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Design and Characterization of Antipodal Vivaldi Antenna for Under Water Communication

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ABSTRACT
This paper proposes the design and characterization of Antipodal Vivaldi antenna, which can be applied in the field of ocean communication. Since Vivaldi antenna have the properties such as Ultra-Wide Band (UWB), high directivity, better radiation pattern, this paper focus on designing and analysis of an Antipodal Vivaldi antenna. The designed Antipodal Vivaldi antenna can be used for wide impedance bandwidth application such as ocean communication.The antenna is designed on low cost FR4 substrate having a thickness of0.306 mm. The performance of the antenna was tested throughout its operating frequency from 3.1GHzto10.6GHz. Experimental results show that the designed Antipodal Vivaldi antennashave better performance interms of VSWR, Return loss and S parameters. Also the designed Antipodal Vivaldi antenna shows nearly stable end-fire radiation pattern throughout the operating frequency from3.1GHz to 10.6GHz.

Keywords-Directivity, FR4 substrate, Ocean communication, Radiation pattern, Vivaldi antenna

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I. INTRODUCTION

Today, there is a rapid growth in communication and electronic devices and the need for portable electronic devices has been highly increased. Therefore the need of compact, wideband smart antennas [1]-[3] is also increasing. As per the FCC regulation 2002 Ultra Wide Band (UWB) antenna [4] operates in the frequency spectrum that ranges from 3.1GHz to 10.6GHz. Vivaldi antenna [5] is one of the antennas that operate in UWB spectrum.

Gibson [6] proposed the Vivaldi antenna for radar applications. This Vivaldi antenna has good features such as symmetric radiation pattern and high gain. It is also easy to fabricate Vivaldi antenna, which has exponential flare aperture. Vivaldi antenna is a type of tapered slot antenna [7]-[8], where the different radiates at different frequencies along its length. This Vivaldi antenna has wide impedance bandwidth and bidirectional characteristics. The performance of Vivaldi antenna mainly depends on the width of the aperture. The frequency of radiation differs at different region. At the wider end, the radiating frequency is lesser, while the narrow end, the radiating frequency is higher. Antipodal Vivaldi antenna [9] is one of the types of Vivaldi antenna where the radiating element is symmetrically etched, half on each side of the substrate. The aperture tapering is derived from the mathematical function in both the antipodal and coplanar Vivaldi antenna. The construction of antipodal Vivaldi antenna [10] eliminates the transition of feed line to slot, which increases the impedance bandwidth.

Recently many researches are done on UWB antipodal Vivaldi antenna that aims to improve the radiating performance when the antenna operates at low-end cut off frequency. Initially Tapered Slot Edge (TSE)antenna [11] structure was designed that aims to reduce the low end cutoff frequency. This design keeps the dimension of the antenna similar to Antipodal Vivaldi antenna. In [12] Balanced Antipodal Vivaldi Antenna (BAVA)has been designed that uses wide band passed arrays. The proposed method aims to design an antipodal antenna that shows a best performance throughout the operating UWB spectrum from 3.1GHzto10.6 GHz.A UWB system commonly uses the antennas such as frequency independent antennas, planar monopole antennas and tapered slot antenna. These three types of antennas almost show a good end-fire ration pattern when compared to radiation pattern of planar monopole antenna. Band-notched Vivaldi antennas show band-notched characteristics that includes the type of antenna such as capacitive loaded loop resonators [13], Ω shaped slot [14], stepped impedance resonator [15] and U-shaped slot [16].

The remaining section of the paper is arranged as follows, section 2 shows the design of proposed Antipodal Vivaldi antenna. Section 3 shows the experimental result and analysis of the proposed antipodal Vivaldi antenna. Finally section 4 concludes the paper.

II. PROPOSED ANTENNA DESIGN

The behavior of Electromagnetic waves (EM) propagation differs highly in seawater and freshwater. The reason is, in seawater the positive and negative ions are bonded by hydrogen molecules. These hydrogen bonds can be broken easily by EM waves since the bonds are very weaker. When small electric field propagates in seawater, these bonds won't break. But when a high electric field propagates in seawater, the hydrogen bond breaks and more positive and negative free ions are formed. For a small electric field, there won't be any free ions which drastically reduce the conductivity.The speed of propagation of EM waves in free space can be represented as,

$$C_f = \frac{1}{\mu\varepsilon} \qquad (1)$$

where μ and ε are magnetic permeability and dielectric permittivity respectively. The relative permittivity of free space communication is one. But the relative permittivity is high for ocean of about 80. Since water is a polar molecule, when an alternating electric field strikes on the water,the polar molecule rotates.

