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BOW-TIE ANTENNA DESIGN WITH GROUND SLOTS FOR WIRELESS ENERGY HARVESTING APPLICATIONS

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ABSTRACT: In this paper a novel ultra-wideband antenna is proposed for WLAN energy harvesting applications. Symmetrical slots have been introduced in antenna to enhance the impedance bandwidth and gain. The proposed planar antenna is having the dimensions of 1.6 mm x 80 mm x 100 mm. It is observed that antenna is effectively tuned at 1.8 GHz - 3.1 GHz with fractional bandwidth of 53.6%. Maximum antenna gain of 5.9 dB is achieved with wider dipole like radiation patterns.

Keywords: Bow-Tie antenna, antenna slots, CPW antenna, Wideband

INTRODUCTION

Recent developments in wireless communication has led new applications for Bluetooth, WLAN, wideband Internet of things (IoT). The electronic devices are becoming more and more compact as the size of chip is reducing. Therefore, the need for efficient, low-profile and wideband antenna is evident. Different types of radiators are being designed and implemented to support upcoming technological advancements (Liu *et al.,* 2013). Wideband antennas find their applications in almost all fields of electronics including GPS receivers, small electronics, smart buildings/cities, intelligent transport system, space exploration and missiles (Rao, 2004; Wang and Liu, 2016).

Wide bandwidth is a major requirement of modern antenna for these applications that has been addressed using various concepts in 3-D feed mechanism (Herscovici, 1998), incorporating slots of different types (Luk *et al.,* 1998), stacking the patches (Guo *et al.,* 2000) and by the use of shorting pins (de Aza *et al.,* 2001). Different antennas with wide slots have been analyzed in (Liu *et al.,* 2004; Li *et al.,* 2005; Dastranj *et al.,* 2008). However, the issue of directivity and broader size remains critical in most cases which in turn reduces the overall gain of antenna at designated frequencies. Design analysis in this paper serves the basis for miniaturized ultra-wideband antenna design for energy harvesting devices. In our proposed antenna wideband characteristics have been achieved with defected ground structure (DGS) and by designing adjacent slots both on ground and in top of radiator itself. In the beginning simple Bow-Tie antenna with CPW grounds was selected for WLAN band which had limited impedance bandwidth. Further, DGS was implemented to achieve desired properties of wide bandwidth and finally using iterative optimization technique, slots are etched in the design to attain improved gain at WLAN 2.45 GHz. In coming section return loss, VSWR, impedance matching, current distributions, radiation patterns and antenna gain for proposed design are discussed in detail (Wang *et al.*, 2018; Wang *et al.*, 2013).

MATERIALS AND METHODS

Traditionally patch antennas are narrowband and to improve the bandwidth additional wide range of techniques have been implemented in literature such as gap coupling, using asymmetric dual feed, embedding slots of different sizes and shapes, using parasitic elements and differential patches (Zhang *et al.,* 2012; Khan *et al.,* 2018; Khan *et al.*, 2016; Luo *et al.,* 2013). Therefore, the selection of geometry for the wideband antenna has a huge impact on energy harvesting system. One of the widely implemented wideband antenna geometry is Bow-Tie design which is usually fed by coplanar waveguide structures but some early designs also implemented coaxial feed mechanism (Chen *et al.,* 2014). As discussed earlier that CPW feed is more convenient than the traditional coaxial feed to attain the easy configuration of the impedance matching. The feed width and gap in between grounds is easy to optimize while in case of coaxial feed impedance matching becomes a huge challenge in determining the optimal position of coaxial feed at the patch (Kusch *et al*., 2017; Khan and Rizvi, 2013).

Bow-Tie geometry has been widely used in applications of imaging, ground penetrating radars, Wi-Fi access points and pulse antennas due to inherent characteristics of low profile, large bandwidth, low losses and high radiation efficiency. The antenna analysis and assessment are done by means of HFSS 16.0 with single-sided printed circuited board (PCB) embedding 50 Ω SMA connector for perfect impedance matching.

Four rectangular slots on each side of the ground are designed and small slots have been created on the top of the radiator to enhance the radiation efficiency characteristics at 2.45 GHz. Major current density is calculated at the feed and around the slots area while moderate EM waves distribution is observed on the right and left side of proposed antenna. Detailed geometry of proposed antenna is shown in Figure 1.

