Effect of Vivaldi Element Pattern on The Uniform Linear Array Pattern

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Effect of Vivaldi Element Pattern on The Uniform Linear Array Pattern

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***Abstract*— This paper presents about the effect of Vivaldi element pattern on the Uniform Linear Array pattern. Vivaldi antenna can operate over wide bandwidth. Geometry of the radiating element influences element radiation pattern especially for frequency far from the center frequency. In this paper, we reported coplanar Vivaldi antenna with dimension 60x60 mm on FR4 substrate with permittivity 4.7. The antenna has differents element pattern at 2 GHz, 3 GHz and 4 GHz. It is shown that bad radiation pattern in certain frequency in broadband antenna can effects on the total array pattern. Differents element pattern, spacing and number of elements resulted different array pattern. We simulated variation 5 mm and 15 mm spacing between adjacent sides of Vivaldi elements and variation 3 and 10 number of elements in each frequency. From simulated resulted shows that the total array pattern has higher back lobe level than main lobe level for N=5, d=0.433λ at 2 GHz due to its elements pattern performance. Gain of the main lobe level is obtained as 10.81 dB at 3 GHz, N=5, d= 0.65λ. Gain of the array pattern increased and HPBW decreased with increasing number of elements. From simulated result, it reveals that good performance of element pattern and total array pattern is achieved at 3 GHz, 4 GHz and 2 GHz respectively. Increasing operating frequency will affect its sidelobe performance due to different spacing between elements relative to certain wavelength. Although broadband antenna has return loss below -10 dB in all band frequency, it must be better to know element pattern in each operating frequency. It can avoid bad performance of total array pattern in certain frequency. Simulation by using multiplication element pattern with array factor can reduce computation time compared with full wave simulation. But it does not consider mutual coupling effect.**

Keywords*— *Vivaldi; radiation pattern; antenna; array factor; array pattern.

I. INTRODUCTION

Array antenna has many advantages compared with individual element because it can increase gain and reduce beamwidth. The total array pattern can be influenced by radiation pattern of element and array factor. Array factor depends on the number of elements and space between elements, amplitude and phase of each elements. Weighting of the signal can improve antenna array performance. It can reject interference or improve beemsteering process without changing physical antenna[1]. Many paper has presented to get Array factor and total array pattern performance with dipole or isotropic elements[2].

There are many broadband Vivaldi antenna has been designed to get return loss performance[3] and radiation pattern performance[4]. Vivaldi antenna can be arranged in array[5] and applied for many application. Nowdays antenna is developed by reducing element size to earn low cost in fabrication. Wideband antenna can be constructed from small size of radiator with comparison of the length and width elements asymmetry[6] or symmetry. Many paper has been published to get vivaldi performance with many variety shape of radiator, variety feeding and substrate[7]. Sometimes broad band antenna has good return loss performance in all band frequency but the radiation pattern at each frequency have different shape especially for frequency which is far from the center frequency.

There are many methods of array antenna analysis in the linear, planar, circular or conformal array[8]. The more discussed array antenna about array configuration and array synthesis to change array factor and array pattern performance. The pattern synthesis by non uniform element position in linear array has been presented[9]. There are many array synthesis to get optimum array pattern with many complex algorithm by dipole or isotropic elements and none of them review about total array pattern of the broad band element. Before we optimise array configuration in broadband antenna. it could be better to know element pattern in each frequency to get better total array pattern.

In this paper we discuss about the effect of Vivaldi element pattern from each frequency in the uniform linear array. Vivaldi antenna has different radiation characteristic with dipole or isotropic element. It has endfire radiation. Principally of Vivaldi antenna is the current distribution happened between two exponential tapered slot. It is shown that bad radiation pattern in certain frequency in broadband antenna can effects on the total array pattern. The best way to improve total array pattern is enhance element radiation pattern performance first in each frequency for broadband antenna and then optimize array factor performance. It can avoid mistakes of mainlobe position of total array pattern. Total array pattern by using multiplication element pattern and array factor can reduce computation time compare with using full wave simulation. In this simulation, we did not consider mutual coupling effect. In the following section, it will explain about the effect of element pattern in each frequency to the total array pattern with varying spacing between element and varying the number of elements.

