

Comparative Studies on Generation of Stair Step Radiation Patterns

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Abstract: Antenna array synthesis is usually done by controlling amplitude and phase levels or element spacing functions of the array to get the desired characteristics of the radiation pattern. In this paper, design of equispaced linear array of dipoles is presented. A new amplitude distribution is proposed for generation of stair step patterns with zero phase. These patterns are produced from dipole elements using Fourier transform method. The goal of the work is to compensate mutual coupling effects of a linear dipole array. The computed patterns are compared with those of the isotropic elements for different number of elements. The deviation in the patterns of array of isotropic radiators and the array of practical element is found to be minimum. These patterns are used to identify multiple targets moving in different altitudes and different angular regions.

Keywords: Luneburg Lens antenna, Geometrical optics, Dipole elements, Broad beam, Ripples, Fourier Transform method.

I. Introduction

In recent years, there has been considerable interest in designing antenna arrays with broad beam patterns. The aim of the antenna synthesis is to find the appropriate excitation coefficients of the elements for the generation of desired radiation pattern [1]. To get desired radiation pattern of the antenna, different types of synthesis methods are used depending on their usability and the convenience in the situation under consideration.

It's the geometry of the aperture and the distribution of the phase and amplitude of excitation across the aperture mainly govern the final pattern of the antenna. In arrays the element pattern is also a controlling parameter [2-3] and the number of elements within a specified aperture has a direct influence on the final pattern.

Desired beam shape can be generated from well shaped reflector antennas. The principle involved in beam shaping can be easily explained in terms of geometrical optics. Its advantage is simplicity in design and fabrication[4-6]. However, it is able to do only very limited beam scanning and wide beam scanning is mostly achieved by mechanical rotation, which needs a powerful motor when the reflector is large and it is expensive. In such case, an attractive alternative is to use a Luneburg lens which offers scan capability over a very wide angular range.

It has been used in a variety of antenna and scattering applications. In antenna applications, the main advantages of lenses are the ability to form simultaneous beams in various directions with equal gain and their broad band behaviour. Recent advances in material technology have enabled the manufacturing of large light weight lenses with the desired electrical permittivity. Moreover, it has lower reflection at the lens surface.

Geometrical optics predicts 100percent efficiency regardless of the feed array size. The actual feed size can be determined from simple diffraction concepts[7]. The geometrical optics aperture distribution is a useful distribution with no spill over. The spill over results in the loss of gain, phase error and amplitude ripples.

Giorgio .V. Borgiotti [8] 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. Luneburg lens antennas are used in multiple beam scanning applications. 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[9] and it is operated in broad band frequency range. Also, the spherical symmetry of the lens allows multiple beams scanning by mean of an array of feeds placed around the lens surface. Arrays with sector patterns can be used as feeds in reflector or lens antennas for providing high aperture efficiency with minimum spill over. The scatter field of the lens antenna is determined by using an analytic technique is based on the Green's function of the multi-layered spherical shell. Due to these excellent features, lens antennas are used more extensively in radars, military and satellite communications.

The aim of these studies has been the reduction of the number of costly control elements, phase shifters or variable power dividers as compared to the number in a phased array designed in a conventional way. Stochastic methods, such as GA, PSO, Firefly and DE which can escape from local optimization solutions. The stochastic methods can solve large optimization problems, but the computation time is huge and will grow rapidly with the problem size. In this paper, Fourier transform method is applied for realization of stair - step pattern [10]. This method can solve large array synthesis with much less time compared with the stochastic methods.

II. Analysis

In this paper, the radiating elements in the array of present interest are considered to be point sources and dipole elements, optical system is described which satisfies the conditions

- a) Aperture efficiency = 100 % for all scan angles
- b) Number of active elements = Number of beam widths of scan

and provides nearly ideal performance comparable to a standard constrained system. The geometry is described in terms of geometric optics where it is shown that a generalized Luneburg Lens is a necessary element[9] in the optical system .Performance can be analyzed for large optical elements using simplified corrections for diffraction effects.

The Luneburg Lens is a spherically symmetric delay-type lens formed of a dielectric with index of refraction ‘n’ which varies as a function of radius, as given by

$$n = \sqrt{\epsilon_r} = \sqrt{2 - \left(\frac{r}{R}\right)^2} \tag{1}$$

Here, r=radial distance from centre of sphere and
R=radius of the sphere.

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 .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 [11].

Consider a circular lens shown in fig1. Its dielectric constant depends on radial distance. Assume that this lens acts as corrective lens of the system. Also assume that the lens bends the rays coming from a point source placed on the lens surface at radial distance ‘d’ to another point at distance D>d. The source, centre of the lens and focal point lie along same straight line .If the above focal condition is true for line pair of points then all points on the circular lens surface will image to unique points on the image surface,radiusD.The distribution of these image sources will be a stretched replica of the source distribution .These sources on the image circle are again mapped to a linear aperture without distortion by means of equal line lengths connecting all point pairs whose arc lengths measured from the line of symmetry are the same.

