Sinc shaped monopole antenna gives good impedance matching and impedance bandwidth between 7 mm to 13 mm for first resonance frequency, and between 11 mm to 19 mm for the second resonance frequency with increasing off center values. The optimum range for off center position of microstrip line and Sinc strip is obtained in the range of 11 mm to 13 mm.

D. Effect of Sinc strip length

The Sinc shaped monopole antenna can be made to resonate at very wide range of resonating frequencies for Sinc length variation, though the total area occupied by the Sinc does not change much. By varying the Sinc strip length (*Lp*) from 10 mm to 30 mm, the first resonant frequency varies from 2.98 GHz to 1.52 GHz. The Sinc strip length variation is shown in Fig. 6 and simulation results are presented in Table 4. In the range of the Sinc strip length (*Lp*) from 10 mm to 18 mm, the second resonant frequency f_2 disappears. Similarly, for length 28 mm and 30 mm, the third resonant frequency f_3 disappears.

Table 1: Effect of ground plane size on antenna parameters

Ground Plane Size, $Wg \times Lg$ (mm^2)	1st Resonance Frequency				2nd Resonance Frequency			
	$\|S_{11}\|$ (dB)	Bandwidth (MHz)	Gain (dBi)	Antenna Efficiency (%)	$\|S_{11}\|$ (dB)	Bandwidth (MHz)	Gain (dBi)	Antenna Efficiency (%)
30×24	-12.4	251	1.39	75.83	-12.9	933	1.67	48.53
30×26	-14.2	302	1.43	79.12	-12.7	1253	1.24	52.82
30×30	-19.5	369	1.43	76.00	-12.4	1317	1.24	54.32
30×34	-38.1	407	1.84	78.90	-10.9	1147	1.74	52.51
32×32	-24.1	406	1.85	77.81	-11.6	1193	1.66	54.92
34×34	-37.8	450	2.01	79.84	-11.2	829	1.85	56.99
38×38	-29.9	595	2.03	82.46	-11.2	535	2.31	51.26
44×38	-29.5	687	2.03	81.32	-11.8	478	2.37	59.59
48×38	-26.6	424	2.02	83.82	-11.6	634	2.72	63.81
52×38	-35.4	588	2.40	94.37	-12.9	508	3.84	81.12

Table 2: Effect of feed gap for Sinc shaped monopole antenna

Feed Gap (mm)	1st Resonance Frequency				2nd Resonance Frequency			
	f_1 (GHz)	$\|S_{11}\|$ (dB)	Bandwidth (MHz)	Gain (dBi)	f_2 (GHz)	$\|S_{11}\|$ (dB)	Bandwidth (MHz)	Gain (dBi)
1	1.84	-26.4	478	2.07	4.50	-15.2	572	3.27
2	1.80	-23.4	413	1.92	4.40	-16.7	489	3.15
3	1.76	-21.2	366	1.67	4.32	-18.2	409	2.99
4	1.72	-19.1	329	1.87	4.24	-20.2	363	3.11
5	1.68	-17.9	301	1.80	4.16	-22.6	339	3.20
6	1.65	-15.8	280	1.72	4.12	-25.1	328	3.12
7	1.64	-14.9	256	1.66	4.04	-35.8	328	3.03
8	1.60	-13.5	220	1.56	3.96	-34.4	320	2.74
9	1.56	-12.8	198	1.50	3.88	-31.5	318	1.75
10	1.53	-12.2	175	1.37	3.83	-27.5	314	0.77

