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Wide Scan Angle Randomly Overlap Subarray Antenna for 5G in 28GHz

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ABSTRACT Synthesizing antenna arrays for fifth-generation communication technology is the most significant issue in the electromagnetic industry and academia. This paper focused on a comprehensive algorithm to design an antenna array used as a 5G base station antenna. The proposed algorithm's goal has an array antenna with high gain, continuous wide scan angle without grating lobe, compact size, minimum cost, and simplicity of construction, particularly in the array feeding network's system. For this purpose, several factors, such as subarray topology, complex weighting function, the minimum number of RF elements, and the optimum number of microstrip layers will be intended. The desired topology is specified with the grating lobe's minimum level by comparing the array factor of different subarray combinations. We consider some limitations in our algorithm that improve the specification than before research and reduce the runtime algorithm. Moreover, the number of phase shifters is decreased to more than 53%, substantially improved than previous works. The GAPSO technique is then used to determine the excitation coefficients' optimal value to control SLL and beam scanning. Amplitude accuracy and phase are considered 0.1 and 1 degree, respectively, to avoid tolerance construction. The proposed method is also applied to design a linear array antenna using a 5G base station antenna in 28 GHz. This aperiodic linear array's electromagnetic parameter consists of HPBW of 2.8°, a gain of 20 dB, scanning up to $\pm 50^\circ$ in one direction, and SLL is below -15 dB.

INDEX TERMS 5G base station antenna, aperiodic array, mm-wave, non-uniform phased array.

I. INTRODUCTION

DURING the past decade, wireless communication technologies have been growing significantly, and various generations of communication networks are proposed. Fifth-generation (5G) cellular network technology has higher data rates with more energy efficiency and lower latencies [1].

Base station (BS) antennas play a crucial role in 5G communication, so a comprehensive design of an antenna array for 5G systems is required. Preliminary research on the upcoming generation's technologies is increasingly recommending utilizing the millimeter-wave spectrum [2]. Therefore, the frequency allocated to the 5G communications is more than 28GHz[3].

The BS antenna used must have a high gain to cope with the losses in the millimeter-wave band. To prevent wave propagation in all directions is essential to narrow beamwidth with a wide scanning angle, without grating lobes for 3D space coverage [4]. Different factors such as scanning resolution, scanning speed, and variation of

HPBW and gain, and lateral lobe level are influential in determining its reliability. In other words, beamforming (BF) is another technology that is critical for communication in the fifth generation. There are several methods to BF, including the mechanical process, phased array antennas [5] (analog BF, digital BF, and hybrid BF[6]), metamaterial antennas, reflector antennas, traveling wave antenna, and switched beam antenna [7].

Phased array antenna with hybrid, digital, and analog BF is the promising solution for multi-user (MU) or single-user (SU) massive MIMO [8]. MU-massive MIMO system has a large number of antenna elements. Various synthesis methods have been presented in the literature to design phased array antennas based on the mentioned conditions, categorized into optimization-based methods, theoretical methods, and numerical methods. In the first category, a genetic algorithm (GA) [9], [10], particle swarm optimization (PSO) [11], [12] are the most prominent algorithm to determine the amplitude, phase, and space tapering. In the theoretical solution group, sinusoidal, Bessel, and Legendre

polynomials [13]–[15] are used to determine the best location of the elements for designing non-periodic array in different coordinates. Numerical methods such as non-uniform fast Fourier transform also are used for synthesis array antenna [16], [17].

Regardless of which techniques are used to synthesize, the phased array antenna has many antenna elements. Consequently, they need a large number of RF devices such as phase shifter (PS), variable gain amplitude (VGA), filter, and mixer. Indeed, high-speed digital signal processing is required, as well. The number of PS is more critical in the phased array antenna. Even though there is much improvement in the phase shifter fabrication, large-scale phase shifters are not affordable [5], [18].

The number Diminishing of the phase shifter, a uniform subarray (USA) technique, is proposed several years ago [19]. Thus, the USA is composed of two arrays. The primary array elements are antenna, and the secondary array elements combine the primary arrays (subarrays). Although the RF device's number is reduced, the GL has occurred. This is because of too large space (concerning the wavelength) between the subarrays. Furthermore, the wide scan angle is not achievable utilizing the USA technique.

