International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor (2018): 7.426

Design, Development and Performance Analysis of Reconfigurable Vivaldi Antenna for RF Front-End Multistandard Transceiver

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Abstract: ***Planar Reconfigurable Patch Antenna is designed on FR4 substrate (ϵ_r=4.4) and simulated in Keysight's Advance Design System (ADS) Momentum Microwave Software. The resonant frequency band of the designed antenna is from 1.0 GHz to 4.0GHz. The return loss for designed antenna over the given band is less than -10 dB, with gain 6.5dBi.This antenna can give the best performance for recent RF Front-end multistandard transceivers.***

Keywords: Reconfigurable antenna, RF, FR4, Return Loss, Multistandard, Front-end, Transceivers etc

1. Introduction

A Reconfigurable Vivaldi antenna or is a co-planar broadband-antenna, which can be made from a solid piece of sheet metal, a printed circuit board, or from a dielectric plate metalized on one or both sides. The Vivaldi antenna is a well known structure that operates over a wide bandwidth. The designed prototype is shown in figure1.1(b). It achieved wideband performance from 1GHz to 4 GHz by means of a gradual taper in a slot transmission line that forms a transition from a guided wave medium to free space radiation.[1-8] In addition, it also has a well defined radiation mechanism in which it radiates different frequencies from different parts. Radiation at high frequencies occurs closer to the narrower end and lower frequencies closer to the wider end of the slot. The radiating area size relative to the corresponding wavelength is constant and the structure expansion is smooth, and therefore the Vivaldi antenna is also classified as a frequency independent antenna[3-5].

Vivaldi antenna is divided into two regions (i) transmission line region, and (ii) radiating region. The transmission line region is the area where the slot line width is less than λ/2 and the radiating region is the area where the slot line width greater than λ/2. The printed Vivaldi is formed by a tapered slot structure etched on substrate[2-6]. It has been invented by Gibson. Generally, it has a symmetrical end-fire beam, good gain, low side lobes and wide bandwidth. These properties depend on flare geometry, dimensions (i.e. length, aperture size), and also the transition from the input to the slot line[3-7].

2. Design & Analysis

The main parameter in designing the Planar Reconfigurable Wideband Vivaldi Antenna (PRWVA) is choosing the appropriate tapered profile. It is totally based on the selected shape. For the designed PRWVA, Tapered Profile is given by

$$y(x) = c_1 e^{Rx} + c_2 \qquad \ldots(1.1)$$

Where, R= opening rate

Based on the structure the equation should be carefully written otherwise it will give rise to out of band interference and tuning to undesired bands. Co-ordinates of origin are given by (C_1, C2)

Where, $c_1 = \dfrac{y^2 - y^1}{e^{Rx^2} - e^{Rx^2}}$ and $c_2 = \dfrac{y^1 e^{Rx^2} - y^2 e^{Rx^1}}{e^{Rx^2} - e^{Rx^1}}$

The effective thickness is given by

$$\frac{teff}{\lambda 0} = (\sqrt{\epsilon r} - 1)\frac{t}{\lambda 0} \qquad \ldots (1.2)$$

Shape of the slot is given by

$$z(y) = \pm A e^{py}$$

where y and z in same unit, z is the substrate axial direction and y horizontal direction

Maximum opening width for lower end is given by

$$\lambda g = \frac{c}{f\min\sqrt{\epsilon r}} \qquad \ldots\ldots (1.3)$$

= 0.046mm

Maximum width of aperture for lower end is given by

$$W\max = \frac{\lambda}{2} \qquad \ldots\ldots (1.4)$$

= 0.023mm

Minimum width of aperture for lower end is given by

$$W\min = \frac{c}{f\sqrt{\epsilon r}} \qquad \ldots\ldots (1.5)$$

= 0.021mm

In the designed Vivaldi antenna as shown in Figure1.1 and 1.2, the radiating element is etched on a single side of the FR4 substrate and fed by microstrip line. Other feeding techniques such as coaxial feed and co-planar waveguide feed can also be used. The feed line to radiating slot transition has a significant effect on the bandwidth. There is also another type called the antipodal Vivaldi as shown in fig 2.2. In this type, the radiating element or slot line is etched symmetrically, half on each side of the substrate.

This configuration removes the feed line transition to slot line and improves further the wide bandwidth of the Vivaldi.

