A Hybrid Technique Linear Sparse Array Antenna Design Approach

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Abstract— **This paper proposed a new approach of linear sparse array antenna design with a hybrid technique of non-uniform elements spacing and combinatorial cyclic different sets (CDS) to achieve high resolution requirement in radar applications. As an example, the spatial dimension of 64 elements linear microstrip full array configuration (d = 0.7λ) is reduced to 32 elements linear sparse array configuration using the proposed technique. The simulation result showed the sparse array beamwidth resolution was improved compared to full array configuration with small sidelobe level degradation.**

Keywords — Hybrid technique; Combinatorial CDS; Non-uniform elements spacing; Sparse array configuration.

I. Introduction

The aim to develop sparse array antenna is to achieve a desired radiation pattern with the minimum number of elements. This is particularly use in many communications system where weight and size of antenna are limited, such as in radar phased array antenna, astronomy communications and satellite communications.

In the phased array antenna applications to achieve high resolution with very narrow beamwidth is highly challenged. High resolution require large spatial dimension of aperture due to large number of antenna elements. In phased array application such as radar application, cost of the system deployment will be higher with massive population of array elements since each subsystem amplifier required for each antenna elements [1].

Sparse array configuration is a solution to aforementioned problems. This design can reduce the number of array elements for high resolution array with low degradation of sidelobe level (SLL). One of published method sparse array antenna is combinatorial mathematic using CDS [2], [3]. This method offers advantage of thinning factor with low sidelobes degradation and reduced computation time demands when compared to stochastic method [4], [5]; compressive sensing and generic algorithm [6], [7]. Moreover CDS offers better performances compare to mutual coupling effect [8].

In this paper a hybrid technique of linear sparse array antenna design is proposed by combining non-uniform element spacing configuration and CDS approach. We develop a procedure to design non-uniform configuration based on observation in the previous result [9] to find sparse array configuration.

II. Cyclic Different Sets

Difference sets is a mathematical combinatorial theory which useful for design sparse array antenna to reduce a number of array elements [9],[10]. A (V, K, Λ) difference set is a set of K unique integers based on V integers of all population. The sparse array design uses K unique integers as series of array elements based on V integer full array elements series [9].

From the set $D = \{d_0, d_1,\ldots, d_{K-1}\}$, with $0 \le d_i \le (V\text{-}1)$ such as that for any integer $1 \le \alpha \le (V\text{-}1)$,

$$d_i - d_u = \alpha \ (\mathrm{mod}\ V),\ i \neq j \qquad (1)$$

This three parameter (V, K, Λ) are used to describe a difference set with only two parameters are independent because there are K (K-1) possible differences ($d_i - d_j$) with i not equal to j and since each (V-1) possible unique difference is to appear exactly Λ times [9], [10]. The three parameters of CDS have relationship as follow:

$$K(K-1) = \Lambda\,(V-1) \qquad (2)$$

Approximation of expected Peak Sidelobe Level (PSL) as function of V and K in the CDS approach was described by [10],

$$\mathrm{PSL} = 10\log[1/K(1- K/V)] + 10\log[0.8488 + 1.128\log V]\ \mathrm{dB} \qquad (3)$$

The condition for this approximation is valid for $V > 50$ and $K < V/2$ [10].

III. Non-uniform Elements Spacing Approach

The array factor (AF) of linear uniform array is defined as,

$$AF = \sum_{n=0}^{N-1} a_m\ e^{j(kd\cos\theta+\beta)} \qquad (4)$$

where a_m is amplitude excitation, $k = 2\pi/\lambda$ is free-space wave number, d is element spacing, θ is phase excitation and β is excitation difference between elements. Based on this expression, we can find array factor depending by amplitude excitation, inter-elements spacing and phase excitation.