Two methods are proposed for phased array antennas to address the GL problem. The first method decreases the distance between the secondary array elements by the uniform overlap subarray (UOSA) technique. [16]–[20]. The second technique uses an aperiodic array that is achieved by random subarray (RSA) [7], [11], and randomly overlap subarray (ROSA) [16]–[21].

In some of these cases, in UOSA, the feeding network is more complicated, and an aperiodic structure may have complex construction. Besides, in previous works, the designs have been done without providing any condition and limitation to choose the topology type for antenna arrays. Moreover, their algorithm needs more runtime. So, there is no comprehensive approach to design a cost-effective antenna in cases with a different value of electromagnetic parameters.

In this paper, an executive yet effective algorithm is proposed to synthesize the array antenna based on desired specifications that consist of specific values of gain, HPBW, RF band, SLL, and scan angle. Some limitations optimize the runtime of our algorithm, and the desired result is determined earlier. Also, these limitations reduced complex of construction.

The following, amplitude, phase, and space tapering can be determined according to the tradeoff between minimum cost, simplicity of construction, and technical specification. Amplitude and phase tapering is highly dependent on cost with a different choice. It is possible using an amplitude tapering of the primary and secondary array or one of them and using phase tapering of the secondary array [26]–[31]. The excitation coefficients can be implementable through the adaptive analog BF in a massive MIMO antenna.

FIGURE 1. show parameter N_x for different topologies.

The proposed method for designing a phased array antenna, the simulation result of the designed linear array antenna for 5G communications is provided in section III. Then, the most recent methods are selected, and their performance is compared with the proposed method. Finally, section IV presents some conclusions of this work.

II. GENERAL METHODE TO DESIGN ARRAY ANTENNA

A. THEORY

The affordable phased array antenna architecture is based on the technique of sub-arraying. In this context, the number of elements is assumed to be the first group to be recognized as the primary array (shown with N_p), and the array whose elements are the first group is considered the second one (offered with N_{psh}). The far-field pattern for a linear subarray of isotropic elements is assumed in the following equation.

$$AF(\theta) = \sum_{p=1}^{N_{psh}} b_p \sum_{q=1}^{N_p} a_{pq} e^{j \frac{2\pi}{\lambda} d_i \sin \theta} \quad (1)$$

The above parameters are defined as follows.

b_p	Complex weight in subarray p
N_{psh}	Subarrays number
a_{pq}	Amplitude weight at subarray m of element n
N_p	Number of subarray's elements
λ	Wavelength
d_i	The distance of element i to wavelengths from the center of the array. $i = (p-1) N_x + q$

N_x 's value that controls the distance between the elements depends on a type of array topology determined according to (2).

$$N_x = \begin{cases} N & USA \\ N/2 & UOSA \\ (R_{m-1} + R_m)/2 & RSA \\ (N_{m-1} + N_m)/2 - RO_m & ROSA \end{cases} \quad (2)$$

R_m is the number of subarray components in the random array, and RO_m is the number of subarray components used in the next subarray in ROSA topology, and m show the number of the subarray. Fig. 1 shows the above relation to four different topologies. Each subarray is represented by a yellow or red color, and for delivering the overlap, elements used the green color. Other values of N_x assemble an aperiodic array to have the best topology.

Three parameters, b_p , a_{pq} , d_i are essential to have the desired radiation pattern. To explain the concept of the method, we choose another variable, assume the (3):

$$AF(u) = \sum_{p=1}^{N_{ps}} b_p \sum_{q=1}^{N_p} a_{pq} e^{j \frac{2\pi}{\lambda} d_i u} \quad (3)$$

$$u = \sin \theta \quad -1 \leq u \leq 1$$

As the array elements are considered symmetrical to have more comfortable fabrication, we consider the synthesis problem in the spectrum $0 \leq u \leq 1$, or $0 \leq \theta \leq \pi/2$ radians. To determine the unknown parameter in (3), the equation is converted to discrete form by considering J points in variation angle (θ).

