Comparison Study of S-Band Vivaldi-Based Antennas

By Nurhayati

Comparison Study of S-Band Vivaldi-Based Antennas

Nurhayati, Eko Setijadi, Gamantyo Hendrantoro
Departement of Electrical Engineering
Institut Technologi Sepuluh Nopember
Surabaya, Indonesia
nurhayati15@mhs.ee.its.ac.id,
ekoset@ee.its.ac.id, gamantyo@ee.its.ac.id

Abstract— **This paper focuses on comparison between coplanar Vivaldi antenna, *Antipodal Vivaldi Antenna* (AVA) and *Balance Antipodal Vivaldi Antenna* (BAVA) on FR4 substrate, in the same size and type of substrate and the same opening rate of the exponential taper. The proposed antenna has overall size 1.1λ x λ x 0.016λ and works in 2-4 GHz. The best return loss has been obtained for BAVA of -47 dB at 2.374 GHz from simulated result. For overall of frequency, coplanar vivaldi antenna gets higher gain than AVA and BAVA. Directivity of coplanar Vivaldi is 7.859 dBi at 4 GHz. AVA has more asymmetric radiation pattern than BAVA. Side lobe level for coplanar Vivaldi antenna has better performance than AVA and BAVA.**

Keywords—vivaldi; coplanar; Antipodal; BAVA; S-Band.

I. INTRODUCTION

There are many S Band application such as mobile satellite communication, radar, microwave imaging, medical imaging, health monitoring, telemetry and ground penetrating radars. A novel multiband square spiral ring (SSR) metamaterial-embedded printed Yagi antenna array in the S-band for WiFi, Bluetooth, WLAN, and WiMAX has been implemented at four distinct frequencies [1]. Patch antenna for S band nanosatellite communications has been presented with Four asymmetric V-shaped slits in the diagonal directions on the square patches [2]. Impedance and radiation characteristics of linear tapered structure has been investigated in the S-band and achieved a very wide frequency band, symmetry radiation pattern, and high gain [3]. But in that papers the return loss not accopy overall frequency in S Band application (2-4 GHz) and It has more area geometry.

One of the famous directional antenna using horn antennas, but horn antenna is too bulky and has more volume area. Vivaldi element is a broadband and directional antenna can be applied in bandwidth 3.4 to 7 GHz [4]. Vivaldi antenna was directional antenna that introduced by Gibson [5]. In that paper, antenna works in UWB frequency and just presented one type of antenna that is called coplanar Vivaldi. Vivaldi antenna has significant gain, with directional radiation pattern, planar structure, less volume than horn antenna, easy to fabricate and low cost.

Another types of Vivaldi antenna is Antipodal Vivaldi Antenna (AVA). Palm Tree with Exponential Slot Edge Antipodal Vivaldi Antenna is designed for main lobe gain improvement[6]. Wideband Antipodal Vivaldi antenna to improve radiation pattern [7]. Parametric study Dual elliptically Tapered Antipodal Slot Antenna is investigated for UWB [8]. Many technique and many application single element of AVA by modification size of geometry or adding corrugate edge has been recently presented to get performance of radiation pattern. Single element Antipodal Vivaldi Antenna, two and four elements of Vivaldi antenna array in planar and H plane have been compared [9]. Research about Antipodal Vivaldi antenna single and array has drawn great investigated.

Antipodal Vivaldi Antenna (AVA) can reach wider bandwidth than coplanar vivaldi. But it accomplished of cross-polarization as the frequency of operation is increased. To get the better performance of this problem, by build on another dielectric layer namely Balanced Antipodal Vivaldi Antenna (BAVA) can improve the performance [10]. Dielectric Lens BAVA introduced can increse radiation pattern performance and cross-polarisation [11].

