Wideband Vivaldi Antenna Design With Reduced Radar Cross Section

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***Abstract*— In this paper, a stealth vivaldi antenna is proposed which covers 7 GHz to 11 GHz operating frequency range with reduced radar cross section (RCS) and high gain. RCS reduction is achieved by the object shaping method fulfilled with the use of introduced circular slots etched in the radiator. These circular slots along the inner exponential profile of the antenna reduce the scattering along the surface of the radiator, which hence causes reduction in monostatic RCS. Compared with the reference antenna, the RCS of the proposed antenna maximally obtains 16 dB reduction. Simulated results related to S11, gain, RCS and VSWR of the reference and proposed antennas are presented. The performance of the proposed antenna is validated.**

Keywords—stealth antenna; object shaping method; radar cross section (RCS); vivaldi antenna

I. Introduction

Radar cross section (RCS) reduction is essentially important in stealth technology for missiles, aircrafts, and ships. It has become an important area of research nowadays. For aircrafts, their nose cone is very threatening for radar detection because they usually contains an antenna that strongly scatter the incoming electromagnetic waves. This scattering from the antenna surface is proportional to radar signature. Vivaldi antenna is mostly used for airborne application due to its high directivity, wide bandwidth, small physical dimension and symmetric radiation pattern [1], [2]. The reflection from an object is quantitatively described in terms of its RCS. Therefore, efficient stealth design requires that these reflections should be minimized or scatted towards the undesired directions without changing the antenna radiation performances. For airborne application therefore the stealth design of Vivaldi antenna is highly desirable.

In literature, many techniques have been reported to reduce the RCS of antennas based on active and passive cancellation, object coating and radar absorbing material (RAM). Active cancellation technique requires biasing which increases the complexity of the antenna design. Passive cancellation techniques includes the modification of the structure in ground, radiator and substrate. By using passive cancellation, removing the metal areas from the surface of radiator that contains the least current distribution has been reported in the literature [3], [4]. An extra layer of absorbing material (RAM) is required for traditional RCS reduction, which increases the thickness. By using EBG structure, about 10dB RCS reduction is achieved in [5] outside of working band. In [6], the incident waves from radar are absorbed by partially selective surfaces to reduce the radar signature. The combination of perfect electric conductor and artificial magnetic conductor is used in [7] to reduce the RCS. Other radar cross section reduction techniques include PIN diodes [8], photonic band gap [9], and substrate integrated waveguide technique [10].

In this paper, a stealth Vivaldi antenna is presented for RCS reduction using object shaping method. This is achieved by structural modification in the radiator after the analysis of antenna surface current distribution in radiating and scattering mode. After these modifications, the proposed antenna provides 16 dB RCS reduction in the frequency band from 7 GHz to 11 GHz without degrading its radiation performance.

II. Antenna Configuration

Fig. 1 shows the geometric diagram of the Vivaldi antenna taken as the reference antenna. It contains a microstrip feed line which has an input impedance of 50 ohm. The design of the reference antenna consist of two symmetrical exponential tapered lines on the top of the substrate. The antenna is printed on a Taconic RF-60A substrate, which has dielectric constant of 6.15 and loss tangent of 0.0038 with thickness of 0.5 mm. The length of microstrip feed line is 9.5 mm.

