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C-Band Vivaldi Antenna and Its Array

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Abstract – **A novel Vivaldi Antenna has been designed for IEEE C-band i.e. 4-8 GHz. The objective of the design is to achieve return loss better than -10 dB over the entire frequency range with a moderate gain ranging from 4-9 dB. The minimum half power beamwidth required in both Azimuth and Elevation planes is 50^0 so that designed Vivaldi Antenna element can be used for wide angle scanning. The designed antenna has been fed by a stripline that helps in efficient coupling of microwave power to slotline. The triplicate structure of Vivaldi Antenna helps in reducing the spurious radiations from stripline feed. A 5x1 H-plane C-Band Vivaldi Antenna array has been designed to find out the effect of array environment on the characteristics of Vivaldi Antenna. All the designs, simulations and analysis have been done in CST Microwave Studio 2011.**

Keywords: **Vivaldi Antenna, IEEE C-Band, Return Loss, Half Power beamwidth, H-plane Array**

I. Introduction

A Taper Slot Antenna (TSA) is a special class of Antennas in which a slotline is flared to provide an aperture for microwave radiations in free space. The flare for widening of slotline can be provided with the help of straight line, exponential, elliptical or parabolic curve equation. For some specific application, a combination of two curves is also used to achieve the desired antenna characteristics. A Taper Slot Antenna (TSA) in which the slotline is flared using an exponential curve equation is termed as "Vivaldi Antenna" [1]. Vivaldi Antenna belongs to the end fire travelling wave antenna hence guide wavelength and the phase velocity are dependent on the substrate height, dielectric constant and taper rate. The length, width and taper profile affect the radiation characteristics of a Vivaldi Antenna as the gain of the Vivaldi Antenna is proportional to the L/λg [2]. The tapered slot is etched out from the thin metal layer deposited on to the substrate. Dielectric based or dielectric free Vivaldi Antenna can be fed through coaxial line, microstrip line, stripline or coplanar waveguide. The stripline or microstrip line fed Vivaldi Antenna can work over large bandwidths with symmetric beamwidth and high radiation efficiency. Vivaldi Antenna can be designed to achieve the bandwidth of 10:1. To achieve a wider bandwidth, the Vivaldi Antenna should have perfect impedance matching at both the feed-slotline and slotline-free space transition. Hence, the most important design aspect is to provide a suitable feeding and reduction in wave reflection at the transition regions [3].

II. Transition Regions and Impedance Matching

A coaxial fed Vivaldi Antenna can't provide broadband impedance bandwidth which is required in many broadband applications. Hence other alternative feeding techniques like microstrip to slotline or stripline to slotline is used and has been reported in literature [2]. In Microstrip-slotline transition, the microstrip feed acts as an impedance transformer and it matches 50Ω coaxial line to a high impedance slotline. The performance of Vivaldi Antenna depends on smoothness of the transition. It is therefore essential for a designer to look into the matching aspect of transition. Transition regions in a Vivaldi Antenna are shown in Fig. 1.

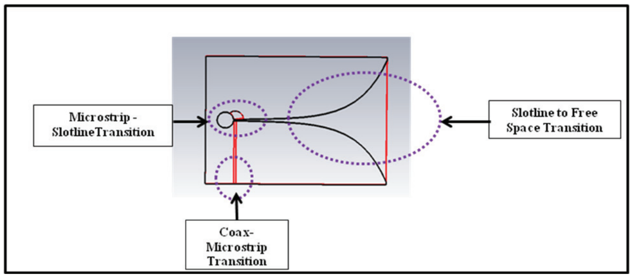

Fig. 1 Transition Regions in Vivaldi Antenna

The broadband impedance matching for Vivaldi Antenna employs orthogonal crossover of microstrip and slotline with radial stub at the end of microstrip and circular cavity at the end of slotline. This cavity acts as a virtual open circuit while the stub acts a virtual short at higher frequencies. This type of transition is commonly used for ultra broadband matching [4].

