International Journal of Electronics and Communications System
Volume 2, Issue 2, 57-63.
ISSN: 2798-2610
http://ejournal.radenintan.ac.id/index.php/IJECS/index
DOI: *10.24042/ijecs.v2i2.14221*

Palm Tree Coplanar Vivaldi Antenna Array on the Same Substrate Size: Design and Performance Evaluation

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Article Info

Article history:

Received: October 31, 2022
Revised: November 26, 2022
Accepted: December 30, 2022

Keywords:

Antenna;
Array;
Radiation Pattern;
Vivaldi.

Abstract

This paper aims to describe the performance of the palm tree Coplanar Vivaldi Antenna Array (CVA) that was simulated from 0.25-6.25 GHz in terms of return loss and radiation pattern. Palm Tree Coplanar Vivaldi Antenna is available in four different configurations: single-element, two-element array, four-element array, and an eight-element array. We create a feeding network and radiator patch for two, four, and eight-array antennas. The simulation results demonstrate that the single-element antenna has the best return loss performance and can cover all frequency work from 0.25-6.25 GHz. In contrast, the antenna array can only cover multiband frequency. At 3 GHz, a single-element antenna has a directivity of 8.77 dBi, a sidelobe level of -2.2 dB, and a beamwidth of 63.7^0. In contrast, an antenna array of 8 elements has a directivity of 15.5 dBi, a sidelobe level of -12.6 dB, and a beamwidth of 8^0. Using the same substrate size, by configuring the Vivaldi Coplanar antenna to be an array at a frequency of 3 GHz, the 1×8 array antenna has a 6.73dBi improvement in directivity, a 10.4 dB boost in side lobe level, and a 55.7^0 enhanced in beamwidth performance compared to a single element. According to the simulation findings, the radiation pattern performance of the. Palm Tree CVA is greater than a single element in the same substrate size. Good directivity, SLL, and beamwidth performance make the proposed Palm Tree CVA array suitable for integration in telecommunication, radar, or cognitive radio applications.

To cite this article: N. Nurhayati*, A. M. D.* Oliveira, M. N. B. M. Yasin, and D. Kurniawan, "Palm Tree Coplanar Vivaldi Antenna Array on the same substrate size: Design and Performance Evaluation," *Int. J. Electron. Commun. Syst.,* vol. 2, no. 2, pp. 57-64, 2022.

INTRODUCTION

The Vivaldi antenna is a planar antenna with a wide bandwidth, a directional radiation pattern, and the ability to be used in a variety of applications[1][2][3]. An examination of the Vivaldi antenna for communication purposes, especially for UWB applications in [4] fulfills frequency at 1-30 GHz, in [5] operates at 13-18 GHz, in [6] works at 3-9 GHz, and in [7][8] conducts at frequency 1-28 GHz. In addition to telecommunications, the Vivaldi Antenna can be applied to radar. The RADAR application can be used for astronomy[8], weather forecasting [9], snow detection[10][11], ground penetrating radar[12][13], and more applications. Radar applications usually require a transmitter and receiver connected to a high-gain antenna[14]. But for GPR applications, a low-frequency antenna operating between 500 MHz and 3 GHz is required.

Antennas that work at low frequencies usually have a large size because the size of the antenna is proportional to the wavelength. The problem is exceedingly expensive to design an antenna with a big substrate size. The

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bandwidth and radiation performance optimization has been studied for single Vivaldi antennas. The single patch antenna's radiator is changed as part of the optimization process, among other things, by adding a corrugated structure. [15], palm tree shape[16], adding a metamaterial structure[17], and adding lenses[18]. Modifying the element's radiator can increase the antenna's gain by only a few decibels. Furthermore, high-gain antennas are needed for a variety of applications. The antenna can be arranged in an array to get a higher gain and a smaller beam width. Antenna array with tens, hundreds to thousands has been carried out for astronomical applications[8], snow thickness detection[10], GPR [19], microwave imaging[20], and others. The Palm Tree Coplanar Vivaldi antenna has the advantage of wide bandwidth and high directional radiation pattern. Antenna for certain applications, namely for telecommunications and radar, requires an antenna with a radiation pattern with high gain, low sidelobe level, and low beamwidth. Particular applications need a certain amount of space to incorporate the antenna into the transmitter and reception devices utilizing the same substrate size. A single-element antenna may be able to fulfill the return loss over a wide bandwidth, but the gain at a given frequency remains modest. Furthermore, antennas can be grouped in MIMO or arrays to attain a certain gain. Single-element antennas organized in MIMO will demand a lot of space and expense. As a result, it is required to compare antennas with single components and antenna arrays utilizing the same substrate size.

