Design, Fabrication and Testing of an Ultra-Wide Band Bowtie Antenna for Wireless Radar (UHF, L and S Band) Communication

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ABSTRACT

A low-cost and light-weight ultra-wideband bowtie antenna for radar applications was simulated, fabricated and tested. A concise and easy to follow step-by-step description of the performed bowtie antenna simulation in Ansys HFSS software is presented. Optimized antenna parameters were utilized to fabricate the antenna. Fabrication was achieved by utilizing an FR4 PCB. The prototype was tested using a spectrum analyzer. The fabricated bowtie antenna results were used to validate the simulation results. The results obtained from the simulation platform were in close agreement to those of the prototype antenna. Results on effect of substrate thickness and frequency on S11 are also presented. The prototype produced improved overall S11 as compared to the simulation. The results indicate that the fabricated antenna satisfies bandwidth requirements for the UHF, L and S bands.

Keywords -**Antenna design; antenna fabrication; bowtie antenna; FR4 substrate; return loss**

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1. INTRODUCTION

Microstrip antennas are critical components of communication systems. The design of different antenna types is strongly guided by the intended applications. Microstrip antennas have been useful in a number of applications including mobile communication systems. Radio detection and ranging (radar) systems are utilized in a wide range of applications including "remote sensing, speed control, synthetic aperture radar, air traffic control, airborne and space borne missions, military applications" [1] and so on. Research is ongoing for more promising applications.

Traditionally, radar systems are designed to detect target range, velocity, direction and even establish the nature of desired objects [2]. All this is facilitated by a directional antenna with good gain and a very wide bandwidth of operation. The advantages of microstrip antennas include low-cost of fabrication, high antenna again and compatibility with mobile terminal equipment where a light and a thin profile may be required [3], [4]. However, most of the existing microstrip antennas have a narrow bandwidth which restricts their applications.

A bowtie antenna is a type of microstrip antenna that continues to be studied by a number of researchers[5]. Radar applications generally require ultra-wideband antennas and bowtie antenna designs promise to facilitate the best performance. There are a number of researchers who have designed bowtie antennas for radar applications [6], [7], [8]. However, most of the proposed antenna structures performed well but were generally large in size. Authors of [9] modified a bowtie antenna for utilization in ground radar penetration systems. Another bowtie antenna dedicated especially for ground radar penetration was proposed by [10].

Numerous research efforts related to the bowtie's antenna compactness, efficiency, increased gain, reduced return loss, directivity, and so on [11] are in progress. Authors of [12] presented a bowtie antenna developed for ultra-wide band respiration radar system application. A microstrip antenna targeted for wireless explosive detection was proposed by [13]. An FR4 substrate was chosen by the authors and simulations were, however, performed using CST software.

One of the major challenges is designing a compact size bowtie antenna exhibiting very wide bandwidth and high gain at the same time. A study conducted by [14] focused on muliti-antenna approaches at different bandwidths. However, the technique was proposed to satisfy the requirements of the Long-Term Evolution (LTE) network. In a recent experiment conducted by [5], it was observed that "smaller substrate thicknesses achieve bandwidth enhancement with lower antenna gain". Therefore, it is essential to optimize antenna parameters to improve antenna performances required for specific applications.

In this research, a modified ultra-wide band microstrip bowtie antenna capable of achieving good gain operating in the ultra-wide, radar frequency range (UHF, S and L bands) with good electrical performance was designed, simulated, constructed and tested. Simulation dimensions of the bowtie antenna were obtained using the "tapered transmission line method algorithm". The antenna dimensions were optimized to enhance antenna performance. The major contributions of this research are as follows:

- A concise and easy to follow step-by-step description of the performed bowtie antenna simulation in Ansys High Frequency Structured Simulator (HFSS) is presented to assist in guiding the research community.
- A fabricated light-weight, portable and low-cost ultra-wide band bowtie microstrip antenna which can be used for radar communication.
- Low profile, wider bandwidth and high gain bowtie microstrip antenna.
- Effect of dielectric thickness of FR4 substrate on return loss over the wide band of operation.
- Three notable frequencies of operation for the fabricated bowtie microstrip antenna.
- The bowtie antenna covers the UHF, L and S band for radar systems.
- Better overall return loss of the fabricated bowtie antenna prototype as compared to the simulation result.

