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Ultra-Wideband Antipodal Vivaldi Antenna for Enhanced Perimeter Surveillances

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ABSTRACT: This study presents the design and simulation of a novel Ultra-Wideband (UWB) Antipodal Vivaldi antenna, optimized for perimeter surveillance applications requiring high range resolution. The proposed antenna operates across an impressive frequency range of 3.09 GHz to over 12 GHz, ensuring seamless coverage and detection capabilities. By leveraging a Rogers RT Duroid 5880 dielectric substrate with a thickness of 1.6 mm, the antenna achieves a remarkable peak realized gain of 10.7 dB at 10 GHz. Simulation results demonstrate a stable end-fire radiation pattern across the entire frequency range, making this antenna an ideal solution for advanced perimeter surveillance applications.

KEYWORDS: Antipodal Vivaldi Antenna, Dielectric Substrate, Perimeter Surveillance Radar, Reflection Coefficient, Ultra-wideband.

I. INTRODUCTION

Radar technology plays a vital role in various fields, including aviation, civil engineering, geology, medicine, and security. Perimeter surveillance radar (PSR) systems are specifically designed to monitor activities around critical infrastructure areas, such as airports, seaports, and military installations (Jasmine, et al., 2014). These systems rely on antennas to detect movement and reflect radio waves from objects. Antennas are a crucial component of radar systems, enabling the detection of targets and determining their positions (Rajesh, et al., 2017).

For security applications, antennas require a directional radiation pattern and wide bandwidthJun Li et al.(2024). While several ultra-wideband (UWB) antennas meet these requirements, the Vivalan antenna stands out due to its desirable features, including:

1. Planar and simple structure
2. Lightweight and low profile
3. Symmetric beam in both radiating planes
4. Conformity with mounting host surfaces

The Vivalan antenna was first proposed by Gibson as a traveling wave, coplanar, tapered slot antenna. Subsequent improvements by Gazit and Langley overcame the limitations of the initial design, making the Vivalan antenna a competitive choice for UWB applications (Alhawari, et al., 2012; Dastranj, 2015; Namas&Hasanovic, 2012; Wang, et al., 2013).

II. PROPOSED AVA STRUCTURE DESIGN

Figure 1 shows the development of the proposed antenna. The antenna is designed on an RT Duriod 5880 dielectric substrate having relative permittivity (εr) of 2.2, dielectric loss tangent δ = 0.0009 and a thickness h of 1.58 mm.

The dimension of the proposed antenna can be obtained from (Moosazadeh, et al., 2017);

$$S_l = \frac{c}{f_{\min}}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (1)$$

Where Sl is antenna length, c is the speed of light, fmin is the lower frequency, and εr is dielectric constant.

$$f_{\min} = \frac{c}{2S_w\sqrt{\varepsilon_{eff}}} \qquad (2)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{S_w}\right)^{-\frac{1}{2}} \qquad (3)$$

where ε_{eff} is the effective permittivity, h is the thickness of the substrate and S_w represents the antenna width.

While the Exponentially Tapered Slot Antenna (TSA) can be obtained from;

$$y(x) = C * e^{K_a x} \qquad (4)$$

Constant C and opening rate Ka are given by

$$C = \frac{W_f}{2} \qquad (5)$$

$$K_a = \frac{1}{L_a}\ln\left(\frac{W_a}{W_f}\right) \qquad (6)$$

Table 1 shows the parameters used to perform the microstrip Vivaldi antenna design that have been obtained based on the literature study.

