Wideband Bow-Tie Slot Antennas with Tapered Tuning Stubs

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Abstract: For the purpose of wideband operations, a bow-tie slot antenna fed by a coplanar waveguide (CPW) is investigated. The design was realized using a tapered metal stub introduced in the middle of the bow-tie slot. The modified structure shows wider bandwidth over the conventional bow-tie slot antenna. Parametric study of this new antenna results in a design procedure that helps design this class of antennas for different frequency bands with wideband characteristics. Two designs of this antenna, working at the X-band centered at 10 GHz and the R-band centered at 2.15 GHz, are fabricated and the measured return losses are presented. The measured bandwidth is 88% at the X-band and 66% at the R-band, with a 50 Ω input impedance.

Keywords: Wideband, Bow-Tie, Slot antennas, Coplanar waveguide.

1. Introduction

In applications where size, weight, cost, performance, ease of installation, and aerodynamic profile are constrains, low profile antennas like microstrip and printed slot antennas are required. Because microstrip antennas inherently have narrow bandwidths (BW) and, in general, are half-wavelength structures operating at the fundamental resonant mode [1], researchers have made efforts to overcome the problem of narrow BW, and various configurations have been presented to extend the BW [2-6], for example, by introducing slots in a microstrip patch configuration. On the other hand, printed slot antennas fed by coplanar waveguide (CPW) have several advantages over microstrip patch antennas. Slot antennas exhibit wider BW, lower dispersion and lower radiation loss than microstrip antennas, and CPW also provides an easy means of parallel and series connection with active and passive elements that are required for matching and gain improvement, and ease of integration with monolithic microwave integrated circuits (MMIC) [7].

Bow-tie and bow-tie slot antennas are planar-type variations of the biconical antenna that has wideband characteristics. A number of bow-tie slot designs are introduced in [8-13], which demonstrate wide BW that range from 17% to 40%. In this paper, a modified version of the bow-tie slot antenna introduced in [12] for 3 to 5 GHz applications with maximum BW equals to 40% is used as a basis for our a new design for X-band operation. We introduced the tapering to the metal stubs at the center of the bow-tie slot antenna to provide better control of the impedance BW. Furthermore, we investigate the effects of the non-uniform stub parameters to enhance the design of these antennas for several frequency band applications. Our parametric study of this antenna yields a design procedure and six designs at different operating frequency bands are introduced to verify that procedure. Measurement results are conducted to verify this design procedure. The related simulation and analysis for these antennas are performed using the commercial computer software package, Momentum of Agilent Technologies’ Advanced Design System (ADS), which is based on the method of moment (MoM) technique for layered
structures. The ADS simulator, Momentum, is used to solve mixed potential integral equations (MPIE) using full wave Green’s functions [14]. Verification of the ADS results is further performed by using our developed finite difference time domain (FDTD) code.

2. Antenna Geometry

The proposed antenna is similar to the structure introduced in [12]; however, our design exhibits a non-uniform metal stub for bandwidth enhancement purposes at X-band operations. Figure 1 shows the conventional bow-tie slot antenna in (a), the conventional bow-tie slot with metal stub [12] in (b) and the modified Bow-tie slot with tapered metal stubs in (c). The parameters of the proposed geometry are shown in Fig. 2 through 3D and x-y plane views, where $W_1$ and $L_1$ represent the outer width and height of the bow-tie slot, respectively, $W_2$ is the width of the stub, $L_2$ and $L_3$ are the outer and inner heights of the metal stub and $L_4$ is the inner slot height. Contrary to the design presented in [12], our design is based on a 50% thinner substrate with a 30-mil thickness and a dielectric constant of 3.2 relative to 10.1 as reported in [12]. This in turn reduces losses and dispersion. In this study, a CPW feedline with a 2.9 mm line width and a 0.15 mm slot width is used in order to obtain a 50 $\Omega$ characteristic impedance.

![Diagram of antenna configurations](image)

Fig. 1. (a) Conventional bow-tie slot, (b) conventional bow-tie slot with stub [12], and modified bow-tie slot with tapered stub.

![3D diagram of antenna structure](image)

Fig. 2. The geometry of the proposed antenna.