The rest of this paper is structured as follows. The next section outlines the bowtie antenna design procedure. Results and discussions are presented under the section "Results and Discussions".
Finally, the paper is concluded under the section "Conclusion".

2. MATERIAL AND METHODS

In this research, the design and simulation of the proposed bow-tie antenna was performed using the Ansys High Frequency Structure Simulator version 15.0 (HFSS 15). The antenna was then fabricated on a low-cost FR4substrate. The antenna specifications comply with guidelines set by the Federal Communication Commission (FCC).

2.1DESIGN AND SIMULATION OF THE PROPOSED MODIFIED BOWTIE ANTENNA

The 3D Modeler Ansys HFSS 15 was utilized to perform simulations. It uses the familiar "Microsoft Windows graphical user interface integrating visualization, simulation, automation and solid modeling, in a user-friendly environment". The simulation dimensions of the bowtie antenna were obtained using the "tampered transmission line method algorithm" [15], [16] for a lower resonant frequency of 300 MHz. This frequency would ensure the antenna designed is not bulky.

The Ansys HFSS software was launched and a selection of the "HFSS-design" was done. This was indicated by the icon " " for 3D modeling. Fig. 1 shows a 3D Modeler grid workspace in "driven modal" mode that shows up. The antenna dimension units were then set as "mm" by using the menu items "3D Modeler >Units". The menu items "Draw > Box" were selected to construct the substrate in 3D form. The substrate type "FR4" is selected and similarly, substrate dimensions were also set.

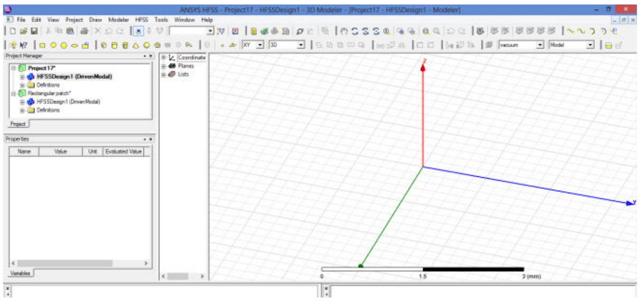

Figure 1: 3D Modeler grid workspace in "driven modal" mode

The dimensions of the bowtie were configured in the same way except that the bowtie was created by selecting a 2D rectangular structure and placed on top of the substrate as presented in Figure 2.

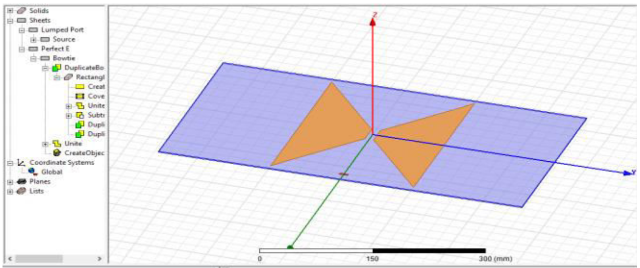

Figure 2: Configuration of bowtie dimensions

From the menu, a yellow rectangle was selected. The coordinates were configured so that the shape sits on top of the substrate. The desired shape adjustment was achieved by selecting the "edit" function along with "cloning, intersecting, unite, duplicate body mirror" functions and so on. The creation of the CPW feed line of the bowtie antenna is shown in Fig.3.

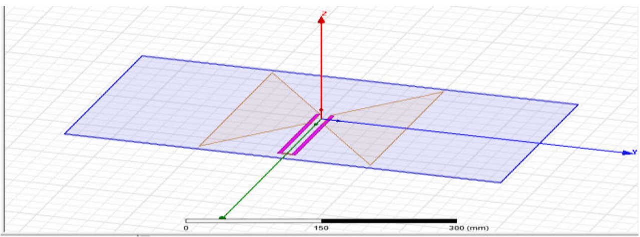

Figure 3:Creation of the CPW feed line of the bow-tie antenna

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Selecting "HFSS>Boundaries>Assign>Perfect conductor" enables the patch to behave like aconductor. Construction of the radiation boundary was also realized by clicking "HFSS>Radiation>Insert far field>Infinity sphere" after having created a wire frame. An "excitation" was also created on the "source port" by clicking"HFSS>Excitation>Assign>lumped port" with an impedance of 50 ohms. An "analysis setup" at a resonant frequency of 1.3 GHz was then created with its frequency sweep from 300 MHz to 4 GHz. This was accomplished by clicking "HFSS>Analysis setup>AddSolution setup>Add sweep".

