A Quasi-Omnidirectional Antenna for Modern Wireless Communication Gadgets

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***Abstract*—A compact, planar, wideband antenna designed by modifying the coplanar waveguide is presented in this letter. The proposed antenna finds a wide range of applications including advanced wireless systems (AWS), DCS-1800, DCS-1900/PCS/PHS, WiBro, BlueTooth/WLAN/WiBree/ZigBee, DMB, Global Star Satellite Phones, and digital cordless phones. Wide bandwidth $> 75\%$ centered at 2.50 GHz, quasi-omnidirectional radiation coverage along with moderate gain and efficiency are the salient features of the antenna. A prototype fabricated on a substrate with dielectric constant 4.4 and thickness 1.6 mm occupies an area of (31 $\times$ 64) mm^2. Details of antenna design and discussions on the effect of various antenna parameters on the radiation characteristics are presented.**

***Index Terms*—Coplanar waveguide, wideband antenna, planar antenna.**

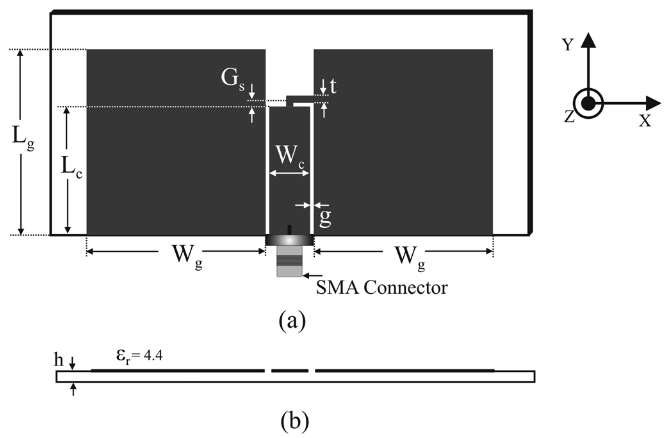

Fig. 1. Geometry of the proposed wideband antenna. (a) Top view. (b) Side view ($L_g = 26, W_g = 25, L_c = 18, W_c = 5.7, g = G_s = 0.5, t = 1, h = 1.6$ [Units mm] $\varepsilon_r = 4.4$).

I. Introduction

RECENTLY, the Federal Communications Commission (FCC) released a number of unlicensed frequency bands like advanced wireless systems (AWS) which triggered the industry to incorporate more applications to the modern handheld communication gadgets. This necessitates the development of an antenna which fulfills the requirements of the present day wireless communication systems, which attracted many researchers around the world and various antenna designs, are reported in [1]–[4]. In these, the technique adopted is the multiresonance phenomenon where the antenna operates over specific narrowband frequencies. However, it would be extremely difficult to accurately support the frequency requirements of future communication systems. Alternately, a broadband antenna which includes all these application bands with omnidirectional radiation characteristics, moderate gain and efficiency would be an ideal candidate not only for the present multiband applications but also for the future communication systems.

Modified coplanar waveguide can act as an efficient radiator embedded with attractive features like planar structure and easy integration with active devices without via holes [5]–[7]. Conventional bandwidth enhancement techniques like slot loading and integration of parasitic patch provide good results at the cost of distorted radiation patterns [8], [9].

In this letter, we propose the development of an antenna from the conventional CPW by embedding a modified short which results in an appreciable improvement in the impedence bandwidth while retaining an almost omnidirectional radiation behavior. The proposed antenna covers a wide range of applications, including Global Star Satellite Phones (uplink:1.61–1.63 GHz, downlink: 2.48–2.49 GHz), Advanced Wireless Systems (1.71–1.76 GHz, 2.11–2.17 GHz), DCS 1800 (1.71–1.88 GHz), Digital Cordless Phones (1.88–1.90 GHz), PHS/PCS/DCS-1900 (1.85–1.99 GHz), WiBro (2.30–2.39 GHz), BlueTooth/WLAN/WiBree/ZigBee (2.40–2.49 GHz) and DMB (2.60–2.66 GHz).

Ansoft's finite element method (FEM)-based high frequency structure simulator (HFSS) is deployed for the analysis and optimization of the proposed antenna. The optimized prototype is analyzed with Agilent E8362B Network Analyzer and it is observed that both simulated and measured results are in good agreement. Development of the antenna from conventional coplanar waveguide along with the results of simulation and experimental analysis are presented and discussed.

II. Antenna Geometry

The geometry of the proposed CPW antenna fabricated on a substrate with relative permittivity, $\varepsilon_r = 4.4$ and thickness 1.6 mm is illustrated in Fig. 1.

