Tuning a Bowtie Slot Antenna with an Equation Based Curve for 900 and 2400 MHz ISM Bands

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***Abstract*—A dual-band bowtie slot antenna is proposed and designed for the 900 and 2400 MHz ISM bands. Using Rogers 4003C substrate ($\epsilon_r = 3.55$) with a thickness of 1.6 mm, the antenna is produced and tested. A comparison is made between measured and simulated data from both a Method of Moments and Finite-Element method software packages. By using a parabolic curve to form the sides of the bowtie slot, the new antenna integrates features from a Vivaldi antenna into its design. Using these features, the antenna achieves dual-band operation while maintaining an omni-directional pattern similar to a normal bowtie slot. The parabolic sides of this bowtie slot antenna offers an additional design element for other CPW fed slot antenna designs.**

I. Introduction

Printed planar antennas today present an attractive option for wireless applications. Using low cost equipment such as a rapid-prototyping machine, a person can create unique designs satisfying specific and demanding needs. A properly designed planar slot antenna, such as a bowtie slot, provide stellar efficiency while exhibiting an omni-directional pattern. Using a coplanar waveguide (CPW) furthers the planar slot antenna's functionality since it does not require a balun. Also, a CPW eases the matching process by allowing simple placement of components in either a shunt or series fashion. Inherent to the slot antenna geometry is the ability to tune the antenna structurally with stubs, patches, resonant structures or other suitable devices [1].

A. The Bowtie Slot Antenna

The bowtie slot antenna, as outlined in [2], demonstrates the characteristics of a CPW fed slot antenna. The bowtie slot antenna used in [2] achieved a bandwidth of 40% between 3 and 5 GHz. It accomplished this by using centrally located tuning stubs, varying their width and height accordingly. The antenna design presented in [1] expanded on the design in [2] by lowering the frequencies of operation to between 1.8 and 2.4 GHz. This modified design obtained a bandwidth of 55%. The overall design of the antenna in [1] differed little from that of the design in [2] except for enlargements in dimensions to obtain a lower operating frequency.

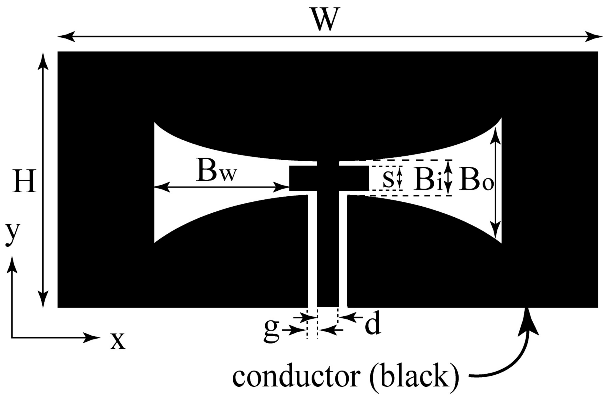

Fig. 1. Bowtie Slot Antenna with the following dimensions: H=140 mm, W=240 mm, Bw=100.2 mm, Bi=8 mm, Bo=70.3 mm, g=0.4 mm, d=4.6 mm, S=7.5 mm.

II. Design of the Bowtie Slot Antenna

A traditional Vivaldi antenna is a traveling-wave antenna. When used in a planar configuration, it takes the form of a tapered slot, where the minimum and maximum distances between the slot edges correspond to its operating frequency range [3]. While normally used in an end-fire configuration with high-directivity, a Vivaldi antenna's broad-bandwidth characteristics prove desirable in many designs [4]. To improve the bowtie slot antenna, we replaced the straight sides of the slot presented in [2] with a parabolic curve. Using this modified bowtie slot antenna, we determined its ability to tune to the 900 and 2400 MHz ISM bands. Figs. 1 and 2 display the results of integrating a Vivaldi style design into a bowtie slot. Fig. 1 also displays the dimensions used in the manufactured antenna. The CPW's dimensions in Fig. 1 optimize the antenna for a 50Ω source load. To accomplish this, the transmission line width d is 4.6 mm and the gap g is 0.4 mm. We determined these parameters using a passive circuit design utility [7].