All those characteristics of vivaldi is accepted for broad band frequency. Performance of Vivaldi is responsive by varying the geometry parameters of the radiators and feeding. In conventional Vivaldi antenna without corrugate or without adding several tehniques, the significant of wave propagation is between two inner exponential tapered generaly in the slotline to the beginning of tapered slot antenna. The completion of the antenna is very dependent on exponential tapered. From above discussion, there were papers that only discuss one type Vivaldi antenna due to the effect of major geometrical parameters and none of three types of antenna are compared collectively. This paper investigates comparison of Coplanar Vivaldi Antenna, AVA (Antipodal Vivaldi Antenna) and BAVA (Balanced Antipodal Vivaldi Antenna) in the same size and type of substrate, in the same opening rate of exponential flare and in the same width of feeding. Three Vivaldi antenna works in S Band (2-4) freequency. This paper presents performance of return loss, VSWR, polar radiation pattern, gain, side lobe level from simulated result of three Vivaldi antenna.

978-1-5090-0931-2/16/$31.00 ©2016 IEEE

This paper is systematized as Section I introduction, Section II discusses design of the antenna, Section III presents the simulated result and discussion and section IV is Conclussion

II. DESIGN OF THE ANTENNA

Vivaldi antenna is designed on a FR4 substrate with a dimension of 1.1λx λx 0.016λ. Vivaldi antenna are defined as three part: patch, substrate and groundplane. Substrate has relative dielectric constant εr= 4.3, loss tangent tan δ = 0.002, substrat height 1.6 mm and copper height 0.035

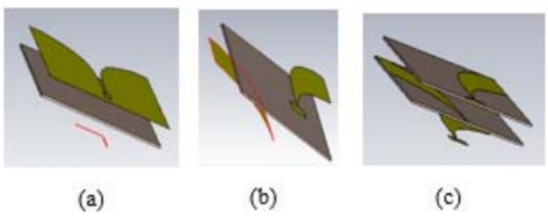


Figure 1. (a) Coplanar Vivaldi (b) AVA (c) BAVA

Fig.1 shows differences between Coplanar Vivaldi Antenna, Antipodal Vivaldi Antenna (AVA) and Balanced Antipodal Vivaldi Antenna (BAVA). Coplanar Vivaldi Antenna only have one radiated layer on the top of substrate and feeding in the bottom side. Antipodal Vivaldi Antenna (AVA) has two radiated layer on the top and bottom side with opposite direction Balance Antipodal Vivaldi Antenna(BAVA) has three radiated layer on the top, middle and bottom and separated by two substrate. The exponential taper is determined by the opening rate (R), point (x1,y1) and (x2,y2) for inner edge of exponential taper and (x3,y3), (x4,y4) for outer edge of tapers and it can be defined as

$$y = C_1 e^{Rx} + C_2 \tag{1}$$

$$C_1 = \frac{y_2 - y_1}{e^{Rx_2} - e^{Rx_1}} \tag{2}$$

$$C_2 = \frac{y_1 e^{Rx_2} - y_2 e^{Rx_1}}{e^{Rx_2} - e^{Rx_1}} \tag{3}$$

R is exponential opening rate, C1 and C2 is denoted as constant that is related with equation (2) and (3). Where x_1,y_1 shows the beginning coordinates of opening rate and x_2,y_2 shows the end point of opening rate (R). Increasing value of R will diminish of mouth opening Vivaldi antenna. Smaller value of R will expand of mouth opening. The slope of opening rate also depends on position of x1,y1 and x2,y2. While for Antipodal Vivaldi Antenna(AVA) and Balanced Antipodal Vivaldi Antenna (BAVA), the outer edge tapers build depend on x_3,y_3 and x_4,y_4 coordinat as shown in figure 2.b