Manuscript received June 04, 2008. First published July 18, 2008; current version published December 19, 2008. This work was supported in part by the Council of Scientific and Industrial Research(CSIR), Government of India, University Grants Commission (UGC), Government of India, Department of Science and Technology (DST), Government of India.

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Digital Object Identifier 10.1109/LAWP.2008.2002317

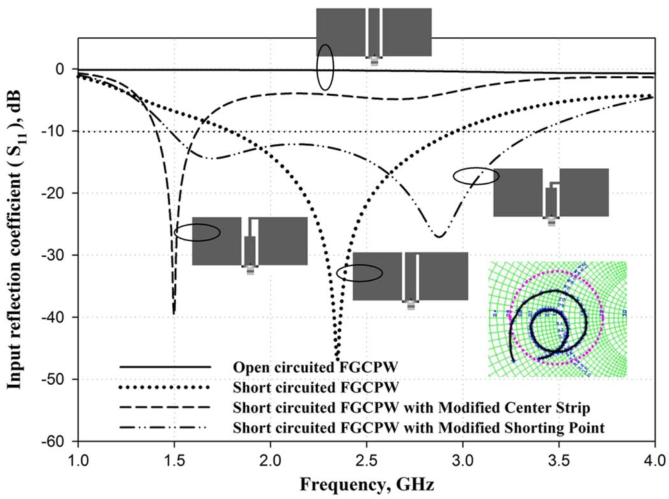

Fig. 2. Reflection characteristics of different FGCPW antenna configurations with the smith chart of the optimized antenna.

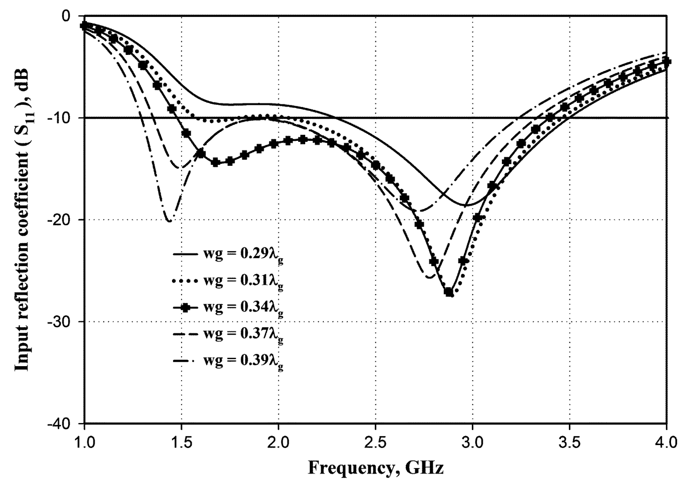

Fig. 4. Variation of reflection characteresitcs with ground plane dimension W_g of the proposed antenna ($L_g = 0.35\lambda_g$).

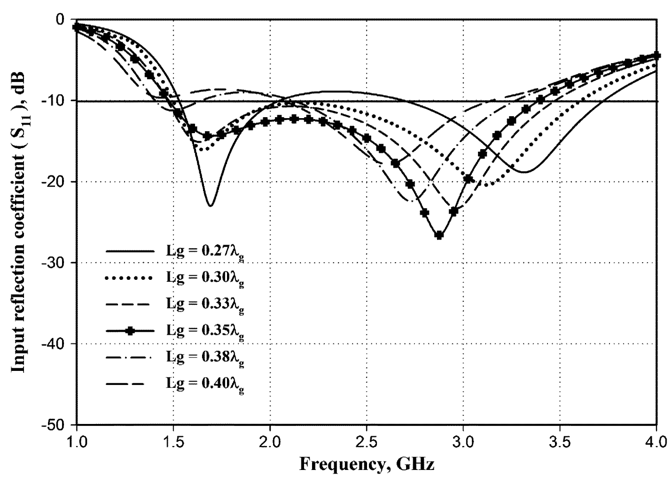

Fig. 3. Effect of ground plane dimension Lg on the reflection characteristics of the proposed antenna ($W_g = 0.34\lambda_g$).

