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Comparision of Radiation Patterns for Thinned and Thicked Arrays

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Abstract: *It is possible to thin an array as well as to improve radiation pattern characteristics with an appropriate spacing function. Array thinning plays a very important role in array synthesis. To analyze the effect of thinning by considering a modulated spacing function. Using a specified spacing function, radiation patterns are evaluated for different array lengths. It is found that the near-in-side lobe level is reduced for a modulated spacing function and that the main beam width is found to remain constant. These advantages are not found in the case of uniform spacing. Even after thinning the array, the modulated spacing function is found to improve the overall radiation pattern characteristics.*

Although some studies are made by the researchers on thinning, the effect of thickening is not reported in the literature. In view of the above facts, intensive studies are carried out to investigate linear arrays with thickening as well as thinning. The patterns are numerically evaluated for different arrays and the radiation patterns are presented for different arrays. The investigations reveal that thickening has caused the reduction of null to null beam width without deteriorating the side lobe levels. On the other hand thinning has resulted in raising the side lobe levels as well as the beam width. If thinning is not carried out properly the resultant radiation patterns contain even grating lobes.

I. Introduction

Hamici et al. [1] proposed a novel genetic algorithm called Immunity Genetic Algorithm (IGA) based on stochastic crossover evolution to solve the synthesis problem of thinned arrays. A new expression of the array factor for a specific number of elements N is expressed as a linear Discrete Cosine Transform (DCT). Using IGA to generate thousands of array bit patterns and the DCT to compute the fitness function will result in a very high speed computation compared to traditional computation techniques. This high performance allows us to find a good approximation of the absolute minimum SLL of synthesized thinned arrays. Simulation results of this novel array signal processing technique show the effectiveness for pattern synthesis with low SLL.

Basu et al. [2] have proposed the Inverse Fast Fourier technique (IFFT) combined with Artificial Bees Colony (ABC) and Modified Particle Swarm Optimization (MPSO) which is used for the synthesis of thinned mutually coupled linear array with uniform element spacing. Coupling effect has been taken into account via induced EMF method and used to calculate the induced current on each element. Proposed technique is employed to thin the array optimally to yield a minimum possible SLL and low return loss (RL). Performances of both the algorithms are compared to show the effectiveness of each optimizer. Introduction of Inverse Fast Fourier transform to calculate the array factor reduces the computation time significantly. The effectiveness of the proposed technique is demonstrated for 100-element linear array and results are compared with that of a fully populated array. This method is very popular for array designers.

A novel algorithm on beam pattern synthesis for linear aperiodic arrays with arbitrary geometrical configuration was presented by Ling Cen et al. [3]. Linear aperiodic arrays are attractive for their advantages on higher spatial resolution and lower side-lobe. However, the advantages are attained at the cost of solving a complex non-linear optimization problem. In this paper, we explain the Improved Genetic Algorithm (IGA) that simultaneously adjusts the weight coefficients and inter-sensor spacing of a linear aperiodic array in more details and extend the investigations to include the effects of mutual coupling and the sensitivity of the Peak Sidelobe Level (PSL) to steering angles. Numerical results show that the PSL of the synthesized beam pattern has been successfully lowered with the IGA when compared with other techniques published in the literature. In addition, the computational cost of our algorithm can be as low as 10% of that of a recently reported genetic algorithm based synthesis method. The excellent performance of IGA makes it a promising optimization algorithm where expensive cost functions are involved[10-12].

Intensive studies are carried out by Raju et al. [4-6] to investigate linear arrays with gradual thickening as well as gradual thinning. The patterns are numerically evaluated for different arrays and the radiation patterns are presented for different arrays. The investigations reveal that thickening has caused the reduction of null to null beam width without deteriorating the side lobe levels. On the other hand thinning has resulted in raising the side lobe levels as well as the beam width. If thinning is not carried out properly the resultant radiation patterns contain even grating lobes.

