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Generation of Asymmetrical Difference Patterns from Array Antennas

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***Abstract*—It is common to produce sum patterns from array antennas. These patterns are basically symmetric with one main lode in bore sight and symmetric sidelobe structure around the main beam. The antennas associated with the marine radars are required to produce patterns with asymmetric side lobes. Asymmetrical patterns are very useful for marine radars when ships sail in turbulent water where roll and pitch exists.In particular the sidelobes in one side are lower than those of the other side. It is also essential to produce difference patterns with asymmetric structure from the boresight direction. These patterns are required to have null in the bore sight and high difference slope in the same direction. When these patterns are required from marine radars, the side lobes associated with the difference pattern on the either side of the boresight is at the different heights.**

In the present work, such useful patterns are generated from the newly designed arrays. The amplitude and phase distributions are designed for small and large arrays. The radiation patterns are numerically computed and they are presented in u- domain.

***Keywords*—asymmetric patterns, arrays; array antennas; marine radars; amplitude and phase distributions.**

I. INTRODUCTION

MARINE radars are used to measure the bearing and distance of ships, to navigate and to fix their position at sea when within range of shore or other fixed references such as islands,buoys, and lightships. The asymmetrical sum and difference patterns are very useful for marine radars when ships sail in turbulent water where roll and pitch exists.The radiation pattern structure is one of the most important specifications for the design of the antennas in all communication and radar applications. Conventionally, the patterns are symmetrical. The work on the symmetric patterns is extensively reported in the literature. Even in these types of patterns, the over all structure in terms of main lobe and the side lobe decay is different.

The patterns specified in terms of its beam width and the side lobes are specified in terms of their levels relative to the main beam. However, the above type of symmetric patters doesn't find application in marine radars. When the ships sail in turbulent waters, the ships are subject to roll and pitch. Under these circumstances the communication is disturbed and some times it totally fails. In view of these facts, intensive investigations are carried out to design array antennas in order to generate asymmetric sum and difference radiation patterns.

In the present work new excitation distributions are proposed and extremely useful asymmetric patterns are generated.

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In most of the modern radar applications, it is often required to produce Sum and Difference patterns sequentially. Sum pattern is used for range detection and Difference pattern for determining angular tracking accuracy. Sum pattern consists of a very narrow beam in the bore sight direction, which is associated with different minor lobes. The difference pattern consists of a null in the bore sight direction with two major lobes adjacent to the null. In order to have high resolution the main beam of the sum pattern should have negligibly small width and side lobe level should be as small as possible. These requirements demand optimally designed array.

Sum pattern is produced from a directional antenna and the difference pattern is created by simultaneously exciting directional and omni-directional antennas [1], [2], [3], [4]. In difference patterns, the depth of the null is significant and the difference slope is not enough for many applications. The sum patterns are generated by several methods. But the methods of generation of difference patterns are limited. It is required to produce them for optimum performance.

It is well known that a magic Tee can be used to produce both sum and difference signals. The cross-polarized characteristics of monopulse difference patterns are obtained by Bodnar [5]. Similar radiation characteristics are also obtained by Cutler [6], Jones, and Chu. These patterns are generated from paraboloidal antennas and not from the arrays. Bodnar analyzed the cross-polarized characteristics of a monopulse antenna consisting of four horn monopulse feed pointed at the vertex of symmetrical parabolodial reflectors. The planar slot array to obtain the sum and difference patterns is designed by David Kim et al [7]. The slot lengths and offsets are found out for a planar array for longitudinal shunt slot fed by rectangular wave guides.

Hinton [8] obtained approximate difference patterns from 32 element weighted array. They obtained a relationship for the amplitude difference pattern response as a function of angle relative to the boresight plane of an incident electric field for amplitude weighted Butler matrix. The results are compared with those of weighted Butler array. Vu [9] described a method of pattern nulling in difference pattern by only amplitude technique. This method is found to provide an alternative approach to the design of adaptive phased arrays.

McNamara [10] presented a design methodology for the generation of optimum difference patterns from discrete arrays. The aperture distributions are expressible in simple form and it is used to produce difference patterns with low side lobes. The generation of low side lobes difference patterns are studied by Hansen [11].

The patterns are compared with Bayliss difference patterns. The planar arrays designed to produce the difference patterns are reported by Botha et al [12]. The method is found to be used in McClellan transformation, trigonometric addition formulas for the above purpose.

