Inverted Sinc Shaped Monopole Antenna for Wireless Devices

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Abstract – **A novel inverted Sinc shaped printed monopole antenna is proposed for wireless devices. The proposed configuration realizes the monopole antenna in compact form and also depicts good radiation characteristics at operating bands. A detailed parametric study has been carried out for different sizes of the ground plane, Sinc strip length, Sinc height, feed gap, etc. Finally, prototype models are developed for the most effective configurations and the simulated results are validated experimentally. It is shown that the proposed antenna occupies a small area and is suitable for operation at DCS/PCS/IMT-2000/WLAN and satellite communication frequencies.**

Keywords – **Monopole antenna, Multifrequency antenna, Multiband antenna, Printed antennas, Sinc antenna.**

I. INTRODUCTION

Modern wireless devices require antennas that are easy to fabricate and integrate with other RF devices due to their features such as light weight, planar conformal construction, low cost, etc. At the same time it must be able to accommodate several frequency bands of operation. Monopole antennas [1] are most suited for such applications as they fulfill most of the requirements of modern wireless devices.

The increasing use of mobile communication systems has stimulated the interest in the dual-frequency design of monopole antennas suitable for application in two different mobile communication bands. Several printed strip monopole antennas have been designed for the wireless applications. Important structures among them are the printed strip antenna [2], the wideband printed monopole [3], Y-shaped antenna [4], Double T-shaped [5], T-shaped [6] monopole with L shaped sleeve, dual frequency meandered feed monopole [7], triple frequency meandered monopole antenna [8], and CPW-fed dual band antenna with two monopole strips [9]. The use of bevels, slots and shorting pins [10-11], Sierpinski antenna [12-14], Minkowski fractal geometry [15], mounting of slots like U-slot [16], etc. have been used in the past to realize multifrequency operation. Most of these antennas have complex geometrical shapes and involve difficult design steps. In this paper, a novel monopole antenna is proposed where the shape of the monopole is derived from the Sinc function, in order to realize a compact and simple antenna configuration. The shape of the monopole configuration resembles an inverted and truncated Sinc strip. By changing the Sinc geometrical parameters, the antenna can be made to operate at the desired band of frequencies. The Sinc shaped microstrip configuration was first proposed by Yang et al. [17] and then Gupta et al. [18] also used a similar configuration to realize a multifrequency antenna. However, in both these configurations the shape of the antenna was only Sinc alike and not exactly derived from the Sinc function. In this paper, a truncated and inverted Sinc shaped printed monopole antenna geometry is obtained directly from the Sinc function. The proposed truncated Sinc geometry results in one of the most compact monopole configurations. In general a Sinc function is represented as, $y=a\{\sin(b\pi x)/(b\pi x)\}$ for normalized Sinc and $y=a\{\sin(bx)/(bx)\}$ for un-normalized Sinc, where a and b are positive constants. The simulation is performed for several truncated Sinc shaped monopole geometries printed on a low cost glass epoxy substrate. Finally a prototype is developed and the results are compared with the simulation results.

The proposed antennas are useful for several wireless applications such as DCS (1.710-1.880 GHz), PCS (1.850-1.990 GHz), IMT 2000 (1.885-2.070 GHz), WLAN (2.4 GHz and 5.2 GHz), fixed satellite to earth (7.450-7.550 GHz and 7.550-7.750 GHz) Communications, and space research (8.400-8.500 GHz).

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II. ANTENNA DESIGN

The antenna designers are always exploring ways to realize compact antenna configuration that can be designed easily; impedance matched easily and yet be capable of covering multiband operating frequencies. One such antenna is an inverted Sinc shaped monopole antenna. The proposed configuration provides several advantages over conventional antennas such as, larger length can be accommodated in a smaller area, thus realizing a compact structure. The shape can be generated by a simple mathematical Sinc function and a single, dual or multi band operation can be realized, simply by selecting a specific length of the Sinc monopole or ground plane parameters. The impedance matching can be achieved easily. 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 strip configuration, the current vectors reinforce along the total strip length thus adding to more self-inductance. This in turn is more effective in realizing a compact antenna configuration. The Sinc shaped antenna of any dimension along the length or width can be visualized as one of the Sinc functions $y=a\{\sin(b\pi x)/(b\pi x)\}$, printed in the form of a strip on a substrate. The antenna dimension can be increased or decreased along the length as much as needed, by taking the suitable value of the coefficient '*b*' of the argument *x*; and along the height by taking the appropriate factor '*a*' of the function. In the proposed truncated Sinc shaped monopole configuration, the constants are considered as $a = 1$ and $b = 2$. 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 proposed antenna configuration with *Sinc(2x)* strip is shown in Fig. 1. The *Sinc(2x)* 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 function. The geometry of the Sinc is obtained from the Sinc function using MATLAB and then imported to the IE3D, a full-wave method of moments (MOM) based simulation software package from Zeland. The desired strip thickness is then set by adjusting the thickness of the line. The vertex of Sinc function imported from MATLAB is then multiplied with the desired factor in order to operate the antenna at a specific band. In the proposed antenna the imported geometry is multiplied by a factor of 10. The radiation characteristic of the Sinc shaped antenna is examined with respect to several design parameters. The parametric analysis of the Sinc strip is performed both on a finite and infinite substrate size, and for different set of design parameters. The monopole strip width is maintained the same way as the width of the 50Ω microstrip line and simple microstrip feeding method used for feeding the inverted Sinc monopole.

