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Compact and Efficient Modified Leaf Shaped Antipodal Vivaldi Antenna Based on EM Based Optimization Techniques for UWB Applications

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Abstract

This paper highlights about a novel modified leaf shaped antipodal Vivaldi antenna for multi-band applications. It is operative at IEEE S-Bands (2.4 GHz) with a bandwidth of 900 MHz, IEEE C-Bands (7.7 GHz) with a bandwidth of 1700 MHz, IEEE X-Bands (10.6 GHz) with a bandwidth of 1300 MHz. The proposed antenna is designed, simulated and fabricated, further optimized by Genetic Algorithm & Particle Swarm Optimization. As a result of which, in GA the volumetric size of proposed antenna was accounted to be miniaturized by 30% without affecting its performance, as compared to that of the PSO. In addition to, GA provided better display of results than that of PSO. The antenna was fabricated on FR-4 substrate with epsilon value of 4.4 and a height of 1.6 mm. It has a dimension of 30 x 25 mm^2 and it operates from 2-12 GHz, with impedance bandwidth of 10 GHz, having broadside radiation pattern and flat gain (> 5 dBi) over these bands. There is a good agreement found in between the simulated and measured outcomes. Prior to that the proposed antenna acts as promising candidate for wideband applications & to certain extent can be extended for the futuristic applications in UWB.

1. Introduction

Since, FCC's choice of allowing unlicensed operation from 3.1-10.6 GHz in 2002, UWB is progressively developed from academics to that of industry. Small size, impedance matching, minimum group delay, omnidirectional radiation pattern are the special features, which the UWB antenna should bear. In past years, Vivaldi antennas have received considerable attention due to bandwidth characteristics. It belongs to the class of periodic and it continuously scaled up antenna structures with the exponentially tapered curve. In frequency range from 2-40 GHz, they exhibit significant gain and the linear polarization [1]. That's why it is widely used in UWB for cases: ground penetration radar, satellite communications, medical treatment and vehicular wireless communication [2-4]. In this space, it shows out stability, constant group delay over these large range of frequencies, wideband characteristics, high gain, features of integration [5]. In the past, a lot of developments have been carried in areas of Vivaldi antenna for the UWB. L-Tianming [6] has proposed a Vivaldi antenna, but due to larger dimensions, it is considered to be bulky and/or its cross-polarization is high, making unviable for UWB. Hood [7] has proposed a compact Antipodal Vivaldi antenna, used FR-4 and Rogers RO 3006, but resulted in unperturbed outcomes in delay, phase response, far field pattern and realized gain. Taking into account of past references, authors would like to draw readers attention towards 'modified leaf shaped antipodal Vivaldi antenna' for witnessing UWB characteristics with wider impedance bandwidth, without any set back towards realized gain and antenna efficiency. To carry optimization and to overcome earlier problems, GA and PSO [8, 9] was implemented with the help of FEM Solver [9].

Here, the authors present a modified leaf shaped antipodal Vivaldi antenna (MLSAVA), fabricated on FR-4 substrate. The antenna is proposed in such a way that the two stubs are integrated in Top and Bottom Leaf, helps in achieving multiple resonating frequencies under UWB, are analyzed in terms of input reflection coefficients (S_{11}), normalized radiation pattern and realized gain. Because in the literature it is observed that, simultaneously getting wider impedance bandwidth and high realized gain is not possible, thereby remained as myth. But here, this myth is generalized and solved. To rationalize claim, EM optimization techniques such as GA and PSO was implemented for optimizing the parameters like W, L etc. for achieving miniaturization and to synthesis the characteristics of stubs in such a way that we obtain three resonating bands under UWB such as the: IEEE S-Bands (2.4 GHz) with a bandwidth of 900 MHz, IEEE C-Bands (7.7 GHz) with a bandwidth of 1700 MHz and IEEE X-Bands (10.6 GHz) with a bandwidth of 1300 MHz, without any sort of compromise with realized gain and antenna efficiency. The antenna was characterized in the lab, where good agreement was noticed in simulation and the measurement outcomes.