A technique is presented by Ronald [13] for obtaining a frequency independent amplitude difference patterns from two broad side arrays. To get the desired pattern the pointing of each array beam is made frequency dependent. This is done by using arithmetically progressive frequency independent phase shift to the array elements. Utilization of the lambda functions in the analysis and synthesis of mono pulse antenna difference patterns is done by Edward [14]. It is found that of the general class of patterns considered, there is one family which gives the best compromise between slope at the boresight and sidelobe level. This method is best suitable for design of monopulse difference patterns for either a specified slope at boresight or a specified side lobe level.

A design method is developed by Elliott [15] for difference patterns with side lobes of individually arbitrary height for line source. The basis is Bayliss patterns which are transformed through an iterative procedure to the desired result. A typical Bayliss pattern consists of a pair of central main lobes plus a specified number of near-in side lobes which are essentially at a common controlled height, with far-out side lobes which decay in height as a function of angular distance from the main beam.

Techniques for designing the minimum power side lobes for a main lobe array factor or difference pattern array factor have been studied by Shnidman [16]. Bucci et al. [17] described about two new approaches to the optimal synthesis of difference patterns which can deal in an effective fashion with arbitrary side lobe bounds. The first method can be applied to completely fixed geometry array and the second one can be applied to uniformly space linear or planar arrays.

Monopulse radar antennas must generate both sum and difference patterns with low side lobe levels, high directivities and narrow beam width. Lopez et al [18] considered a linear array with an excitation distribution for sub array weighting allows the generation of difference patterns from Monopulse antennas. To minimize the interference signals coming from jammers, stationary clutters, or other environmental disturbance, pattern nulling or pattern steering is required. Difference pattern designs, used for finer resolution from the sum patterns are often based on the Bayliss technique [19]. Optimization of the difference patterns for Monopulse Antennas by a Hybrid Real Integer-coded Differential evolution algorithm is developed by Salvatore [20]. The results have shown that the requirements concerning the SLL have been fulfilled with good accuracy even by using a simplified sub array configuration.

It is evident from the above discussion; the works are centered on symmetric sum and difference patterns. But the marine radars require assymetrical patterns. For such applications, the present work is directed to design suitable amplitude and phase distributions using interpolation technique to produce assymetrical sum and difference patterns. The weights of the each element are estimated at the source position. The source positions are found out according to Ishimuru [21]. The patterns are computed for small and large arrays.

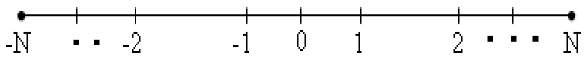

Fig. 1. Symmetric array.

II. Difference Patterns from Uniform Arrays of Isotropic Elements

A symmetric broadside array of $2N+1$ isotropic elements as shown in fig (1). The radiation field of the array of $2N+1$ elements is given by

$$E(u) = a_0 + \sum_{i=1}^{N} a_n \cos u_n \tag{1}$$

$$E(u) = a_0 + \sum_{i=1}^{N} a_n \cos\left(b_n \beta d_n u_n\right) \tag{2}$$

where a_0 is Amplitude Excitation level of the center element.
a_n is Amplitude Excitation level of the n^{th} element.
β is progressive phase shift $\frac{2\pi}{\lambda}$
d_n interelement spacing.
d_N distance from the center element to the N^{th} element
θ is the angle of observation from broadside

$$u_n = \beta d_n \cos\theta \tag{3}$$

$$u = \cos\theta \tag{4}$$

$$b_n = \frac{d_n}{d_N} \tag{5}$$

It is possible to replace dual antennas namely a directional and omni directional antennas by dual excitations. It is required to phase the antenna to obtain both sum and difference patterns. The sum patterns is given by

$$\begin{aligned} E_s(u) &= E(u+u_s) + E(u-u_s) \\ &= 2a_0 + 4\sum_{i=1}^{N} a_n \cos\left(b_n \beta d_N u_s\right)\cos\left(a_n \beta d_N u\right) \end{aligned} \tag{6}$$

The difference pattern is given by

$$E_d(u) = 4\sum_{i=1}^{N} a_n \sin\left(b_n \beta d_N u_s\right)\sin\left(a_n \beta d_N u\right) \tag{7}$$

In the above expressions,

$$u_s = \cos\theta_s \tag{8}$$

θ_s is the squint angle of the beam. The difference pattern for a fixed amplitude distribution $A(x_n)$ is given by

$$\begin{aligned} E_d(u) = &\sum_{n=1}^{\frac{N}{2}} A(x_n) e^{\left(j\frac{2\pi}{\lambda}x_n u + \phi(x_n)\right)} + \\ &\sum_{n=\frac{N}{2}+1}^{N} A(x_n) e^{\left(j\frac{2\pi}{\lambda}x_n u + \phi(x_n) + \pi\right)} \end{aligned} \tag{9}$$