After completion of a validation, a simulation was performed. The antenna behavior was viewed by clicking "HFSS>Results>Create report from file>" and choosing the desired parameter to observe.

An S11 against frequency plot was utilized for antenna optimization. The substrate thickness was varied to improve the antenna return loss and therefore increase the impedance band width. This was realized by "report tuning" of the S11 against frequency plot.

2.2CONSTRUCTION AND TESTING OF PROTOTYPE

The obtained optimized antenna parameters were used to construct a prototype bowtie antenna. This was done by utilizing an FR4 PCB board which was dipped in an etching solution. A network analyzer was used to test the fabricated prototype.

3. RESULTS AND DISCUSSIONS

3.1 SIMULATION RESULTS OF BOWTIE ANTENNA S11PARAMETER AND IMPEDANCE BANDWIDTH

When an RF signal is fed to an antenna, a part of it will be reflected. The return loss of the antenna indicates the amount of energy reflected by the antenna. The return loss plot for the bowtie antennais shown in Fig. 4.

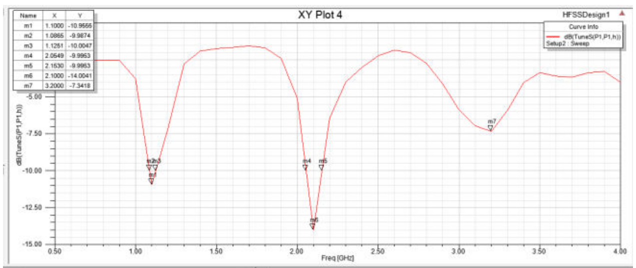

Figure 4: Return loss plot for the proposed bow-tie antenna

The resonant frequency of the first impedance band was 1.1 GHz (at -10.9555 dB) with the impedance bandwidth being 38.6 MHz (1.0865 GHz - 1.1251 GHz) at the -10 dB threshold (which accounts to below 11% loss of the fed RF). The second band had a resonant frequency of 2.1 GHz(at -14.0041 dB) with an impedance bandwidth of 98.1 MHz (2.0549 GHz - 2.153 GHz) below the -10 dB threshold. A poor return loss of -7.3418 dB at 3.2 GHz was obtained in the third band. This value of return loss is undesirable for patch antennas (Naumann, 2018).

3.2 RADIATION PATTERN

The radiation pattern in Fig. 5 is a 2D plot of the **E** and **H** plane of the proposed bowtie antenna. The horizontal plane (**H**-plane, phi = 90̊) is a plane of staring straight down an antenna at the center of the polar plot, 0̊ is the North (directly facing the receiver), 90̊ is the East, 180̊ is the South and270̊ is the West direction. The radial lines each represent 30̊ of the compass giving the direction part of the polar coordinate plane. The elevation plane (**E**-plane, phi = 0̊) is the vertical plane of staring through the field of the antenna. the antenna has two main lobes with peak bandwidth of about 6.5 dB directly ahead and behind.

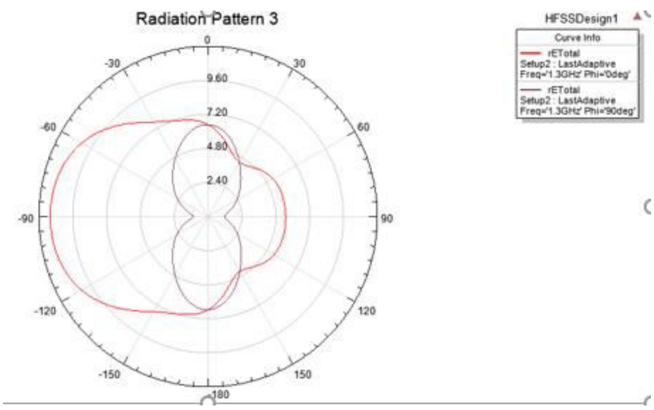

Figure 5: 2D plot of the E and H plane of the proposed bowtie antenna

3.3 SUBSTRATE THICKNESS VARIATION

The dielectric thickness of the FR4 substrate was increased to 1.76 mm and it was observed from the S11 plot that the return loss significantly improves. The comparison plot for the 1.6 mm and1.76 mm substrate thicknessesis shown in Fig.6.

