

Investigations on the Generation of Patterns for Marine Radar Applications

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Abstract

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 patterns are very useful for 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 sometimes it totally fails. In the applications, where the main beam is to point in desired direction and the sidelobes are to be suppressed to the desirable extent to reduce the ground clutter, the sum patterns with symmetric sidelobes are not suitable. The modified Elliott pattern is an excellent low-sidelobe distribution and has good efficiency. The modified Elliott pattern is itself a convenient illumination, that it can produce asymmetric patterns on both sides of the main beam. In the present work suitable amplitude and phase distributions are derived by using Fourier Transform technique to produce asymmetrical sum patterns. The weights of the each element are estimated at the source position. The source positions are found out according to Ishimaru spacing. These patterns are computed for small and large arrays. These patterns are useful in high resolution radars in point to point communication and also used in the marine radars.

Keywords: Asymmetric Sum Pattern, Ishimaru Spacing, Modified Elliott Pattern, Marine Radar Applications

1. Introduction

Antenna systems used in marine radar applications are required to produce sum and sidelobe suppressed type of difference patterns. These Sum and Difference patterns are used for radar range detection and angular tracking applications. The sum pattern having a single narrow main lobe in the desired direction surrounded by a set of undesired sidelobes. The narrow beamwidth improves the target resolution and low sidelobes around the main beam suppress EMI problems. As it is well known that a sum pattern produced from a uniform linear array which contains a main beam with first sidelobe level of -13.5dB^{1-5} .

In high angular resolution radars and for point to point communications it is essential to generate low sidelobe narrow beams. For the above case uniform linear

arrays are not suitable. In terms of excitation the uniform linear arrays are cost effective but it is not preferred due to the presence of high first sidelobe level of -13.5dB . The arrays must be appropriately designed to meet the radiation pattern characteristics. For this purpose, the tapered amplitude distributions find a better place than uniform ones⁶⁻¹⁰.

By using the Chebyshev polynomials Taylor developed a distribution to generate narrow beamwidth for a specified sidelobe level for an array. The designed array produces equal amplitude sidelobes which are undesirable for large arrays. The equivalent distribution peaks at the ends and the average value of the sidelobes limit the directivity to 3dB above the sidelobe level. Consequently, it will cause large edge peaking of the distribution, which requires a feed network containing a large ratio of coupling values. Mutual coupling between elements causes unwanted

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excitation for a large ratio of element amplitudes and loss of control over sidelobes. It is common practice to sample a Taylor distribution for large arrays. The distribution has limited edge peaking, so that large arrays can realize high gains.

Synthesis of line source aperture distribution yields radiation pattern containing a narrow main beam and symmetric sidelobes is reported by Dolph¹¹. According to Taylor¹², the Dolph-Chebyshev aperture distribution is physically unrealizable and it should be approximated for practicality. From Taylor's method of synthesis, it has been possible to maintain specified number of equal sidelobes on both sides of the main beam even in the entire visible region, with the far away sidelobes reducing in height gradually. The modification of the Taylor's distribution has been found to provide a design to control over levels of the sidelobes on both sides of the main beam. For such applications, Elliott has given a method of design of distribution function by modifying Taylor's distribution. Elliott considered a method of design which leads to the presence of high sidelobes in the unwanted regions while maintaining low sidelobes in the required regions¹³⁻³⁰.

In this work, a continuous line source is designed for the generation of optimized patterns. It is obvious that the continuous line source does not exist in practice and it is only of theoretical significance. However, the theory developed for continuous line source can easily be extended for discrete arrays. The continuous line source can be considered to be a discrete array with infinite number of radiating elements over a finite length. Though symmetric sum patterns are considered for several applications, asymmetric structure is essentially required for marine radar applications. In view of the above facts, the width of main beam and associated sidelobe levels decide suitability of the patterns for the required application. When the radiating elements are grouped in a linear array it is required to consider suitable spacing and also optimal excitation distribution.