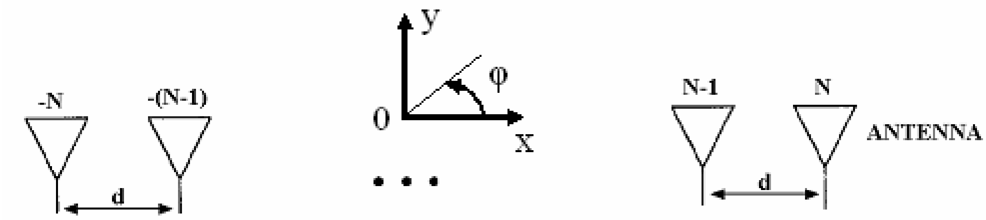
The non-resonant spacing is proposed using a well-developed formula. This formula is useful for the determination of space distribution for even and odd elements of the array. Introducing space distribution so determined, the sector beams of specified width are realized. The radiation patterns are compared with those of specified ones. The patterns are presented in u (sinθ) – domain.

Symmetric linear antenna arrays are described using Genetic Algorithm (GA) by Das etal. [6] Genetic Algorithm has many advantages over other conventional optimization techniques. Real coded GA (RGA) is a high performance evolutionary optimization algorithm. It is used in this paper to find optimum inter-element spacing and excitation coefficients for the symmetric linear antenna array in order to minimize the maximum relative sidelobe level (SLL) in the radiation pattern of the array for minimum possible First Null Beamwidth (BWFN) increment.\

Hsing Hsu et al. [7] described an innovative optimal radiation pattern of an adaptive linear array which is derived by phase-only perturbations using a Particle Swarm Optimization (PSO) algorithm. An antenna array is often made as an adaptive antenna. An optimal radiation pattern design for an adaptive antenna system is not only to suppress interference by placing a null in the direction of the interfering source but also to derive the maximum power pattern in the direction of the desired signal. The Signal Interference Ratio (SIR) can be maximized. The PSO algorithm is a new methodology in this study area, which can handle adaptive radiation pattern of antenna array. In this paper, an optimal radiation pattern of linear array is derived by phase-only perturbations using a PSO algorithm.PSO algorithms will be stated and computed for this problem. Then, the optimal solution can be derived, and simulation results are also presented [13-15].

Mandal et al. [8] proposed an evolutionary swarm intelligence technique; Craziness Particle Swarm Optimization (CRPSO) is propounded for nullifying the radiation pattern of asymmetrical linear antenna array in a particular direction. Multiple wide nulls are achieved by optimum perturbations of elements current amplitude weights to have symmetric nulls about the main beam. Different numerical examples are presented to illustrate the capability of CRPSO for pattern synthesis with a prescribed wide nulls locations and depths. Further, the peak sidelobe levels are also reduces when compared to a uniformly excited array having equal number of elements[9].

II. Formulation



Geometry of a 2*N*-element symmetric linear array along the *x*-axis

The free space far field pattern E(u) in X-Y plane along the X-axis is shown below and is
Given by Eq (1) for thinning

$$E(u) = \sum_{n=1}^{N} (2\, a_n \cos[(n - 0.5)\, \beta\, d \cos(u)]) \qquad (1)$$

u = sinθ

a_n =Amplitude excitation of the n^{th} element

If a_n =1 turn ON

If a_n =0 turn OFF

d=Inter element spacing= λ / 2

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

The free space far field pattern E(u) for thickening is given by Eq (2)

$$E(u) = \sum_{n=1}^{N} a(x)\ e^{j[(2\pi d/\lambda) u x_n + \phi(x)]} \qquad (2)$$

a(x)=Amplitude excitation

u= sin θ

x_n = spacing=(2n – N -1) / N (ishmaru) [12]
Φ(x) = phase excitation =0

III. Results

Table1: Comparison of SLL and Beamwidth for thinned and thicked arrays

S.NO	Number of Elements	Thinning		Thickening	
		SLL in dB	Beam width	SLL	Beam width
1	10	-30.4	0.2458	-19.0	0.328
2	20	-24.3	0.12	-18.8	0.18
3	30	-23.34	0.0792	-17	0.132
4	50	-22.5	0.04	-15.45	0.08
5	70	-19.19	0.04	-14.82	0.06
6	90	-18.28	0.02	-14.5	0.04

