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A Triple Band Bow Tie Array Antenna Using Both-sided MIC Technology

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ABSTRACT

A single-fed linearly polarized 2x2 microstrip bow tie array antenna is proposed. The feed network has microstrip line and slot line where microstrip-slot branch circuit is connected in parallel. The feed network of the array is designed using both-sided MIC Technology to overcome the impedance matching problem of conventional feed networks. The 2x2 half bow tie array antenna is also truncated with spur lines for optimization of antenna performance. The array antenna unit can be realized in very simple and compact structure, as all the antenna elements and the feeding circuit is arranged on a Teflon glass fiber substrate without requiring any external network. The design frequency of the proposed antenna is 5 to 8 GHz (C-Band) and the obtained peak gain is 12.41 dBi. The resultant axial ratio indicates that linear polarization is achieved.

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1. INTRODUCTION

Antenna is a vital element of radio transmission system. The choice of antennas is based on application constraints such as frequency, gain, cost, coverage, weight etc. Bow tie antennas are well known for their multiband abilities and advantageous characteristics. If an antenna is made using perfect conductors and dielectrics and its dimensions change, the characteristics of that antenna (impedance, polarization, radiation pattern, etc.) will remain the same, as long as the wavelength of operation is changed in the same amount. Therefore, if the shape of an antenna is determined only by angles, the performance of that antenna would be independent of frequency since it would be invariant to a change of scale [1]. Bow tie antenna is a perfect example of frequency independent antenna. And the sole motivation behind choosing this antenna is to incorporate a new communication technology enhanced and efficient for advanced applications.

In this paper, we have designed a 2x2 half bow tie array antenna using both sided-MIC Technology with an aim at optimization and comparative analysis of different designs of structure and feed circuit. The resultant axial ratio indicates that linear polarization is achieved. The design and the basic operation along with the simulation results of the proposed bow tie array antenna are demonstrated in this paper. Possiblity of C-band application using the proposed antenna for satellite communications transmissions, Wi-Fi devices, wireless telecommunication, and weather radar systems are also explored.

2. LITERATURE REVIEW

2.1. Bow Tie Array Antenna

Abri proposed a simple equivalent and accurate transmission line model for bi-band bow tie antennas array design over a band of frequencies for satellite communications. The model used the resistance of a square element that appears at the edges of the antenna (radiating slots) [2]. Didouh et al. used a transmission line model to design corporate-fed multi-layered bow tie antenna arrays; the simulated antennas arrays were designed to resonate at the frequencies 2.4 GHz, 5GHz, and 8GHz corresponding to RFID, Wi-Fi, and radars applications [3]. Liu et al. presented a novel frequency reconfigurable bow tie antenna array for Bluetooth, worldwide interoperability for microwave access (WiMAX) and wireless local area network (WLAN) applications [4]. Boursianis et al. presented the design procedure of a wideband UHF RFID reader antenna with polarization diversity suitable for searching tagged items.

The antenna consisted of a microstrip array with alternating orthogonal bow tie elements, which are fed in series by a pair of microstrip lines [5]. Cyr et al. carried out a simulation project incorporating 4 sets of bowtie elements into an array [6]. Guesmi et al. proposed fractal bow tie antennas for designing RFID reader resonating at 2.45 GHz [7]. Mehadji et al. proposed design of printed bow tie antennas antennas for wireless networks and the optimized antennas were to be integrated on laptops [8]. Otman et al. presented a miniature microstrip antenna with 2GHz bandwidth for a reflection coefficient under -10dB and centered on the ISM band at 5.8 GHz [9]. Hossain et al. presented a circularly polarized microstrip array antenna using dual orthogonal feed technique [10]. The relation between antenna dimensions and characteristics were also investigated in this study with parametric analysis of the antenna. Alvina et al. experimentally evaluated a rectenna employing a bow tie antenna. Parametric studies of a bow tie antenna were conducted by using electromagnetic simulation and two types of bow tie rectennas were fabricated based on the antenna design for 5.8 GHz [11].