II. THEORY

A. Array Antenna

Antenna array can reach high gain and small half power beamwidth. Fundamental of array antenna is Uniform linear Array. Array Pattern(AP) in antenna array is multiplication radiation pattern of antenna element (g) and Array Factor

$$AP(\theta,\varphi) = g_{ae}.AF(\theta,\varphi) \tag{1}$$

Array factor from the isotropis point source is summing of the receive weighting

$$w_n = a_n e^{j\delta_n} \tag{2}$$

$$AF = \sum_{n=0}^{N} a_n\, e^{j\psi_n} e^{j\delta_n} = \sum_{n=0}^{N} a_n e^{j(\psi_n+\delta_n)} \tag{3}$$

$$\psi_n = kdu \tag{4}$$

$$kd\ cos\varphi\ or\ kd\ sin\theta\quad along\ x\ axis$$

$$kdsin\varphi\ or\ kd\ sin\theta\quad along\ x\ axis$$

$$kd\ cos\theta\qquad along\ z\ axis \tag{5}$$

$$\psi_n = -kd\sin\varphi \quad \delta_n = -\beta d\sin\varphi_0 \tag{6}$$

Array factor will be maximum if ψ=0. For array antenna in the E plane configuration, Vivaldi elements is arranged along of y axis. It is endfire (φ_0=0^0) radiation.

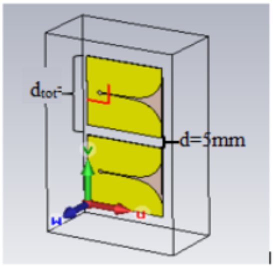

Fig.1. vivaldi antenna in E plane

d total in E plane is summation of width of the substrate ($w_{substrate}$) and spacing(d) between adjacent sides of elements.

B. Broadband Vivaldi Antenna.

Broadband or Ultra Wide Band antenna can be used in many application. Bandwidth of antenna relative from the center of frequency.

$$f_c = \frac{1}{2}(f_h + f_L) \tag{7}$$

Fractional bandwidth (FBW) can be defined :

$$BW = \frac{BW}{fc} = 2\frac{f_H - f_L}{f_H + f_L} \tag{8}$$

UWB have FBW more than 50% and Wideband has FBW 20% Vivaldi antenna is one types of broadband antenna, and the exponential tapered slot can be designed with the equation:

$$y = C_1 e^{Rx} + C_2 \tag{9}$$

$$C_1 = \frac{y_2 - y_1}{e^{Rx_2} - e^{Rx_1}} \tag{10}$$

$$C_2 = \frac{y_1 e^{Rx_2} - y_2 e^{Rx_1}}{e^{Rx_2} - e^{Rx_1}} \tag{11}$$

R=0.13 is exponential rate. Coplanar Vivaldi antenna is designed by FR4 substrate, with substrate thickness is 1.6 mm

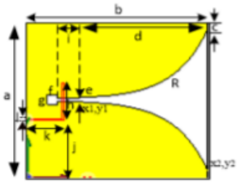

Fig.2. Coplanar Vivaldi Antenna

TABLE.I. PARAMETER OF ANTENNA

Dimension in mm			
a=60	d=40	g=5	j=15
b=60	e=0.6	h=28	k=25
c=17.5	f=5	i=0	l=2

III. SIMULATED RESULT AND DISSCUSSION

A. Return Loss

Bandwidth impedance of the antenna will be match if return loss has value below of -10 dB and it related with Voltage standing Ratio. If we set VSWR is 2, Reflection coefficient (|Γ|) of the antenna is 0.33 and in the decible scale will be found as -10dB. From the graph, it shows that from 2 GHz until 3 GHz, antenna have good return loss performance with minimum return loss is -34.08 at 2.166 GHz and the best VSWR is 1.04.

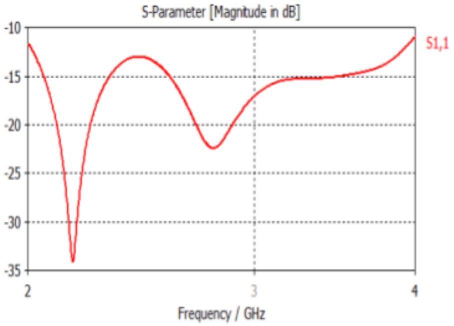

Fig.3. Return loss of vivaldi antenna

B. Radiation Pattern.

Radiation pattern is variation of the power radiated as function of elevation and azimuth degree.

