Square Printed Monopole Antenna for Wireless Applications

Rekha P. Labade, Shankar B. Deosarkar, Narayan Pisharoty

***Abstract*—**In this article design and optimization of square printed monopole antenna for wireless application is proposed. Theory of characteristics mode (TCM) is used for analysis of current modes on the antenna. TCM analysis shows that beveled ground plane improves the impedance bandwidth. The antenna operates over the frequency range from 1.860 GHz to 5 GHz for a VSWR ≤ 2, covering the GSM (1900-1990MHz), IMT-2000(1920-2170MHz), Bluetooth (2.400-2484 MHz) and lower band of ultrawideband (UWB). Stable radiation pattern shows minimal pulse distortion. The radiation pattern is omni-directional along the H-plane and figure of eight along the E-plane. Size of proposed antenna is 39 mm x 29 mm x 1.6mm. Antenna is simulated using CAD FEKO suite (6.2) using method of moment. A prototype antenna is fabricated using FR4 dielectric substrate with a dielectric constant of 4.4 and loss tangent of 0.02 to validate the simulated and measured results of the proposed antenna. Measured results are in good agreement with simulated results.

***Keywords*—**Destructive Ground Surface (DGS), Method of moment, Theory of characteristics mode, UWB, VSWR.

I. Introduction

SINCE February 2002 u. s. Federal Communication Commission (FCC) declared the unlicensed use of 3.1-10.6 GHz frequency band for commercial operation of a ultrawideband technology, demand for design of ultrawideband antenna has fostered larger significance [1]. UWB antenna is the important part of ultrawideband system. Commercial ultrawideband (UWB) systems require small, low-cost antennas with omni-directional radiation pattern and large bandwidth [2-3]. Design performance parameters of ultrawideband antenna include impedance matching, radiation pattern stability, small size and low cost for electronic applications.

In recent years, researchers have proposed several bandwidth enhancement techniques [4]-[8]. Gap between the ground plan and patch have been changed to improve the operating frequency band [9]. Scaling factor technique is used to improve the performance of antenna [10]. Effect of increase in dielectric constant shifts the lower edge frequency of the UWB to lower side and hence improves the impedance bandwidth [11]. Dual band monopole antenna is designed using transmission line model [12].

Characteristic modes correspond with the Eigen current of the matrix. Hence depend on the shape and size of the antenna [12] and are independent of any source or excitation [13]. Eigen values associated with the modes are used for determining the resonance frequency and the operating bandwidth of antennas [14]. Recently TCM is used to analyze and optimize the excitation and radiation behavior of antenna [15]. Modal VSWR and modal significance provides the detail physical insight into the operating mechanism of different antenna's [16].

In this paper a compact square monopole antenna is designed and optimized. Theory of Characteristic Modes gives the systematic design approach for antenna. It is used to analyze radiating modes of conducting bodies. It was formally developed by Robart Garbacz and refined by Harrington and Mautz in seventies, sometimes referred as Inagaki modes [13]. It gives actual visualization of surface current and field radiated by antenna. It helps to understand operating principle of antenna [17] and is therefore used in this article to observe surface current on the radiating patch and destructive ground surface (DGS) of antenna. DGS is beveled accordingly to operate antenna at the lower edge of ultrawideband frequency range.

Following parameters are associated with the theory of characteristic modes [17].

A. Eigenvalue (λ_n)

Power radiated by a mode is inversely proportional to $|\lambda_n|$. Range of λ_n is from $-\infty$ to $+\infty$ and at resonance λ_n is equal to 0.

If λ_n is positive then mode stores magnetic energy and if λ_n is negative then mode stores electric energy.

B. Modal Significance (MS)

It determines how much a particular mode contributes to total radiation. MS=1 ensures 100% contribution of mode for radiation.

C. Characteristic Angle (α_n)

It is the phase angle between characteristic current (J_n) and characteristic field (E_n). It is given as,

$$\alpha_n = 180^o - \tan^{-1}(\lambda_n)$$

Range of α_n is from 0^o to 360^o at resonance α_n is equal to 180^o.

For $0^o < \alpha_n < 180^o$, mode J_n has inductive behavior and for $180^o < \alpha_n < 360^o$, mode J_n has capacitive behavior.