Here, $A(x_n)$ is Amplitude distribution and $\phi(x_n)$ is excitation phase function.$u = sin\theta$,θ is the angle of the observer,x_n is spacing function,$x_n = \frac{2n-1-N}{N}$ The polynomial equations for $A(x_n)$ and $\phi(x_n)$ by using interpolation technique is given by

$$A(x_n) = 0.1201x^6 + 0.7164x^4 - 1.1196x^2 + 0.98862 \quad (10)$$

$$\phi(x_n) = -3.8117x^9 - 1.5422\ 10^{-14}x^8 + 5.3922x^7 +2.8496\ 10^{-14}x^6 - 0.61636x^5 - 1.6278 * 10^{-14}x^4 +0.73237x^3 + 2.9489 * 10^{-15}x^2 - 0.2321x - 7.8976\ 10^{-17} \quad (11)$$

From the above expression (9), it is evident that the difference pattern produces a null in the boresight direction.

Generation of null in the bore sight direction

Consider

$$E(u) = \sum_{n=1}^{N} A(x_n) e^{j\left[\frac{2\pi L}{\lambda} x_n u + \phi(x_n)\right]} \quad (12)$$

$$E_d(u) = \sum_{n=1}^{N} A(x_n) e^{j\left(\frac{2\pi L}{\lambda} x_n \sin\theta + \phi(x_n)\right)} + \sum_{n=\frac{N}{2}+1}^{N} A(x_n) e^{j\left(\frac{2\pi L}{\lambda} x_n \sin\theta + \phi(x_n)\right)} \quad (13)$$

Here $A(x_n)$ is the n^{th} sample value of excitation function, which is a constant. To generate a null in the bore sight direction 180^0 phase shift is introduced to one half of the array i.e. ,

$$\phi(x_n) = 0 \quad 1 \le n \le \frac{N}{2}; \qquad = \pi \quad \frac{N}{2} + 1 \le n \le N \quad (14)$$

Let $u = sin\theta$. Substituting (14) in (13), the radiation pattern is now given by

$$E(u) = \left[\sum_{n=1}^{N/2} A(x_n) e^{j\left(\frac{2\pi L}{\lambda} x_n u\right)} + \sum_{n=\frac{N}{2}+1}^{N} A(x_n) e^{j\left(\frac{2\pi L}{\lambda} x_n u + \pi\right)} \right] \quad (15)$$

$$E(u) = \left[\begin{array}{l} A(x_n)\left(\cos\left(\frac{2\pi L}{\lambda} x_n u\right) + j\sin\left(\frac{2\pi L}{\lambda} x_n u\right)\right) + \\ A(x_n)\left(\cos\left(\frac{2\pi L}{\lambda} x_n u + \pi\right) + j\sin\left(\frac{2\pi L}{\lambda} x_n u + \pi\right)\right) \end{array} \right] \quad (16)$$

For the boresight direction at $\theta = 0, u = 0$. By substituting this value in the above equation, we get

$$E(u) = f(\theta)\left[A(x_n)(1) + A(x_n)(-1)\right] \quad (17)$$

Hence $E(\theta) = 0$. This means a null is generated corresponding in the boresight direction.

III. Amplitude and Phase Distributions for Asymmetrical Difference Patterns

The amplitude and phase distributions are computed for different arrays containing different number of elements and they are presented in tables 1, 2. For N = 20, 50 are presented in the following tables.

TABLE I
DISTRIBUTIONS FOR $N = 20$ ELEMENTS

No. of elements, N	Spacing Position, x_n	Amplitude Distribution, $A(x_n)$	Phase distribution, $\Phi(x_n)$
1	-1.0000	0.7137	0.0063
2	-0.9000	0.6669	0.0067
3	-0.8000	0.6343	0.1442
4	-0.7000	0.6140	0.2273
5	-0.6000	0.6044	0.2329
6	-0.5000	0.6039	0.1922
7	-0.4000	0.6111	0.1382
8	-0.3000	0.6246	0.0898
9	-0.2000	0.6433	0.0524
10	-0.1000	0.6661	3.1416
11	0.1000	0.6919	3.1176
12	0.2000	0.7199	3.0892
13	0.3000	0.7492	3.0518
14	0.4000	0.7790	3.0034
15	0.5000	0.8088	2.9494
16	0.6000	0.8378	2.9087
17	0.7000	0.8657	2.9143
18	0.8000	0.8918	2.9974
19	0.9000	0.9157	3.1349
20	1.0000	0.9372	3.1353