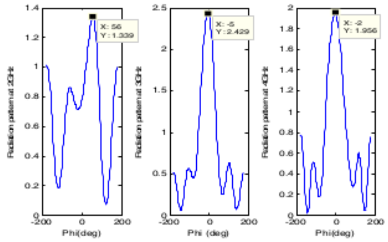

Fig.4. Element pattern in each frequency

Cartesian plot of gain in linear scaling at 2 GHz, 3 GHz and 4 GHz in theta 90 and varying phi is shown in fig 4. Absolute gain is obtained for 2 GHz is 1.339, for 3 GHz is 2.429 and for 4 GHz is 1.956. The best gain is reached in the center frequency at 3 GHz. Backlobe at 2 GHz is 1.002, at 3 GHz is 0.5147 and at 4 GHz is 0.7615. The worst backlobe is happened at 2 GHz.

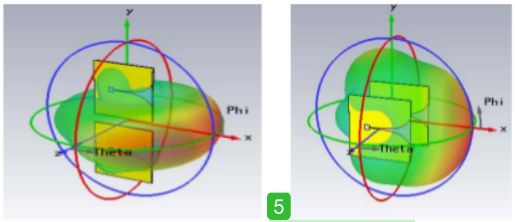

Fig.5. Vivaldi array in E plane and H plane

E plane and H plane in 3D plot of two Vivaldi array antenna is denoted in fig.5.We just simulate array in E plane and not simulated in the H plane yet. It is simulated by cst and matlab. We set spacing between elements by summation of width of substrate and distance of the adjacent side between elements(d). Array Factor and array pattern will be changed with varying space and varying number of element.

C. Array Pattern with varying spacing of elements

We simulated two different spacing of elements. For this simulation, we set the number of elements is 5.

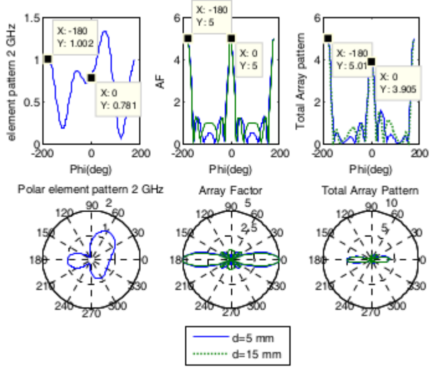

Fig.6. Cartesian and polar plot radiation pattern at f=2 GHz

Radiation pattern of Vivaldi antenna at 2 GHz shows asymmetry pattern. It has large main beam, high peak side lobe level and high back lobe level. It can be happened because the dimension of antenna smaller than a half of wavelength in 2 GHz (150mm). Difference radiation pattern for d=5mm and d=15mm is denoted in fig.6. For d=5mm, Spacing between adjacent sides of the elements is 5 mm and the the total space is 65mm. The total space for d=15mm is 75mm. It gets from summation of width of the substrate and d. It is related with wavelength as 0.433λ for d_total is 65mm and 0,5λ for d_total is 75 mm at 2GHz. Spacing between elements in dipole array antenna is different from in Vivaldi elements. In dipole array if we set spacing between elements more than 1 λ, it will appear grating lobe but in Vivaldi its depend on its element pattern. In coplanar Vivaldi antenna, current distribution propagate in the middle of radiator. It radiated between two exponential tapered slot. Width of the substrate in Vivaldi antenna will interfere spacing between element in array configuration. If element pattern has bad radiation pattern, the total array pattern will be bad too. Wider spacing between elements, it will slighty smaller beamwidth and higher side lobe level. It is seen that back lobe level higher than mainlobe level at 2 GHz.

