International Journal of Advances in Engineering Research http://www.ijaer.com

(IJAER) 2016, Vol. No. 11, Issue No. VI, June e-ISSN: 2231-5152, p-ISSN: 2454-1796

INVESTIGATIONS ON RADIATION BEAM SHAPING

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ABSTRACT

The conventional patterns like narrow beams are often used for point-to- point communications and also for high angular resolution radars. These patterns are not preferred for search and track as it takes considerable number of scans. When the target is moving very fast, it is difficult to follow narrow beam into sector beam and then scan them. This conversion is attempted in the present work by designing optimized phase distribution it by the narrow beams. It is more so with analog phase shifters. It is therefore, preferred to convert with specified beamwidth. Taylor's amplitude distribution is designed for SLL of -35dB. Phase function is evaluated using energy relations and stationary phase. Introducing amplitude along with phase function to the arrays, patterns are generated. They are presented in u-domain for both small and large arrays.

***Keywords**: Resolution; Phase shifters; beamwidth; array; patterns;*

INTRODUCTION

Modern radars demand high radiation beam scan rate, number of scans can be reduced by choosing wide flat beams or sector beams. The uniform excitation to the elements of the array, produce narrow beams with relatively high sidelobe levels. The narrow beams find application in point-to-point communications as well as high angular resolution radars. In these applications the beamwidth should be very small like an impulse and the first sidelobe level and closing sidelobe level should be considerably low. The high side lobe levels create EMI problems in the radar receivers. It is evident from the literature that the narrow beams are generated using several techniques like Standard distribution, Dolph Chebyshev technique, Woodword technique, Fourier Transform technique, Laplace Transform techniques and Taylor's technique etc.,

The Standard distributions include uniform, rectangular, triangular, circular, hyperbolic, parabolic, stair-step etc. However the standard distributions do not have much control on the sidelobe levels. On the otherhand, by the other techniques, it is possible to control sidelobe structure. It is well known that Taylor's method of design of line sources gives narrow beam with restricted side lobes. More over it is possible to have required number of side lobes at equal heights.

Uniform linear arrays are analyzed and designed by several authors [1-3]. They yield radiation patterns with one main lobe and symmetric side lobe levels. Radiation patterns are specified in terms of main beamwidth and sidelobe level. Array synthesis produces the specified patterns depending on the amplitude and phase of the excitations, spacing of the elements and type of the radiating elements in the array. Some of the synthesis methods include

Schelkunoff Polynomial method [4] produces a pattern with the nulls in the specified directions. The number of nulls and their locations are specified for the design of the array. Woodward method [5, 6] is useful for beam shaping and is used to find out the excitation function for a continuous line source and the excitation levels for a discrete array, but there is no control over the side lobe levels. Dolph-chebychev [7] method yields a radiation pattern containing one main beam and side lobes with the same level. Villenenue [8] reported a method of application of Taylor's method to linear arrays. Stern [9] also presented pattern synthesis techniques useful for arrays which are applicable to the arrays of uniformly spaced isotropic elements. Oten et al. [10] reported a numerical technique for the design of arrays containing radiating elements of their own radiation pattern. Wu et al. [11] described an iterative method for array synthesis, to produce patterns of linear arrays with arbitrary side lobes. The narrow beams obtained from array of radiators are used to achieve high gain, precise direction finding and high degree of resolution of complex targets. But the narrow beams require multi scans which is highly involved and time consuming. These difficulties can be overcome by providing sector beams or flat top beams which are broad basically. Sector beams can be produced from the arrays using several methods.

The modern search and track radars require flat beams or sector beams and also require digital scanning with high standards. Amplitude control method is used to produce sector beams for non scan applications, whereas phase control method can be used to produce sector beams for both scan and non scan applications. This is possible by phase only techniques. In this technique, amplitude distribution is designed satisfying specified beamwidth and side lobe levels. By fixing the amplitude distribution, the desired phase distribution is designed. Although there are several techniques to design such a phase like perturbation method, iteration method, and random method, an analytical technique involving the use of energy relations and phase only method is applied. This method is valid for reasonably large arrays. In the present work, the amplitude and phase distributions have been designed by above the technique and the realized patterns are presented in u- domain.

