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ARTICLE

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LOW OBSERVABLE VIVALDI ANTENNA ARRAY FOR ELECTRONIC WARFARE APPLICATIONS

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Vivaldi antennas have been widely used in phased array for aerospace platforms due to high gain, wide bandwidth and large scan angles. Further these antennae are end-fire radiating elements with low radar signatures. In this work, the main objective is to design a wideband Vivaldi antenna (2-18 GHz) with high gain and low radar cross-section (RCS) without disturbing other radiation parameters such as VSWR and gain. Firstly, a single Vivaldi antenna with proximity coupled microstrip feed has been designed to achieve the reflection coefficient below -10 dB for the frequency range of 2-18 GHz and the antenna gain greater than 5 dBi. The monostatic and bistatic RCS of the designed Vivaldi antenna was simulated for normal/oblique angles of incidence in vertical/horizontal polarizations. Further, the slots were introduced into the antenna structure for reducing the antenna RCS. It is shown that RCS reduction of 4-5 dB has been achieved without any degradation in the antenna performance. Next, a 4-element low RCS Vivaldi antenna array has been designed to achieve gain of 15 dBi. The inter-element spacing has been kept greater than half-wavelength to avoid mutual coupling. Such low observable Vivaldi array have Electronic Warfare applications.

Keywords: *Vivaldi antenna, array, gain, VSWR, reflection coefficient, monostatic/bistatic RCS*

Introduction

Low observable or stealth technology implies reduction in radar cross-section (RCS) of aerospace structures. In particular, low RCS antenna/sensors are essential requirements for electronic warfare applications because the antenna being radiating element is a major contributor to overall RCS signature. Vivaldi antennas are highly desirable for airborne applications[1, 2], owing to their compact design, wideband frequency operation and large scanning angle. However due their large metallic structure, they are prone to scatter incident electromagnetic (EM) waves from broadside direction, thereby increasing the antenna RCS [3, 4]. Hence, it is an essential to reduce antenna RCS without hindering the radiation performance.

In this paper, a conventional Vivaldi antenna has been designed with optimized parameters, and is used as reference antenna. Then, this antenna has been modified towards RCS reduction using object shaping method[5]. In this method, metal portions are reduced without hindering the surface currents from the radiating part of the antenna. The EM design and simulations are performed using CST Microwave Studio. The EM performance parameters such as reflection coefficient, VSWR, gain and monostatic/bistatic RCS for the frequency range of 1-18 GHz has been provided. Four element arrays have been designed using both the reference and modified Vivaldi antenna. It is

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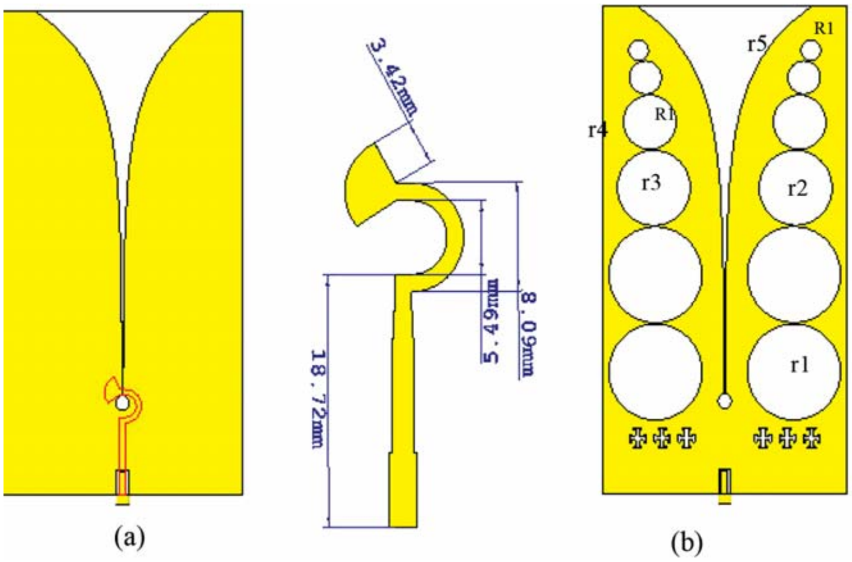


Fig. 1: Vivaldi antenna configuration. (a) Reference (b) Modified

shown that noticeable RCS reduction is achieved with good radiation performance.

Proposed Antenna Design

Reference Antenna Design: The simple Vivaldi antenna shown in Fig. 1(a) has been taken as a reference antenna. It consists of two exponential tapers on either side of the substrate. The opening rate is governed by '**s**', known as the taper factor with a taper length of 93mm. The substrate used is RT Duroid 5880 (ε_r = 2.2; tanδ=0.0009) of 117mm× 96mm× 1.574 mm dimensions. A coaxial cable is connected to the feed which is terminated by a radial stub. The radial stub and elliptical slot provide proximity coupling between the feed and the antenna. The thickness of the copper part of the antenna is 0.00175mm. The feed is 18.72mm long with a circular stripline with inner radius of 5.49mm and outer diameter 8.09mm terminated by a radial stub subtending an angle of 125 degree.