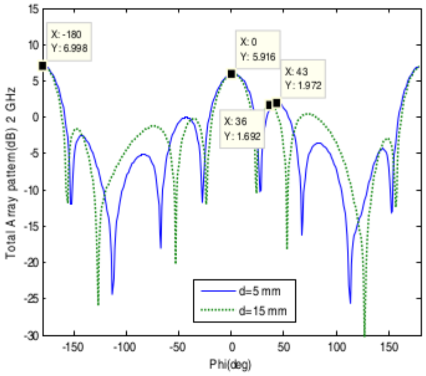

Fig.7. Total Array Pattern in decibel scale at f=2 GHz

TABLE.2. VARY SPACING AT 2 GHZ

Space elements	d=0.433λ (65mm)	d=0.5 λ (d=75mm)
Main lobe (dB)	5.916	5.916
Back lobe (dB)	6.998	6.998
Peak Side Lobe Level (dB)	1.972	1.692
HPBW(degree)	30	36

Wider spacing between elements can not higher gain and smaller HPBW with significantly of the total array pattern. It is shown that total array pattern yields higher back lobe level at 2 GHz than main lobe level. If we arrange array pattern from bad element pattern at certain frequency It could be reason that the main lobe not in the right direction.

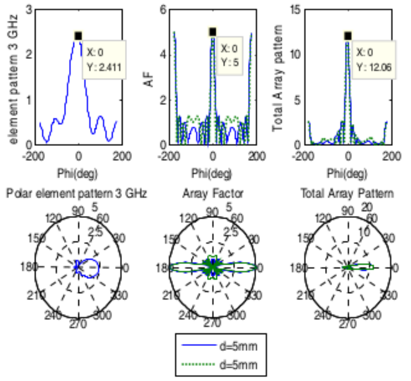

Fig.8. Cartesian and polar plot at f=3 GHz

In the center frequency (3 GHz), if spacing between elements is set at d= 5mm (0.65 λ), it will get smaller peak side lobe level than peak side lobe level at d=15mm (0.75 λ). It is different array pattern at 2 GHz. At 3 GHz, mainlobe gain can reach 12.06 in linear scale and lower backlobe level than at 2 GHz.

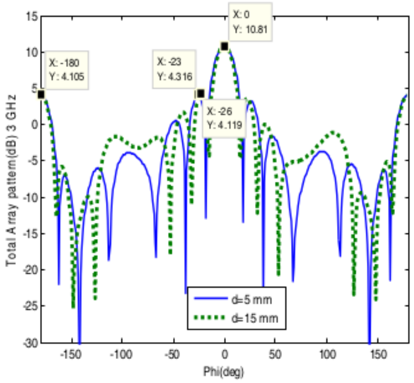

Fig.9. Total Array Pattern in decibel scale at f=3 GHz

TABLE.3. VARY SPACING AT 3 GHZ

Space elements	d=0.65λ (65mm)	d=0.75 λ (d=75mm)
Main lobe (dB)	10.81	10.81
Back lobe (dB)	4.105	4.105
Peak Side Lobe Level (dB)	4.119	4.316
HPBW(degree)	22	20

The total array pattern level has the same value for both diferent spacing. Extensive spacing of elements will increase side lobe level and reduce HPBW. It can shown from table 3 that side lobe level increase from 4.119 dB to 4.316 dB.

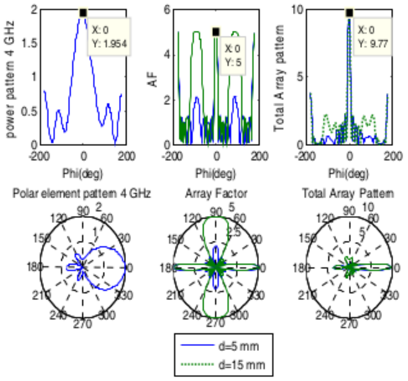

Fig. 10. Cartesian and polar plot at f=4 GHz

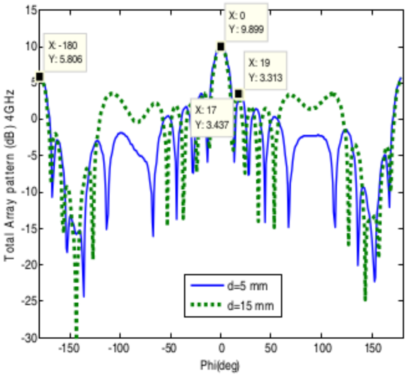

Fig.11. Total Array Pattern in decibel scale at f=4 GHz

TABLE.4. VARY SPACING IN 4 GHZ

Space elements	d=0.867λ (65mm)	d=1 λ (d=75mm)
Mainlobe (dB)	9.899	9.899
Backlobe (dB)	5.806	5.806
Peak Side Lobe Level (dB)	3.313	3.437
HPBW(degree)	16	14

Back lobe level and side lobe level at 4 GHz get worse performance than Back lobe level and side lobe level at 3 GHz. But the worst backlobe is get for 2 GHz. The best HPBW is get at 4 GHz. HPBW at 3GHz better than HPBW at 2 GHz.