2. Antenna Design and Geometry

The geometry of proposed antenna is shown in Figure 1. FR-4 substrate is used with an epsilon value of 4.4, height of 1.6 mm. The top and bottom layer of the antenna consists of copper material. Initially, a simple leaf shaped antipodal Vivaldi antenna was taken into consideration, aimed for UWB applications, having resonance from 3.1-10.6 GHz. But in order to increase the functionality of antenna in an intuitive manner, two stubs are integrated in the main part of the structure, making it to form a modified leaf shaped antipodal antenna for multi-band characteristics. All these developments are shown in Figure 2. As a result of it, the proposed antenna was deemed witness flatter gain, wider bandwidth, throughout the 2-12 GHz frequency range. In order to strengthen them, in a precise way, GA/PSO as the parametric optimization method based on EM solver was implemented, in which the physical variables: W, L, L_d, W_f etc. are optimized, as shown in Fig. 3.

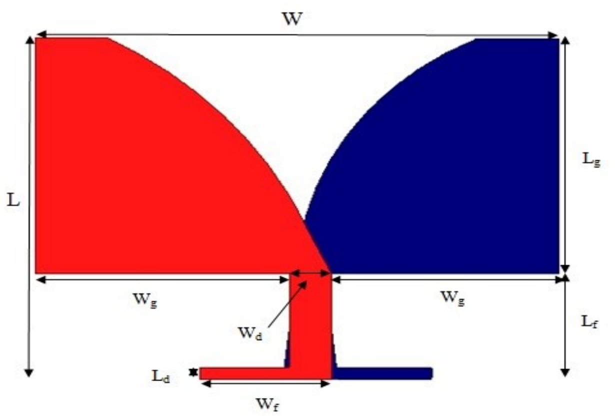


Figure 1. Geometry of the proposed antenna (Top portion shown in Red and Bottom portion shown in Blue).

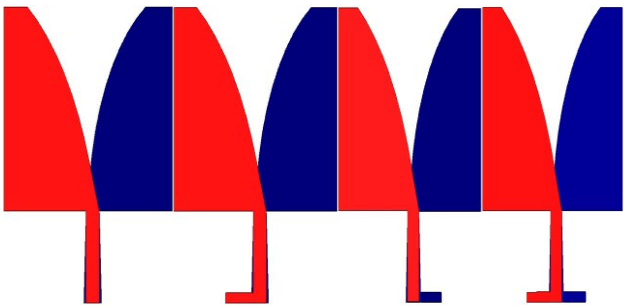


Figure 2. Development Stages: (a) Leaf Shaped (b) Top Leaf with Stub (c) Bottom Leaf with Stub (d) MLSAVA (Top portion shown in Red and Bottom portion shown in Blue).

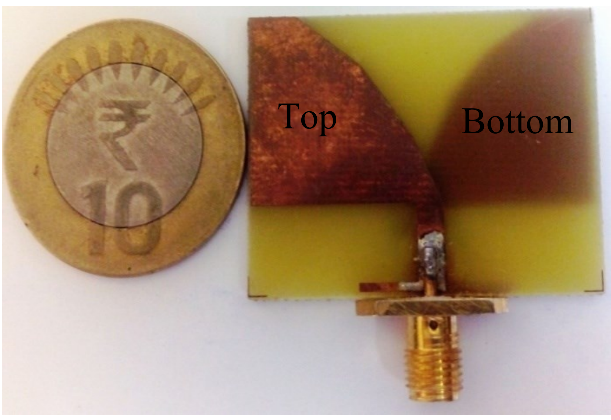


Figure 3. Fabricated prototype of the proposed antenna.

The dimensions of the proposed antenna were calculated by P. J. Gibson. GA and PSO [8] was implemented for the miniaturization and for advancing characteristics of multi-band operations by optimizing *W*, *L* with characterization of stubs: L_d, W_f, etc. The calculated dimensions, along with optimized dimensions are in Table 1. It is obtained as an intake from rigorous parameters sweeping, that is initiated in the FEM solver (ANSYS-HFSS). Before utilizing these dimensions for characterization, a specific target was set: impedance bandwidth > 5 GHz, gain > 5 dBi & volumetric reduction of antenna size > 25% with the advent of multi-resonating characteristics. From Table I, it is observed that by implementing genetic algorithm (GA), volumetric size was reduced by 30%, without affecting its performance.