It is evident from the layout that the antenna has a simple structure which consists of a modified short in the finite ground coplanar waveguide (FGCPW). The FGCPW is designed for an impedance of 50 Ω with design parameters $g = 0.5$ mm and $Wc = 5.7$ mm on a finite ground plane of $Lg = 0.35\ \lambda_g$ and $Wg = 0.34\ \lambda_g$, where λ_g is the effective wavelength which corresponds to the centre frequency of the resonant band. In the proposed design, the conventional FGCPW is modified by a stepped center strip shorted at the optimum position to achieve good impedance bandwidth with quasi-omndirectional radiation coverage. Various antenna parameters including the center strip length (L_c), gap between the centre strip, and short (G_s) and dimension of the finite ground plane $(L_g \times W_g)$ are optimized with the help of simulation software. The optimum design comprises of $L_g = 0.35\ \lambda_g$, $W_g = 0.34\ \lambda_g$, $L_c = 0.25\ \lambda_g$, $G_s = 0.007\ \lambda_g$, $t = 1$ mm, and $W_c = 5.7$ mm.

III. Results and Discussion

The transformation of a non radiating coplanar waveguide to an efficient radiator is illustrated in Fig. 2.

The input reflection coefficient (S_{11}) of an open ended FGCPW is shown as solid curve in Fig. 2. The structure is not exhibiting any resonance in the band. When the center conductor is short circuited at the edge, the system is resonating with 49% (1.8–3.0 GHz) bandwidth at 2.38 GHz. Further modifications on the center strip results in a significant shift in the resonance to the lower side without any change in the overall dimensions of the antenna. Then the short is moved to the optimum position so that a broad band is obtained with a bandwidth of 79% (1.48–3.49 GHz) centered at 2.44 GHz. It is also observed from the small loop in impedance locus, that the wideband resonance is obtained by the excitation of two resonant modes at close frequencies.

The influence of the finite ground dimensions on the reflection characteristics of the optimized prototype is studied. Effect of ground dimension L_g is illustrated in Fig. 3.

It is observed that there is only a slight variation in the bandwidth with L_g while the returnloss in the midband region is more dependent on L_g. Therefore $L_g = 0.35\ \lambda_g$ is a good selection which provides minimum reflection at the center portion of the resonant band. It is also worth noting that the second resonant frequency is more affected by the ground dimension L_g than the first resonance. The second resonance shifted to higher side as L_g decreases and, hence, the modes fall apart.

Fig. 4 depicts the effect of width W_g of the ground plane, on reflection coefficient.

It is observed that the first resonance is more shifted to a higher frequency region than the second resonance with the decrease in ground plane width W_g. Also impedance matching becomes poor as W_g is lowered. Therefore an optimum value of $W_g = 0.34\ \lambda_g$ is selected which is a compromise between impedance matching and bandwidth.

The variation of reflection coefficient with the gap G_s is depicted in Fig. 5.

It is observed that the gap between shorting point and center conductor (G_s) has a crucial relevance on the reflection characteristics of the proposed antenna. That is, smaller values of G_s result more reflections in the lower side of the resonant band while larger values result more reflections in the higher side of

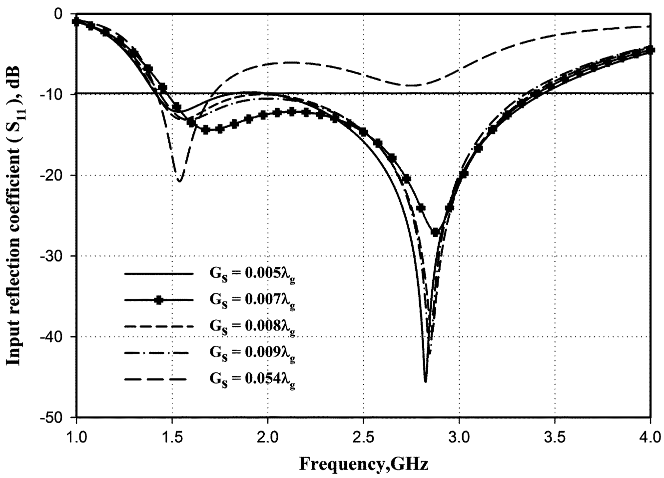

Fig. 5. Effect of shorting gap (G_s) over the reflection characteristics of the proposed antenna.

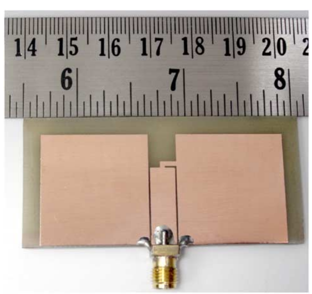

Fig. 6. Photograph of the fabricated prototype.