Table 1.1: Total Parameters of designed Planar Vivaldi Antenna including both ends for 1 to 4 GHz (substrate FR4)

Parameters	Values in mm
Total length	123.45
Total width	96.77
Strip length	5
Strip width	1.30
Offset of strip length	7.38
Backwall offset	5
Balun length	7.38
Balun width	7.38
Substrate thickness	1.6

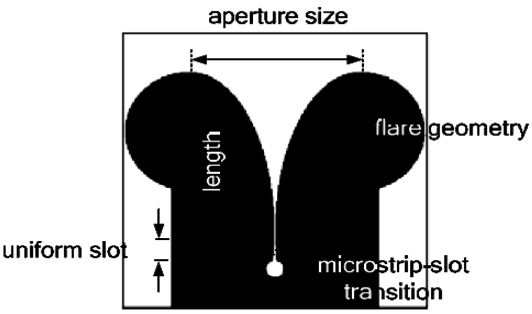


Figure1.1: (a) Vivaldi Antenna showing microstrip feed

Figure1.1: (b) Designed Prototype

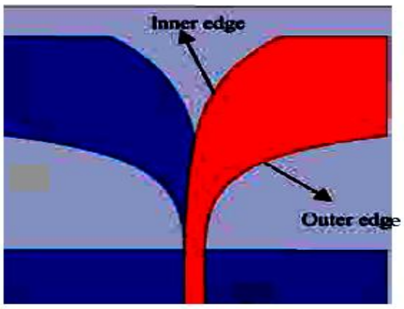


Figure 1.2: Antipodal Vivaldi Antenna [4]

The novel switched band Vivaldi antenna is relatively small, simple to manufacture (no shielding box) and fewer complexes in biasing circuit (fewer switches) compared to the reconfigurable log periodic patch array. To demonstrate its functionality, the proposed antenna shows reconfiguration between a single wideband mode (1.0 to 4 GHz) and three narrowband modes. Potentially, it can be designed to cover a very wide bandwidth and can have a wide range of frequency reconfiguration. To achieve switched band properties, eight ring slots which form filters were inserted to the antenna as shown in designed prototype in fig 1.3. The overall operating band can be switched by coupling each ring slot into the slot edges through the gaps controlled by means of PIN diode switches, which stop or pass the edge current to obtain frequency reconfiguration capability. Details of the proposed design are described.

A Vivaldi antenna has been chosen as a basic structure due to the fact that it can operate over wide bandwidth. In addition, it also has a well defined radiation mechanism where most of the current flow is at the edge of the tapered slot. These characteristics help in designing a wideband-narrowband reconfiguration. The Vivaldi used was based on [82], and has been scaled to operate over a bandwidth of 1.0-4.0 GHz. The bandwidth of 1.0 - 4.0 GHz was chosen to demonstrate the concepts because the PIN diode parasitic is less significant at low frequency. The antenna is simulated and fabricate on FR4 substrate which has Ɛr= 4.4. The height of the substrate is 1.6 mm. The slot consists of a 4.6 mm radius circular hole and an elliptical pointed slot with 40 mm horizontal and 80 mm vertical radius respectively. The tapered slot is fed with a W = 2.75 mm wide feed line terminated in a R = 5.1 mm radius quarter circle. The substrate size is m = 144 mm x n = 140 mm. The aperture size a = 81.2 mm and the antenna length b = 120 mm.

Figure 1.3: Four band Planar Reconfigurable Wideband Vivaldi Antenna

The Vivaldi can be reconfigured by perturbing the edge of the tapered slot, distorting the current flow. Figure 1.4(a) shows the surface current before the insertion of a ring slot into the antenna. Figure 1.4(b) shows actual prototype without ring slots. After insertion of ring slot the current along the radiating edges is significantly reduced.

