Optimized Cosecant Patterns from Arrays of Discrete Sources

M. Chandrasekhar
Research Scholar,
Dept. of Electronics and Communication Engineering, College of Engineering (A),
Andhra University, Visakhapatnam,
Andhra Pradesh, India-530 003

G.S.N. Raju
Professor,
Dept. of Electronics and Communication Engineering, College of Engineering (A),
Andhra University, Visakhapatnam,
Andhra Pradesh, India-530 003

ABSTRACT

In this paper, an aperture distribution for the synthesis of a specified radiation pattern is designed and it is applied to a linear array of discrete sources. The cosecant pattern is achieved by an optical antenna system with Luneburg lens.These patterns are produced using Fourier transform method. Computed cosecant patterns for different beamwidths are presented. These patterns are used in ground-mapping airborne radars and ground-based search radars applications.

Keywords

Luneburg lens antenna, cosecant beam, ripples, sidelobes, Fourier Transform method.

1. INTRODUCTION

Ground-mapping airborne radars and ground-based search radars typically use a variation of cosecant beam. When the beam is stationary in azimuth, an airplane flying across the beam is illuminated for a certain period [1-2] .This period is proportional to its distance from the antenna. Low intensity broadened beam is desired to increase the time of illumination on moving targets. If a fixed minimum illumination is required at a specified linear distance, a shaped beam called cosecant pattern is used.

Traditionally, shaped beams can be generated from well shaped reflector antennas and phased arrays. The parabolic reflector based antenna is most commonly used for this purpose. This was most popular and easy to fabricate. However, this arrangement has major disadvantages[3-4] when put into use, they are: 1.Difficult to realize large aperture due to mechanical constraints like back up structure and gears, 2.Blockage by the feed structure, 3.Slow in response as related to scanning in comparison to electronics scanning. Suffers reliability problem from shock and vibration, 4.Due to edging, angle of coupling and other mechanical disorders are common defects.

Phased arrays also used to generate the shaped beams. It consists of many phase shifters and power dividers, which can be expensive and induced RF losses. In such cases, an attractive and potential alternative is optical antenna system. Borgiotti [7] described a radiating structure to generate shaped beams which consists of a bootlace lens with linear outer and circular inner profiles resulting excellent scan performance over moderate frequency band. Basically, a Luneburg lens transforms a point source radiation into a plane wave by correcting the phase of the source. Since the main principle of the Luneburg lens is based on the geometric optics concepts [8] and it is operated in broad band frequency range.

In this paper, a technique for the synthesis of shaped beam patterns of an optical antenna system is described. Performance can be analyzed for large optical elements using simplified corrections for diffraction effects. A Luneburg lens is fabricated using the dielectric material such as polystyrene or polyethylene. These dielectric materials have dielectric losses. At higher frequencies, the dielectric loss will be greater [9-10].The effect of dielectric loss is less than effect of air gaps if low loss dielectric material is used for lens fabrication. However, the gain loss cannot be ignored at higher operating frequencies. Air-gaps between spherical shells may be unavoidable in the process of constructing the Luneburg lens with a finite number of spherical shells. The air -gaps affect the performance of the Luneburg lens antenna.

The Bootlace aperture lens used in this system is not the commonly used Abbe or Rotman lens [11-15]. Only broadside incidence will focus all the rays to a single point. At maximum scan all incoming rays are tangent to the lens. The portion of the lens which will be illuminated on receive must not overlap the feed array.

The cosecant shaped beams can be precisely produced from array antenna with an appropriate aperture distribution without additional phase. These beams are generated by amplitude only control method over the specified angular region. In this methodology, the amplitude distributions are tapered with oscillating amplitudes towards the ends of the array. An aperture distribution is proposed for generation of cosecant patterns for null to null beam widths of 0.3, 0.5and 0.8 with M=21elements.