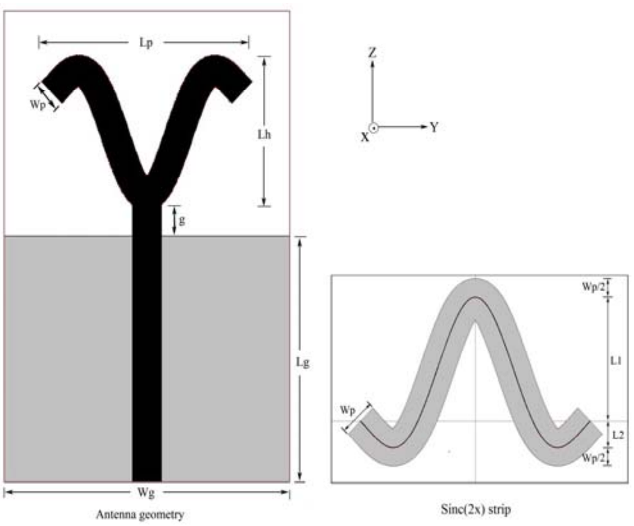


Fig. 1. Inverted Sinc shaped monopole antenna configuration

The various parameters are selected as dielectric constant (ε_r) = 4.4, loss tangent (*tanδ*) = 0.018, dielectric thickness (*h*) = 1.57 mm, width of the 50Ω microstrip line is equal to the width of the Sinc strip (*Wp*) = 3.0 mm, feed gap (*g*) = 3 mm, the ground plane size *Wg* = 30 mm , *Lg* = 24 mm , Sinc parameters: *Lp* = 20 mm, *Lh* = 15.18 mm *(Lh = L1 + L2+ Wp)* for *Sinc(2x)* and *Lh* = 27.36 mm for *2Sinc(2x)* configuration. Where, *L1* is Sinc maxima height from the origin and *L2* is height of first minima from origin as shown Fig. 1. For the proposed antenna *L1* = 10 mm, and *L2* = 2.18 mm, for *Sinc(2x)* and *L1* = 20 mm and *L2* = 4.36 mm for *2Sinc(2x)* configuration. The simulation results for these two monopole configurations are shown in Table I. It is shown that for the inverted *Sinc(2x)* and *2Sinc(2x)* monopole configuration the antenna resonates at dual and triple resonant frequencies respectively.

TABLE I
COMPARISON OF SINC(2X) AND 2SINC(2X) MONOPOLE CONFIGURATIONS

Antenna	Dielectric constant (ε_r)	Substrate thickness 'h' (mm)	Antenna Dimensions		Operating resonance frequency (GHz)
			Ground size (mm^2)	Total area (mm^2)	
Proposed Inv. Sinc(2x)	4.4	1.57	30 × 24	30 × 45	2.45, 7.55
Proposed Inv. 2Sinc(2x)	4.4	1.57	30 × 24	30 × 56	1.85, 5.2, 8.5

The conductor and dielectric loss of the antenna are functions of frequency. However, in the simulation model both are considered to be constant throughout the frequency band of simulation.