Table 3: Effect of off center position of Sinc patch

Off Center Position Towards Right of Origin (mm)	1st Resonance Frequency				2nd Resonance Frequency			
	f_1 (GHz)	$\|S_{11}\|$ (dB)	Bandwidth (MHz)	Gain (dBi)	f_2 (GHz)	$\|S_{11}\|$ (dB)	Bandwidth (MHz)	Gain (dBi)
1	1.80	-23.1	414	1.89	4.40	-16.0	457	3.23
3	1.80	-26.5	463	1.93	4.36	-15.2	441	3.41
5	1.80	-26.4	445	1.72	4.35	-15.0	434	3.05
7	1.76	-34.1	476	1.88	4.34	-14.8	453	3.01
9	1.76	-27.3	507	1.78	4.36	-15.3	450	2.92
11	1.72	-24.3	530	1.59	4.40	-15.3	531	3.64
13	1.68	-18.6	517	1.29	4.49	-15.1	698	3.56
15	1.64	-19.4	416	1.63	4.52	-19.7	656	2.65
17	1.60	-17.3	366	1.51	4.68	-18.3	672	1.96
19	1.56	-16.8	325	1.34	4.76	-18.4	587	2.5
21	1.52	-15.0	277	1.36	4.78	-12.3	410	1.59
23	1.51	-14.5	249	1.42	4.75	-9.8	-	-

Table 4: Effect of Sinc strip length for Sinc(*2x*)

Sinc Strip Length, *Lp* (mm)	f_1 (GHz)	$\|S_{11}\|$ (dB)	BW (MHz)	f_2 (GHz)	$\|S_{11}\|$ (dB)	BW (MHz)	f_3 (GHz)	$\|S_{11}\|$ (dB)	BW (MHz)
10	2.98	-11.6	471	-	-	-	8.40	-11.9	1067
12	2.58	-14.6	663	-	-	-	8.25	-14.3	1540
14	2.38	-18.3	707	-	-	-	7.80	-13.4	1651
16	2.21	-22.9	703	-	-	-	7.44	-12.9	1864
18	2.05	-28.8	667	-	-	-	6.99	-13.6	1509
20	1.90	-35.4	588	4.6	-12.9	508	6.68	-13.5	1290
22	1.84	-28.8	522	4.49	-14.4	504	6.27	-11.8	1008
24	1.75	-27.3	431	4.20	-17.1	411	6.14	-10.6	527
28	1.60	-20.1	318	3.95	-23.0	330	-	-	-
30	1.52	-17.3	245	3.80	-27.9	294	-	-	-

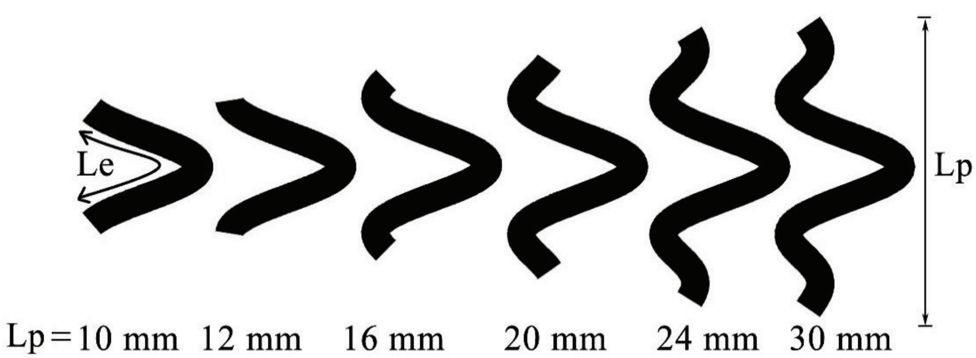


Fig. 6. Various Sinc monopole lengths for Sinc(*2x*) monopole antenna.

IV. EXPERIMENTAL RESULTS

Finally, the prototype model is developed as shown in Fig. 2, and the experimental $|S_{11}|$ characteristic of the proposed antenna is obtained using PNA series of Vector Network Analyzer. In the developed prototype model, the length of the Sinc strip (*Lp*) is considered to be 20 mm and first two resonant modes are considered. The proposed

