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Low Sidelobe and Wideband Characteristics of Density Tapered Arrays for 5G Mobile Systems

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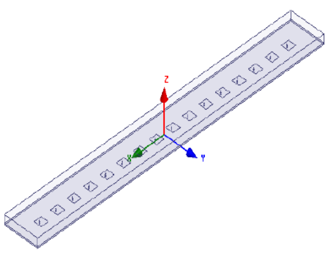
Graphical abstract



Abstract

Conventional mobile base station antennas are composed of equally spaced linear array antennas. In order to achieve low side lobe characteristics, excitation coefficients for array elements are determined by a feeding network. Because of complexity of the feeding network, applicable frequency range is limited. In 5G mobile system, multi frequency band operation is requested. For achieving low sidelobe and wide frequency characteristics, a density tapered array configuration is promising. Because of uniform excitation coefficients, feed network has no frequency dependence and wide frequency range application is expected. In this paper, abilities and design method of low sidelobe characteristics are investigated. By density tapering, sidelobe levels are reduced from -13dB to -16dB. As for wide band characteristics, low sidelobe characteristics are maintained during 28GHz to 56GHz operations. Usefulness of a density tapered array is numerically clarified.

Keywords: 5G mobile; millimeter wave; mobile base station antenna; density tapered array

1.0 INTRODUCTION

In the next generation 5G mobile system, may new technologies are requested [1]. For mobile base station antennas, multi beam, multi frequency and low side lobe characteristics are requested [2]-[3]. In the present mobile base station antenna, an equally spaced linear array configuration is employed [4].Radiation pattern of mobile base station antenna is shown in Figure 1. In order to reduce interference radiations to other frequency reuse cell, low sidelobe characteristics are requested. Low sidelobe characteristics are achieved by giving adequate excitation coefficients (amplitude and phase) to array elements. In this case, feeding network is composed of many power dividers and feeder lines that have different values. Here, phase values determined by feeder line lengths have severe frequency dependences. Therefore, present base station antennas are difficult for multi-frequency use.

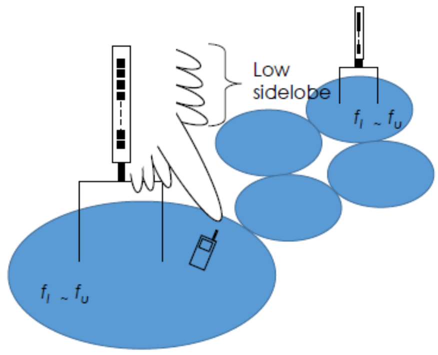


Figure 1 Radiation pattern of a mobile base station antenna

For achieving low side lobe characteristics over wide frequency range, a density tapered array configuration of unequally spaced arrays [5] is promising. The important point of a density tapered configuration is having uniform amplitude and phase in all array elements. Because of equal feed line lengths to array elements, no frequency dependence occurs in the feed network. Therefore, low sidelobe characteristics are expected over wide frequency bands.

There are many researches of antenna have been proposed for unequally spaced array antennas. King, Packard and Thomas [6] presented the use of unequal spacing in a linear array to reduce grating lobes and computed the pattern. Harrington [7] presented a method for reducing sidelobe levels down to 2/N times of the field intensity of the main lobe of linear array with retaining uniform excitation by using non-uniform element spacing. Ishimaru [8], using the Poisson summation expansion. It is based on reduce the pattern function of a finite sum to an infinite sum in order to produce a desired radiation pattern. Schuman and Strait [9] presented the spacing and amplitudes of the array elements are allowed to vary in order to achieve specified side lobe level of array antenna by using computerized design technique. However, wide frequency band characteristics were not investigated previously.

In this paper, practical data of low sidelobe and wide band characteristics are numerically clarified through calculation results of a High Frequency Structure Simulator (HFSS). 16 elements linear array of patch antenna elements is employed. Relation of sidelobe levels and unequally element spacing are obtained. Frequency changes of 28GHz, 42GHz and 56GHz are calculated. Useful design data for introducing a density tapered array for a mobile base station are clarified.

2.0 ARRAY CONFIGURATION

2.1 Array Element Spacing

Calculated array configuration is shown in Figure 2. In the case of use for mobile base station antenna, the x-axis corresponds to the vertical axis. Radiation pattern is designed in the vertical plane shown as the x-z plane. For radiation elements, patch antennas are employed.