Low RCS Antenna Design: Fig. 1 (b) shows the modified Vivaldi antenna for RCS reduction. Circular slots have been inserted in the flare region of varying diameters[6,7]. Jerusalem crosses have been added near the bottom of the flare to obtain RCS reduction. Table I provides the dimensions of the slots made on the exponential flare. The dimensions of Jerusalem cross are 4 mm × 3mm with strip width of 1mm.

Table 1: Slot dimensions of Vivaldi antenna array.

Slot	Dimension (mm)
r1	11.5
r2	9
r3	6.5
r4	4
r5	2.5

Single Vivaldi Antenna

The radiation performance and RCS of the designed Vivaldi antenna has been analyzed. It is taken care that RCS reduction does not degrade its radiation characteristics.

EM Performance of Designed Vivaldi Antenna: Fig. 2 presents the simulated reflection coefficient over 1-18 GHz. The results of reference and modified Vivaldi antenna have been compared. It is apparent that S_{11} is mostly less

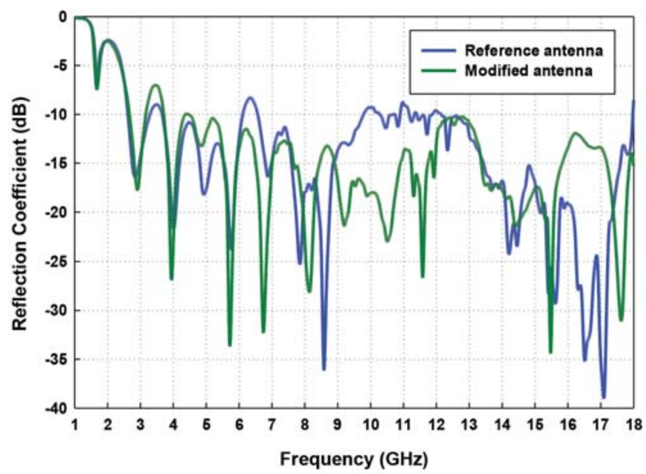


Fig. 2: Reflection coefficient of designed Vivaldi antenna.

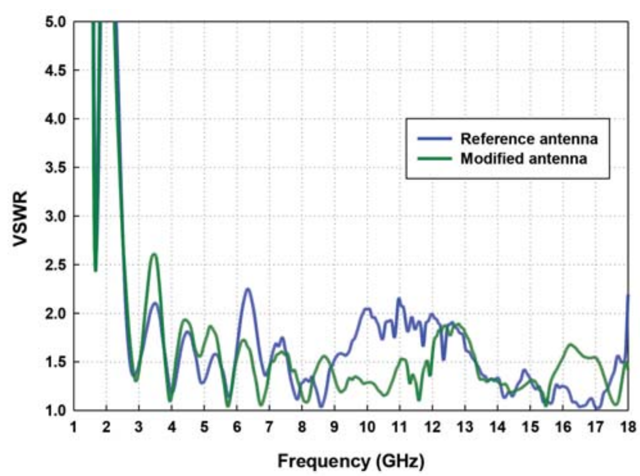


Fig. 3: VSWR of designed Vivaldi antenna.

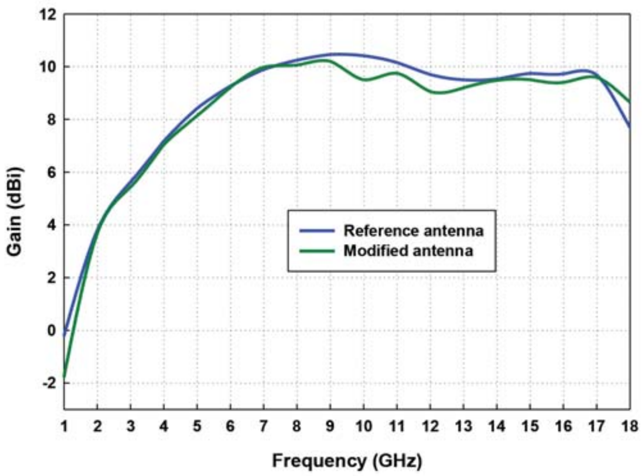


Fig. 4: Gain of designed Vivaldi antenna.