Coplanar Vivaldi

$$x_1 = b - d \quad y_1 = \frac{a}{2} - \frac{e}{2} \tag{4}$$

$$x_2 = b \quad y_2 = \frac{a}{2} - c \tag{5}$$

AVA/BAVA

Inner edge taper

$$x_1 = b - d \quad y_1 = \frac{a}{2} - \frac{e}{2} \tag{6}$$

$$x_2 = b \quad y_2 = \frac{a}{2} + \frac{e}{2} \tag{7}$$

Outer edge taper

$$x_3 = b - d \quad y_3 = \frac{a}{2} - \frac{e}{2} \tag{8}$$

$$x_4 = b - h \quad y_4 = 0 \tag{9}$$

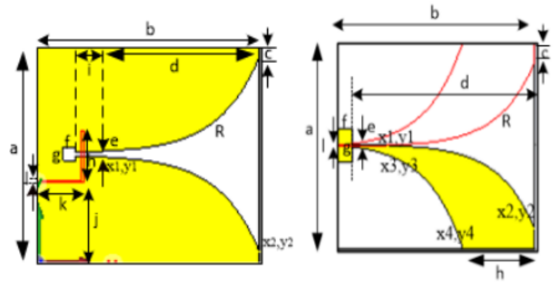


Fig. 2. (a) Geometri Vivaldi (b) Geometri AVA and BAVA

Fig 2a. Shows coplanar Vivaldi antenna on the top view and fig 2b shows Antipodal Vivaldi Antenna(AVA) and Balanced antipodal (BAVA) on the top view. Difference types of AVA and BAVA can be shown in fig 1b and 1c. An optimal structure parameters are obtained as follows in Table.1.

Table 1. Dimension Of Design Parameters

Parameter	Coplanar (in mm)	AVA (in mm)	BAVA (in mm)
a	110	110	110
b	100	100	100
c	7.5	7.5	7.5
d	72	98	98
e	1.1	1.5	1.5
f	6	8	8
g	6	16	16
h	27	-	-
i	16	-	-
j	36	-	-
k	28	-	-
l	1.5	1.5	1.5
R	0.05	0.05	0.05

Table 1 presents the optimal parameter result for coplanar Vivaldi antenna, AVA and BAVA. It is shown that AVA and BAVA has identical size. Antenna dimension in a, b, c, k, l and R have the same value for all type of antennas. a and b is width and length of antenna,c and R is parameter that specify opening rate of the antenna and l is width of the feeding.

A. *Coplanar Vivaldi antenna*

Coplanar Vivaldi antenna has two tapered slots on the same side of the dielectric substrate. Feeding antenna in the opposite of dielectric substrate. Coplanar Vivaldi antenna operates without ground layer. Bandwidth of the antenna is purposeful by configuration of feeding , geometry of cavity, substrate size, and exponential opening rate. All of that parameter will influence the return loss performance. Bandwidth for Vivaldi antenna can be indicated with a half of comparison high frequency by lower frequency and it is related with comparatively of length and width of the substrate with the equation:

$$b/_{a} \sim 0.5\, {f_{hi}}/_{f_{lo}} \quad (10)$$

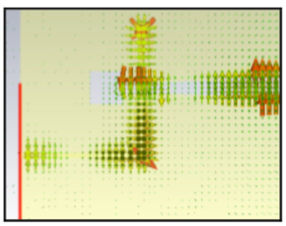


Fig. 3. E Field Coplanar Vivaldi antenna

Fig. 3 shows E Field Coplanar Vivaldi antenna. We can see that wave will propagate in slotline and between two inner edge taper. It shows linier polarization in the feed line and in the slotline between two inner exponential taper. Balun is the region where the unbalunced feed line into a balanced slotline to the exponential tapered. Cavity is rectangular shape of the beginning slotline

B. *AVA and BAVA*

Antipodal Vivaldi Antenna (AVA) is one kind of Vivaldi antenna that consists of two copper radiator in the top and bottom side of the antenna substrate. AVA only has one layer of substrate. The two radiators are symmetry in the center width of substrate in the opposite direction. One part radiator behaves as ground. In AVA, electromagnetic field will be radiated in slotline because there is transition radiated wave from one part of radiated layer to another side which is separed by one dielectric substrate. Dimension of exponential radiator and ground will effect return loss and radiation pattern performance.