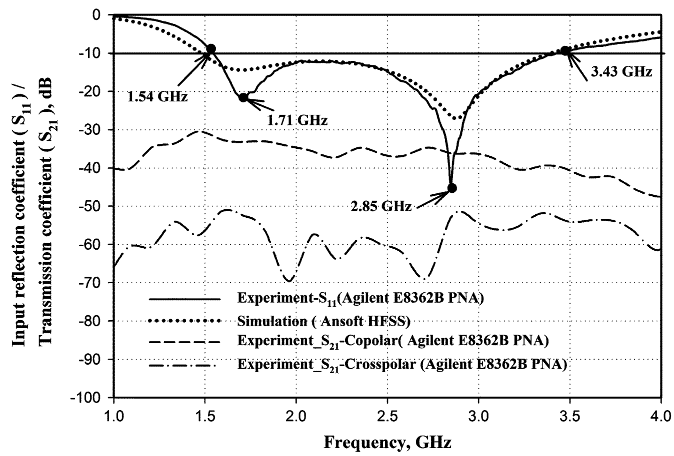

Fig. 7. Simulated and measured reflection characteristics. Transmission characteristics of the proposed antenna.

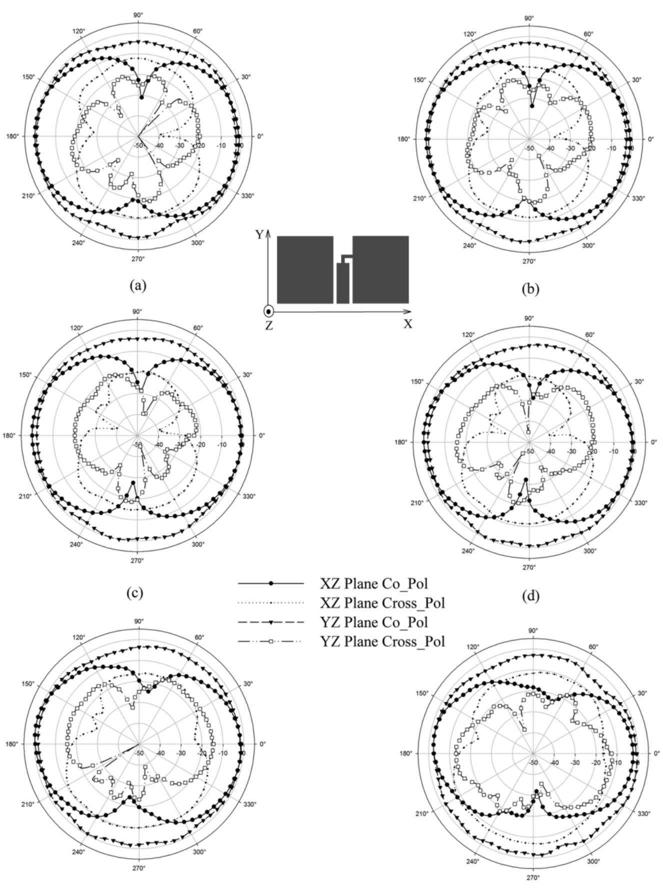

Fig. 8. Measured radiation patterns of the proposed antenna. (a) 1.54 GHz. (b) 1.71 GHz. (c) 2.0 GHz. (d) 2.50 GHz. (e) 2.85 GHz. (f) 3.43 GHz.

the band. Hence, an optimum value of $G_s = 0.007\,\lambda_g$ is chosen for the proposed antenna.

Photograph of the prototype antenna is shown in Fig. 6.

Fig. 7 depicts the simulated and measured reflection coefficient (S_{11}) of the proposed design along with measured transmission characteristics. It is observed that the measured and simulated results are in good agreement. The measured 10 dB bandwidth is about 76% (1.54–3.43 GHz) at the center frequency of 2.50 GHz. The experimental impedance plot given in the inset confirms the merging of two resonant modes as predicted in the simulation. The measured bandwidth meets all the bandwidth requirements for the applications mentioned earlier. It is clear from the transmission characteristics that the antenna exhibits linear polarization along the X direction in the entire operating band.

The radiation behavior of the antenna in the two principle planes, including the lower and higher end of the 2:1 impedance bandwidth is measured and is illustrated in Fig. 8.

It is seen that the measured radiation patterns are stable and quasi-omnidirectional in the entire operational band which is highly suitable for the proposed modern wireless communication bands.

A better understanding of the antenna behavior can be obtained by analyzing the current distributions at different frequencies as depicted in Fig. 9. It is evident from the plot that the resonant length $L_1 = (W_g + L_g + \Delta)$ contributes for the first, while $L_2 = (L_g + \Delta)$ contributes for the second resonance. These two resonant modes merge together to form the wideband characteristics.