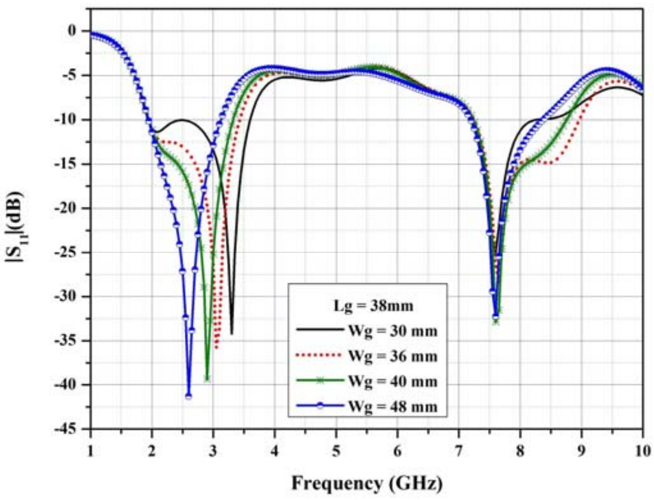
III. PARAMETRIC STUDY

A. Effect of the Ground Plane

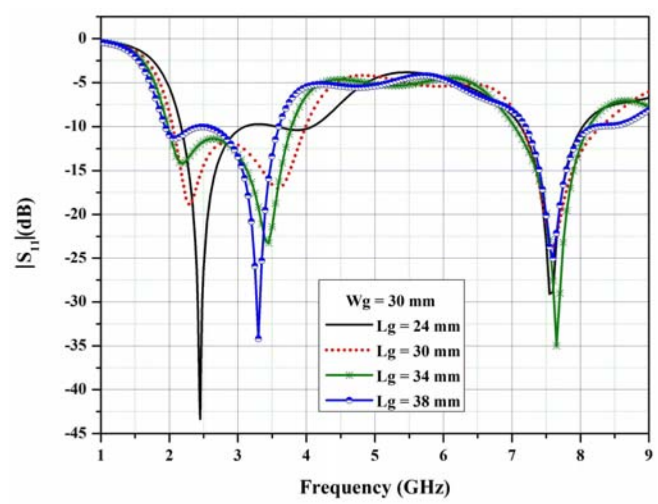
The size of the ground plane plays an important role in achieving the optimum characteristics of the antenna. It has strong dependence on gain, bandwidth and antenna efficiency. Simulation is performed with various ground plane parameters and the effect of ground plane size on resonant frequency is shown in Fig. 2(a) and 2(b) for *Sinc(2x)* configuration. As evident from Fig. 2(a), the ground plane width (*Wg*) has little impact on the second resonant frequency, however it has some impact on the bandwidth. Moreover, the first resonant frequency decreases up to 900 MHz by increasing *Wg*. On the other hand, the first resonant frequency is affected considerably by ground plane length (*Lg*) variation while the second resonant frequency remains almost constant. The results for the other antenna parameters are tabulated in Table II. As seen, with an increase in the ground plane size, the gain of antenna increases. The ground plane size of *Wg* = 30 mm and *Lg* = 24 mm are selected to operate the monopole antenna at the specific resonant frequencies covering the WLAN standard. The other antenna parameters are also acceptable.

TABLE II
EFFECT OF GROUND PLANE SIZE ON ANTENNA PARAMETERS

Ground size (Wg × Lg) (mm^2)	f_1 (GHz)	$\|S_{11}\|$ (dB)	Bandwidth (MHz)	Gain (dBi)	f_2 (GHz)	$\|S_{11}\|$ (dB)	Bandwidth (MHz)	Gain (dBi)
52 × 38	2.45	-38.96	1096	2.81	7.58	-35.61	1143	4.32
48 × 38	2.60	-41.60	1182	2.36	7.58	-31.56	1185	3.02
40 × 38	2.91	-38 .29	1378	2.46	7.61	-32.71	1522	2.33
38 × 38	2.99	-41.08	1434	2.50	7.64	-31.15	1624	2.11
30 × 38	3.30	-33.50	1073	3.74	7.58	-24.72	1662	1.36
38 × 34	3.03	-22.40	1540	2.30	7.75	-26.13	1138	2.07
38 × 30	2.31	-24.15	1605	2.51	7.66	-36.21	1038	1.37
30 × 38	3.30	-33.50	1073	3.74	7.58	-24.72	1662	1.36
30 × 30	2.28	-18.71	1940	1.66	7.58	-23.71	1151	1.63
30 × 24	2.45	-43.12	936	2.52	7.55	-29.09	922	4.32
30 × 22	2.51	-22.03	762	1.83	7.58	-32.84	931	2.74



(a)



(b)

Fig. 2. Effect of ground plane dimensions on reflection coefficient ($|S_{11}|$) with respect to (a) Wg, (b) Lg

B. Effect of Sinc Height

Next, the characteristics of the proposed antennas have been examined by varying Sinc height. Sinc height '*a*' is defined as the height from origin to maxima of Sinc function. The Sinc height can be adjusted by multiplication factor '*a*' which in this case is varied from 0.5 to 2 in *Sinc(2x)* configuration. It is shown in Fig. 3, that by increasing '*a*', all the resonant frequencies get shifted to a lower range. Multiplication factors 1.5 and 2 make the antenna resonate at three frequencies, and for a = 0.5 and 1 the third resonant frequency f_3 shifts toward higher frequencies. The resonant frequency and the bandwidth for all the cases decrease by increasing factor '*a*'. However, maximum antenna bandwidth is attained for a minimum value of '*a*'. In all these cases, the feed gap (g) of 3 mm is used. In the proposed configurations the Sinc height is multiplied by a factor of 10 to offer lengths $L1$ = 10 mm and 20 mm for a = 1 and 2 respectively.

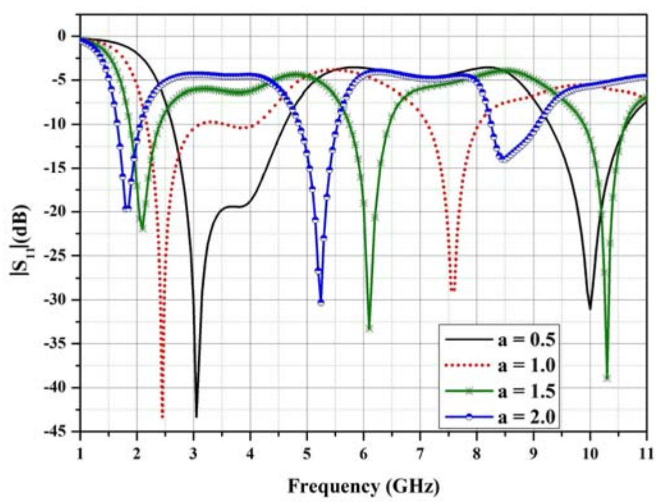


Fig. 3. Effect of Sinc height on resonant frequency and reflection coefficient ($|S_{11}|$)

C. Effect of the Feed Gap

Next the effect of the feed gap on the characteristics of the antenna is examined. The effect of the feed gap on the resonant frequency and reflection coefficient is plotted and shown in Fig. 4. For the different feed gaps *(g)* between the inverted *Sinc(2x)* strip and ground plane, it is found that the resonant frequency reduces with increasing the feed gap for both lower and higher resonant modes. However the impedance bandwidth deteriorates for larger values of 'g' for both cases. On the other hand, the impedance matching the first increases untill g = 3 mm and then decreases with the feed gap at a lower resonant frequency while at the second resonant frequency it deteriorates for a larger feed gap. It is further seen that for both modes, the resonant frequencies decrease linearly with increase in feed gap, however, the bandwidth reduction in both 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.

