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Research Article

A Proposed Design Method for Sparse Array Antenna by Using the Spacing Coefficient Algorithm

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One of the major challenges in developing various practical communication systems is reducing device complexity and development costs. In this study, a linear sparse array antenna design problem is addressed and a new approach for density taper element spacing by using the spacing coefficient algorithm is proposed. This method is a mathematical approach to obtain the distance between array elements by developing a spacing coefficient d_n for each element to achieve radiation performances with a minimum number of antenna elements. The simulation and measurement results show a significant improvement in array performance compared to other sparse array design methods, such as the CDS sparse array method in our previous work.

1. Introduction

Sparse array antennas were developed to increase cost efficiency by reducing the number of array antenna elements, with the performance degradation being relatively small or even close to the performance of conventional arrays. The configuration of the sparse array design is widely needed in various practical communication systems that have limited antenna size and weight, as well as cost efficiencies, such as radar equipment, satellite communications, and other space communications [1]. To obtain high-performance antenna arrays, such as narrow beamwidth and high directivity, it is necessary to configure many array elements and large sizes. Consequently, the cost efficiency is low because apart from requiring many antenna elements, radar, and space communication also require additional equipment and radio system components, such as microwave radio equipment, amplifiers, filters, and other transmitter and receiver systems [2]. Thus, efforts and strategies to increase the efficiency of the antenna array elements in some communication systems become an engineering challenge to find a better solution.

Sparse array antenna design can be classified into at least five methods such as mathematical calculation methods and structured algorithms [3–7], probability statistics and stochastic processes [8, 9], polynomial factorization method [10], a combinatory mathematical method by using cyclic different sets (CDS) [11, 12], and mutual coupling effects method [12, 13]. Combinatorial methods offer the advantages of thinning factors and reduced computation time demands compared to the stochastic and deterministic methods, and they perform better than the mutual coupling effect method. Unfortunately, combinatorial methods also have the disadvantage of performance degradation [13, 14], particularly for the sidelobe level (SLL) performances, compared to the deterministic algorithm method, which performs better than the controlled SLL performance degradation.

In the investigation in our previous work, the main problem in the combinatorial method by using CDS is the degradation of the side lobe level performance, which drops significantly when compared to the initial performance of full arrays with half-wave uniform spacing [14]. This performance degradation is certainly very disturbing in radar and space communication applications that require a scanning process and the accuracy of radar measurements. Thus, the solution to maintain performance in the sparse array design becomes very important.

This study is a continuation of previous work in developing an analytical deterministic method with simple

procedures and controls for performance degradation of sparse arrays. We propose a new method for designing sparse array configurations by developing the distance coefficient between elements. We studied the spacing characteristics of elements in an array configuration with uniform weights (isophoric arrays), which are widely used in various communication system applications, and compared their performance with our proposed sparse array method. We further find that the correlation between uniform weight, array configuration, and spacing between elements provides a formula that can be simplified to produce the desired radiation pattern by using the spacing coefficient algorithm to obtain the distance between elements in the sparse array configuration. The synthesis of the distance coefficient between elements was developed from the Taylor line distribution algorithm, which has been used for a long time to calculate the excitation of uniform arrays [15, 16]. However, this method has only been used in our early work on developing this method [17] and we continue to construct the procedure in this study.

The main contribution of this paper is the sparse array design method by using a deterministic method with a simple approach and short mathematical calculations compared to the existing deterministic methods [3–7]. Besides, the proposed method can find better performance than the CDS method [11, 12].

The outline of this paper is as follows: The first part is the introduction in Section 1; the problem formulation and observation of a sparse-array synthesis design are described in Section 2. Section 3 shows the numerical analysis and assessment of the proposed method and presents experimental results to strengthen and validate our proposal. Section 4 discusses the summary of work results and recommendations for further development.

2. Sparse Array Design Method

Basically, the sparse array configuration can be synthesized based on the desired radiation pattern. This pattern is generated based on the phase excitation parameters of each element, the amplitude, and the relative phase difference between the array elements.

Furthermore, the radiation pattern can be estimated by determining the array factor of an array configuration. The basic function of array configuration for both even and odd numbers can be determined from the series of equations which is the sum of the cosine form, M or $M+1$ [18]

$$(AF)_{2M}\,(\text{even}) = \sum_{n=1}^{M} a_n \cos[(2n-1)u], \tag{1}$$

$$(AF)_{2M+1}\,(\text{odd}) = \sum_{n=1}^{M+1} a_n \cos[(2n-1)u], \tag{2}$$

where

$$u = \frac{\pi d}{\lambda}\cos\cdot\theta, \tag{3}$$

where M is an integer of the even number of elements, $M+1$ is an integer of the odd number of elements, a_n denotes the excitation coefficients, and d is the element spacing.