FORMULATION

The procedure for designing an array has been described by Taylor [3]. The expression for radiation pattern as given by Taylor is

$$E(u) = cosh\pi A \frac{sinu}{u} \prod_{n=1}^{\bar{n}-1} \left[\frac{1 - \dfrac{u^2}{\sigma^2 \pi^2 \left\{A^2 + (\bar{n} - \frac{1}{2})^2\right\}}}{(1 - \dfrac{u^2}{(\pi n)^2}} \right] \qquad (1)$$

Where 'n' is an integer which divides the radiation pattern into uniform sidelobe region surrounding the main beam and the region of decaying sidelobes.

Similarly

$$u = \frac{2L}{\lambda} sin\theta$$

2L = length of the array

θ = angle measured form the direction of maximum radiation.

'A' is an adjustable real parameter having the property that cosh (πA) is the side lobe ratio

$$\sigma = \frac{\bar{n}}{\left[A^2 + (\bar{n} - \frac{1}{2})^2\right]^{1/2}} \qquad (2)$$

From the expression (1) the aperture distribution of the array can be found by applying Woodward's method [5]. The aperture field distribution A(x) can be expressed as

$$A(x) = \sum_{n=-\alpha}^{\alpha} a_n e^{-jn\pi x}$$

Where

$x = z/L$ (z being the variable point on the aperture)

The pattern E(u) is related to A(x) by the expression

$$E(u) = \int_{-1}^{1} A(x) e^{jux} dx \qquad (3)$$

From expressions (2) and (3) we get

$$E(u) = \sum_{n=1}^{\alpha} a_n \frac{\sin(u - n\pi)}{u - n\pi} \qquad (4)$$

This gives

$$a_n = E_u | \quad u = n\pi \qquad (5)$$

Hence expression for E(u) reduces to

$$E(u) = \sum_{n=1}^{\alpha} E(n\pi) \frac{\sin(u - n\pi)}{u - n\pi} \qquad (6)$$

From expressions (2) and (5) the aperture function may be expressed as

$$A(x) = a_0 + \sum_{n=1}^{\alpha} 2a_n\, cosn\pi x$$

$$= E(u) + 2\sum_{n=1}^{\alpha} E(n\pi) cosn\pi x \qquad (7)$$

From the expression (6) it is found that

$E(n\pi) = 0 \; for \; n \geq \bar{n}$

For a stationary phase [13], we have

$$\frac{d}{dx}\left(ux + \psi(x)\right) = 0 \qquad (8)$$

This means

$$u = -\frac{d}{dx}\psi(x)$$

The energy relation between x and u domains are given by

$$\frac{L}{2\lambda}\int_{-\infty}^{\infty}|E(u)|^2\,du = \int_{-\infty}^{\infty}A^2(x)dx \qquad (9)$$

To obtain shaped beams matching with the desired one's the phase function should be optimized. This requires an appropriate amplitude distribution other than uniform. Taylor's method [12] is applied to find out an amplitude distribution for a specified sidelobe level and the desired radiation characteristics. The amplitude so obtained is fixed and the phase function is designed.

$$\frac{L}{2\lambda}\int_{-u_0/2}^{u_0/2}|E_d(u)|^2\,du = \int_{x_1}^{x_2}A^2(x)dx \qquad (10)$$

Where

$E_d(u) = K \; for \; -\frac{u_0}{2} \leq u \leq \frac{u_0}{2}$

u_0 = Field pulse width

A(x) = Tapered amplitude distribution

$$L.H.S = \frac{L}{2\lambda}\int_{-\frac{u_0}{2}}^{\frac{u_0}{2}}K^2\,du$$

$$i.e, \quad L.H.S = K^2\,\frac{L}{2\lambda}u_0$$

In the R.H.S. of the above expression, if x extends from -1 to 1 the constant K^2 (K_1) becomes

$$K_1 = \frac{2\lambda}{Lu_0}\int_{-1}^{1}A^2(x)dx \qquad (11)$$

The expression (10) is written as

$$\frac{L}{2\lambda}\int_{-\frac{u_0}{2}}^{u}|E_d(u)|^2\,du = \int_{-1}^{x}A^2(x)dx \qquad (12)$$