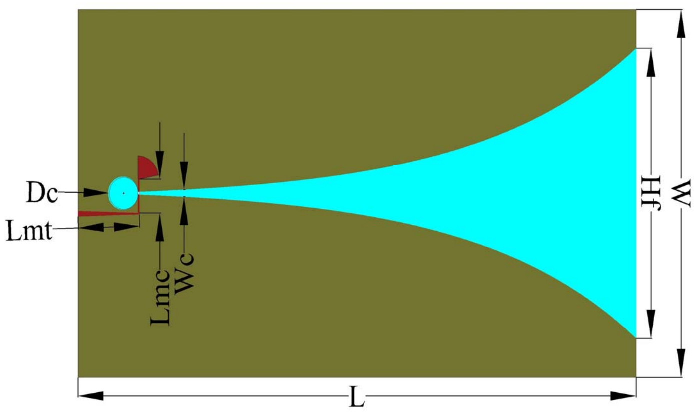
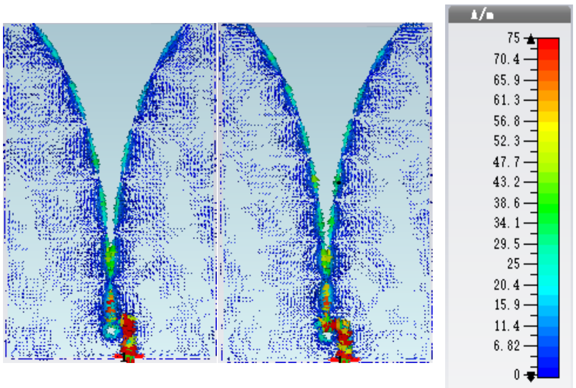


Fig. 1. Geometric diagram of the reference antenna. L = 88 mm, W = 52 mm, Hf = 42 mm, h = 0.5 mm, Dc = 4.7 mm, Lmt = 9.5 mm, L mc = 4.7 mm, and Wc = 0.375 mm.

The RCS of an antenna is the combination of its antenna mode and structure mode components. The antenna mode is due to the improper termination and mismatch of the input impedance and it has a very low value. The structure mode is due to the perpendicular reflections from the radiator and it contributes more in the RCS of the antenna. In this paper, the proposed work focuses on the structure mode component, to minimize the RCS of the antenna. Fig. 2 represents the surface current distribution of the reference antenna at different frequencies. This surface current distribution causes radiation along feeding structure and transmission line. Therefore, by using object shaping method, the metal pieces along the tapered profile of the reference antenna is removed by introducing the circular slots. These circular slots reduce the perpendicular reflections from the surface of the antenna that cause to have a reduced RCS with same radiation performance.



9 GHz 11 GHz

Fig. 2. Surface current distribution of the reference antenna at different frequencies.

Fig. 3 shows the structure of the proposed antenna. It is obtained by removing metals pieces from the radiator where the current distribution was weaker. It can be observed from Fig. 4 that compared with the reference antenna, the reflection coefficient characteristic of the proposed antenna is preserved after introducing the circular slots in the radiator.

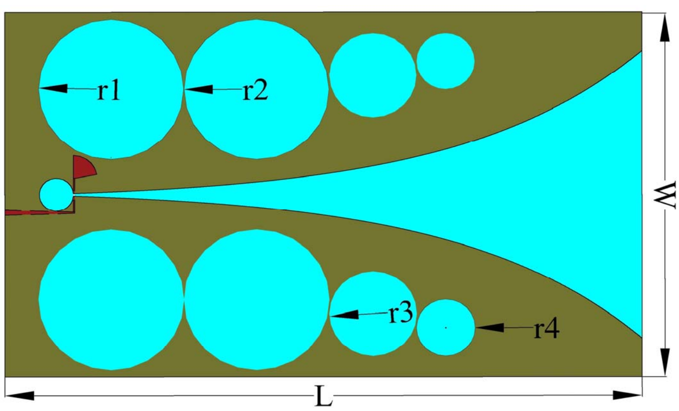


Fig. 3. Geometric diagram of the proposed antenna with L = 88 mm, W = 52 mm, r1 = 10 mm, r2 = 10 mm, r3 = 6 mm, and r4 = 4 mm.