By using relations (1) and (2), we find that the excitation phase, excitation amplitude, and relative phase difference between elements will affect the value of the factor array. Thus, we can conclude that with the array factor, we can maintain by adjusting the excitation value or amplitude even though the distance between elements is no longer the same.

This is the basic concept in determining the configuration of the sparse array to maintain the desired performance.

Thus, we approach by developing a distance coefficient between elements based on the inverse of the reference continuous source distribution of excitation amplitude Taylor series [4] to adjust the distance between elements to the ideal distance reference of the half-wave array elements [19, 20] and our previous work [17] as shown in Figure 1. The method is quite simple, and of course, it can also cut computational time when compared to using a generic mathematical algorithm method in the previous deterministic tapering technique.

Through the nonuniform distribution relation of the tapering amplitude with the distance between the elements of Figure 1, we can produce a synthesis and approach the distance coefficient as the following equation [17]:

$$d_n = \frac{1}{I_n}, \tag{4}$$

where

d_n: coefficient of distance between array elements

I_n: excitation coefficient of each element amplitude.

While the amplitude excitation coefficient can be determined from the source distribution shown [17, 21, 22]:

$$I(z) = J_o\left[j\pi B\sqrt{1-\left(\frac{2z}{l}\right)^2}\right], \quad -\frac{1}{2} \le z \le \frac{1}{2}, \tag{5}$$

where J_0 is the Bessel functions of the first type of zero order, l is the total length of the line source, and B is the Taylor one-parameter distribution algorithm, which can be determined by [23] as shown in Table 1.

This form can be translated into array configuration with p even or odd number of elements, and the amplitude excitation coefficient for each array element can be determined by the following equation [17, 21–23]:

$$I_n = J_o\left[j\pi B\sqrt{1-\left(\frac{2z_n}{p}\right)^2}\right], \quad -\frac{p}{2} \le z_n \le \frac{p}{2}, \tag{6}$$

where p is the number of array elements $(2N\ or\ 2N+1)$ and z_n is the position of the array element on the array side configuration based on the center point of the array configuration.

Furthermore, the amplitude current excitation coefficient by (6) will be transformed to the element spacing

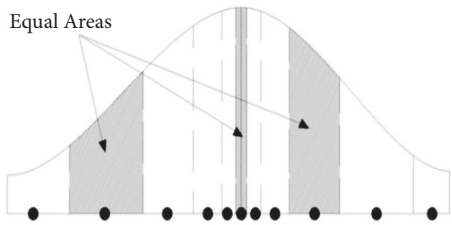


Figure 1: The relation between the excitation amplitude and the distance between the array elements [2, 17].

Table 1: The value of constant B in Taylor one-parameter distribution characteristic.

SLL (dB)	B
−10	0.4597
−15	0.3558
−20	0.7386
−25	1.0229
−30	1.2762
−35	1.5136
−40	1.7415
−45	1.9628
−50	2.1793

coefficient for each element by (4) and multiplied by the ideal distance between array elements $\lambda/2$. This parameter is the coefficient for determining the distance of each element in the sparse array configuration and determining its location in the sparse array arrangement.

To explain in more detail, the stages of the process in the proposed deterministic design method can be explained from Figure 2. The process of this method starts by determining the aperture length of the sparse array antenna configuration and calculating the distance coefficient between elements (d_n) for each array element. Then, we calculate the number of elements that match the aperture length, then multiply the distance coefficient (d_n) by the distance between standard elements $\lambda/2$, and finally set up a linear configuration of the sparse antenna array from the result of multiplying the distance coefficient by $\lambda/2$.

3. Simulated and Measured Result

To confirm our proposed method, we conducted several experiments on various configurations of sparse arrays and compared their performance with the results of other sparse design methods in our previous work [13, 14, 24] and the results of other studies [7–10, 12]. Experiments on the sparse array design method were carried out using Taconic TLY-5 substrate material with a thickness = 1.58 in and a dielectric permittivity $\varepsilon_r = 2.2$. Simulations and experiments were carried out by using a frequency of 5 GHz.