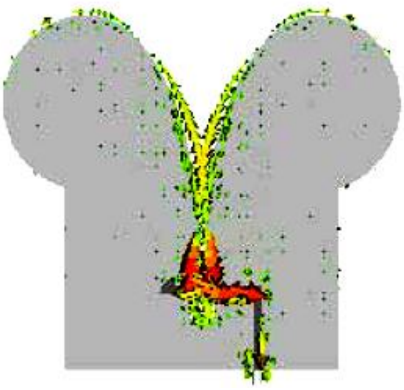


Figure1.4: (a) current distribution without ring slots

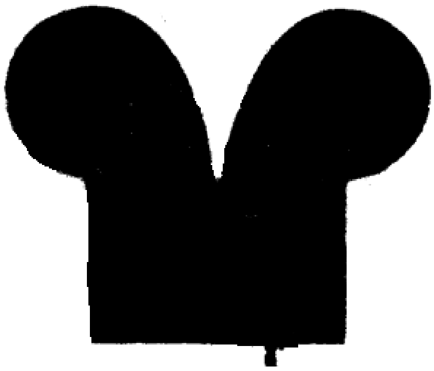


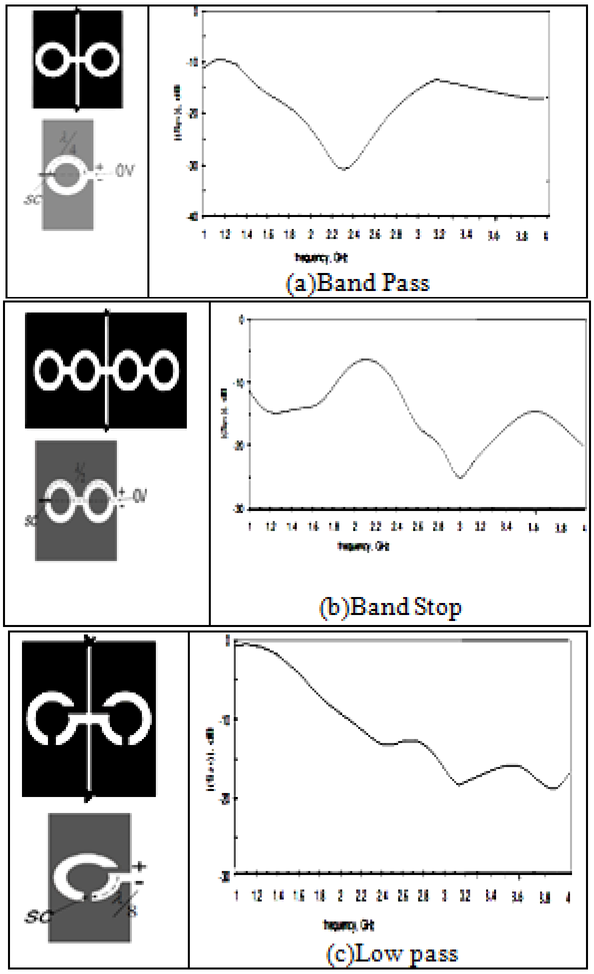
Figure1.4: (b) Prototype structure without ring slots

There are a number of candidate shapes for the insertion, like ring, triangle, rectangle and thin rectangle. In terms of frequency band, losses and size, the slot resonator has to be low stop band Q in order to have wide stop band ranges

The out of band rejection is relatively poor. This can only be expected as the filtering or reconfiguration is achieved with single resonator which has relatively low Q due to being mounted in an antenna, as well as the switch losses. However the main factor of that relatively poor rejection in S11 mainly comes from the dielectric losses of the FR4 substrate. It is seen that the loss that contributed to poor rejection is small from the switch but very pronounced from the FR4 substrate[7].

As stated earlier, Vivaldi can be divided into two regions, namely the propagation and active regions. The propagation region is the area which acts like a transmission line and the active region is the area where the signals start to radiate. The radiation occurs when the slot width is roughly half of the wavelength, which makes each part of the Vivaldi radiate at different frequencies. The radiation at lower frequencies occurs closer to the wider end of the slot whilst higher frequencies occur at the narrower end.[4-5] This suggests that the ring slots should be placed at various positions along the tapered slot to control the frequency performance. The way this is done is now described. Wideband to narrowband reconfiguration can be made by integrating a switched ring slot in the Vivaldi. For simplification purposes three narrowband modes were select, namely low band, mid band and high band. Ideally the frequency response of each ring slot should be chosen depending on which narrowband configurations it is designed for. For example a low pass filter response is used in select low band mode while a band pass response can be used to select mid band mode. Figure 2.5 shows the geometry and simulated response of the ring slots on a uniform slot line. A single ring slot produced a stop band response while cascaded ring slots produced a pass band response. In addition, adding bridges as shown in Figure 2.5(c) transformed the band stop to low pass response.