The Fourier transform method is applied for realization purpose and this type of synthesized patterns has the least mean squared deviation from the desired pattern. The rest of this paper is organized as follows: Section 2 describes the mathematical formulation, the numerical simulation results are reported in Section 3 and finally the conclusion is given in Section 4.

2.FORMULATION

For desired cosecant beam represented by an expression of the form,

$$\begin{aligned} F(u) &= 1; \quad u_1 \le u \le u_2 \\ &= \frac{u_2}{u}, \quad u_2 \le u \le u_3 \\ &= 0, \quad \text{elsewhere} \end{aligned} \qquad (1)$$

The current aperture distribution can be obtained by Fourier transform formula,

$$A_n = \frac{1}{2}\int_{u_1}^{u_3} F(u)e^{-j2\pi z(n)u}\,du \qquad (2)$$

$$\text{Here, } z(n) = -\frac{MS}{2} + \frac{S}{2} + S.(n-1)$$

For pattern calculation, current aperture distribution is introduced in the expression given below,

$$E(u) = \left(\frac{kS\sqrt{1-u^2}}{2\pi}\right)^{1/2} \sum_{n=-N}^{N} A_n e^{jnkSu} \qquad (3)$$

For an odd number of elements $M = 2N+1$, the elements are

$n = 0, \pm 1, \pm 2, \ldots\ldots \pm N$

Here,

$u = \sin\theta$

A_n = aperture distribution,

S=element spacing,

n=zero for an element centred on the geometric focus.

3. SIMULATION RESULTS

The aperture distribution function is designed using Fourier Transform method. The radiation patterns are numerically evaluated by introducing the designed current aperture distribution functions in the equation (3). The aperture excitation levels are calculated using equation (2) for null to null beam widths of 0.3, 0.5, and 0.8 for M=21 elements, these are tabulated in tables (1, 2 and 3). Patterns are shown in figures (2, 4 and 6).