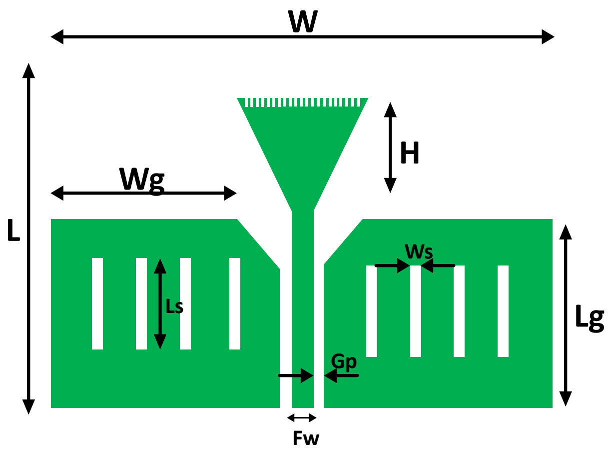

Figure 1: Geometric model of slotted Bow-Tie antenna (SBA)

Reflection coefficient: One of the most important antenna performance parameters is return loss. Figure 2 represents the reflection coefficient for this novel design. This plot shows the amount of return loss due to the port mismatch as S11 that is well below -10 dB threshold value. The return loss is quite acceptable and it controls the operational frequency band of this antenna. Wide bandwidth from 1.8 GHz to 3.1 GHz is measured at 2.45 GHz and 53.06% fractional impedance bandwidth is achieved. Second resonance band is also observed at 4.5 GHz that can also be utilized for dual-band operation of the antenna when desired. The peak S11 value of -32.4 dB and -14.5 dB is measured at 2.45 GHz and 4.5 GHz respectively. This radiator is tuned for WLAN band to avoid complexity. Through repetitive parametric studies it is observed that when we intend to tune this antenna at both frequency bands, the impedance bandwidth of first resonance band is shrinked to couple of hundred M Hz.

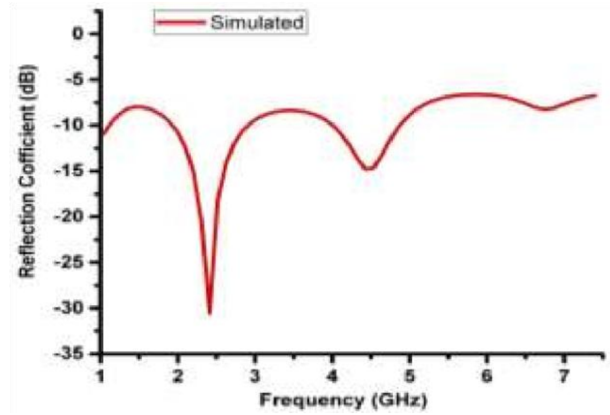

Figure 2: Reflection *coefficient* of Slotted Bow-Tie antenna

Voltage standing wave ratio (VSWR): The reflection coefficient represented in terms of voltage standing wave ratio is plotted in Figure 3. This represents the overall power reflected back from input port at the operational range of frequencies. VSWR is calculated from the following equation.

$$VSWR = \frac{1+|S_{11}|}{1-|S_{11}|} \quad (1)$$

At 2.45 GHz, VSWR is calculated to be 0.02 which shows excellent matching while at 4.5 GHz VSWR value is around 2.6 which implies that port does not support for this frequency and thus huge power reflection is calculated.

Input impedance: Simulated values for real and imaginary part of input impedance are plotted in Figure 4. At 2.45 GHz excellent impedance matching is observed for imaginary part which is quite stable over wide range of frequencies while real part input impedance varies along with varying frequencies. Realized values for impedance are calculated to be 50.21 + j 0.002 Ω. From the plot it is clearly evident that this novel design can be easily tuned to three resonance bands simultaneously for multiband operation.

