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Synthesizing Uniform Sum and Difference Patterns by Controlling Steer Angle and using Sub-Arrays

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Abstract- Synthesizing sum and difference patterns are usually achieved by controlling two separate sets of the amplitude and phase excitations of the radar antenna elements. In this paper, an alternative and effective approach is proposed. First, by equally partitioning the uniform array elements into two sub-arrays and then by suitably controlling the steered angle of the beam pattern of each sub-array individually, it is possible to generate the required sum and difference patterns. Since the steering angle parameter is the most important in the proposed method, a general strategy is shown for the selection process of its value. Unlike the existing techniques, the feeding network in the proposed approach is much simpler in practical implementation.

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I. INTRODUCTION

Effective design, in terms of cost and simplicity of the feeding network, of a monopulse radar antenna that able to generate the required sum and difference patterns is very desirable. In order to get a feed network as simple as possible, and thus reduce the costs while still generating both patterns, several techniques have been proposed. These include sub-array architectures [1-2], or arrays having common excitations when reconfiguring the pattern from a sum to a difference pattern [3-5], or even the exploitation of using two extra side elements [6-7]. More recently, global optimization techniques such as genetic algorithm or particle swarm optimization, with capability of incorporating some constraints in the design process, have been also used [8-9].

In most of the aforementioned techniques, the sum and difference patterns are usually synthesized by using non uniform amplitude distribution se.g., Dolph or Taylor distributions for sum pattern formation and Bayliss distribution for difference pattern formation. Implementation of these distributions require dedicated attenuators/amplifiers and phase shifters (i.e., a variable attenuator and a variable phase shifter for each array element). Accordingly, such implementation requires fairly complex, and expensive feeding network. In addition, these aforementioned non uniform amplitude distribution arrays suffer from directivity saturation for large number of array elements [10].

In contrast, the practical implementation of the uniform amplitude distribution arrays does not actually require any additional hardware (i.e., attenuators/amplifiers and phase shifters) since the phase shifters are already there for scanning. Thus, the implementation of such a uniform distribution array requires a very less expensive feeding network. Besides the simplicity in the feeding network, the other advantage of the uniform amplitude distribution arrays is their capabilities to provide desired directivity. One of the main drawback of such an array is its high sidelobe level (-13.4 dB) which is not adequate for radar applications that requiring low sidelobe levels.

In this paper, a simple and a new technique for synthesizing sum and difference patterns with uniform amplitude distribution in the linear arrays is presented. In particular, by dividing the array elements into two equally sub-arrays and controlling the steered angles of these two sub-array patterns individually. Then the required sum and difference patterns can be generated by adding or subtracting the steered radiation patterns of these two sub-arrays. Furthermore, by suitably choosing the steer angle of each sub-array pattern, it is also possible to significantly reduce the sidelobe level of the resulting sum pattern while still maintaining uniform amplitude distribution in the feeding network. The sidelobe reduction and the half power beam width (HPBW) in the resulting sum pattern are directly proportional to the selecting values of the steered angles of both sub-arrays.

II. THE METHOD

The structure of the proposed array is shown in Fig.1. In this structure, the total $N=2M$ elements of the uniformly excited equally spaced linear array is divided into two sub-arrays, i.e., left and right subarrays. The index of each element on the left and right sides are ranged from $-M$ to -1 and from 1 to M , respectively.

In each sub-array, the M elements array has uniform amplitude excitations $a_n = 1$ and equally spaced elements with the peak of the main beam steering at desired direction.

Assuming the phase center is at the center of the array and between the two sub-arrays, then the array factors of both sub-arrays are given by

$$AF_{Sum}(\theta) = \underbrace{\sum_{m=-N}^{-1} e^{-j\left(\frac{2m-1}{2}\right)[kdsin(\theta)+\beta_l]}}_{\text{Left side sub array}} + \underbrace{\sum_{m=1}^N e^{+j\left(\frac{2m-1}{2}\right)[kdsin(\theta)+\beta_r]}}_{\text{Right side sub array}} \quad (1)$$

where k is the wave number, d is the element spacing, β_l and β_r are the specified scan angles of the main beams for the left and right sub-arrays, respectively, and θ is the observation angle from the normal to array axis and varies from -90° to 90° . It should be mentioned that the array factor expressions which are available in the literature are always real

quantity. In contrast, the array factors in (1) for the left and right sides sub-arrays are complex quantities. If the values of steered angles β_l and β_r are not equal it is not possible to get a real array factor expression. Furthermore, it must be noted that the reference axis is at the centre of the array which invariably must generate a real valued array factor.