D. Array Pattern with varying number of elements

Different number of elements can affect on array factor and total array pattern. In this paper, we simulated different number of element with equal spacing at d=15mm

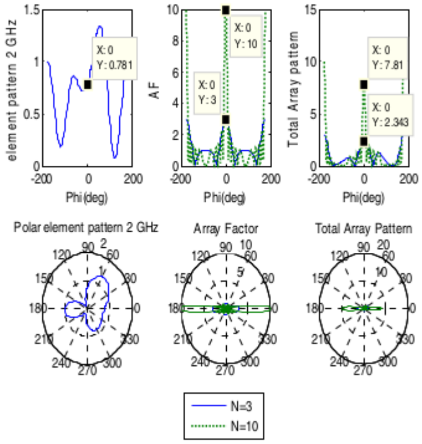

Fig.12. Cartesian and polar plot at f=2 GHz

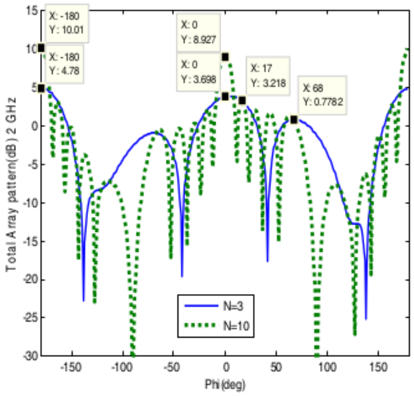

Fig.13. Array Pattern in decibel scale for f=2 GHz

TABLE.5. VARYING NUMBER OF ELEMENT IN 2 GHZ

Space elements	N=3	N=10
Mainlobe (dB)	3.698	8.927
Backlobe (dB)	4.78	10.01
Peak Side Lobe Level (dB)	0.7782	3.218
HPBW(degree)	58	14

Increasing number of elements will effect on total array pattern. It influences performance of main lobe, back lobe, peak side lobe level and HPBW. If antenna has bad radiation pattern, by increasing number of element, it will make higher back lobe level than main lobe level. It is shown that backlobe level for N=3 is 4.78 dB and back lobe level for N=10 is 10.01 dB. This appearance could make the peak of main beam not in the desired direction. HPBW for N=10 smaller than HPBW N=3.

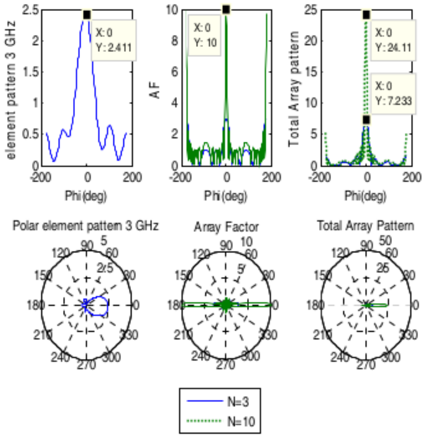

Fig.14. Cartesian and polar plot at f=3 GHz

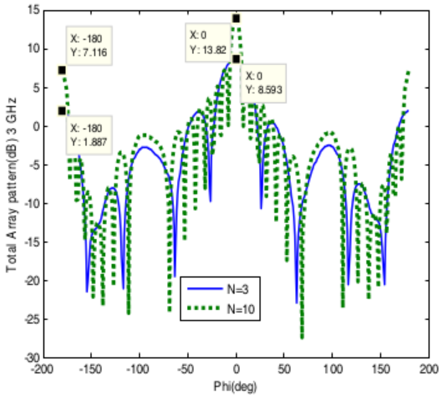

Fig.15. Array Pattern in decibel scale for f=3 GHz

TABLE.6. VARYING NUMBER OF ELEMENT IN 3 GHZ

Space elements	N=3	N=10
Main lobe (dB)	8.593	13.82
Back lobe (dB)	1.887	7.116
Peak Side Lobe Level (dB)	0.346	6.998
HPBW(degree)	36	8

