Total Array Pattern Characteristics of Coplanar Vivaldi Antenna in E-plane with Different Element Width for S and C Band Application

By Nurhayati

Total Array Pattern Characteristics of Coplanar Vivaldi Antenna in E-plane with Different Element Width for S and C Band Application

Nurhayati^{1,2}, **G. Hendrantoro**^{1}, **and E. Setijadi**^{1}

^{1}Institut Teknologi Sepuluh Nopember, Indonesia
^{2}Universitas Negeri Surabaya, Indonesia

Abstract— Co-planar Vivaldi antenna can be designed for broadband applications. The operating band of a Vivaldi depends on antenna parameters such as antenna length and width, feeding, substrate, the slope and opening width of the tapered slot. Moreover, a broadband antenna might exhibit varying radiation pattern in each its operating frequency. In a Vivaldi array, width of the element antenna determines the total array pattern especially on the E-plane. If the wideband Vivaldi elements are arranged without gaps between elements on the E-plane, it would obtain the less desirable total array pattern at higher frequency, specifically for antenna width more than one wavelength of its operate frequency. Our paper presents total array pattern of Co-planar Vivaldi antenna as influenced by the element width. Each element is designed with the same length but different widths. It can improve main lobe and side lobe level performance at center and higher frequency if it compared to array with the same width of elements. For center frequency 5 GHz, directivity of array with different width of element is 11.6 dBi and it has side lobe level is −9.2 dB. Whereas array with the same width of element has directivity is 10.7 dBi and SLL as −4 dB. It is generally shows a promising potential after further development for use in applications in the S and C band.

1. INTRODUCTION

Vivaldi antenna can be applied for many application such as UWB communication [1], vehicular communication systems [2], cognitive radio [3], Imaging construction material [4], medical imaging [5], breast cancer detection [6], brain tumors [7, 8], GPR [9] and etc. Vivaldi antenna research firstly developed by Gibson [10]. Vivaldi antenna has many advantages because of its low profile, directional radiation pattern and it can work in wide bandwidth [11]. Over the last few year, there are many papers have been published about antenna design to improve bandwidth and radiation pattern performance. Representation of the Vivaldi element pattern depends on its parameter such us feeding, antenna length and width, opening rate of the exponential tapered slot, and opening mouth of the antenna element [12]. Radiation pattern of Vivaldi antenna in each frequency work has difference exhibition. Increasing bandwidth of antenna element can influence the radiation pattern especially for frequency that far for center frequency.

Array antenna has many advantages compared with individual antenna element because it can increase gain and reduce beam width. There are many application for array Vivaldi antenna such as UWB application [13], astronomy [14], and snow radar [15], arrays for UWB see through wall application [16]. The total array pattern can be influenced by radiation pattern of element and array factor. Array factor depends on the number of elements and spacing between elements, amplitude and phase of each elements. Weighting of the signal and configuration array can improve antenna array performance [17].

Wide band array has different total array pattern at each operated frequency. It has different total array pattern especially if antenna is arranged in the E plane. Width of the antenna will effect on total array performance. Larger width of antenna element will impact larger spacing between feeding. It will lead higher side lobe level, even grating lobe, especially for higher frequency. Grating lobe can be resulted if spacing between element more than one wavelengths of its frequency work. This paper will discussed total array pattern characteristic of coplanar Vivaldi antenna in E plane with different width of element at wide band frequency.

From the proposed array we derive improvement of main lobe and SLL level in the center frequency and at higher frequency if it compared with array with the same width. Higher side lobe level and grating lobe can be interference and it can reduce transmitter or receiver performance. But our purposed design makes slightly worse VSWR performance at lower frequency. This paper consist of four section. First section is introduction. Second section is design of antenna element. Third section is simulated result and discussion. And the last section is conclusion.

2. DESIGN OF THE ANTENNA ELEMENT AND ARRAY

2.1. Element Design

Vivaldi antenna is designed based on previous work [18]. But we use another dimenssion and substrate. We use FR4 substrate with permittivity 4.6. and the substrate height is 1.6 mm, loss $\tan\delta = 0.002$ with copper height of the patch is 0.035 mm.

Figure 1 shows coplanar Vivaldi antenna geometry and the dimension parameter of Figure 1 is shown in Table 1.

