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Research paper

An ultra-wide band printed small aperture tapered slot phased array antenna covering 6-18GHZ

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Abstract

For phased array applications covering ultra wide bandwidth, it is necessary to restrict the size of the aperture to less than λ/2 at highest frequency of operation. For 6-18 GHz coverage, an aperture size of less than 9.76mm is required for scanning to ±450 without appearance of grating lobes and occurrence of element pattern nulls over the band. Meeting this requirement a printed tapered slot antenna has been designed with the above aperture size. Detailed parametric studies have been carried out over 6-18 GHz and dimensions have been opti-mized for return loss. The design has been carried out with HFSS software. A return loss of less than -7.5dB across 5.6 - 20 GHz has been obtained for a single antenna. Also satisfactory radiation patterns have been obtained.

Keywords: *Ultra Wideband; Phased Arrays; Printed Tapered Slot Antenna; Parametric Analysis; Grating Lobes.*

1. Introduction

Ridged horns, Equiangular spirals, Archimedean spirals, Log periodic antennas and some planar slot loaded printed antennas have been used for large bandwidth applications. Tapered slot antennas (TSA) and their variants have recently come into focus particularly for wideband phased array applications. Some ridge gap wave guide designs have also been reported in literature. For Communications and EW applications covering frequency range of 1-18GHz and for use in phased arrays several variants of TSA have been successfully used. For operation over 6-18GHz in phased arrays which is the bandwidth of interest in this paper, the spacing between elements should be less than about 0.586 λ_h, where λ_h is the wavelength corresponding to the highest frequency, for scanning to ±45^0, and for avoidance of grating lobes and element pattern nulls. The spacing between the elements for this condition should be no more than 9.76mm. With this spacing at 6GHz, the spacing between the elements becomes 0.195 λ_L, where λ_L is the wavelength corresponding to lowest design frequency. Vivaldi radiators can easily be made to operate from 8-18GHz with this spacing and a return loss of less than -10dB (VSWR=2.0) can be obtained with satisfactory radiation patterns. At lower than 8GHz the resistive part of the input impedance becomes very small resulting in large VSWR. In the following paragraphs printed multi octave band phased array antennas are surveyed.

Nurad and MIT jointly developed a 3:1 and 9:1 bandwidth dual polarized planar phased arrays using Vivaldi antenna [1]. The 9:1 array is reported to be operating over 2:18GHz with an inter element spacing of 7.5mm. In this paper, an overview of the development is given without much dimensional details. In another paper, a wideband Vivaldi antenna array with a 5:1 bandwidth intended for radio astronomy applications is reported [2]. A phased array with 3:1 bandwidth has been described in literature with a frequency range of 6-18GHz and scanning to ±45^0 [3].

A dual polarized Vivaldi antenna with capability for wide angle scanning has also been reported. This antenna covers 6-18GHz. Only simulations have been reported using FDTD technique [4]. In another design, Antipodal Vivaldi antenna using parasitic elliptic patch has been designed. This has an aperture size of 66mm covering 6-21GHz [5]. A 2.4GHz to 18 GHz antenna with an aperture size of 44mm is also found in literature [6].

A BAVA antenna with an aperture size of 14.5mm operating over 3-9GHz has been reported [7]. Another BAVA antenna with an aperture size of 44mm covering 1-20GHz can be found in literature [8]. A multi octave band antipodal Vivaldi antenna with a return loss of less than -7.5dB and an aperture size of 20mm has also been reported [9]. This is the largest bandwidth of 1-40 GHz reported with an aperture size of 20mm. A novel, small aperture tapered slot antenna has been reported covering 7.2-18.0 GHz with a return loss of less than -7.5dB in simulation and with frequency coverage of 7.7-18.0GHz in hardware with an aperture size of 9.5mm [10].

It can be seen from the above, that almost all the printed antennas excepting one or two designs have an aperture size of more than 20mm and therefore are not suitable for phased array applications for scanning to ±45^0 and for a frequency coverage of 6-18GHz. The Nurad antenna cited above is reportedly the only printed antenna covering 6-18GHz with a VSWR of less than 2.0.

In view of the above, the authors have designed a modified Vivaldi antenna which yielded a return loss of less than -7.5dB over 6-18GHz using HFSS software and satisfactory radiation patterns have been obtained. The reference antenna for this design is the small aperture antenna with a 9.5mm aperture cited above [10].