2.2. Both Sided MIC Technology

A Microwave Integrated Circuit (MIC) is a special group of highly integrated analog circuits, designed for operation at frequencies of approximately 1 gigahertz (GHz) or more. In this frequency range, the various circuit functions that were usually implemented in the past using bulky metal waveguides and coaxial lines, can now be implemented using printed microstrip lines or other forms of planar transmission lines. Such components are physically small, in some cases having less than one square millimeter (1 mm^2) of surface area. Advantages of MICs include excellent circuit functions and greater design flexibility [12].

MIC Technology enables all the optical and electrical functions to be performed on a single chip technology. It offers potential for low cost manufacture, as well as reduction of parasitic effects associated with packaging and interconnects. It also ensures uniformity of the device. Both-Sided MIC Technology is composed of microstrip lines and slot lines. This type of array antenna needs no impedance matching circuits and have very simple circuit configuration, which are mainly due to the excellent performances of both the microstrip-slot parallel branch circuit and the slot-microstrip series branch circuit [13].

The use of both-sided MIC Technology for antenna optimization is a completely new technology and has immense potential to improve antenna performance. Hossain et al. designed circular polarization switchable microstrip array antenna using magic-T bias circuit using both-sided MIC Technology [14]. Rahman et al. also designed a planar array antenna using both-sided MIC [15]. Rahman et al. designed a circularly polarized array antenna with inclined patches using both-sided MIC [16]. However, to the best of authors' knowledge, none of the researchers have incorporated both-sided MIC Technology for the optimization of bow tie array antennas till date, which is the prime focus of this paper.

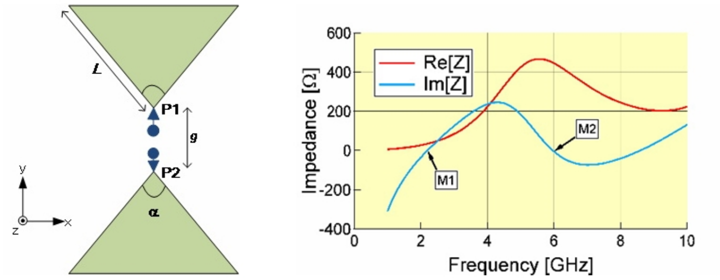
3. DESIGN AND LAYOUT

3.1. Characteristics of a Typical Bow Tie Antenna

A bow tie antenna is a theoretically frequency independent antenna, i.e., a wideband antenna. In case of half-wavelength dipole antenna, the antenna design is specified by the length of the antenna elements. The length must be equal to a half wavelength at the frequency of interest. When a bow tie antenna with infinitely long elements is considered, it is specified solely by the angle of two metal pieces. In this case, wavelength never comes into the equation. Consequently, bow tie antenna has an infinite bandwidth theoretically; if it works in one frequency, it must be working in all frequencies.

Figure 1(a) shows a schematic structure of a typical bow tie antenna. Two triangle antenna elements are placed vis-à-vis on a substrate. A feed point is between the antenna elements. This Figure also shows dimensional parameters of the antenna. □ and L are the vertex angle and length of the triangle elements, respectively. g is the gap width between the two antenna elements.

Figure 1(b) shows a typical antenna impedance of a bow-tie antenna. Red and blue shows the real and imaginary parts respectively. Here M1 is the first resonant frequency and M2 is the second resonant frequency. The bow-tie antennas are usually used in the first resonant frequency. But as antenna real impedance is high at second resonant frequency so it can be also considered.