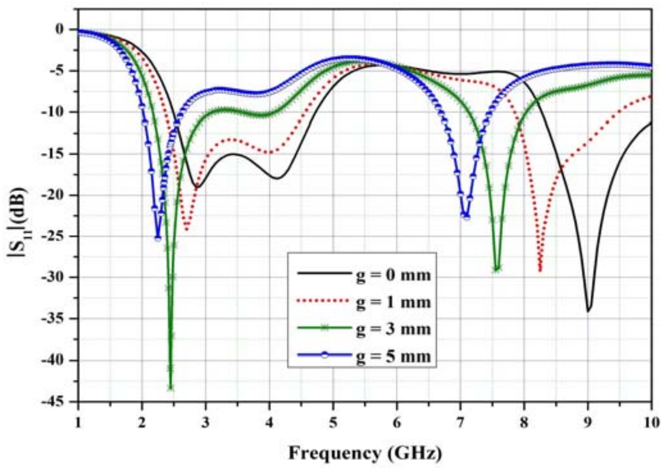


Fig. 4. Effect of feed gap on resonant frequency and reflection coefficient ($|S_{11}|$)

D. Effect of Sinc Strip Length

The inverted Sinc shaped monopole antenna can be made to resonate over a very wide range of resonant frequencies by varying Sinc length, though the total area occupied by the Sinc does not vary much. By varying the Sinc strip length from 10 mm to 30 mm, for a constant strip width (Wp) = 3.0 mm as shown in Fig. 5, the resonant frequency varies from 3.18 GHz to 2.20 GHz for the first resonance mode and from 10.34 GHz to 6.74 GHz for the second resonance mode as shown in Fig. 6. The impedance matching the behavior of the inverted Sinc shaped monopole antenna for both the resonance bands are also depicted here.

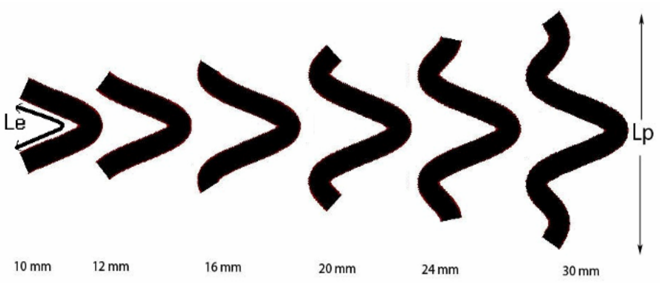


Fig. 5. Variable Sinc strip lengths for Sinc(2x) monopole antenna

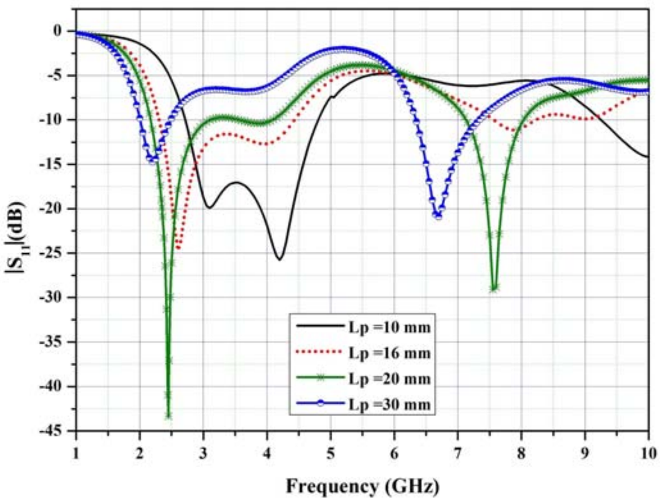


Fig. 6. Effect of Sinc strip length on resonant frequency and reflection coefficient ($|S_{11}|$)