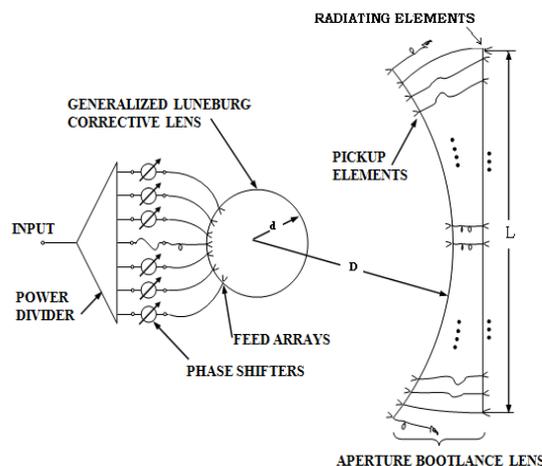


Fig1. Major Components of Optical Antenna System[9].

The Bootlace aperture lens used in this system is not the commonly used Abbe or Rotman lens[12]. Only broadside incidence will focus all the rays to a single point. At maximum scan all incoming rays are tangent to the lens. This gives maximum scan angle and usable D/L ratio. The portion of the lens which will be illuminated on receive must not overlap the feed array.

In general, there exist diffraction effects. These can be obtained by adopting the sub array view point and by applying a mixture of geometrical optics and diffraction theory to estimate the aperture distribution [13]. A spacing of $\lambda/2$ of radiating elements are assumed to be matched for all angles and to have a cosine type of element pattern as in the case of large array. A similar array with spacing S is placed on the inner feed of the aperture lens. One element in the feed array is excited with unit power. The distribution in a reference circle of radius (D-d) centered on the receiving element located on the geometrical focus is obtained using geometrical optics. It is used to generate stair step type of beams. It is well known that the stair step types of beams are widely required to detect multi level targets. This method is also extend for practical radiating elements, dipoles of 21 and 61 elements.

Antenna array generally consists of identical antennas. This is not necessary but it is more practical, Simple and convenient for design and fabrication because each identical antenna will have identical radiation characteristics and impedances [14]. The antenna elements may be any type wire, dipole, loop, aperture etc.

Dipoles of finite length are widely used as simple antennas and as radiating elements in arrays. Dipole is antenna composed of simple radiating element split into two sections and fed into the split. Not all dipoles are split and fed in the center because currents can be excited on it electromagnetically or it can be center fed. For a short dipole the length is less than $\lambda/2$ and the self-impedance is generally capacitive. For half wave dipole the length is generally $\lambda/2$ and the self impedance of 40 - 70 ohms with no reactive component and provides good match for coaxial cables [15-16]. The self-impedance of dipole varies with its length and height above the ground. It is possible to use a center fed dipole over a wide range of frequencies by feeding it with low pass transmission line and providing impedance matching. The significant advantage as regards bandwidth with respect to pattern quality in the presence of a backing ground plane and mainly concerned with the mechanisms contributing to the scattering and the resulting fields and their patterns. The radiation pattern of dipole array is computed by taking element pattern of dipole into account.

III. Formulation

Case: I

For sector beam represented by an expression of the form

$$F(u)=1, \quad -u_0 \leq u \leq u_0$$

$$=0, \quad \text{otherwise} \tag{2}$$

For an odd number of elements $N=2M+1$, the normalised excitation coefficients can be obtained by the Fourier formula .

$$A_n = \frac{1}{2} \int_{-u_0}^{u_0} E(u) e^{-jn\pi u} du \tag{3}$$

In the present work, the stair –step pattern represented by an expression of the form.

For three stair –steps

$$F(u) = \frac{1}{3}, \quad \frac{-3}{3} \leq u \leq \frac{-2}{3}$$

$$= \frac{2}{3}, \quad \frac{-2}{3} \leq u \leq \frac{-1}{3}$$

$$= \frac{3}{3}, \quad \frac{-1}{3} \leq u \leq \frac{1}{3}$$

$$= \frac{2}{3}, \quad \frac{1}{3} \leq u \leq \frac{2}{3}$$

$$= \frac{1}{3}, \quad \frac{2}{3} \leq u \leq \frac{3}{3}$$

For four stair-steps

$$\begin{aligned}
 F(u) &= \frac{1}{4}, & -4 \leq u \leq -3 \\
 &= \frac{2}{4}, & -3 \leq u \leq -2 \\
 &= \frac{3}{4}, & -2 \leq u \leq -1 \\
 &= \frac{4}{4}, & -1 \leq u \leq 1 \\
 &= \frac{3}{4}, & 1 \leq u \leq 2 \\
 &= \frac{2}{4}, & 2 \leq u \leq 3 \\
 &= \frac{1}{4}, & 3 \leq u \leq 4
 \end{aligned}$$

For five stair-steps

$$\begin{aligned}
 F(u) &= \frac{1}{5}, & -5 \leq u \leq -4 \\
 &= \frac{2}{5}, & -4 \leq u \leq -3 \\
 &= \frac{3}{5}, & -3 \leq u \leq -2 \\
 &= \frac{4}{5}, & -2 \leq u \leq -1 \\
 &= \frac{5}{5}, & -1 \leq u \leq 1 \\
 &= \frac{4}{5}, & 1 \leq u \leq 2 \\
 &= \frac{3}{5}, & 2 \leq u \leq 3 \\
 &= \frac{2}{5}, & 3 \leq u \leq 4 \\
 &= \frac{1}{5}, & 4 \leq u \leq 5
 \end{aligned}$$