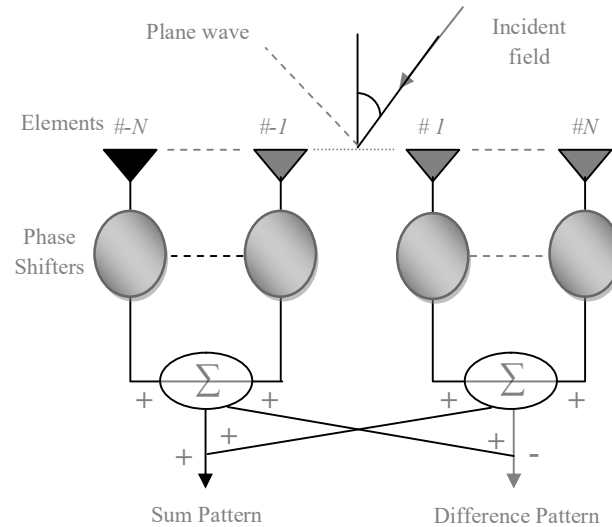


Fig. 1: Sub-array configuration for the proposed technique

Fig.2 shows the radiation patterns of the left and right sub-arrays computed separately according to the first and second terms of (1) for used parameters; $d = \lambda/2$, $N=20$, β_l and β_r are equal to -8° and $+8^\circ$ respectively. It can be seen that the sum pattern can be easily generated by simply adding these two patterns according to (1). Moreover, the sidelobe structures of both patterns are out of phase (anti-phase). This means that the resulting sum pattern will have some reduction in its sidelobe level with compare to the main uniform array where its peak sidelobe value is at -13.4dB .

On the other hand, by just subtracting the pattern of left side sub-array from that of right side sub-array the difference pattern can be easily generated using the same values of β_l and β_r (see Fig.3).

Note that the parameters, β_l and β_r should be carefully chosen as they are responsible for the shape formation of the resulting sum and difference patterns. This issue is investigated in Section IV.

III. FEEDING NETWORK

As mentioned earlier, the antenna array under investigation has uniform amplitude distribution. Thus it is not requires any attenuators or amplifiers. On the other hand, the antenna arrays based on electronic steering already contains a variable phase shifter in each element of the array for main beam steering, thus

the practical implementation of the proposed method does not actually require any additional hardware.

In comparison with existing techniques which are usually use two separate hardware sets of attenuators and phase shifters to reconfigure between sum and difference patterns, the proposed method uses one hardware set that consists only phase shifters.

Moreover, these phase shifters are fully shared in the proposed method to generate the required sum and difference patterns. Although there are a various techniques for synthesizing sum and difference patterns, the proposed configuration with fully common element excitations has not been previously tried to the best of my knowledge and is able to provide a significant reduction in the complexity and cost of feeding network. Table I shows the complexity of the feeding network for different techniques. From this table, it can be seen that for 20 elements radar antenna, the total number of the required attenuators and phase shifters for synthesizing sum and difference patterns under the case of no common (or separate) excitation are 40 attenuators and 20 phase shifters, while these numbers are reduced to 30attenuators and 20 phase shifters using the method presented in [4] and it is further reduced to only 20phase shifters with the proposed method.

IV. SIMULATION RESULTS

To illustrate the effectiveness of the proposed approach, a number of numerical experiments have been performed. In the following examples, we assume a uniform linear array with $N=20$ elements and half-wavelength element spacing. The two sub arrays are then formed by dividing the main array elements into two equally sub arrays, each with $M=10$ elements. Figures from Fig.4 to Fig.7, shows the resulting sum and difference patterns under various values of steering angles. In all these figures, the values of steering angles are chosen such that $\beta_l = -\beta_r$ (i.e., symmetric).

From all these figures, it can be seen that the required sum and difference beam patterns can be achieved when setting the steered angles at small values and near to the broadside direction. Also note that for Figs 4 to 6, the intersection area between main beams of the two sub-arrays is large and the half power beam width (HPBW) of the resulting sum pattern is exactly equal to that of the standard uniform array. On the other hand, and for large values of steering angles, the HPBW of the resulting sum patterns are significantly increased with respect to that of the standard uniform array and the main beams become nearly flat top with some ripples at the top of the main beam (see Fig.7). Note that this case can be considered as a multiple-pattern antenna arrays that capable to radiate more than one pattern by only varying the steered angle.