Table 1: Antenna parameters.

parameter	1st Ant	2nd Ant	3rd Ant	4th Ant	UWB Ant
a	60	60	60	60	60
b	60	50	40	35	60
c	30	30	20	20	30
d	2.5	2.5	2.5	2.5	2.5
e	7.5	7.5	7.5	7.5	7.5
f	-6	-6	-6	-6	-6
g	42.5	42.5	42.5	42.5	42.5
h	3	3	3	3	3
i	120°	120°	120°	120°	120°
j	3	3	3	3	3
k	0.9	0.9	0.9	0.9	0.9
l	4	4	4	4	4
m	5	5	5	5	5
R	0.15	0.15	0.15	0.15	0.15
tpatch	0.035	0.035	0.035	0.035	0.035
tsubs	1.6	1.6	1.6	1.6	1.6
Freq. range	2-4 GHz	3-5 GHz	4-6 GHz	5-7 GHz	2-10 GHz
fc	3 GHz	4 GHz	5 GHz	6 GHz	5 GHz

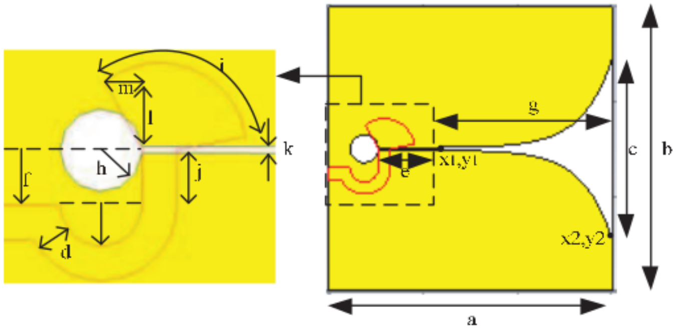


Figure 1: (a) Coplanar Vivaldi, (b) AVA, (c) BAVA.

Table 1 describes optimal parameter of five antenna element that operate in variant frequency range. From that table, it shows that parameter b and c is different between each type of antenna but the other parameter has the same parameter. Parameter b shows width of the antenna, and c is opening mouth of the coplanar Vivaldi antenna. Antenna with higher frequency can be designed by smaller antenna width. It can have smaller opening width. Coplanar Vivaldi antenna can be constructed with dimension of the opening mouth is a half of its lower operate frequency. Antenna 2 has smaller width compare with antenna 1 because it work at higher frequency range than antenna

1. Antenna 3 has smaller width if it compared with antenna 2 an so on. The smallest width is shown at antenna 4 because its work at highest operating frequency range.

The tapered slot has exponential tapered with fulfil equation:

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

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

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

where R is opening rate, (x_1, y_1) and (x_2, y_2) are first point and the end slope of the tapered slot.

2.2. Array Configuration

Figure 2 describes array antenna with five antenna element. The first array compose of antenna element with different width of elements. The second array consist of the same width of element and each element work at wide band frequency (2–10 GHz) with the center frequency of each element is 5 GHz. The frequency bandwidth of 1st Antenna, 2nd Antenna, 3rd Antenna, 4th Antenna is 2 GHz. But range frequency for UWB element antenna for the second array antenna is 8 GHz. Bandwidth is freque. The first array compose of antenna element with different width of elements. The second array consist of the same width of element and each element work at wide band frequency (2–10 GHz) with the center frequency of each element is 5 GHz. Bandwidth Vivaldi antenna can be categorized as broad band antenna because of fractional bandwidth of antenna more than 0.2. It can be denoted by

$$FBW = 2\frac{f_H - f_L}{f_H + f_L} > 0.2$$

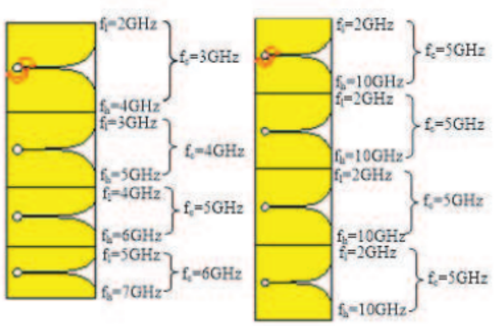


Figure 2: Array antenna with different width of element and the same width of elements.