In the sparse array antenna design, elements spacing arrangement with uniform amplitude and phase excitation is addressed to control null of sidelobe region when inter-element spacing more than wavelength. Through antenna dimension stretching efficiency and best performances strategy of non-uniform inter-element spacing [9], [11], can be approximated as follow:

$$N = 2^{n+1} \qquad (5)$$

where N is total number elements in the full array configuration, n is number of total elements will be stretched. For increasing elements spacing each n number, following scheme is proposed:

- Starting from center of array configuration with minimum element spacing.
- Increasing 0.1λ for each n element sequences

As an example to verify the pattern relation as Eq. (5), a 64 elements full array is considered, with N = 64 and n = 5. With following scheme to increase 0.1λ for each 5 elements from the center of array configuration, an array configuration is proposed as shown in Fig.1. The total aperture length is 71.93λ from original 46.03λ.

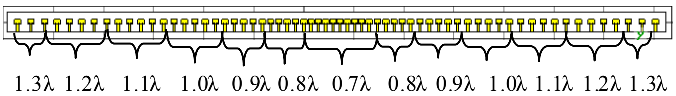


Fig. 1, Non-uniform elements spacing technique

IV. Proposed Hybrid Technique

As aforementioned, a hybrid technique of linear sparse array antenna design is proposed by combining non-uniform element spacing configuration and CDS approach. This approach configures the placement of elements in the linier array configuration.

To proof the proposed technique, we use microstrip array antenna to perform as a linear full array compare with sparse array antenna configurations. The linier microstrip antenna array is designed at frequency 9.75 GHz, uses the substrate material of Roger 5880 with dielectric permittivity $\varepsilon_r = 2.2$ and thickness = 1.575 in.

The linear full array is configured for 64 elements with 0.7λ inter-elements spacing from the center of each elements. Configuration of sparse array elements is constructed based on non-uniform pattern approach as shown in Fig.1 with applied CDS (63 31 15) to reduce number of elements. The elements will be placed in the configuration of *D set integer* (*0 1 2 3 4 5 6 8 9 10 12 16 17 18 20 23 24 27 29 32 33 34 36 40 43 45 46 48 53 54 58*) position and keep one element from original one (element 64). Furthermore 32 elements sparse array configuration with proposed hybrid technique is shown in Fig 2.

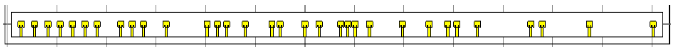
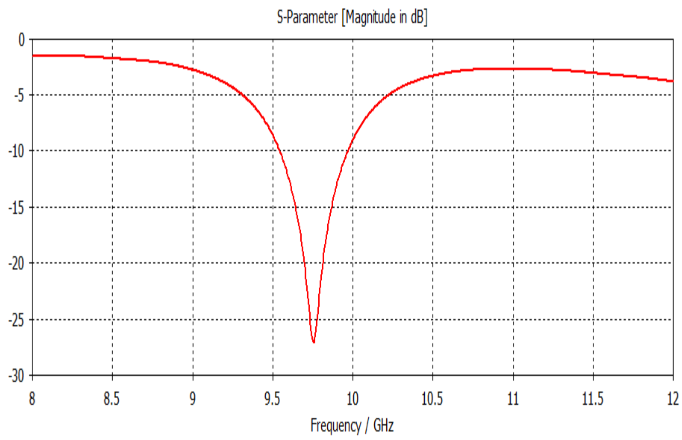


Fig. 2, Linear sparse array configuration with proposed hybrid technique

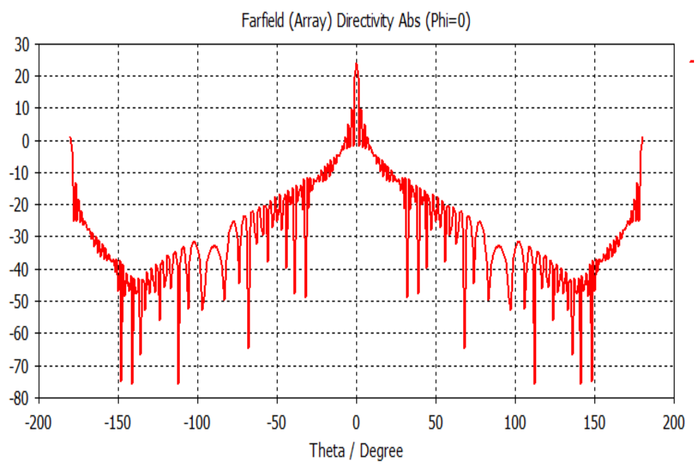
Based on approximation in Eq. (3), PSL of sparse array antenna with CDS approach (63 31 15), where $V = 63$, $K = 31$ and $\Lambda = 15$, the PSL approximation is -13.26 dB. This value is target to achieve in the proposed hybrid technique with more high resolution compare to full array configuration and sparse array design using CDS approach.