This pattern reconfiguration issue is desirable in many applications such as radar, remote sensing, and telecommunications. The resulting difference patterns are adequately locating a null at desired direction since there are still some intersection area between the main beams of both sub-array patterns. Fig.8 shows the variations of the HPBW versus the steering angle values. From this figure, it can be seen that, for small steer angle values which are ranging from $\beta_l = -\beta_r = 1^\circ$ to 17° , the HPBW of the resulting sum pattern is at 5° which is nearly equal to that of the standard uniform array. For other values of $\beta_l = -\beta_r = 18^\circ$ to 24° , the HPBW of the resulting sum pattern is at 17° and its main beam top become flat with some ripples between 0 dB and -2 dB. For $\beta_l = -\beta_r = 30^\circ$ or any other larger values, the resulting sum pattern fails in its operation where it is starting to locate a null instead of peak main beam at the broadside direction. This effect is clearly shown in Fig. 9.

Finally, the sidelobe level in the resulting sum pattern can be significantly reduced if we chose asymmetric values for the steering angles (i.e., $\beta_l \neq \beta_r$) such that the sidelobe structures of both sub-array patterns are approximately equal in magnitude and out of phase. Fig. 10 shows such contradiction in the sidelobe structures of both patterns for choosing values $\beta_l = 0^\circ$ and $\beta_r = 5.74^\circ$. As a result, the sum pattern have a low sidelobe level (an improvement of 6

dB with respect to the standard uniform array). This improvement is come at the cost of little shifting in the main beam of the resulting array.

V. CONCLUSIONS

An alternative method for synthesizing sum and difference beam patterns with uniformly excited equally spaced linear arrays has been presented. By suitably choosing the steering angle of the beam patterns of the left and right sub-arrays, it is possible to generate the required sum and difference patterns. It is evident from the present investigation that there is a general strategy to assist the selection process of the steering angle adjustment. First, the generated sum pattern may be exactly same as that of the standard uniform array with narrow HPBW if the steering angles chosen at small values and near to the broadside direction. This imply that the steered main beams of both sub-arrays are intersected at a large area. Next, for small intersection area, the choosing value of the steering angle may lead to reconfiguration the overall array pattern from pencil beam to a pattern like a flat-top beam with wide HPBW.

Finally, for the case of no intersection area between main beams of both sub-array patterns, the steering angle values are not recommended as the resulting sum patterns fails in its operation. Besides the diversity of use, other advantage of the proposed technique is that it is suitable for practical implementation.

REFERENCES RÉFÉRENCES REFERENCIAS

1. Alvarez-Folgueiras, M., J. Rodriguez-Gonzales, and F. Ares-Pena, "Optimal compromise among sum and difference patterns in monopulse antennas: Use of subarrays and distributions with common aperture tail," *Journal of Electromagnetic Waves and Applications*, Vol. 23, Nos. 17-18, 2301-2311, 2009.
2. HuaGuo, ChenjiangGuo, and Jun Ding, "Pattern Synthesis of Sub-Arrayed Monopulse Planar Arrays," *Electromagnetics* Vol. 34, Iss. 7, 2014.
3. Morabito, A. F. and P. Rocca, "Optimal synthesis of sumand difference patterns with arbitrary sidelobes subject to common excitations constraints," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, 623-626, Jul. 2010.
4. Mohammed, J.R., "Synthesizing Sum and Difference Patterns with Low Complexity Feeding Network by Sharing Element Excitations", *International Journal of Antennas and Propagation*, vol.2017, Article ID 2563901, 7 pages, 2017.
5. Alvarez-Folgueiras, M., J. Rodriguez-Gonzales, and F. Ares-Pena, "Synthesizing Taylor and Bayliss linear distributions with common aperture tail," *Electron. Lett.*, Vol. 45, No. 11, 18-19,2009.
6. Mohammed, J.R., and K. H. Sayidmarie, "A New technique for Obtaining Wide-Angular Nulling in the

Sum and Difference Patterns of Monopulse Antenna", IEEE Antennas and Wireless Propagation Letters, vol. 11, pp. 1242-1245, 2012.