The configuration of our sparse array is designed by developing a 9-element sparse array, as shown in Figure 3. Determination of the distance between the elements of the sparse array is carried out using equation (4) and following the provisions of equations (5) and (6) and expects the resulting radiation pattern to have an SLL = −30 dB

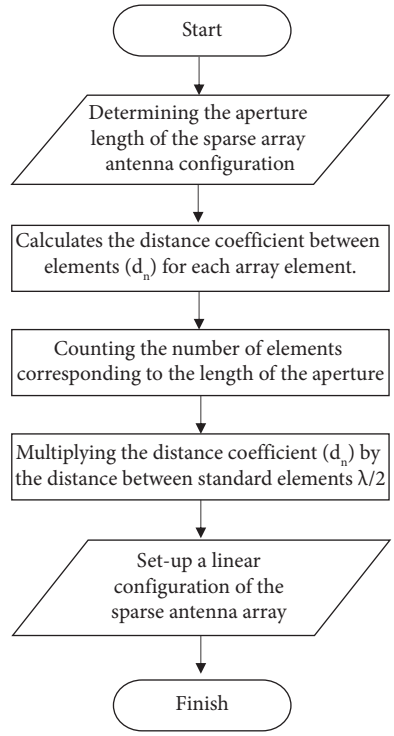


Figure 2: Flowchart proposed design method.

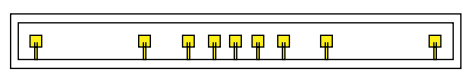


Figure 3: Proposed 9-element sparse array configuration based on Table 2.

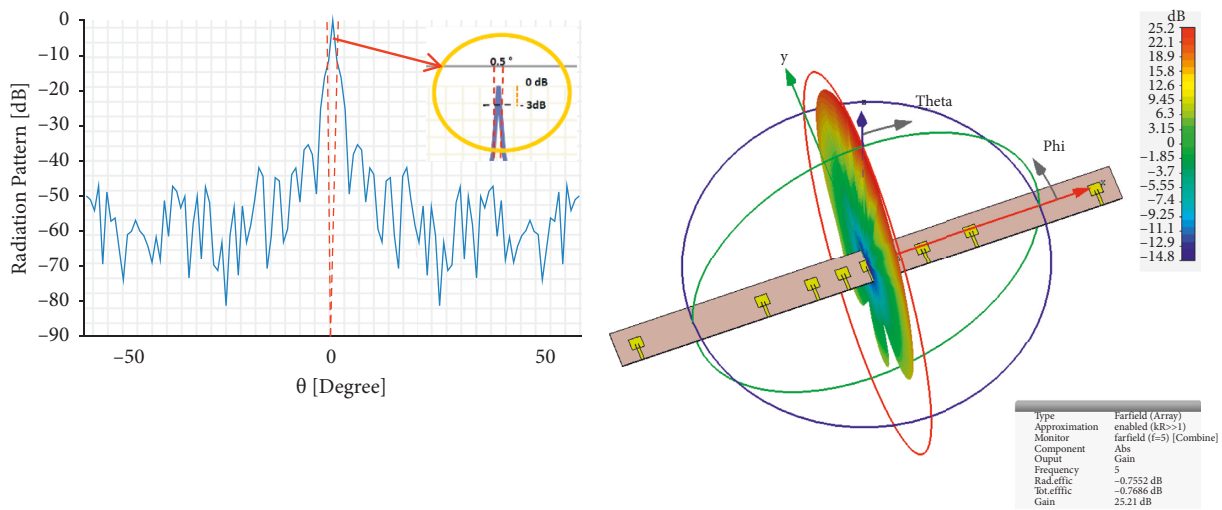
according to the provisions of the Taylor line source distribution parameter function [22] and the excitation coefficient current [23]. All parameter calculations for each element in the 9-elements sparse array design are as shown in Table 2. The performances of sparse array configuration will be compared to the uniform spacing conventional array with equal aperture dimension and combinatorial CDS method in the previous work [13, 14, 24].

Simulation of this sparse array configuration uses simulation software CST microwave studio (2016) at a frequency of 5 GHz as shown in Figure 4. The radiation pattern produced by this sparse array configuration has a main lobe magnitude of 25.1 dB with a half power bandwidth (HPBW) of 0.5° and a peak SLL performance of −33.4 dB. These results show a significant improvement when compared to the conventional uniform spacing array configuration with equal aperture, which is the main lobe magnitude of 19.6 dB with HPBW 3.8° and a peak SLL of −13.3 dB.

Furthermore, the experiment was carried out on a 17-element sparse array configuration and a 33-element sparse array configuration. The results are also compared with conventional uniform spacing arrays, which have the same aperture dimensions, and compared with other sparse array methods in previous work [13, 14, 24]. The design process uses the same sequence and procedure as the 9-element configuration.