II. Square Monopole Antenna Design

Initial antenna geometry (before the application of theory of

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characteristics mode) is shown in Fig. 1. Antenna consists of radiating patch and microstrip feed line on one side of substrate and DGS on the other side. Following formulae are used to design the monopole antenna. Instead of resonant frequency, lower edge frequency of the UWB is considered for design [18].

$$L = \frac{\lambda}{4} - 2 * \Delta L \qquad (1)$$

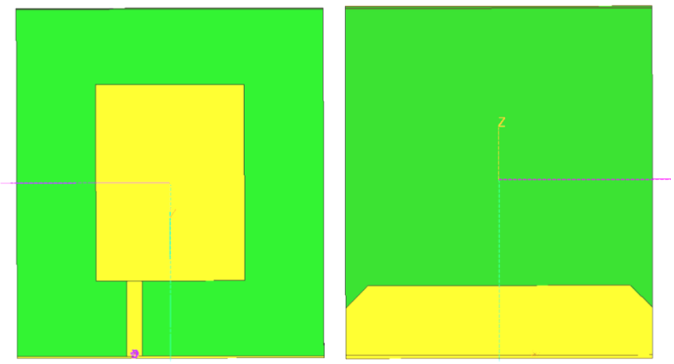
$$W = \frac{c}{4 f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (2)$$

$$\lambda = \frac{C_0}{(f * \sqrt{\varepsilon_r})} \qquad (3)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12 * \left(\frac{h}{w}\right)\right]^{\frac{-1}{2}} \qquad (4)$$

$$\Delta L = 0.412h\,\frac{(\varepsilon reff + 3)(\frac{W}{h} + 0.264)}{(\varepsilon reff - 0.258)(\frac{W}{h} + 0.8)} \qquad (5)$$

where L= length of patch, W= width of patch, λ = wavelength, ε_{eff} = effective dielectric constant, ε_r = dielectric constant of substrate, ΔL = extension along length, h = substrate height, w = width of substrate.



(a) Top view (b) Back view

Fig. 1 Geometry of Square monopole antenna

III. Modal Analysis

For VSWR ≤ 2, simulation result shows the dual band behavior of antenna from 1.80 GHz to 3.35GHz and 4.25 GHz to 5 GHz without modified DGS. To obtain the VSWR ≤ 2 over the entire lower ultrawideband frequency range, optimization of structure has been carried out using modal analysis. Fig. 2 shows the Eigen values of the first four characteristic modes. Capacitive and inductive nature of the intrinsic impedance can be judge from negative and positive signs of Eigen value respectively. Modal significance (MS) provides the additional information about the antenna. MS versus frequency graph in Fig. 4, shows only the first mode has value close to unity.

Fig. 3 shows the current distribution on the antenna indicating no current distribution at the two top edges of DGS. Hence it is beveled to improve the VSWR bandwidth over required band of frequency. Fig. 5 indicates that first and second mode attain MS value close to unity at higher end frequency. Before beveling it was found that only first mode contributes for radiation whereas beveling causes contribution of second mode to the radiation along with first mode. Fig. 5 and Fig. 7 validate the results.

Normalized current distribution of the first four characteristics mode is shown in Fig. 6. First mode is characterized by vertical, second by horizontal, third by circular and fourth by downward currents. Out of these four modes only the first two modes contributes for the radiation whereas the other two modes mainly stores the energy.