2. Formulation

By using perturbation method for continuous line sources to convert symmetric sum patterns into asymmetric sum patterns. When the designed pattern shapes are complicated, then the designed aperture distribution also becomes complicated. To obtain the aperture distribution for a discrete array by sampling the continuous aperture distribution or by designing directly with the desired pattern.

$$E(\theta) = \sum_{n=1}^N A_n e^{in\beta d \sin \theta} \quad (1)$$

A_n is the n^{th} element complex current excitation

$$\beta = \frac{2\pi}{\lambda}$$

d is the spacing between the elements

θ is the angle measured from broadside.

It is also possible to make use of Taylor's method of synthesis for producing sum patterns which are symmetric in nature. It can be modified to produce asymmetrical patterns. For the generation of asymmetrical sum patterns, modified Taylor's method is proposed.

The Conventional Taylor's pattern can be expressed in the following form

$$E(z) = \frac{\sin \pi z}{z} \left[\frac{\prod_{n=1}^{\bar{n}-1} \left(1 - \frac{z^2}{\sigma^2 [A^2 + (n-0.5)^2]^{1/2}} \right)}{\prod_{n=1}^{\bar{n}-1} \left(1 - \frac{z^2}{n^2} \right)} \right] \quad (2)$$

Here $z = (2a/\lambda) \cos \theta$ with $2a$ the length of the aperture, ' θ ' is the angle measured from the end fire direction, λ is the wavelength and σ is dilation factor.

A is an adjustable real parameter such that $\cosh \pi A$ is the voltage sidelobe ratio and it is given by

$$A = \frac{1}{\pi} \cosh^{-1} r \quad (3)$$

Here r is the sidelobe ratio.

Thus σ is known as dilation factor or scaling factor which is equal to

$$\sigma = \frac{\bar{n}}{\sqrt{[A^2 + (\bar{n}-0.5)^2]}} \quad (4)$$

Here σ dilates the ideal space factor to move its zeros away from the main beam and it plays the transitional role of spacing the inner $\pm(\bar{n}-1)$ nulls so that they smoothly blend into the outer null sequence $\pm n$.

The modified Taylor's equation is expressed in the following form

$$E(z') = \frac{\sin \pi z'}{\pi z'} \cdot \frac{\prod_{n=1}^{\bar{n}_r-1} \left(1 - \frac{z'}{r_n}\right) \prod_{n=1}^{\bar{n}_l-1} \left(1 - \frac{z'}{l_n}\right)}{\prod_{n=1}^{\bar{n}_r-1} \left(1 - \frac{z'}{n}\right) \prod_{n=1}^{\bar{n}_l-1} \left(1 - \frac{z'}{n}\right)} \quad (5)$$

Here, the root positions of left and right side are

$$r_n = \sigma_r \left[A_r^2 + (n - 0.5)^2 \right]^{1/2}$$

$$l_n = \sigma_l \left[A_l^2 + (n - 0.5)^2 \right]^{1/2}$$

$$z' = \left(\frac{2a}{\lambda} \right) \cos \theta$$

2a is the length of the aperture,

θ is the angle measured from the broadside direction,

λ is the wavelength

Let the left and right sides of the pattern refer to the regions, for which $z < 0$ and $z > 0$ respectively.

$$\sigma_r = \frac{\bar{n}_r}{\sqrt{(A_r^2 + (\bar{n}_r - 0.5)^2)}}$$

$$\sigma_l = \frac{\bar{n}_l}{\sqrt{(A_l^2 + (\bar{n}_l - 0.5)^2)}}$$

Here,

$\bar{n}_r$ and $\bar{n}_l$ are the number of constraint sidelobes on the both sides of the main beam,

A_r and A_l Represents the measure of right and left side-lobe level,

$\cos \pi hA$ = Voltage sidelobe ratio,

$\cos \pi hA = b$ with, $20 \log_{10} b = \text{SLL}$

r_{sl} = Right sidelobe level,

l_{sl} = Left sidelobe level.

