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Synthesis of Dipole Array Antenna

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Abstract: In this study, a dipole array antenna has been designed and simulated using triangular amplitude distribution for a different range of elements to establish and arrive at the benefit of low side-lobe level. The level of side-lobes is the result of element excitation amplitude and their positioning in the array, hence, an efficient amplitude distribution pattern has been implemented. The proposed non-uniform, element amplitude excitation design of antenna can be used for long-range, high-frequency and point-to-point communication applications. By implementing triangular amplitude distribution (Non-Uniform) the side-lobe level has been significantly reduced when compared to the uniform distribution. The simulated results confirm that the side-lobe, level has improved by -15.2 dB with the triangular distribution. The problem of high sidelobes, large beam-width and radiation spill-over can be suppressed with the proposed method of antenna array element excitation design, then the uniform-amplitude element excitation.

Key words: Antenna array, array synthesis, dipole antenna, radiation pattern, side-lobes reduction, triangular distribution, excitation

INTRODUCTION

Today's wireless world mostly and widely revolves around the radio frequency communication. The role of antennas is not only crucial in the field of wireless communication but also in medical (Staderini, 2002), defence security and so, to serve the requirements of the modest. Different types of antennas are developed for various purposes and the antenna characteristics are selected, according to the required functionalities.

To achieve high gain and directivity of the antenna where a single antenna cannot serve the purpose, multiple antennas help in achieving the aimed result. Hence, an array antenna is considered where a considerably specific number of antennas are arranged in a pattern resulting in high gain and directivity compared to the outputs of a single antenna (Akdagli and Guney, 2003; Sengupta, 1960; King, 1959; Cheng and Ma, 1960; Palacios *et al*., 2016). The radiation pattern of an array antenna is determined by the amplitude and phase of excitation currents over the array, interspacing between the elements (Adnan *et al*., 2017) of the array, operating frequency of antenna and choice of radiating elements. Variety of antennas are designed and analysed by several researchers (Raju, 2008), the type of antenna selected depends on the application, specified radiation patterns and desired polarizations (Wong *et al*., 2017).

The radiation patterns produced by the antennas contain have a common problem of high side lobes and mutual coupling resulting in electromagnetic interference in receiver systems (Dong-An *et al*., 2014; Zhi-yong and Jiang-feng, 2007). A single antenna has low directivity, high beam-width which is not suitable for tracking systems like Radars when there are multiple obstacles in the antenna radiation range. It is well known that linear antenna arrays yield radiation patterns and contain one main beam and set of side lobes (Yu-wei *et al*., 2016). With uniform excitation, the linear array generates a pattern with 1st Sidelobe Level (SLL) at -13.5 dB, this is not acceptable in many applications (Mandal *et al*., 2011). The high side lobe creates electro-magnetic interference problem in Radar receivers.

In the antenna radiation pattern depends on the amplitude, phase, interspacing and frequency of excitation (Ram *et al*., 2012). Hence, the study of uniform and non-uniform spacing and the feed to the antenna array helps in designing an optimized and efficient antenna with less side lobe ripples and less number of antenna elements. A dipole antenna serves as an important role in many wide-band applications such as satellite and wideband communications in the ultra-high frequency range (Fenn *et al*., 2010). These factors motivate to design an optimal antenna for high directivity, low-side lobe applications whose radiation characteristics gives a promising result. Amplitude excitation distribution of the elements such as uniform and non-uniform excitation (Ridwan *et al*., 2011) in the antenna array has a suggestive effect on the radiation sidelobe level.

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Suitable methods for suppressing the side lobe interference are to be chosen to achieve high gain, directivity and high bandwidth of the antenna. These advantages are achieved with the variation of element excitation amplitude, phase and position of antenna element.