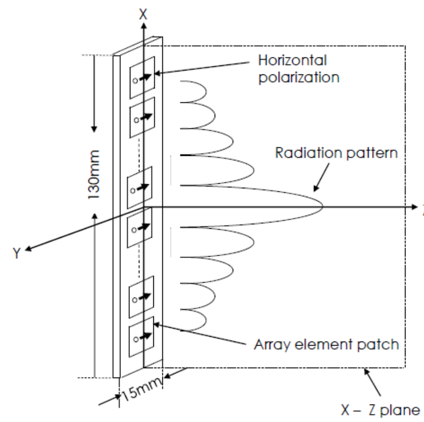


Figure 2 Array configuration

Concepts of array element spacing are shown in Figure 3 where by 16 elements array is considered.

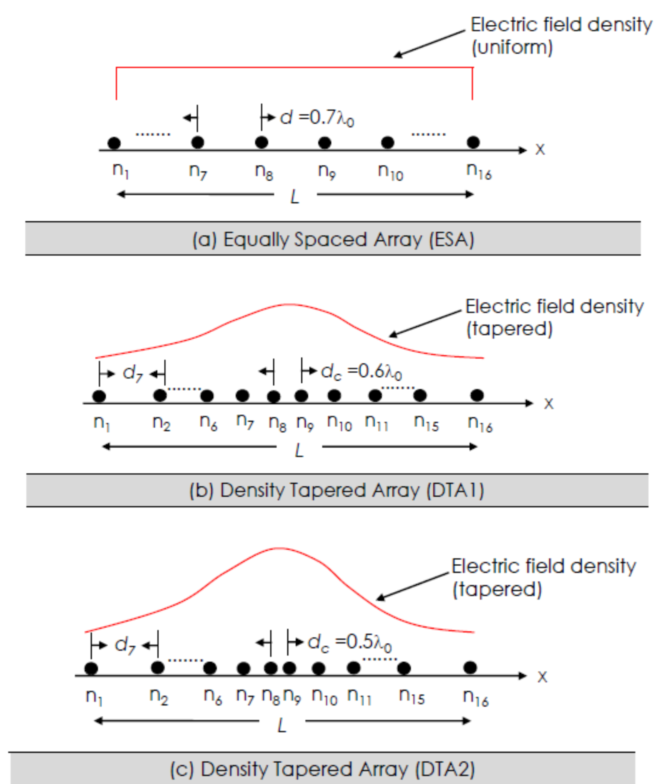


Figure 3 Array antenna spacing configuration

At the lowest frequency (f_0), element spacing is set d=0.7λ_0(λ_0; wave length at f_0) in the equally spacing array. In density tapered arrays, element spacing at the center elements (d_c) are set d_c = 0.6λ_0 and 0.5λ_0. Here, the total array length (L) is set constant so as to L = 15x0.7λ_0(=112.5mm). Array spacings are considered symmetrical around the array center. In the case of density tapered array, elementspacings are given by the next expression.

$$d_i = d_c + i.\ \Delta d \ (i= 0\sim7) \quad (1)$$

Δd is determined by the next relation.

$$L = 15d_c + 56\Delta d \qquad (2)$$

When d_c is given, Δd is determined by (2). Then, each element spacing is determined by (1). In calculation, a High Frequency Structure Simulator (HFSS) is employed. The simulation parameters are listed in Table 1. The simulation is done in frequency 28GHz, 42GHz and 56GHz. 1.5 hours and 3.4GB memory at least is needed to complete the calculation for one array design using this simulator software.

Table 1 Simulation parameters

ITEM	CONTENTS
Simulator	HFSS(16.0)
Computer	Memory:32GB
Frequency	28GHz, 42GHz, 56GHz
Calculation Area	130mmx15mmx3.32mm
Solution Type/Excitation	Driven terminal
Absorbing Boundary	Perfect E Boundary
Calculation Memory	3.38GB
Calculation Time	1.5hours

2.2 Array Element Structure

The single patch antenna structure is shown in Figure 4. The patch element with dimension of W=3.27mm and L=3.27mm is designed to operate at f_0=28GHz. The printed circuit board (PCB) 15mm x 15mm x 0.508mm^3 (Length x Width x Height) was used with pcb substrate of Rogers RT/duroid 5880 (ε_r=2.2 and tan δ=0.0009). A conventional transmission line microstrip feed networks suffer from high loss and may introduce spurious radiation especially at high frequency. However, choosing the suitable feeding techniquecan potentially eliminates spurious feed radiation and achieve wider bandwidth. Therefore the coaxial probe feed is chosen as a feed technique and easy for array configuration.