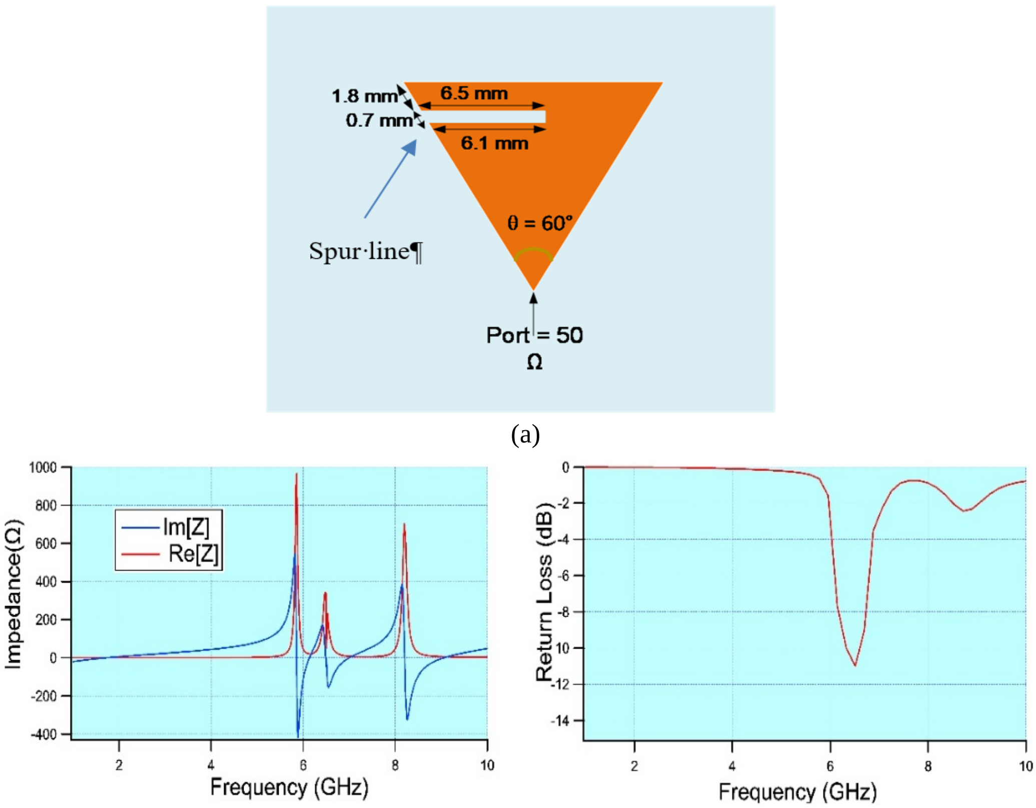


(a) (b)

Figure 1. (a) Structure of a typical Bow Tie Antenna (b) typical antenna impedance of a Bow Tie Antenna

3.2. Design of a Single Bow Tie Antenna

The geometry of a single bow tie element is proposed and shown in Figure 2(a). From the impedance graph shown in Figure 2(b), the second and third resonant frequencies were checked to select the antenna impedance (100 ohm). The data of S(1,1) parameter in Figure 2(c) provides the return loss less than -10 dB, which indicates good performance of the proposed single bow tie element. The frequency of single bow tie antenna is obtained around 6.5 GHz. The same bow tie element has been used in a 2x2 half bow tie array.



(b) (c)

Figure. 2 (a) Geometry of a half Bow Tie Element (b) Antenna impedance for half Bow Tie Element (c) Return loss of the half Bow Tie element

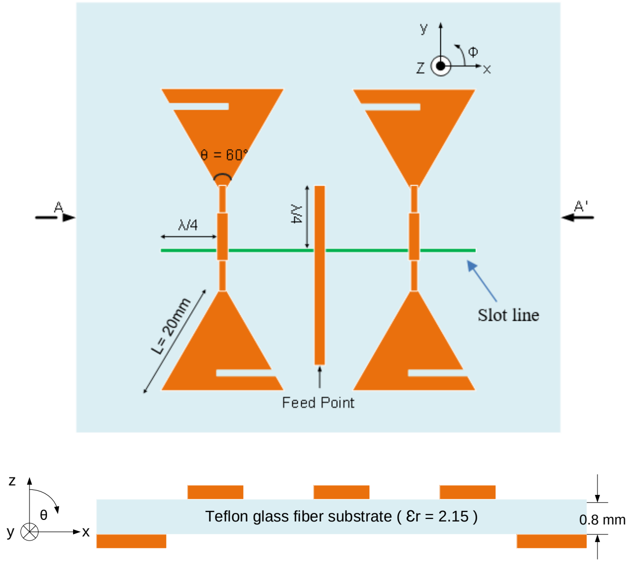


Figure 3. (a) Layout of the proposed 2x2 Bow Tie Array Antenna (Top View) (b) Cross Sectional View (AA')