$$i.e, \quad \frac{L}{2\lambda}\int_{-\frac{u_0}{2}}^{u}K^2\,du = \int_{-1}^{x}A^2(x)dx \qquad (13)$$

$$u = \frac{2\lambda}{LK_1}\int_{-1}^{x}A^2(x)dx - \frac{u_0}{2} \qquad (14)$$

$But \; \psi(x) = -u$

$$Therefore \; \psi(x) = \frac{u_0}{2} - \frac{2\lambda}{LK_1}\int_{-1}^{x}A^2(x)dx \qquad (15)$$

Substituting the expression for K_1 in the expression of ψ(x), it becomes

$$\psi(x) = \frac{u_0}{2} - \frac{u_0\int_{-1}^{x}A^2(x)dx}{\int_{-1}^{1}A^2(x)dx} \qquad (16)$$

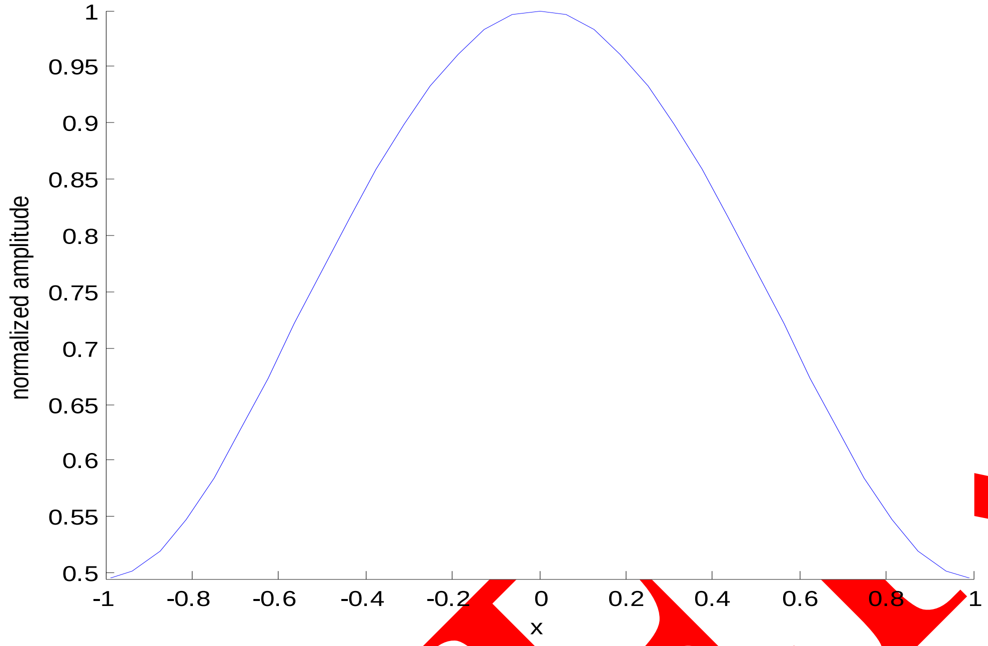

Fig. 1 Taylor's amplitude distribution for SLL = -35dB, $\bar{n}$ = 4

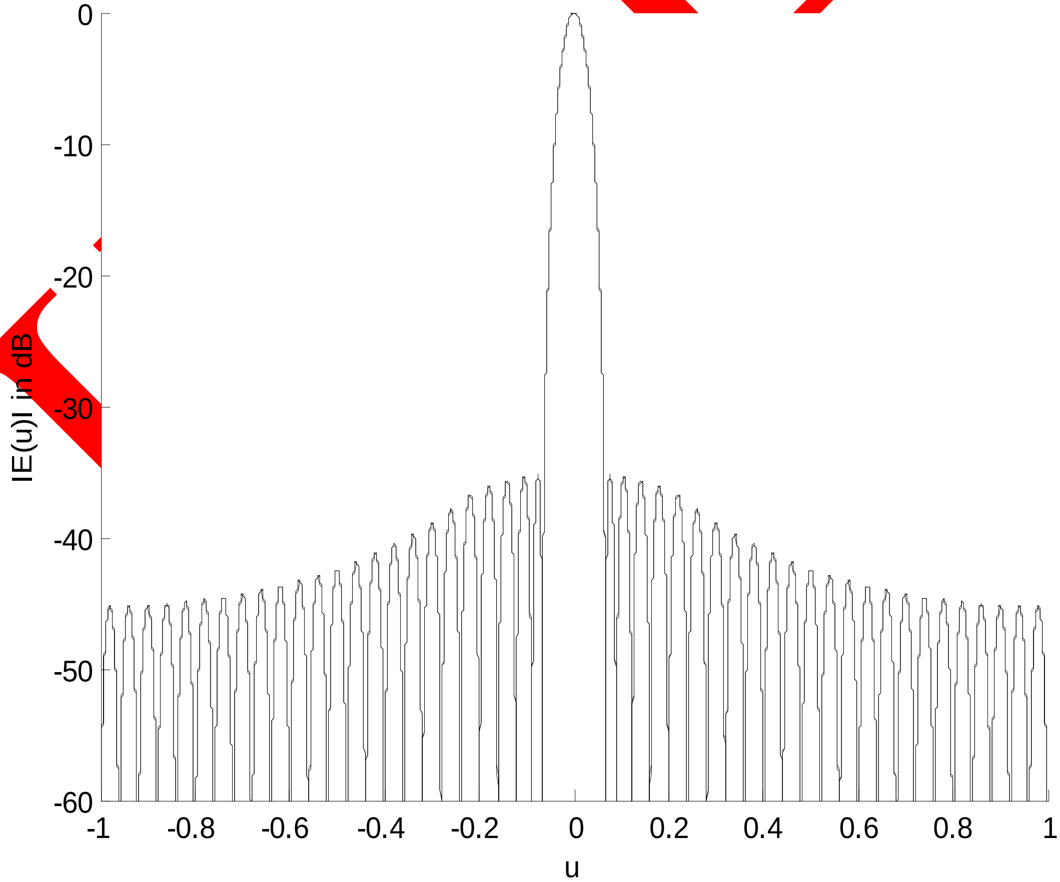

Fig. 2 Taylor's radiation pattern for SLL = -35dB $\bar{n}$ = 4

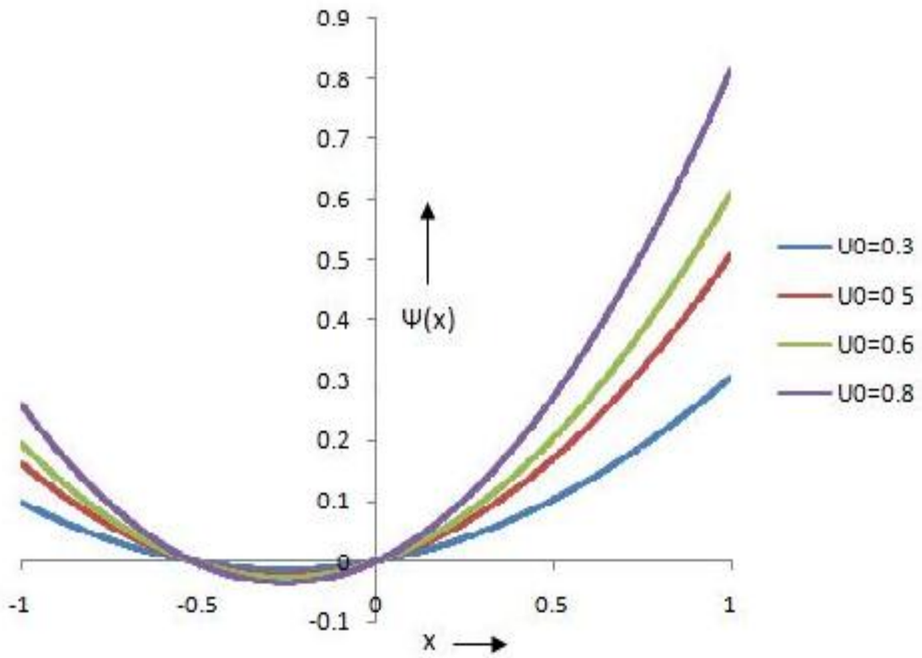

Fig.3 Phase distribution function using Taylor's amplitude function with SLL=-35dB, $\bar{n}$=4.