7. Mohammed, J.R., "An Alternative Method for Difference Pattern Formation in Monopulse Antenna", Progress in Electromagnetics Research Letters, vol. 42, pp. 45-54. August 2013.
8. LakshmanPappula, and DebalinaGhosh, "Synthesis of linear aperiodic array using Cauchy mutated cat swarm optimization, "AEU - International Journal of Electronics and Communications, Volume 72, February 2017, Pages 52-64.
9. Sudipta Banerjee and Durbadal Mandal, "Array pattern optimization for steerable linear isotropic antenna array using novel particle swarm optimization," Journal of Electromagnetic Waves and Applications Vol. 31, Iss. 2, 2017.
10. Ahmad Safaai-Jazi and W. L. Stutzman, "A New Low-Sidelobe Pattern Synthesis Technique for Equally Spaced Linear Arrays," IEEE Trans. On Antennas & Propagation, Vol. 64, no.4, 2016.

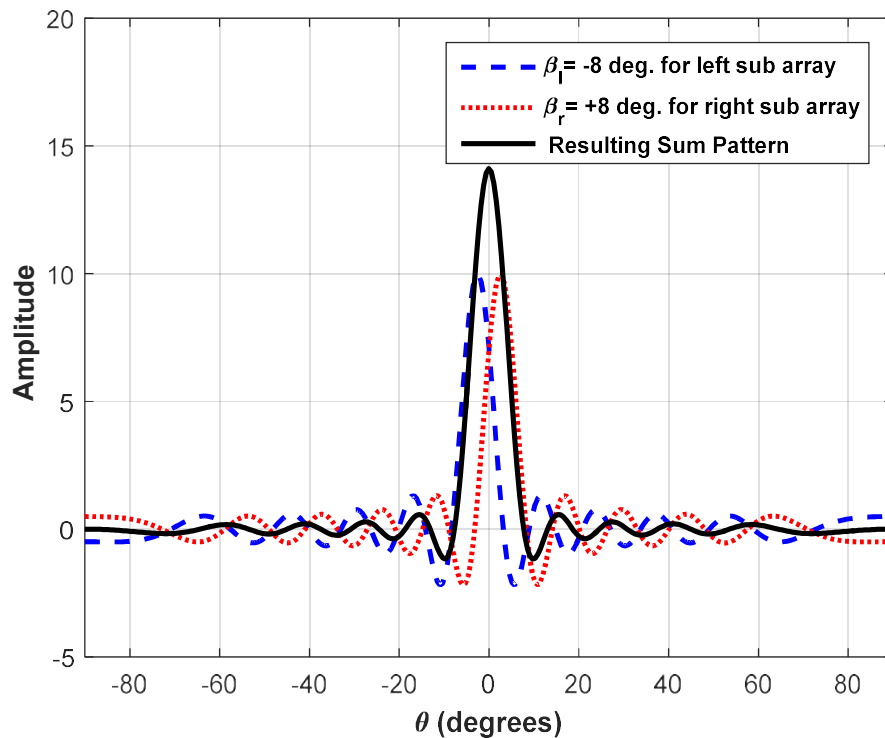


Fig. 2: The beam patterns due to left and right sides sub-arrays and the resulting sum pattern.