In designing the antenna, the width of the slot Bw determines the operating frequency. The overall height of the antenna, H, greatly affects both resonant points in a complementary manner. With this design, increasing the tuning stub

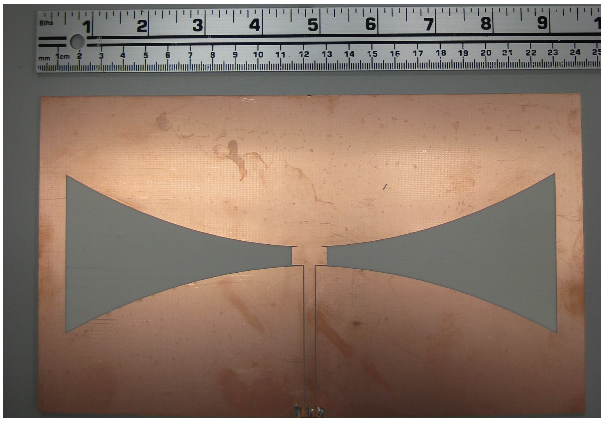

Fig. 2. Bowtie Slot Antenna manufactured on Rogers 4003C substrate.

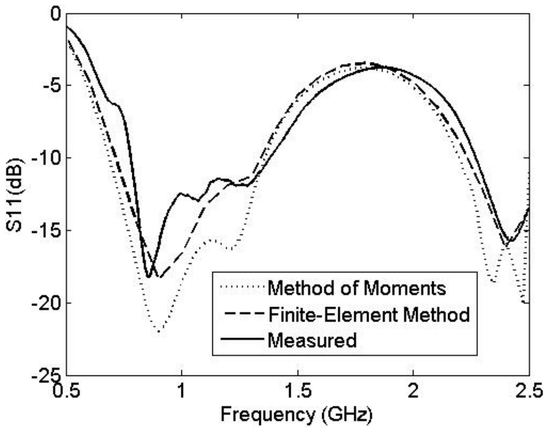

Fig. 3. Simulated and measured S11.

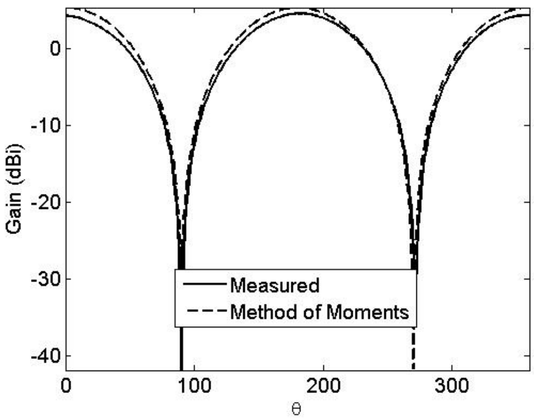

Fig. 4. Simulated and measured gain in the y-z plane at 900 MHz.

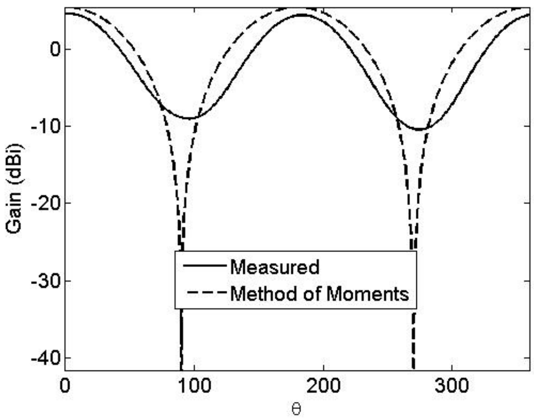

Fig. 5. Simulated and measured gain in the x-z plane at 900 MHz.

length ($Bw - \frac{d}{2}$ in Fig.1) resulted in a higher frequency and return loss for the upper resonance while lowering the return loss of the lower resonance. $Ax^2 + Bx + C$ describes the sides of the slot where C is half of the inner height of the bowtie slot, Bi, and the origin is centered in the middle of the antenna. Increasing A shifts the upper resonance slightly higher while greatly increasing its return loss. For the antenna produced, we used the following values: A=400, B=50, C=4.