For three stair-steps

$$A_n = \frac{1}{2} \left[\int_{\frac{-3}{3}}^{\frac{-2}{3}} \frac{1}{3} e^{-jn\pi u} du + \int_{\frac{-2}{3}}^{\frac{-1}{3}} \frac{2}{3} e^{-jn\pi u} du + \int_{\frac{-1}{3}}^{\frac{1}{3}} \frac{3}{3} e^{-jn\pi u} du + \int_{\frac{1}{3}}^{\frac{2}{3}} \frac{2}{3} e^{-jn\pi u} du + \int_{\frac{2}{3}}^{\frac{3}{3}} \frac{1}{3} e^{-jn\pi u} du \right]$$

After integration and simplification, we get

$$A_n = \frac{-2}{9} \frac{\sin(n\pi \frac{2}{3})}{n\pi \frac{2}{3}} + \frac{1}{3} \frac{\sin(n\pi)}{n\pi} - \frac{2}{9} \frac{\sin(n\pi \frac{1}{3})}{n\pi \frac{1}{3}} + \frac{4}{9} \frac{\sin(n\pi \frac{2}{3})}{n\pi \frac{2}{3}} + \frac{1}{3} \frac{\sin(n\pi \frac{1}{3})}{n\pi \frac{1}{3}} \tag{4}$$

For four stair-steps

$$A_n = \frac{1}{2} \left[\int_{-\frac{3}{4}}^{\frac{-3}{4}} \frac{1}{4} e^{-jn\pi u} du + \int_{\frac{-3}{4}}^{\frac{-2}{4}} \frac{2}{4} e^{-jn\pi u} du + \int_{\frac{-2}{4}}^{\frac{-1}{4}} \frac{3}{4} e^{-jn\pi u} du + \int_{\frac{-1}{4}}^{\frac{1}{4}} \frac{4}{4} e^{-jn\pi u} du + \int_{\frac{1}{4}}^{\frac{2}{4}} \frac{3}{4} e^{-jn\pi u} du + \int_{\frac{2}{4}}^{\frac{3}{4}} \frac{2}{4} e^{-jn\pi u} du + \int_{\frac{3}{4}}^{\frac{4}{4}} \frac{1}{4} e^{-jn\pi u} du \right]$$

After integration and simplification, we get

$$A_n = \frac{-3}{16} \frac{\sin(n\pi \frac{3}{4})}{n\pi \frac{3}{4}} + \frac{1}{4} \frac{\sin(n\pi)}{n\pi} - \frac{4}{16} \frac{\sin(n\pi \frac{2}{4})}{n\pi \frac{2}{4}} + \frac{6}{16} \frac{\sin(n\pi \frac{3}{4})}{n\pi \frac{3}{4}} - \frac{3}{16} \frac{\sin(n\pi \frac{1}{4})}{n\pi \frac{1}{4}} + \frac{6}{16} \frac{\sin(n\pi \frac{2}{4})}{n\pi \frac{2}{4}} + \frac{1}{4} \frac{\sin(n\pi \frac{1}{4})}{n\pi \frac{1}{4}} \tag{5}$$

For five stair – steps,

$$A_n = \frac{1}{2} \left[\int_{-\frac{4}{5}}^{\frac{-4}{5}} \frac{1}{5} e^{-jn\pi u} du + \int_{\frac{-4}{5}}^{\frac{-3}{5}} \frac{2}{5} e^{-jn\pi u} du + \int_{\frac{-3}{5}}^{\frac{-2}{5}} \frac{3}{5} e^{-jn\pi u} du + \int_{\frac{-2}{5}}^{\frac{-1}{5}} \frac{4}{5} e^{-jn\pi u} du + \int_{\frac{-1}{5}}^{\frac{1}{5}} \frac{5}{5} e^{-jn\pi u} du + \int_{\frac{1}{5}}^{\frac{2}{5}} \frac{4}{5} e^{-jn\pi u} du + \int_{\frac{2}{5}}^{\frac{3}{5}} \frac{3}{5} e^{-jn\pi u} du + \int_{\frac{3}{5}}^{\frac{4}{5}} \frac{2}{5} e^{-jn\pi u} du + \int_{\frac{4}{5}}^{\frac{5}{5}} \frac{1}{5} e^{-jn\pi u} du \right]$$

After integration and simplification, we get

$$A_n = \frac{-4}{25} \frac{\sin(n\pi \frac{4}{5})}{n\pi \frac{4}{5}} + \frac{1}{5} \frac{\sin(n\pi)}{n\pi} - \frac{6}{25} \frac{\sin(n\pi \frac{3}{5})}{n\pi \frac{3}{5}} + \frac{8}{25} \frac{\sin(n\pi \frac{4}{5})}{n\pi \frac{4}{5}} - \frac{6}{25} \frac{\sin(n\pi \frac{2}{5})}{n\pi \frac{2}{5}} + \frac{9}{25} \frac{\sin(n\pi \frac{3}{5})}{n\pi \frac{3}{5}} - \frac{4}{25} \frac{\sin(n\pi \frac{1}{5})}{n\pi \frac{1}{5}} + \frac{8}{25} \frac{\sin(n\pi \frac{2}{5})}{n\pi \frac{2}{5}} + \frac{1}{25} \frac{\sin(n\pi \frac{1}{5})}{n\pi \frac{1}{5}} \tag{6}$$