This study compares four types of palm tree Coplanar Vivaldi Antenna (CVA), i.e., one antenna element, two-element array, four-element array, and eight-element array with the same substrate size. The simulation results show that a single element gets the best return loss compared to an array antenna with two, four, and eight-element arrays. By arranging the antenna in the form of an array, there is an improvement in the directivity of 6,73 dBi and a sidelobe level improvement of 10.4 dB compared to the directivity of a single element at 3 GHz.

METHODS

We design four types of Palm tree Coplanar Vivaldi antennae in the same substrate dimension, i.e., 600×600×1.6 mm³. All four antenna designs are shown in Figure 1, with dimensions in Table 1. The antenna has a big substrate because we propose this antenna for Radar application that works in low frequency. In the same substrate size, the more the array of elements, the more complex the feeder network and the smaller the element radiator patch size. The working frequency of the antenna is inversely proportional to the wavelength.

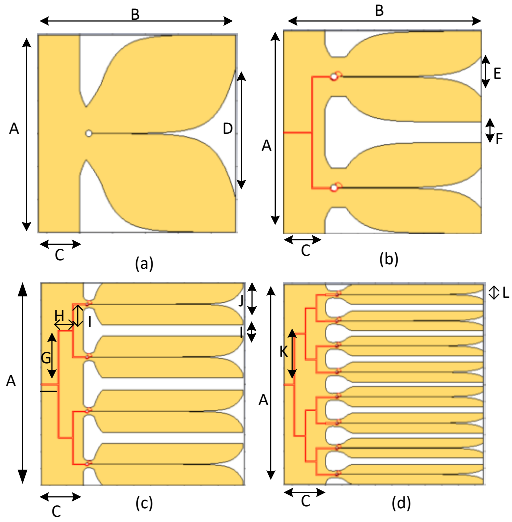

Figure 1. Palm Tree Coplanar Vivaldi Design: (a) Single Element, (b). Two-Element Array, (c). Four-Element Array, (d). Four-Element Array

Table 1. Dimension Parameter of Antenna

Antena Dimension	Value (mm)
A	600
B	600
C	125
D	400
E	125
F	61.5
G	159
H	40
I	78.5
J	100
K	32
L	153.5
M	30

Antennas that work at low frequencies usually have a large size, whereas antennas that work at high frequencies have a small size. All tapered slots are designed according to equation (1) [21].

$$y = C_1 e^{Rx} + C_2,\ C_1 = \frac{y_2 - y_1}{e^{Rx_2} - e^{Rx_1}},\ C_2 = \frac{y_1 e^{Rx_2} - y_2 e^{Rx_1}}{e^{Rx_2} - e^{Rx_1}} \quad (1)$$

Where C_1 and C_2 are variables built upon the x and y variable, x_1 and x_2 are the starts and the end of the x-axis of the tapered slot, and y_1 and y_2 are the beginning and the finishing of the y-axis of the tapered slot. The feeding network for two, four, and eight elements will influence the impedance bandwidth beside the radiator patch dimension.