To understand the effect of adding the tuning stub, an initial design of the proposed geometry has $W_1$, $W_2$, $L_1$, $L_2$, $L_3$, $L_4 = 17$, 14.1, 11.62, 0.875, 1.875, 2.68 mm, respectively, that is simulated with and without tuning stub. The input impedance of these two cases is shown in Fig. 3. It can be noticed that adding the stub increases the input resistance, which results in better matching. Moreover, it shifts the main resonance to a lower frequency because it increases the total length of the slot, where the magnetic current flows. On the other hand, it creates a new resonance at a higher frequency. Many parameters
contribute to these two resonances; however, the main contribution seems to be mainly affected by the choice of W1 and W2. When W2 is not much smaller than W1, the two resonant frequencies, $f_L$ and $f_H$, become close to each other, which gives this design the potentiality of wideband operation. If the return loss levels at the frequencies in-between $f_L$ and $f_H$ are less than −10dB, the antenna will have a wide BW, which can be achieved by a proper selection of the antenna parameters. Thus, the knowledge about the effect of each parameter on the return loss is of great value for determination of a required design.

To confirm the results produced by ADS Momentum, an internally developed FDTD code was used to simulate a bow-tie slot antenna with W1, W2, L1, L2, L3, L4 = 19, 14.2, 11.36, 1.76, 1.76 and 2.72 mm, respectively, with a CPW feedline of 3 mm line width and a 0.16 mm slot width on a substrate of $\varepsilon_r = 3.2$ and height = 30 mils. The symmetry of the geometry is utilized to perform the numerical simulation on half of the domain. The convolutional perfect matched layer (CPML) [15, 16] is used to truncate the geometry in all directions except in the negative x-direction, where the symmetry plane is defined. Figure 4 shows a comparison between the results of ADS Momentum and FDTD simulations, where good agreement is observed, which validates the results of ADS Momentum and the developed procedure for this parametric study.

3. Design Procedure

To develop a design technique, a parametric study has been performed on this antenna using ADS simulation results. The conclusion of this parametric study is given in Tables 1 and 2. Table 1 shows our assessment of the proper initial values of each parameter with respect to $\lambda_L$ and $\lambda_H$. Using this table, an initial guess of the value of each parameter can be assigned when $f_L$ and $f_H$ are defined. Table 1 shows the effect of increasing each parameter on $f_L$, $f_H$, and the BW when the parameter values are around the values selected based on Table 2. Using the data in Table V, one can modify the initial design for BW and return loss level enhancement.
Table 1. The design parameters of a bow-tie antenna with a tapered stub with respect to $\lambda_0$ at $f_L$ or $f_H$, where $\lambda_L$ and $\lambda_H$ are $\lambda_0$ at $f_L$ and $f_H$, respectively.

<table>
<thead>
<tr>
<th></th>
<th>$W_1$</th>
<th>$L_1$</th>
<th>$L_2$</th>
<th>$L_3$</th>
<th>$L_4$</th>
<th>$W_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>0.77$\lambda_H$</td>
<td>0.33$\lambda_L$</td>
<td>0.03$\lambda_L$</td>
<td></td>
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<tr>
<td>L2</td>
<td>0.09$\lambda_H$</td>
<td>0.10$\lambda_H$</td>
<td>0.40$\lambda_L$</td>
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</table>

Table 2. The effects of increasing each parameter on $f_L$, $f_H$ and BW, where “I” and “D” mean an increase and decrease in the parameter value, respectively.

<table>
<thead>
<tr>
<th></th>
<th>$f_L$</th>
<th>$f_H$</th>
<th>BW</th>
</tr>
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<tbody>
<tr>
<td>L1</td>
<td>I</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>L2</td>
<td>D</td>
<td>-</td>
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<tr>
<td>L3</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>L4</td>
<td>-</td>
<td>-</td>
<td>D</td>
</tr>
<tr>
<td>W2</td>
<td>D</td>
<td>I</td>
<td>I</td>
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The outcome of this study became even more valuable as it became suitable for designing this type of antenna for different frequency bands. As an example, an antenna is designed to operate at 1.75 and 2.45 GHz for personal communications and wireless local area networks (WLAN). For this case, $f_L = 1.75$ GHz and $f_H = 2.45$ GHz. Using Table I, we construct an initial design of $W_1 = 0.77 \lambda/H = 94.286$, $L_1 = 0.33 \lambda_L = 56.57$, $L_2 = 0.03 \lambda_L = 5.14$, $L_3 = 0.09 \lambda_H = 11.02$, $L_4 = 0.1 \lambda_H = 12.25$, and $W_2 = 0.4 \lambda_L = 68.57$ mm, with a CPW of a 3 mm feedline width and a 0.16 mm slot width on a substrate of $\varepsilon_r = 3.2$ and thickness = 30 mils. Using Table 2, slight changes in the initial design is performed to improve the return loss and the BW. The modified design has $W_1$, $W_2$, $L_1$, $L_2$, $L_3$, $L_4 = 94.25$, 66.5, 61.4, 5.14, 10.58, and 12.25 mm, respectively. Figure 5 shows the simulated return loss of the initial and modified designs. The initial design is operating from 1.67 to 2.9 GHz, which covers the entire operating frequency band of interest, while the resonances for the modified design are more close to $f_L$ and $f_H$. The modified designed antenna has two main resonances at 1.75 and 2.445 GHz, approximately the same as specified in the design goals. The final designed antenna operates from 1.62 to 2.81 GHz with BW = 54% relative to 2.2 GHz center frequency.

