High Gain Vivaldi Antenna for Radar and Microwave Imaging Applications

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***Abstract*—An Ultrawideband (UWB) high gain compact Vivaldi antenna with end fire radiation patterns is presented for radar and microwave imaging applications. The antenna is operating for 2.9GHz to more than 11GHz with -10dB impedance bandwidth and is designed on low cost FR4 substrate of thickness 0.8mm. While designing the proposed antenna, initially a compact exponential tapered slot Vivaldi antenna is presented for wide impedance bandwidth performances. Further, the Vivaldi antenna is modified by incorporating corrugations on the edges of exponential metallic flaring section and some periodic grating elements consists of small metallic strips on the slot area, which results in improvement in gain significantly along with increased directivity and lower frequency band coverage. The proposed antenna shows nearly stable end-fire radiation patterns throughout the frequency range. The surface current distributions and input impedance plots are presented to understand the antenna mechanism.**

***Index Terms*—vivaldi antenna, end-fire, microwave imaging, ultrawideband (UWB), radar**

I. Introduction

UWB antennas with compact size, stable end-fire radiation patterns, and high gain find lots of applications like radar, microwave imaging, remote sensing, and UWB communication systems. To achieve such goals, end-fire tapered slot antenna (TSA) with compact size is a good candidate as it provides wide impedance bandwidth, stable radiation patterns, and high gain characteristics.

Further, UWB refers to radio technology with a bandwidth exceeding the lesser of 500 MHz or 20% of the arithmetic center frequency [1], according to the U.S. Federal Communications Commission (FCC). The frequency range from 3.1 to 10.6GHz is allocated by FCC for UWB application which is 7.5GHz wide.

TSAs are of large interest for Ultrawideband application from the time they were introduced by Lewis et al. [2]. Vivaldi antenna is a kind of tapered slot antenna working on the principle of travelling wave antennas having exponential tapered profile, which provide large bandwidth and end-fire radiation patterns. Vivaldi antenna was first proposed by P. J. Gibson in 1979 [3].

The UWB Vivaldi antennas are used in many applications where UWB and end-fire radiation pattern is required like imaging of tissues for detection of cancerous cell [4], for detection of on-body concealed weapons detection [5], see through wall applications [6] which is used where it is difficult to go beyond the wall or as a purpose of security, high range radar systems [7], and many more applications are possible with the unique characteristics of Vivaldi antenna.

In this paper, design and characterization of a high gain Vivaldi antenna is proposed. Initially, a compact exponential tapered slot Vivaldi antenna (Antenna 1) is designed for UWB operations. Further, to enhance the gain of the designed UWB Antenna 1, tapered corrugated profile is incorporated on the sides of exponential flaring along with grating elements on the slot area in the direction of the antenna axis (Antenna 2). Due to the addition of the corrugated structure and grating elements, the gain of the Vivaldi antenna increases significantly with decrease in the lower frequency of operations. The design of the proposed antenna is presented in detail along with simulated results in the following sections. All the simulations are carried out using Finite Integration Technique (FIT) based computer simulation technology microwave studio (CST MWS) [8] and further validated by finite element method (FEM) based Ansoft's High frequency structure simulator (HFSS) [9].

II. Antenna Design and Configurations

The geometrical configuration of the proposed antennas (Antenna 1 and Antenna 2) is shown in Fig. 1. Both the antennas are designed on the 0.8 mm thick FR4 substrate with permittivity (ε_r) 4.4 and size $45\times40\text{mm}^2$. The proposed Vivaldi antennas consist of a microstrip feed line, microstrip line to slot line transition, and the radiating structure. Radiating structure is exponential tapered and the radiation takes place along the axis of the tapering. The continuous scaling and gradual curvature of the radiating structure ensures theoretically unlimited bandwidth [3], which is, in practice, constrained by the taper dimensions, the slot line width, and the transition from the feed line.

On the one side of the substrate of Antenna 1, exponential tapered slot is designed with one end of the slot is a circular cavity and other end is opened. The cavity act as an open circuit that minimizes the reflections from microstrip line to slot-line transition. The shape of the flaring and cavity determine most of the characteristics of the antenna. To provide feed to the

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Vivaldi antenna, a microstrip line to slot line transition is designed so that antenna remains matched over wider frequency band which is shown in Fig. 1. The microstrip line is designed on the another side of the substrate.