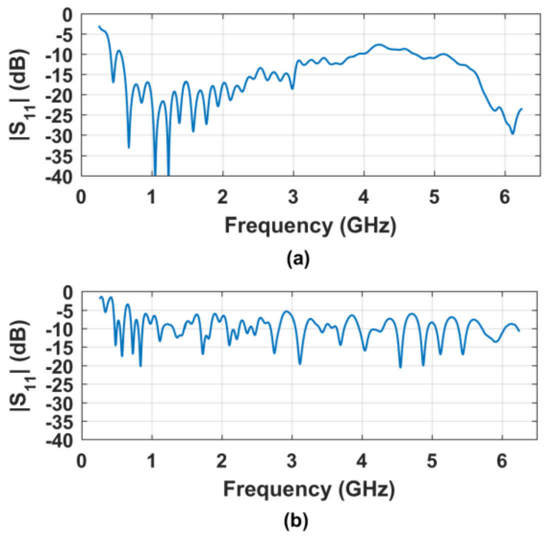

Figure 2. Return loss performance of (a) one element, (b) two-element array.

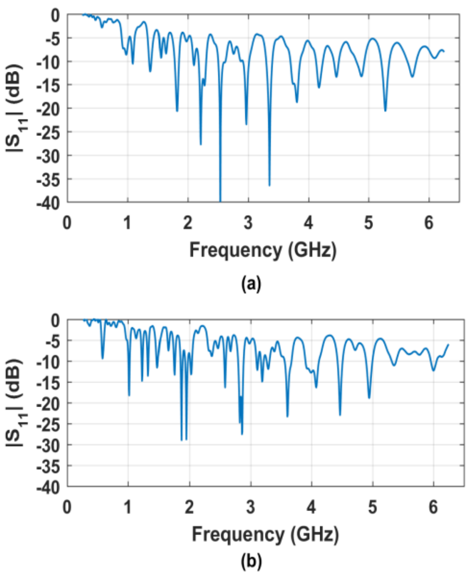

Figure 3. Return loss performance of (a) four-element, (b) eight-element array.

RESULTS AND DISCUSSION

Return Loss Performance

Return loss is one of the parameters used to determine how much power is lost to the load and does not return as a reflection. Return loss has a synergistic origin with VSWR, which is caused by mixing between the transmitted wave and the reflected wave, which both determine the matching between the transmitter and the antenna. Return loss can also be used to view or indicate the loss of transmitted power and how much the receiver receives the transmitted power. The smaller the Return loss value, the better the antenna performance, which can be concluded that less power is lost in transmitting the antenna. The performance of the return loss of the antenna can be shown in Figure 2 and Figure 3.

Figure 2 shows the return loss performance of the single-element antenna and two-element array. The simulation results show that the single-element antenna has the highest impedance bandwidth performance, from a frequency of 0.416 GHz to 3.9 GHz. In [22], a single microstrip antenna element generates a bandwidth of 73.2 MHz, whereas a 1×2 array produces a bandwidth of 66.5 MHz. Square-shaped microstrip antenna microstrip 1×4, also designed in [23], operates at narrowband 2.4 GHz. To get higher bandwidth, that antenna is bent in a curve shape that can be applied for breast tumor detection. However, the curve form requires a unique material substrate and is difficult to integrate into the system. The elliptical antenna array 1×4 patch is optimized for 24 GHz and 27.8 GHz frequencies[24]. The antenna has only two resonant frequencies. The microstrip antenna has only one or two resonance frequency bands. However, the palm tree Coplanar Vivaldi Antenna Element has a wide bandwidth and, when arrayed, produces numerous resonant frequencies. Whereas references discussing linear array antennas in the E-plane field at frequencies less than 6 GHz are still lacking. Most use a form of MIMO arranged in an H-plane

To design an antenna array on the same substrate size, the more elements, the smaller the radiator element size and the more complex the supply network design. Palm tree CVA with two, four, and eight elements have a return loss only covers some frequencies. It has a multiband frequency with only a few frequencies with a return loss of less than -10 dB. At 2.5GHz, the array antenna has the lowest return loss of the four components, which is -43.64dB.