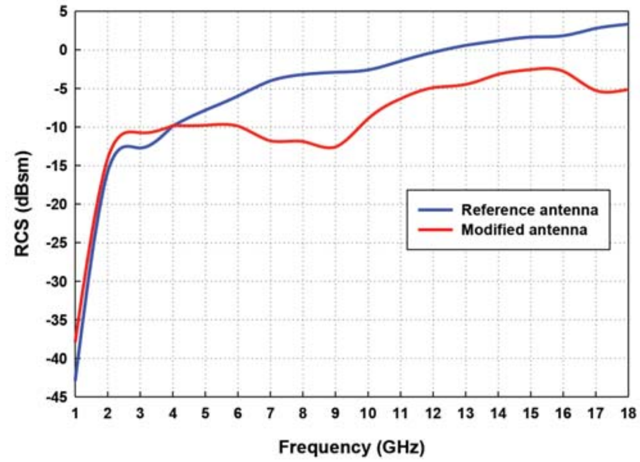
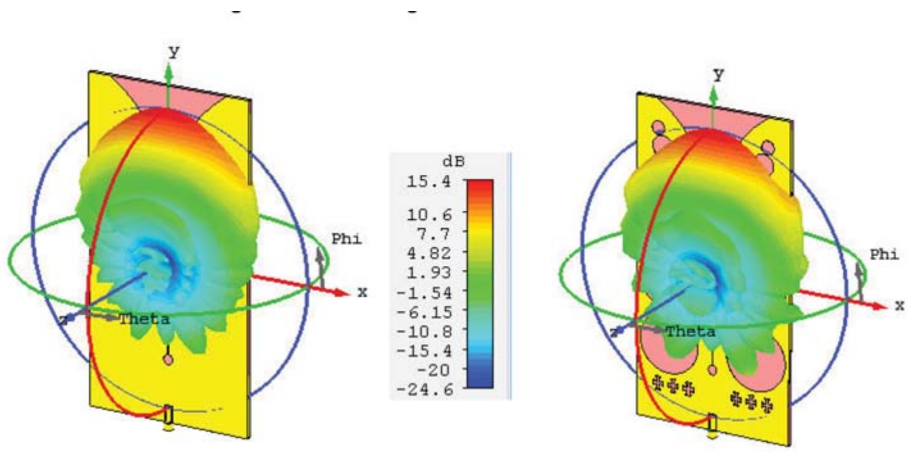
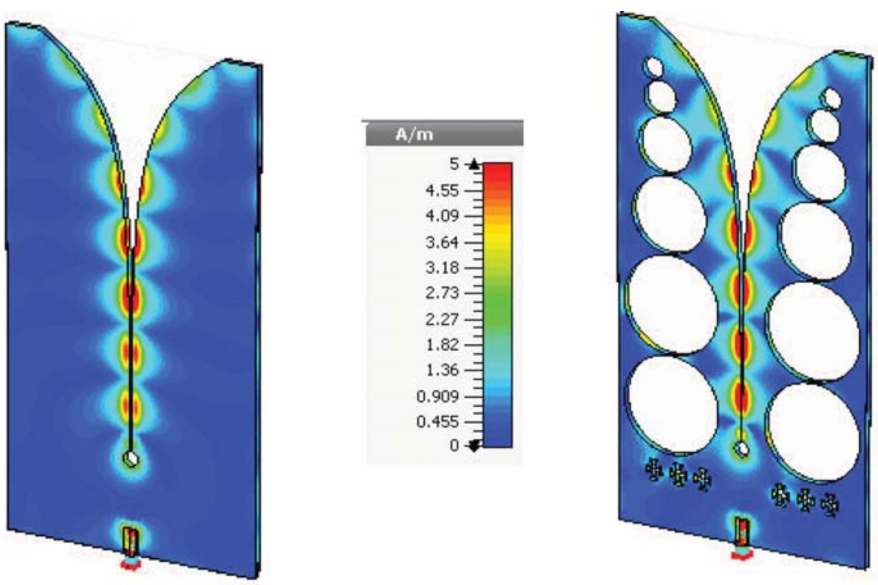


Fig. 7: (a) Monostatic RCS of Vivaldi antenna. θ=0º, ϕ=90º; Horizontal pol.



(a) Reference antenna (b) Modified antenna

Fig. 5: Radiation pattern of Vivaldi antenna.



(a) Reference antenna (b) Modified antenna

Fig. 6: Surface current distribution over Vivaldi antenna at 10 GHz

than -10dB. The corresponding VSWR of the designed antennas is shown in Fig. 3. The simulated antenna gain is depicted in Fig. 4. The 3D radiation pattern of the antennas at 10 GHz is shown in Fig. 5. It can be noted that even after inserting slots and Jerusalem cross-shaped slots in Vivaldi antenna, the radiation performance is maintained. The surface current distribution over the designed antennas at 10 GHz is shown in Fig. 6. It can be inferred that the circular slots and Jerusalem crosses have been designed in portions where surface current distribution was small, and hence creation of slots has not disturbed the performance of the antenna.

RCS of Designed Vivaldi Antenna: The monostatic RCS of designed Vivaldi antenna in both horizontal and vertical polarizations for different cuts (θ=0º, ϕ=90º; θ=0º, ϕ=60º) has been shown in Fig. 7 and Fig. 8 respectively. The plane wave is assumed to be incident on Vivaldi antenna from the broadside direction. It can be seen that there is 4-5 dB RCS reduction over 4-

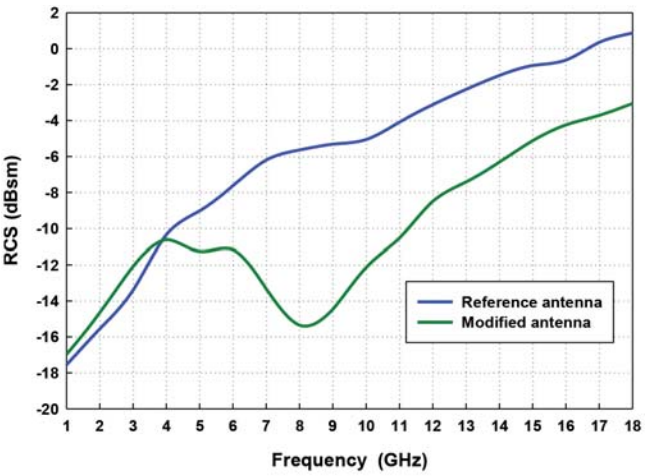


Fig. 7: (b) Monostatic RCS of Vivaldi antenna. θ=0º, ϕ=90º; Vertical pol.