2. Antenna geometry

The sketch of the antenna is shown in Fig.1. The antenna is designed using a substrate with a dielectric constant of 3.66. The antenna has two substrates joined together. The top one is a Vivaldi Tapered slot antenna (TSA) having exponential taper with a sinusoidal function superimposed on it. The slot is terminated at the backend by two circular slots and is excited by a microstrip line located on the bottom substrate. The input power is electromagnetically coupled to the narrow slot having TSA. This input micro stripline is terminated in a sectoral stub. Optimization of various parameters has been done which is given below and has led to a frequency coverage of 6-18GHz.

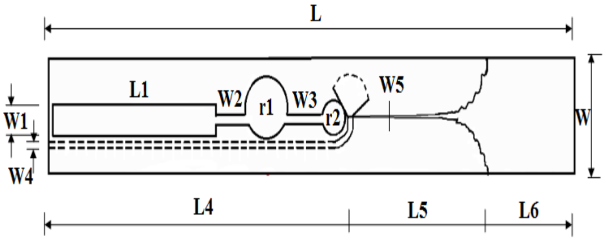


Fig. 1: Antenna Geometry.

3. Parametric studies

Referring to Fig 1. some of the important parameters that have been varied to achieve a bandwidth of 6-18GHz with a return loss of less than -7.5dB are given below.

- Growth rate of the exponential taper superimposed by a sinusoidal function 'a'
- Circular cavity radius 'r_2'
- Line width 'W_3' between first and second circular cavities
- Circular cavity radius 'r_1'
- Line Width 'W_2' between stub and first circular
- cavity
- Length of the slot line stub 'L_1'
- Width of the stub 'W_1'
- Extension of substrate beyond the taper 'L_6'.

With the above parametric variation the dimensions have been optimized to achieve 6-18GHz coverage with a return loss of less than -7.5dB and these are given at table1.

3.1. Return loss variation with growth rate 'a'

Initial design specifications derived from the reference paper [10] are

L=50mm, L_1=17.0mm, W_1=2.0mm, W_2=W_3=0.7mm, r_1=2.3mm, r_2=1.38mm, a=0.7.

Firstly, keeping all the other variables constant as given above, the exponential growth rate of the tapered slot (a) is varied from 0.2 to 0.9 and return loss curves are obtained. However growth rate variation from 0.5 to 0.9 is only shown in Fig.2 for clarity. Others have not yielded desired bandwidth and hence omitted. a=0.6 yielded a return loss of less than -5dB over [6-18] GHz which is the optimum value.

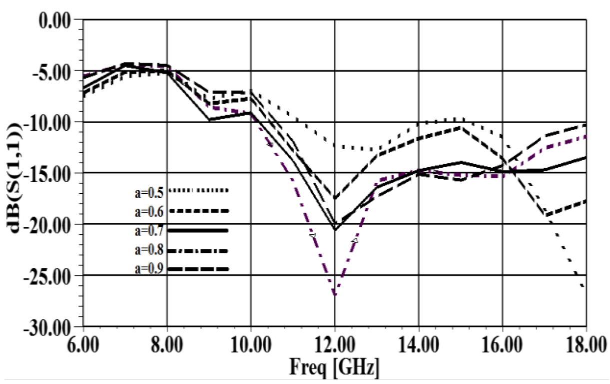


Fig. 2: Frequency vs. Return Loss with Growth Rate 'A'.

3.2. Return loss variation with circular cavity radius 'r2'

Second circular cavity radius r_2 is varied from 1.38mm to 1.45mm. Substantial variation of return loss is observed between 11GHz to 16GHz. while a resonant behavior is observed at 12GHz. Return loss is less than -7.5dB from 7.5GHz to 18GHz for r_2=1.42mm.

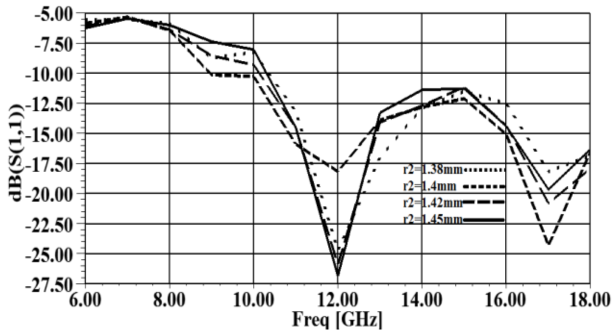


Fig. 3: Frequency vs. Return Loss with Length 'R_2'.