Main lobe level at 3 GHz can reach 13.82 dB for N=10 and 8.593 dB for N=3. Increasing number of element will increase main lobe level of the antenna and reduce HPBW. HPBW for N=10 smaller than N=3. It is shown that HPBW for N=10 is 8^0 and HPBW for N=3 is 36^0. Performance of back lobe level and peak side lobe for N=3 better than for N=10. Backlobe level for N=3 smaller than backlobe level for N=10. Peak side lobe level for N=3 smaller than N=10.

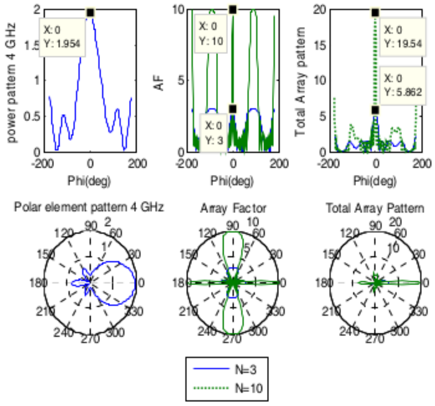

Fig.16 Cartesian and polar plot for f=4 GHz

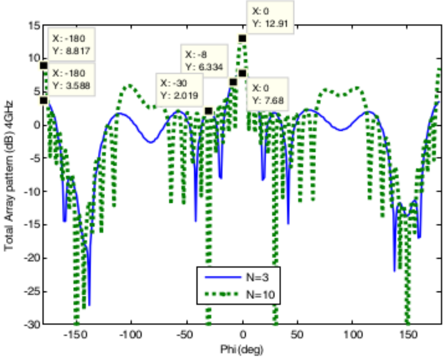

Fig.17. Array Pattern in linear and decibel scale at f=4 GHz

TABLE.6. VARYING NUMBER OF ELEMENT AT 3 GHZ

Space elements	N=3	N=10
Main lobe (dB)	7.68	12.91
Back lobe (dB)	3.588	8.817
Peak Side Lobe Level (dB)	2.019	6.334
HPBW(degree)	24	6

Peak side lobe level at 4 GHz higher than at 3 GHz. If we set spacing from adjacent sides is 15 mm or the total spacing is 75mm, it can be related in wavelength as 0,5λ at 2 GHz (wavelength=150mm), 0,75λ at 3 GHz (wavelength=100mm) and 1λ at 4 GHz (wavelength=75mm). It shows that In the same spacing from adjacent sides of elements (15mm or the total spacing=75mm) resulted difference spacing relative to the wavelength. It means that higher operating frequency in broadband antenna will increase spacing between element relative to the wavelength at certain frequency. It can effect on the total array pattern performance especially for side lobe level performance. Different spacing and different number of antenna element has different properties in each operating frequency.

IV. CONCLUSION

This paper studies the effect of Vivaldi element antenna from each frequency to the total array pattern. Broadband antenna could have different element pattern in different operating frequency. It depends on it's geometry of the radiating element and substrate. Antenna element could have asymmetry radiation pattern, high sidelobe and backlobe especially for frequency far from the center frequency. It will impact on the total array pattern. It makes backlobe or peak side lobe level of the total array pattern more than main lobe level. In coplanar Vivaldi antenna, current distribution propagate in the middle between two exponential tapered slot. Width of the substrate in Vivaldi antenna will interfere spacing between element in array configuration. Increasing spacing of antena element can not improve gain. It reduces slighty of HPBW and increase peak side lobe level. More number of antennas will create higher gain, smaller HPBW, higher peak of side lobe level of the total array pattern and increase number of side lobe. Operating frequency in broadband antenna will influence spacing between element. it can effect on the total array pattern performance. From simulated result shows that good performance of total array pattern can be reached for frequency 3 GHz, 4 GHz and 2 GHz repectively. It is consider that if we want to design array antenna from broadband antenna, it must be better to know the element pattern in each operating frequency.

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