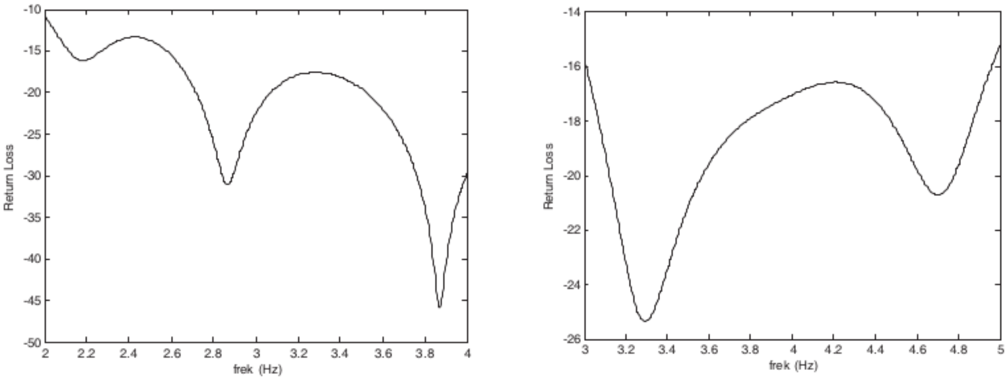
3. SIMULATED RESULT AND DISCUSSION

3.1. Return Loss Antena Element

Return loss parameter is antenna performance that is very important to antenna design. Because it describes frequency of the antenna work. The following figure shows return loss performance for all antenna element that work in frequency range respectively.

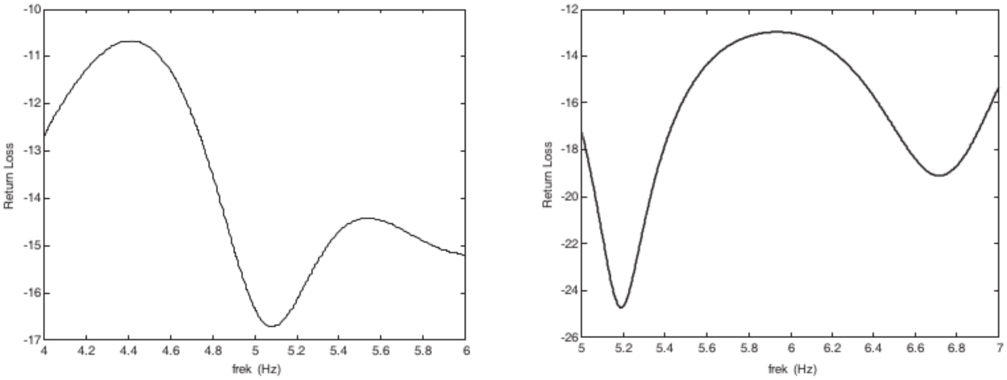
Figure 3 and Figure 4 describe return loss performance of the antenna element with different width that work at different range of operating frequency. All of those antenna has return loss below −10 dB with difference center frequency. Antenna at higher frequency can be designed in smaller size to get return loss below −10 dB.

Table 2 denotes operate frequency of each antenna element. It can show that a half wavelength for higher frequency is smaller than a half wavelength for at lower frequency. Width of the element antenna depend on frequency work of the antenna and It can influence radiation pattern of its frequency work.



(a) (b)

Figure 3: (a) Return Loss 1st antenna (2–4 GHz) and (b) return loss 2nd antenna (3–5 GHz).



(a) (b)

Figure 4: (a) Return Loss 3rd antenna (4–6 GHz) and (b) return Loss 4th antenna (5–7 GHz).

Table 2: Frequency and wavelength.

f (GHz)	λ (mm)	0.5λ (mm)
3	100	50
4	75	37.5
5	60	30
6	50	25

3.2. VSWR Array Antenna

Our purposed design, in the first array, it consists of four antenna element with different width that is arranged in the E plane. In the second array, it consists of four UWB element with the same width and it is arranged in the E-plane.

Figure 6 represents VSWR of array antenna. In the first array, the second element has smaller width than third element. The third element is smaller than second element and the smallest element is antenna four. Fourth element is designed in order to cover frequency 5–7 GHz. It can be shown at lower frequency that VSWR result for smaller width of element antenna is higher than VSWR result for wider antenna. It can be caused spacing between feeding of antenna element is smaller than spacing between feeding for wider antenna. VSWR result for array antenna with the same width of antenna element produces better performance than antenna array with different width of elements.