Current distribution: Surface current distribution for WLAN frequency is illustrated in Figure 5 that shows even pattern of low surface currents at the far right and far left the side of the antenna. Maximum current density at the feed line along with Bow-Tie patch is measured. Creation of slots in the ground structures and at the top of the patch is justified as more and more current is evenly distributed along the antenna to avoid surface losses. Maximum surface current ranges from 6.46 A/m^2 to 9.29 A/m^2. By analyzing the distribution of current it can be easily noted that top and bottom sides of the left and right ground planes suffer low current flow which is due to the large area of the antenna and reduced size of feeding structure. This can be further improved by introducing more slots near such dimensions to obtain better radiation efficiency. In general, this design performed as expected from the slots embedding and the current density is well controlled using the optimized values of slots.

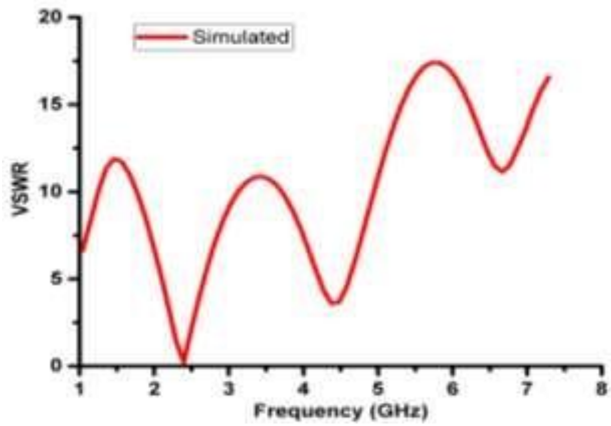

Figure 3:Plot of VSWR for SBA

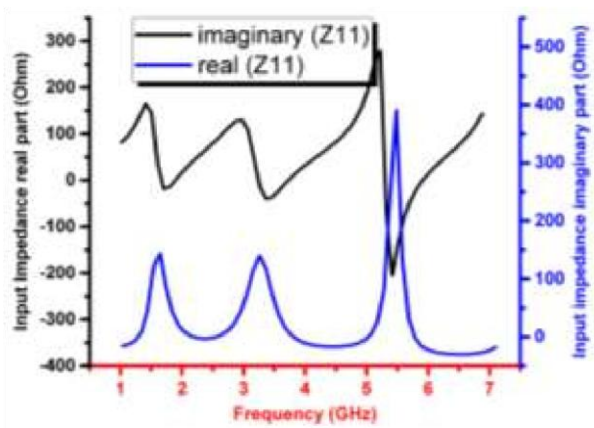

Figure 4: Input impedance plot of Bow-tie antenna

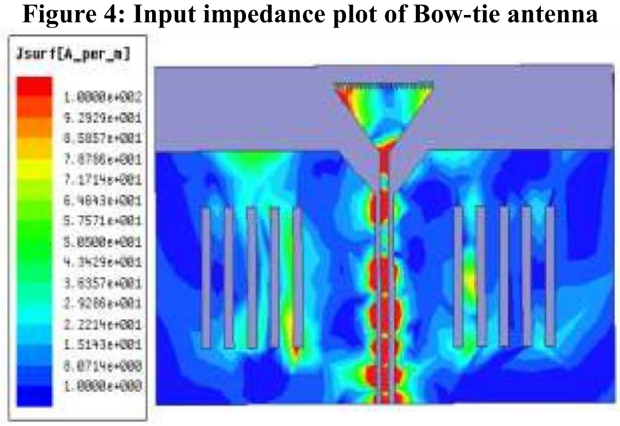

Figure 5: Surface current distributions of novel Bow-Tie antenna

RESULTS AND DISCUSSION

Radiation pattern: Free space radiation pattern for E-Plane and H- Plane are measured at 2450 MHz as depicted in Figure 6 (a), (b). Solid lines represent co-polarization and cross-polarization components for both planes.