Figure 3 shows that the antenna with 8 array elements has more multiband frequencies than the four-element array. However, some working frequencies that meet the return loss are less than -10dB and only cover narrow bandwidth. The poor return loss performance happened due to the smaller distance between adjacent elements, so it will affect the mutual coupling. The imperfect feeding network and radiator design also cause it. However, the return loss performance is also influenced by the antenna dimensions. So it is necessary to optimize the feeding network's design and the radiator's shape. So it is necessary to optimize the feeder's design and the radiator's shape.

Table 2. Radiation pattern performance at 2 to 4 GHz.

number of element	Main lobe (dBi)	Main lobe direction (^{0})	Angular width (3 dB)	SLL (dB)
		at frequency 2GHz		
Single	8,45	0	108.3	-11,6
2 Array	10,4	0	11,5	-0,9
4 Array	14,1	0	12,5	-10,4
8 Array	12,4	0	13,2	-5,8
		At a frequency of 3 GHz		
Single	8,77	0	63,7	-2,2
2 Array	12,3	0	7,2	-1,4
4 Array	14,7	0	8,1	-6,6
8 Array	15,5	0	8	-12,6
		At frequency 4 GHz		
Single	7,93	15	43,7	-1,5
2 Array	13	0	3,2	-2,3
4 Array	13,3	0	6,2	-3,3
8 Array	14,5	0	6,2	-8,9

Radiation Pattern performance

The radiation pattern can be interpreted as a field pattern. If the strength of the radiation is defined as a power pattern, the radiation strength is a pointing vector. The radiation pattern is calculated in the far field where the distribution of the transmitted angular power is independent of distance. Figure 4 compares the radiation pattern of an antenna with a single element and an antenna arranged in 8 arrays at a frequency of 2 GHz in the E-plane and phi 90^0 fields. From the simulation results at a frequency of 2 GHz, the main lobe value for a single antenna is 8.45dBi. The single-element has a main lobe direction of 0^0, angular widths of 108.3^0, and a side lobe level of -11.6 dB. The antenna array with 8 elements has a main lobe of 12.4 dBi, and a main lobe direction of 0^0. It results in an angular width of 13.2^0 and a side lobe level of -5.8 dB. At a frequency of 2 GHz, the antenna is arranged in an 8-element array. This results in an improvement in the directivity of 3.95 dBi and a decrease in beamwidth of 95.1^0 compared to single elements if the antennas are designed using the same substrate size.

