DESIGN OF A MODIFIED W-SHAPED PATCH ANTENNA ON AL_2O_3 CERAMIC MATERIAL SUBSTRATE FOR KU-BAND

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An influx of research has been devoted to use different di-electric substrate materials for antenna miniaturization. Design of A modified W-shaped ka band antenna on Al_2O_3 ceramic substrate is presented in this paper. The W shape is obtained from slotted conventional rectangular shaped patch. The ceramic substrate made with Aluminum oxide (Al_2O_3) with high dielectric constant and 1.5 mm thickness and the 3.3 mm x 5.5 mm patch is introduced for antenna miniaturization. The finite element method is employed to design and analyze the presented antenna and result shows that the impedance bandwidth (VSWR $\leq$ 2) of the proposed antenna is 1.23 GHz (20% of entire Ku-Band). The proposed miniaturized antenna is also able to obtain the stable radiation performance with maximum gain of 4.89 dB in the operating frequency band of 16.7 GHz to 17.95 GHz. The projected antenna is designed and simulated by using Ansoft's 3D full-wave electromagnetic field software HFSS and obtained return loss is below -10dB from 16.7 GHz to 17.9 GHz.

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1. Introduction

Recently, application oriented material research plays a great role in modern communication engineering development, especially in antenna technology. Low loss material substrate based antenna miniaturization is always interesting topic for communication engineering researchers [1]. Al_2O_3 ceramic material substrate is a competitive solution for antenna miniaturization due to low loss and high dielectric constant. Moreover, there are numerous advantages associated with ceramic material for antenna design over a wide frequency range. Antenna technology for wireless systems is continuously evolving with today's mobile antennas, necessarily has to be small and efficient. The need for compact and multifunctional wireless communication systems has spurred the development of wideband antennas with small size [2]. However, antenna size reduction and efficiency improvement tend not to go hand-in-hand. In order to reduce antenna size, there is an increasing focus on electrically small antennas as a research topic. Because of the fundamental short comings of electrically small antennas, careful choice of geometry and material properties is required to utilize a small available volume efficiently. Micro strip patch antennas are commonly used for antenna miniaturization because their distinguished advantages; such as, low-cost, lightweight and easily can be integrated into mobile systems as a part of the circuit board containing other sub-systems [3].

A demand for lightweight, low-profile antennas with a small footprint has been obligatory for the increasing use of broadband satellite systems to provide ubiquitous and high-capacity communications-on-the move that can be installed unobtrusively on land vehicles and aircrafts. Antenna technology for satellite applications is an increasingly interesting commercial market for mobile satellite terminals. Such systems must be able to receive satellite broadcasting services on-the-Move either for maritime, aeronautical or land applications. Current and future multimedia services claim for low-cost high performing terminals. The possibility of realizing a compact cost-effective full electrically small antenna for automotive tracking applications in Ku-band is considered in this study. The key items in the design of this antenna terminal by using Al2O3 ceramic substrate are a high degree of cost effectiveness and smaller sizes so that the terminal can easily be integrated with vehicles.

With the ever-increasing need for mobile communication and the emergence of wireless systems, it is being highly concentrated on antenna design for Ku-band application [4]. Due to the bandwidth availability for Ku-band satellite links, the system is widely used in satellite communication; especially in mobile antenna systems used in vehicles. There are numerous Ku-band applications such as weather forecasting radars, vehicle tracking, fire detection radars etc. Recently, in [5] A W-shaped micros trip feed patch antenna is designed with radiating patch dimension 72 mm x 50 mm and 16 mm thick substrate, which obtained very good result. However, there is still much afford need to be given to miniaturize the antenna for small form factor applications. In [6], authors designed 1.8 GHz–2.6 GHz W-shaped enhanced-bandwidth patch antenna for wireless communication and obtained antenna bandwidth of 36.7%. Nevertheless, there are still roam to explore the design for higher frequency application. In [6] a CPW- fed folded w-shape antenna for UWB application and Band notched design is presented for WLAN application. However, traditional slot antennas had the shortcoming of larger dimension, for that they were not suitable for WLAN applications. A 15 mm × 15 mm dual polarized microstrip patch antenna for is designed Ku-band application [7] and obtained 950 MHz bandwidth with maximum gain 7.6 dB. Nevertheless, the designed antenna not sufficient miniaturized for small form factor applications. In this paper, an Al_2O_3 ceramic material substrate based electrically small W shaped slotted patch antenna is proposed for Ku-band satellite applications where the overall antenna size is significantly reduced.