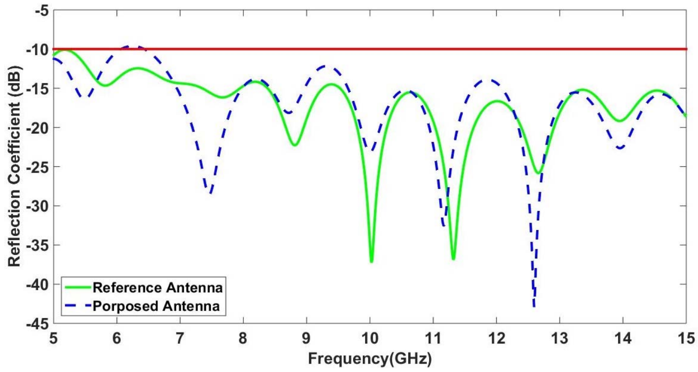


Fig. 4. Simulated S11 characteristics of the reference and proposed antenna.

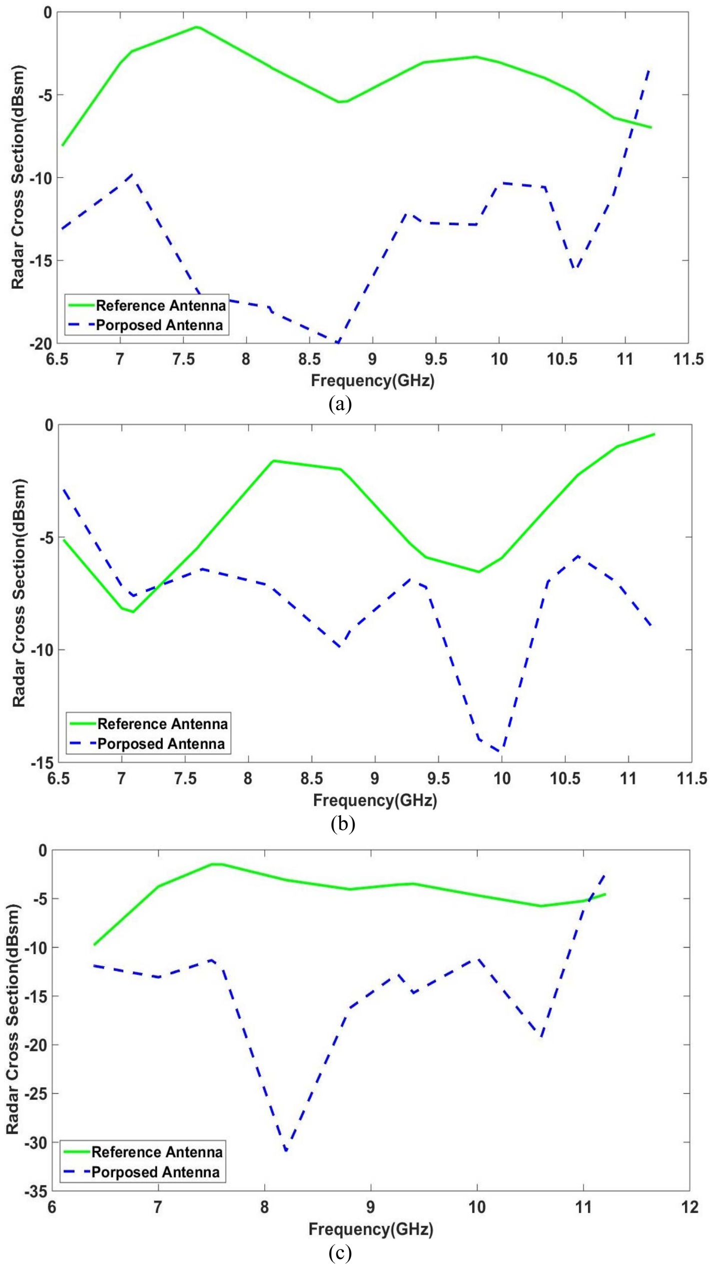


Fig. 5. Simulated RCS of the reference and proposed antenna. (a) theta = 0°, phi= 0°. (b) theta = 10°, phi = 0°. (c) Y- Polarized.