III. Measurement and Simulation Results

We simulated the antenna design using both the Method of Moments and Finite-Element methods [5] - [6]. Both simulations assumed 1.4 mm Rogers 4003C substrate (ϵ_r=3.55) due to a 0.2 mm reduction in thickness during manufacturing. In both simulations, a finite conductor was taken into account with a thickness of 35μm. We present both measured and simulated S-parameter results from both Method of Moments and Finite-Element methods. We also present measured and simulated results from only the Method of Moments for the gain. The simulated results for the field patterns also result from Method of Moments. The Finite-Element method simulation data provides the surface current plots [5] - [6].

A. S-Parameters

Fig. 3 displays the simulation and measurement results for S11. From the plot, dual-band operation at 900 and 2400 MHz is evident. Simulated and measured results correlate well with differences resulting from simulation methods and manufacturing tolerances. At the 900 MHz band, the bandwidth of the antenna is 602 MHz (Return loss $>$ 10 dB). At 2400 MHz, the bandwidth is 229 MHz. This antenna design offers improved return loss at lower frequencies when compared to the original bowtie design in [2].

B. Gain

Figs. 4-7 display the gain plots at 900 and 2400 MHz in both the y-z and x-z planes. In Figs. 5 and 7 the measured nulls are not as pronounced as those produced by simulation. Ideal assumptions in the simulation software offers an explanation, as well as measurement errors caused by reflections and cable losses in the anechoic chamber. The measured results in Fig. 6 display an attenuated gain between 180 and 360 degrees. This is when the antenna was pointing away from the measurement antenna in the anechoic chamber. The affect of the dielectric

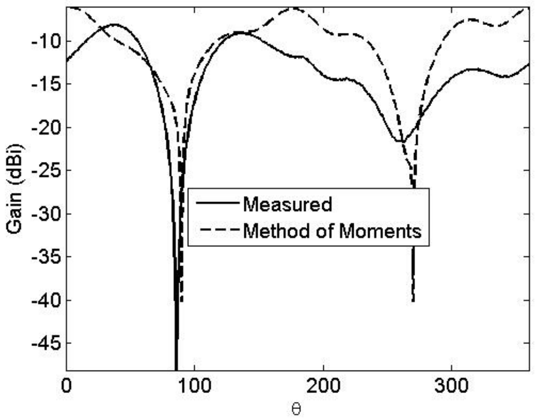

Fig. 6. Simulated and measured gain in the y-z plane at 2400 MHz.

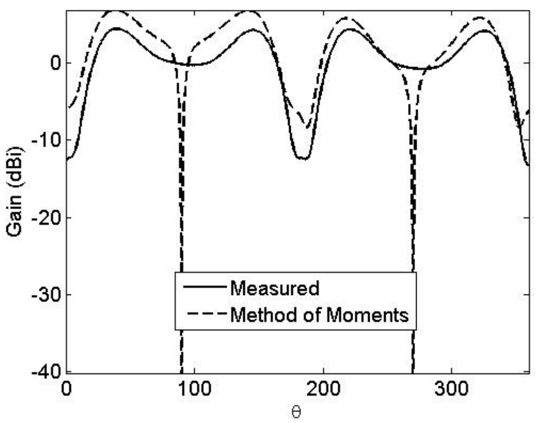

Fig. 7. Simulated and measured gain in the x-z plane at 2400 MHz.

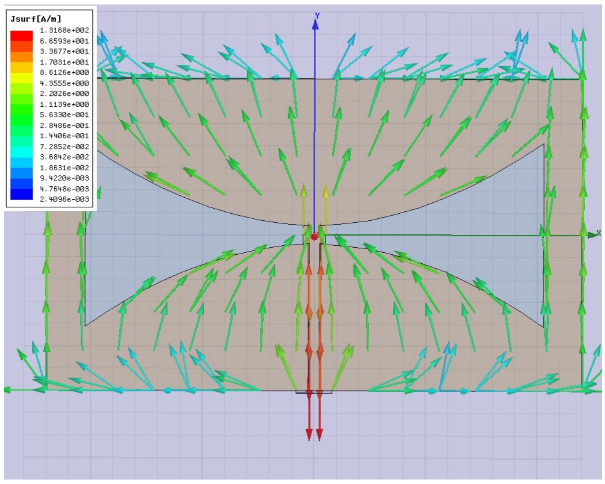

Fig. 8. Finite-Element method simulated surface currents at 900 MHz.