When the radiating elements are isotropic in nature, the transmit pattern E (u) of a distribution A_n on the inner array of the aperture lens is given by

$$E(u) = \left(\frac{ks}{2\pi} \sqrt{1-u^2} \right) \frac{1}{2} \sum_n A_n e^{jkn\pi su} \tag{7}$$

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

$$x_n = ns, n = 0, \pm 1, \pm 2, \dots, \pm N$$

Here,

$$u = \sin\theta$$

A_n = Amplitude excitation of nth element,

s=element spacing,

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

Case: II

The normalized radiation field of half wave dipole is given by

$$E_p = \left[\frac{\cos\left(\frac{kL}{2}\cos\theta\right) - \cos\left(\frac{kL}{2}\right)}{\sin\theta} \right] \tag{8}$$

For the non-isotropic radiating element, the resultant pattern is given by

$$E(u) = E_p \times \left(\frac{ks}{2\pi} \sqrt{1-u^2} \right)^{\frac{1}{2}} \sum_n A_n e^{jkn\pi u} \tag{9}$$

Here,

E_p = Element Pattern.

IV. Simulation Result

Using the equations (4-6), the variation of source distribution is presented in figures (2,4,6,8,10 and 12) and corresponding excitation tables are given for 21 and 61 elements. Introducing the excitation so obtained, radiation patterns are numerically computed using MATLAB software for array of dipoles and isotropic elements and which are compared shown in figures(3,5,7,9,11 and 13).

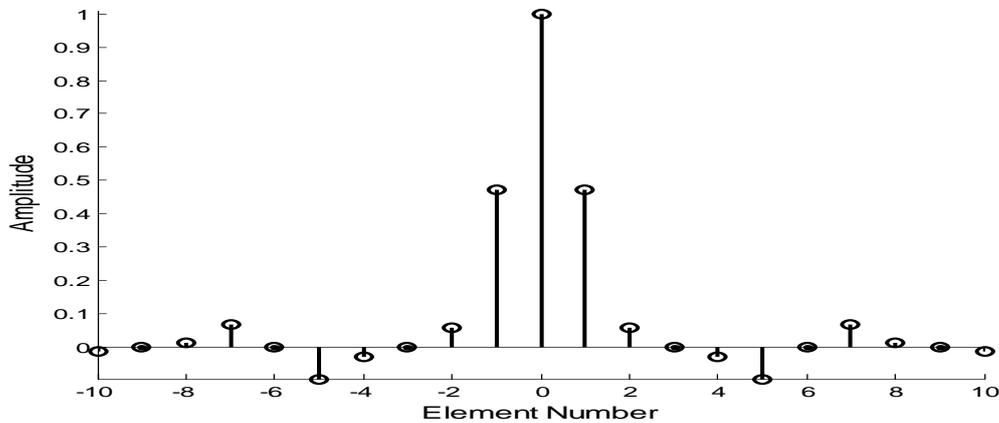


Fig.2. Amplitude distribution of central sub array for N=21

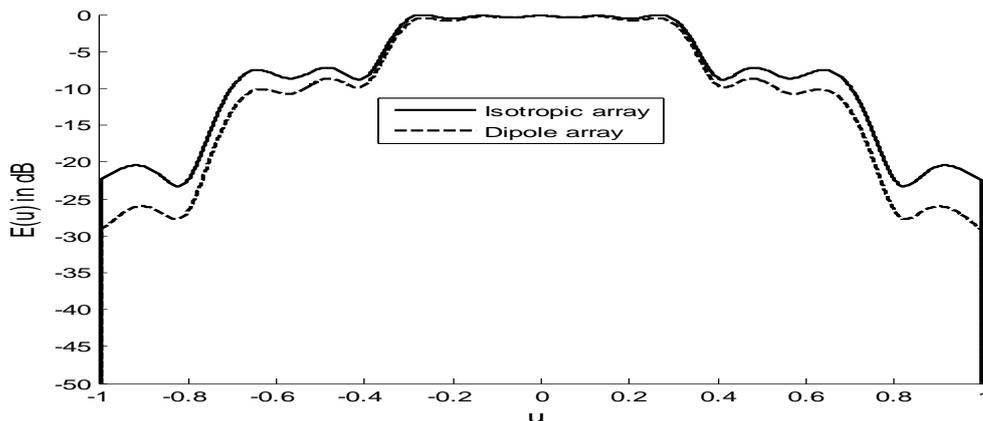


Fig.3. Radiation pattern of central sub array for N=21

Table.1. Excitation levels of 21 elements for Three Stair-step pattern .