IV. Experimental Results

Finally, the prototype models are developed for *Sinc(2x)* and *2Sinc(2x)* configurations as shown in Fig. 7, and the experimental results of the reflection coefficient ($|S_{11}|$) of the proposed antenna is obtained using an Agilent N5230A PNA series of Vector Network Analyzer (VNA). In the prototype model developed, the length of the Sinc strip is considered as Lp = 20 mm and the feed gap as g = 3 mm for both *Sinc(2x)* and *2Sinc(2x)* configurations. A comparison of the experimental and simulation results is shown in Fig. 8. A good agreement between the results is evident. The current distribution of inverted *Sinc(2x)* and inverted *2Sinc(2x)* antenna is shown in Fig. 9 and Fig. 10 respectively. The radiation patterns of the proposed antennas are measured using the PNA series VNA. Two similar proposed Sinc shaped antennas are connected to each port of the VNA as shown in Fig 11, and the radiation pattern and gain measurements are performed using existing techniques [19-20]. The normalized radiation patterns of the inverted *Sinc(2x)* monopole antenna for simulation and measurement at 2.45 GHz and 7.55 GHz (for ground size 30×24 mm^2) are shown in Fig. 12. The simulated and measured normalized radiation patterns of the inverted *2Sinc(2x)* monopole antenna at 1.85, 5.20 and 8.50 GHz (for ground size 30×24 mm^2) are shown in Fig. 13. A good agreement is evident between the simulated and measured results and it can be seen that the radiation patterns in the X-Y plane are nearly omnidirectional for all the frequencies. The antenna also shows a good cross polarization characteristic for the proposed monopole configuration. The simulated and measured peak gain, directivity and efficiency of the inverted *Sinc(2x)* and the inverted *2Sinc(2x)* monopole antennas are shown in Table III. The performance of the proposed antenna is finally compared with several other monopole antennas from references. The performance comparison is shown in Table IV. It is observed that the proposed antenna outperforms several other antennas in terms of compactness, and a good impedance matching together with simplicity in shape.

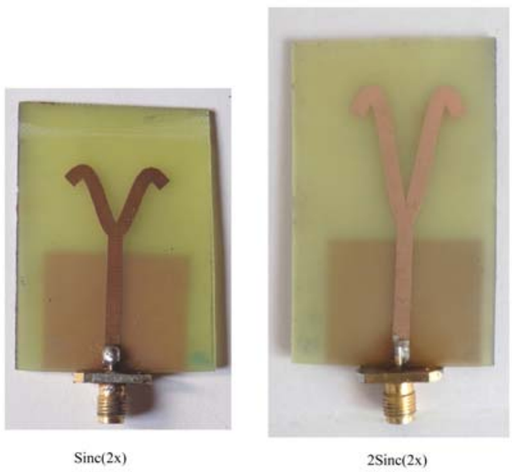


Fig. 7. Fabricated inverted Sinc(2x) and 2Sinc(2x) monopole antenna

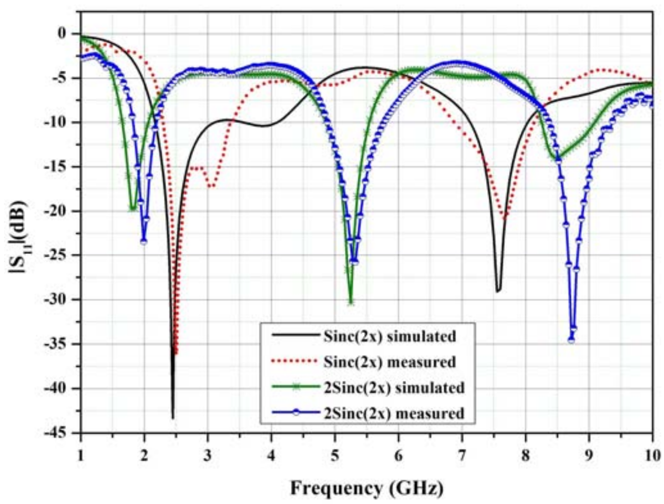
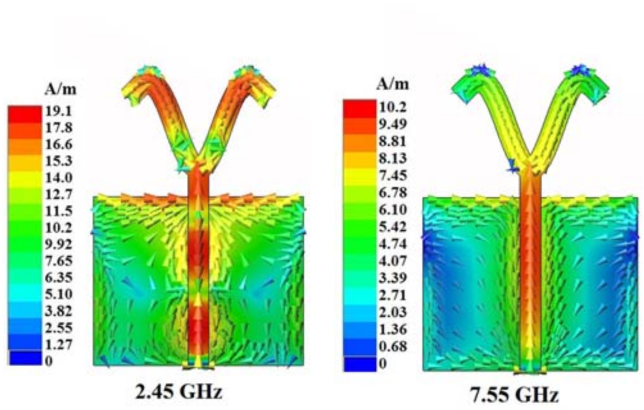
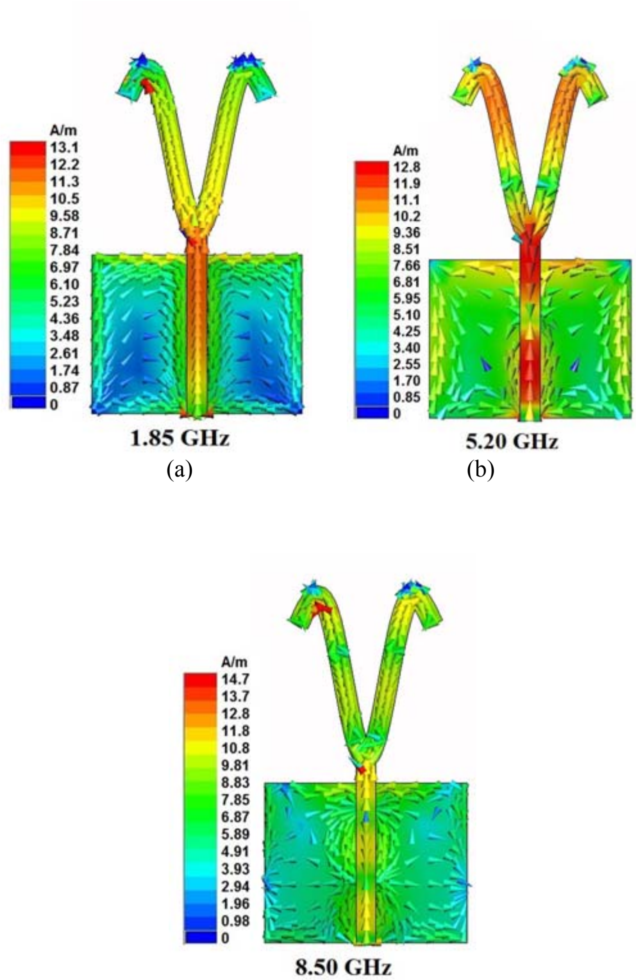