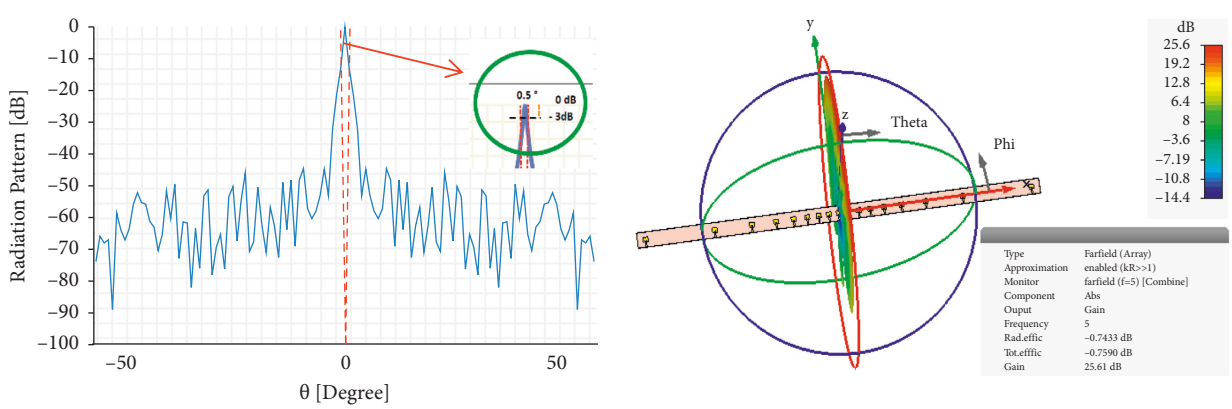
Table 2: Element spacing for 9-elements sparse array.

Spacing number (n)	Taylor coefficients (I_n)	Spacing coefficients (d_n)	Element spacing ($d_n.(\lambda/2)$)
1	0.19	5.26	2.63
2	0.48	2.08	1.04
3	0.78	1.28	0.64
4	0.97	1.03	0.52
5	0.97	1.03	0.52
6	0.78	1.28	0.64
7	0.48	2.08	1.04
8	0.19	5.26	2.63



(a) (b)

Figure 4: 9-Element sparse array configuration radiation pattern.

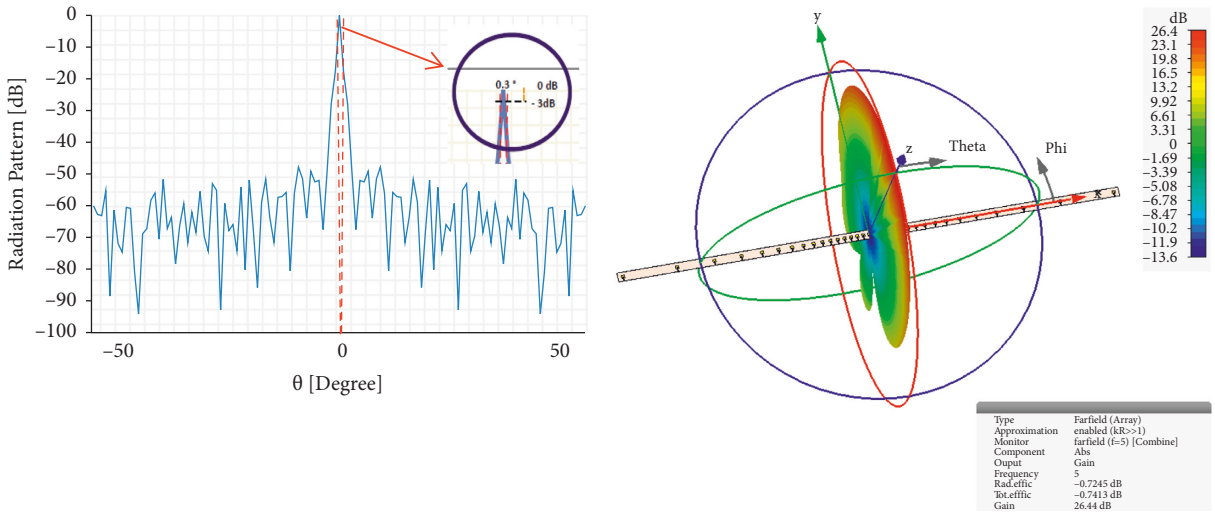


(a) (b)

Figure 5: 17-Element sparse array configuration radiation pattern.