V. Result and Discussion

Using uniform amplitude excitation for each element, the simulation result of the return loss and 2D far field plot linear full array configuration is showed in Fiq.3. It is found the directivity 24.0 dBi with 1.4° 3dB beamwidth and sidelobe level -14.2 dB.

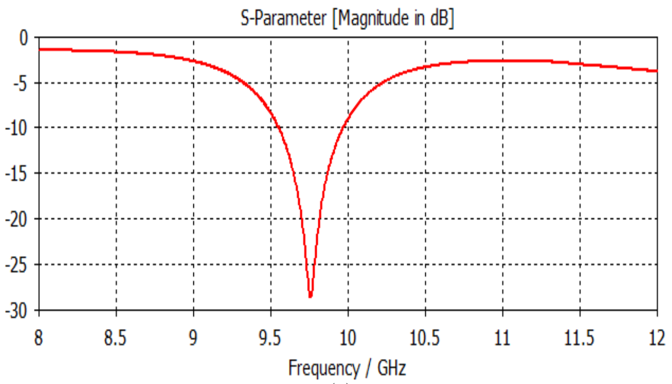


(a)

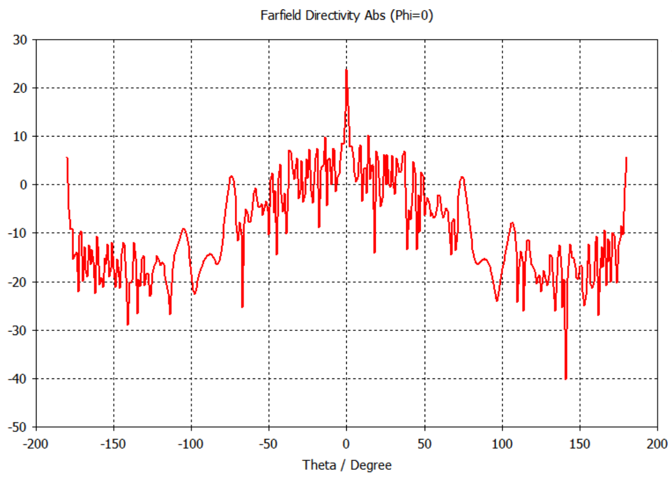


(b)

Fig. 3, Radiation pattern full array configuration: (a) Return loss; (b) 2D far field Plot.



(a)



(b)

Fig. 4, Radiation pattern sparse array configuration: (a) Return loss; (b) 2D far field Plot.

The simulation result of the proposed technique with uniform amplitude excitation is showed in Fiq.4. The beamwidth resolution is improved compared to the full array configuration with slightly lower for directivity and small SLL degradation. The overall comparison is shown in Table I. It is observed that sparse array design with proposed hybrid technique is achieved the performances for phased array antenna application with significant reduce number of elements. In addition, the proposed technique much more better resolution compare to the sparse array CDS based on classic full array.

TABLE I. PERFORMANCES COMPARISON

No	Array Configuration	Number of Elements	Radiation Performances		
			Directivity (dBi)	*3dB Beamwidth (°)*	*SLL (dB)*
1	Full Array ($d = 0.7\lambda$)	64	24.0	1.4	-14.2
2	Sparse Array with CDS	32	23.1	1.4	-13.5
3	Sparse Array with Hybrid Technique	32	23.8	0.7	-13.6

VI. CONCLUSION

A new technique linear sparse array antenna design has been demonstrated. The main idea of the proposed technique is develop a new approach of non-uniform pattern elements spacing configuration and combine with CDS approach. The proposed technique for sparse array antenna design was improve beamwidth resolution compared full array configuration with slightly SLL degradation and significantly reduce number of elements.

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