Fig. 8. Simulated and measured reflection coefficient (|S_{11}|) for inverted Sinc(2x) and 2Sinc(2x) monopole antenna



(a) (b)

Fig. 9. Current distribution of inverted Sinc(2x) monopole antenna at (a) 2.45 GHz, (b) 7.55 GHz



(a) (b) (c)

Fig. 10. Current distribution of inverted 2Sinc(2x) monopole antenna at (a) 1.85 GHz, (b) 5.20 GHz, and (c) 8.50 GHz

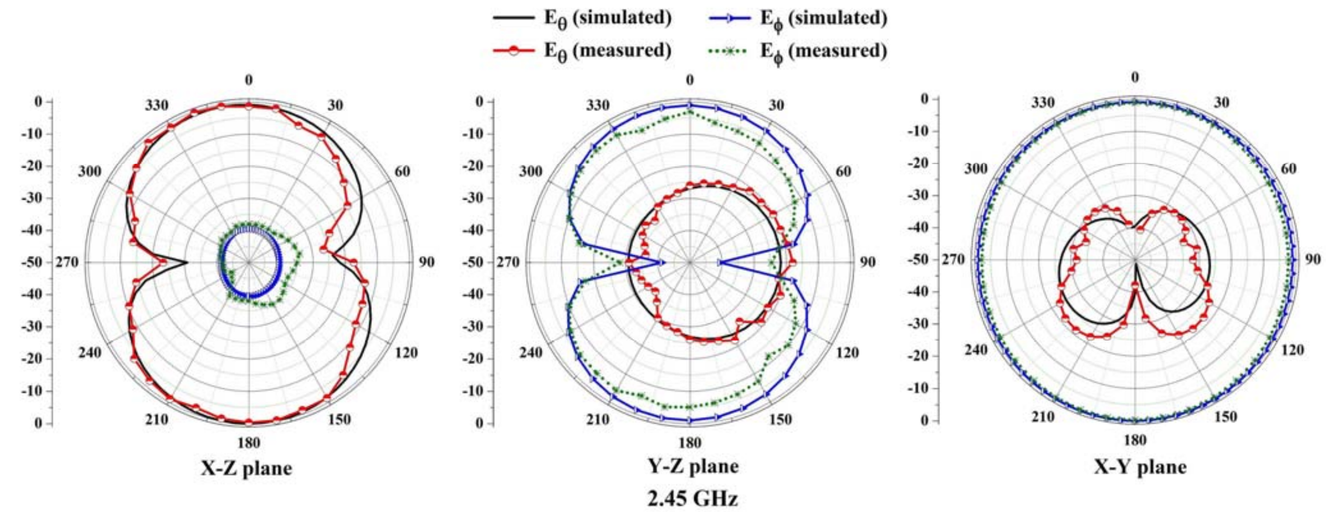
Fig. 11. Radiation pattern experimental set up.