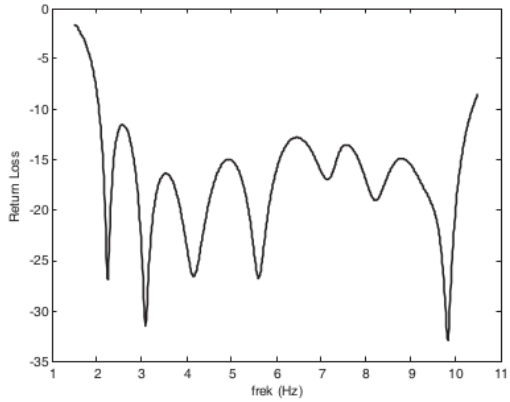


Figure 5: Return Loss UWB antenna (2–10 GHz).

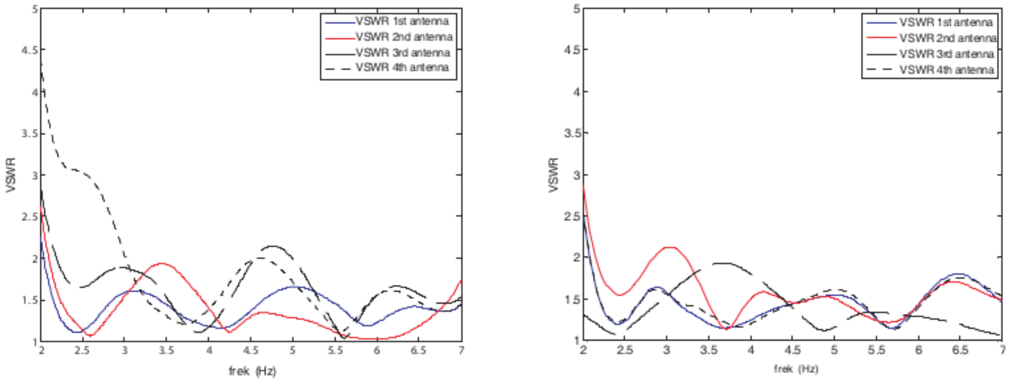


Figure 6: VSWR array antenna with different width and VSWR array antenna with the same width of element.

3.3. Simulated Result of Total Array Pattern

Figure 7 illustrates the antenna directivity. It operates at frequency 3 GHz. For frequencies below the center frequency of wideband array (5 GHz), it appears that the same size of the antenna has higher directivity than the antenna array which has different antenna width. From the simulation results, it is obtained that main lobe magnitude for antenna with the same element as 10.7 dBi, while the main lobe for array antenna with different elements as 9.7 dBi. The array antenna with the same element width will have larger area radiator array than array antenna with different width of element. It will cause the directivity of array with larger radiator is bigger than array with smaller radiator.

$$D = \frac{4\pi}{\lambda^2} A_{em}$$

where A_{em} is the maximum effective aperture of antenna element. From simulated result, antenna with the same width of element has Side Lobe Level (SLL) as -9.6 dB and antenna with different size of element width has SLL -9.1 dB. From that result we can conclude that it has slightly different of side lobe level.

From simulated result, at $f = 4$ GHz, main lobe for antenna with the same element equal to 11.6 dBi while for different elements has main lobe as 1.7 dBi. In addition, for frequencies that operates less than center frequency, array antenna that consist of the same width of element has smaller SLL than array with different sizes of element. It is shown by the SLL value for antenna with the same element equal to -11.3 dB whereas the array antenna with different element has SLL -10.2 dB. Two designed array at frequency 4 GHz have 1.1 dB different of SLL.

Frequency 5 GHz is the center frequency of our purposed array antenna. From Figure 9, it shows main lobe of array pattern for different elements is better than the main lobe of array that has the same element. Main lobe of frequency 5 GHz as 11.6 dBi and main lobe of the same element

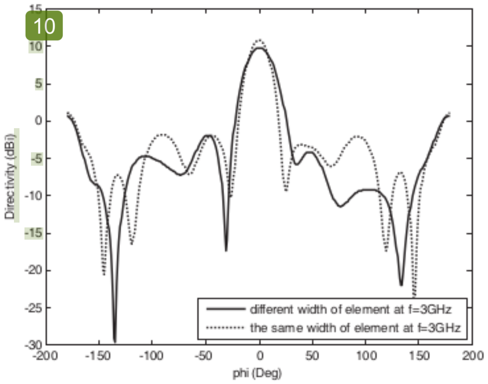


Figure 7: Comparison directivity at $f = 3\,\mathrm{GHz}$.