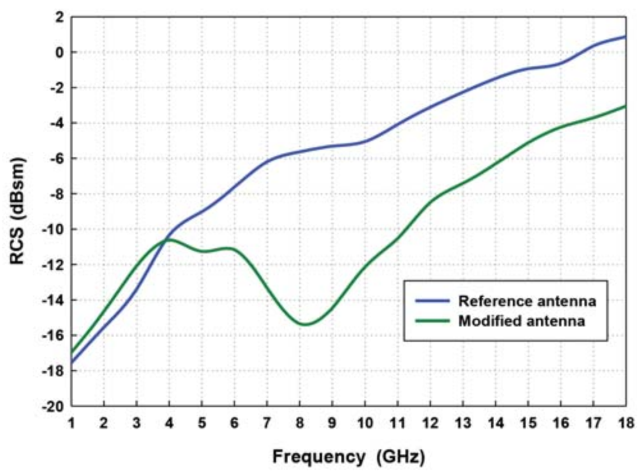


Fig. 8: (a) Monostatic RCS of Vivaldi antenna. θ=0º, ϕ=60º; Horizontal pol.

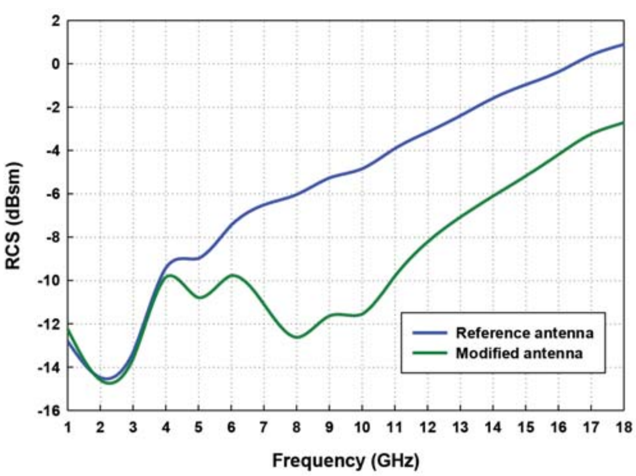


Fig. 8: (b) Monostatic RCS of Vivaldi antenna. θ=0º, ϕ=60º; Vertical pol.

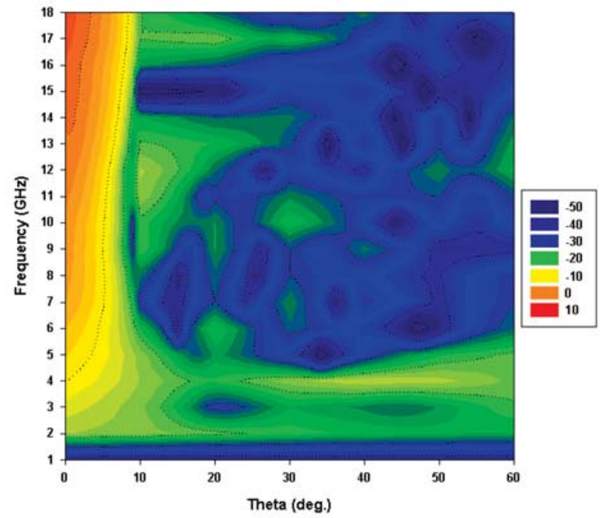


Fig. 9: (a) Bistatic RCS for reference Vivaldi antenna. ϕ=90º; Horizontal pol.

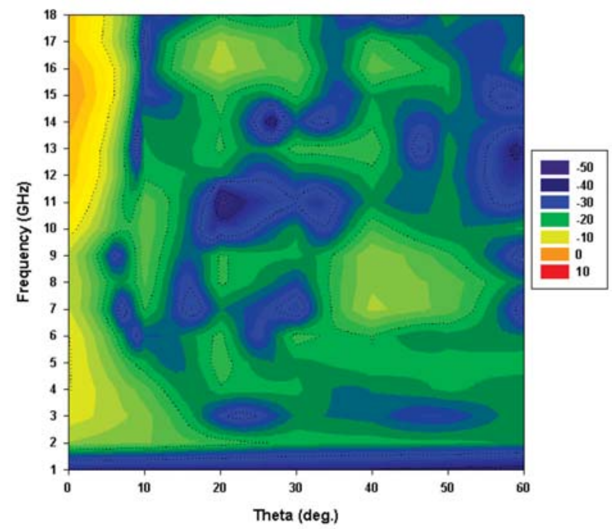


Fig. 9: (b) Bistatic RCS for modified Vivaldi antenna. ϕ=90º; Horizontal pol.