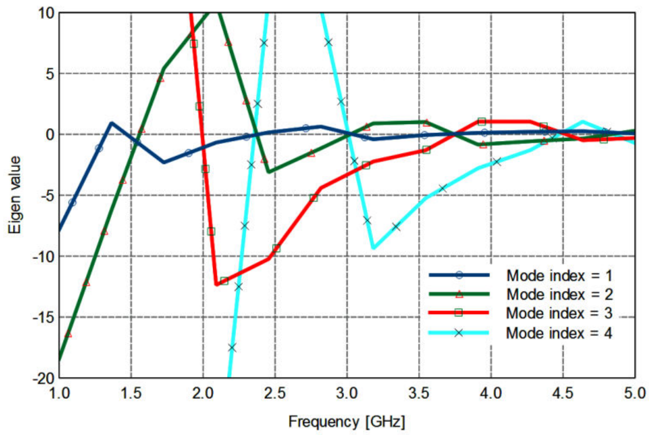


Fig. 2 Eigen Value of Square Monopole Antenna

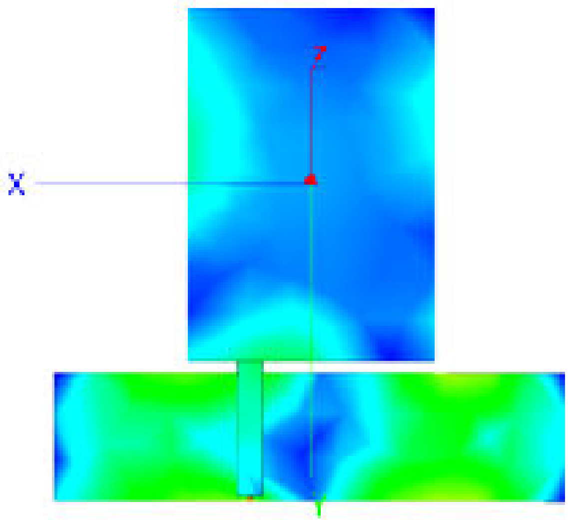


Fig. 3 Current distribution on the surface of antenna at 4.1GHz frequency

Radiation pattern at 3.5 GHz frequency is shown in Fig. 8 which shows an omni-directional radiation pattern along the H-plane and a directional radiation pattern along the E-plane.

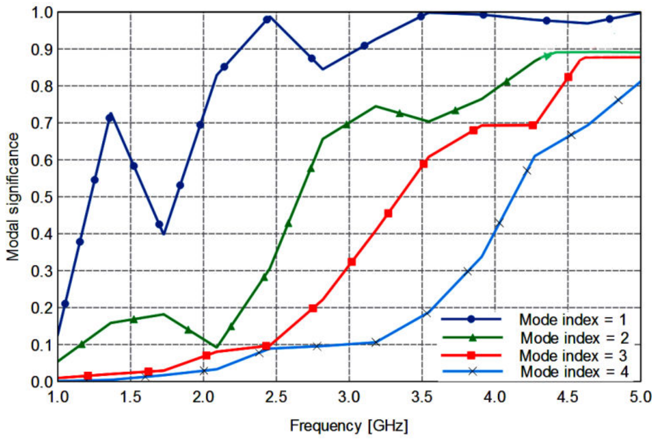


Fig. 4 Modal significance versus frequency (before bevel ground)

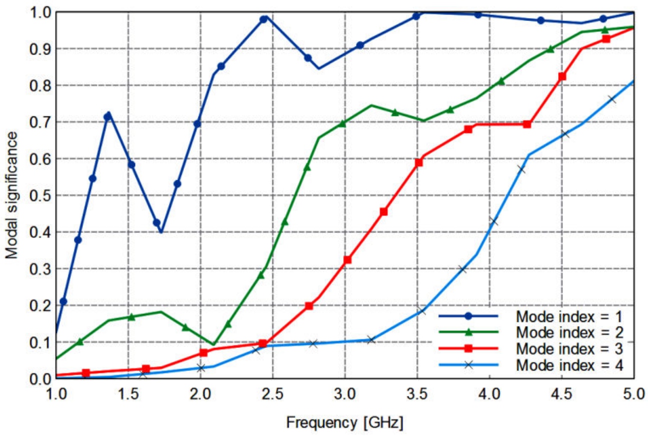
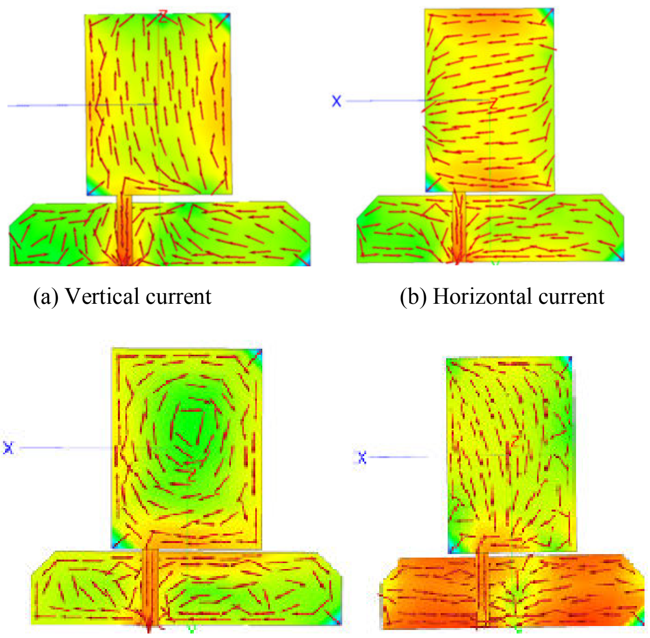


Fig. 5 Modal significance versus frequency (after bevel ground)