RADIATION PATTERNS FOR SECTOR BEAMS

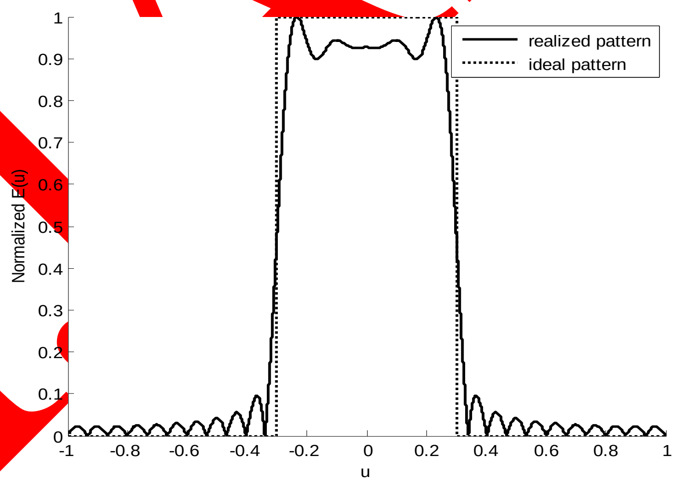

Fig.4. Sector beam for beamwidth=0.6, u_0=0.3, N=30

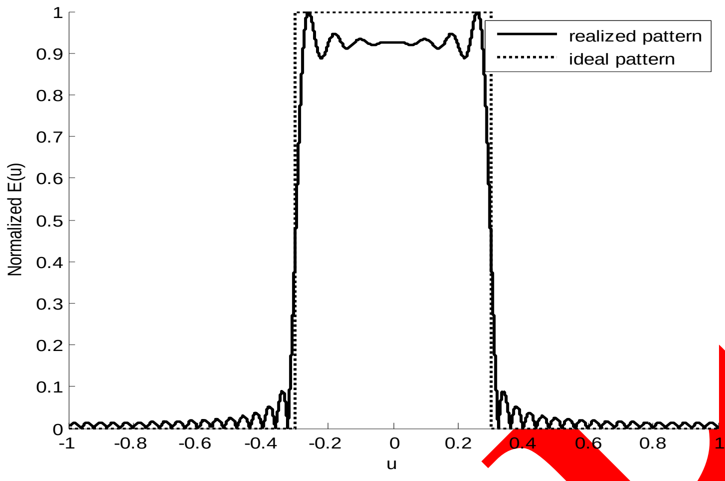

Fig.5 Sector beam for beamwidth=0.6, u_0=0.3, N=50

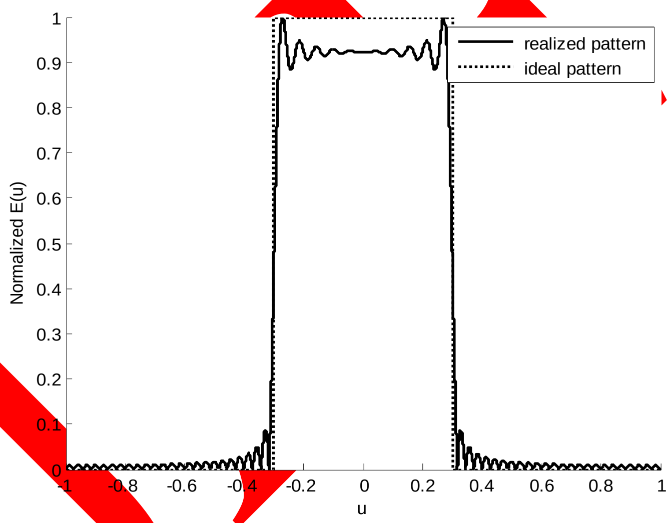

Fig.6 Sector beam for beamwidth=0.6, u_0=0.3, N=70

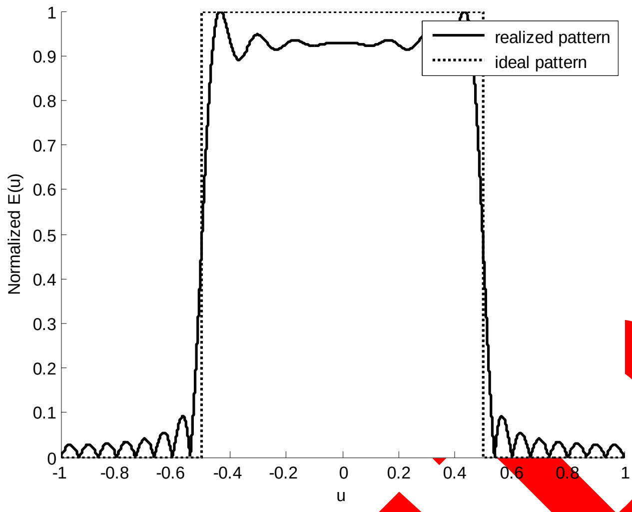

Fig.7 Sector beam for beamwidth=1.0, u_0=0.5, N=30

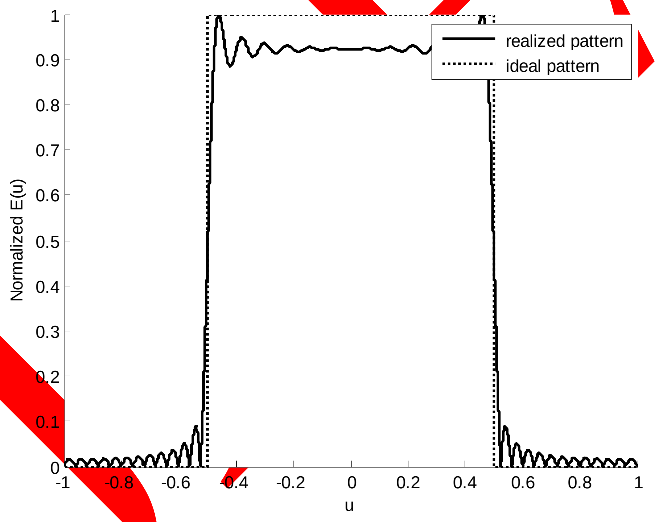

Fig.8 Sector beam for beamwidth=1.0, u_0=0.5, N=50

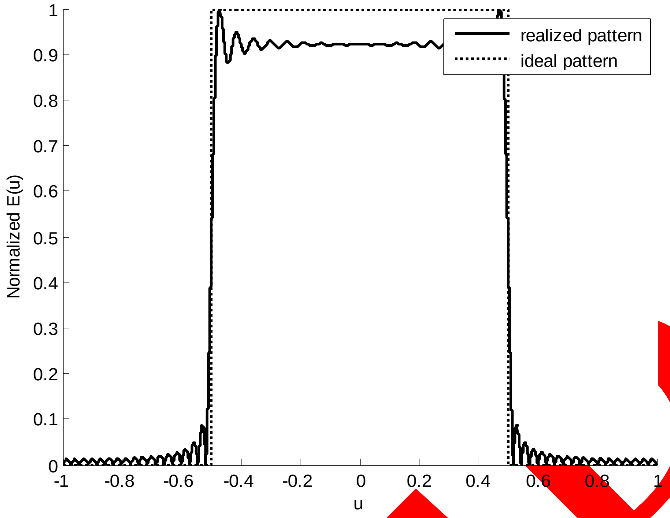

Fig.9 Sector beam for beamwidth=1.0, u_0=0.5, N=70

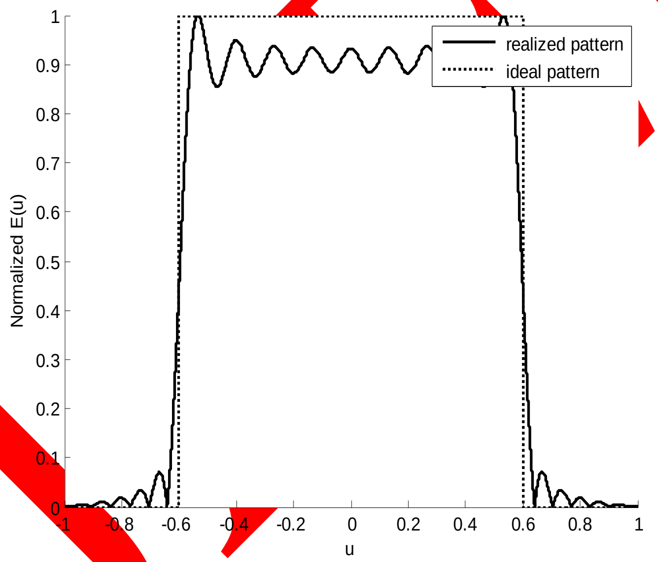

Fig.10 Sector beam for beamwidth=1.2, u_0=0.6, N=30