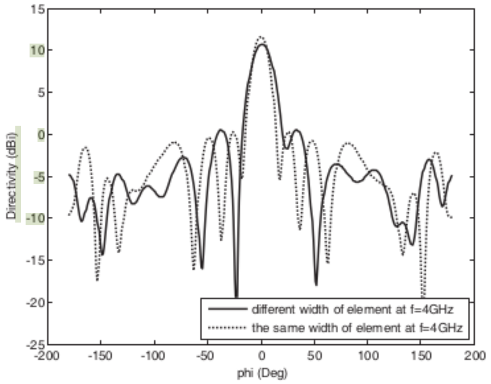


Figure 8: Comparison directivity at $f = 4\,\mathrm{GHz}$.

of 10.7 dBi. While the SLL at frequency 5 GHz for different elements is -9.2 dB and SLL for the same element is -4 dB. The difference main lobe magnitude for two array is 0.9 dBi. The difference SLL for array with the same width and our purposed as -5.2 dB. It can concluded our purposed is better to improve SLL performance at center frequency.

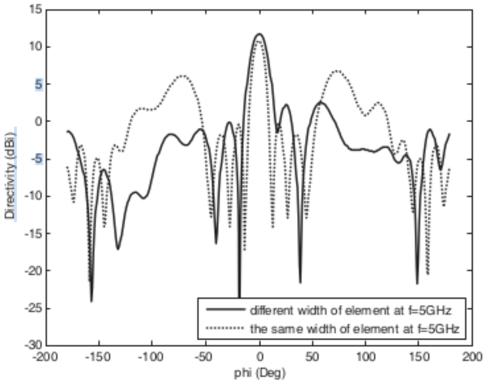


Figure 9: Comparison directivity at $f = 5\,\mathrm{GHz}$.

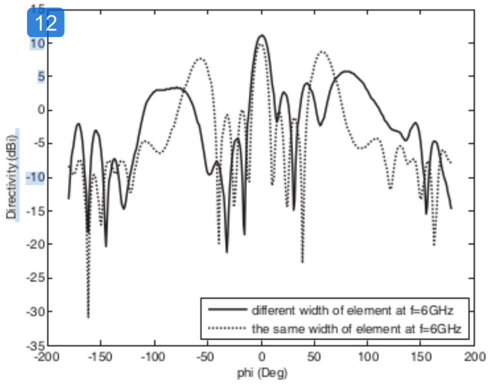


Figure 10: Comparison directivity at $f = 6\,\mathrm{GHz}$.

Figure 10 shows main lobe magnitude of 6 GHz frequency is 11.1 dBi and main lobe of the same element is 9.8 dBi. While the SLL at a frequency of 6 GHz for different elements of -5.4 dB and for the same element SLL of -1.2 dB. The difference main lobe magnitude for two array is 1.3 dBi and difference of SLL is 4.2 dB Antenna array for different width of element has main lobe magnitude and SLL is better than array with the same element at center frequency also at frequency more than center frequency. The reason is for wider width of the antenna, the radiator surface is wider and the spacing feeding between two antenna elements is larger. It will effect on the total array pattern. Total array pattern is influenced by element pattern and array factor. Farfield of the total array pattern is expressed by multiplication of element pattern and array factor [19].

$\mathit{Total\ Pattern} = \mathit{Element\ pattern\ x\ Array\ Factor}$
Where Array factor can be described as sum of all single element
$AF = 1 + e^{j\psi} + e^{j2\psi} + e^{j3\psi} + \ldots + e^{j(N-1)\psi}$
$\psi = kd\cos\theta + \xi$
ξ is phase differenceadded to antenna element
$k = \frac{2\pi}{\lambda}$
$\theta =$ main beam steering (endfire)
d is spacing between element
N is number of element
Array factor also can be expresed:
$AF = \frac{\sin(N\psi/2)}{\sin(\psi/2)}$

Array factor is function of geometrical element, current excitation, number of element, spacing between elements, frequency operating. In our purposed, we used the same current excitation for all the antenna elements. It denotes geometry of element, spacing between element, and frequency operating greatly effect of the array factor. Wider element of antenna will affect spacing between element and it will impact for factor array. At frequency 5 GHz and 6 GHz, the performance of total array pattern for array with the same width of element has less main lobe and worse SLL performance compared to array with different width of element. If array is designed from element with width of element 60 mm, it means spacing between feeding is 60 mm. Based on Table 2, spacing 60 mm will be equal to or more than one wavelength at frequency 5 GHz (1λ) and 6 GHz (1.2λ) at its operate frequency. It would yield higher SLL due to the array factor has grating lobe.