MATERIALS AND METHODS

Method formulation: The synthesis of antenna array requires some pre-requisites to satisfy the formulation of the desired radiation pattern where Fig. 1 and 2 represent the dipole antenna and linear array antenna, respectively. To prevail the low-side lobes and narrow beam pattern, triangular amplitude distribution is used to excite the linear dipole array antenna. The following are the equations of array factor, excitation expression for array synthesis:

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

Where:

- u = $\sin(\theta)$, $-\pi<\theta<\pi$
- $A(x_n)$ = The amplitude distribution
- θ = The elevation angle
- χ_n = 2n-1-N/N, nth element location
- $\phi(x_n)$ = 0, phase of the array
- 'N' = The number of the elements

The excitation equation of the half-wave dipole antenna is as follows:

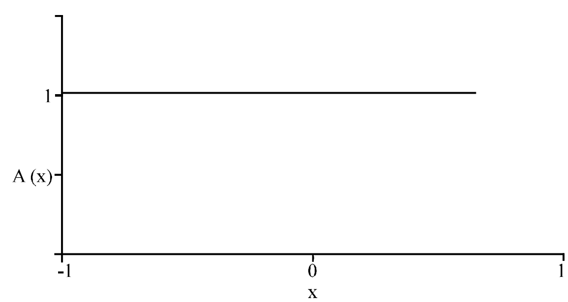

Fig. 1: Uniform amplitude distribution

$$E_d = \frac{\cos\left(\frac{(k\times d)}{2}\times(\cos(\theta))-\cos\left(\frac{(k\times d)}{2}\right)\right)}{(\sin(\theta))} \quad (2)$$

Where:

- λ = Wavelength
- k = $2\pi/\lambda$ wave number
- d = $\lambda/2$ length of the dipole array
- θ = Elevation angle [$\pi<\theta<\pi$]

Substituting the above values in (Eq. 2), the resulting equation is as follows:

$$E_d = \frac{\cos\left(\frac{2\pi}{\lambda}\times\frac{\lambda}{2}\times\frac{1}{2}\times(\cos(\theta))-\cos\left(\frac{2\pi}{\lambda}\times\frac{\lambda}{2}\times\frac{1}{2}\right)\right)}{\sin(\theta)} \quad (3)$$

$$E_d = \frac{\cos\left(\frac{1}{2}\times\pi\times(\cos(\theta))-\cos\left(\frac{1}{2}\times\pi\right)\right)}{\sin(\theta)} \quad (4)$$

The excitation of the dipole antenna array can be obtained with the help of the array factor which is different for different amplitude distributions of the linear array. The total radiation excitation of the linear array is the product of dipole excitation and the array element excitation:

$$E_t = E_d \times E(u) \quad (5)$$

Uniform amplitude distribution: In uniform amplitude distribution, each element of the array is excited with equal and constant amplitude. But the drawback is that the side lobes which arise in the radiation nearly dissipate power equal to the main-lobe radiation power. Equation 6 gives the amplitude expression and Fig. 1, pictorially represents the uniform amplitude distribution:

$$A(x_n) = 1 \quad (6)$$

Triangular amplitude distribution: A general fact is that high side-lobe level leads to loss of radiation power in