III. Design of Exponential Flare

The slotline to free space transition (as shown in Fig 1) is governed by exponentially flared slotline. The return loss of a Vivaldi Antenna is greatly affected by this transition. Hence, in order to get efficient radiation in free space, the width of the open end is generally kept greater than $\lambda_0/2$ [2]. This criterion plays an important role in lowering the reflections at the slotline-free space transition. Moreover, the flare and the rate of flare also affect the VSWR of the Antenna. An exponential flare [5] is selected and the equation of the flare is mentioned in equation 1.

$$y = C_1 e^{Px} + C_2 \tag{1}$$

Where,

$$C_1 = \frac{(y_2 - y_1)}{[e^{Px_2} - e^{Px_1}]}$$

$$C_2 = \frac{(y_1 e^{Px_2} - y_2 e^{Px_1})}{[e^{Px_2} - e^{Px_1}]}$$

P = flare or taper factor

(x_1, y_1) = flare start point coordinates

(x_2, y_2) = flare end point coordinates

The flare opening rate is controlled by flare factor P.

IV. Stripline-Slotline Matching

The exponentially opened slotline is generally fed by a microstrip feed because it is impossible to achieve an impedance of 50Ω for a slotline and hence various matching networks are employed to feed slotline with microstrip. To overcome this problem the concept of balanced slotline is used and instead of microstrip feed, stripline feed is used. As the stripline transmission line requires ground plane on both the sides hence the slotline printed on both the sides appear in parallel and can be matched with a 50Ω stripline. As explained earlier, for a broadband performance the slotline is terminated by a circular cavity and the stripline is terminated with a radial stub. This cavity-stub model is useful for designing broadband Vivaldi Antenna especially for Microwave frequencies. Cavity and radial stub cancel the reactance of each other which facilitates the impedance matching. The design of Stripline-Slotline transition is shown in Fig 2.

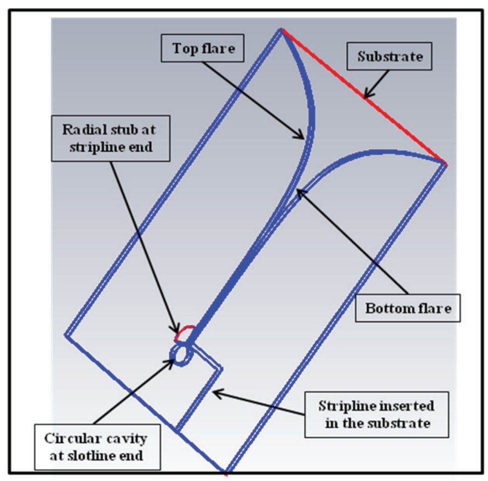

Fig. 2 Triplicate Vivaldi structure and Stripline-slotline transition

V. Design of C-Band Vivaldi Antenna

The mechanical dimensions for a Vivaldi Antenna operating for 4-8 GHz has been obtained by using design equations and a model has been designed simulated and optimized using CST Microwave Studio. As stated earlier, the substrate height and dielectric constant plays an important role in impedance matching hence 40 mil of Rogers RT/Duroid 5880 (ε_r= 2.22) has been found appropriate to achieve the desired bandwidth [6]. The design parameters are tabulated in Table I.

TABLE I DESIGN PARAMETERS OF C- BAND VIVALDI ANTENNA

Substrate	Slotline	Stripline	Circular Cavity	Radial stub
Rogers RT/Duroid 5880 (ε_r= 2.22)	Width = 0.25 mm	Width = 0.8 mm	Radius = 2 mm	Radius = 3 mm
Substrate height = 40 mil	100 Ω	50 Ω	Open circuit	Angle = 110^0

The taper length of the Antenna is chosen as 0.7*λ_0 where λ_0 is the free space wavelength calculated at 4 GHz to work as a travelling wave Antenna and the opening width of the Antenna is chosen as 0.66*λ_0 at lowest frequency of operation [6] [7]. These dimensions provide an efficient radiation from the Vivaldi Antenna in 4-8 GHz frequency range.

In the optimization process, the length width and the other parameters are varied in the ±10% range to check the effects of parameters on the Antenna characteristics [8]. The objective is to achieve the return loss better than -10 dB for the entire C-band.

The stripline fed C-Band Vivaldi Antenna is a complex structure and can give errors in simulated results. To ensure the accuracy of simulated results, we use adaptive meshing feature available in CST Microwave Studio. This feature helps in enhancing the accuracy of simulated results by using finer mesh cells. The return loss after four passes of simulation for our designed C-band Vivaldi Antenna is shown in Fig 3.

The return loss result for optimized C-band Vivaldi Antenna is shown in Fig. 4.