TABLE I
Dimensions of The Proposed Antenna

Parameters	**Calculated (in mm)**	**GA-Optimized (in mm)**	**PSO-Optimized (in mm)**
W	40	35	38
L	35	28	27
L_g	20	15	17
W_g	18	11	13
L_f	9	7.5	9.5
W_d	3	2.8	3.8
L_d	2	0.8	1.8
W_f	8	6.5	7.5
Distance Between Patch and Ground	26	---	---

3. Antenna Characteristics and Analysis

The authors would like to draw your attention towards the fact that the implementation of GA and PSO optimization techniques by FEM Solver is similar to that of the case [9]. At the time of implementing GA/PSO, authors kept vigil look for specific target, impact on parameters & objective function. The S_{11} parameters were studied initially, because they are termed as initial measure, shown in Figure 4-6.

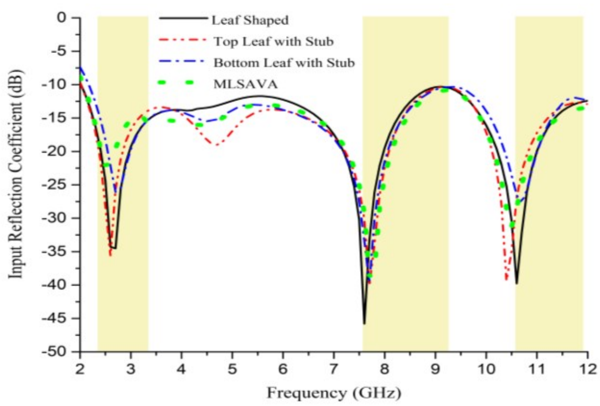


Figure 4. S_{11} Characteristics-Developmental Stage.

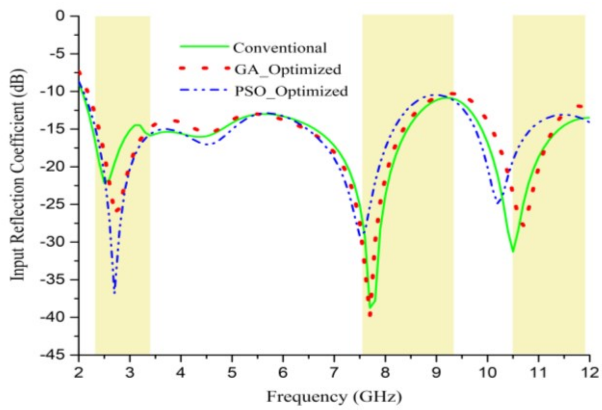


Figure 5. S_{11} Characteristics-Optimized Stage.

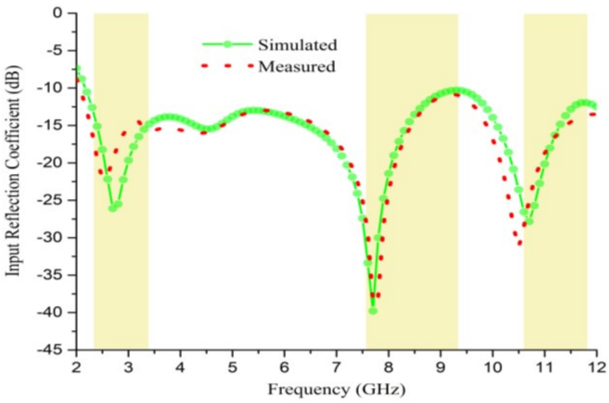
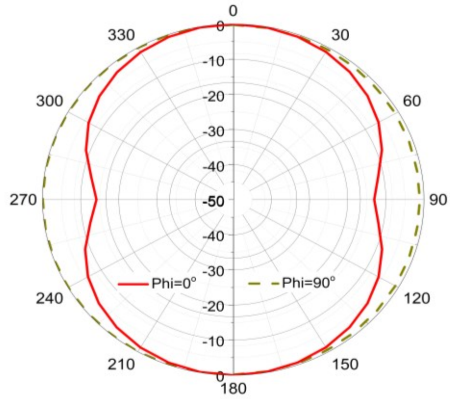