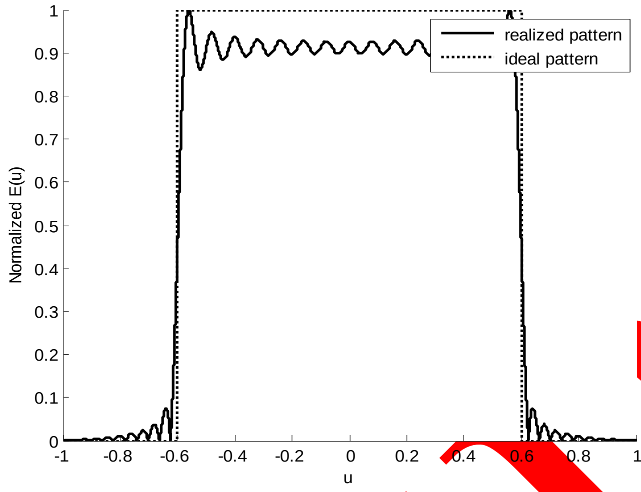

Fig.11 Sector beam for beamwidth=1.2, u_0=0.6, N=50

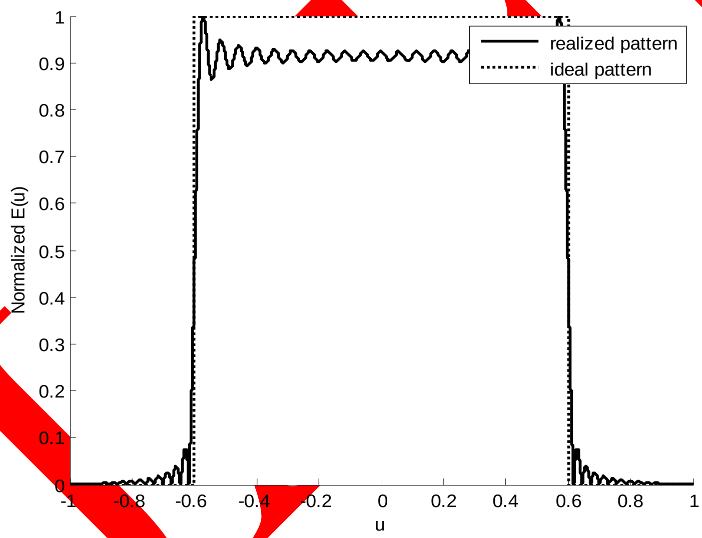

Fig.12 Sector beam for beamwidth=1.6, u_0=0.8, N=70

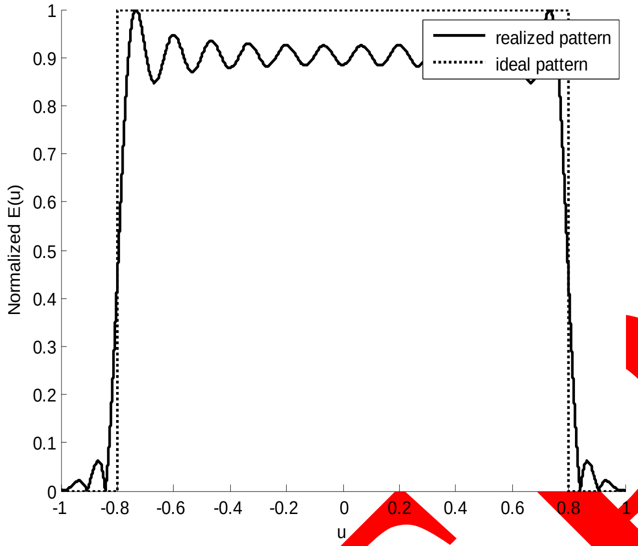

Fig.13 Sector beam for beamwidth=1.6, u_0=0.8, N=30

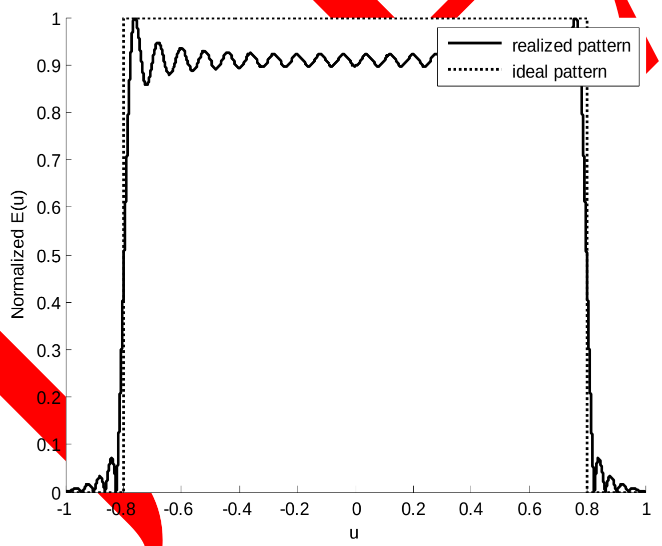

Fig.14 Sector beam for beamwidth=1.6, u_0=0.8, N=50

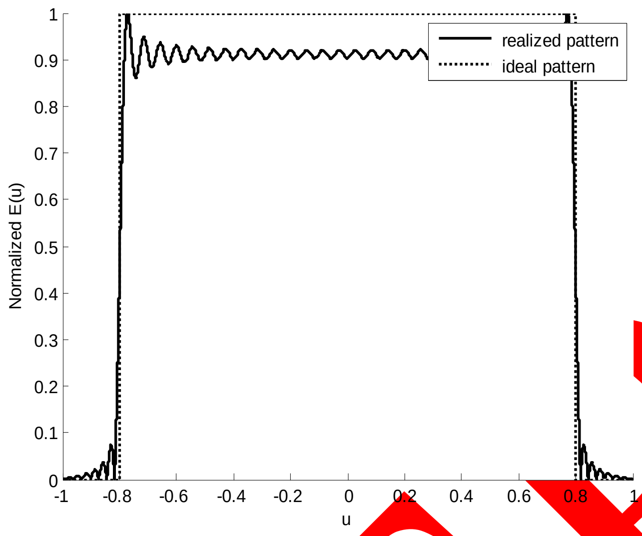

Fig.15 Sector beam for beamwidth=1.6, u_0=0.8, N=70

RESULTS

Applying Taylor's method, narrow beams are generated by introducing requisite discrete amplitude levels. The amplitude distribution is evaluated using the expressions given. The generation of the above patterns does not require a new additional phase. However, a well designed phase is obtained using the analytical reports. This approach consists of applications of fundamental concepts namely energy relations and stationary concept. The phase function is optimized with a given set of beam width and the number of elements. The resultant phase function is computed using the expression 16. Its variation as a function of 'x' for various beam widths is presented in figure3.

It is evident that there is a beam conversion from narrow to sector. The sector beams are presented in figures 4-15. The sector beams are compared with the ideal beams.

CONCLUSION

It is found from the results presented in this paper that, the sector beams have flat shape in trade-in region with no nulls in the trade-off. However, the patterns converted from narrow beams are also of sectored in nature with marginal ripples in the trade-in region and vary low side lobes in the trade-off. The ripple magnitude has become lower with increase in number of elements. The stationary concept is more valid to large arrays as the stationary point is more stable over rapid variation. The sum patterns obtained with Taylor's method is useful for point to point communication and sector beams are useful for search radars even with limited scans.

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