3.3. Return loss variation with width of the stub 'w3'

The spread in the variation is maximum at 12GHz, where a resonance is observed. The solid curve with w_3=0.69mm gives maximum bandwidth with a return loss of less than -7.5dB over 7.7GHz to 18GHz.

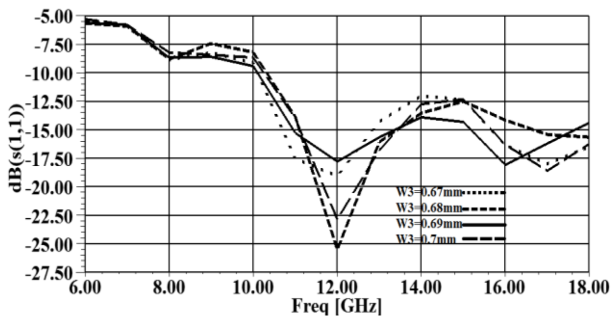


Fig. 4: Frequency vs. Return loss with Width 'W_3'.

3.4. Return loss variation with circular cavity radius 'r1'

Return loss curves are similar to that of variation with respect to r_2 given above. Once again a resonance is obtained at 12GHz. It can be observed that spread in the curves is much less compared to r_2 variation shown in Fig3.The solid curve with r_1=2.6mm gives the maximum frequency bandwidth with a return loss less than -7.5dB between 7.6GHz to 18GHz.

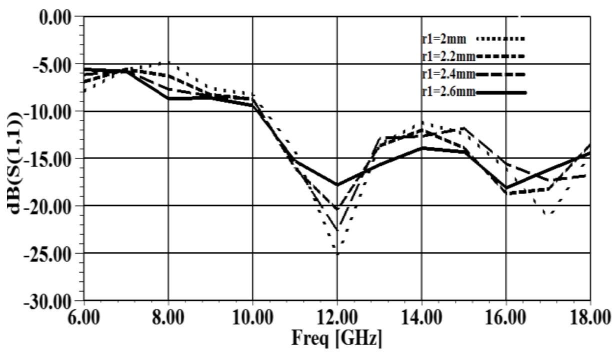


Fig. 5: Frequency vs. Return Loss of Radius 'R1'.

3.5. Return loss variation with 'w2'

From Fig.6 it is clear that there is a resonance occurring at 12GHz and 17GHz. The solid curve with w_2=0.68mm gives the largest bandwidth with a return loss of less than -7.5dB from 7.9 GHz to 18GHz.

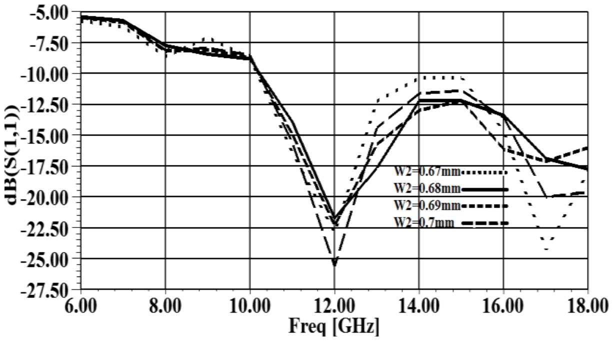


Fig. 6: Frequency vs. Return Loss of Line Width ‘W_2’.

3.6. Return loss variation with length of the stub 'L1'

L_1 is varied from 18.0mm to 19.3mm. There is no significant variation of return loss with L_1 over 8GHz to 18GHz. However, at lower frequencies between 6GHz and 8GHz, there is substantial variation in the return loss. The solid curve with L_1=19.3mm gives the optimum result with a return loss -7.5dB over 6-18GHz (Fig.7).

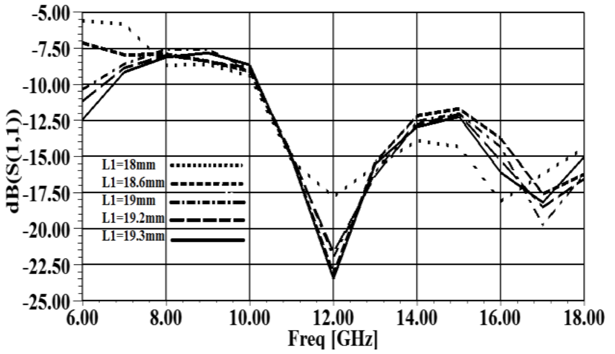


Fig. 7: Frequency vs. Return loss of Length ‘L_1’.