In sea water at high frequencies, the energy loss will be greater than conduction loss. Let σ bethe conductivity in sea water, the speed of EM wave in sea water can be derived from (1) as,

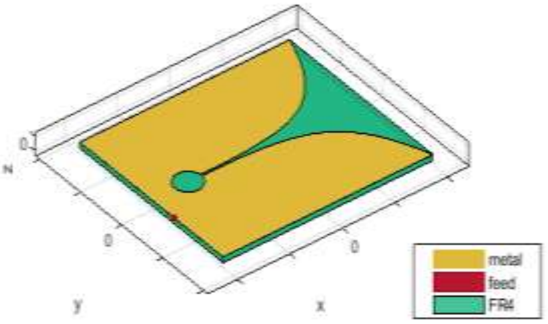


Fig 1:Antenna Design

$$C_s = \sqrt{\frac{4\pi f_s}{\sigma_s \mu}} \qquad (2)$$

wheref_s is the frequency. Since sea water is a high loss medium, the absorption coefficient can be represented as,

$$\propto_a = \sqrt{\sigma_s \mu \pi f_s} \qquad (3)$$

The transition frequency (f_T) is the ratio of conductivity to the dielectric permittivity, which can be mathematically expressed as,

$$f_T = \frac{\sigma_s}{\varepsilon} \qquad (4)$$

The bandwidth requirement of traditional Vivaldi antenna is high. Therefore this paper proposes an Antipodal Vivaldi antenna that overcomes the drawback of conventional Vivaldi antenna. This antenna uses a pair of flare wings on either side of the substrate. Let (x_1, y_1) and (x_2, y_2) be the bottom and peak points of the tapered exponential shape respectively. Let M be the exponential factor of the antenna. The ground plane exponential tapered slot can be estimated using the relation

$$y = U_1 e^{Mx} + U_2 \qquad (5)$$

Where, $U_1 = \frac{y_1 - y_2}{e^{Mx_1} - e^{Mx_2}}$ (6)

$$U_2 = \frac{y_2 e^{Mx_1} - y_1 e^{Mx_1}}{e^{Mx_1} - e^{Mx_2}} \qquad (7)$$

Let D_i and D_o represents the distance from the slot center to inner and outer edges respectively.

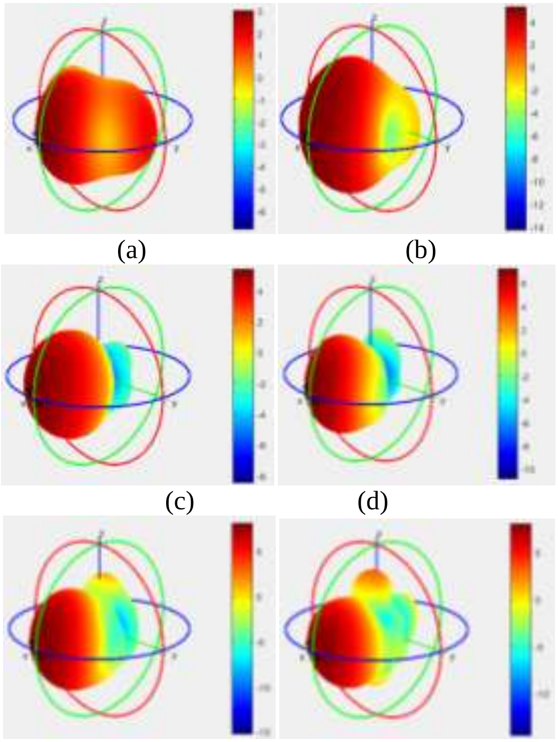
$$D_i = C_s \times e^{k_s y} \qquad (8)$$

$$D_o = C_w \times e^{k_w y} \qquad (9)$$

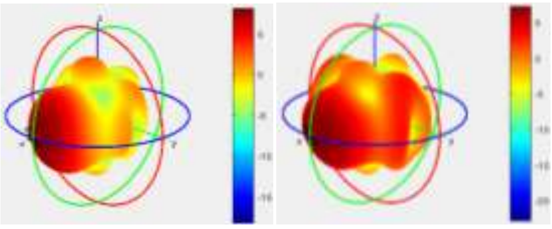
Where C_s,k_s,C_w,k_w represents the constants of FR4 substrate.