BAVA consists of three copper layers and separated by two dielectric substrats. One of the radiated layered in the middle side has opposite direction with two radiated layered in the top and in the bottom side. Top and bottom radiated layer have the same direction. BAVA antenna can reduce the crosspolarisation compared with AVA because the ratio of slot width to dielectric thickness is large especially for low frequency.

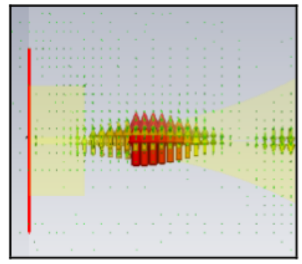


Fig. 4. E Field feeding AVA/BAVA antenna

Figure 4 shows E field polarization for AVA/BAVA antenna. Polarization is defined as the orientation of electric field component to the plane that contains waveform. We can see from figure 4 AVA and BAVA has linear polarization and wave will propagate in the middle of two tapered slotline.

III. SIMULATED RESULT AND DISSCUSSION

A. *Return Loss (S11) and VSWR*

Return loss (S11) indicates how matched an antenna to the input transmission line. Return loss is parameter in decibel unit that related with ratio reflected power to incident power. The best return loss is below -10 dB and it is related to reflection coefficient and Voltage Standing Wave Ratio. Good return loss indicated good impedance matching and wave will be radiated perfectly to free space . Simulated result of reflection coefficients (S11) coplanar Vivaldi antenna, AVA and BAVA are shown in fig.5.

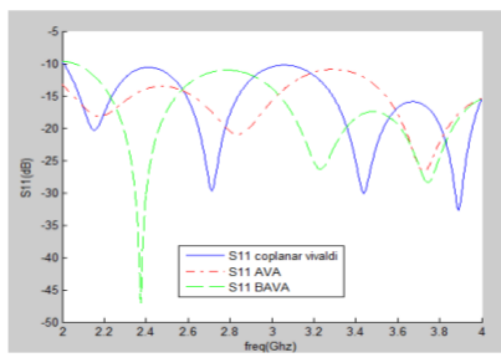


Fig 5. Simulated Return Loss S11 (dB) vs frequency (GHz)

Fig.5 presents the return loss of three antennas. Antennas are designed in the same dimension of substrate, same opening rate, same material and operate over 2 to 4 GHz. It shows that the return loss is good and less than -10 dB in desired frequency range. The best return loss has been obtained for

BAVA is -47 dB at 2.374GHz and the second for coplanar Vivaldi antenna is -32.68 dB at 3.89 and the third ruturn loss for AVA is -26.755 dB at 3.76 GHz. Bandwidth Vivaldi antenna can be categorized as broad band antenna because fractional bandwidth of antenna more than 0.2 and it can be denoted by

$$FBW = 2\frac{f_H - f_L}{f_H + f_L} > 0.2 \quad FBW = 2\frac{4-2}{4+2} = \frac{4}{6} = 0.67 > 0.2 \qquad (11)$$

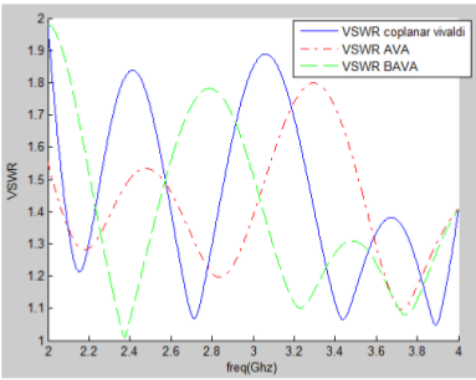
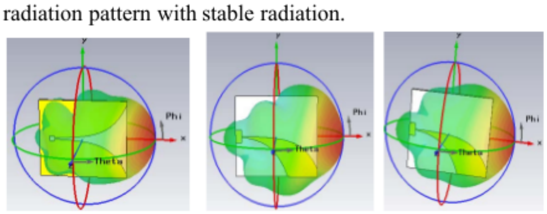