Figure 4 Structure of single patch antenna (for 28GHz)

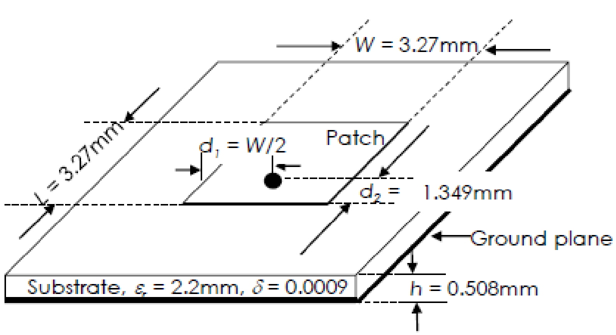
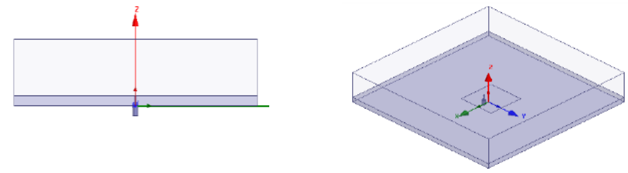
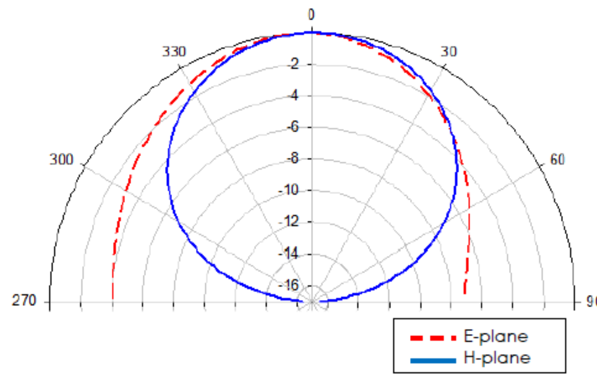


Figure 5 shows the simulated resultsfor single element in frequency 28GHz. The E- and H-plane radiation patterns are obtained by setting $\phi = 0^0$ and $\theta = 90^0$.



(i) (ii)

(a) Simulated Design: (i)Left view (ii) Isometric view



(b) Radiation Pattern

Figure 5 Simulated structure for single antenna (28GHz)

Figure 6 shows the VSWR of an equally spaced array. The bandwidth is usually specified as frequency range over which VSWR is ≤2. 6% bandwidth is achieved at VSWR=2.