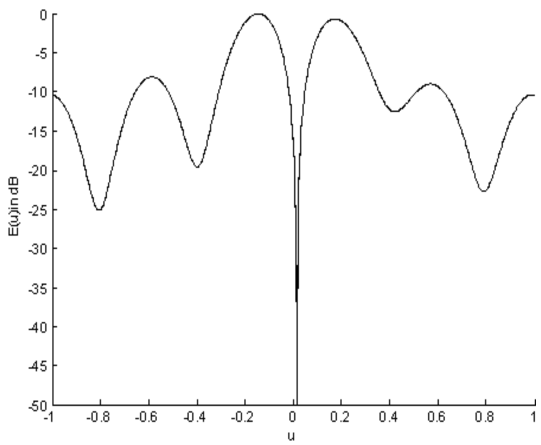

Fig. 2. Difference Pattern for discrete array of 10 elements.

IV. Results

The data presented in tables (1–3), is introduced in equation (9) and the radiation patterns are computed for the following arrays. The results on the variation of E(u) as a function of u of the arrays containing number of elements equal to 10, 20, 30, 50, 80, 100 and 150 for difference patterns are presented in figs (2 -8).

TABLE II
DISTRIBUTIONS FOR $N = 50$ ELEMENTS

No. of elements, N	Spacing Position, x_n	Amplitude Distribution, $A(x_n)$	Phase distribution, $\Phi(x_n)$
1	-1.000	0.713	0.006
2	-0.960	0.666	-0.034
3	-0.920	0.634	-0.015
4	-0.880	0.614	0.033
5	-0.840	0.604	0.090
6	-0.800	0.603	0.144
7	-0.760	0.611	0.187
8	-0.720	0.624	0.217
9	-0.680	0.643	0.233
10	-0.640	0.666	0.238
11	-0.600	0.691	0.232
12	-0.560	0.719	0.220
13	-0.520	0.749	0.202
14	-0.480	0.779	0.181
15	-0.440	0.808	0.159
16	-0.400	0.837	0.138
17	-0.360	0.865	0.117
18	-0.320	0.891	0.098
19	-0.280	0.915	0.081
20	-0.240	0.937	0.066
21	-0.200	0.955	0.052
22	-0.160	0.971	0.040
23	-0.120	0.983	0.029
24	-0.080	0.992	0.018
25	-0.040	0.998	0.009
26	0.040	0.998	3.132
27	0.080	0.992	3.122
28	0.120	0.983	3.112
29	0.160	0.971	3.101
30	0.200	0.955	3.089
31	0.240	0.937	3.075
32	0.280	0.915	3.060
33	0.320	0.891	3.043
34	0.360	0.865	3.024
35	0.400	0.837	3.003
36	0.440	0.779	2.981
37	0.480	0.749	2.960
38	0.520	0.719	2.939
39	0.560	0.691	2.921
40	0.600	0.666	2.908
41	0.640	0.643	2.903
42	0.680	0.624	2.907
43	0.720	0.611	2.924
44	0.760	0.603	2.954
45	0.800	0.604	2.997
46	0.840	0.614	3.051
47	0.880	0.634	3.108
48	0.920	0.634	3.157
49	0.960	0.666	3.176
50	1.000	0.713	3.135

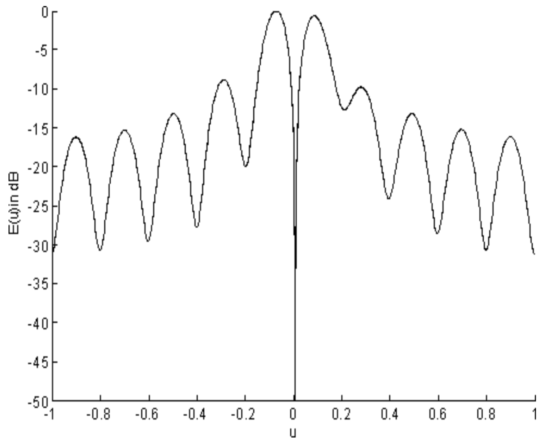

Fig. 3. Difference Pattern for discrete array of 20 elements.

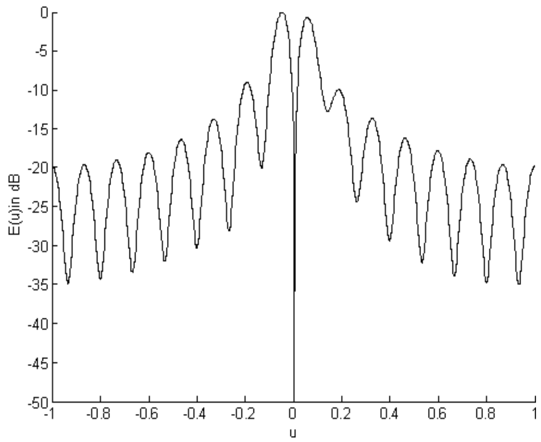

Fig. 4. Difference Pattern for discrete array of 30 elements.