Where r and l show the right and left hand sides of the main lobe. It is obvious that, if $\bar{n}_r = \bar{n}_l = \bar{n}$ and $\sigma_r = \sigma_l$ and $A_r = A_l = \bar{A}$ then the above expression becomes that of standard Taylor's pattern.

Considering a Continuous line source with length '2L' extending from $-L$ to L Then the pattern is represented by radiation integral is given by

$$E(\theta) = \int_{-L}^L A(x) e^{j \frac{2\pi L}{\lambda} ux} dx \quad (6)$$

Here,

$$u = \sin \theta$$

$A(x)$ = Aperture distribution

Substitution of equation (6) in (7) gives

$$E(\theta) = \sum_{m=-\infty}^{\infty} b_m \int_{-L}^L e^{jmx \frac{x}{a}} e^{j \frac{2\pi L}{\lambda} x \left(\sin \theta - \beta \frac{\lambda}{2\pi L} \right)} dx$$

$$E(\theta) = \frac{a}{\pi} \sum_{m=-\infty}^{\infty} b_m \int_{-\pi}^{\pi} e^{jny} e^{juy} dy \quad (7)$$

$$\text{Here, } y = \frac{\pi x}{a}$$

Simplifying the above integral we get

$$E(m) = 2xb_m$$

If the aperture distribution is $A(x)$ represented by the transform of equation (5) is

$$A(x) = \frac{1}{2\pi} \sum_{m=-\bar{n}_l+1}^{\bar{n}_r-1} E(m) \exp(-imx) \quad x^2 \leq \pi^2$$

$$= 0 \quad x^2 \geq \pi^2$$

Here, m is an integer

$E(m)$ is shorthand notation for $E(z')$.

This expression represents variation of amplitude distribution along with the phase to produce the asymmetric patterns, where the actual aperture varies from $x=-a$ to $x=+a$.

The expression for radiation pattern of discrete array is given as

$$E(u) = \sum_{n=1}^N A(x_n) e^{j \left[\frac{2\pi L}{\lambda} ux_n + \phi(x_n) \right]} \quad (8)$$

Here, $A(x_n)$ = Amplitude distribution of the ' n^{th} ' element

$\phi(x_n)$ = Excitation phase distribution ' n^{th} ' element

$$\frac{2L}{\lambda} = \text{Normalized array length}$$

$u = \sin \theta$, θ is the angle of observer and broadside

$$X_n = \text{Spacing function} = \frac{2n - N - 1}{N}$$

N = Total number of elements

The spacing function used in the above expression is suggested by Ishimaru [27].

Table 1. Sidelobe levels for asymmetric 15/25 dB pattern

NUMBER OF ELEMENTS N	FSL (LEFT) (dB)	SSL (LEFT) (dB)	FSL (RIGHT) (dB)	SSL (RIGHT) (dB)
10	-16.61	-17.14	-23.78	-22.56
20	-16.65	-17.35	-24.50	-23.50
50	-16.78	-17.38	-24.54	-23.56
100	-16.79	-17.40	-24.58	-23.62
150	-16.80	-17.42	-24.62	-23.67
200	-16.80	-17.43	-24.68	-23.76

Table 2. Sidelobe levels for asymmetric 15/35dB pattern

NUMBER OF ELEMENTS N	FSL (LEFT) (dB)	SSL (LEFT) (dB)	FSL (RIGHT) (dB)	SSL (RIGHT) (dB)
10	-19.81	-21.59	-32.66	-32.56
20	-19.83	-22.30	-32.67	-32.58
50	-19.87	-22.38	-32.68	-32.62
100	-19.94	-22.43	-32.68	-32.67
200	-19.94	-22.50	-32.68	-32.71
200	-16.80	-17.43	-24.68	-23.76