The proposed antipodal Vivaldi antenna uses a FR4 substrate having a thickness of $t_s = 0.306\text{mm}$, relative permittivity of $\varepsilon_r = 4.35$ and loss tangent of $\delta = 0.02$. The feed line has a length of 16.3 mm and a width of 6 mm. The flare height is set as 164 mmwith its outer height as 415 mmand inner height as 180.6 mm.

III. EXPERIMENTAL RESULTS AND ANALYSIS



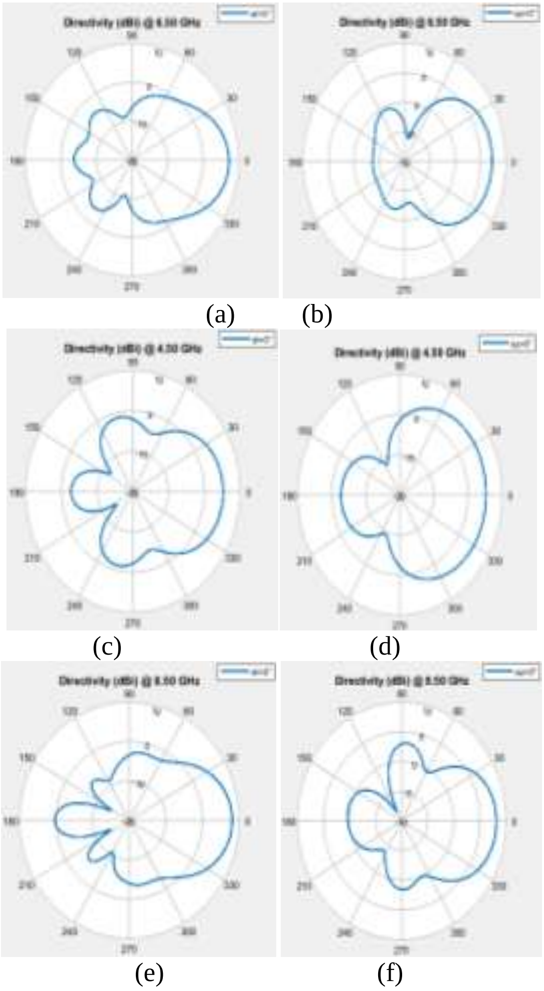
(a) (b) (c) (d) (e) (f)



(g) (h)

Fig.2 Radiation pattern of proposed antipodal Vivaldi antenna at different frequency (a) 3.5GHz (b) 4.5GHz (c) 5.5GHz (d) 6.5GHz (e) 7.5 GHz (f) 8.5 GHz (g) 9.5GHz (h) 10.5GHz

The antenna was designed using the simulation tool MATLAB 2018 and was tested using the metrics such as Radiation pattern, VSWR (Voltage standing Wave ratio), Return loss, S-parameters and impedance of antenna. The antenna was tested throughout its UWB operating frequency from 3.1GHzto10.6GHz. Especially, we have chosen 8 uniformly spaced frequencies between 3.1GHz to 10.6GHz such as 3.5GHz, 4.5GHz, 5.5GHz, 6.5GHz, 7.5GHz, 8.5GHz, 9.5GHz and 10.5GHz. Fig 2 shows the radiation pattern of the proposed antipodal Vivaldi antenna for different frequency ranges.



(a) (b)

(c) (d)

(e) (f)

Fig.3 Azimuth and Elevation pattern at different frequency (a) Azimuth Pattern at 4.5GHz (b) Elevation Pattern at 4.5GHz (c) Azimuth Pattern at 6.5GHz (d) Elevation Pattern at 6.5GHz (e) Azimuth Pattern at 8.5GHz (f) Elevation Pattern at 8.5GHz

Fig 3 shows the azimuth and elevation pattern of the proposed antipodal Vivaldi antenna for different frequency ranges such as 4.5GHz, 6.5GHz and 8.5GHz where Fig 6 shows the azimuth and elevation pattern of the proposed antipodal Vivaldi antenna at lower and higher end frequencies such as 3.1GHz and 10.6GHz.