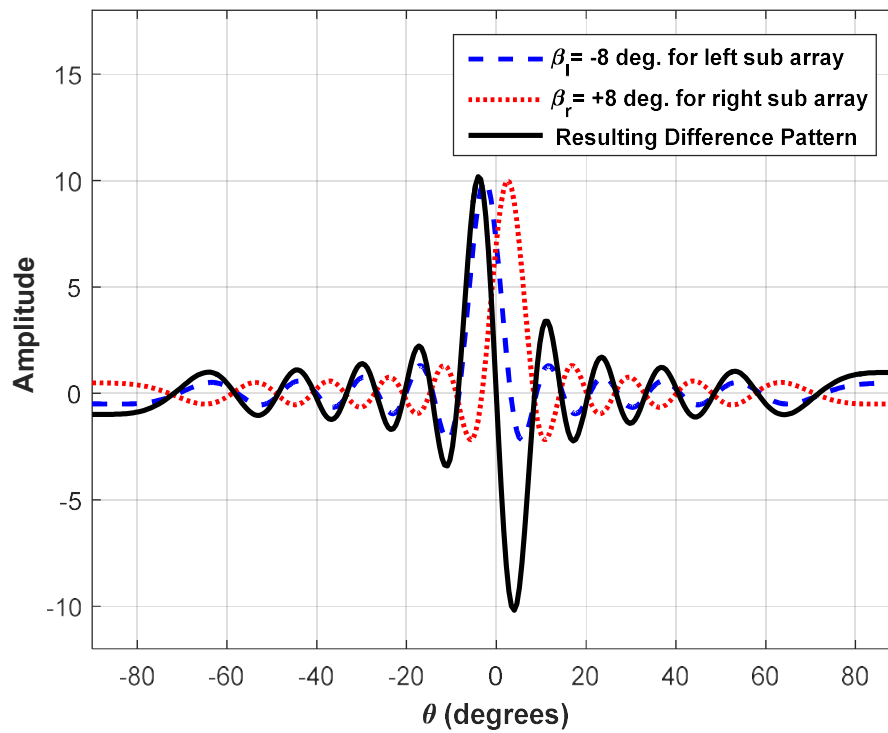


Fig. 3: The beam patterns due to left and right sides sub-arrays and the resulting difference pattern.

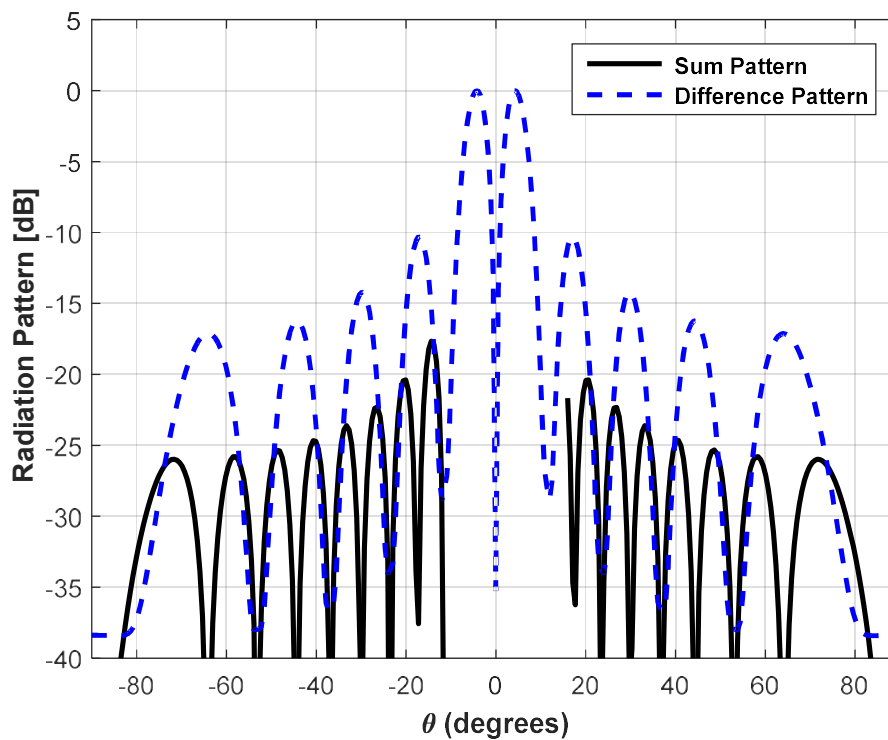


Fig. 4: The resulting sum and difference beam patterns for $2N = 20$, $d = \lambda/2$, $\beta_l = -\beta_r = 1^\circ$.