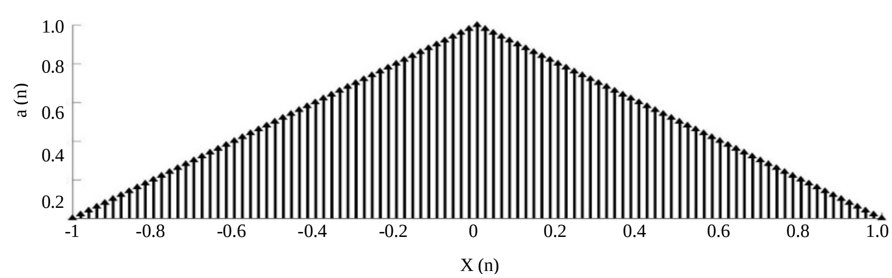

Fig. 2: Triangular amplitude distribution of discrete array

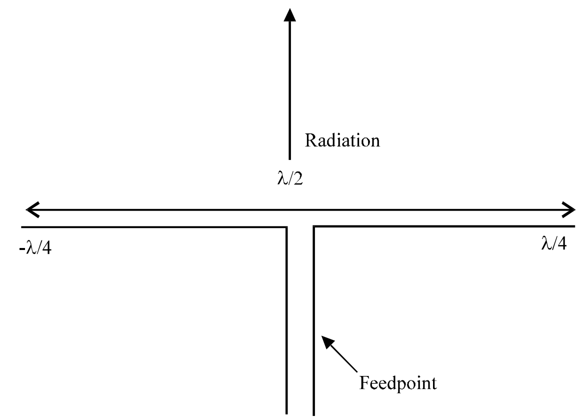

Fig. 3: Half-wave dipole antenna

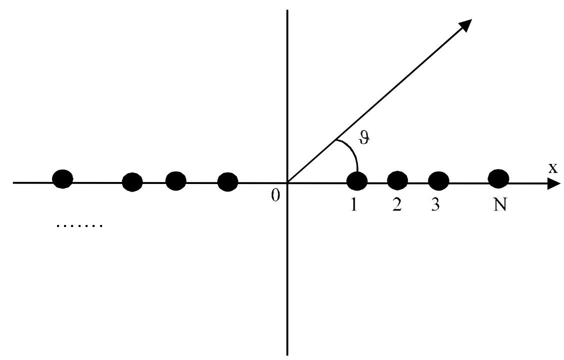

Fig. 4: N element linear dipole array antenna

unsought directions, non-uniform amplitude distribution based on the triangular model has been proposed. The triangular amplitude distribution model warrants lower side-lobe level compared to uniform amplitude distributions in array antennas. Equation 7 computes the amplitude values and Fig. 2 pictorially represents triangular amplitude distribution whereas Fig. 3 and 4 represent a half-wave dipole and N-element linear array antenna, respectively.

$$A(x_n) = \left(1+\frac{2x}{1}\right) \text{for-}\frac{1}{2} \leq x \leq 0 = \left(1\text{-}\frac{2x}{1}\right) \text{for-}0 \leq x \leq \frac{1}{2} \quad (7)$$

where, l = length of array

RESULTS AND DISCUSSION

The dipole antenna radiation patterns are analysed for different lengths of the dipole, its 3 dB beam-width and first null beam-width values are tabulated in Table 1-5

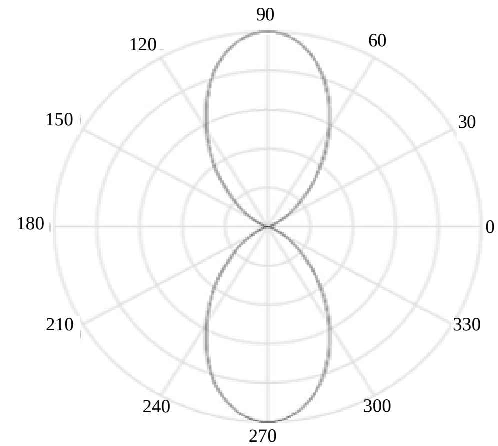

Fig. 5: Polar plot of dipole for d = 0.5 λ

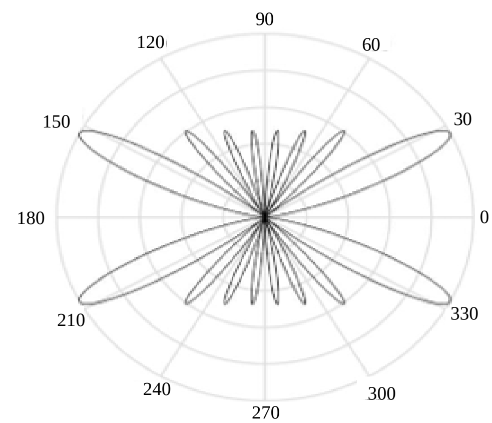

Fig. 6: Polar plot of dipole for d = 4 λ

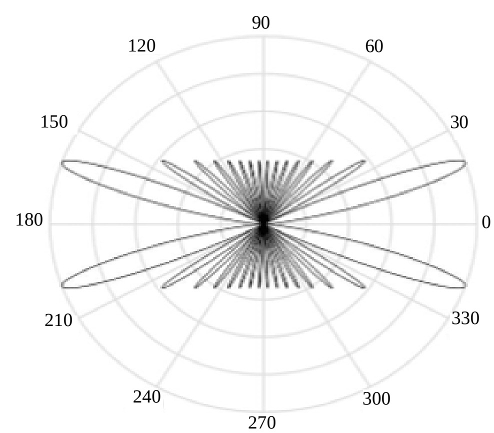

Fig. 7: Polar plot of a dipole for d = 8λ

and Table 2 notes the element position and element amplitude values, respectively and Fig. 5-9 represent the polar plots of a dipole for different lengths. From the