This equation is sampled in J points shown in (4), and a better J includes a lot of issues in the corresponding interval.

$$AF(u_j) = \sum_{p=1}^{N_{ps}} b_p \sum_{q=1}^{N_p} a_{pq} e^{jk\beta_q} \quad j = 0, 1, 2, \dots, J-1 \quad (4)$$

$$k\beta_q = \frac{2\pi}{\lambda} d_i u_j = \frac{2\pi}{\lambda} d_i j \Delta u = \frac{2\pi}{\lambda} d_i j \frac{1}{j-1}$$

As a result, a multidimensional non-linear system is formed as described in (5), consisting of amplitude vector, desired pattern vector, and a non-linear function of the distance between elements in each point.

$$\begin{bmatrix} AF(u_1) \\ AF(u_2) \\ \dots \\ AF(u_j) \end{bmatrix}_{j=1}^J = \begin{bmatrix} X(u_1, d_1) & X(u_1, d_2) & \dots & X(u_1, d_i) \\ X(u_2, d_1) & X(u_2, d_2) & \dots & X(u_2, d_i) \\ \dots & \dots & \dots & \dots \\ X(u_j, d_1) & X(u_j, d_2) & \dots & X(u_j, d_i) \end{bmatrix}_{j=1}^J \begin{bmatrix} I_1 \\ I_2 \\ \dots \\ I_i \end{bmatrix}_{i=1}^{N^*} \quad (5)$$

By assuming the amplitude and vector of the desired pattern already known, solving this non-linear system manifests the distance between elements in the array. So, from a space between the subarrays, the number of phase shifters, a key parameter in the phased array antenna, could be determined. Since there is no analytical solution to solve this non-linear system, we handle it in numerical, and optimization space explained in the next part.

B. GUIDELINE DESIGN

The illustrated algorithm is general to synthesize any linear phased array antenna that is developed in MATLAB. The flowchart of the designed algorithm is demonstrated in Fig. 2. In the proposed algorithm, the general solution is considered, which contains not only a periodic array such as a conventional array (without using subarray technique), USA (Traditional subarray), UOSA but also aperiodic arrays such as RSA and ROSA.

At first, gain, HPBW, scan angle, maximum SLL, the maximum number of the phase shifter, and the complexity of the feeding network should be defined. Then, the total number of elements (N_t), number of primary array Elements (N_p) could be determined from the preliminary data.

By having the value of N_t and N_p , the USA will be determined. It is noticeable that this topology (USA) uses the least number of phase shifters among all topology. So we can be considered as a reference in our algorithm.

Generally, the desired topology is determined by comparing various structures' radiation patterns to the defined cost function. Based on the USA as a reference, the worst condition of angle (the angle with GL or high level of SLL) in the scanning range is estimated.

We start to determine the proper topology according to the angle identified to ensure better specifications can be obtained than to use the boresight angle to design. Although the variation of the gain and HPBW in the scanning angle is not ideal, we consider that these parameters should not change as much as the reference array does in the USA.

Now, it is time to determine the distance between the subarrays; in other words, what the vector d in (5) does. To determine vector d , we have two approaches:

Firstly, we consider a similar uniform primary array (N_p element per subarray) with similarity in excitation coefficients to have simple fabrication. To determine the type of topology, we suppose a different situation related to repeatable usage of an element to form each subarray. If each component is used only in one subarray, we will have the USA, and if it has a role in more than one subarray, overlapping is accrued in the subarray. When they are used only twice, we have the UOSA, and if an element uses equal or more than two times randomly, we have ROSA.

Secondly, we choose a different number of elements for primary array N_{p1} , N_{p2} , and others, so we have RSA. just symmetrical arrays are used in this approach.

According to the N_t , N_p , and the phase shifter's minimum number, all combinations are matrix. This matrix shows different subarray placement is next to each other.

According to previous work, the dimension of this matrix is massive. To minimize the matrix dimensions, we assume three conditions simultaneously; the array is symmetrical, the length of the array is constant, and does not use an element more than four times. So, some of the combinations are omitted.

The array factor of the residual combination by the minimum number of phase shifters is calculated. Based on

the cost function and the value of the SLL, the related score is determined. Then, the number of phase shifters is increased and repeated the same procedure for each phase shifters up to a maximum number of phase shifters. The final topology array could be chosen by comparing the value of each array's score related to each phase shifters. The amplitudes of primary arrays and amplitudes and phases of the second array are determined simultaneously by using the GAPSO optimization algorithm, To form a pattern.

The main beam for assessing the optimum scanning angle is steered in small-angle increments (typically 0.1°) until the level of the SLL reaches the maximum allowable side lobe level (MASLL). This angle of scan is reported as the actual maximum angle of the scan.