Table 3. Amplitude and Phase distributions for N = 20 Elements

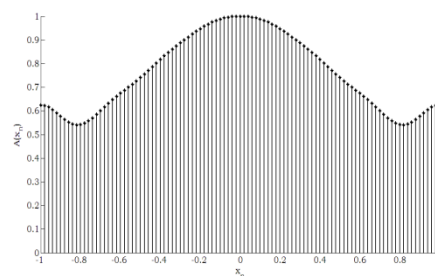
N	X_n	$A(X_n)$	$\phi(X_n)$
1	-0.9500	0.5224	0.0063
2	-0.8500	0.5299	0.0123
3	-0.7500	0.5628	0.0162
4	-0.6500	0.6215	0.0175
5	-0.5500	0.6877	0.0172
6	-0.4500	0.7572	0.0154
7	-0.3500	0.8297	0.0124
8	-0.2500	0.8963	0.0087
9	-0.1500	0.9513	0.0044
10	-0.0500	0.9877	0.0000
11	0.0500	0.9877	-0.0044
12	0.1500	0.9513	-0.0087
13	0.2500	0.8963	-0.0124
14	0.3500	0.8297	-0.0154
15	0.4500	0.7572	-0.0172
16	0.5500	0.6877	-0.0175
17	0.6500	0.6215	-0.0162
18	0.7500	0.5628	-0.0123
19	0.8500	0.5299	-0.0063
20	0.9500	0.5224	0.0063

3. Results

The current distributions are computed for different arrays containing different number of elements and they are presented in tables (3-4) for $N = 20$. Using the equation (8), the asymmetrical sum patterns of discrete arrays are computed. These patterns are computed numerically for 15/25 dB and 15/35 dB sidelobe levels and the sidelobe levels for 15/25 dB and 15/35 dB are presented in tables (1-2). The asymmetric sum patterns are presented in figures (1-14).

Table 4. Amplitude and Phase distributions for N = 20 elements

N	X_n	$A(X_n)$	$\phi(X_n)$
1	-0.9500	0.6250	0.0000
2	-0.8500	0.5763	0.0003
3	-0.7500	0.5414	0.1349
4	-0.6500	0.6008	0.2432
5	-0.5500	0.6740	0.2500
6	-0.4500	0.7404	0.2324
7	-0.3500	0.8181	0.1935
8	-0.2500	0.8873	0.1396
9	-0.1500	0.9467	0.0925
10	-0.0500	0.9880	0.0429
11	0.0500	0.9880	-0.0429
12	0.1500	0.9467	-0.0925
13	0.2500	0.8873	-0.1396
14	0.3500	0.8181	-0.1935
15	0.4500	0.7404	-0.2324
16	0.5500	0.6740	-0.2500
17	0.6500	0.6008	-0.2432
18	0.7500	0.5414	-0.1349
19	0.8500	0.5763	-0.0003
20	0.9500	0.6250	0.0000

**Figure 1.** Amplitude distribution for the desired pattern of 15/25 dB for N=100.

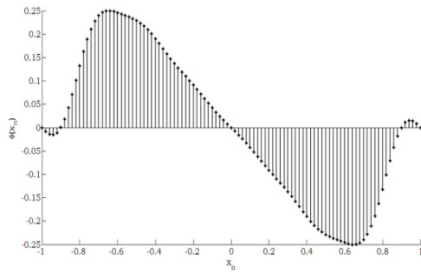


Figure 2. Phase distribution for the desired pattern of 15/25 dB for N=100.

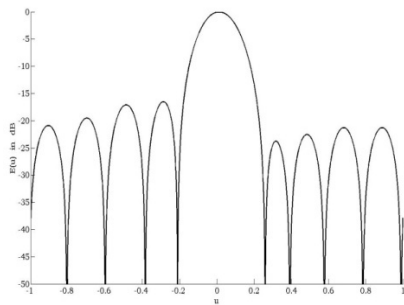


Figure 3. Asymmetric sum pattern for array of discrete elements for N=10.