Average gain of the proposed antenna at different frequencies are measured and plotted in Fig. 10. The antenna provides a gain better than 3.5 dBi over the resonant band.

Efficiency of the antenna is measured experimentally using Wheeler cap method and an average efficiency of 89% is obtained for the optimized design.

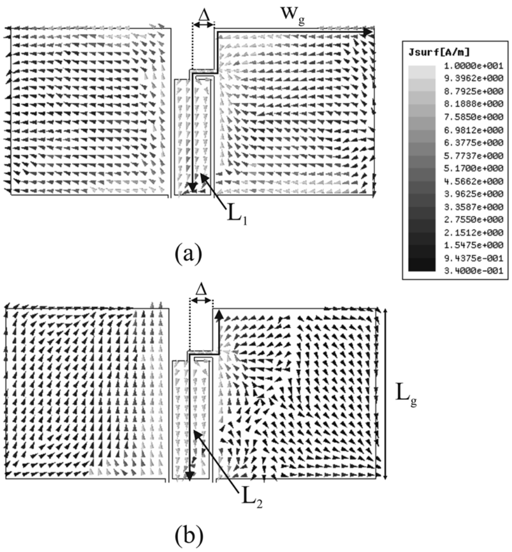

Fig. 9. Simulated current distribution of the proposed antenna at (a) 1.71 GHz and (b) 2.85 GHz.

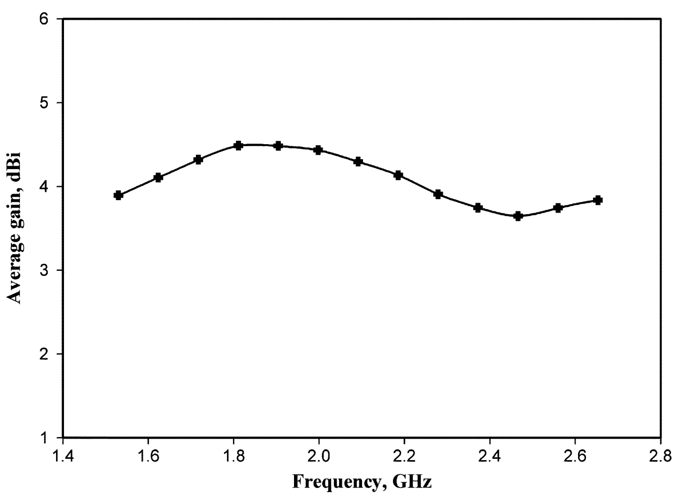

Fig. 10. Measured average gain of the proposed antenna.

From exhaustive experimental and simulation studies resulted the following design equations:

$$L_{c(\mathrm{cm})} \approx \frac{7.5}{\sqrt{\varepsilon_{\mathrm{eff}}} \times f_{(\mathrm{GHz})}} G_{s(\mathrm{cm})} \approx \frac{0.21}{\sqrt{\varepsilon_{\mathrm{eff}}} \times f_{(\mathrm{GHz})}}$$
$$W_{g(\mathrm{cm})} \approx \frac{10.2}{\sqrt{\varepsilon_{\mathrm{eff}}} \times f_{(\mathrm{GHz})}} L_{g(\mathrm{cm})} \approx \frac{10.5}{\sqrt{\varepsilon_{\mathrm{eff}}} \times f_{(\mathrm{GHz})}}$$

TABLE I
MEASURED RESULTS OF THE PROPOSED ANTENNA FOR DIFFERENT FREQUENCY BANDS

Design Freq. (GHz)	Design Parameters(mm)				Exp. Band (GHz)	% BW
	L_g	W_g	L_c	G_s		
0.9	71	69	51	1.4	0.61-1.25	69
5.2	12	12	8.8	0.2	2.81-6.49	79

where "$\varepsilon_{\mathrm{eff}}$" is the average relative permittivity of the substrate (ε_r) and air, $\varepsilon_{\mathrm{eff}} = (\varepsilon_r + 1)/2$ and f is the center frequency of the resonant band.

The design equations are validated for different frequencies and two typical data are shown in Table I .

IV. CONCLUSION

In this letter, a quasi-omnidirectional, modified coplanar waveguide antenna for modern wireless communication systems is presented. The prototype exhibits a wide 2:1 VSWR bandwidth of 76% centered at 2.5 GHz that covers a wide range of applications including advanced wireless systems (AWS), DCS-1800, DCS-1900/PCS/PHS, WiBro, BlueTooth/WLAN/WiBree/ZigBee, DMB, Global Star Satellite Phones, and digital cordless phones. The proposed design is validated experimentally for different frequencies.

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