Element number	Amplitude level
-10	-0.0118
-9	0.0000
-8	0.0148
-7	0.0675
-6	-0.0000
-5	-0.0945
-4	-0.0295
-3	0.0000

-2	0.0591
-1	0.4726
0	1.0000
1	0.4726
2	0.0591
3	0.0000
4	-0.0295
5	-0.0945
6	-0.0000
7	0.0675
8	0.0148
9	0.0000
10	-0.0118

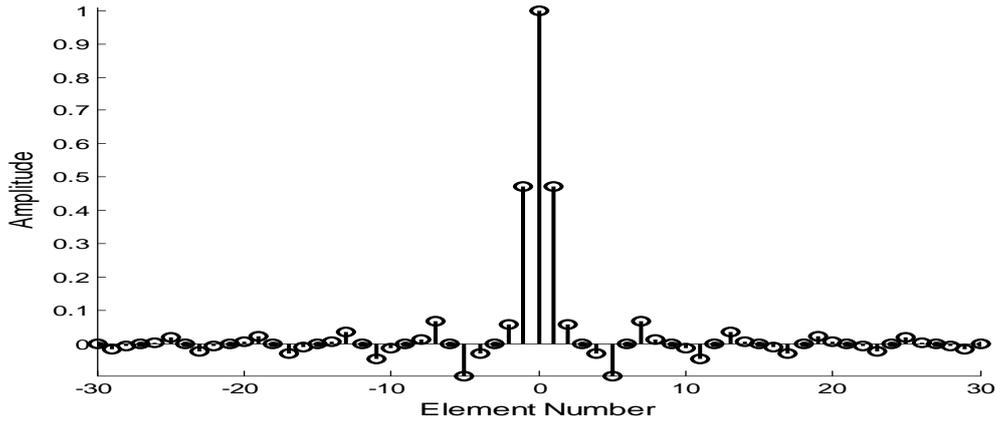


Fig.4. Amplitude distribution of central sub array for N=61

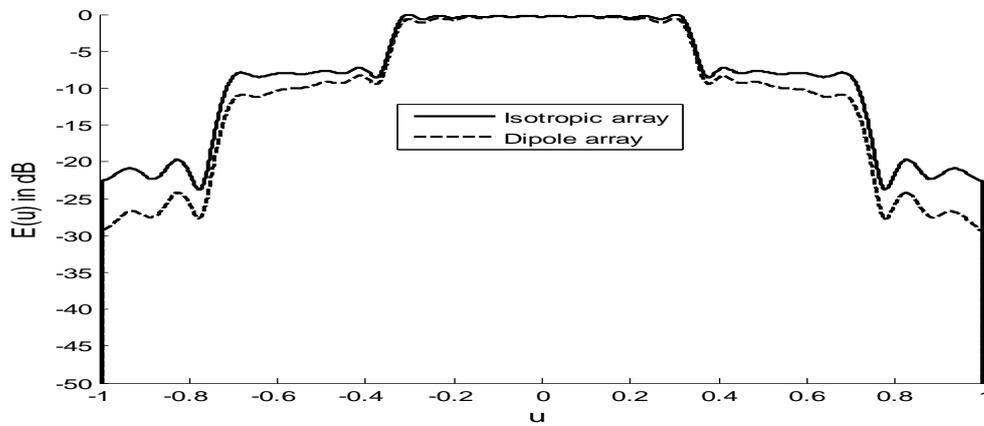


Fig.5. Radiation pattern of central sub array for N=61

Table.2. Excitation levels of 61 elements for Three Stair-step pattern.

Element number	Amplitude level	Element number	Amplitude level
-30	-0.0000	1	0.4726
-29	-0.0163	2	0.0591
-28	-0.0042	3	0.0000
-27	0.0000	4	-0.0295
-26	0.0045	5	-0.0945
-25	0.0189	6	-0.0000
-24	-0.0000	7	0.0675
-23	-0.0205	8	0.0148
-22	-0.0054	9	0.0000
-21	-0.0000	10	-0.0118
-20	0.0059	11	-0.0430
-19	0.0249	12	-0.0000
-18	-0.0000	13	0.0364
-17	-0.0278	14	0.0084

-16	-0.0074	15	0.0000
-15	0.0000	16	-0.0074
-14	0.0084	17	-0.0278
-13	0.0364	18	-0.0000
-12	-0.0000	19	0.0249
-11	-0.0430	20	0.0059
-10	-0.0118	21	-0.0000
-9	0.0000	22	-0.0054
-8	0.0148	23	-0.0205
-7	0.0675	24	-0.0000
-6	-0.0000	25	0.0189
-5	-0.0945	26	0.0045
-4	-0.0295	27	0.0000
-3	0.0000	28	-0.0042
-2	0.0591	29	-0.0163
-1	0.4726	30	-0.0000
0	1.0000		