Table 1: Characteristics of dipole antenna by varying its length

'd' (length of dipole)	No. of lobes	3-dB beam width (Degrees)	First null beam width (Degrees)
λ/2	2	47.790	173.770
1λ	4	26.690	87.725
3λ/2	6	20.830	68.710
2λ	8	17.680	58.430
3λ	12	14.160	46.930
4λ	16	12.160	40.330
5λ	20	10.810	36.320
6λ	24	9.830	32.670
7λ	28	9.080	30.180
8λ	32	8.480	28.180
9λ	36	7.980	26.540
10λ	40	7.570	25.160
11λ	44	7.220	23.970
12λ	48	6.890	23.510
13λ	52	6.620	22.010
14λ	56	6.370	21.240
15λ	60	6.160	20.470
16λ	64	5.970	19.820
17λ	68	5.773	19.220
18λ	72	5.620	18.680
19λ	76	5.457	18.170
20λ	80	5.310	17.710

Table 2: Proposed amplitude distribution for n = 10

(x_n)	(a_n)
-1.0000	0.0000
-0.7000	0.3000
-0.5000	0.5000
-0.3000	0.7000
-0.1000	0.9000
0.1000	0.9000
0.3000	0.7000
0.5000	0.5000
0.7000	0.3000
1.0000	0.0000

Table 3: Proposed amplitude distribution for n = 20

(x_n)	(a_n)
-1.0000	0.0000
-0.8500	0.1500
-0.7500	0.2500
-0.6500	0.3500
-0.5500	0.4500
-0.4500	0.5500
-0.3500	0.6500
-0.2500	0.7500
-0.1500	0.8500
-0.0500	0.9500
0.0500	0.9500
0.1500	0.8500
0.2500	0.7500
0.3500	0.6500
0.4500	0.5500
0.5500	0.4500
0.6500	0.3500
0.7500	0.2500
0.8500	0.1500
1.0000	0.0000

experimental results, it can be inferred that as the size of the dipole antenna increases the number of side-lobes is increasing and the width of the beam is

Table 4: Proposed amplitudebdistributionc for n = 40

(x_n)	(a_n)
-1.0000	0.0000
-0.9250	0.0750
-0.8750	0.1250
-0.8250	0.1750
-0.7750	0.2250
-0.7250	0.2750
-0.6750	0.3250
-0.6250	0.3750
-0.5750	0.4250
-0.5250	0.4750
-0.4750	0.5250
-0.4250	0.5750
-0.3750	0.6250
-0.3250	0.6750
-0.2750	0.7250
-0.2250	0.7750
-0.1750	0.8250
-0.1250	0.8750
-0.0750	0.9250
-0.0250	0.9750
0.0250	0.9750
0.0750	0.9250
0.1250	0.8750
0.1750	0.8250
0.2250	0.7750
0.2750	0.7250
0.3250	0.6750
0.3750	0.6250
0.4250	0.5750
0.4750	0.5250
0.5250	0.4750
0.5750	0.4250
0.6250	0.3750
0.6750	0.3250
0.7250	0.2750
0.7750	0.2250
0.8250	0.1750
0.8750	0.1250
0.9250	0.0750
1.0000	0.0000