TABLE III
SIMULATED AND MEASURED GAIN, DIRECTIVITY AND EFFICIENCY

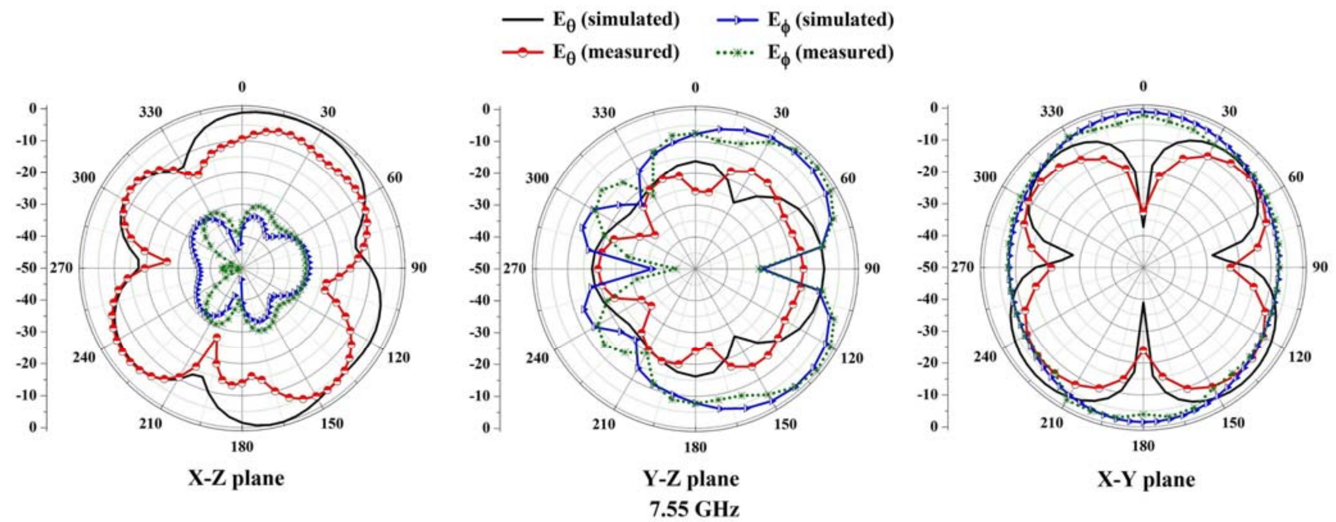
Antenna	Resonance frequency (GHz)	Gain (dBi)		Directivity (dBi)		Efficiency (%)	
		Sim.	Meas.	Sim.	Meas.	Sim.	Meas.
Inverted Sinc(2x)	2.45	2.52	2.25	2.75	2.69	94.03	90.36
	7.55	4.32	4.20	4.93	5.07	89.16	81.85
Inverted 2Sinc(2x)	1.85	2.05	1.90	2.45	2.59	87.25	85.31
	5.20	5.50	5.25	6.03	5.89	91.80	86.30
	8.50	4.73	4.92	5.12	5.55	92.73	86.50

TABLE IV
COMPARISON WITH VARIOUS ANTENNA STRUCTURES

	Dielectric Constant (ε_r)	Substrate Thickness '*h*' (mm)	Antenna Dimensions		Operating Resonance Frequency (GHz)
			Ground size (mm^2)	Total area (mm^2)	
Ref. 1	4.4	1.6	70 × 70	70 × 110	2.1, 5.3, 8.5
Ref. 2	4.36	1.6	93 × 63	93 × 63	2.4
Ref. 3	4.7	0.8	40 × 55	40 × 75	2.4, 5.2
Ref. 4	4.4	0.8	75 × 50	75 × 65	2.4, 5.2
Ref. 5	4.4	1.6	30 × 41	30 × 60	2.4, 5.2
Ref. 6	4.4	0.8	40 × 55	40 × 68	2.4, 5.8
Proposed Inv. Sinc(2x)	4.4	1.57	30 × 24	30 × 45	2.45, 7.55
Proposed Inv. 2Sinc(2x)	4.4	1.57	30 × 24	30 × 56	1.85, 5.2, 8.5

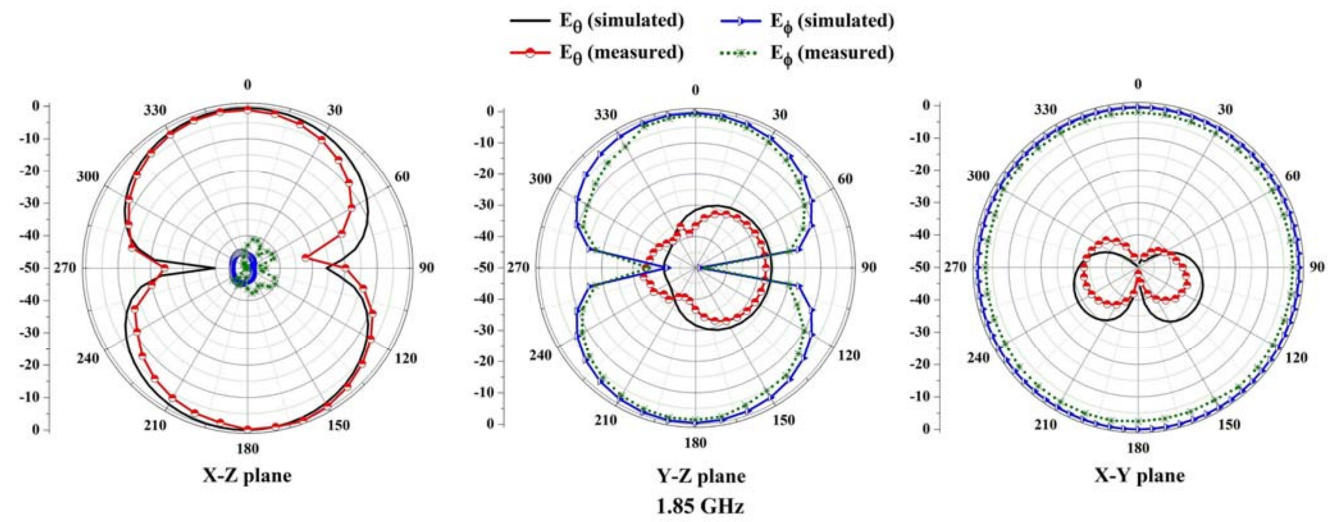


(a)