The average circumference of the single ring slot in Figure1.6(a) is 52.3 mm which is approximately a half wavelength at 2.4 GHz. The differential operation of the slot line creates a virtual short circuit, denoted as *SC*, at the middle point of the structure as shown in the figure. The short circuit transforms over a quarter wavelengths to an open circuit at the excitation point which produces a stop band at 2.4 GHz. On the other hand, the cascaded ring slots in Figure1.6 (b) make the length approximately half wavelength long at 2 GHz. This thus makes a short circuit at the excitation point, which produces a passband around 2 GHz. Finally, with added bridges, the ring slot shown in Figure 2.6(c) becomes a very short slot, an eighth wavelength long. This transforms to a stop band at 4 GHz or to an inductance at a low band 1 GHz at the excitation point.



(a)Band Pass

(b)Band Stop

(c)Low pass

Figure1.5: Simulated S21 of ring slot resonator pass

Since the Vivaldi radiates from different parts of the structure at different frequencies, the narrower end area will become the radiating region for high frequency signals. It is thus appropriate to locate the ring slot there, in order to get the low band mode. Figure 2.6 shows a pair of low pass ring slots at the lower end. From the S11 it is clear that this produces a low band response. In order to stop the low band, the top end of the antenna has the band stop ring slot. Figure 3.7 shows the effect of ring slot radius on the Vivaldi S11. With r =15 mm good return loss of top end band is achieved. This is because the larger the value of r, the lower is stop-band, resulting in less perturbation of the pass-band thus giving better S11.

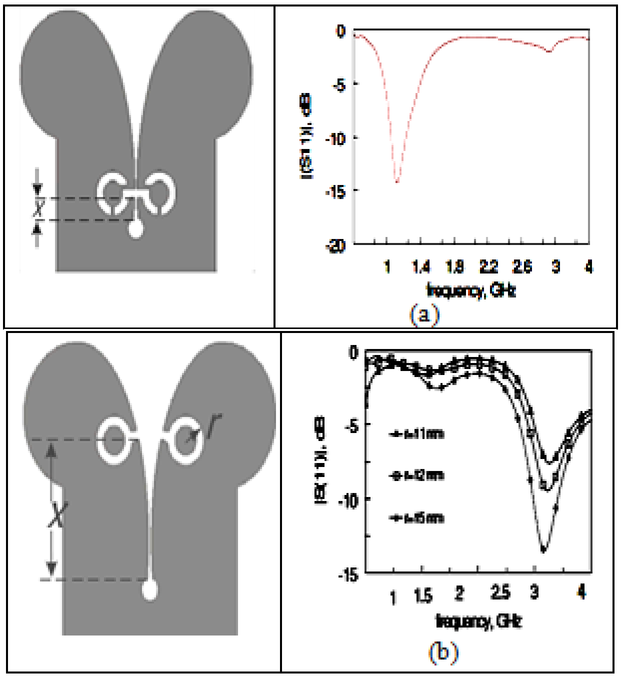


Figure1.6: Simulated S11 of (a) low band (b) high band configurations

Practical & Simulation Result

A wideband to 3 narrowband modes reconfigurable antenna is confirmed here by inserting all three sets of ring slots into the antenna. To fit all in, the position of the middle ring slots is shifted up by 10mm from the matched position. The outer radius of the uppermost ring slots have also been reduced to 10 mm to allow integration. This makes all ring slots have an inner radius of 6 mm and an outer radius of 10 mm. The positions of the switches necessary for reconfiguration are also shown in the figure1.7.

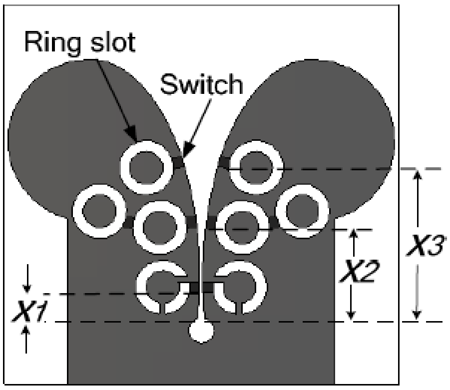


Figure 1.7: Four band reconfigurable antenna

Figure1.8 gives the simulated return loss for wideband operation. It is noticed that the S11 between 1.0 and 4.0 GHz has been improved by the ring slots. The results show that a good matching for wideband operation is achieved over a 1.0 – 4 GHz bandwidth. The return loss for the other three states, low band 1 GHz, mid band 2.4 GHz and high band 4 GHz are shown and below -10dB . A small frequency shift between the measurement and simulation is presumably due to the effect of parasitic in the PIN diodes, fabrication tolerances and biasing components. However, in general, a good agreement has been achieved.