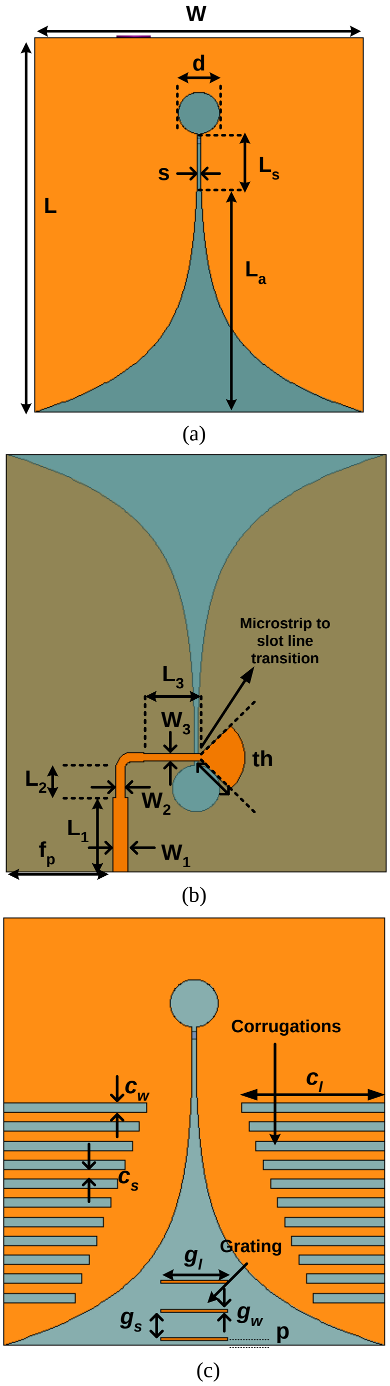

Figure 1. Geometry of the proposed vivaldi antennas, (a) top view of antenna 1, (b) bottom view of antenna 1, and (c) antenna 2

The tapered profile of the antenna is given as,

$$y(x) = ce^{K_a x} \tag{1}$$

where, constant c and opening rate Ka is given by,

$$c = \frac{s}{2} \tag{2}$$

$$K_a = \frac{1}{L_a}\ln\left(\frac{W_a}{s}\right) \tag{3}$$

where, L_a, W_a, and s are the aperture length, the aperture width, and width of slot at origin.

In order to enhance the gain of the Antenna 1 further, two techniques are used to design Antenna 2. First, tapered corrugations with decrease factor (f_t) are incorporated on the edges of the flaring of the Vivaldi antenna and second, grating elements are placed on the slot area of the antenna in the direction of antenna axis. The corrugation is designed by cutting rectangular slots of variable length from the copper of exponential flaring of both sides. The width of slots and distance between the rectangular slots of corrugation remain same but the length of the slot decreases as factor of f_t from one to another. The loading of the corrugation on the edges of the tapered slot, work like a resistive loading, due to which maximum field remain concentrated towards the slot area and contribute to the end-fire radiation patterns. In the same manner, the grating elements composed of three metallic strips placed in direction of radiation, work as directive elements as in the case of the Yagi-Uda antenna, therefore it contributes to the enhancement of radiation in the end-fire direction. Due to the combined effect of both the corrugations and grating elements, the gain of the antenna increases significantly in the end-fire direction.

All the optimized parameters of the proposed antennas are given in Table I.

TABLE I. DESIGN PARAMETERS OF THE PROPOSED ANTENNA

Parameter	Dimension	Parameter	Dimension
L	45mm	W_3	0.75mm
W	40mm	th	45^0
L_s	5mm	f_p	11.2mm
L_a	28.5mm	c_l	15mm
s	0.4mm	c_w	1mm
d	5mm	c_s	1mm
L_1	8mm	f_t	0.75
L_2	3.2mm	g_l	7mm
L_3	1.3mm	g_w	0.3mm
W_1	1.5mm	g_s	3mm
W_2	1mm	p	0.5mm

III. SIMULATION RESULTS AND DISCUSSIONS

A. Reflection Coefficienct

The variations of the reflection coefficient (S_{11}) with frequency are shown in Fig. 2, for both the Antenna 1 and Antenna 2. It is observed that the reflection coefficient is below -10dB for the frequency range from 3.1GHz to more than 11GHz in the case of Antenna 1 whereas in the case of Antenna 2 it is below -10dB for the frequency range from 2.9GHz to more than 11GHz. Both the antennas show more than 112% fractional impedance bandwidth.