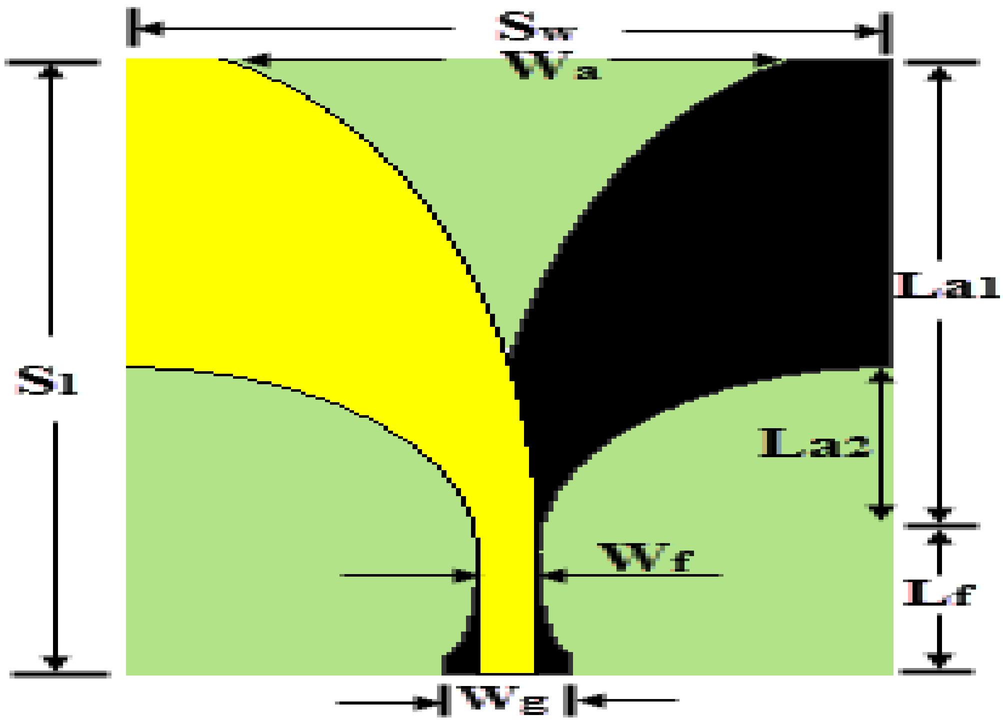

Figure 1. Geometry of Proposed Antipodal Vivaldi Antenna

Table 1. Parameters used in designing Vivaldi antenna.

Parameter	Dimension (mm)	Note
Sl	60	Substrate Length
Sw	45	Substrate Width
Wa	44	Aperture Width
Wg	8	Ground Plane Width
Wf	3.2	Feed Line Width
La1	45	Inner Taper Profile Arc Length
La2	14	Outer Taper Profile Arc Length
Lf	15	Feed Line Length

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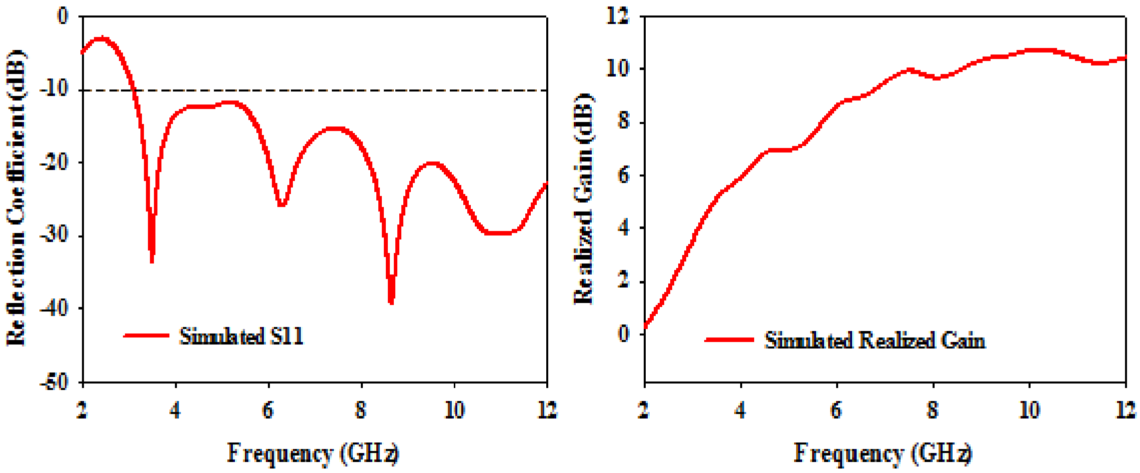
III. RESULTS AND DISCUSSION

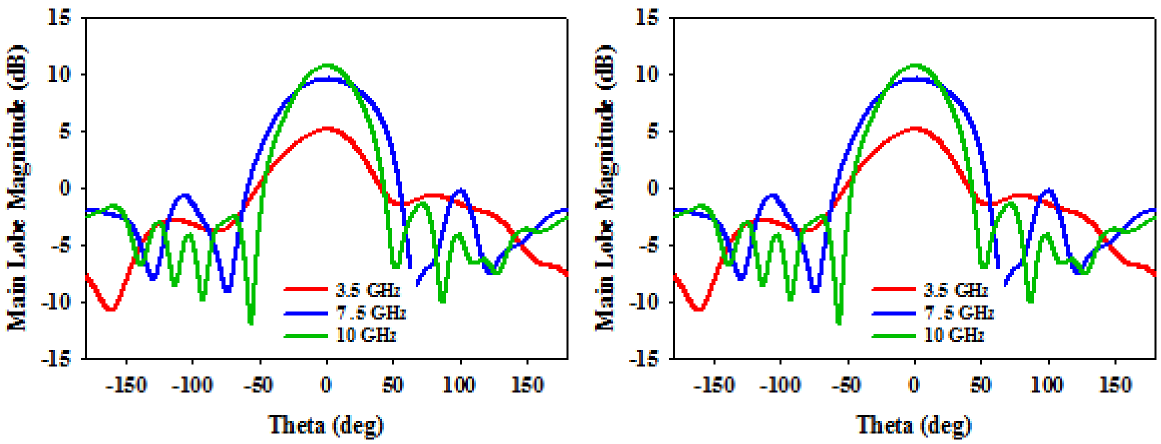
The Reflection coefficient S11 is an indicator of how well an antenna is matched to the input transmission line which defines the quality of signal transmission. Simulation result of the variation of reflection coefficient (S11) with frequency is shown in Figure 2(a). From this result, it can be observed that proposed antipodal Vivaldi antenna has an impedance bandwidth from 3.09 GHz to more than 12GHz.