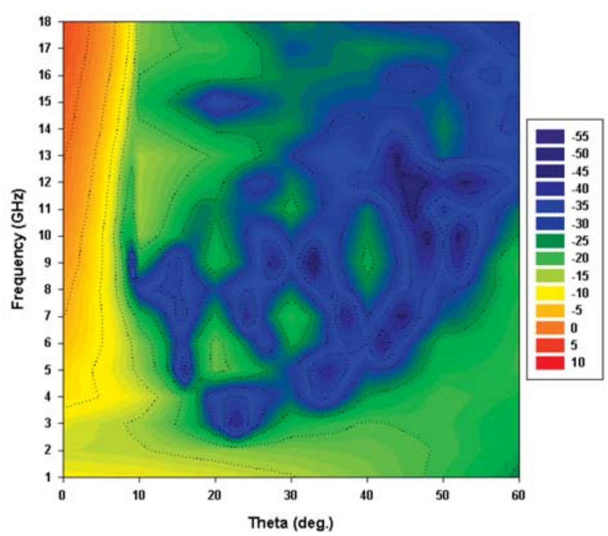


Fig. 10: (a) Bistatic RCS for reference Vivaldi antenna. ϕ=90º; Vertical pol.

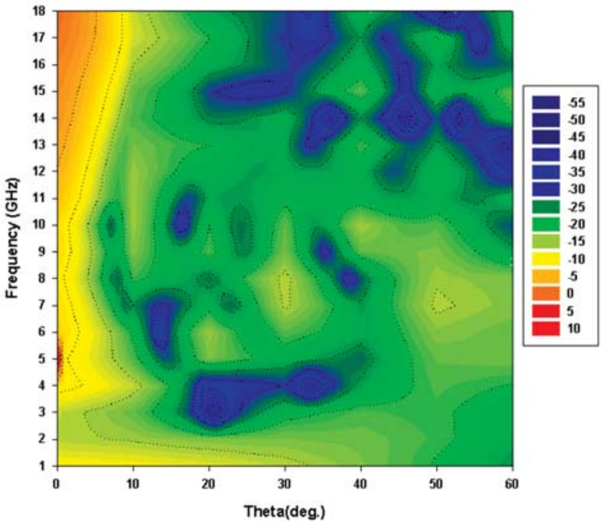


Fig. 10: (b) Bistatic RCS for modified Vivaldi antenna. ϕ=90º; Vertical pol.

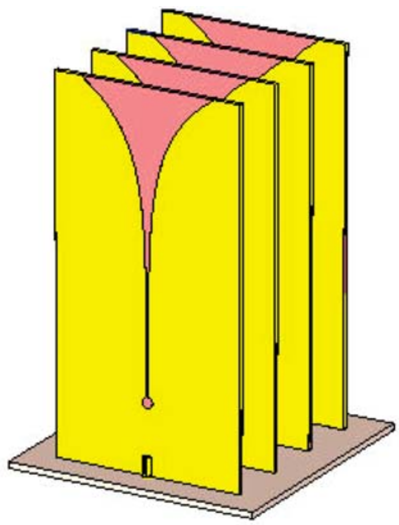


Fig. 11: Array 1: Four element Vivaldi antenna array using reference Vivaldi antenna.

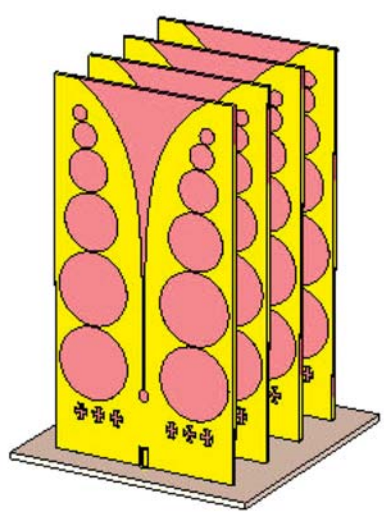


Fig. 12: Array 2: Four element Vivaldi antenna array using modified Vivaldi antenna.

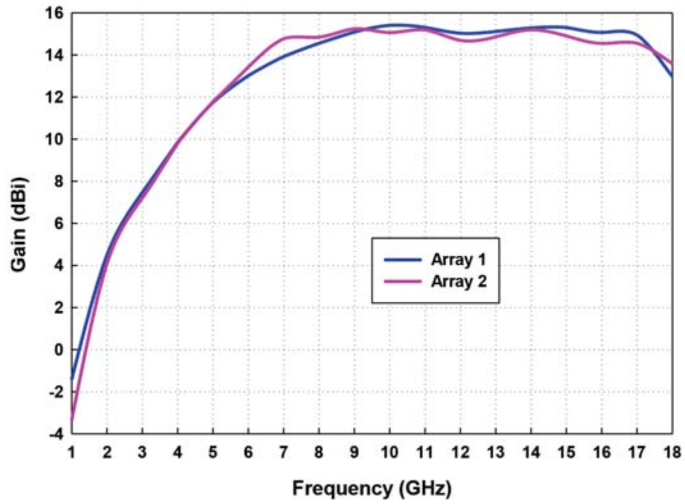


Fig. 13: Gain of four-element Vivaldi antenna arrays.