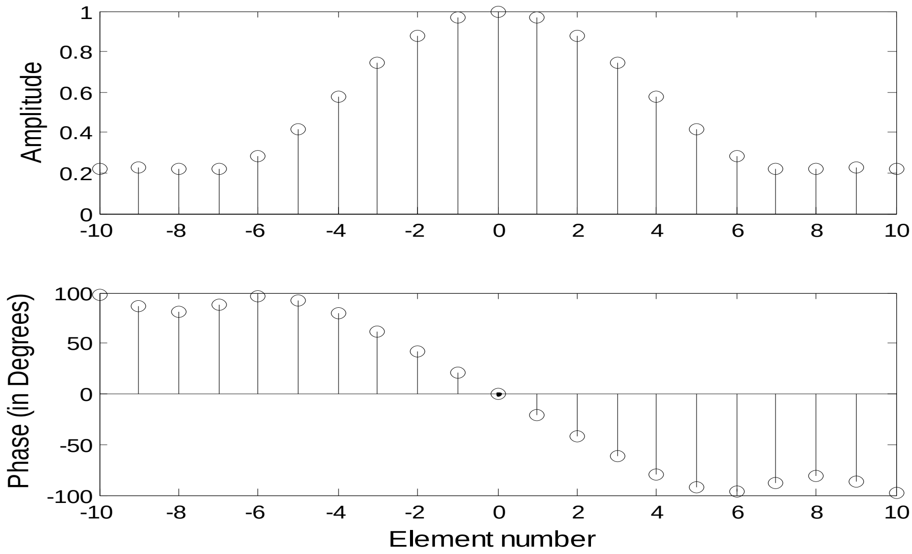

Fig.1.Aperture distribution of central subarray for N=21

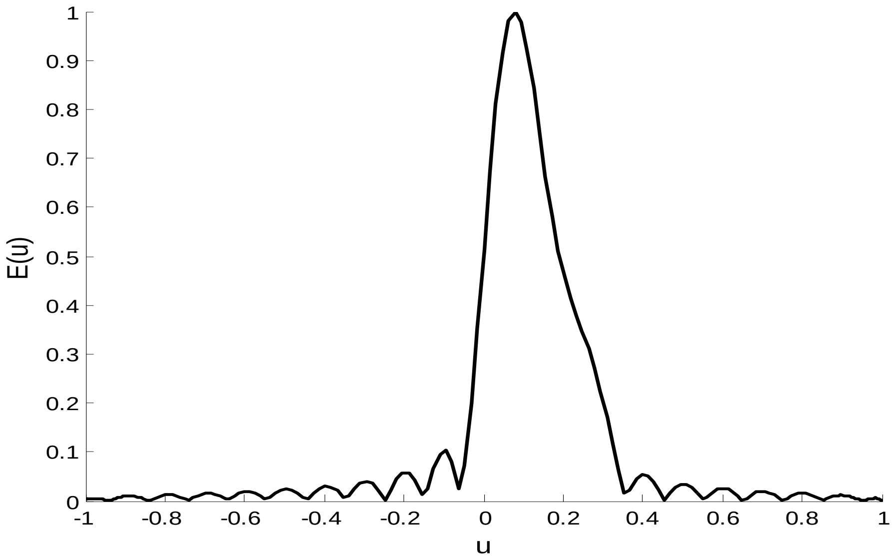

Fig.2.Radiation pattern of central subarray for N=21 and u_0 =0.3

Table.1 Excitation levels of 21 elements and u_0 =0.3 for cosecant pattern.

Element number	Amplitude level	Phase in degrees
-10	0.2210	97.8137
-9	0.2306	86.1232
-8	0.2188	81.2753
-7	0.2196	87.7593
-6	0.2850	95.8396
-5	0.4169	92.2133
-4	0.5800	79.4218
-3	0.7424	61.9882
-2	0.8784	42.2510
-1	0.9685	21.3673
0	1.0000	0
1	0.9685	-21.3673
2	0.8784	-42.2510
3	0.7424	-61.9882
4	0.5800	-79.4218
5	0.4169	-92.2133
6	0.2850	-95.8396
7	0.2196	-87.7593
8	0.2188	-81.2753
9	0.2306	-86.1232
10	0.2210	-97.8137