Consequently, the maximum scanning angle and the maximum SLL are mutually dependent, and there is a tradeoff between them.

We used the hybrid algorithm to get better results and to achieve the advantages of both genetic algorithm (GA) and particle swarm optimization (PSO) simultaneously[32]. Thus, the first half of the population is optimized with the GA, and the remaining half will join the PSO algorithm. The optimization process will continue until the end conditions are met.

As mentioned, the array factor varies as a function of the distance between elements, excitation coefficients, and antenna scan angle. So, an explanation of the minimax criterion follows:

$$\max_{\theta} \min_{N_{psh}} [AF(d_n, w_n, \theta_{scan})] \quad n = 1, \dots, N_{psh} \quad (6)$$

Suppose that m sampling angles are belonging to the scan range. The optimization model can be described as follows:

$$\min_{n_1, \dots, n_{N_{psh}}} E(n_1, \dots, n_{N_{psh}}) = \max_{j=1, \dots, m} [AF(d_n, w_n, \theta_{Scan})] \quad (7)$$

$$s.t \begin{cases} n_{min} \leq n_i \leq n_{max} & i = 1, \dots, N_{psh} \\ d_i \geq \lambda/2 \end{cases}$$

Where n_{min} and n_{max} denote the lower and upper bounds of the phase shifters. And the given upper and lower mask implements the efficiency of the algorithm with minimum mean square error (LMSE) between the desired and the synthesized pattern according to the cost function (CF). The C.F. used here is given by (8);

$$ore = \min \left[\frac{1}{P} \sum_{i=1}^P (AF(i) - Mask(i)) \right] \quad (8)$$

The user needs to be determined to limit the desired pattern as an upper and lower mask. So, it should be minimized. M is the number of pattern points that should be sufficiently large enough to cover the desired pattern variations. For a given desired radiation pattern, each pattern point that lies outside the specified limits contributes value to the cost function

Other proposed algorithms' advantages are considering the feeding network and mutual coupling, quantized amplitude, and phase weight.

The obtained results of the suggested method verify the higher-performance of limited- scan arrays. This is because of using a smaller number of phase shifters (tapering distance), tapering amplitude, phase using the GAPSO hybrid algorithm, and controlling the complexity of the feeding network by using of uniform and non-uniform element grouping simultaneously. Other features of this method consist of:

- Solving the problem with the minimum number of phase shifter;
- The length of the array antenna is constant;
- A fair tradeoff between SLL and scan angle by omitting grating lobe;
- The obtained amplitude and phase coefficient being practical and the ratio of the largest to the smallest of them respectively being ten and ninety;
- The complexity of the feeding network is being controlled by limiting the repeated. Usage of an element in the subarrays resulting in the speeding up of our code;
- We are choosing the best topology of the array.

Finally, the utilization of a general algorithm to determine the most acceptable design is defined by

- the type of topology of the array
- distance between elements
- complex weight (in other words, means phase shifters and amplifiers)

It can be claimed that a new toolbox is presented to design a phased array antenna, similar to the available MATLAB toolbox to design single-element antennas. The selection type of the primary array based on whether it is the uniform subarray (subarray with the same number of elements) or the random array (subarray with a different number of factors), is the first step. The physical specification consists of the total number of arrays, the number of phase shifters, and the number of elements in the subarray is defined in the toolbox. The controlling amplitude and phase coefficient affect the result. The tradeoff between simplicity and cost can determine the practical feeding network. Other technical specifications, such as maximum scan angle and variations of HPBW, gain, and SLL in the scanning range, is provided by determining the electrical size of the array, HPBW, and SLL. By the proposed toolbox, a better result

would be obtained for any number of elements and any frequency range.

III. SIMULATION AND RESULT

A. DESIGN MU-MASSIVE MIMO AS BS 5G ANTENNA

Due to the mm-wave high losses, a massive antenna with high gain is required in the range of 28dB to 35 dB. The planner antenna with 256 elements (16*16) until 2401(49*49) could be used to get the required gain. Since the number of elements increases, the design will be more complicated. Then we have chosen a planner array antenna with 49*49 elements.