3.7. Return loss variation with width 'w1'

The width of the stub is varied from 2.0 to 2.6mm. The resonance is observed at 12GHz. Similar but less significant resonances are observed at 8GHz and 16GHz. The spread in the return loss variation is maximum at 12GHz. The solid curve with w_1=2.6mm gives the optimum result with return loss of -7.5dB from 7.7 GHz to 18GHz.

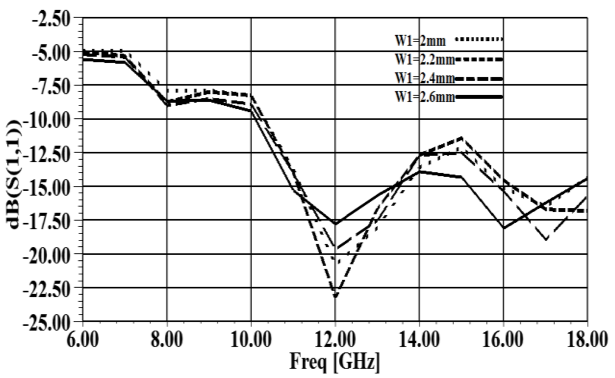


Fig. 8: Frequency vs. Return Loss Variation with Width ‘W_1’.

3.8. Return loss variation with dielectric extension 'l6'

This is a novel introduction in this paper. This has substantial effect on return loss as can be seen from the curves. L_6 is varied from 2.0mm to 6.0mm and the largest bandwidth with less than -8dB return loss is obtained for L_6=10mm.

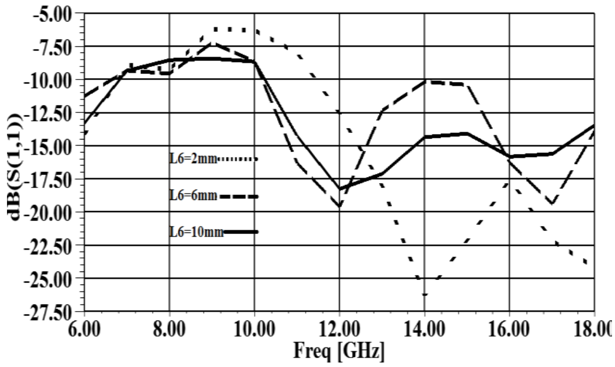


Fig. 9: Frequency vs. Return Loss of Dielectric Extension ‘L_6’.

4. Results

With the above optimization of various parameters a return loss of less than -7.5dB over 5.6-20GHz is observed. The optimized dimensions are given in table1.

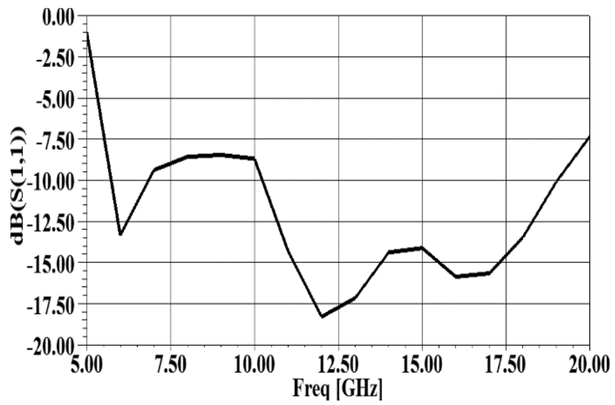


Fig. 10: Frequency vs. Return Loss Plot of the Optimized Antenna.

Table 1: Optimum Dimensions

Parameter	Value (in mm)	Parameter	Value (in mm)
L	63.0	W2	0.69
W	9.5	W3	0.68
L1	19.3	W4	0.544
W1	2.6	W5	0.2
r1	2.6	L4	34.0
r2	1.45	L5	18.0
L2	2.7	L6	10.0

Gain is variation over 6-20GHz is plotted in Fig.11. Gain varies from -10dB at 5 GHz to +5.8dB at 20GHz.