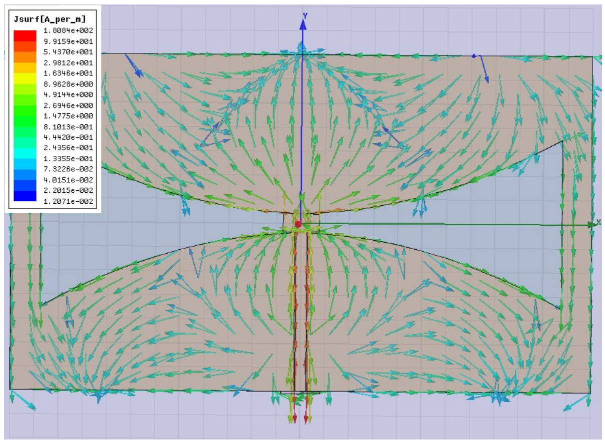

Fig. 9. Finite-Element method simulated surface currents at 2400 MHz.

shielding the antenna as well as test cable radiation possibly explains this deviance.

C. Surface Currents

Fig. 8 displays the surface currents at 900 MHz. Observing the plot, the currents follow the parabolic curve of the bowtie slot. This curved path is longer than a straight path as presented in [1] and [2]. This results in an antenna whose size is decreased since the currents see a longer path. Also, the currents on the ends of the embedded tuning stub have a large magnitude. Observing Fig. 8 which displays surface currents at 900 MHz, any change in the dimension of the tuning stub will result in a change of the operation of the antenna. Fig. 9 displays the surface currents at 2400 MHz.

D. Fields

Figs. 10-13 display simulated field plots for 900 and 2400 MHz in the y-z and x-z planes. Cross-polarization is negligible in all but Fig. 12 where it is more dominate in comparison to the co-polarization.

IV. Discussion

While a typical Vivaldi antenna is a traveling wave antenna with high directivity, the bowtie slot antenna we present maintains an omni-directional gain pattern. Observing Fig. 4 the gain pattern correlates well to the traditional bowtie slot designs presented in [1] and [2]. However, at 2400 MHz the gain patterns in both planes do not perform as well. First observing Fig. 6, the gain in the y-z plane at 2400 MHz is greatly attenuated and the pattern is also asymmetrical. Fig. 7 does display gain similar to that at 900 MHz, although a null exists at 180 degrees. The asymmetric pattern in Fig. 6 was possibly caused by cable radiation and propagation losses through the dielectric as the antenna faced away from the measurement antenna from 180 to 360 degrees. The greatly attenuated gain in Fig. 6 and the null in Fig. 7 result from the design of the antenna. At 2400 MHz, the embedded tuning stub is the main radiating element. Observing Fig. 9, the tuning stub causes a disturbance in the current distribution along the slot. This is thought to negatively impact its performance. With its small size and interaction with the surrounding structure, the observed gain pattern differences seem reasonable. The field

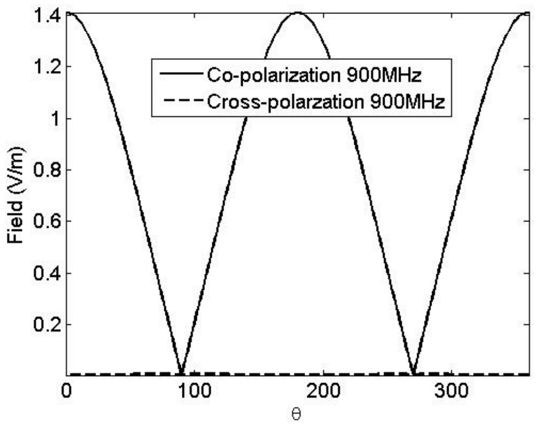

Fig. 10. Method of Moments simulated field pattern in the y-z plane at 900 MHz.