Sinc shaped antenna operates at 1.90 GHz and 4.60 GHz with an operating bandwidth of 588 MHz (1606-2194 MHz) and 508 MHz (4346-4854 MHz) respectively. The experimental results are then compared with the simulation results as shown in Fig. 7. As seen in Fig. 7, the measured result of the reflection coefficient is better than the simulated result. This is due to the fact that coarse meshing is considered for simulation on finite dielectric material due to memory limitation. The radiation pattern of Sinc($2x$) monopole antenna for simulation and measurement at 1.90 GHz and 4.60 GHz are shown in Figs. 8 (a) and 8 (b) respectively. A good agreement is evident between the simulated and measured results. The antenna shows a good cross-polarization characteristic at first resonant frequency compared to the second resonant frequency, which may be attributed to the asymmetric structure of the monopole configuration. The measured peak gain and radiation efficiency of the Sinc($2x$) monopole antenna for first and second operational bands are shown in Figs. 9 (a) and 9 (b) respectively.

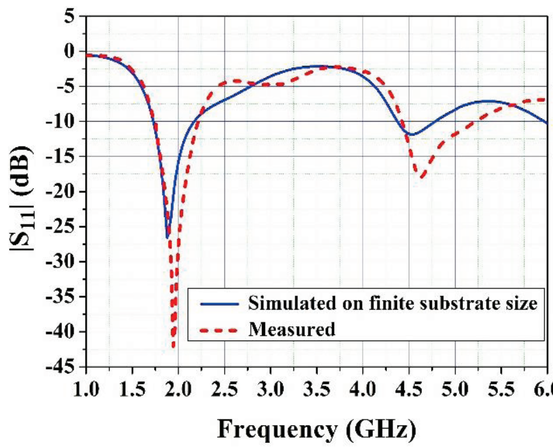
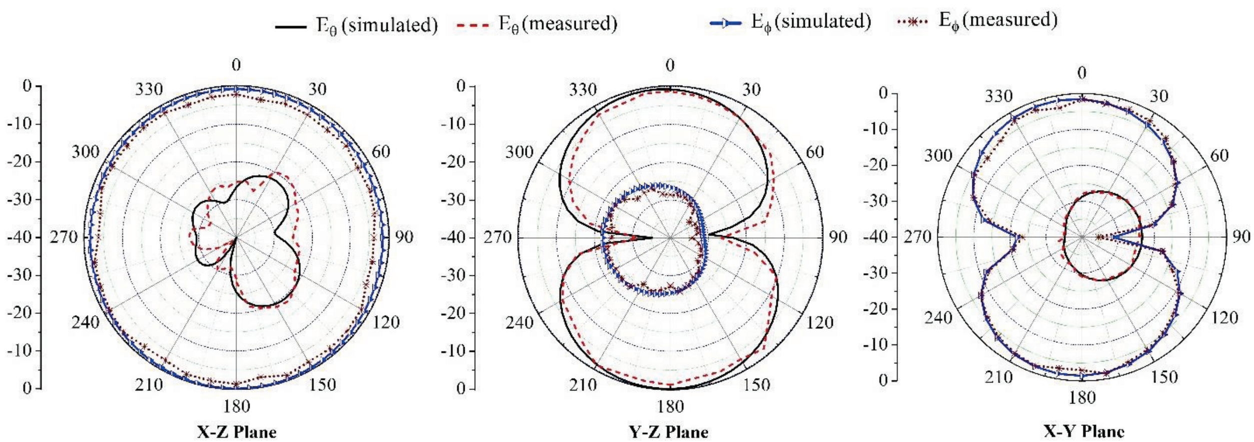
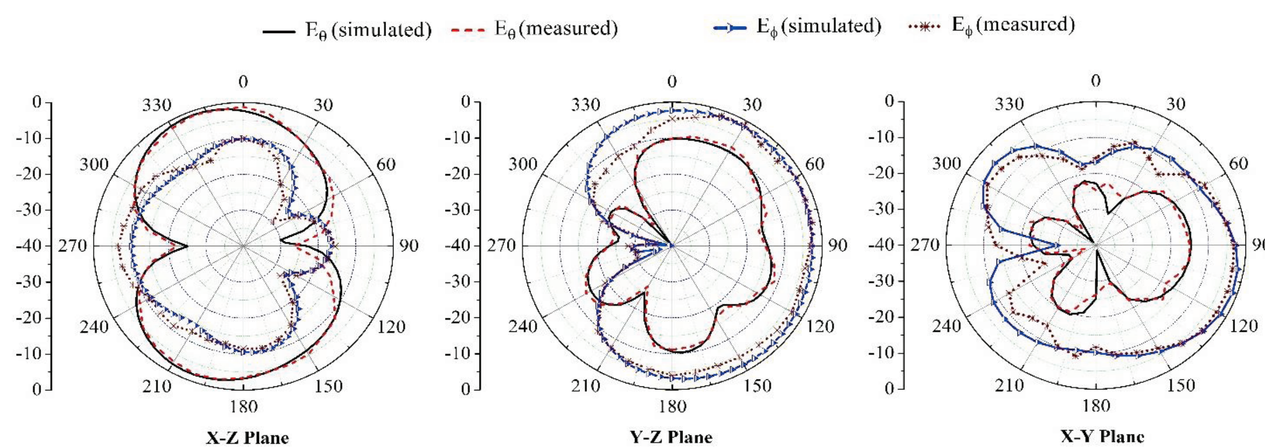