4. CONCLUSION

Total array pattern of Co-planar Vivaldi antenna in E plane with different antenna element has been presented. Our purposed array consist of four elements with different width and operated in different frequency center and It is compared with array with the same width of antenna element. Antenna element with the same width of element has dimensions of elements is 60×60 mm ($0.6\lambda_L \times 0.6\lambda_L$) and each element operates at wide band frequency (2–10 GHz). Array with different width of element reached SLL and main lobe magnitude performance improvement mainly at frequency equal to and more than center frequency. Performance SLL and main lobe at frequency less than center frequency for both array is different slightly. At center frequency the SLL performance for array with different width of element is increase 5.2 dB and main lobe magnitude increase 0.9 dBi. For design wideband array of coplanar Vivaldi antenna in the E-plane, it would be better if element width has dimension less than a wavelength of its highest frequency. It will avoid the occurrence of high side lobe or grating lobe that can be interference of array system.

ACKNOWLEDGMENT

Our research is supported by BPPDN scholarship. It also supported by doctoral dissertation funding program from Institut Teknologi Sepuluh Nopember. Nurhayati is lecturer at Universitas Negeri Surabaya that doing her PhD research in Institut Teknologi Surabaya.

REFERENCES

1. Natarajan, J. V. G., M. Kanagasabai, L. Lawrance, B. Moorthy, D. B. Rajendran, and M. G. N. Alsath, "Modified antipodal Vivaldi antenna for ultrawideband communications," *IET Microwaves, Antennas & Propagation*, Vol. 1, No. 4, 401–405, 2016.
2. He, S. H., W. Shan, C. C. Mo, F. H. Yang, and J. H. Chen, "Improved Vivaldi antenna for vehicular wireless communication systems," *IEEE Antennas And Wireless Propagation Letters*, Vol. 13, 2014.
3. Bitchikh, M. and F. Ghanem, "A three-resolution UWB Frequency reconfigurable antipodal vivaldi antenna for cognitive radios," *The 8 th European Conference on Antennas and Propagation (EuCAP)*, 2014.
4. Moosazadeh, M., S. Kharkovsky, and J. T. Case, "Microwave and millimeter wave antipodal Vivaldi antenna with trapezoid shaped dielectric lens for imaging of construction materials," *IET Microwaves, Antennas & Propagation.*, Vol. 10, No. 3, 301–309, 2016.
5. Abosh, A. M., "Directive antenna for ultrawideband medical imaging systems," *Hindawi Publishing Corporation*, Vol. 2008, Article ID 854012, doi 10.1155/2008/854012.
6. Yang, F. and A. S. Mohan, "Microwave imaging for breast cancer detection using Vivaldi antenna array," *Proceeding of ISAP2012*, Nagoya, Japan, 2012.
7. Zhang, H., B. Flynn, A. T. Erdogan, and T. Arslan, "Microwave imaging for brain tumour detection using an UWB Vivaldi antenna array," *Loughborough Antennas & Propagation Conference.*, Vols. 12–13, Loughborough, UK, Nov. 2012.
8. Angel, J. and A. J. T. Mary, "Design of Vivaldi antenna for brain cancer detection," *International Conference on Electronics and Communication Systems (ICECS)*, India, Feb. 13–14, 2014.
9. Elsheakh, D. M. and E. A. Abdallah "Novel shapes of Vivaldi antenna for ground penetrating radar (GPR)," *European Conference on Antennas and Propagation (EuCAP)*, IEEE, 2013.
10. Gibson, "The Vivaldi aerial," *9th European Microwave Conference*, 101–105, 1979.