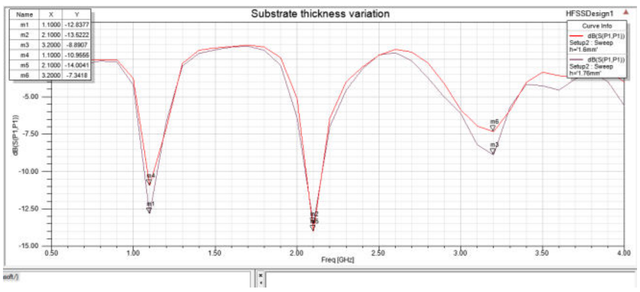

Figure 6: S11plot for the 1.6 mm and 1.76 mm substrate thicknesses

The red plot represents the 1.6 mm thickness and the blue plot represents the 1.76 mm. It is worth noting that there was an improvement in the impedance bandwidth at the 1.1 GHz operation frequency from -10.9555 dB to about -

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12.8677 dB. The next band with an operation frequency of2.1 GHz also had an improved return loss from -13.5552 dB to -14.0041 dB. Although the third band exhibited an improved return loss, the value did not meet the -10 dB threshold for acceptable losses.

3.3 PROTOTYPE OF PROPOSED BOW-TIE ANTENNA

The results of the fabricated antenna were obtained using a Rohde and Schwarz FSH4 spectrum analyzer as shown in Fig. 7. The measured fabricated antenna results in Fig. 8 showed three notable frequencies of operation which were M2 = 1.09 GHz with a return loss of -23.99 dB, M4 = 2.12 GHz with a return loss of -20.37 dB and M5 = 2.96 GHz with a return loss of -16.80 dB.

Figure 7: Measurements using Spectrum Analyzer

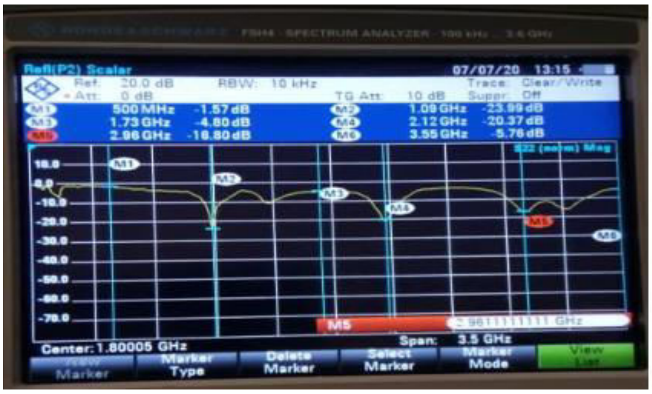

Figure 8: Return loss results of fabricated bowtie antenna

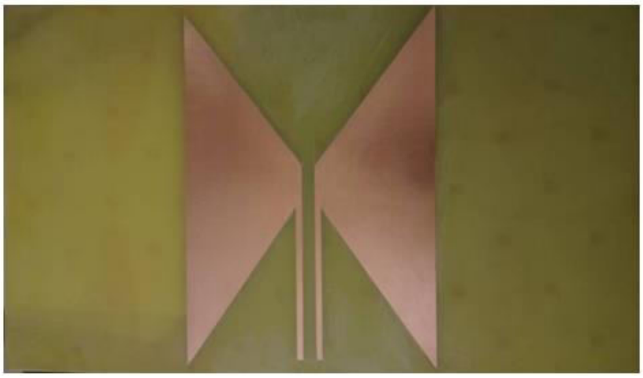

Figure 9: Prototype of proposed bow-tie antenna

The observed impedance bandwidths were wideband at all the three bands below the -10 dB threshold. The complete ultra-wideband bowtie antenna proposed in this work is presented in Fig. 9.

4. Conclusion

A modified ultra-wide band microstrip bowtie antenna capable of achieving good gain operating in the ultra-wide radar frequency range (UH, S and L bands) was fabricated and experimentally tested. The results obtained from the simulation platform were closely related to those measured from the prototype antenna in terms of the resonating frequencies. It was also observed that increasing the dielectric thickness of the FR4 substrate significantly improves the return loss. The prototype produced improved overall return loss as compared to the simulation result. The results obtained indicate that the proposed bowtie microstrip antenna satisfies the bandwidth requirements for the UHF, L and S band for radar communications. Further research can be conducted on the Bowtie antenna like variation in structure e.g. fractals, defective ground structure and meta materials.

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