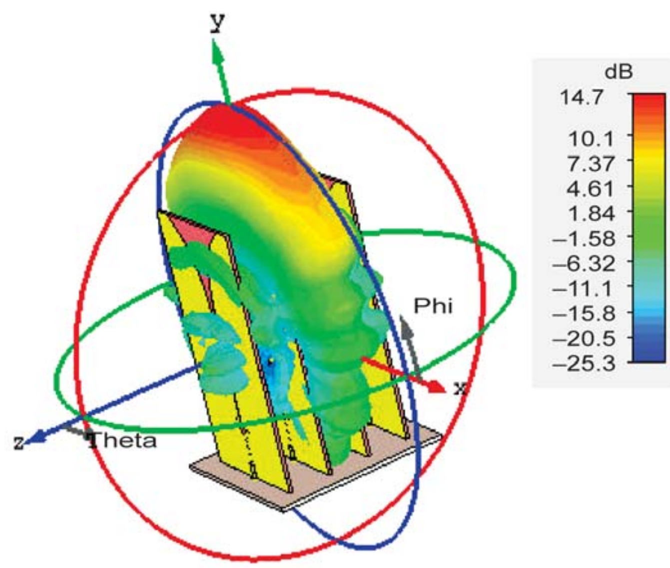


Fig. 14: Radiation pattern of Array 1 at 10 GHz.

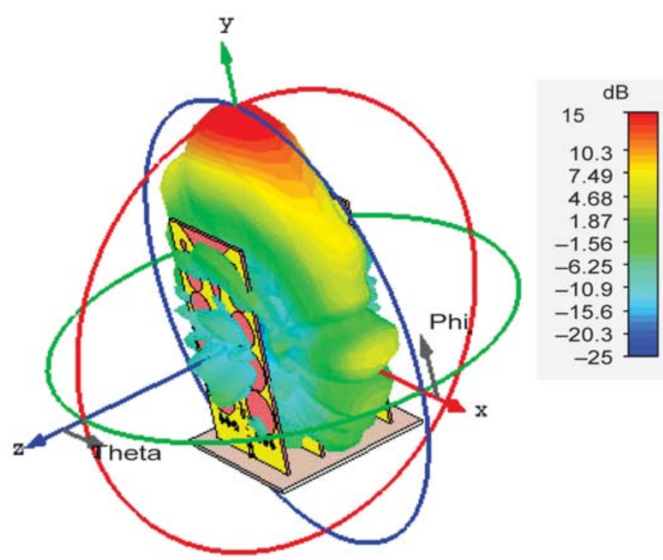


Fig. 15: Radiation pattern of Array 2 at 10 GHz.

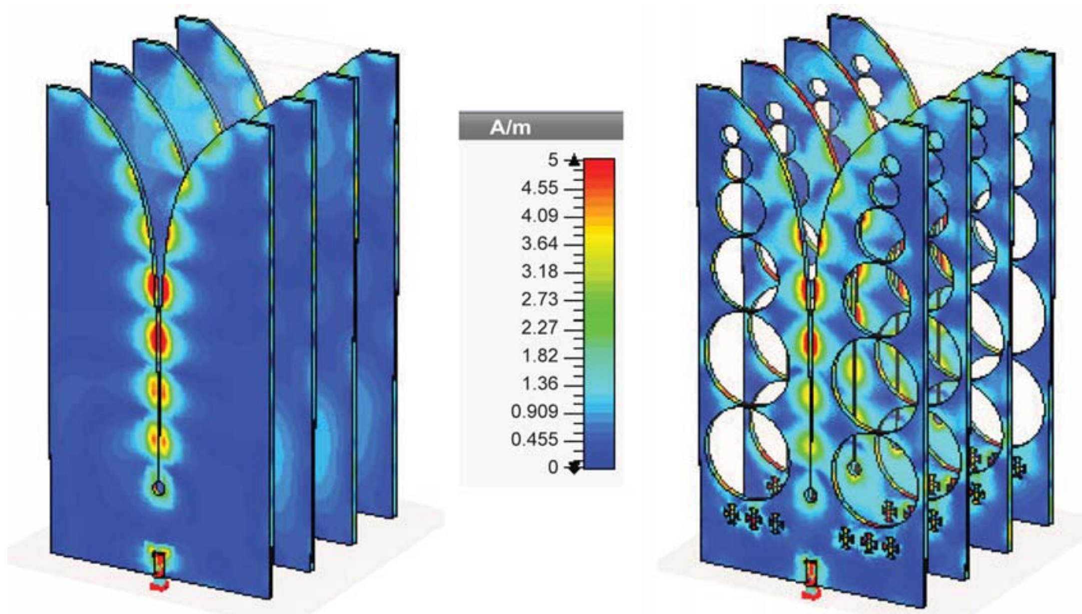


Fig. 16: Surface current distribution over Vivaldi antenna array.