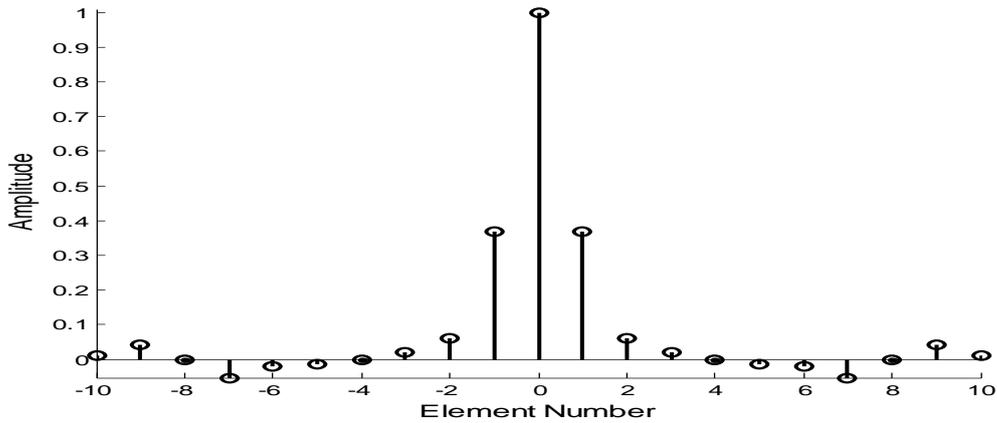


Fig.6.Amplitude distribution of central sub array for N=21

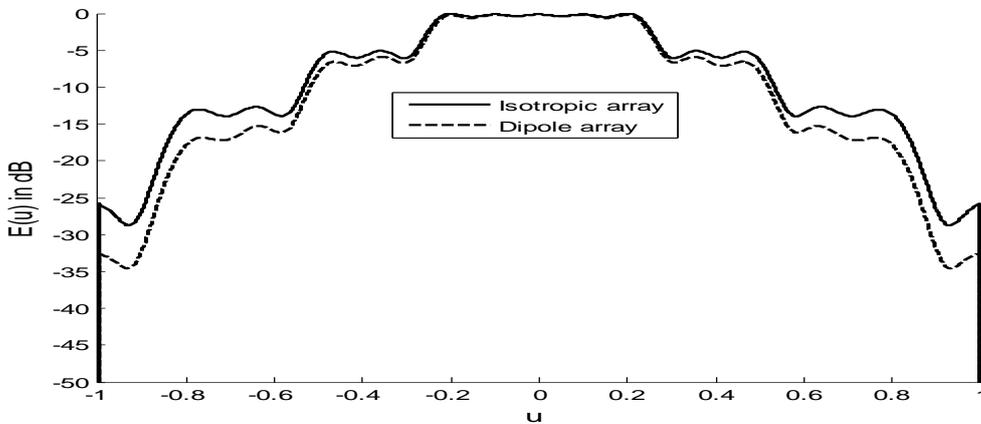


Fig.7.Radiation pattern of central sub array for N=21

Table.3.Excitation levels of 21 elements for Four Stair-step pattern.

Element number	Amplitude level
-10	0.0122
-9	0.0410
-8	-0.0000
-7	-0.0527
-6	-0.0204
-5	-0.0127
-4	0.0000
-3	0.0211
-2	0.0611
-1	0.3689
0	1.0000
1	0.3689
2	0.0611
3	0.0211