Table 2: Amplitude and spacing values for thinned and thicked arrays for N=10

S.NO	Amplitude distribution for thinning	Spacing for thinning	Amplitude distribution for thickening	Spacing for thickening
1	1	-2.5	1	-0.9000
2	1	-2	1,1	-0.700,-0.800
3	1	-1.5	1	-0.5000
4	1	-1	1	-0.3000
5	1	-0.5	1	-0.1000
6	1	0.5	1	0.1000
7	0	1	1	0.3000
8	0	1.5	1	0.5000
9	1	2	1,1	0.7000,0.8000
10	1	2.5	1	0.9000

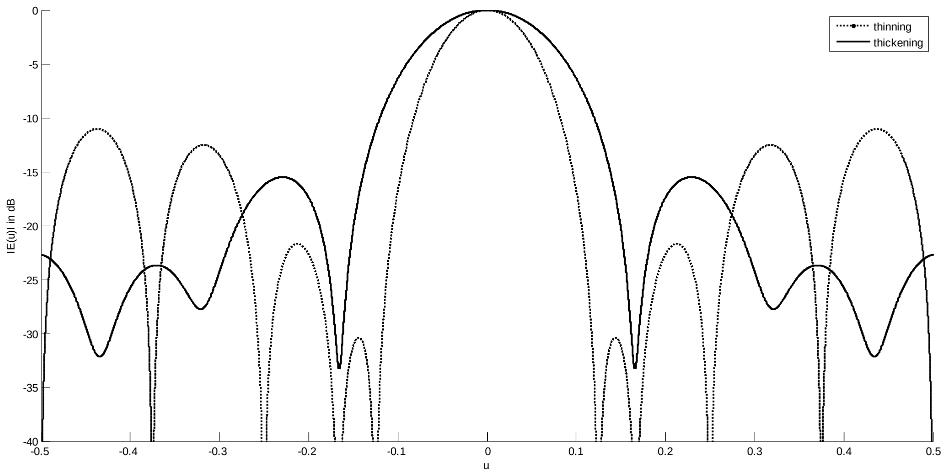


Fig1: Radiation pattern for thinned and thicked array for N=10

Table 3: Amplitude and spacing values for thinned and thicked arrays for N=20

S.NO	Amplitude distribution for thinning	Spacing for thinning	Amplitude distribution for thickening	Spacing for thickening
1	1	-5	1	-0.9500
2	1	-4.5	1,1	-0.8500,-0.9
3	1	-4	1	-0.7500
4	1	-3.5	1	-0.6500
5	1	-3	1	-0.5500
6	1	-2.5	1	-0.4500
7	1	-2	1	-0.3500
8	1	-1.5	1	-0.2500
9	1	-1	1	-0.1500
10	1	-0.5	1	-0.0500
11	1	0.5	1	0.0500

12	1	1	1	0.1500
13	0	1.5	1	0.2500
14	0	2	1	0.3500
15	1	2.5	1	0.4500
16	1	3	1	0.5500
17	1	3.5	1	0.6500
18	1	4	1	0.7500
19	0	4.5	1,1	0.8500,0.9
20	0	5	1	0.9500