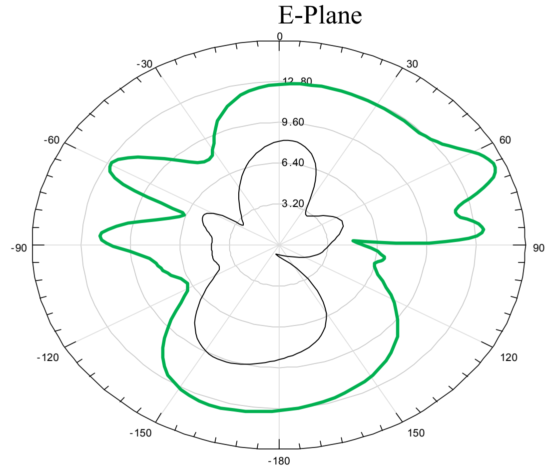

Figure 6 (a) Radiation pattern of SBA at E-plane,

It is worth to note that higher amplitude for radiation pattern is expected when the VSWR value is below 2 and vice versa. Major lobes have been observed at 2.45 GHz and minor lobes are calculated for subsequent frequencies. At ±600 and ±900 maximum radiation efficiency has been simulated on E-Plane and H-Plane that represents two-dimensional radiation pattern behavior. The pattern resembles typical monopole antenna due to higher order harmonics involved at higher frequencies.

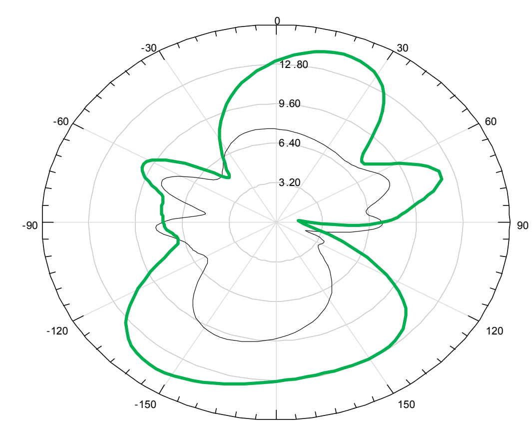

Figure 6 (b): Radiation pattern of SBA at H-plane

Antennas gain: As the matter of fact, electrical length of antenna increases at the higher frequencies therefore the feeding structure effects at higher frequencies become smaller as compared to lower frequencies. The simulated gain at 2.45 GHz for Bow-Tie antenna is plotted in Figure 7. Maximum value of gain is measured to be 5.9 dB at 2.2 GHz and at our desired frequency, the gain is calculated to be 5.4 dB which is quite acceptable value with wide radiation pattern at E-plane and directional pattern at H-plane. At 2.8 GHz, gain of antenna is observed to be lowest which resembles the expected trend as next resonance frequency is around 4.5 GHz when we analyze the reflection coefficient plot. Gain is almost constant from 2 GHz to 2.5 GHz which is our operational frequency range for this novel antenna. In general, it is concluded that this design is easy to reconfigure and meets the expected performance for RF energy harvesting application with reduced overall area of this antenna.

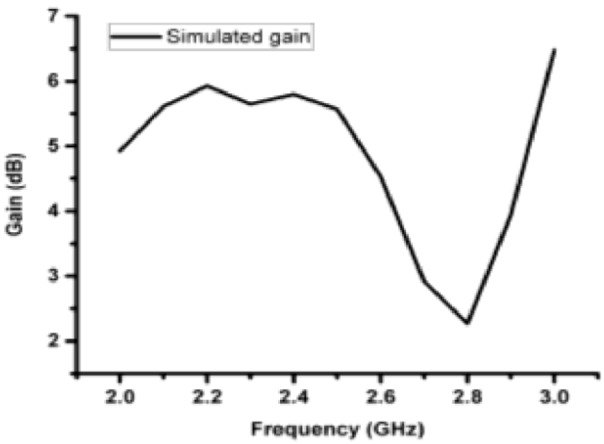

Figure 8: Simulated gain of Bow-Tie CPW antenna

Conclusion: In this paper, broadband planar antenna with wide bandwidth and effective radiation parameters have been analyzed thoroughly for 2.45 GHz RF energy harvesting applications. It is confirmed that feed gap, size and shapes of antennas have a significant effect on antenna performance parameters. Further, it is shown that surface current densities have improved and widened the bandwidth with the proper slot engravings. Further, It is confirmed that spacing between antenna and feed has significant impact on impedance matching which is optimized in the design by using parametric analysis. The current distributions and radiation pattern have significantly improved by using DGS and vertical slots. The overall gain of antenna is stable and found to be 5.4 dB at designated frequency which makes it suitable candidate for WLAN applications.

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