Fig. 6. Performance simulated VSWR

Fig 6. Shows VSWRof three antennas . It is indicating that in the frequency range 2-4 GHz, antenna has VSWR less than 2. The best VSWRis obtained for BAVA at 2.374 GHz as 1.0089

B. *Radiation Pattern*

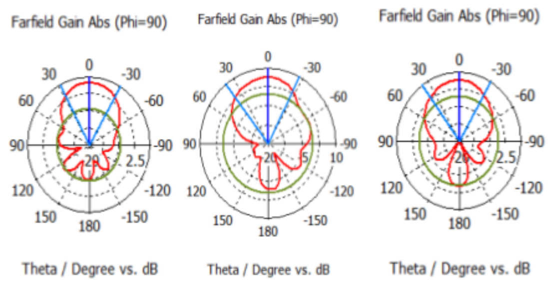
A valuable parameter for identify the performance of an antenna is gain. 3D radiation pattern at 3 GHz of the proposed Antenna is shown in fig.7. Vivaldi antenna has directional radiation pattern with stable radiation.



(a) (b) (c)

Fig. 7. 3D Radiation pattern at 3 GHz

Fig.7 depicts gain for coplanar Vivaldi antenna as 7.300 dB or directivity of coplanar is 7.859 dBi. gain for AVA is 6.281 dB or directivity of AVA is 6.698 dBi and gain for BAVA is 6.345 dB or directivity of BAVA is 6.907 dBi.Thats value is shown from simulated result. It can show that highest gain is given by coplanar Vivaldi antenna and BAVA has better gain compared with AVA at frequency 3 GHz in the same size of geometry, same type of substrat and the same opening rate.



(b) (b) (c)

Fig.8.Simulated radiation patterns theta 90

(a) coplanar (b) AVA (c) BAVA

Fig. 8 shows polar plot for theta 90 with angle step width phi. From radiation pattern in fig.8 at 3 GHz, coplanar Vivaldi antenna has smaller side lobe than AVA and BAVA. From polar plot, AVA has asymmetric radiation pattern and BAVA has more symmetric radiation pattern than AVA in the same model. From simulated result, Angular width (3dB) coplanar Vivaldi antenna is 58.7 deg with side lobe level -11.4 dB. Angular width(3dB) AVA shows 66.3 deg with side lobe level -6.7 dB. Angular width(3dB) BAVA is 66.8 deg with side lobe level -7 dB. From that result we can make conclusion that in polar plot for theta 90 degree, coplanar Vivaldi antenna has the best angular width and side lobe level. And BAVA has better angular width and side lobe level than AVA.

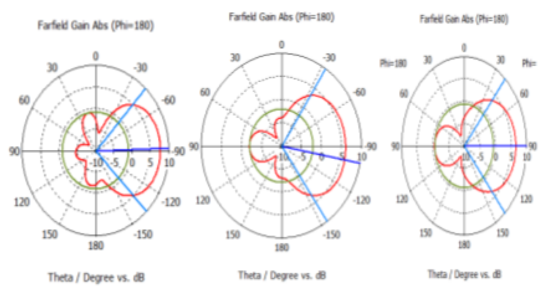


Fig. 9. Simulated radiation patterns Phi 180

(a) coplanar (b) AVA (c) BAVA

Fig.9 presents polar plot for phi 180 with angle step width theta in XYZ coordinates. From simulated result, angular width(3dB) of coplanar Vivaldi antenna is 100.2 deg with side lobe level is -9.2 dB. AVA shows angular width(3dB) is 111.6 deg. with side lobe level -8.2 dB. BAVA shows angular width(3dB) 103.7 deg with side lobe level -7 dB. From that result, for phi 180 degree coplanar Vivaldi antenna gets the best angular width(3dB) and side lobe level. And angular width(3 dB) of BAVA better than AVA. But sidelobe level of AVA better than BAVA.