3.3. Design of Proposed Bow Tie Array Antenna Using MIC Technology

To design the bow tie array antenna, the antenna impedance for several dimensions were simulated using ADS (Advanced Design System) Momentum of Keysight Technologies. The target design frequency is 6.5 GHz. The complete layout of the proposed bow tie array antenna is shown in Figure 3(a). And the cross-sectional view is shown in Figure 3(b). The considered design parameters are shown in Table 1. In substrate layer, Teflon with a thickness of 0.8 mm and relative dielectric constant of 2.15 is used to design the proposed antenna. Copper is used as the conductor metal and the thickness is 18 µm. The impedance of the microstrip line in the design is 50 ohms (2.42 mm) and $\lambda/4$ is 8.472 mm. The impedance of the slot line in the design is 100 ohms (0.19 mm) and $\lambda/4$ is 9.953 mm. To incorporate MIC Technology as there is ground plane, so the designed antenna is considerably microstrip half bow tie element.

Table 1. Considered Values of the Design Parameter

Design Parameters	Values
Dielectric Constant	2.15
Thickness of Conductor (copper)	18 µm
Thickness of Substrate	0.8 mm
Tanδ	0.001
Port Impedance	50 Ω

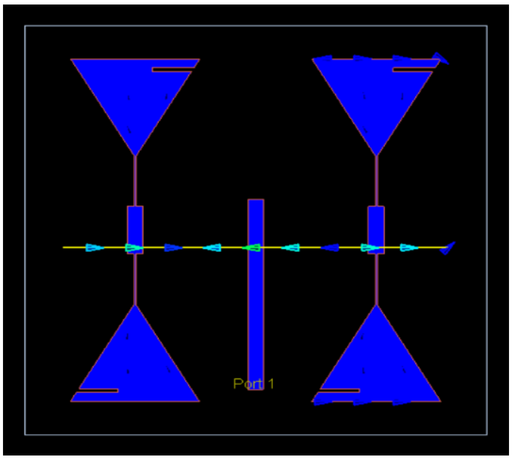


Figure 4. Current Distribution through the proposed layout

Embedding a pair of spur lines in the bow tie antenna, a new resonant mode with a lower resonant frequency than that of the fundamental mode can be excited. Due to the presence of the spur lines, the excited bow tie surface current path is lengthened and thus the resonant frequency of the bow tie element is lowered. Due to the existence of truncated corner with spur lines, the size of radiating bow tie elements can be reduced considerably. In the layout, width of microstrip line and slot line are 2.4 mm and 0.19 mm respectively. The impedance of microstrip line and slot line in the layout are 50 ohm and 100 ohm respectively. For proper matching between microstrip line and slot line, 350 ohm quarter-wavelength transmission line is used as impedance transformer with a width of 0.34 mm and $\lambda/4$ of 8.905 mm. The impedance transformer was evaluated from the equation (1):

$$Z_1 = \sqrt{Z_0 Z\_ant} \tag{1}$$

Where Z_0 and Z_ant is the characteristic impedance of the microstrip line and single bow tie antenna respectively. The feeding part consists of microstrip-slot branch circuit which is connected in parallel. Thus, the feeding structure has the effect of multiple feed but without complicated feeding network. To design this type of feed network Both-sided MIC Technology is very useful. Figure 4 shows the distribution of current through the proposed layout.

4. RESULTS AND DISCUSSIONS

In the simulated results of S (1,1), the data are evaluated for the feed network near the optimized value. The data of S (1,1) parameter from Figure 5 indicates the excellent performance of the proposed antenna. It is observed that the return losses are far below than -10 dB. The maximum obtained antenna gain is about 12.41 dBi.