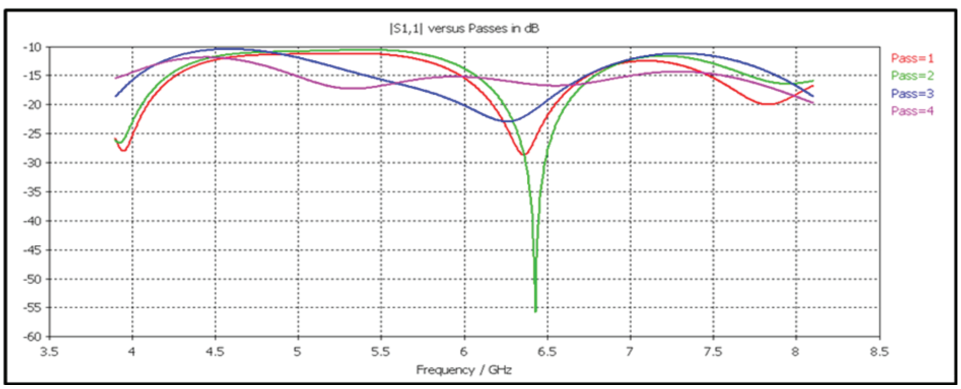

Fig. 3 Return Loss after Adaptive Meshing

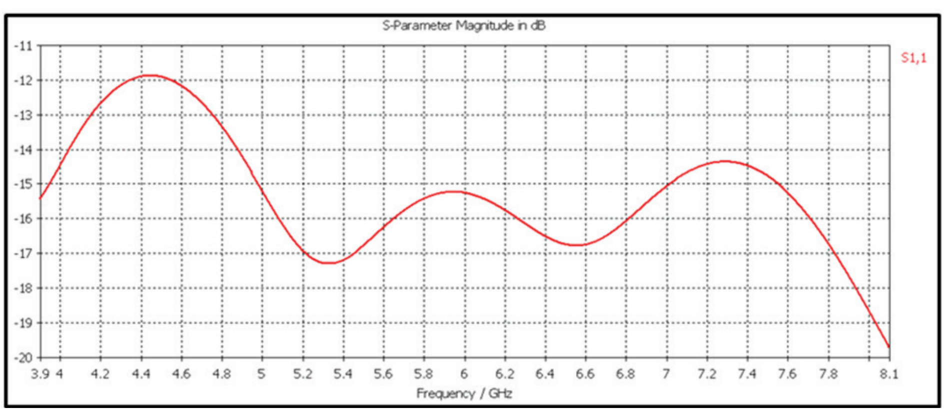

Fig. 4 Return Loss of the C-band Vivaldi Antenna

In general, the acceptable range of VSWR for broadband antenna is 2:1; however it is clear from Fig 5 that achieved VSWR for designed Vivaldi Antenna is 1.7:1 that is well below the maximum accepted VSWR. This helps in improving the radiation efficiency of antenna and minimizing the reflection losses.

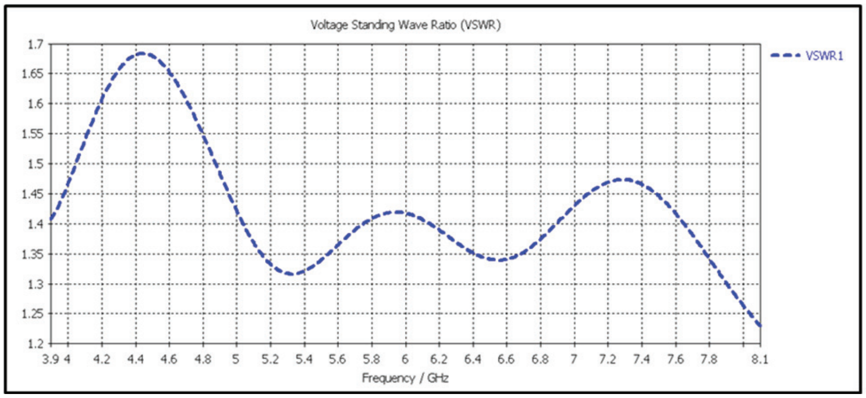

Fig. 5 VSWR of the C-band Vivaldi Antenna

The designed C Band Vivaldi antenna exhibits moderate gain of 4.5-8.6dB over the entire frequency range. The plot of Gain variation with frequency is shown in Fig 6.