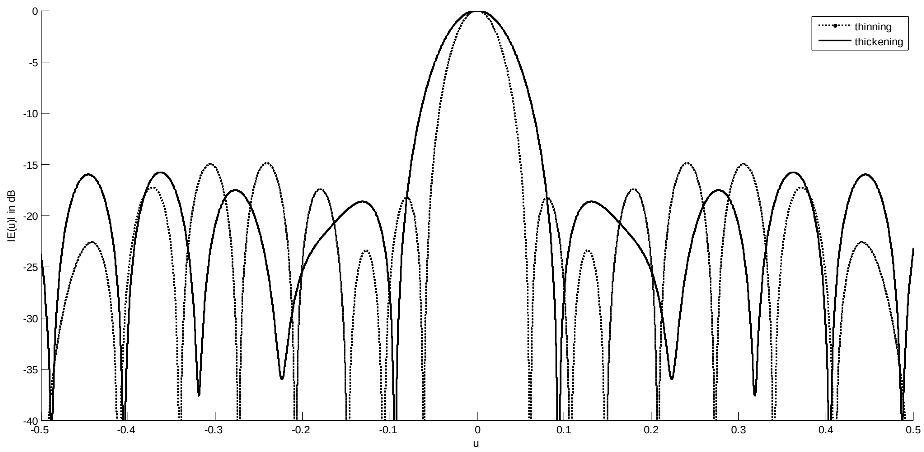


Fig2: Radiation pattern for thinned and thicked array for N=20

Table 4: Amplitude and spacing values for thinned and thicked arrays for N=30

S.NO	Amplitude distribution for thinning	Spacing for thinning	Amplitude distribution for thickening	Spacing for thickening
1	1	-7.5	1	-0.9667
2	1	-7	1,1	-0.90,-.93
3	1	-6.5	1	-0.8333
4	1	-6	1	-0.7667
5	1	-5.5	1	-0.7000
6	1	-5	1	-0.6333
7	1	-4.5	1	-0.5667
8	1	-4	1	-0.5000
9	1	-3.5	1	-0.4333
10	1	-3	1	-0.3667
11	1	-2.5	1	-0.3000
12	1	-2	1	-0.2333
13	1	-1.5	1	-0.1667
14	1	-1	1	-0.1000
15	1	-0.5	1	-0.0333
16	1	0.5	1	0.0333
17	0	1	1	0.1000
18	1	1.5	1	0.1667
19	0	2	1	0.2333
20	1	2.5	1	0.3000
21	0	3	1	0.3667
22	1	3.5	1	0.4333
23	1	4	1	0.5000
24	0	4.5	1	0.5667
25	1	5	1	0.6333
26	0	5.5	1	0.7000
27	1	6	1	0.7667
28	0	6.5	1	0.8333
29	1	7	1,1	0.90,0.93
30	1	7.5	1	0.9667