In this paper, to verify the algorithm, the linear array with 49 elements antennas with $\lambda/2$ spacing (with the length array of 24.5λ) to synthesize a radiation pattern is designed. The other specifications are consist of the value of SLL less than 2dB, and the frequency center is 28GHz. The proposed antenna needs to be guaranteed simply feeding network; the higher the scan angle, the directive beam, and the more coverage in space with the phase shifter's minimum number.

In our algorithm, the phase shifters' number is swept from 7 to 23 to find better topology from the USA as a reference subarray to ROSA. A linear array diagram composed of 49 elements resulting from our numerical method is given in Fig. 2. As shown in Fig. 2, using one element more than four times is limited to have a more straightforward design. In this simulation, the primary array groups are uniform with equal spacing D_p (Fig. 3) that have been exited only

FIGURE 2. Feeding network and symmetrical randomly overlap subarray ($N_{total}=49$, $N_{psh}=23$, $N_p=7$)

FIGURE 3. Uniform primary array groups with equal spacing $D_p=\lambda/2$ and symmetrical amplitude control

through amplitude.

The final optimized results are displayed in Fig. 4. The desired scan range is $\pm 25^\circ$ with SLL better than 24 dB, suitable for the 5G base station antenna. With a minimum number of phase shifters. To cover all space, the number of these arrays can use in cylindrical topology.

The performance of the proposed algorithm is in removing the location of GL in comparison with the USA.

FIGURE 4. Normalized radiation patterns with GAPSO amplitude and phase tapering for $\pm 25^\circ$ scan for aperiodic array in 28GHz

FIGURE 5. Array factor of primary array (blue line) and secondary array in uniform subarray (red line) with six GL and ROSA (purple line).

As shown in Fig.5, there are six GL in the USA, whereas there is no GL in ROSA.

Fig. 6 illustrates the amplitude of the primary array in different scan angles. The amplitude and the phase of the secondary elements are shown in Fig.7 and Fig. 8.

FIGURE 6. Amplitude of 7 elements in primary array for scan angle (0°, 5°, 10°, 15°, 20°, 25°).

FIGURE 7. Amplitude of 23 elements in secondary array for scan angle (0°, 5°, 10°, 15°, 20°, 25°)

FIGURE 8. Phase of 23 elements in secondary array for scan angle (0°, 5°, 10°, 15°, 20°, 25°)

FIGURE 9. Normalized radiation patterns with GAPSO amplitude and phase tapering up +50° scan for aperiodic array with 16 elements.

Due to the variation of the excitation coefficient during scanning, we will design an adaptive BF to implement the array antenna. The results show that instead of 49 phased shifters, we have used 23 to mean our code can diminish the number of phase shifters by 53 percent. In comparison with the recent literature, the achievable improvement in the result is observed.

The scan angle relies on the value of HPBW and SLL. To have a wide scanning angle, we consider another study with 3.5 degrees as HPBW and 15dB as SLL. The 55 degrees for scan angle can be achieved using 16 elements in a subarray with two elements. In this design, the best number of phase shifters will be 11. The array factor

FIGURE 10. HPBW comparison of the proposed subarray architecture ($N_{psh}=23$) with the filled array architectures.

FIGURE 11. Variation of the Gain according to the scan angle for the proposed subarray architecture ($N_{psh}=23$) with the traditional subarray ($N_{psh}=7$).

display in Fig.9.

As mentioned, gain and HPBW are changed during scanning in the USA. This variation also exists in our design, but it has been improved. As like, shown in Fig. 10, the variation HPBW is similar to the USA, but less than it does, and Fig.11 shows increasing the exact value of the gain and decreasing gain variation of the proposed subarray in comparison with the USA as a traditional subarray.

B. COMPARING THE PROPOSED METHOD WITH the PREVIOUS WORK

Our article's approach has been better resulted by surveying several cases from the literature review and comparing the products and the performance demonstration.

Table I shows the comparison result of them in the value of SLL, the phase shifter's number, the variation of the gain and HPBW, and the scan angle. In the first case, although the type of the array is the same in both method and the phase shifter number of equalities is used, SLL and the variation of the gain are lower in our algorithm during 8° scanning angles.

It is because of using a better algorithm to determine complex weighting, choosing the best topology for array by considering all ROSA combinations according to the cost function.

Also, in case 2, our code's effectiveness had been shown the smaller number of phase shifters; the better result is obtained. For the third case, using two additional phase shifters significantly affects the design proposed by our algorithm. Also, the HPBW changes observed in this paper, and Other references did not report the HPBW variations .