Table 5: Proposed amplitude distribution for n = 80

(x_n)	(a_n)
-1.0000	0.0000
-0.9625	0.0375
-0.9375	0.0625
-0.9125	0.0875
-0.8875	0.1125
-0.8625	0.1375
-0.8375	0.1625
-0.8125	0.1875
-0.7875	0.2125
-0.7625	0.2375
-0.7375	0.2625
-0.7125	0.2875
-0.6875	0.3125
-0.6625	0.3375
-0.6375	0.3625
-0.6125	0.3875
-0.5875	0.4125
-0.5625	0.4375
-0.5375	0.4625
-0.5125	0.4875
-0.4875	0.5125
-0.4625	0.5375
-0.4375	0.5625
-0.4125	0.5875
-0.3875	0.6125
-0.3625	0.6375
-0.3375	0.6625
-0.3125	0.6875
-0.2875	0.7125
-0.2625	0.7375
-0.2375	0.7625
-0.2125	0.7875
-0.1875	0.8125
-0.1625	0.8375
-0.1375	0.8625
-0.1125	0.8875
-0.0875	0.9125
-0.0625	0.9375
-0.0375	0.9625
-0.0125	0.9875
0.0125	0.9875
0.0375	0.9625
0.0625	0.9375
0.0875	0.9125
0.1125	0.8875
0.1375	0.8625
0.1625	0.8375
0.1875	0.8125
0.2125	0.7875
0.2375	0.7625
0.2625	0.7375
0.2875	0.7125
0.3125	0.6875
0.3375	0.6625
0.3625	0.6375
0.3875	0.6125
0.4125	0.5875
0.4375	0.5625
0.4625	0.5375
0.4875	0.5125
0.5125	0.4875
0.5375	0.4625
0.5625	0.4375
0.5875	0.4125
0.6125	0.3875
0.6375	0.3625
0.6625	0.3375
0.6875	0.3125
0.7125	0.2875
0.2625	0.7375
0.7625	0.2375
0.7875	0.2125
0.8125	0.1875
0.8375	0.1625
0.8625	0.1375
0.8875	0.1125
0.9125	0.0875
0.9375	0.0625
0.9625	0.0375
1.0000	0.0000

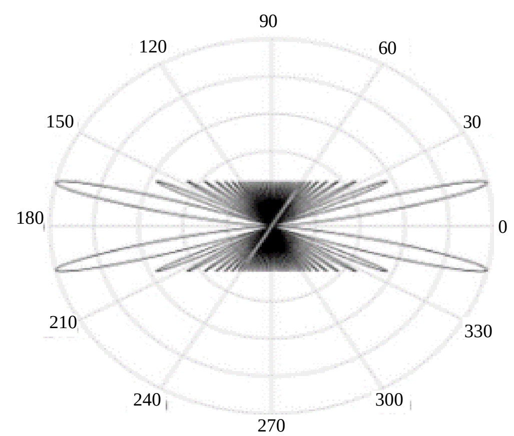

Fig. 8: Polar plot of a dipole for d = 16 λ

narrowed. In Table 1 the values of number of lobes produced, 3 dB beam-width which is commonly termed as Half-power beam-width and First Null Beam Width (FNBW) of dipole antenna for lengths ranging from λ = 0.5-20 have been tabulated. From the results, it can be easily perceived that the increase in number of lobes is proportional to the loss of radiated power in unwanted directions, resulting in low power radiation from the main beam. Hence, half-wave dipole is widely used as an ideal antenna for real-time applications.

Table 2-5 represents the element position (x_n) and element amplitude (a_n) at that particular position of the dipole array antenna using triangular distribution for 10, 20, 40 and 80 elements, respectively. The radiation patterns of uniform and triangular distributions are shown in Fig. 10-15 where the plain line and dotted line represent the triangular and uniform amplitude distributions, respectively.

The radiation patterns of a half-wave dipole array antenna with number of elements ranging from n = 10, 20, 40, 60, 80, 100 have been presented below in Fig. 10-15 for uniform amplitude and triangular amplitude distributions