2. Antenna design

The proposed modified W-shaped antenna is designed and simulated by using Ansoft's 3D full-wave electromagnetic field software HFSS. The design procedure starts with the radiating patch. The W-shape patch is obtained by cutting slots from a traditional rectangular shape of the copper patch on substrate with no ground plane. This antenna can be mounted on non conducting plane for fabrication. To further exploit the enviable antenna miniaturization, a w shape coaxial probe feed antenna geometry is designed on the Al_2O_3 ceramic material substrate with dielectric constant 9.8, relative permeability 1 and loss tangent is 0 in this study. There are three main advantage of Al_2O_3 ceramic material convinced the author to use as substrate [8]. Firstly, due to low dielectric constant of more available and less expensive conventional FR4 substrate is lower (ε_r =4.2), which is not appropriate for higher frequency antenna design. Using square Al_2O_3 ceramic as the substrate, the size of proposed slot antenna could be reduced as compared to FR4 based antennas due to the higher dielectric constant of Al_2O_3 ceramic (ε_r=9.8). Secondly, the printing method of Al_2O_3 ceramic material has lower environment pollution problem because Al_2O_3 ceramic material substrate does not need to use $FeCl_3$ solution to etch the Cu plate from the surfaces of Duroid and the FR4 substrates. lastly, the printing method of Al_2O_3 substrate is easy for mass production. the dimension of the radiating patch is determined from the mathematical equation (1 & 2) [9].

$$w = \frac{c}{2f_o}\sqrt{\frac{\varepsilon_r+1}{2}} \tag{1}$$

$$L = \frac{c}{2f_o\sqrt{\varepsilon_r}} - 2\Delta l \tag{2}$$

where W is the width and L is the length of the patch, f_o is the center target frequency, c is the speed of light in vacuum. The effective dielectric constant can be calculated by using following the equation (3) [9]:

$$\varepsilon_e = \frac{1}{2}(\varepsilon_r + 1) + \frac{1}{2}(\varepsilon_r - 1)\sqrt{(1 + \frac{10h}{W})} \quad (3)$$

where ε_r is the relative dielectric constant and h is the thickness of the substrate. Due to the fringing field around the periphery of the patch, the antenna electrically looks larger than its physical dimensions. The increment to the length, *Δl* due to fringing field can be express as [9]:

$$\Delta l = 0.412h \frac{(\varepsilon_e + 0.3)\left[\frac{w}{h} + 0.8\right]}{(\varepsilon_e - 0.258)\left[\frac{w}{h} + 0.8\right]} \quad (3)$$

The antenna is primarily designed to operate in Ku-band (12GHz-18GHz) the requirements of design such as bandwidth and dielectric constant are taken in to account. To obtain the most efficient size of the radiating patch the design is optimized by using finite element method based full-wave electromagnetic field simulator HFSS.

The proposed W-shape patch slotted antenna is designed with the following radiating patch dimension; length (*l*) = 3.5 mm, Width (*w*) = 5.5 mm and substrate thickness (*h*) = 1.5 mm. The W shape is obtained from the conventional rectangular patch by cutting two 2.5 mm x 0.5 mm slots. The patch is fed by conventional coaxial probe with 0.5 mm radius and 1.5 mm height intersects the substrate. The 3D view of overall proposed antenna geometry is shown in figure 1. This antenna gives a bandwidth of around 1.23 GHz at the Ka-band of operation from 16.72 GHz to 17.95 GHz with a return loss lower than -10 dB. The achieved gain 4.56 dB and VSWR value is 1.03 in resonant frequency 17.27 GHz from the proposed antenna.

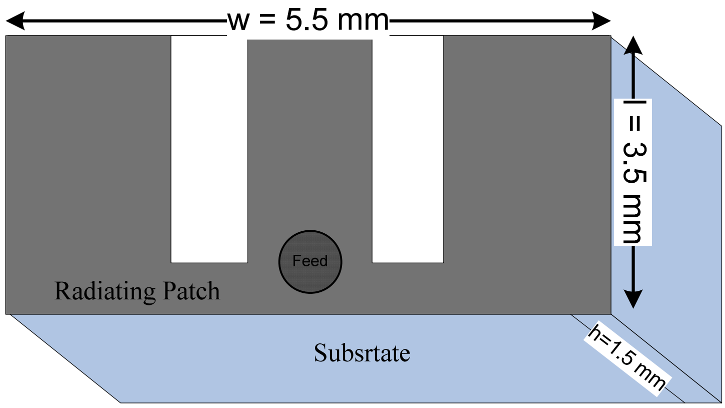


Fig. 1. 3D view of W-shaped antenna geometry.