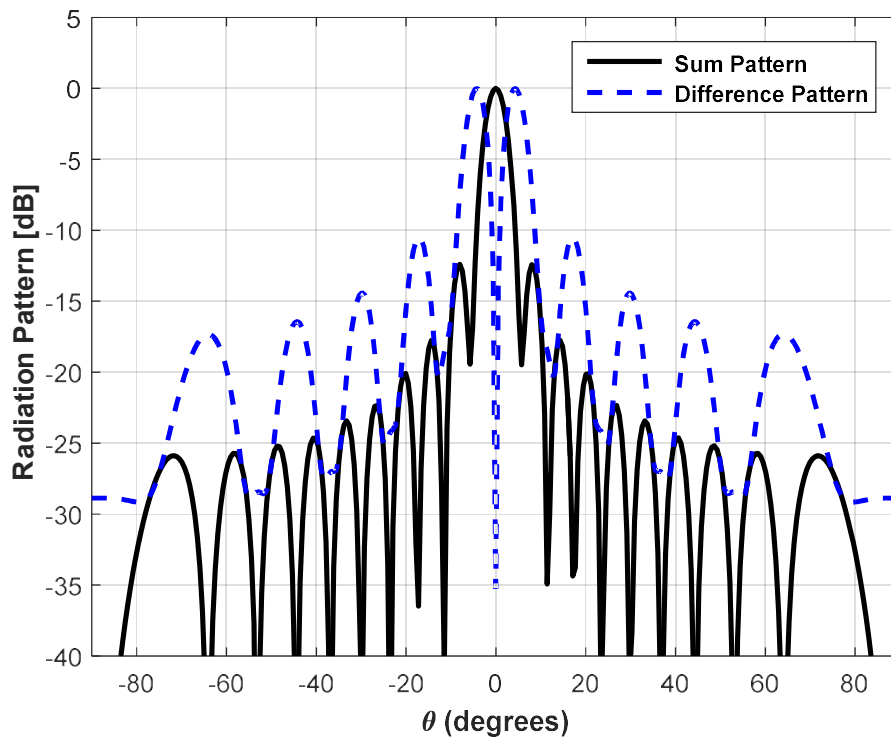


Fig. 5: The resulting sum and difference beam patterns for $2N = 20$, $d = \lambda/2$, $\beta_l = -\beta_r = 3^\circ$.

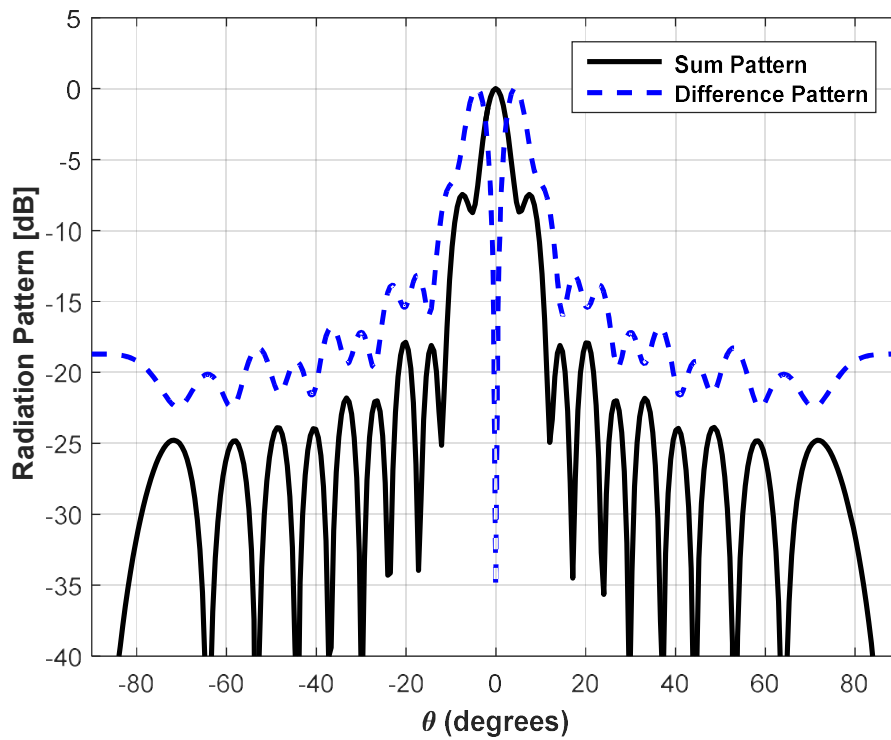


Fig. 6: The resulting sum and difference beam patterns for $2N = 20$, $d = \lambda/2$, $\beta_l = -\beta_r = 10^\circ$.