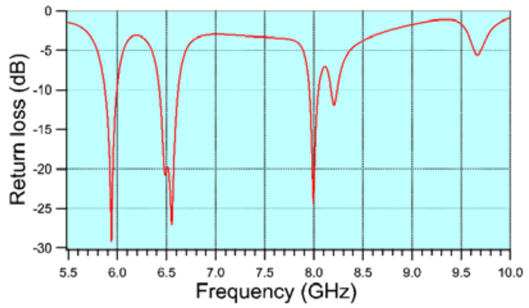


Figure 5. Performance of S (1,1) parameter for proposed layout of Bow Tie Array Antenna

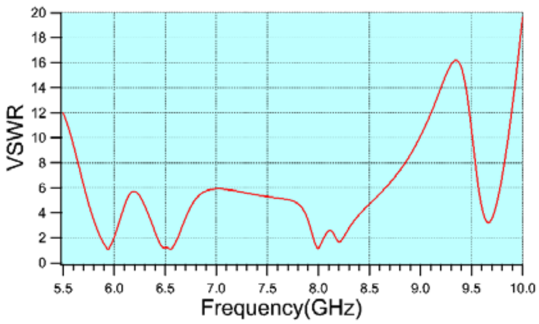


Figure 6. VSWR Graph for proposed layout

The smaller the VSWR is, the better the antenna is matched to the transmission line and the more power is delivered to the antenna. The VSWR graph for the proposed antenna layout Figure 6 shows values less than 2 for the three operating frequencies. The simulation radiation patterns (2D view) for the maximum gain frequency are shown in Figure 7 and 8.

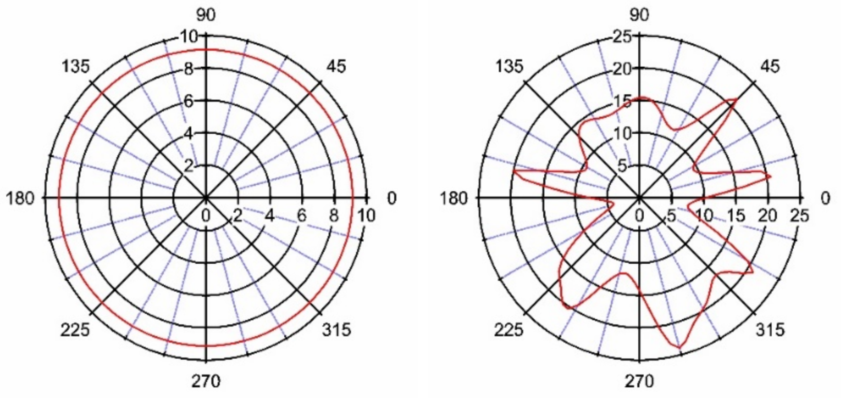


Figure 7. Radiation pattern for Theta=0 (left) and Theta=90 (right) for frequency 6.5 GHz

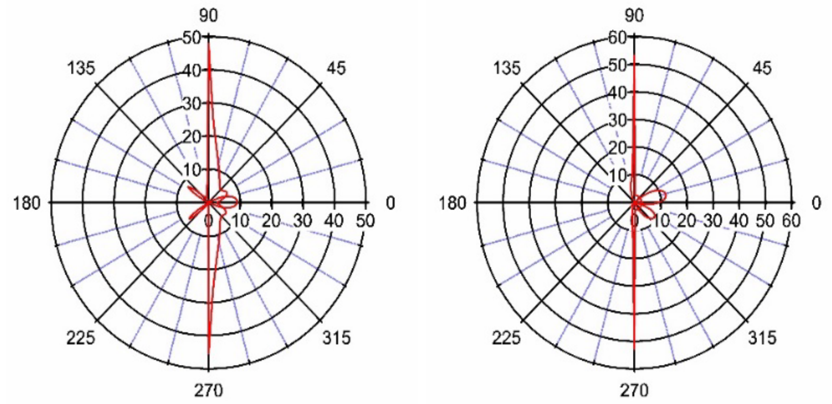


Figure 8. Radiation pattern for Phi=0 (left) and Phi=90 (right) for frequency 6.5 GHz