![Simulated return loss of initial and modified designs](image1)

Fig. 5. Bow-tie slot with stub for 1.75 and 2.45 GHz.

To verify the above study in a different frequency band, another antenna is designed for Ku band operation with $f_L$ and $f_H$ are proposed to be 12 and 18 GHz, respectively, to let the antenna cover the entire Ku band. The initial design using Table I suggested that $W_1$, $W_2$, $L_1$, $L_2$, $L_3$, $L_4 = 12.83$, 10, 8.25, 0.75, 1.5 and 1.67 mm, respectively, and the tuned design makes $W_1$, $W_2$, $L_1$, $L_2$, $L_3$, $L_4 = 13.08$, 9.8, 8.25, 0.75, 1.5, and 1.67 mm, respectively.
8.25, 0.65, 1.58 and 1.67 mm, respectively, with a CPW of a 1.53 mm feedline width and a 0.1 mm slot width on a substrate of $\varepsilon_r = 3.2$ and thickness = 30 mils. The simulated return losses of these two designs are shown in Fig. 6. The initial design exhibits wide BW from 10.7 to 21 GHz, while the modified design is closer to $f_L$. The modified design has two main resonances at 11.6 and 17.7 GHz, which are close to the required design values of $f_L$ and $f_H$, with an operating band from 11.1 to 21 GHz and BW = 57.5% relative to 15.5 GHz center frequency. These two examples at two different frequency bands beside the original examples at the X-band validate the design procedure presented here.

4. Measurements

Two antennas of dimensions (W1, W2, L1, L2, L3, L4) = (18.85, 14.1, 11.62, 0.875, 2.2, 2.68 mm) and (94.25, 66.5, 61.4, 5.14, 10.58, 12.25 mm) proposed for X and R frequency bands are fabricated and measured using the HP 8510C vector network analyzer (VNA). The fabricated antennas have finite ground plane truncated at 1.8 cm and 5 cm away from the bow-tie slot edge for the X-band and R-band antennas, respectively. The return loss of these two antennas is shown in Fig. 7 and 8. As shown in these two figures, there is a very good agreement between the measurements and simulation results. However, the difference between the measured and the computed return loss is a result of the physical difference between the fabricated and simulated antennas, as ADS Momentum package assumes an infinite substrate even with finite ground plane, which is not the case with the fabricated antennas. The antenna at the X-band has an operating range from 8 GHz to 16.8 GHz, achieves 88% bandwidth relative to the X-band center frequency. The second antenna operating at the R-band operates from 1.61 GHz to 3.04 GHz with a 66.5% bandwidth relative to the center frequency of the R-band.

5. Conclusions

A bow-tie slot antenna with symmetrical non-uniform width metal stubs has been introduced for wideband operations with wide bandwidth characteristics. A design procedure has been devised and used
to design antennas for different frequency bands of operation. This new design procedure shows great promise in controlling the BW while keeping the antenna gain in the same order for the entire band of operation [13]. BW improvement from 40% to 88% relative to a center frequency of 10 GHz with a gain of approximately 6.7 dB for one of the presented designs is shown to be feasible by tuning the antenna parameters. The measurement results confirm the validity of the designed antennas for wideband operation. Further study is currently in progress for one and two dimensional array configurations of this type of single antenna element for applications in different frequency bands.

References