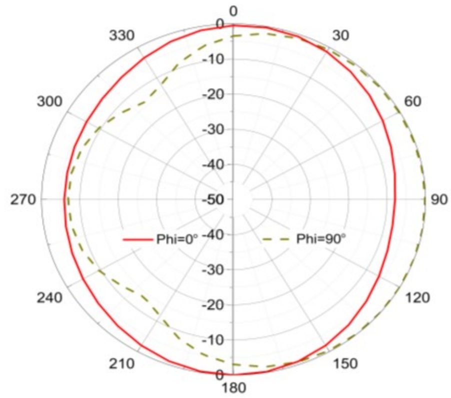
Figure 6. S_{11} Characteristics-Characterized Stage.

With added intuition, getting miniaturization without sort of compromising with multi-resonating frequencies and the bandwidth functionality was difficult. Combination of duo facts, makes important for futuristic applications in UWB.

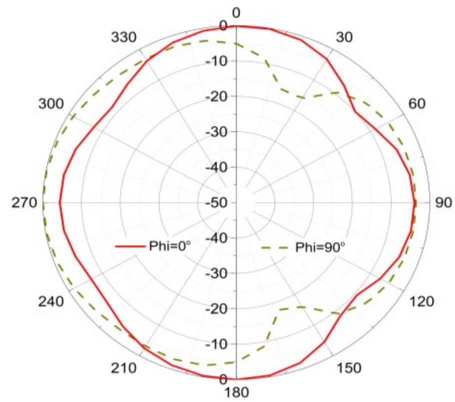
The normalized radiation pattern for the proposed antenna is shown in Figure 7 (a)-(d). Behavior of the realized gain at Phi=0º and Phi=90º for E (θ, φ) is studied for 2.4 GHz, 7.7 GHz, 10.6 GHz, 12 GHz. It can be seen that; broadside radiation pattern is obtained out. As the range of frequency increases, radiation pattern gets distorted, due to presence of higher order modes, for which changes are seen in the equivalent radiation area with frequencies for an unequal phase distribution. The electric field distribution is shown in Figure 8 (a)-(d). Their behavior is studied for 2.4 GHz, 7.7 GHz, 10.6 GHz and 12 GHz. It is observed that there is a uniform distribution of electric fields on patch & ground with maximum fields in feed line near the power port. At higher frequencies, maximum fields, flow in the flares of patch & ground, resembling Vivaldi antenna. Realized gain is vital, in case of UWB antenna. Previously, observed that monopole and planar antenna [8] restrict for gain within 5 dBi. But, it is more than 5 dBi, for most of range, shown in Figure 9. A comparison is shown in between simulated and measured gain. It is clearly evident, it has flat gain for all band and maximum gain of 11.45 dBi at 9.5 GHz, gain > 9 dBi, which is of higher side as compared to that paper [10].



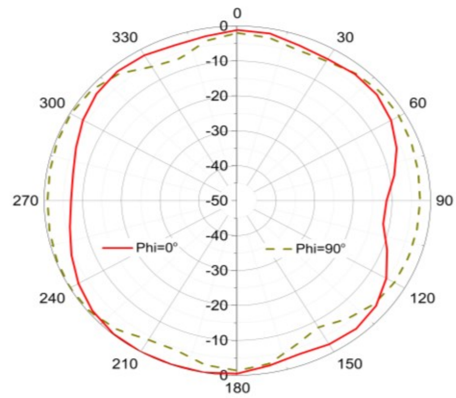
(a)



(b)



(c)



(d)

Figure 7. Normalized Radiation Pattern Characteristics of the proposed antenna (a) 2.4 GHz (b) 7.7 GHz (c) 10.6 and (d) 12 GHz.