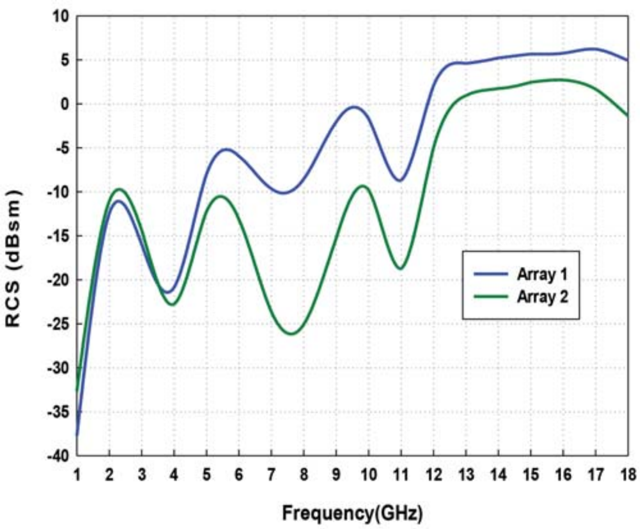


Fig. 17: (a) Monostatic RCS of Vivaldi antenna array. θ=0º, ϕ=90º; Horizontal pol.

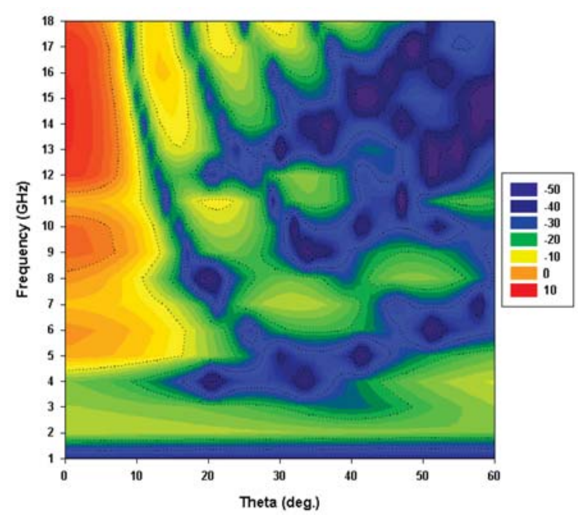


Fig. 19: (a) Bistatic RCS of Vivaldi antenna array (Array 1). ϕ=90º; Horizontal pol.

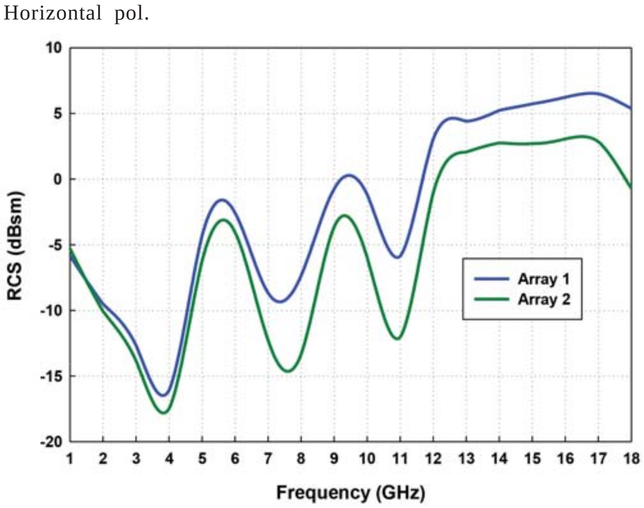


Fig. 18: (b) Monostatic RCS for Vivaldi antenna array. θ=0º, ϕ=60º; Vertical pol.

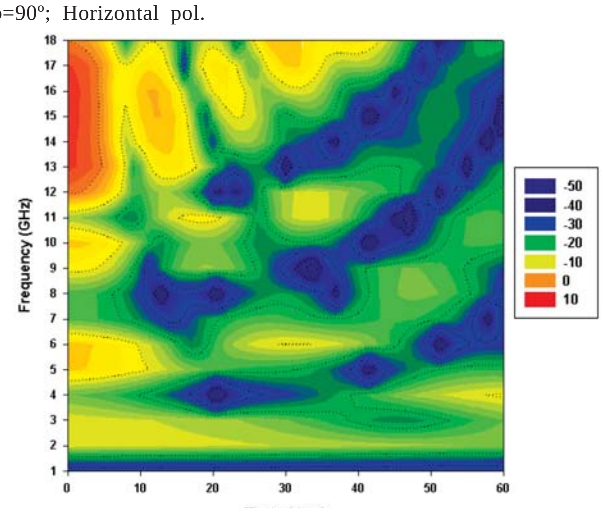


Fig. 19: (b) Bistatic RCS of Vivaldi antenna array (Array 2). ϕ=90º; Horizontal pol.

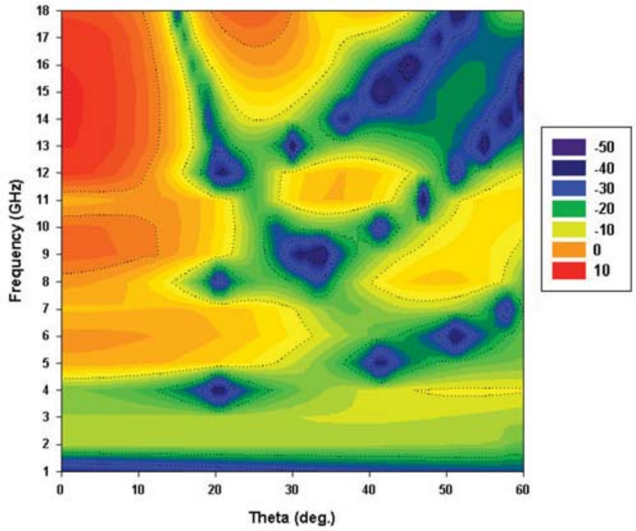


Fig. 20: (a) Bistatic RCS of Vivaldi antenna array (Array 1). ϕ=0º; Horizontal pol.