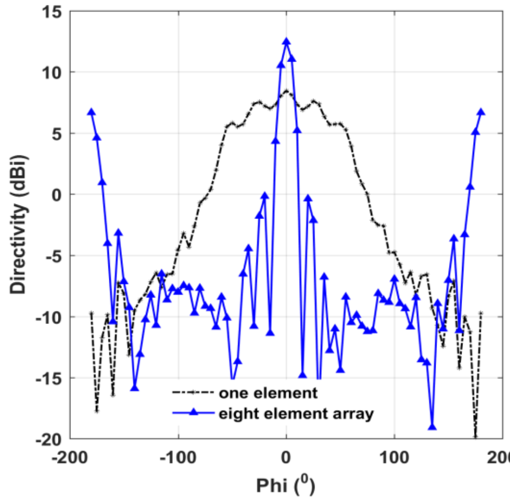

Figure 4. Radiation Pattern Performance in E-plane at phi=90^0

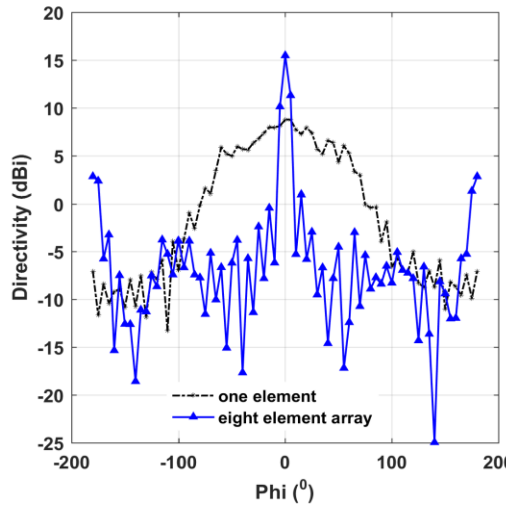

Figure. 5. Radiation Pattern Performance in E-Plane at phi=90^0

However, the single-element antenna has a better side lobe level than the 8-element array at a frequency of 2 GHz. Figure. 5 shows the radiation pattern's performance at a frequency of 3 GHz between a single-element and an array antenna with 8 elements in the E and phi 90^0 fields. At a frequency of 3 GHz, a single-element antenna has a main lobe of 8.77 dBi, a main lobe direction of 0^0, an angular width of 63.7^0, and a side lobe level of -2.2 dB. For 8 elements antenna array has a 15.5 dBi main lobe, 0^0 deg main lobe direction, 8^0 angular widths, and -12.6 dB side lobe level.

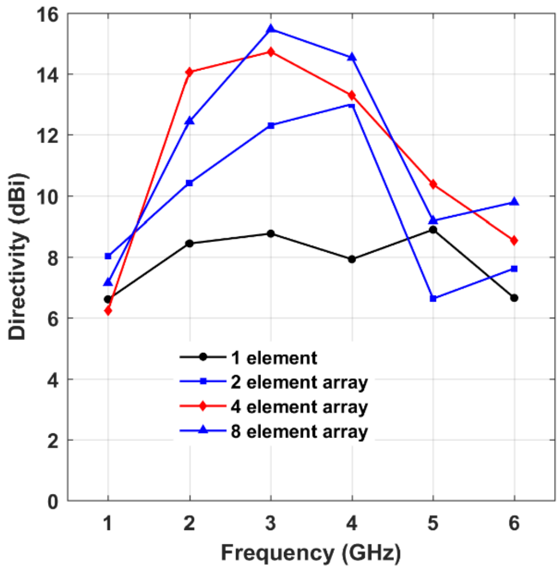

Figure 6. Simulation Results of the Radiation Pattern of VWS-CVA and HWS-CVA at 2 GHz (E-plane)

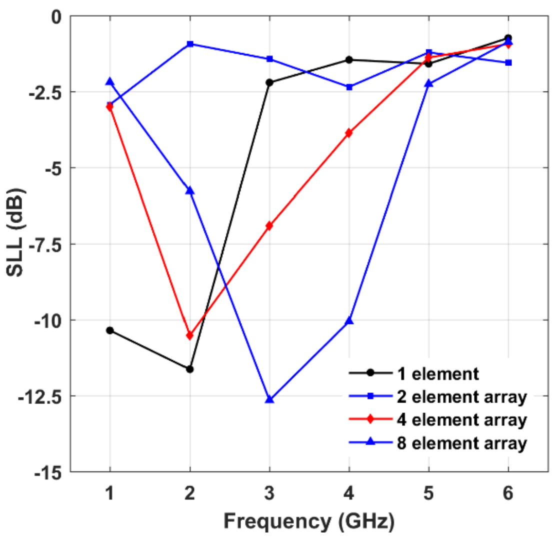

Figure 7. Comparison of Directivity Performance vs. Frequency in the E-plane

At 3 GHz, the directivity increased by 6.73dBi. Figure. 6 and Figure. 7 illustrates the directivity performance and side lobe level for the four antennas. At a frequency of 3 GHz, a sidelobe level of 8 elements is better than a single element. This can be seen in Figure. 7, which is an increase in the side lobe level of 10.4 dB. In certain frequencies, antenna arrays have better directivity, side lobe level, and beamwidth performance when compared to single elements. The maximum directivity is 15.5 dBi, and the lowest SLL is -12.6.