The radiation pattern of the 17-element sparse array configuration shows the main lobe magnitude of 25.6 dB with HPBW 0.5° and a peak SLL of −44.5 dB. This performance shows a significant increase compared to the 29-element uniform spacing conventional array configuration, which is the main lobe magnitude of 22.8 dB with HPBW 1.7° and a first SLL of −13.3 dB. The results of these simulations and experiments show that the proposed sparse array design method can achieve high performance with a more efficient number of elements. The radiation pattern of 17-element sparse array software simulation results is as shown in Figure 5.

The next simulation and experiment are on the design of a 33-element sparse array antenna. The resulting performance will be compared with the performance of a conventional 59-element uniform spacing array that has the

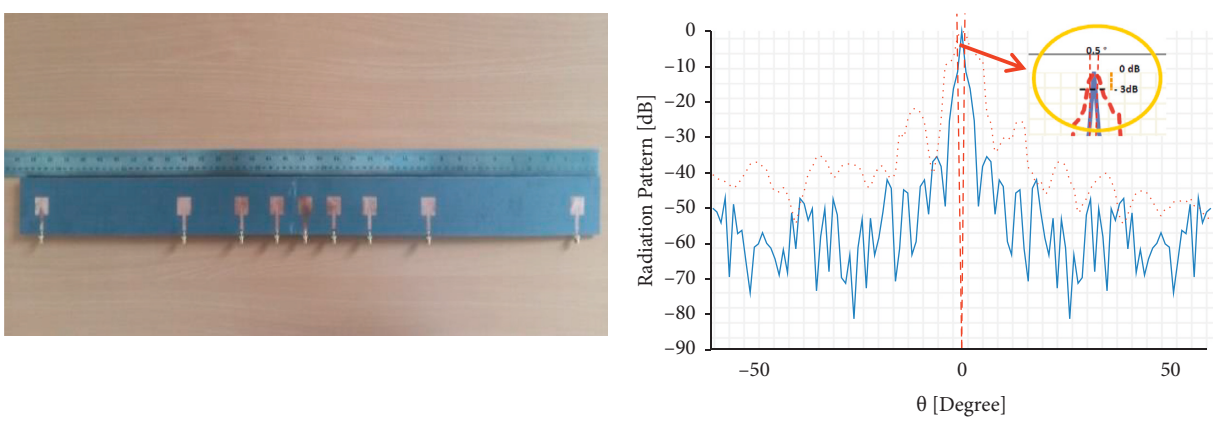


(a) (b)

Figure 6: 33-Element sparse array configuration radiation pattern.

Table 3: The simulation result of proposed sparse array.

No	Number of element	Length (λ)	*Radiation performances*		
			Main lobe (dB)	HPBW°	SLL (dB)
1.	9	21.18	25.1	0.5	−35.4
2.	17	41.97	25.6	0.5	−44.5
3.	33	85.07	26.4	0.3	−47.8



(a) (b)

Figure 7: Comparison of simulation and measurement of 9-element sparse array design.

same aperture dimensions. The simulation result of the performances is shown in Figure 6. The overall parameters performance of the proposed method is shown better radiation performances compared to sparse array design by using combinatorial CDS in the previous work [13, 14, 24]. The overall simulation results of several sparse array antenna design configurations using the proposed method are shown in Table 3.

To validate the proposed method and result, we used 9-element proposed sparse array fabricated microstrip antenna and measured the performances as shown in Figure 7. The measured SLL is higher than the simulated. It is the impact of the nonideal environment in the measurement. However, it is certain that the measurement of the performance of the radiation pattern of the sparse array by using the proposed method can significantly improve the performance of the array compared to the CDS sparse array method.

The results of these experiments show that the application of the proposed sparse array method is more

significant in maintaining the degradation of array performance for a small number of elements. For many array elements (massive array), it is relatively lower in maintaining array performance degradation. As indicated by all sample performance results, we found that the sparse array design based on the proposed spacing coefficient (d_n) for each element spacing is a suitable and simple procedure for constructing a sparse array configuration with high radiation performances.

4. Conclusions

The proposed method to design the sparse array antenna by applying the spacing coefficient algorithm was described. The proposed new design method for the sparse array can maintain array performance degradation by reducing the number of antenna elements significantly at the same aperture dimension, especially for SLL and beamwidth. These results also show better performance than the CDS sparse array design method in our previous work. The proposed design method is a new technique in the deterministic design method without an optimization process and increases the efficiency of computation time.

Data Availability

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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