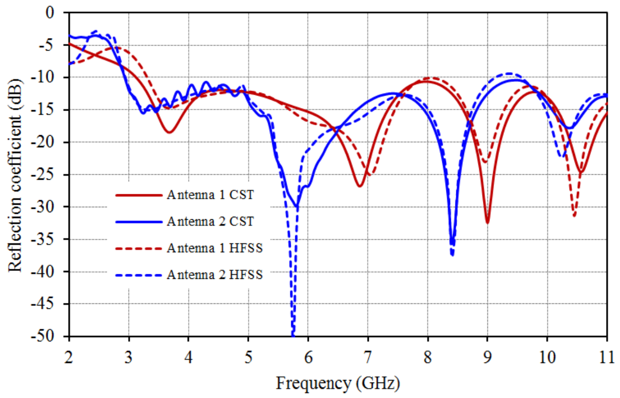

Figure 2. Variation of reflection coefficient (S11) with frequency for antenna 1 and antenna 2.

B. Input Impedance

The variations of the input impedance for both the antennas with frequency are shown in the Fig. 3. It is noted that the real part of impedance is oscillating about the 50Ω and imaginary part of impedance oscillating about 0Ω with variation in frequency. Which results in matching with 50Ω SMA (Sub Miniature A) connector used to feed the antennas and wide impedance matching is achieved through microstrip to slot line transition.

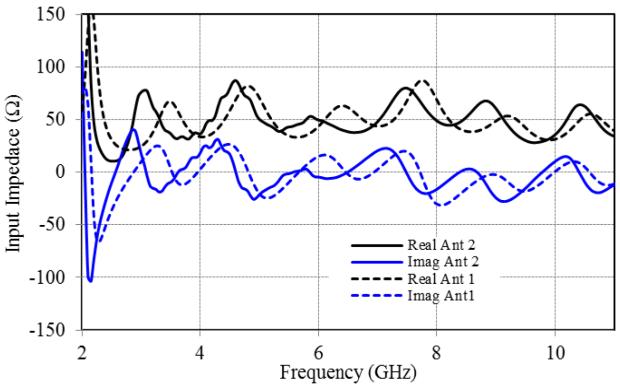

Figure 3. Variation of real and imaginary part of input impedance of the proposed antenna 1 and antenna 2 with frequency

C. Surface Current Distribution

To understand the radiation mechanism of the proposed Antenna 1 and Antenna 2, the surface current distributions at different frequencies (4GHz, 7GHz, and 10GHz) are shown in Fig. 4. From the current distributions plot, it is observed that when the corrugation is loaded on the edges of the tapering then surface current is concentrated on the inner edge of the exponential tapering and add to the radiation in bore sight direction. Since the corrugation act like resistive loading therefore less current configuration is observed in the corrugated region while more current near edges of the tapered slot. The effect of the grating elements come into picture at higher frequency side which is observed from the surface current plot that at 7GHz and 10GHz the current concentration is observed on grating elements.

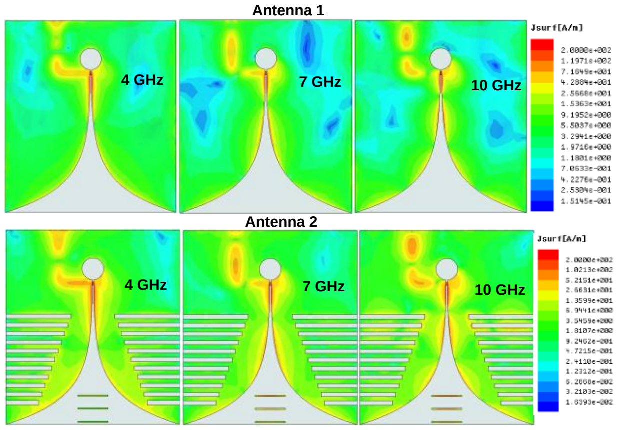

Figure 4. Surface current distributions of the proposed antenna 1 and antenna 2 at different frequencies

D. 3-D Radiation Patterns

The 3-D radiation patterns of the proposed Antenna 1 and Antenna 2 at frequencies 4GHz, 6GHz, 8GHz, and 10GHz are shown in Fig. 5(a) and Fig. 5(b), respectively. It is observed that Antenna 2 shows low side and back lobe levels due to which the radiation in the bore sight direction of the antenna increases with improved directivity and gain. Both, the Antenna 1 and Antenna 2 show the stable end-fire radiation pattern with frequency variation.