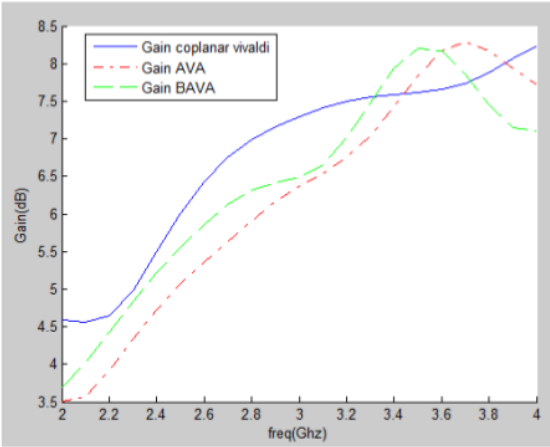


Fig. 10. Gain Vivaldi Antenna

Maximum gain can be observed in Fig.10 and it shows a rising trend across the frequency range especially for coplanar Vivaldi antenna. Gain for coplanar Vivaldi improve from 4.56 to 8.224 dB over the operating frequencies 2-4 GHz with the max gain 8.224 dB. Gain for AVA increase from 3.50 to 7.72 dB with the max gain 8.286 dB at frequency 3.59 GHz. Gain for BAVA go up from 3.59 to 7.667dB with the max gain 8.103 dB. From fig.10 we can see that in frequency 2 – 3.3 GHz, for the same size and types of substrate and the same opening rate, maximum gain is reached by by Coplanar Vivaldi antenna , BAVA, and AVA respectively. But for frequency 3.3-3.9 GHz maximum gain is reached by AVA in 3.59 GHz of 8.286 dB

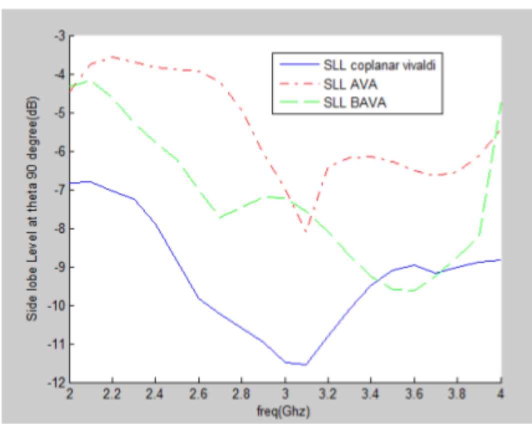


Fig. 11. Side Lobe Level at theta 90 degree

Besides gain, sidelobe level is used to characterize radiation patterns. Sidelobes are smaller beams that are away from the main beam. These sidelobes are usually radiation in avoid directions, because it will decrease mainlobe. As demonstrated in fig.11 Side lobe level Coplanar Vivaldi antenna is better than AVA in all frequency, and BAVA has better Side Lobe Level than AVA in overall frequency.

Table 2. Comparisan radiation pattern at 3GHz

Vivaldi Antenna	**Coplanar**	**AVA**	**BAVA**
f (GHz)	3	3	3
Rad.effic (dB)	-0.5588	-0.4169	-0.5623
Total.Effic (dB)	-0.9626	-0.5330	-0.7467
Gain(dB)	7.300	6.281	6.351
Farfield Gain Abs (Phi=180)			
Angular width(3deg)	100.2	111.6	103.9
Side lobe level(dB)	-9.2	-8.2	-7
Farfield Gain Abs (Theta=90)			
Angular width(3deg)	58.7	66.3	66.8
Side lobe level(dB)	-11.4	-6.7	-7

Table.2 shows the comparison 3D radiation pattern and Polar plot XYZ coordinates for coplanar Vivaldi, AVA and BAVA. It can be observed, at phi 180 degree, coplanar vivaldi antenna has smallest angular width (3dB) and followed by BAVA and AVA respectively. From the table coplanar has better side lobe level than AVA and BAVA

Table 3. Comparison in S-Band frequency (2-4GHz)