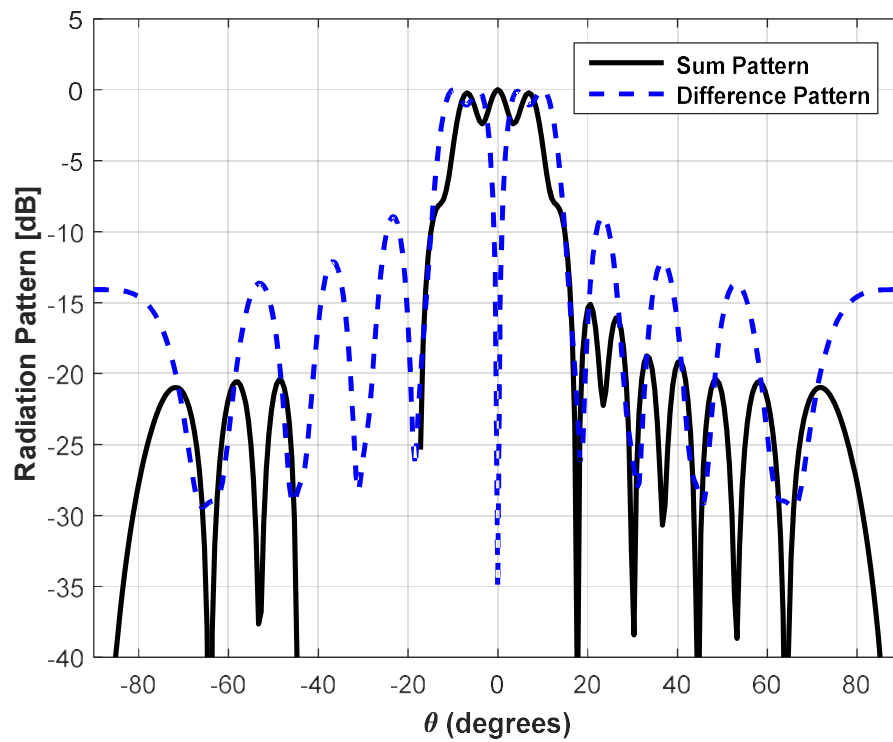


Fig. 7: The resulting sum and difference beam patterns for $2N = 20$, $d = \lambda/2$, $\beta_l = -\beta_r = 20^\circ$.

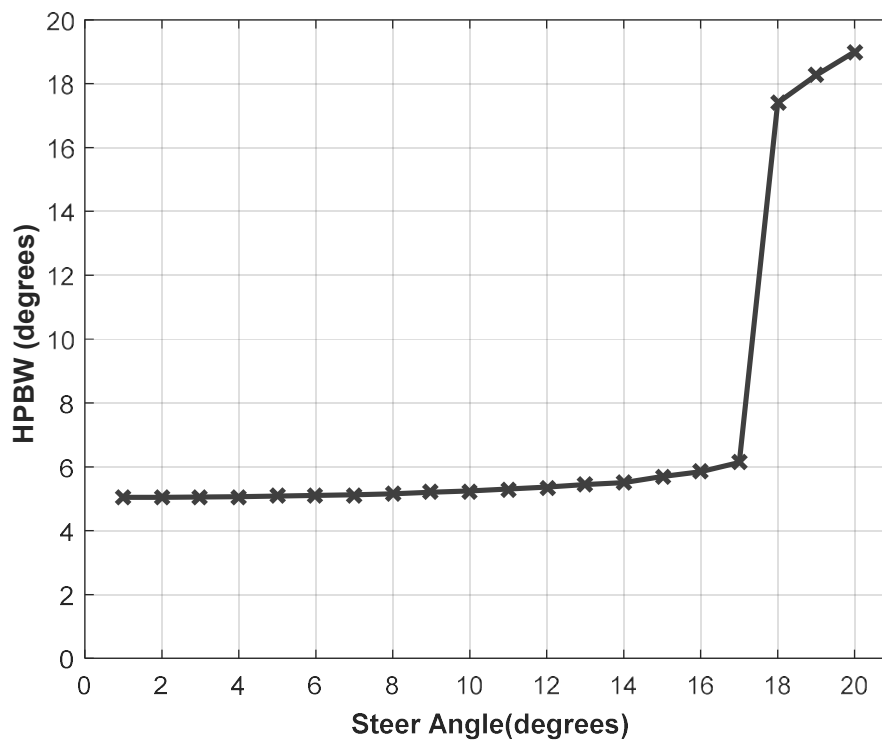


Fig. 8: The HPBW versus Steering Angles $\beta_l = -\beta_r$.