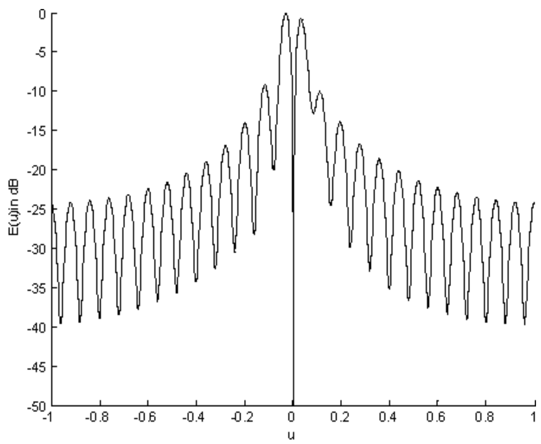

Fig. 5. Difference Pattern for discrete array of 50 elements.

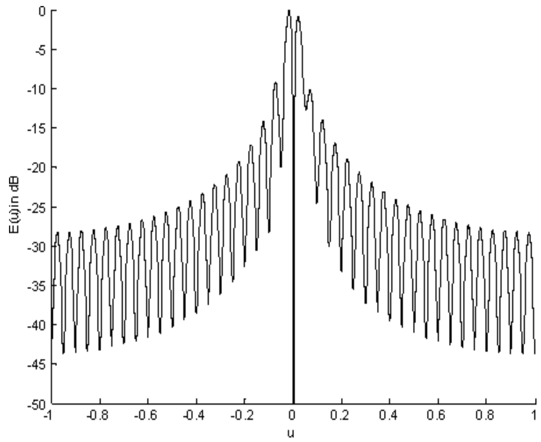

Fig. 6. Difference Pattern for discrete array of 80 elements.

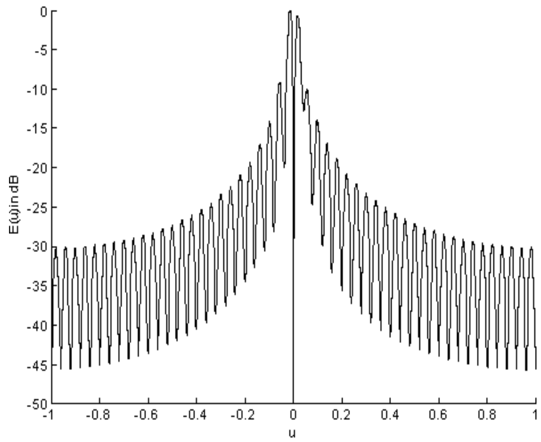

Fig. 7. Difference Pattern for discrete array of 100 elements.

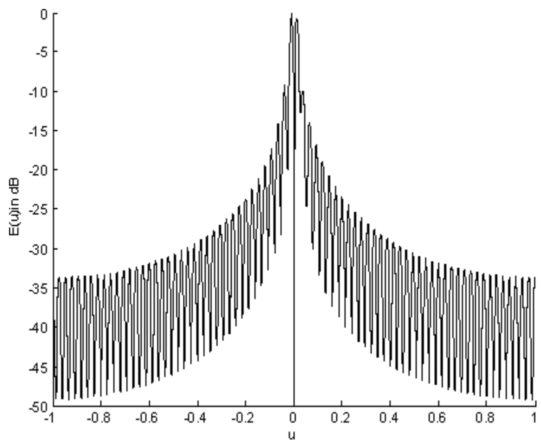

Fig. 8. Difference Pattern for discrete array of 150 elements.

V. CONCLUSIONS

It is evident from the data presented in tables (1-2) the spacing is uniform and the elements are symmetric. The amplitude distribution $A(x_n)$ is tapered to some extent and it increases towards the end marginally. On the other hand the phase distribution is not symmetric. The difference patterns computed with the above data on spacing, amplitude and phase distribution is found to have deep null in the boresight. The patterns are not symmetric as the introduced phase is not symmetric. The patterns are found to exhibit high difference slope in the boresight which is an essential requirement in Radar applications. The number of lobes including minor one is found to increase with the increasing in the number of elements. The width of the difference slopes is small for large and vice versa for small arrays.

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