Vivaldi Antenna	Coplanar	AVA	BAVA
Return Loss	-32.6 dB at 3.89 GHz	-26.75dB at 3.76 GHz	-47,00 dB at 2.374 GHz
VSWR	1.047 at 3.89 GHz	1.096 At 3.89 GHz	1.008 At 2.374 GHz
BAVA is best in return loss and VSWR			
Gain (dB)	8.224 dB at 4 GHz	8.286 dB At 3.7 GHz	8.104 dB At 3.5 GHz
AVA is highest gain But for general of frequency Coplanar Vivaldi antenna is the best gain from 2 –3.3 GHz			
Side lobe level	-11.535dB at 3.1 GHz	-8.080 dB At 3.1 GHz	-9.627 dB At 3.6 GHz
Coplanar is good performance in Side Lobe level at phi 90 degree			

Table 3. presents comparison Return loss, VSWR, Gain and Sidelobe level for three Vivaldi antenna. BAVA shows the best return loss and VSWR. AVA and BAVA attain wider bandwidth than coplanar Vivaldi antenna. Although AVA gets best gain in 3.7 GHz, but long term of frequency coplanar is the best gain and side lobe level.

Table 4. Comparison references paper

Ref	Types of antenna	freq(GHz) S11<-10dB		Size (mm)	Gain
1	Yagi array Square spiral Ring	S Band	2.79	140x61	10.6 dB
			3.86		5.26 dB
			4.01		6.7 dB
2	Patch with four asymmetric V shaped slits	S Band	2.245-2.307	80x 80	7.29 dBi
3	Linear Tapered Antenna	S Band	1.3 - 2.65	385 x 300	12 dB
4	Coplanar Vivaldi	UWB	3.4-7	112x40	7.4 dB
6	AVA		5.6-11	36.3x59.81	8.3 dB
7	AVA		6-18	31.2x45	8.4 dB
8	AVA	UWB	4-20	75x51	10 dB at 10GHz
9	AVA	S-Band	3.04-4	120.3-87.2	5.287 dBi
10	Coplanar Vivaldi	UWB	3.5-10.6	123.51 x 96.77	-
11	BAVA	UWB	3-18	96x50	4-13dB

In table.4 Reference [1],[2] antenna not accopy all S Band frequency. Reference [3] used linear tapered antenna and has larger size than our design. Reference [4][6][7][8] not accopy all S-Band (2-4 GH) but it is started operating in higher frequency than our design (more than 3 GHz) so it has smaller geometry area. Reference [9] has less gain than our design. Reference [10] gain not presented and it work in UWB frequency from 3.5 GHz for return loss <-10 dB. Reference [11] with smaller size and started from 3GHz. All those paper just compared only one type of Vivaldi antenna due to the effects of major geometrical parameters and none of those compared three types of antenna collectively. in the same size, type of substrate and the same opening rate of flare.

IV. CONCLUSION

Comparison study between coplanar Vivaldi antenna, *Antipodal Vivaldi Antenna* (AVA) and *Balance Antipodal Vivaldi Antenna* (BAVA) on FR4 substrat with a dielectric constant of 4.3 in the same size, same type of substrate and the same opening rate of the exponential taper has been presented. Coplanar vivaldi antenna, AVA and BAVA has good radiation and reflection characteristics in S-Band frequency band. The best return loss has been obtained for BAVA -47 dB at 2.374 GHz and the second for coplanar Vivaldi antenna -32.68 dB at 3.89 and the third ruturn loss for AVA -26.755 dB at 3.76 GHz. Three element antenna has VSWR lower than 2. Although AVA gets best gain in 3.7 GHz, but from long term of frequency coplanar is the best gain. Gain for coplanar vivaldi antenna is 7.300 dB or directivity of coplanar 7.859 dBi. From polar radiation pattern at phi 180 degree and theta 90 degree, coplanar Vivaldi antenna has smaller side lobe than AVA and BAVA. AVA has more asymmetric radiation pattern than BAVA. Side lobe level for coplanar Vivaldi antenna better than AVA. Thus this paper can be references which type of Vivaldi antenna with the best performance to our S band Application. Furthermore there is still room for improvement vivaldi performance and compared it performance with measurement result.