11. Moosazadeh, M., "A compact high-gain and front-to-back ratio elliptically tapered antipodal Vivaldi antenna with trapezoid-shaped dielectric lens," *IEEE Antennas And Wireless Propagation Letters*, Vol. 15, 2016.
12. Nurhayati, E., Setijadi, and G. Hendrantoro, "Effect of Vivaldi element pattern on the uniform linear array pattern," *IEEE International Conference on Communication, Networks and Satellite (Comnetsat)*, 2016.
13. Natarajan, R., J. V. George, M. Kanagasabai, and A. K. Shrivastav, "A compact antipodal Vivaldi antenna for UWB applications," *IEEE Antennas And Wireless Propagation Letters*, Vol. 14, 2015.
14. Reid, E. W., L. O. Balbuena, and A. Ghadiri, "A 324-element Vivalddi antenna array for radio astronomy instrumentation," *IEEE Transactions on Instrumentation And Measurement*, Vol. 61, No. 1, Jan. 2012.
15. Yan, J. B., S. Gogineni, B. C. Raga, and J. Brozena, "A dual-polarized 2–18-GHz Vivaldi array for airborne radar measurements of snow," *IEEE Antennas And Propagation*, Vol. 64, No. 2, Feb. 2016.
16. Yang, Y., Y. Wang, and A. E. Fathy, "Design of compact Vivaldi antenna arrays for UWB see through wall application," *Progress In Electromagnetics Research*, Vol. 82, 401–418, 2008.
17. Stutzman, W. L. and G. A. Thiele, *Antenna Theory and Design*, 3rd Edition, Sons, Inc., 2012.
18. Abbak, M., M. Akinnci, M. Cayoren, and I. Akdukman, "Experimental microwave imaging with a novel corrugated Vivaldi antenna," *Transaction on Antennas and Propaation*, 2017.
19. Balanis, C. A., *Antenna Theory Analysis And Design*, 2nd Edition, John Wiley & Sons, Inc., 1997.

Total Array Pattern Characteristics of Coplanar Vivaldi Antenna in E-plane with Different Element Width for S and C Band Application

ORIGINALITY REPORT

14%

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	106 words — 3%
2	link.springer.com Internet	71 words — 2%
3	Nurhayati, , Eko Setijadi, and Gamantyo Hendrantoro. "Comparison study of S-Band Vivaldi-based antennas", 2016 IEEE Region 10 Symposium (TENSYMP), 2016. Crossref	57 words — 2%
4	L. F. Diaz, J. Vrba, D. Vrba. "Extraction of electrical properties of strokes from magnetic resonance scans — Testing on simplified head phantoms", 2017 Progress in Electromagnetics Research Symposium - Fall (PIERS - FALL), 2017 Crossref	52 words — 2%
5	www.semanticscholar.org Internet	30 words — 1%
6	www.its.ac.id Internet	23 words — 1%
7	www.admiral-microwaves.co.uk Internet	22 words — 1%

8	Paulbert Thomas, Neeraj K. Pushkaran, C. K. Aanandan. "Preparation and microwave characterization of novel polyaniline-graphene composite for antenna applications", 2017 Progress in Electromagnetics Research Symposium - Fall (PIERS - FALL), 2017 Crossref	20 words — 1%
9	George V. Tsoulos. "Arrays and Smart Antennas", Modern Antenna Handbook, 08/08/2008 Crossref	14 words — < 1%
10	itis.swiss Internet	12 words — < 1%
11	annuaire.ifremer.fr Internet	11 words — < 1%
12	Enrique G. Plaza, German Leon, Susana Loredo, Fernando Las-Heras. "On the limits of an array-based model for planar lenses", The 8th European Conference on Antennas and Propagation (EuCAP 2014), 2014 Crossref	9 words — < 1%
13	A. V. Gevorkyan, Yu. V. Yukhanov, T. Yu. Privalova. "The radiation characteristics of the Vivaldi antenna located on a cylindrical surface", 2017 Progress in Electromagnetics Research Symposium - Fall (PIERS - FALL), 2017 Crossref	9 words — < 1%
14	Lei Sang, Xiangxiang Li, Tao Chen, Guoqiang Lv. "Analysis and design of tapered slot antenna with high gain for ultra-wideband based on optimisation of the metamaterial unit layout", IET Microwaves, Antennas & Propagation, 2017 Crossref	9 words — < 1%
15	Jianrong Bao, Yunxuan Lin, Chao Liu, Bin Jiang, Fang Zhu, Jianhai He. "Optimized Antenna Selection and Adaptive Power Allocation for Physical Layer Network Coding with Selective Soft-Message-Forward Cooperation", IEEE Access,	8 words — < 1%

2020
Crossref

16	www.digchip.com Internet	8 words — < 1%
17	Nurhayati, Gamantyo Hendrantoro, Eko Setijadi. "Mutual coupling and radiation pattern of vivaldi antenna with slit", Proceedings of the 3rd International Conference on Communication and Information Processing - ICCIP '17, 2017 Crossref	6 words — < 1%

EXCLUDE QUOTES ON
EXCLUDE BIBLIOGRAPHY ON
EXCLUDE MATCHES OFF