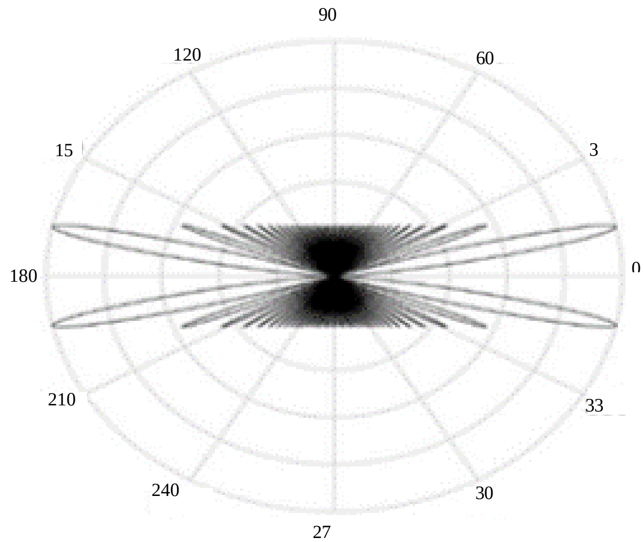

Fig. 9: Polar plot of a dipole for d = 20 λ

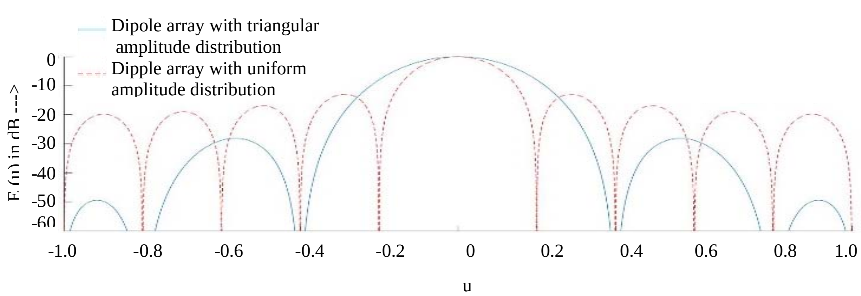

Fig. 10: Dipole array antenna radiation pattern with n = 10 using uniform and triangular amplitude distributions

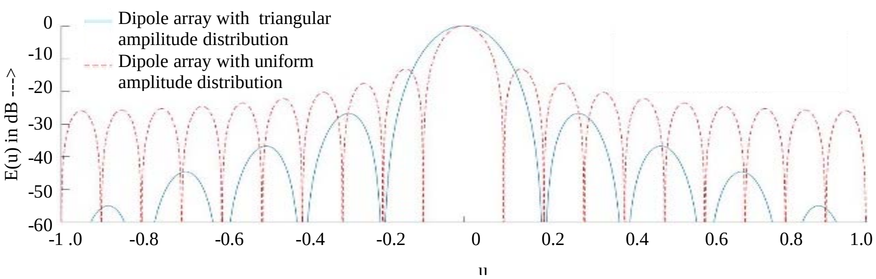

Fig. 11: Dipole array antenna radiation pattern with n = 20 using uniform and triangular amplitude distributions

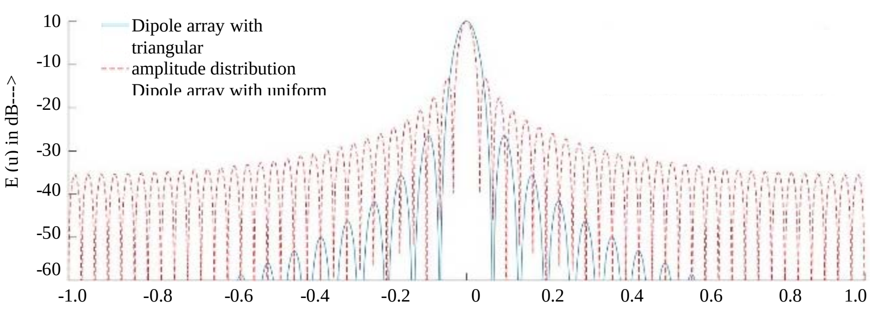

Fig. 12: Dipole array antenna radiation pattern with n = 40 using uniform and triangular amplitude distributions