3. Results and analysis

The performance of the proposed antenna is analyzed and optimized by using commercially available Ansoft's 3D full-wave electromagnetic field simulator HFSS 13.0. Fig. 2 shows the result of the return loss of the proposed patch antenna. The return loss achieved less the -10 dB from 16.7 GHz to 17.9 GHz. The simulated bandwidth of 1.2 GHz 60% of simulated frequency band and 20% of entire Ku-Band (12 GHz-18 GHz). Figure 3 illustrates the maximum gain 4.89 dB obtained from the proposed design and 4.86 dB achieved in the resonance frequency 17.27 GHz. the gain variation across the operating band is about 0.11 dB. Although the size of proposed antenna is reduced, the gain is remain higher compared to that of the corresponding antennas. The voltage standing wave ratio (VSWR) of the proposed antenna is shown in figure 4. It can be observed from the result that the VSWR value is less than 2, which considered as suitable for the antenna.

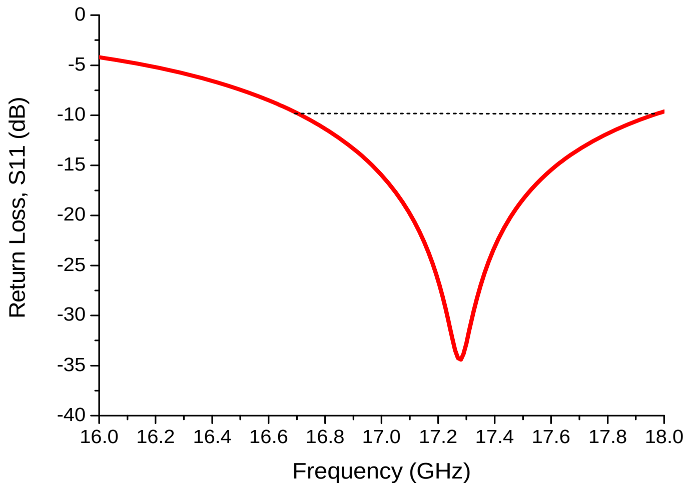


Fig. 2: Return loss of the proposed antenna

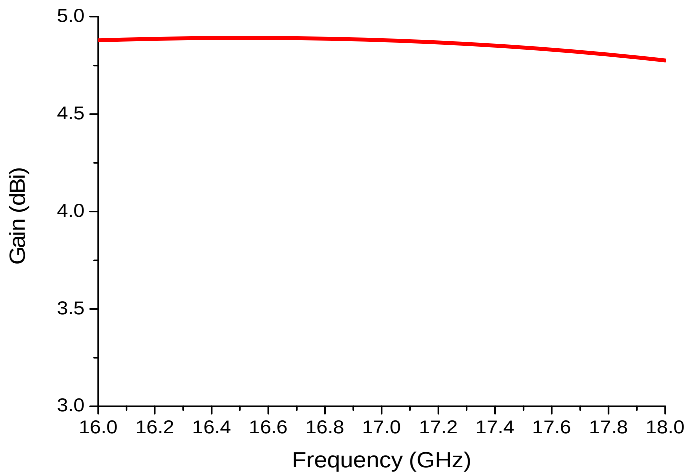


Fig. 3: Gain of the proposed antenna

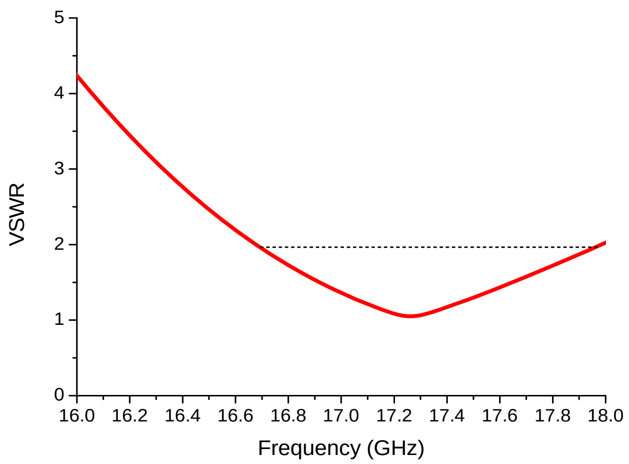
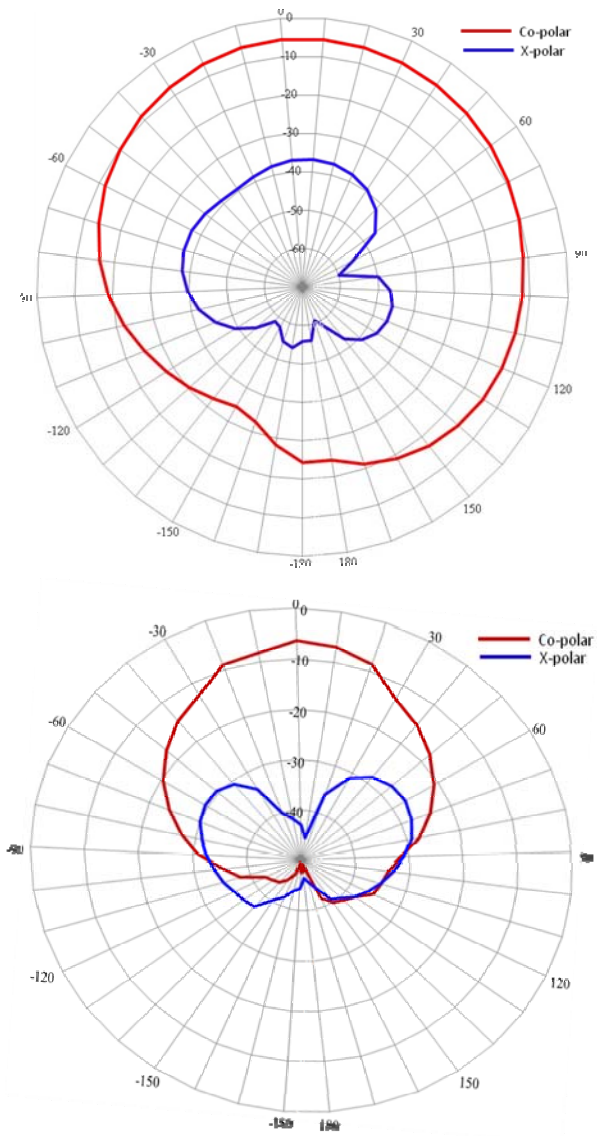


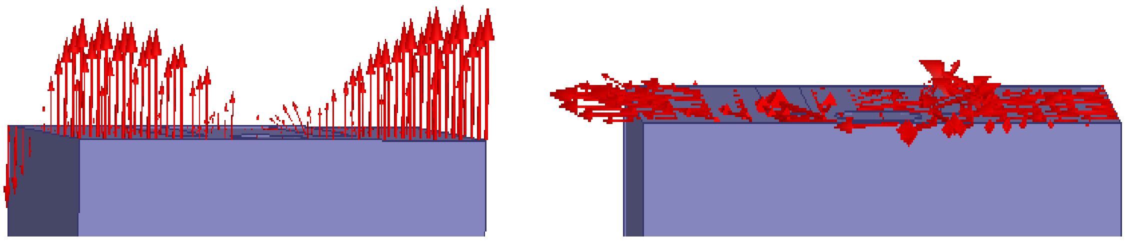
Fig. 4: VSWR of the proposed antenna.



(a) E - Plane (b) H – Plane

Fig. 5: Co and Cross polarization of proposed antenna.

Figure 5(a) and 5(b) shows the radiation pattern for E-plane and H-plane of the proposed antenna at resonance frequency of 17.27 GHz. The co-polarization patterns are symmetric and the cross-polarization levels in E- and H-plane are better than -35 dB and -28 dB respectively. It can be easily observed from the