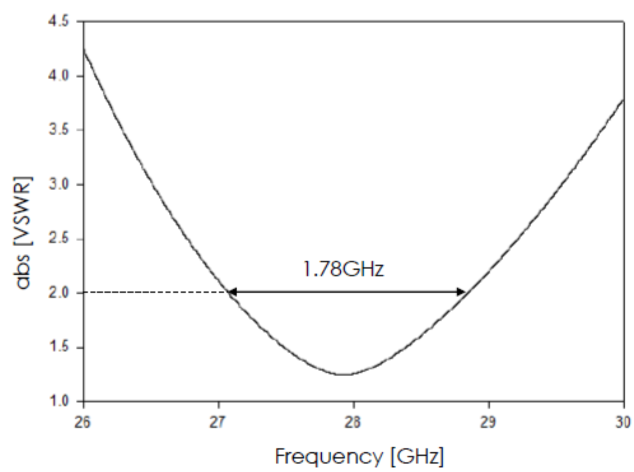


Figure 6 VSWR characteristics

3.0 LOW SIDELOBE CHARACTERISTIC

Array radiation patterns at 28GHz are shown in this chapter. In Figure 7, a cross sectional view of 3D radiation pattern is shown. The radiation pattern in the x-z plane is emphasized. 2D radiation patterns are shown in Figure 8. Excitation condition to array elements is equal amplitude and phase. In the case of the equally spaced array of Figure8(a), the first sidelobe level becomes -13.21dB. As for the sidelobe slope, the slope almostlinearly degrades from -13.21dB to -35dB. In the case of the density tapered array (DTA1) of Figure 8(b), the first sidelobe level decreased to -14.73dB compared to the equally density array. However, sidelobe slope becomes dull such as -14.73dB to -30dB. In the case of density tapered array (DTA2) of Figure 8(c), the first sidelobe level becomes -16.34dB and sidelobe slope end becomes -25dB. As a result, by introducing density taper, the first side lobe level can be reduced rather well. However sidelobe levels far from the main lobe are increased appreciably. In Figure 9, relation of sidelobe levels and unequally spacing is shown. The degree of unequally is expressed by *Δd* value. In the case of *Δd*=0.573mm, the smallest spacing is $0.5\lambda_0$ and the largest spacing is $0.8749\lambda_0$. In large value of *Δd,* changes of element spacing become large. Sidelobe levels can be reduced rather well for use as a mobile base station antenna.

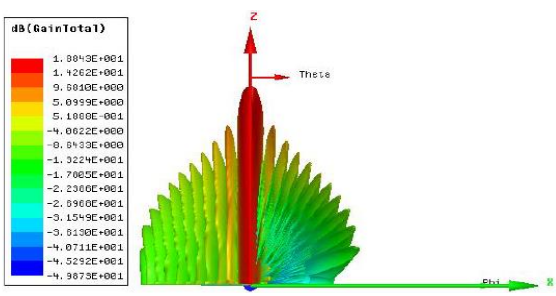
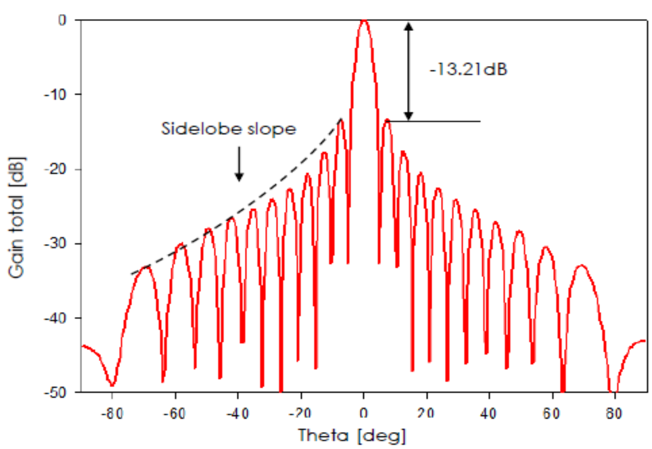
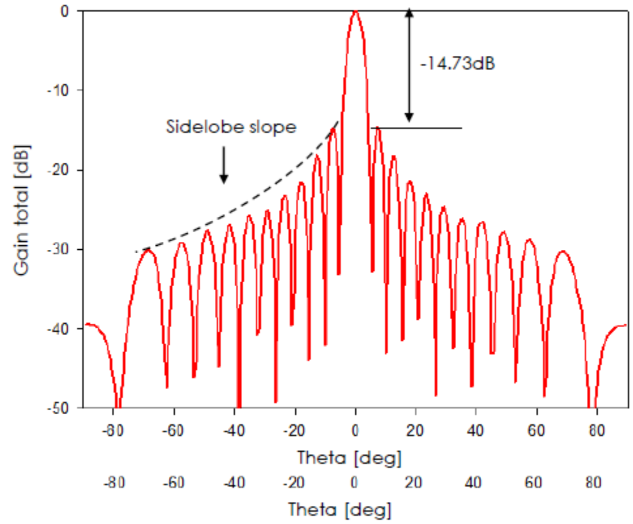


Figure 7 3D pattern



(a) Equally SpacedArray (ESA)
(b) Density Tapered Array (DTA1)



(c) DensityTapered Array (DTA2)