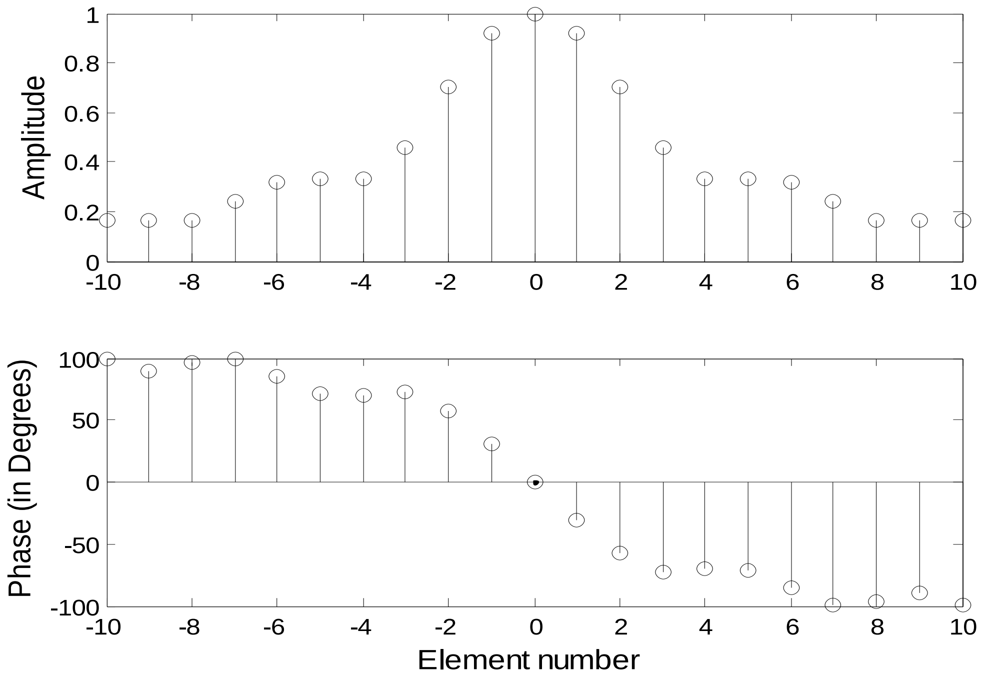

Fig.3.Aperture distribution of central subarray for N=21

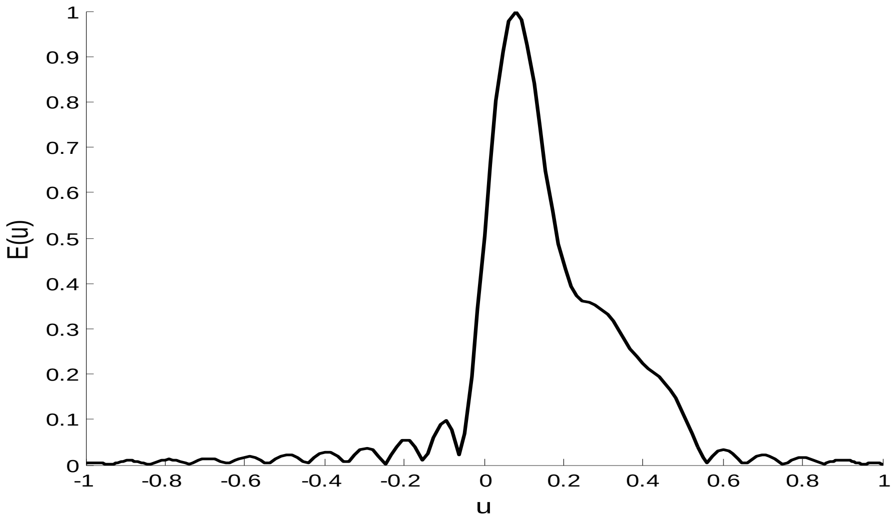

Fig.4.Radiation pattern of central subarray for N=21 and u_0 =0.5

Table.2 Excitation levels of 21 elements and u_0 =0.5 for cosecant pattern.

Element number	Amplitude level	Phase in degrees
-10	0.1626	99.4535
-9	0.1612	89.7141
-8	0.1662	97.1324
-7	0.2380	98.9841
-6	0.3150	85.0649
-5	0.3337	70.6603
-4	0.3331	69.9307
-3	0.4608	72.7779
-2	0.7028	57.1866
-1	0.9166	30.5037
0	1.0000	0
1	0.9166	-30.5037
2	0.7028	-57.1866
3	0.4608	-72.7779
4	0.3331	-69.9307
5	0.3337	-70.6603
6	0.3150	-85.0649
7	0.2380	-98.9841
8	0.1662	-97.1324
9	0.1612	-89.7141
10	0.1626	-99.4535