Fig. 7. Simulated and measured reflection coefficient ($|S_{11}|$) for Sinc($2x$) monopole antenna.

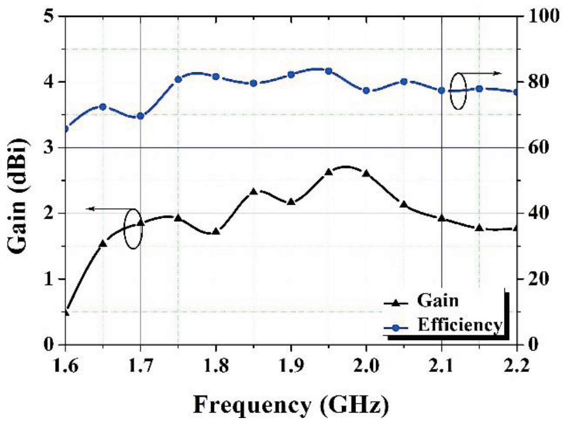


(a)

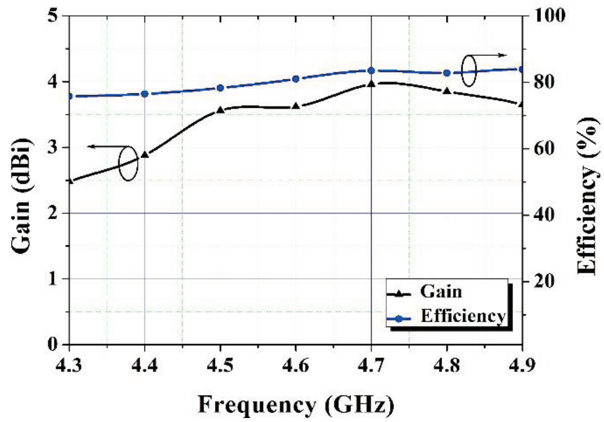


(b)

Fig. 8. 2D normalized radiation patterns for Sinc($2x$) monopole antenna at: (a) 1.90 GHz, and (b) 4.60 GHz.



(a)



(b)

Fig. 9. Measured peak gain and radiation efficiency of Sinc shaped monopole antenna for: (a) first operating band, and (b) second operating band.

VI. CONCLUSION

A new configuration of monopole antenna is proposed for wireless communication. It has been shown that the Sinc shaped monopole antenna is a very good candidate for wireless devices, especially for non-hand held devices used in wireless communication. A detailed parametric study of the proposed antenna indicates that the desired band of operation can be obtained simply by setting the Sinc monopole design parameters without much affecting the area occupied. The antenna occupies an area of $\lambda_0/3\times3\lambda_0/7$. The antenna is found to be useful for several wireless devices operating at DCS/PCS/IMT-2000/UMTS bands.

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