Figure 8 Sidelobe characteristics

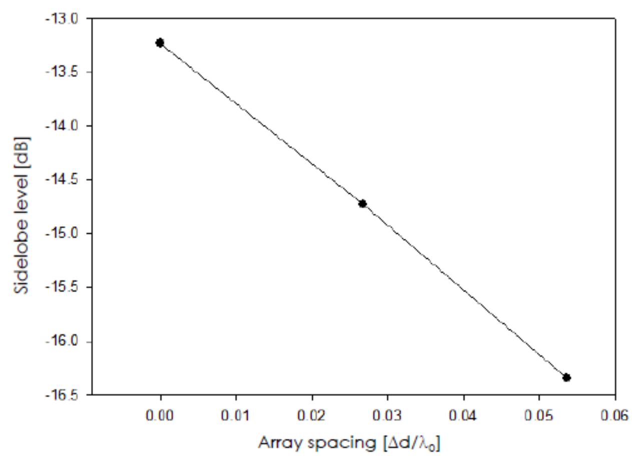
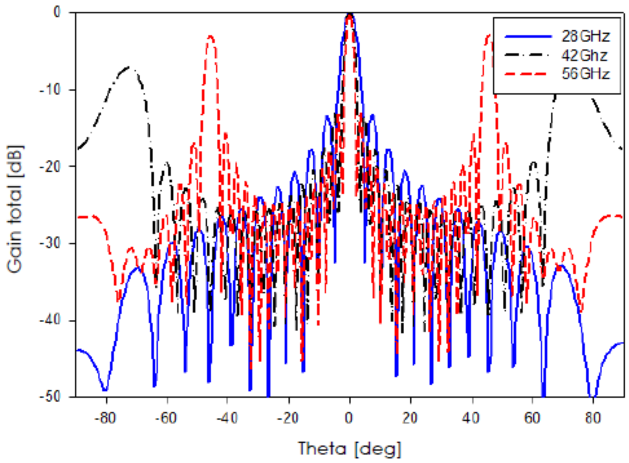


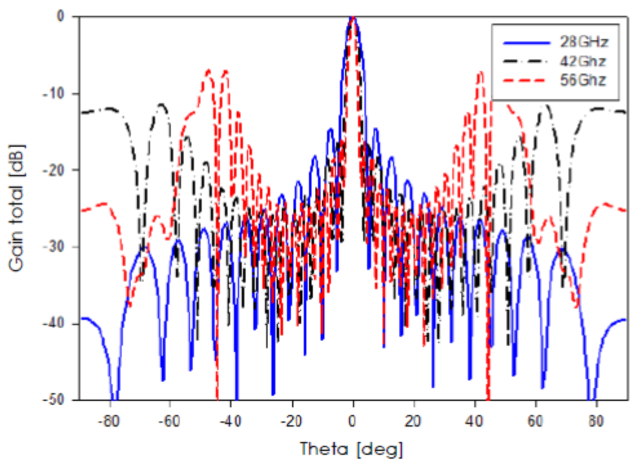
Figure 9 Sidelobe vs. array spacing

4.0 WIDE BANDWIDTH CHARACTERISTICS

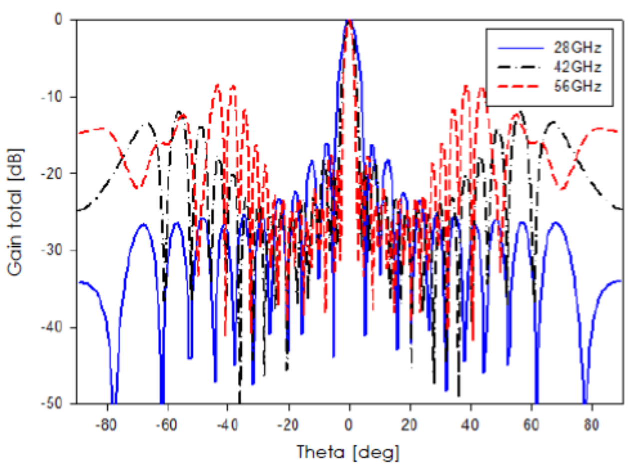
Frequently characteristics of radiation patterns are shown in Figure 10. Three frequency cases of f_0= 28GHz, f_1=1.5f_0 and f_2=2f_0 are calculated. In higher frequencies $f_1$and f_2, patch antennas suitable for frequencies are employed. In the case of the equally spaced array of Figure 10(a), grating lobes are appeared in high frequencies. The first sidelobe levels are -13dB at all frequencies. At DTA1 and DTA2 of Figures 10(b) and (c), the first sidelobe levels become same at all frequencies. As for grating lobes, peak levels are reduced by density tapering. Table 2 is summarized simulated result for wide bandwidth characteristics.In Figure 11, frequency dependences of first sidelobes are summarized. It is clearly shown that sidelobe levels are constant for frequency changes. This is the feature of a density tapered array configuration. As a result, it is shown that low sidelobe levels of no frequency dependence can be achieved by a density tapered array.