(a) (b)

Figure 2. (a) Reflection Coefficient (S11) and (b) Realized Gain of Proposed Antenna.

Figure 2 (b) illustrate the simulation result of the variation of realized gain with frequency. A high realized gain of 3.86 dB to 10.70 dB is achieved by the proposed antenna throughout the operating frequency bandwidth with the highest realized gain at 10 GHz. Similarly, Figure 3 shows the E-Plane and H-Plane radiation pattern of the antenna. A high directive and symmetric beam is achieved especially at high frequencies which proved the suitability of the antenna for the proposed application as shown in Figure 3. Table 2 gives the numerical values of the simulated radiation pattern parameters.



(a) (b)

Figure 3. Radiation Pattern of Proposed Antenna at 3.5 GHz, 7 GHz and 10 GHz (a) E-Plane and (b) H-Plane

Table 2. Radiation Pattern Parameter Values

Frequency	Parameter	E-Plane	H-Plane
3.5 GHz	Main Lobe Magnitude (dB)	5.15	5.15
	HPBW (deg)	68.9	142.1
	Side Lobe Level (dB)	-5.8	-3.6
7 GHz	Main Lobe Magnitude (dB)	9.57	9.57
	HPBW (deg)	75	38.6
	Side Lobe Level (dB)	-9.8	-11.4
10 GHz	Main Lobe Magnitude (dB)	10.8	10.8
	HPBW (deg)	50.6	31.7
	Side Lobe Level (dB)	-12.1	-4.6

To further study the behaviour of the designed antenna structures, surface current distribution at 3.5 GHz and 7 GHz are illustrated in Figure 4. It can be observed from the figure that the radiating current flows uniformly along the inner taper profile of the radiating arm of the antenna. This indicates that the antenna has uniform surface current distribution with high amplitude.

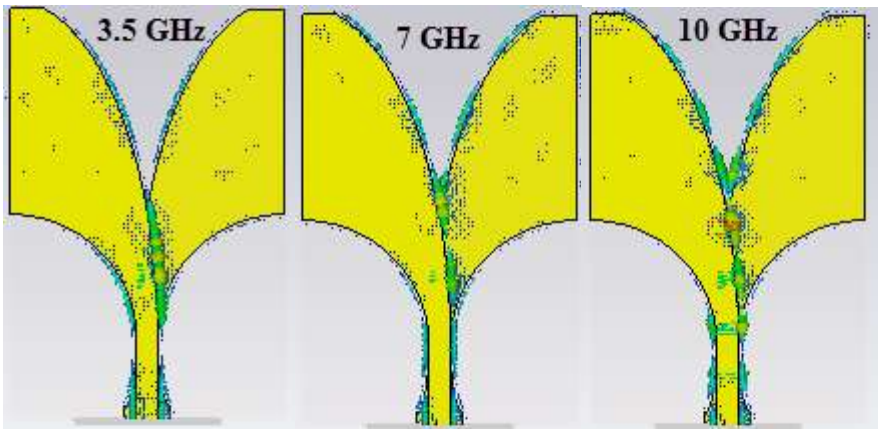


Figure 4. Surface Current Distribution of Proposed AVA at 3.5GHz, 7 GHz and 10 GHz

IV. CONCLUSION

This study successfully investigated and proposed a compact, high-gain antipodal Vivaldi antenna tailored for perimeter surveillance applications. The designed antenna boasts a remarkably compact footprint of 60 x 45 mm², making it an ideal candidate for integration into surveillance systems. Key performance highlights include:

1. Impressive Bandwidth: A wide relative bandwidth of more than 118%, ensuring seamless operation across a broad frequency spectrum.
2. High Realized Gain: A peak realized gain of 10.7 dB at 10 GHz, facilitating enhanced detection and tracking capabilities.
3. Directive Beam: A high directive beam in both principal planes, providing accurate target positioning and reduced interference.

The proposed antenna's simple structure, asymmetric and stable end-fired radiation pattern, and exceptional performance characteristics make it an attractive solution for perimeter surveillance applications. Future work will involve fabricating and measuring the proposed antenna to validate the simulation results, paving the way for its integration into real-world surveillance systems.

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