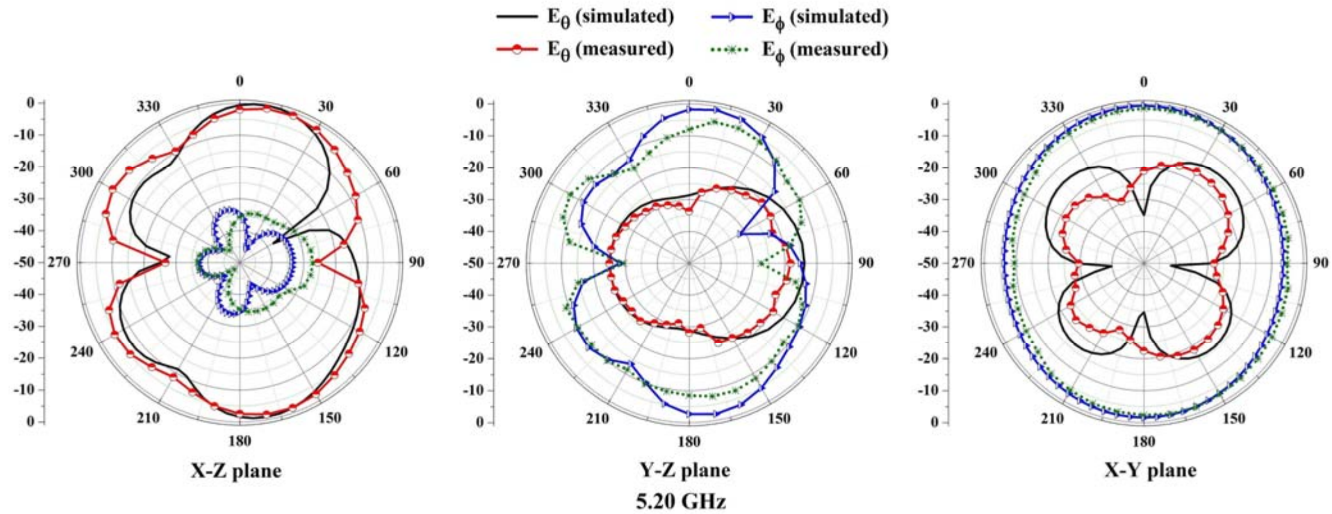


(b)

Fig. 12. Normalized radiation patterns for the inverted Sinc(2x) monopole antenna at (a) 2.45 GHz, (b) 7.55 GHz



(a)



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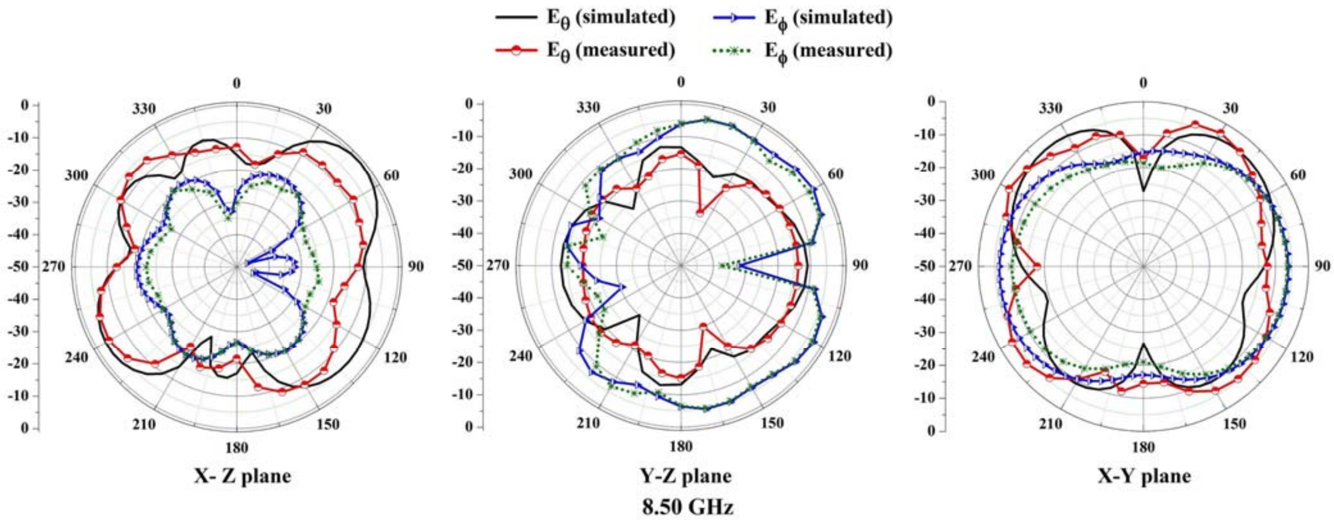

(c)

Fig. 13. Normalized radiation patterns for the inverted 2Sinc(2x) monopole antenna at (a) 1.85 GHz, (b) 5.20 GHz and (c) 8.50 GHz

V. Conclusion

A new configuration of monopole antenna is proposed for wireless communication. It has been shown that the inverted Sinc shaped monopole antenna is a very good candidate for multifrequency applications 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 changing the shape of the proposed configuration. The proposed antenna configurations occupy an area of 30×45 mm^2 and 30×56 mm^2 respectively. The antenna is found to be useful for several wireless applications such as DCS/PCS/IMT-2000/UMTS/Bluetooth/WLAN/fixed mobile and fixed satellite communication.

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