(a) Equally Spaced Array (ESA)



(b) DensityTapered Array (DTA1)



(c) Density Tapered Array (DTA2)

Figure 10 Frequency characteristics

Table 2 Summary of wide bandwidth characteristics simulated results

Frequency[GHz]	Array	Gain[dB]	HPBW[º]	SLL[dB]
f_0 = 28	ESA	18.84	4.47	-13.21
	DTA1	18.84	4.65	-14.73
	DTA2	18.71	4.75	-16.34
f_1 = 42	ESA	19.29	3.02	-13.23
	DTA1	19.35	3.22	-16.49
	DTA2	19.25	3.29	-19.35
f_2 = 56	ESA	19.12	2.2	-13.23
	DTA1	19.35	2.36	-16.14
	DTA2	19.29	2.46	-19.86

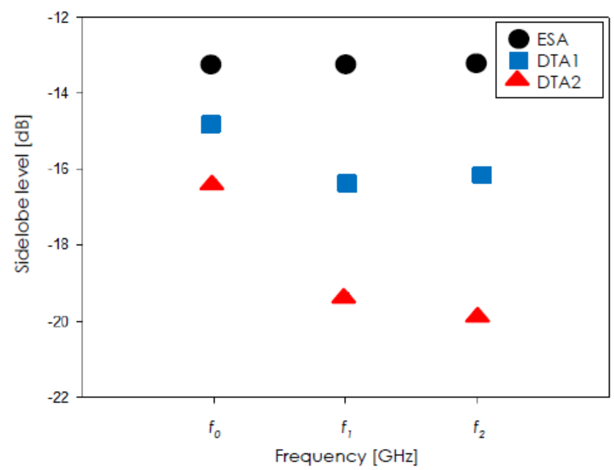


Figure 11 Sidelobe level vs. frequency

Antenna gain changes are shown in Figure 12. The remarkable tendency is low gain at f_2. The reason is that grating lobes come near to the main lobe. However, DTA1 and DTA2 gains become higher than ESA. This is because grating peaks are suppresses at DTA1 and DTA2.

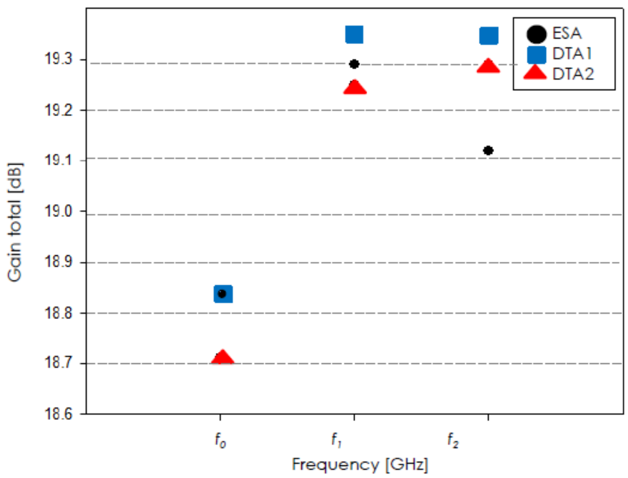


Figure 12 Antenna gain vs. frequency

5.0 CONCLUSION

Density tapered array configuration is performed in order to achieve low sidelobe characteristics. Element positioning is applied to the design of a low sidelobe level microstrip linear array base station antenna. This paper presents a study ofdensity tapered antenna arrays that have unequally spacing. The effects of unequal spacing, as reflected by sidelobe level are studied in detail. The results show that improvement in array performance in radiation characteristics can be obtained compared to uniformly spaced array antenna with the same number of elements. In high power applications of single frequency broadside arrays, use of unequal spacing is a possible method of reducing sidelobe which is more efficient than tapering the amplitude illumination. Finally the abilities and design method of low sidelobe characteristic have been investigated. From the theory and simulated result presented in this paper, it is clear that a considerable reduction in the sidelobe level obtained for optimum interelement spacing of array antenna.

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