The radiation pattern of the above examples is shown in Fig. 12. As shown in the figure, the result of three cases by our algorithm can respond better in SLL and give the wider scan angle.

Because our algorithm determines the best topology among

FIGURE 12. Total array factor (product of primary and secondary array) for three cases: (a) linear array with 50-elements in 10GHz and $\pm 8^\circ$ scan angle (b) array with 32 elements that scan from -20° to $+20^\circ$ (c) 30-element array with 21° as a scan angle.

all possible plans from the USA till UOSA, ROSA, ROA.

TABLE I
Results of our code for some cases in comparison with references.

	$f(\text{GHz})$	N_t	Type array	N_{psh}	Scan angle	SLL (dB)	HPBW variation (deg)	Gain variation (dB)	Ref
1	10	50	ROSA	16	$\pm 8^\circ$	-16	-	0.9	[33]
			ROSA	16	$\pm 8^\circ$	-28	2.4	0.7	Our code
2	7.9	32	ROA	13	$\pm 20^\circ$	-15	-	2	[34]
			ROSA	12	$\pm 20^\circ$	-26	1.4	1.8	Our code
3	7.9	30	ROA	12	$\pm 14^\circ$	-15	-	2	[34]
			ROSA	14	$\pm 21^\circ$	-24	2.7	2.1	Our code

VII. CONCLUSION

The general algorithm as a practical toolbox for designing an affordable phased array antenna with the minimum number of the phase shifters has been proposed. In fact, several subarray combinations are considered, and the best response is that first, the desired electromagnetic parameters, and second, the feed network architecture also consists of three-layer structures. And also, using the GAPSO optimization algorithm has been got implementable excitation coefficients. The primary condition for solving the problem in the proposed algorithm is to have a simple feeding network and needs to be remarked. We use the proposed approach to design 5G base station antenna in 28GHz, not only this antenna has a minimum cost but also has simple configuration; the achieved result involves reducing the number of phase shifters more than 53%, removing GL, and having maximum scan angle equal to $\pm 25^\circ$ with 24 dB as SLL. The obtained result verifies the suitability of our method. Additionally, the antenna radiation pattern is a pencil beam that can be used in the 5G base station antenna with 3D beamforming.

VII. Declaartion

- Availability of data and material

Not applicable

- Competing interests

Not applicable

- Funding

Not applicable

- Authors' contributions

Not applicable

- Acknowledgements

Not applicable

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electromagnetic field and wave interactions with phased array antenna and base station antenna for fifth-generation communication.

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Figures

Figure 1

Show parameter N_x for different topologies.

Figure 2

Feeding network and symmetrical random overlap subarray ($N_{total}=49$, $N_{psh}=23$, $N_p=7$)

Figure 3

Uniform primary array groups with equal spacing $D_p=\lambda/2$ and symmetrical amplitude control

Figure 4

Normalized radiation patterns with GAPSO amplitude and phase tapering for $\pm 25^\circ$ scan for aperiodic array in 28GHz

Figure 5

Array factor of primary array (blue line) and secondary array in uniform subarray (red line) with six GL and ROSA (purple line).

Figure 6

Amplitude of 7 elements in primary array for scan angle (0°, 5°, 10°, 15°, 20°, 25°).

Figure 7

Amplitude of 23 elements in secondary array for scan angle (0°, 5°, 10°, 15°, 20°, 25°)

Figure 8

Phase of 23 elements in secondary array for scan angle (0°, 5°, 10°, 15°, 20°, 25°)

Figure 9

Normalized radiation patterns with GAPSO amplitude and phase tapering up +50° scan for aperiodic array with 16 elements.

Figure 10

HPBW comparison of the proposed subarray architecture ($N_{psh}=23$) with the filled array architectures.

Figure 11

Variation of the Gain according to the scan angle for the proposed subarray architecture ($N_{psh}=23$) with the traditional subarray ($N_{psh}=7$).

(a)

(b)

(c)

Figure 12

Total array factor (product of primary and secondary array) for three cases: (a) linear array with 50-elements in 10GHz and $\pm 8^\circ$ scan angle (b) array with 32 elements that scan from -20° to $+20^\circ$ (c) 30-element array with 21° as a scan angle.