ACKNOWLEDGMENT

This work is supported by Indonesian Ministry of Research and higher Education. Nurhayati is a lecturer of Universitas Negeri Surabaya that is doing her Ph.D in ITS and it is funded by Indonesian Government through BPPDN scholarship

REFERENCES

[1] O.M.Khan, Z.U.Islam, Q.U. Islam, and F. A. Bhatti, " Multiband High-Gain Printed Yagi Array Using Square Spiral Ring Metamaterial Structures for S-Band Applications", IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 13, 2014

[2] M. T. Islam, M. Samsuzzaman, S. Kibria , Mengu Cho," Development of S band antenna for Nanosatellite", 2014 IEEE Asia-Pacific Conference on applied Electromagnetics (APACE), 8 - 10 December, 2014 at Johor Bahru, Johor, Malaysia

[3] Z. Wei-gang, Z. Xing-jjan, YU Tong-bing, W.Pei-zhang, "Design of a High Gain S-band Antenna based on a Linear Tapper Slot", IEEE , 2014.

[4] C. Sarkar, "Some Parametric studies on Vivaldi Antenna", International Journal of u-and e-Service, Science and Technology, Vol.7, No.4, pp.323-328, 2014

[5] Gibson , "The Vivaldi aerial," 9th European Microwave Conference, 101–105, 1979.

[6] M.De Oliveira, B.Perotoni, Kofuji,Justo,"A Palm Tree Antipodal Vivaldi Antenna With Exponential Slot Edge for Improved Radiation Pattern", IEEE Antennas And Wireless Propagation Letters, Vol 14, 2015..

[7] A. Dastranj," Wideband Antipodal Vivaldi Antenna with Enhanced Radiation Parameters", IET Microwaves, Antennas & Propagation, 2015, Vol 9,Iss 15, pp 1755-1760

[8] X. Qing, Z.N.Chen, W.Chia, " Parametric Study of Ultra-Wideband Dual Elliptically Tapered Antipodal Slot Antenna", Hindawi Publishing CorporationInternational Journal of Antennas and Propagatio, Volume 2008, Article ID 267197, 9 pages, doi:10.1155/2008/267197

[9] N.Ardelina, E.Setijadi, P hari, B Manhaval, "Comparison of Array Configuration for Antipodal Vivaldi Antenna", Conferences on Radar, Antenna, Microwave, Electronics and Telecommunications, 2015

[10] N.Vignesh, G.A.S.Kumar, R.Brindha, "Design and Development of a Tapered Slot Vivaldi Antenna for Ultra-Wide Band Application", International Journal of Advanced Research in Computer Science and Software Engineering, Volume 4, Issue 5, May 2014.

[11] A.Molaei,M.Kaboli,A.Mirtaheri,S.Abrishamian, "Dielectric lens balanced Antipodal Vivaldi Antenna with low cross-polarisation for ultra-wideband application", IET Microwave, Antennas Propagation, 2014 Vol 8,Iss14,pp.1137-1142

Comparison Study of S-Band Vivaldi-Based Antennas

ORIGINALITY REPORT

3%

SIMILARITY INDEX

PRIMARY SOURCES

1	Nurhayati, Eko Setijadi, Gamantyo Hendrantoro. "Effect of Vivaldi element pattern on The Uniform Linear Array Pattern", 2016 IEEE International Conference on Communication, Networks and Satellite (COMNETSAT), 2016 Crossref	51 words — 1%
2	Adibifard, Somayeh. "Design of Wideband Rotman Lenses with Dummy Ports for Wide-Scan Phased Array Applications", Ecole de Technologie Superieure (Canada), 2020 ProQuest	18 words — 1%
3	www.semanticscholar.org Internet	16 words — < 1%
4	www.jees.kr Internet	8 words — < 1%
5	research.birmingham.ac.uk Internet	7 words — < 1%

EXCLUDE QUOTES	ON	EXCLUDE MATCHES	OFF
EXCLUDE BIBLIOGRAPHY	ON		