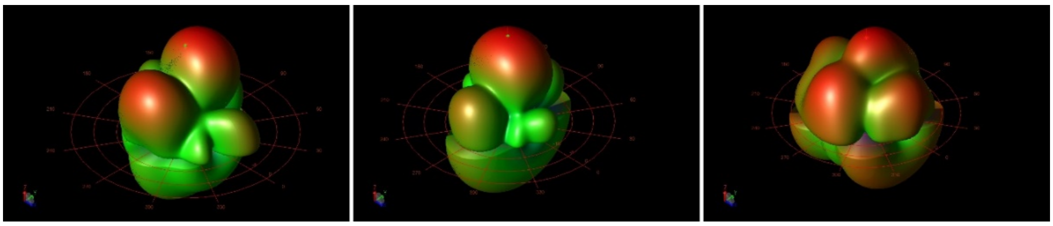


Figure 9. 3D view of the radiation pattern (f=5.8 GHz, 6.5 GHz, 8 GHz) of Bow Tie Array Antenna

Table 2. Summary Table for Proposed Antenna Parameters

Frequency	Gain (dBi)	Directivity (dBi)	Radiated Power (Watts)
5.8 GHz	11.91	12.88	0.0019
6.5 GHz	12.4122	12.85	0.0022
8 GHz	7.8471	8.81	0.0018

The 3D view of the radiation patterns for the three maximum gain frequencies (f=5.8 GHz, 6.5 GHz, 8 GHz) are shown in Figure 9. The operating frequencies, Gain, Directivity and Radiated Power of simulated bow tie array antenna are reported in Table 2. A comparative analysis is carried out to study the performance of the designed antenna with that of the antennas designed in established literatures in Table 3. The table presents a summary of the findings from the comparison, combining microstrip and bow tie array antennas with and without the incorporation of both sided MIC Technology.

Table 3. Summary Table of Antennas with and without Both Sided MIC

Literature	Antenna Configuration	Type of Antenna	MIC Technology	Frequency	Gain	Substrate
Cyr, 2011 [6]	2 × 2 bow tie array antenna	2x2 bow tie microstrip array antenna	No	2.4 GHz	3 dBi	Woven Fiber Glass (1.6 mm)
Hossain et al., 2014 [14]	2 x 2 circularly polarized switchable array antenna	2x2 microstrip antenna	Yes	3.8 GHz	6.24 dBi	Teflon Glass (0.8 mm)
Rahman et al., 2017 [16]	2 × 2 circularly polarized array antenna with inclined patches	2x2 microstrip antenna	Yes	9.86-10.23 GHz	6.36 dBi	Teflon Glass (0.8 mm)
Proposed Structure	2 × 2 bow tie array antenna	2x2 bow tie microstrip array antenna	Yes	5 to 8 GHz	12.41dBi	Teflon Glass (0.8 mm)

5. CONCLUSION

The design of a 2x2 linearly polarized half bow tie array antenna with truncated spur lines has been designed. The incorporation of both sided MIC Technology to overcome impedance matching problems of feed circuits has enhanced the antenna performance. The peak antenna gain across the overall operating band is measured to be 12.46 dBi at 6.55 GHz, which is noteworthy improvement over previously designed antennas under similar constraints. The same antenna is able to operate at three different frequencies: 5.8 GHz, 6.55 GHz and 8.0 GHz. The major advantage of the single-feed, bow tie array antennas is their simple structure, which does not require an external polarizer. Therefore, they can be realized more compactly by using less board space than dual-feed linearly or circularly polarized microstrip antennas. The simple and compact structure makes the proposed antenna exclusively suitable for large scale extensible array antennas.

Since the frequency range of the proposed antennas falls within the spectrum of IEEE C-Band, its implementation in satellite communication can be a potential field of future research. The C-band is primarily used for open satellite communications, whether for full-time satellite television networks or raw satellite feeds. Since overloading of the C-band due to terrestrial microwave links led to the development of Ku-band, optimization of the proposed antenna for Ku-band can be researched. The use of MIC Technology was found to further improve the overall antenna performance. In this study, the bow ties were truncated with spur lines. Reconfiguration of the proposed antenna using different truncation methods, such as square ring, triangular ring, cross strip, circular slot etc. can be explored to further improve the antenna performance and investigate its extensive applications in wireless communication technologies.

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