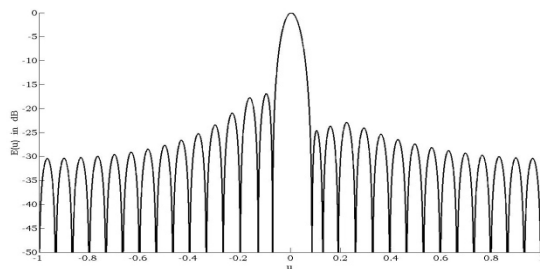


Figure 4. Asymmetric sum pattern for array of discrete elements for N=30.

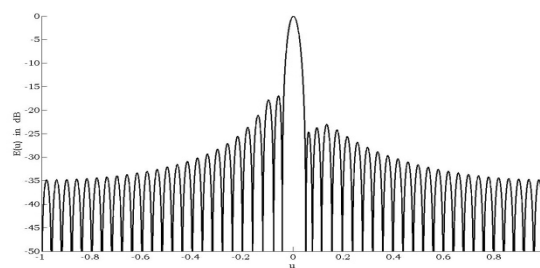


Figure 5. Asymmetric sum pattern for array of discrete elements for N=50.

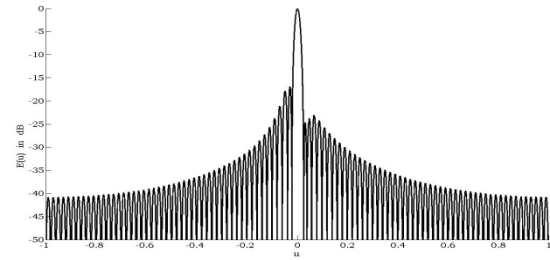


Figure 6. Asymmetric sum pattern for array of discrete elements for N=100.

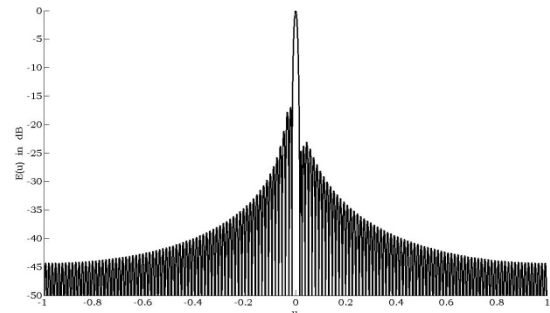


Figure 7. Asymmetric sum pattern for array of discrete elements for N=150.

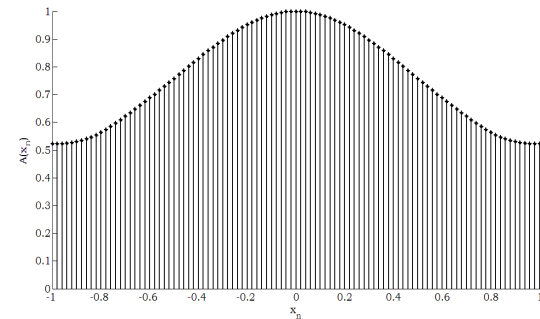


Figure 8. Amplitude distribution for the desired pattern of 15/35 dB for N=100.

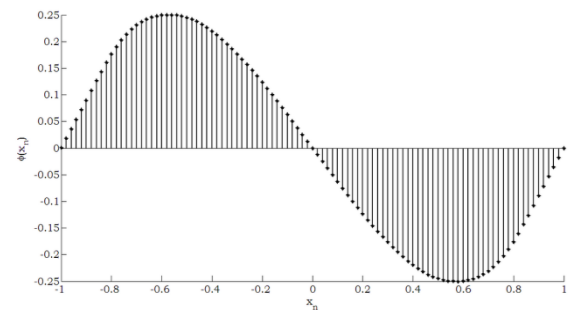


Figure 9. Phase distribution for the desired pattern of 15/35 dB for N=100.