radiation pattern that the designed antenna produces directional radiation and almost stable radiation pattern throughout the whole operating band with low cross polarization. There are some significant advantages if a patch antenna has stable and symmetrical radiation pattern. One of the major advantages is that during construction of an antenna array, the radiation pattern would be more stable across the operating bandwidth. The current distribution of E and H plane on the radiating patch at resonance frequency 17.27 GHz is illustrated in figure 6(a) and 6(b) respectively. The direction of current is indicated by arrow sign. From the current distribution display, it is observed that the electric current strongly flows near the feeding probes of the patch. However, the current distribution at different part of the patch is almost regular.



(a) E-Field (b) H-Field

Fig. 6. Current distribution of E and H plane of the proposed antenna

4. Conclusion

A W shape electrically small coaxial probe fed antenna on Al_2O_3 ceramic material substrate without ground plane has been designed and analyzed in this paper. The proposed antenna designed in 17.27 GHz resonant frequency for ku-band satellite application. Average gain of 4.53 dB and 1.2 GHz bandwidth 60% of simulated frequency band and 20% of entire Ku-Band (12 GHz-18 GHz) has obtained from the proposed W shape slotted antenna. By using Al_2O_3 ceramic material substrate with 9.8 dielectric constant, the size of the antenna significantly reduced. The proposed antenna can be easily fabricated and place on the small devices due to its smaller dimension and available material.

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