The simulated model of dielectric based strip line fed C- Band Vivaldi Antenna has been shown in Fig 7. The antenna is quite compact in size as compared to that of available Antenna in this frequency range. This design offers exclusive advantages like lesser volume and ease of fabrication.

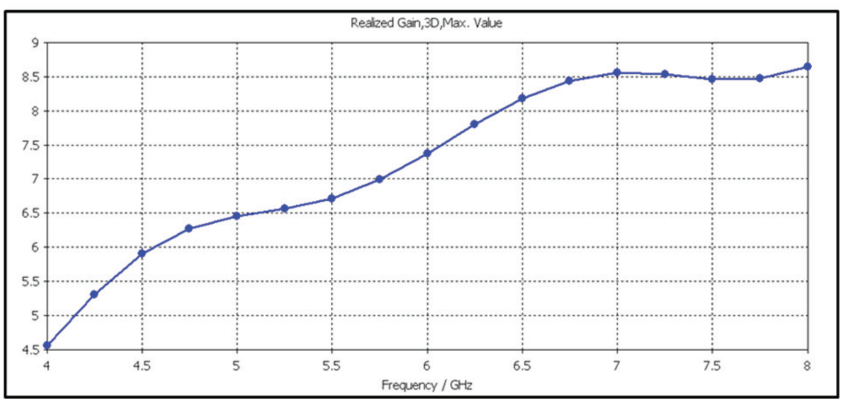

Fig. 6 Gain vs. Frequency Plot of C-band Vivaldi Antenna

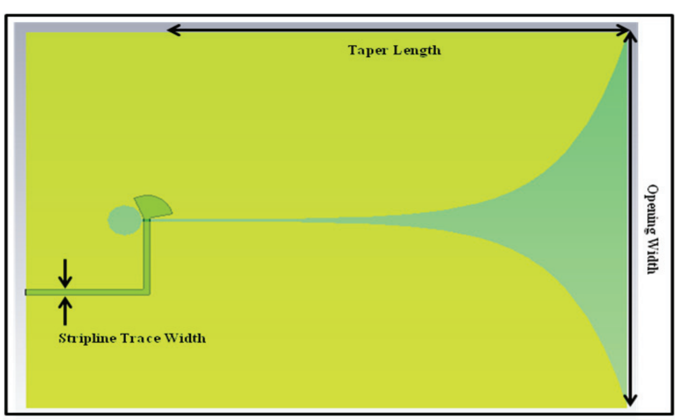

Fig. 7 Simulated C-Band Vivaldi Antenna

The half-power beamwidth for the optimized model is obtained in both Azimuth and Elevation planes. A typical radiation pattern of C-band Vivaldi Antenna at 4 GHz is shown in Fig 8.

The variations of half-power beamwidth with respect to the operating frequency band in both the principle planes are shown in Fig 9 & Fig 10 respectively.