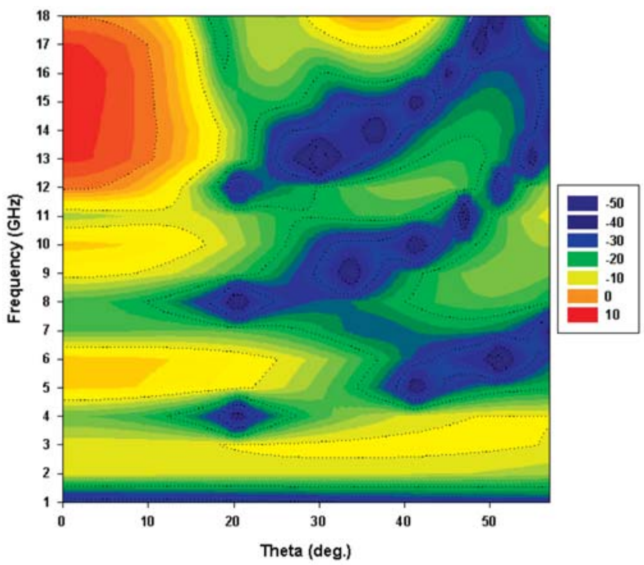


Fig. 20: (b) Bistatic RCS of Vivaldi antenna array (Array 2). ϕ=0º; Horizontal pol.

18 GHz. The bistatic RCS of Vivaldi antenna for the horizontal and vertical polarizations in ϕ = 90º cut has been shown in Fig. 9 and Fig. 10 respectively. It can be inferred that RCS reduction in single Vivaldi antenna has been achieved in the bistatic case as well for incidences closer to the normal.

Vivaldi Antenna Array

Using Vivaldi antennas designed in the earlier sections, two 4-element Vivaldi arrays are designed, one with the reference antenna as the antenna element and another with the modified Vivaldi antenna. The spacing between the antenna elements of the array has been kept at 20mm, greater than half-wavelength in order to avoid mutual coupling effect. Fig. 11 shows the Vivaldi antenna array using reference Vivaldi antenna (Fig.1a), and is referred to as Array 1. The Vivaldi antenna array designed using modified Vivaldi antenna (Fig. 1b), referred to as Array 2, is shown in Fig. 12.

EM Performance of Designed Vivaldi Antenna Array: The simulated gain of the Vivaldi antenna array has been shown in Fig. 13. The 3D radiation pattern for the designed arrays at 10GHz is shown in Fig. 14 and Fig. 15. It is evident that there is no change in the EM performance of both the Vivaldi arrays. Fig 16 shows the surface current distribution over the designed arrays at 10 GHz. It is evident that modified design of Vivaldi antenna array by inserting slots has not altered the surface current distribution responsible for the radiation behavior of the antenna.

RCS of Vivaldi Antenna Array

For broadside plane wave incidence, the monostatic RCS of both the arrays is shown in Fig. 17 and Fig. 18 for different cuts. Fig. 17 shows the monostatic RCS of Vivaldi antenna arrays for θ=0º, ϕ=90º in horizontal/vertical polarization. The RCS reduction of 2-4 dB has been achieved over 4-18 GHz. Fig. 18 presents the monostatic RCS of Vivaldi arrays for θ=0º, ϕ=60º in horizontal/vertical polarization. A 2-5 dB reduction in RCS can be noted in both the polarization. Also, the RCS reduction in the case of horizontal polarization is better Bistatic RCS results in horizontal polarization for ϕ=90º cut are depicted in Fig. 19. It is apparent that RCS reduction has been achieved in the Vivaldi antenna array for incidences closer to the normal. For angles greater than 30°, the RCS of Vivaldi antenna is already very low and insignificant. Fig. 20 presents bistatic RCS of Vivaldi antenna arrays in horizontal polarization for ϕ=0º. It is well evident that RCS reduction in Vivaldi antenna array is achieved for angles close to normal incidence.

Conclusions

Vivaldi antenna is an end-fire high gain antenna with wideband operating frequency range. It is a preferred choice for fire control radar (FCR) applications. This electronic warfare (EW) antenna is required to have low RCS. In this paper a novel design of low RCS Vivaldi antenna/array with desired radiation performance is presented. A conventional Vivaldi antenna is modified by introducing circular slots of varying dimensions onto the exponentially tapered flare. Further small Jerusalem crosses are included on the lower side of the antenna. The EM performance in terms of reflection coefficient, VSWR, gain and radiation pattern has been compared. The monostatic and bistatic RCS for the modified antenna/array is shown to be reduced by 2-4 dB for both horizontal and vertical polarizations, over 4-18 GHz. Such low observable high performance Vivaldi antenna/array can be a preferred choice for EW applications.

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