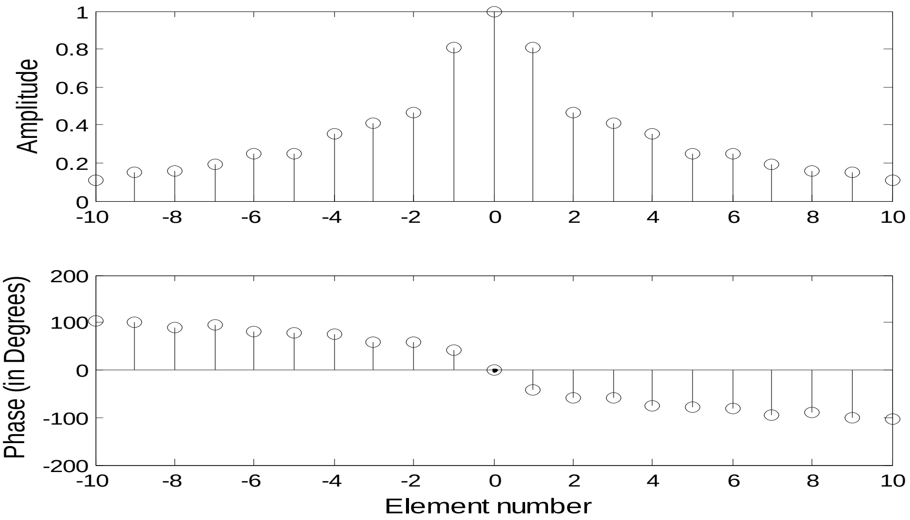

Fig.5 Aperture distribution of central subarray for N=21

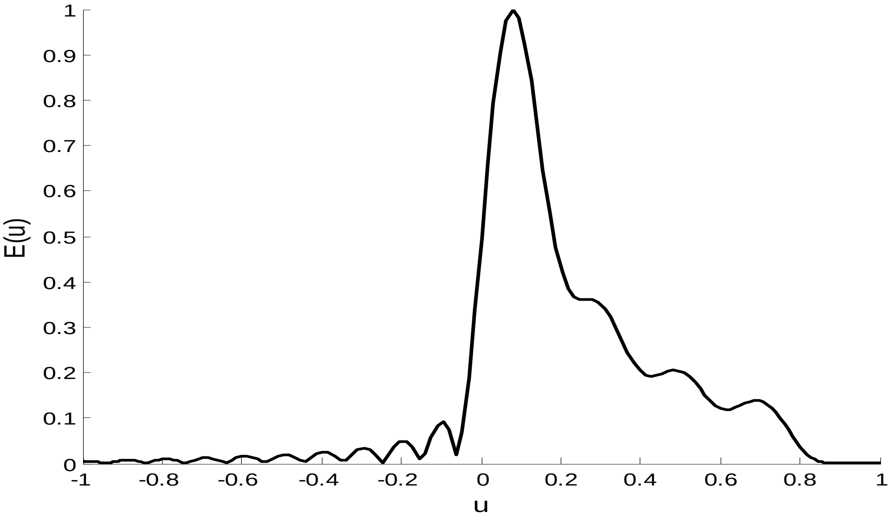

Fig.6 Radiation pattern of central subarray for N=21 and u_0 =0.8

Table.3 Excitation levels of 21 elements and u_0 =0.8 for cosecant pattern.

Element number	Amplitude level	Phase in degrees
-10	0.1054	103.3993
-9	0.1531	101.2881
-8	0.1595	90.1648
-7	0.1930	95.9999
-6	0.2509	82.3961
-5	0.2515	78.1893
-4	0.3533	75.5747
-3	0.4064	57.5334

-2	0.4659	59.3397
-1	0.8046	40.9835
0	1.0000	0
1	0.8046	-40.9835
2	0.4659	-59.3397
3	0.4064	-57.5334
4	0.3533	-75.5747
5	0.2515	-78.1893
6	0.2509	-82.3961
7	0.1930	-95.9999
8	0.1595	-90.1648
9	0.1531	-101.2881
10	0.1054	-103.3993

4. CONCLUSION

Cosecant beam radiation patterns are generated for null to null beam widths of 0.3, 0.5and 0.8 of M=21elements. These beams are generated by amplitude only control method over the specified angular region. In this methodology, the amplitude distributions are tapered with oscillating amplitudes towards the ends of the array.

It is clear from the patterns obtained using the Fourier transform method that cosecant beams are found to have considerable ripples in the trade-in region and faraway side lobes are fully controlled in the trade-off region. As the sidelobes are fully controlled, they are useful for EMC applications. Moreover, the Fourier transform synthesized patterns have the least mean squared deviation from the desired pattern and the patterns are optimal in case of larger arrays. These patterns are used in ground-mapping airborne radars and ground-based search radars applications.

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