Table 1 : Comparison of VSWR, Return loss and S-parameter at different frequencies

Frequency	**VSWR (dB)**	**Return loss (dB)**	**S-Parameter (dB)**
4.5 GHz	1.84	10.55	0.296
6.5 GHz	1.64	12.26	0.243
8.5 GHZ	1.67	11.97	0.252

Table 1 shows the comparison of VSWR, Return loss and S-parameter at different frequencies such as 4.5GHz, 6.5GHz and 8.5GHz. The average VSWR is around 1.71dB, the average Return loss is around 11.59db and the average S-parameter is around 0.296Db

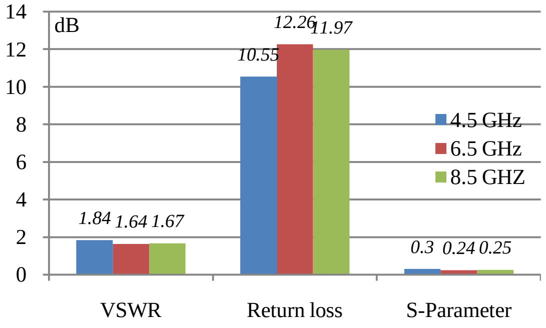


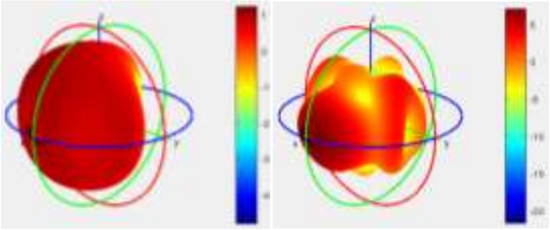
Fig 4: Variation of VSWR, Return loss and S-parameter at different frequencies

Fig 4 shows the graphical comparison of VSWR, Return loss and S-parameter at 3 UWB frequencies. Table 2 shows the comparison of Antenna Impedance and Directivity Gain at different frequencies such as 4.5 GHz, 6.5GHz and 8.5GHz. Fig 4 shows the radiation pattern at lower and upper end frequencies such as 3.1 GHz and 10.6 GHz.

The Antenna Impedance was measured by connecting the antenna with a transmission line having a characteristic impedance of$Z_0 = 50\Omega$. The antenna impedance (both Resistance and Reactance) changes rapidly for change in frequency. The average of maximum Directivity Gain is 6.89dB and the average of minimum Directivity Gain is -13.26dB

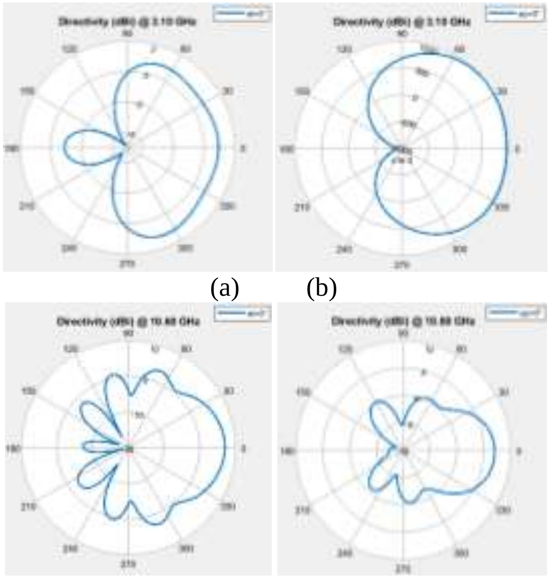
Table 2 : Comparison of Antenna Impedance and Directivity Gain at different frequencies

Frequency	Antenna Impedance (Ohm)		Directivity Gain (dBi)	
	Resistance	**Reactance**	**Max**	**Min**
4.5 GHz	29.05	11.05	5.3	-14.34
6.5 GHz	67.71	23.28	7.26	-10.9
8.5 GHZ	43.22	-23.26	8.12	-14.55



(a) (b)

Fig5: Radiation pattern at lower and upper end frequencies (a) 3.1 GHz (b) 10.6GHz



(a) (b)

(c) (d)

Fig 6: Azimuth and Elevation pattern at lower and upper end frequencies 3.1 GHz and 10.6GHz(a) Azimuth Pattern at 3.1 GHz (b) Elevation Pattern at 3.1GHz (c) Azimuth Pattern at 10.6GHz (d) Elevation Pattern at 10.6 GHz

The proposed antipodal Vivaldi antenna shows a nearly stable radiation pattern throughout the frequency range. However it has a good directive gain. The next section shows the conclusion of the paper.

IV. CONCLUSION

This paper proposes a design and characterization of an Antipodal Vivaldi antenna, which can be suited in the field of ocean communication. The designed Antipodal Vivaldi antenna has a wide impedance bandwidth. The antenna is designed on low cost FR4 substrate which is having a thickness of0.306 mm. Also the designed Antipodal Vivaldi antenna nearlyshows stable end-fire radiation pattern throughout the operating frequency from 3.1GHzto 10.6GHz. The experimental shows that the proposed Antipodal Vivaldi antenna shows a good performance interms of the metrics such as VSWR, antenna impedance and Return loss

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