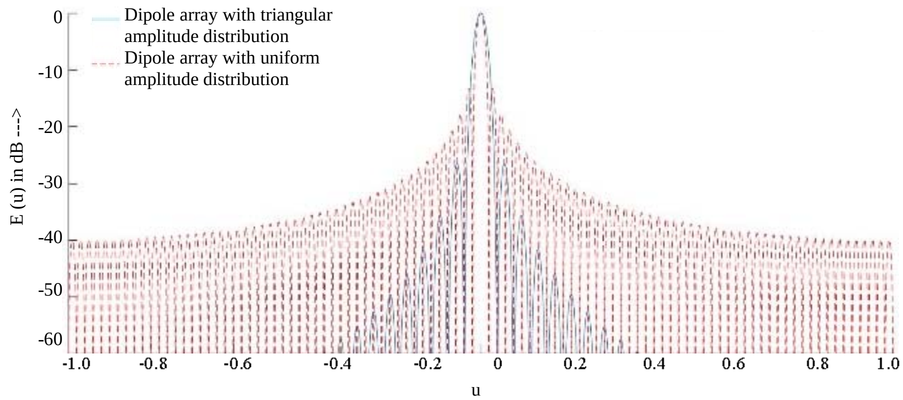

Fig. 13: Dipole array antenna radiation pattern with n = 60 using uniform and triangular amplitude distributions

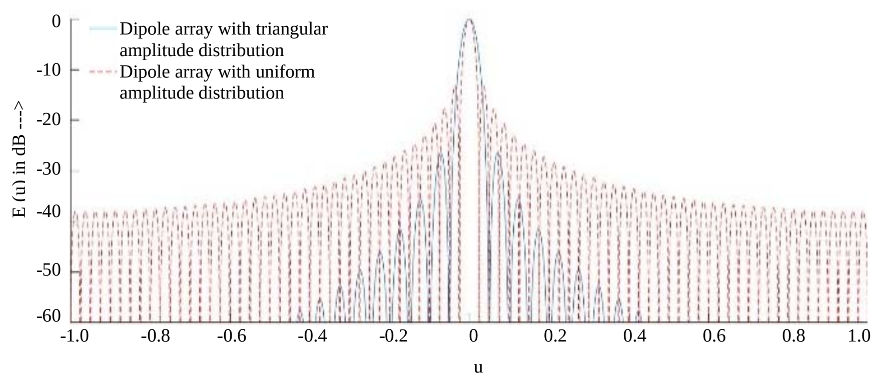

Fig. 14: Dipole array antenna radiation pattern with n = 80 using uniform and triangular amplitude distributions

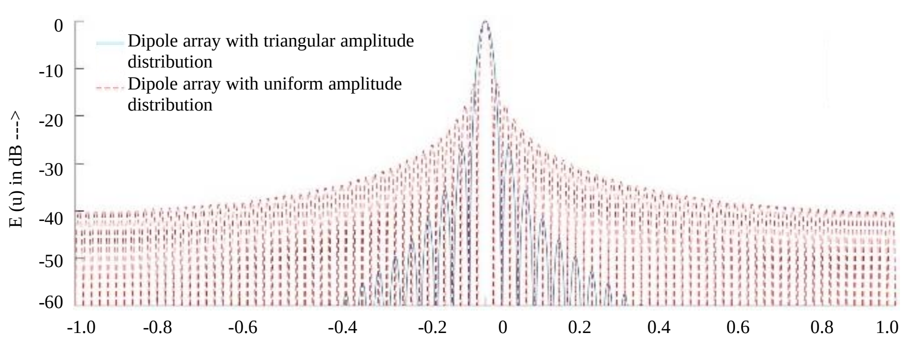

Fig. 15: Dipole array antenna radiation pattern with N = 100 using uniform and triangular amplitude distributions

using (Eq. 6 and 7), respectively. Triangular amplitude distribution has been proposed to fulfil the low-side lobe level and the following plots prove that the side-lobe level has been reduced from -13.03 dB (uniform amplitude distribution) to -28.22 dB.

CONCLUSION

A non-uniform amplitude distribution based triangular model distribution has been proposed in the study to arrive at the point of low radiation power loss in the directions which are objectionable. The linear array antenna which is designed according to the specifications required helps to serve long range compatibility. Radiation spill-over can be overcome by varying the antenna element amplitude excitation distribution and normalizing them. The radiation patterns of linear dipole array antenna using triangular amplitude distribution reveal a drop of -15.2 dB to its side-lobe level from the level of uniform excitation.

Hence, the conclusion is that from the obtained simulated results on MATLAB Software, the triangular amplitude excitation solves the issue of high sidelobes, wastage of radiation power in the directions which are not of interest and large beam-width problem to a greater extent in Radar applications when compared to uniform amplitude distributions.

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