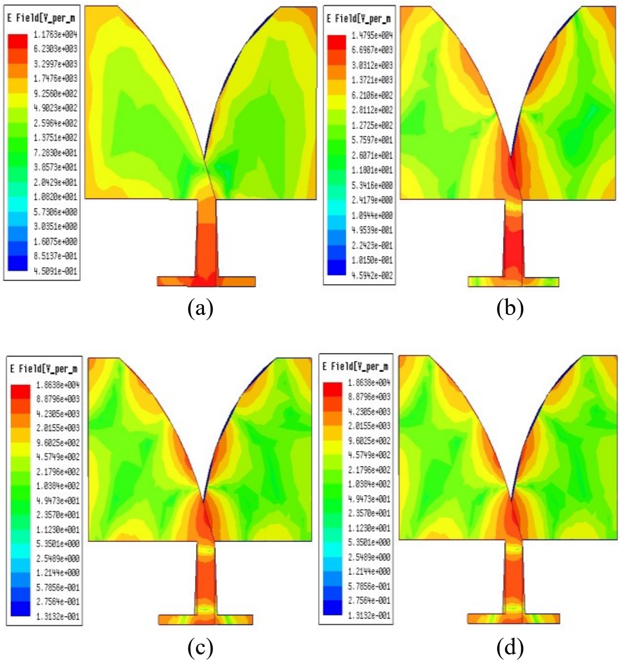

(a) (b) (c) (d)

Figure 8. Electric Field Distribution Characteristics of the proposed antenna (a) 2.4 GHz (b) 7.7 GHz and (c) 10.6 GHz (d) 12 GHz.

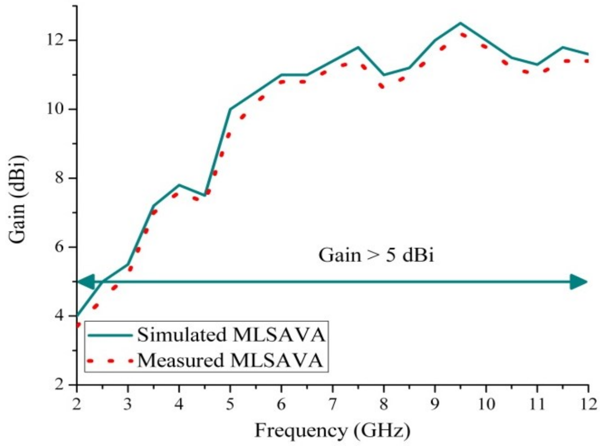


Figure 9. Gain Characteristics of the proposed antenna.

TABLE II
Comparison of Outcomes of the Proposed Antenna

Parameters	Initial	GA	PSO
S_{11}	3.1-10.6 GHz	2-12 GHz	2-12 GHz
B.W.	> 7 GHz	> 10 GHz	> 8 GHz
Gain	> 5 dBi	> 8.5 dBi	> 7.2 dBi
Efficiency	80%	88%	82%
Reduction	----	30%	

(*GA- Genetic Algorithm, PSO- Particle Swarm Optimization The Measurement results are in agreement with GA)

4. Conclusion

Here, a novel & compact modified leaf shaped antipodal Vivaldi antenna is designed, fabricated and characterized. The journey from a leaf shaped AVA to MLSAVA, shown in the developmental stages. It can be used for UWB, right from 2-12 GHz, an impedance bandwidth of 10 GHz. With addition of stubs, it is a multi-band antenna with wideband characteristics, having resonating frequencies such as IEEE S-Bands (2.4 GHz) with bandwidth of 900 MHz, C-Bands (7.7 GHz) with bandwidth of 1700 MHz and X-Bands (10.6 GHz) with bandwidth of 1300 MHz). Besides, it has realized gain > 5 dBi from 2-12 GHz. GA and PSO was implemented for miniaturization & to obtain characteristics of multi-band operations in a better way. GA yields better result than PSO in our case. The antenna was fabricated and characterized in lab, acts a promising candidate for UWB.

5. References

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