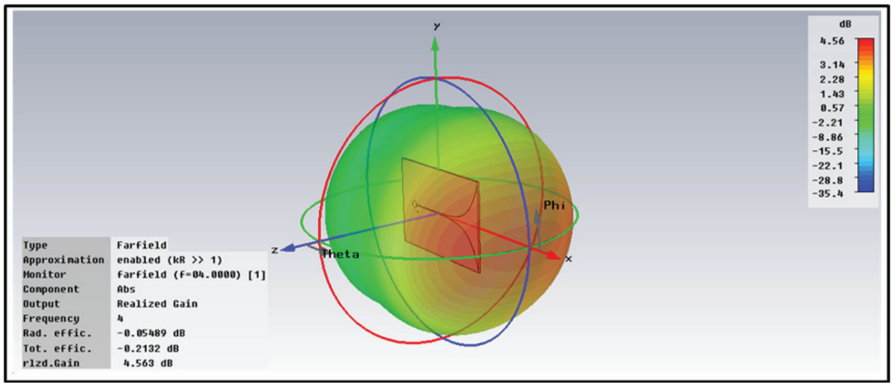

Fig. 8 Radiation Pattern at 4 GHz

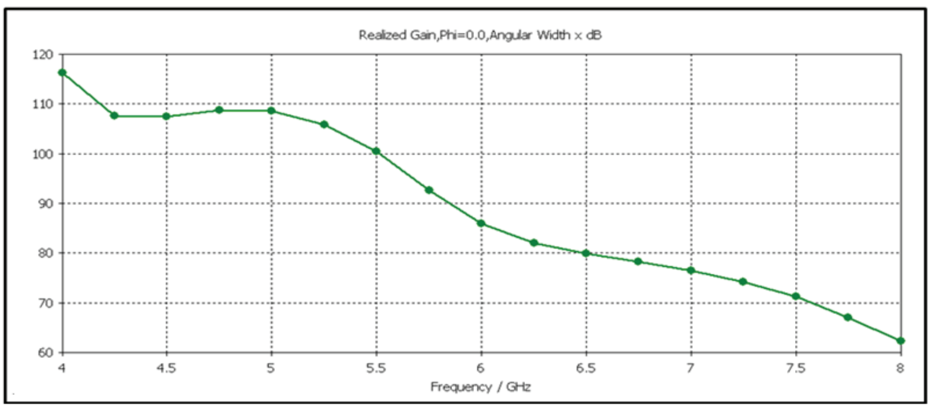

Fig. 9 Half-power beamwidth in Azimuth Plane

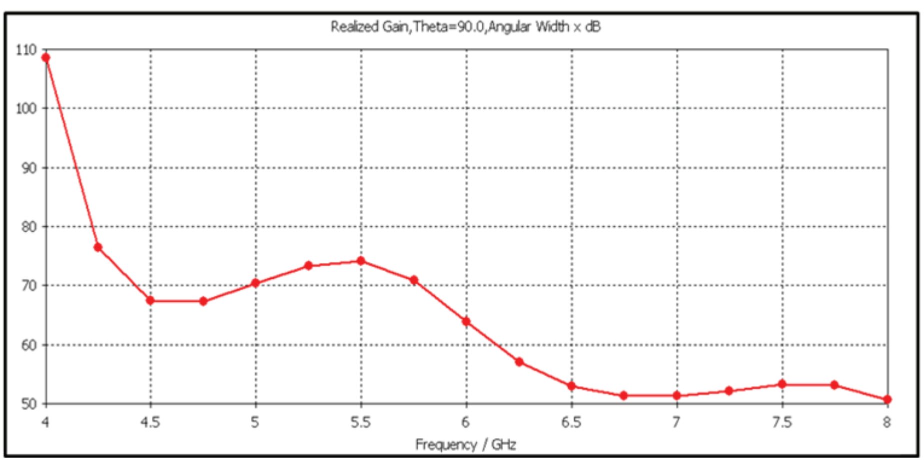

Fig.10 Half-power beam width in Elevation Plane

The Fig 9 and Fig 10 suggest that the minimum half-power beamwidth of the designed C-Band Vivaldi Antenna is more than 50^0. This makes this antenna a suitable candidate for wide angle scan array operating in C-band. Based on this performance, a 5x1 H-plane array is designed and simulated.

VI. Design of 5X1 H-Plane Array

In phased array of Vivaldi Antenna elements, the grating lobes occur at wide angle scanning. The grating lobe is an unwanted radiation beam having magnitude almost equal to the main lobe. The grating lobes free region is always preferred and can be achieved by proper interelement spacing. The grating lobes free interelement spacing is given in equation 2:

$$d = \frac{\lambda_0}{1+\sin\theta} \quad (2)$$

Where,

d = interelement spacing in mm

λ_0 = free space wavelength at highest frequency of operation in mm

θ = Maximum scan angle from array boresight

For 8 GHz and 75^0 scan in Azimuth plane we get d = 19mm. Hence, we design a 5x1 H-plane Vivaldi Antenna array in which Vivaldi elements are separated with each other (centre to centre) by 19 mm. The designed H-plane array is shown in Fig 11.

In an antenna array, all the antenna elements are kept very near to each other in order to reduce the possibility of grating lobes. This creates mutual coupling among the antenna elements. The mutual coupling affects the antenna performance. The performance of antenna in array can be obtained by exciting the centre element and terminating all the remaining elements. Then the performance parameters like Return Loss/VSWR, Radiation Patterns in principle planes and Gain are simulated.

In our 5x1 H-plane C-Band Vivaldi Antenna Array, the centre element (as shown in Fig 11) is excited and all other antenna ports are terminated to find out the effect of mutual coupling on Antenna performance. The obtained results have been compared with the individual antenna performance and shown in Fig 12, Fig 13, Fig 14 and Fig 15.