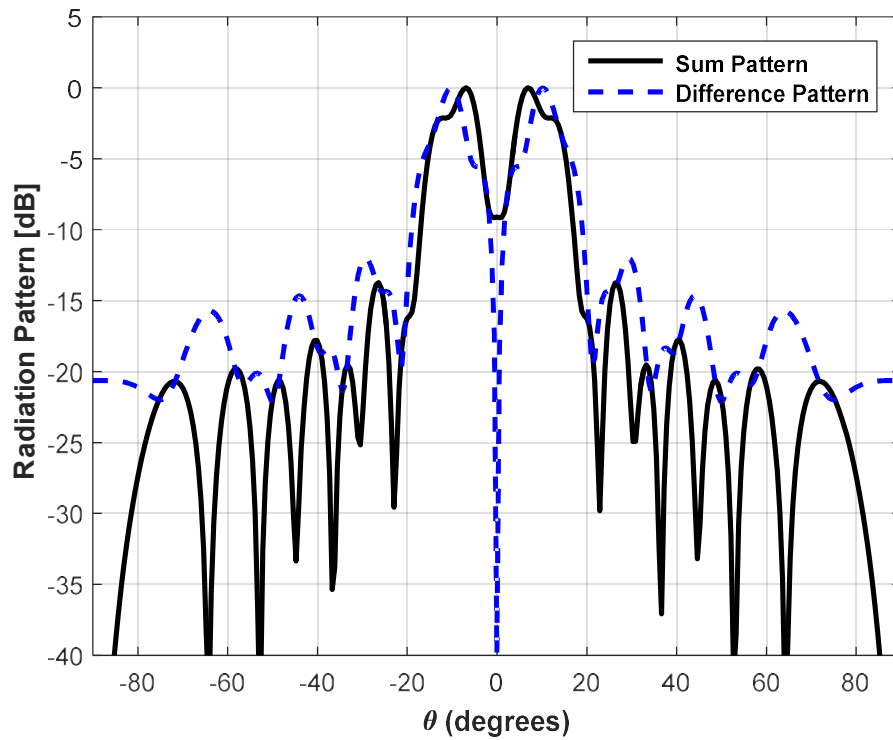


Fig. 9: The resulting sum and difference beam patterns for $2N = 20$, $d = \lambda/2$, $\beta_l = -\beta_r = 30^\circ$.

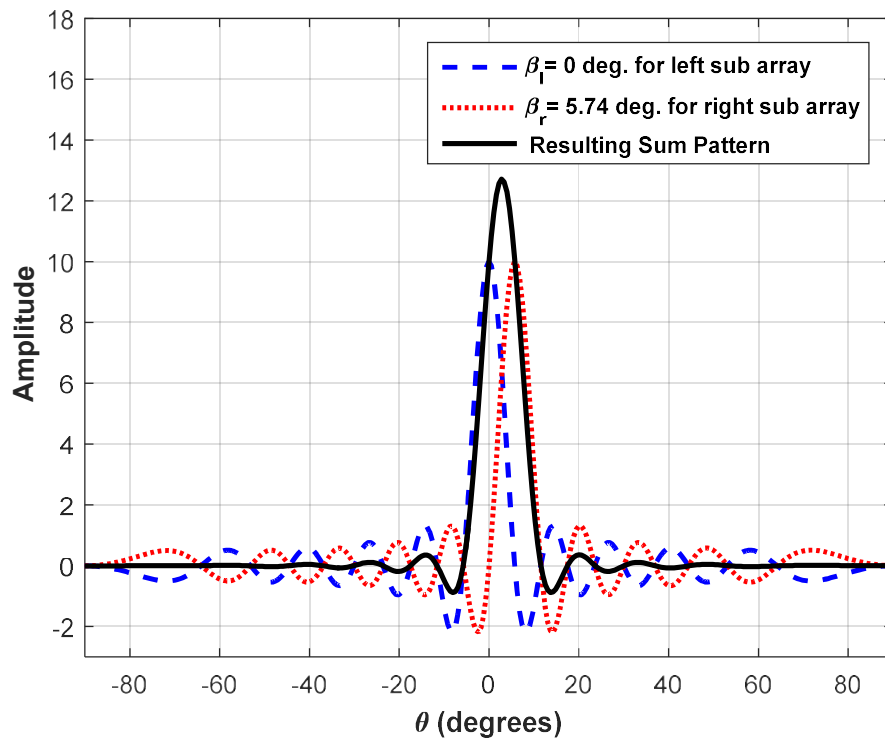


Fig. 10: The resulting sum and difference beam patterns for $2N = 20$, $d = \lambda/2$, $\beta_l = 0^\circ$ and $\beta_r = 5.74^\circ$.

Table 1: Complexity of the Feeding Network for Different Techniques

Technique	Feeding Network Complexity	
	Total No. of Attenuators for both Sum & Difference Patterns	Total No. of Phase Shifters for scanning both Sum & Difference Patterns
Separate excitations (No common excitations)	$2N$	N
Common excitations [4] (Sharing percentage 50%)	$2N-N/2$	N
Proposed Array	0	N