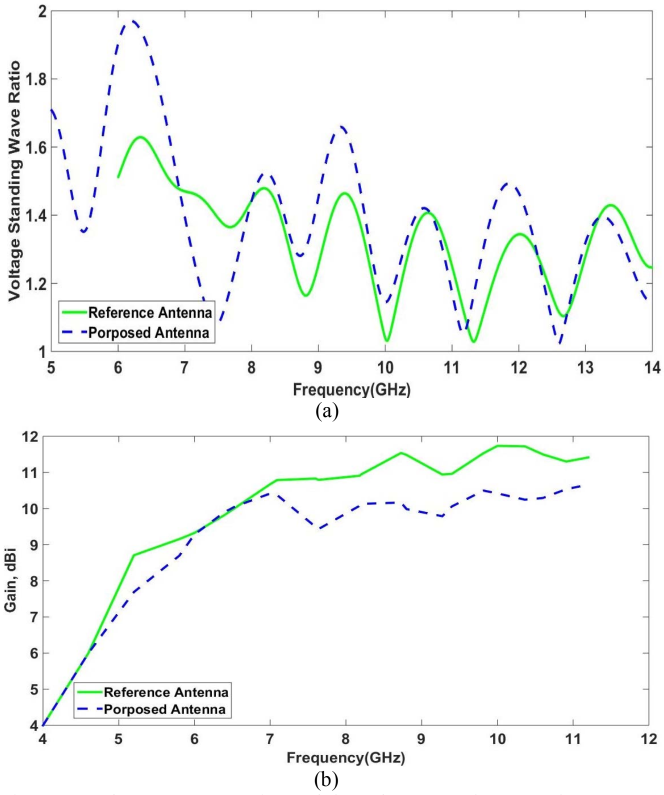


Fig. 6. Performance comparison of the reference and proposed antenna. (a) VSWR. (b) Gain.

III. Results and Disscussion

It is very difficult to maintain the tradeoff between the reflection coefficient and RCS of the low profile antenna. The structural modification through object shaping method should not affect the radiation performance of the reference antenna. From Fig. 4, it can be seen that the proposed antenna maintains the reflection coefficient below -10 dB within the whole band of operation (7 GHz -11 GHz) and suitable for engineering applications.

Antenna RCS measurements can be carried out by directing a radar signals towards the antenna. The amount of electromagnetic energy backscattered by the surface of the antenna gives the backscatter measurement. In the proposed work, the monostatic RCS of the antenna is presented. Fig. 5(a) and 5(b) represent the RCS reduction of the reference and proposed antenna at different incident angles. The structural modification in the design of the reference antenna causes a maximum of 16 dB and minimum of 6 dB RCS reduction in the working frequency band. According to the radar range equation, 16 dB RCS reduction will decrease the radar detection range by 60% and 6 dB RCS reduction in operating band will decrease the radar detection range by 29%. RCS reduction at different azimuth and elevation planes validate the operation of the proposed antenna. Fig. 5(c) represents the co-polarization of the reference and proposed antenna. Reflections from Y-polarized wave is most important according to the structure of the antenna, which is set for polarization in Y-axis. It shows the RCS reduction of 20 dB maximally and 10 dB minimally in the whole frequency band of operation.

Fig. 6(a) represents the voltage standing wave ratio (VSWR) of the reference and proposed antenna. Clearly, the introduced circular slots only impact the VSWR performance of the proposed antenna slightly. It can be noticed that the maximum value of VSWR is approximately 1.6 in working band for the proposed antenna. Fig. 6(b) represents the gain of the reference and proposed antenna. The reference and proposed antenna have a 1.0 dB difference in antenna gain. The maximum value of gain is 10 dBi for the proposed antenna and larger than certain previous reported work [3], [4].

IV. Conclusion

In this paper, a stealth antenna is proposed for operating in 7GHz -11GHz frequency band. The stealth antenna provides the minimum RCS of 6 dB and maximum of 16 dB in operating band without using any additional layers. The gain of the proposed antenna is approximately 10dBi. The analysis and simulated results have demonstrated that proposed antenna with structural modification through object shaping method can be used for RCS reduction without any degradation of antenna performance.

Acknowledgment

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