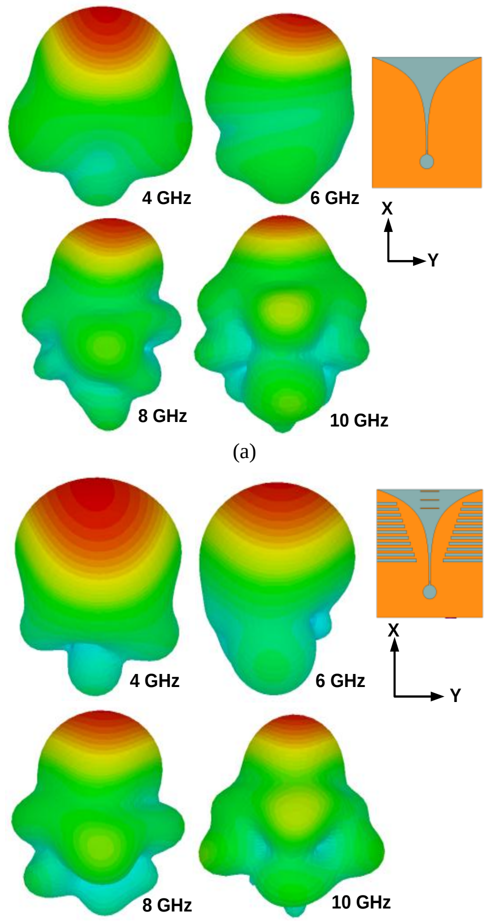

Figure 5. 3D-Radiation patterns of the proposed (a) antenna 1 and (b) antenna 2 at different frequencies

E. Realized Gain

The variation of the realized gain of the proposed Antenna 1 and Antenna 2 is shown in Fig. 6. It is observed that due to the loading of the corrugation on the edges of tapering and grating elements on the slot area, the realized gain of the antenna improved significantly throughout the operating frequency band. Due to the corrugation and grating elements, radiation minimizes in the direction other than the bore sight direction which results in the improved realized gain and directivity of antenna in the bore sight direction. The Antenna 2 with improved gain can be used for applications like microwave imaging and radars.

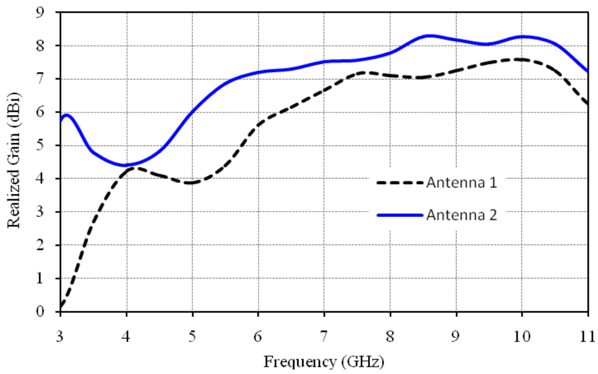

Figure 6. Variation of realized gain with frequency.

IV. CONCLUSION

A high gain Vivaldi antenna (Antenna 2) has been proposed in this paper for microwave imaging and radar applications. The Antenna 2 is designed with the loading of corrugation and grating elements near the tapering profile of a compact UWB Vivaldi antenna (Antenna 1). The overall size of the antenna is not affected by the techniques used to increase the gain and improve the radiation patterns of the antenna in bore sight direction, therefore, the overall size of the antenna remain compact. The proposed antenna covers the FCC defined UWB and has more than 112% of fractional bandwidth (from 2.9GHz to more than 11GHz). The input impedance, surface current distributions, and radiation patterns of the antennas have been plotted to understand the antennas operating principles. The proposed antenna can be used in high range radar applications when used in array configuration and is a good candidate for microwave imaging applications.

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