4	0.0000
5	-0.0127
6	-0.0204
7	-0.0527
8	-0.0000
9	0.0410
10	0.0122

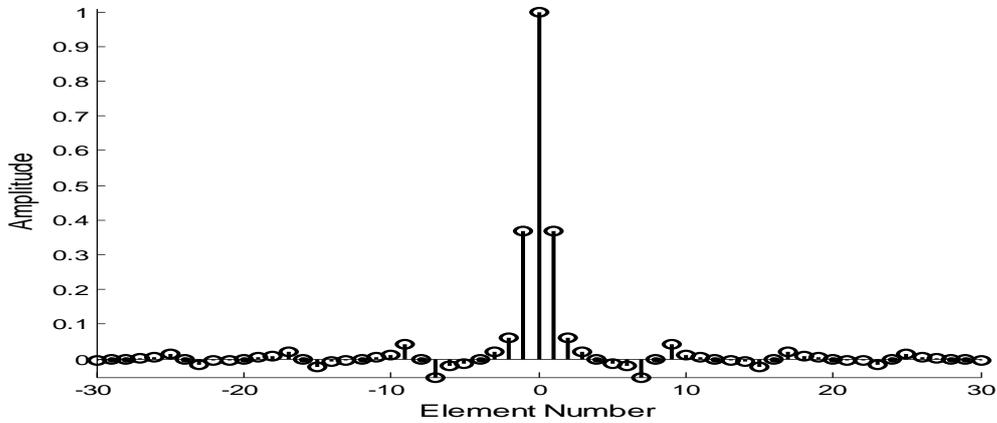


Fig.8.Amplitude distribution of central sub array for N=61

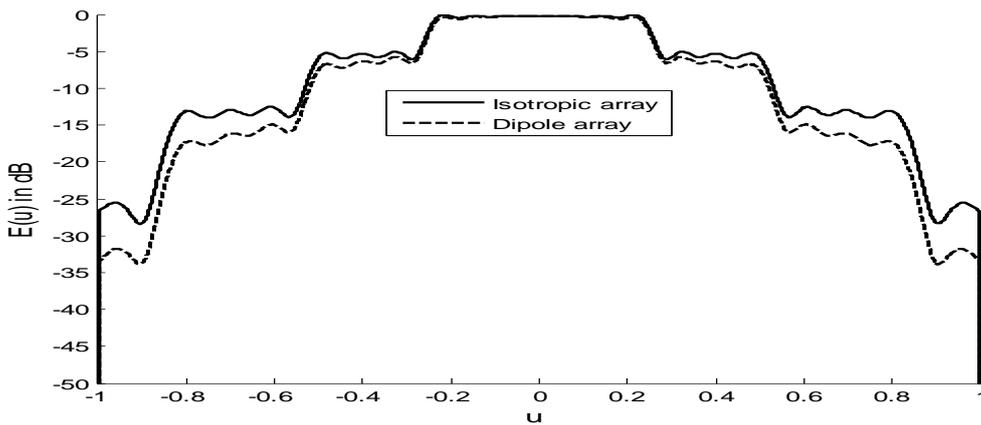


Fig.9.Radiation pattern of central sub array for N=61

Table.4.Excitation levels of 61 elements for Four Stair-step pattern.

Element number	Amplitude level	Element number	Amplitude level
-30	-0.0041	1	0.3689
-29	-0.0022	2	0.0611
-28	-0.0000	3	0.0211
-27	0.0023	4	0.0000
-26	0.0047	5	-0.0127
-25	0.0148	6	-0.0204
-24	-0.0000	7	-0.0527
-23	-0.0160	8	-0.0000
-22	-0.0056	9	0.0410
-21	-0.0030	10	0.0122
-20	0.0000	11	0.0058
-19	0.0033	12	0.0000
-18	0.0068	13	-0.0049
-17	0.0217	14	-0.0087
-16	-0.0000	15	-0.0246
-15	-0.0246	16	-0.0000
-14	-0.0087	17	0.0217
-13	-0.0049	18	0.0068
-12	0.0000	19	0.0033
-11	0.0058	20	0.0000
-10	0.0122	21	-0.0030

-9	0.0410	22	-0.0056
-8	-0.0000	23	-0.0160
-7	-0.0527	24	-0.0000
-6	-0.0204	25	0.0148
-5	-0.0127	26	0.0047
-4	0.0000	27	0.0023
-3	0.0211	28	-0.0000
-2	0.0611	29	-0.0022
-1	0.3689	30	-0.0041
0	1.0000		

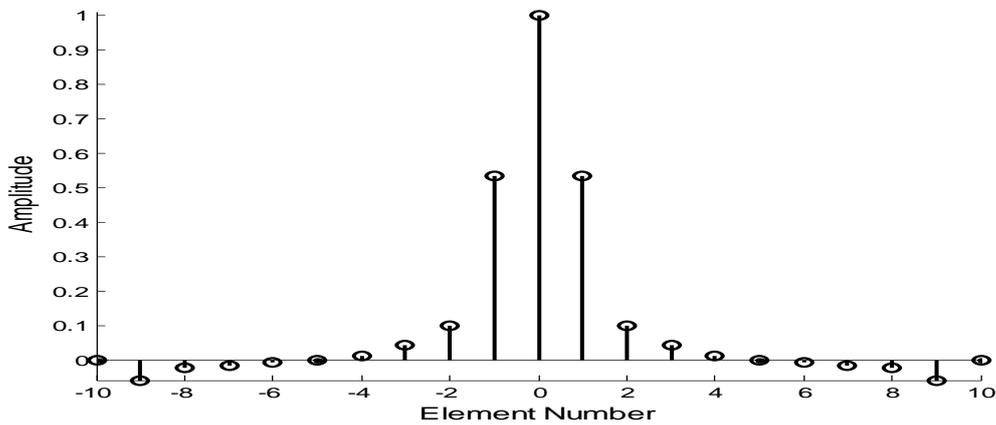


Fig.10. Amplitude distribution of central sub array for N=21

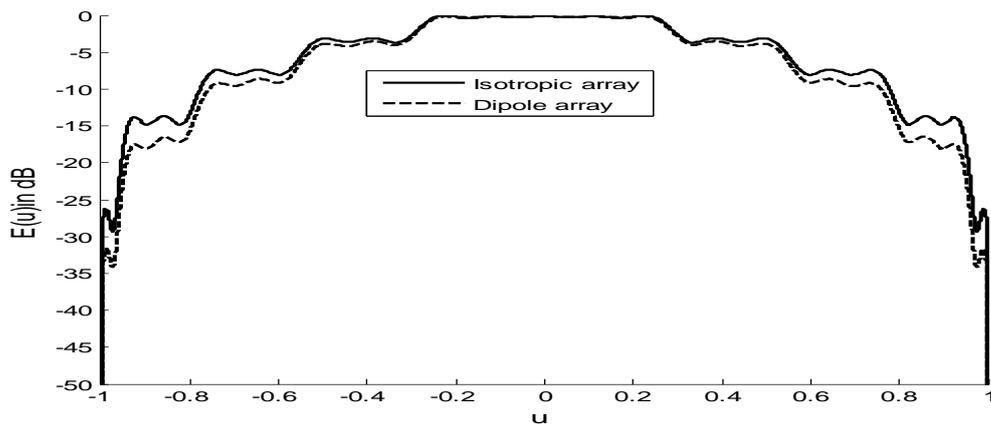


Fig.11. Radiation pattern of central sub array for N=21

Table.5. Excitation levels of 21 elements for Five Stair-step pattern .