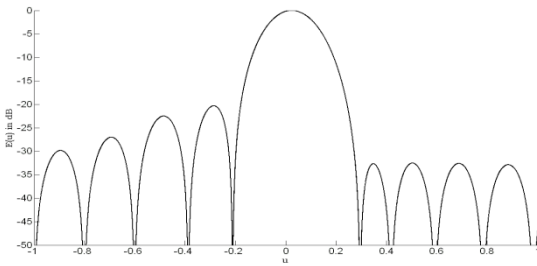


Figure 10. Asymmetric sum pattern for array of discrete elements for $N=10$.

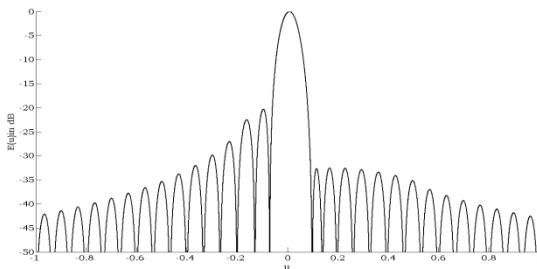


Figure 11. Asymmetric sum pattern for array of discrete elements for $N=30$.

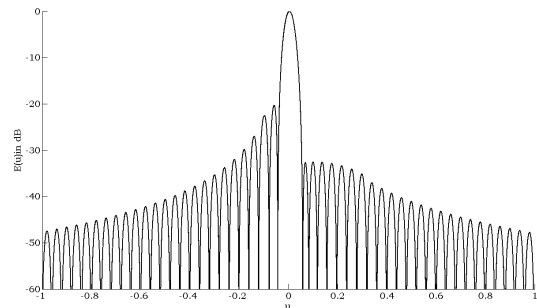


Figure 12. Asymmetric sum pattern for array of discrete elements for $N=50$.

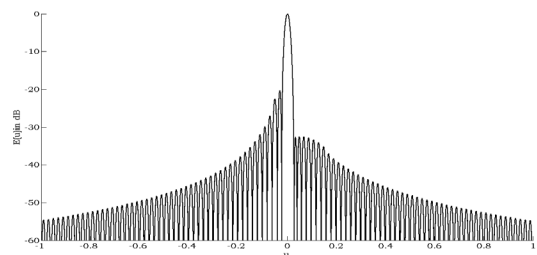


Figure 13. Asymmetric sum pattern for array of discrete elements for $N=100$.

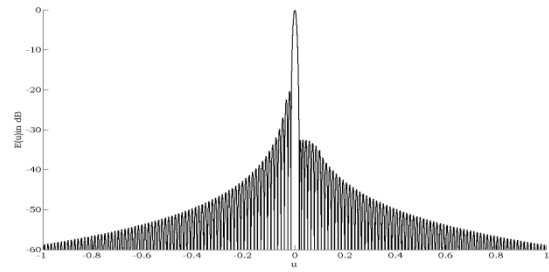


Figure 14. Asymmetric sum pattern for array of discrete elements for $N=150$.

4. Conclusion

The computed asymmetric pattern is found to have symmetric amplitude and the phase distribution is asymmetric. The realized asymmetric pattern consists of a central main beam with smoothly decaying asymmetric sidelobes. The sidelobes on one side of the main beam are at lower height when compared to those on other side. When the number of elements is increased in the array, the width of the main beam is reduced. The asymmetry of the pattern structure causes a small shift in the position of the main beam towards right (i.e. for 15/25 dB offset is 0.07, for 15/35 dB offset is 0.175). This can be compensated easily by slight change in the uniform progressive phase of the distribution. The realized asymmetric sum patterns for 15/25 dB and 15/35 dB are well controlled. The method can be extended for other type of arrays. These asymmetric sum patterns are used for marine radars where pitch and roll of the ship exists.

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