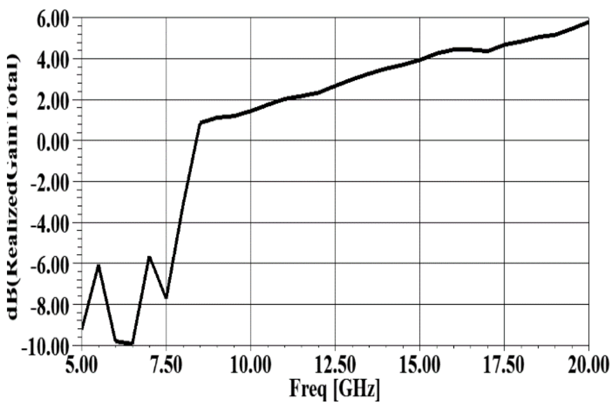
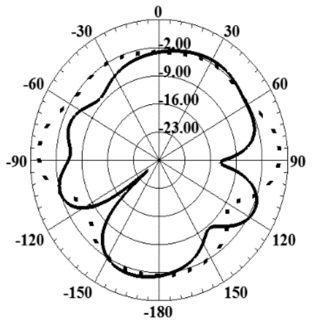


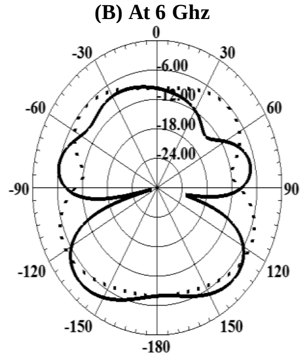
Fig. 11: Frequency vs. Gain Plot.

Radiation patterns of E-plane (solid line) and H-plane (dotted line) are shown in Fig.12 (a-g). It is observed that the radiation patterns are regular and satisfactory over 6-20GHz frequency range.

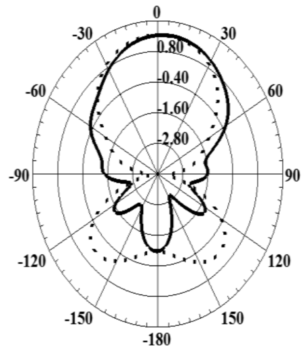
(A) At 5.6 GHZ



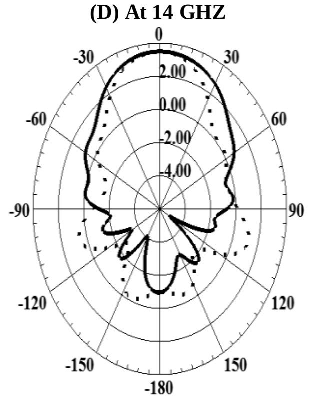
(B) At 6 Ghz



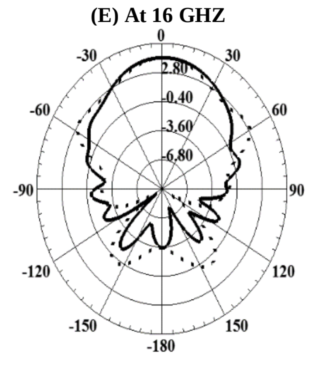
(C) At 10 Ghz



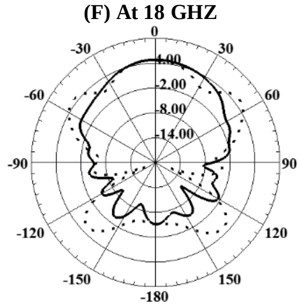
(D) At 14 GHZ



(E) At 16 GHZ



(F) At 18 GHZ



(G) At 20 GHZ

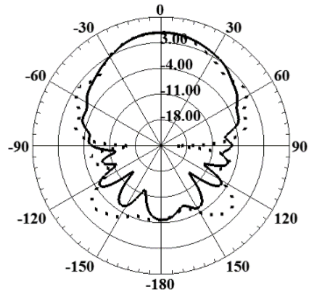


Fig. 12: Radiation Patterns of the Simulated Antenna.

5. Conclusion

A modified Vivaldi radiator with an aperture size of 9.5mm has been designed using ANSYS HFSS software. This antenna has an exponential taper with a novel sinusoidal function superimposed on it. In addition to this two substrates are used which are joined together each having a dielectric constant of 3.66 and a thickness of 0.5mm. Beyond the tapered portion dielectric is extended to obtain desired bandwidth. Parametric studies have been carried out on all the important parameters of the antenna design. These optimization studies have resulted in a design having a return loss of less than -7.5dB over 5.6-20GHz with satisfactory radiation patterns.

Acknowledgement

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