Element number	Amplitude level
-10	-0.0000
-9	-0.0594
-8	-0.0249
-7	-0.0180
-6	-0.0078
-5	0.0000
-4	0.0118
-3	0.0420
-2	0.0996
-1	0.5344
0	1.0000
1	0.5344
2	0.0996
3	0.0420
4	0.0118
5	0.0000
6	-0.0078
7	-0.0180
8	-0.0249
9	-0.0594
10	-0.0000

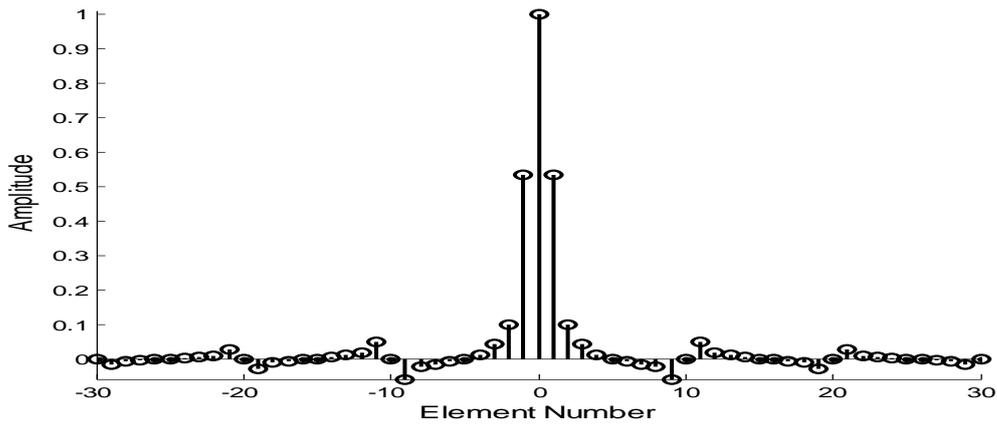


Fig.12. Amplitude distribution of central sub array for N=61

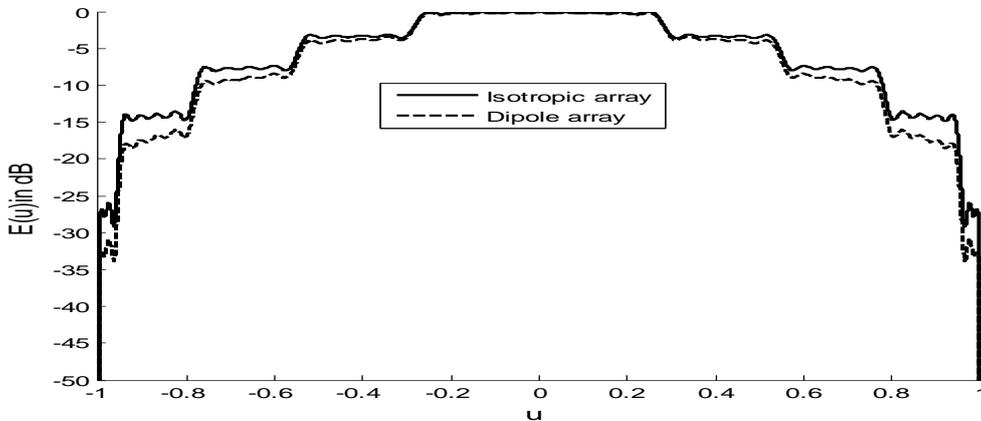


Fig.13. Radiation pattern of central sub array for N=61

Table.6. Excitation levels of 61 elements for Five Stair-step pattern.

Element number	Amplitude level	Element number	Amplitude level
-30	-0.0000	1	0.5344
-29	-0.0184	2	0.0996
-28	-0.0071	3	0.0420
-27	-0.0047	4	0.0118
-26	-0.0018	5	0.0000
-25	0.0000	6	-0.0078
-24	0.0020	7	-0.0180
-23	0.0055	8	-0.0249
-22	0.0091	9	-0.0594
-21	0.0254	10	-0.0000
-20	-0.0000	11	0.0486
-19	-0.0281	12	0.0166
-18	-0.0111	13	0.0097
-17	-0.0074	14	0.0034
-16	-0.0029	15	0.0000
-15	0.0000	16	-0.0029
-14	0.0034	17	-0.0074
-13	0.0097	18	-0.0111
-12	0.0166	19	-0.0281
-11	0.0486	20	-0.0000
-10	-0.0000	21	0.0254
-9	-0.0594	22	0.0091
-8	-0.0249	23	0.0055
-7	-0.0180	24	0.0020
-6	-0.0078	25	0.0000
-5	0.0000	26	-0.0018
-4	0.0118	27	-0.0047
-3	0.0420	28	-0.0071
-2	0.0996	29	-0.0184
-1	0.5344	30	-0.0000
0	1.0000		

V. Conclusion

In this work, we proposed a new amplitude distribution for a array, patterns are computed for different stair steps. Using Fourier transform method, stair step patterns are produced from array of dipoles. The results are compared with those of array of isotropic radiators. It is clear from the computed patterns, there exists considerable deviation in the patterns of isotropic and dipole arrays. These patterns are intensively used to identify more than one target moving in different altitudes and different angular regions.

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