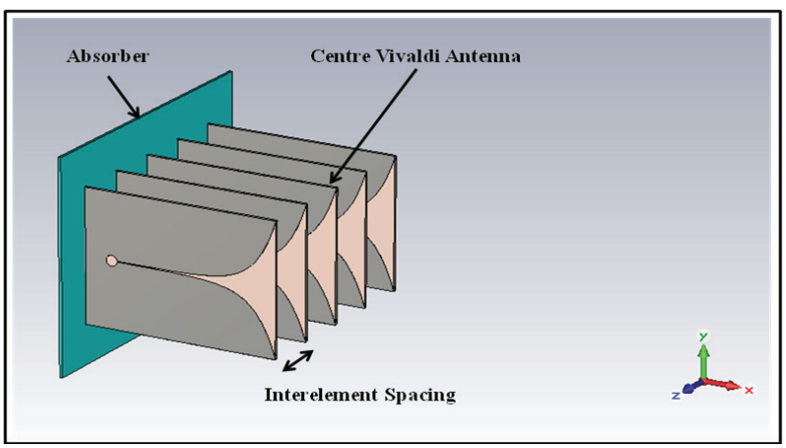

Fig. 11 5x1 H-plane C-Band Vivaldi Antenna Array

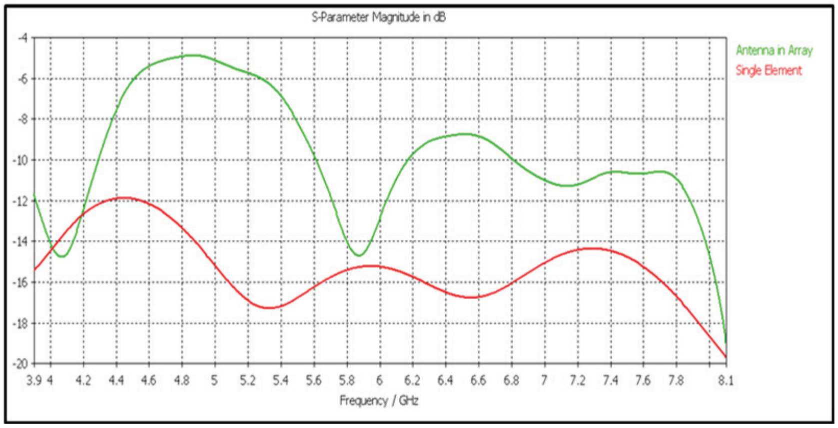

Fig. 12 Return Loss Comparison

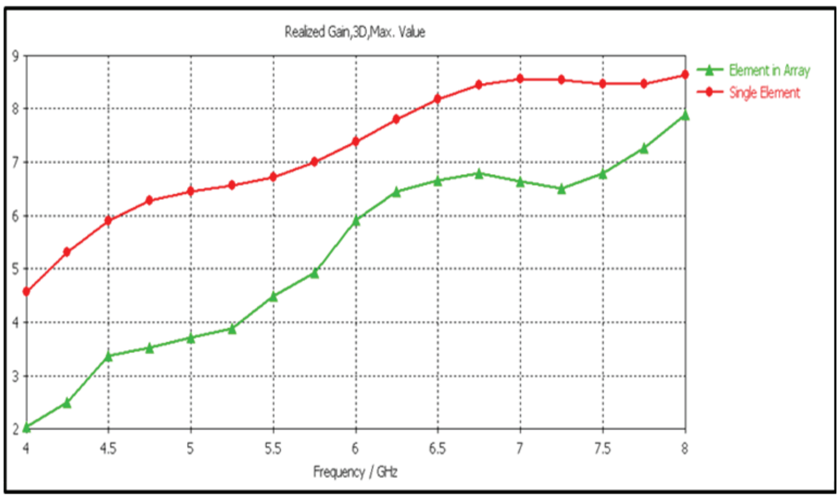

Fig. 13 Gain Comparison

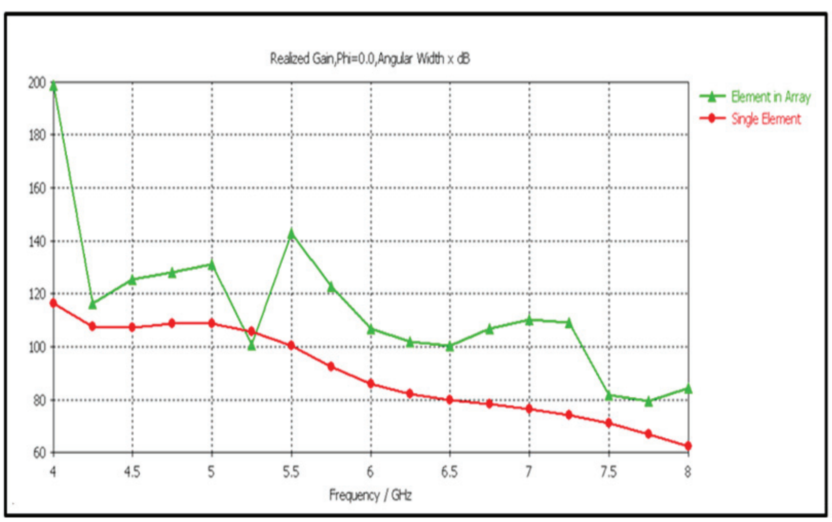

Fig. 14 Azimuth Beamwidth Comparison

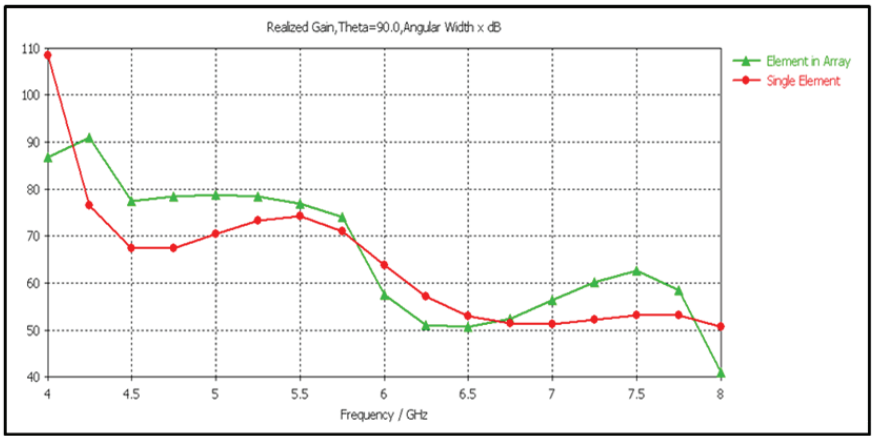

Fig. 15 Elevation Beam width Comparison

VII. Discussion and Conclusion

A single C-Band Vivaldi Antenna and its 5x1 H-plane array have been designed and the performance of single Vivaldi Antenna has been compared with Vivaldi Antenna in Array. The comparison shows that although the Vivaldi Antenna has been optimized for return loss better than -10 dB but the return loss degrades, once the element is put in the array of same Vivaldi antenna elements (as shown in Fig 12). This indicates that the power reflection from the Vivaldi Antenna in array is more as compared to single Vivaldi Antenna.

Fig 13 suggests that the gain of the Vivaldi Antenna in Array is less as compared to the individual Vivaldi Antenna. The reduction of gain in array is ranging from 0.5 to 2.5 dB for higher to lower frequency respectively.

The half-power beamwidth in principle planes (Fig 14 & Fig 15) for Vivaldi Antenna in array is more than single Vivaldi Antenna (except some frequencies). This feature helps in designing phased arrays for wide angle scanning. The minimum Azimuth-plane beamwidth is 800 for Vivaldi antenna in array, hence scanning for $\pm 40^0$ in azimuth plane can be done within 3dB loss in radiated power.

C-band Vivaldi Antenna and its array simulation have given expected results in terms of VSWR, Gain, and Radiation pattern. The Antenna presented in this paper can be used as an Antenna for low gain and limited range applications like cordless telephony and Wi-Fi communication. For high gain applications like Satellite Communication and weather Radars, H-plane phased array of C-band Vivaldi Antenna can be used and the number of elements can be calculated based on the Effective Radiated Power (ERP) requirement. In case of Weather Radars, which are mostly operating in C-band and using parabolic dishes for high ERP, the H-plane Vivaldi Antenna arrays can be designed using the reported C-Band Vivaldi Antenna element. Also, this Antenna can be used in C-Band mobile military battlefield surveillance and ground surveillance radar sets with short or medium range. The compact size of Antenna offers competitive advantage of lighter weight, lesser volume, better accuracy and resolution.

Acknowledgement

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