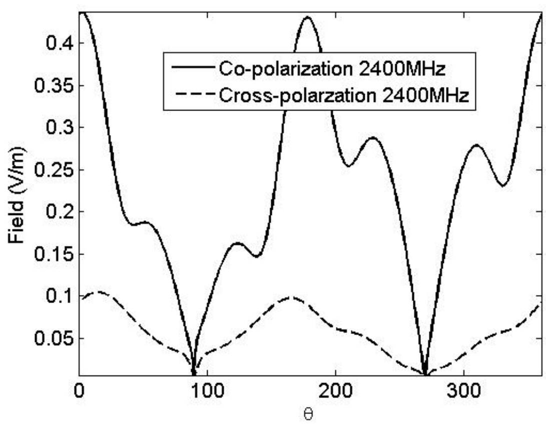

Fig. 12. Method of Moments simulated field pattern in the y-z plane at 2400 MHz.

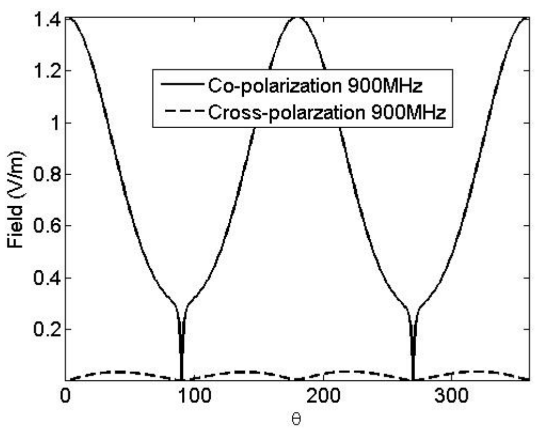

Fig. 11. Method of Moments simulated field pattern in the x-z plane at 900 MHz.

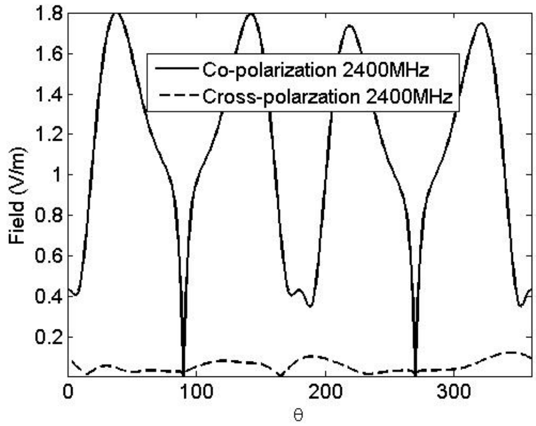

Fig. 13. Method of Moments simulated field pattern in the x-z plane at 2400 MHz.

plots in Figs. 12 and 13 also further validate the gain patterns by displaying similar co-polarization plots and a large cross-polarization in the y-z plane, explaining the attenuated gain.

While operating at lower operating frequencies when compared to the bowtie slot designs in [1] and [2], the bowtie slot antenna we present still maintains a large bandwidth over its operating frequency range. Observing Fig. 3, the bandwidth at 900 MHz is 602 MHz and at 2400 MHz the bandwidth is 229 MHz (Return Loss $>$ 10). This is comparable to the designs in [1] and [2]. The overall size of the antenna is also smaller than the design in [1] while operating at a lower frequency. We attribute this to the longer path currents must take when traveling along the curved slot side versus the straight side of a traditional bowtie slot.

V. Conclusion

Presented is a new design of a bowtie slot antenna incorporating key elements from a Vivaldi antenna. The antenna is simulated using both a Method of Moments and Finite-Element method and it is manufactured on Rogers 4003C substrate with a thickness of 1.6 mm. We present both measured and simulated data to validate our design. Using this design, the antenna exhibits dual-band operation at both 900 and 2400 MHz. We observed an omni-directional gain pattern at 900 MHz. While the gain at 2400 MHz exhibits omni-directional characteristics, the performance at that frequency is diminished. In comparison to a previous bowtie slot design, this modified design allowed a reduction in overall size while operating at a lower frequency.

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