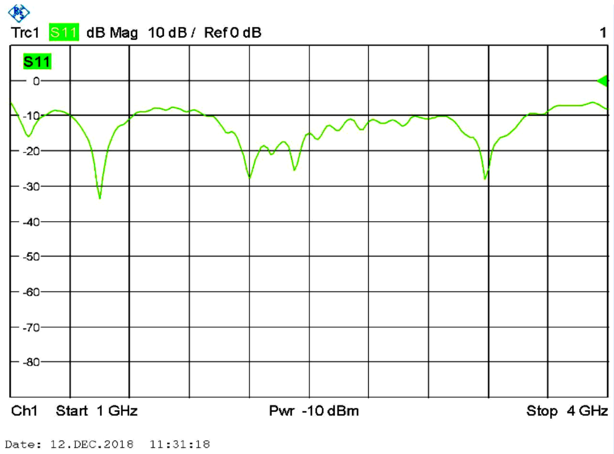


Figure 1.8: Measured S11 for complete modes of operation

Table 1.2: Gain of the proposed antenna

Gain, dBi	Gain, dBi Wide band (3.5GHz)	High Band (4GHz)	Mid Band (2.1GHz)	Low Band (1GHz)
Measured	2.27	1.9	0.76	0.97
Simulated	2.61	2.33	1.5	1.65

3. Conclusion

A Reconfigurable Vivaldi antenna is designed on FR4 substrate using ADS momentum. The layout is simulated in momentum microwave simulator. The designed antenna gives a resonant frequency 4.0 GHz with good return loss. The results are obtained on VSWR.

References

[1] A.F.Sheta and S.F.Mahmoud, "A widely tunable compact patch antenna,"*IEEE Antennas and Wireless Propagation Letters*, vol. 7, pp. 40-42, 2008.

[2] T.Wu,R.L. Li, S.Y. Eom, S.S. Myoung, K. Lim, J. Laskar, S.I. Jeon, and M.M. Tentzeris, "Switchable Quad-Band Antennas for Cognitive Radio Base Station Applications," *IEEE Transactions on Antennas and Propagation*, vol. 58, pp. 1468-1476, May 2010.

[3] Y.Tawk and C.G.Christodoulou, "A New Reconfigurable Antenna Design for Cognitive Radio," *IEEE Antennas and Wireless Propagation Letters*, vol. 8, pp. 1378-1381, 2009.

[4] F.Ghanem, P.S.Hall, and J. R. Kelly, "Two port frequency reconfigurable antenna for cognitive radios," *Electronics Letters*, vol. 45, pp. 534-535, May 21 2009.

[5] P.S.Hall, P. Gardner, J. Kelly, E. Ebrahimi, M. R. Hamid, F. Ghanem, F. J. Herraiz-Martinez, and D. Segovia-Vargas, "Reconfigurable Antenna Challenges for Future Radio Systems," *2009 3rd European Conference on Antennas and Propagation, Vols 1-6*, pp. 902-908, 2009.

[6] P. S. Hall, M. R. Hamid, F. Ghanem, A. Mirkamali, and P. Gardner, "Reconfiguration of Vivaldi and log periodic antennas," in *Proc. Allerton Antenna Symposium* USA, 2009.

[7] C. Christodoulou, "Reconfigurable Antenna and the Military Applications," *IDGA* 7th Military Antennas, http://www.militaryantennasevent.com.

[8] C. Cordeiro, K. Challapali, D. Birru, and N. Sai Shankar, "IEEE 802.22: the first worldwide wireless standard based on cognitive radios," in New Frontiers in Dynamic Spectrum Access Networks, 2005. DySPAN 2005. 2005 First IEEE International Symposium on, 2005, pp. 328-337.