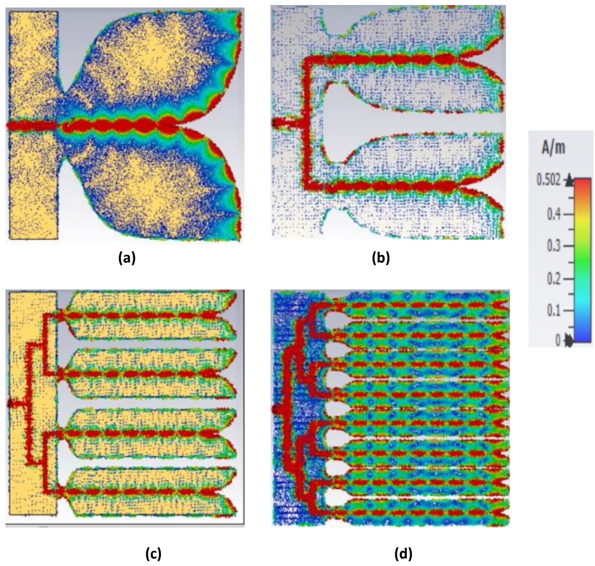

Figure 8. Surface current at 2 GHz of (a). Single element, (b). Two element arrays, (c). Four element arrays and (d) Eight element arrays.

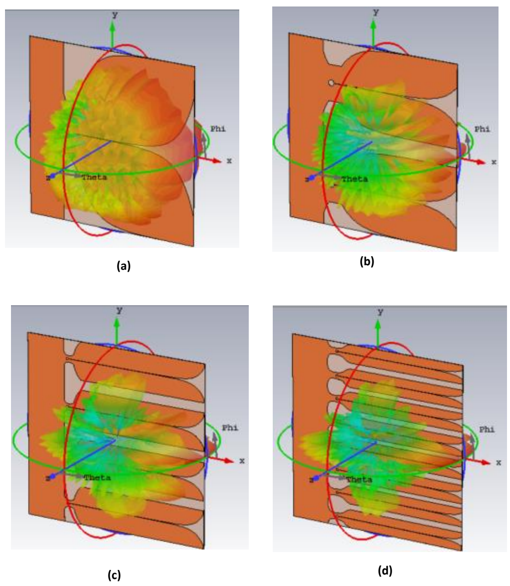

Figure 9. 3D Radiation Pattern of (a). Single Element, (b). Two Element Arrays, (c). Four Element Arrays and (d) Eight Element Arrays

However, the array element performs better in gain, side lobe level, and beamwidth, but a return loss performance does not cover all frequencies in the 0.25-6.25 GHz. However, the surface current at 2 GHz and 3D Radiation Pattern of a single element, 2×1 elements array, 4×1 element array, and 8×1 element arrays are shown in Figure 8 and Figure 9, respectively.

The closer the feed distance between the antenna elements, the easier the surface current and E-field to adjacent elements. It will affect the scattering parameter so that with the same substrate size, the return loss becomes worst but the gain higher. It also could be shown in Table 2 that the more elements, the larger the main lobe formed. The array element performs better in gain, side lobe level, and beamwidth, but a return loss performance does not cover all frequencies of 0.25-6.25 GHz frequencies.

From the discussion above, it can be concluded that by using the same type and the same size of substrate dimensions, the performance of the antenna radiation pattern can be improved at certain frequencies by arranging the antenna into an array.

CONCLUSION

This study evaluates the performance of return loss and radiation pattern of 4 antennas, namely palm tree Coplanar Vivaldi Antenna, i.e.: single element and antenna array with 2, 4, and 8 elements. The antenna was designed and simulated using the same type and substrate size that operated at 0.25 GHz to 6.25 GHz. From the simulation results, the antenna with a single element has the best return loss performance because it reaches S_{11} below -10 dB almost in all frequency work from 0.25-6.25 GHz. In contrast, the 2, 4, and 8 element array has a return loss performance only covering multiband frequencies with a narrow bandwidth. The simulation results show that the antenna array with 4 and 8 elements has better directivity performance at almost all frequency work if compared to a single element. At 3 GHz frequency, there is an improvement in the directivity of 6.73 dBi and a sidelobe level of 10.4 dB when compared to 8 element array to a single-element array. As a result, the findings of this study can be applied as a consideration when building antennas for certain applications that operate at particular frequencies and demand high gain while taking the size of the substrate into account.

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