(a) Vertical current

(b) Horizontal current

(c) Circular current

(d) Downward current

Fig. 6 Normalized current distribution for first four modes

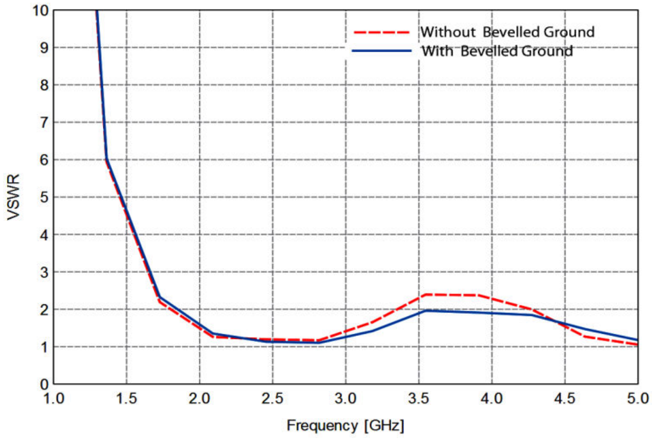


Fig. 7 Graph of Frequency versus VSWR

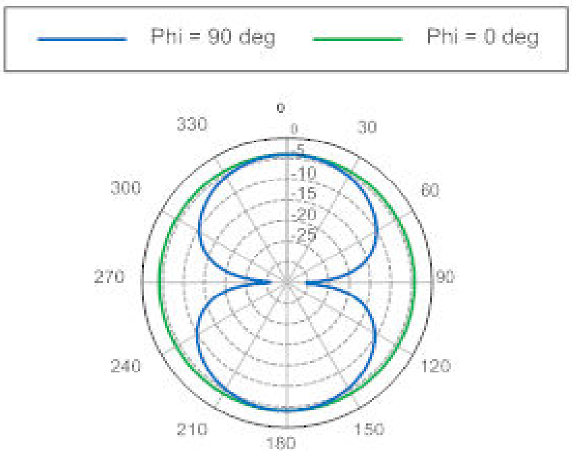


Fig. 8 Radiation pattern at 3.5GHz frequency

IV. Experimental Results

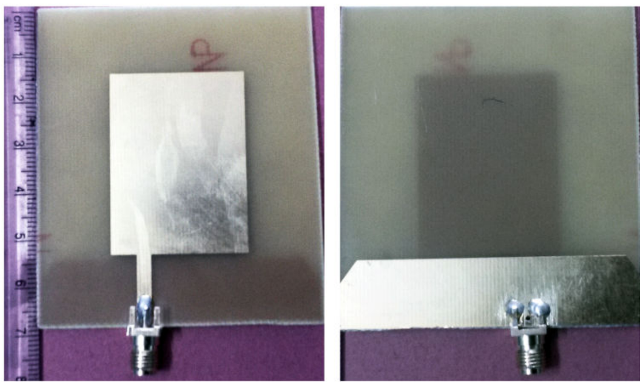


Fig. 9 Prototype of the proposed square monopole UWB antenna

To validate the design of the proposed antenna, a prototype of square monopole antenna with beveled ground plane is fabricated using photolithographic technique and antenna VSWR is measured by the Agilent N9912A, 30 MHz to 6 GHz vector network analyzer. Measured VSWR versus frequency graph is shown in Fig. 10. The measured frequency range for VSWR ≤ 2 is obtained from 1.860 GHz to 5 GHz which agrees with the simulated one.

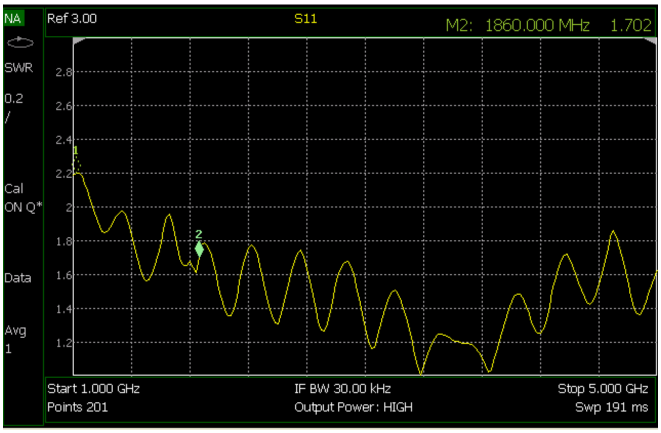


Fig. 10 Measured VSWR versus frequency of proposed square monopole UWB antenna

V. Conclusion

In this paper design, simulation and measurement of novel square monopole antenna with bevel DGS is proposed and investigated. Theory of characteristics mode is used to operate the antenna over the lower edge of ultrawideband frequency band by beveling the DGS and making mode two to resonate. Optimized antenna operates satisfactorily from 1.860 GHz to 5 GHz, covering the different wireless applications.

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