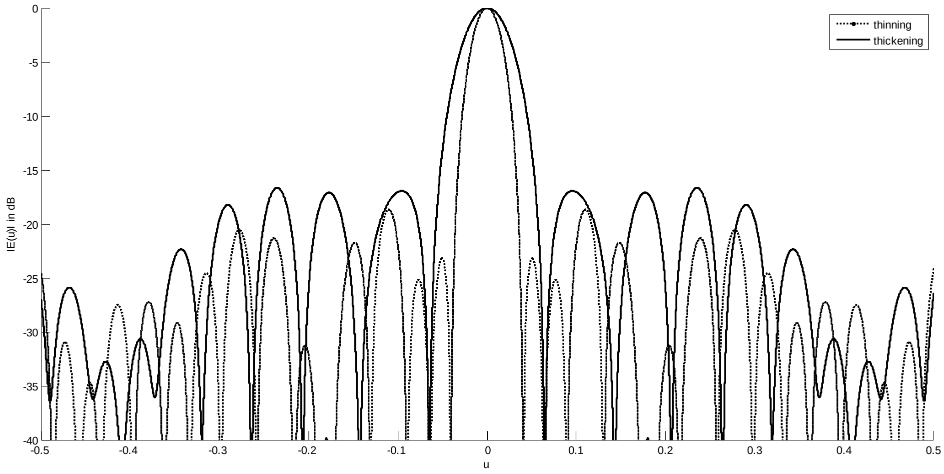


Fig3: Radiation pattern for thinned and thicked array for N=30

Table 5: Amplitude and spacing values for thinned and thicked arrays for N=50

S.NO	Amplitude distribution for thinning	Amplitude distribution for thickening	Spacing
1	1	1	-0.9800
2	1	1,1	-0.9400,0.96
3	1	1	-0.9000
4	1	1	- 0.8600
5	1	1	-0.8200
6	1	1	-0.7800
7	1	1	-0.7400
8	1	1	-0.7000
9	1	1	-0.6600
10	1	1	-0.6200
11	1	1	-0.5800
12	1	1	-0.5400
13	1	1	-0.5000
14	1	1	-0.4600
15	1	1	-0.4200
16	1	1	-0.3800
17	1	1	-0.3400
18	1	1	-0.3000
19	1	1	-0.2600
20	1	1	-0.2200
21	1	1	-0.1800
22	1	1	-0.1400
23	1	1	-0.1000
24	1	1	-0.0600
25	1	1	-0.0200
26	1	1	0.0200
27	0	1	0.0600
28	1	1	0.1000
29	0	1	0.1400
30	1	1	0.1800
31	0	1	0.2200
32	1	1	0.2600
33	1	1	0.3000
34	0	1	0.3400
35	0	1	0.3800
36	1	1	0.4200
37	1	1	0.4600
38	0	1	0.5000
39	1	1	0.5400
40	1	1	0.5800
41	0	1	0.6200
42	1	1	0.6600
43	1	1	0.7000
44	0	1	0.7400

45	1	1	0.7800
46	0	1	0.8200
47	1	1	0.8600
48	0	1	0.9000
49	1	1,1	0.9400,0.96
50	1	1	0.9800

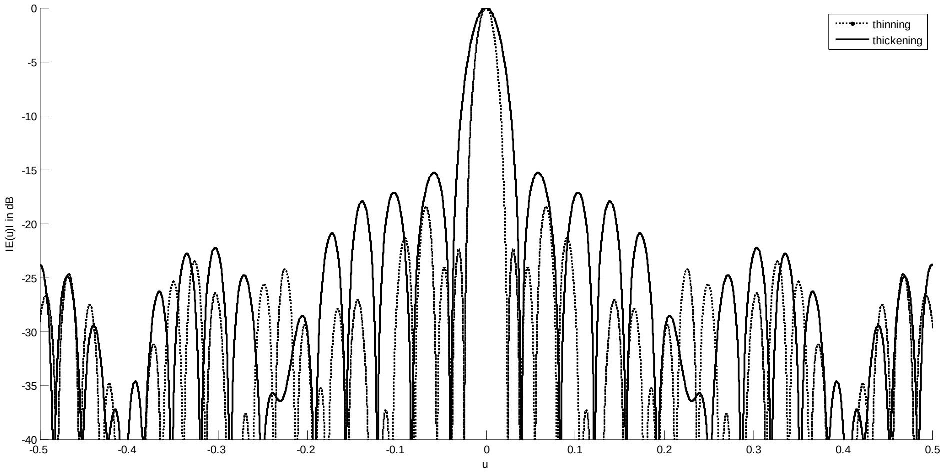


Fig4: Radiation pattern for thinned and thicked array for N=50

Table 6: Amplitude and spacing values for thinned and thicked arrays for N=70

S.NO	Amplitude distribution for thinning	Amplitude distribution for thickening	Spacing
1	1	1	-0.9857
2	1	1,1	- 0.9571.-0.965
3	1	1	- 0.9286
4	1	1	- 0.9000
5	1	1	-0.8714
6	1	1	- 0.8429
7	1	1	- 0.8143
8	1	1	-0.7857
9	1	1	-0.7571
10	1	1	-0.7286
11	1	1	-0.7000
12	1	1	-0.6714
13	1	1	-0.6429
14	1	1	-0.6143
15	1	1	-0.5857
16	1	1	- 0.5571
17	1	1	- 0.5286
18	1	1	- 0.5000
19	1	1	- 0.4714
20	1	1	-0.4429
21	1	1	- 0.4143
22	1	1	-0.3857
23	1	1	-0.3571
24	1	1	-0.3286
25	1	1	-0.3000
26	1	1	-0.2714
27	1	1	-0.2429
28	1	1	-0.2143
29	1	1	-0.1857
30	1	1	-0.1571
31	1	1	-0.1286
32	1	1	-0.1000
33	1	1	-0.0714
34	1	1	-0.0429
35	1	1	-0.0143
36	1	1	0.0143
37	1	1	0.0429

38	0	1	0.0714
39	1	1	0.1000
40	0	1	0.1286
41	1	1	0.1571
42	0	1	0.1857
43	1	1	0.2143
44	0	1	0.2429
45	1	1	0.2714
46	0	1	0.3000
47	1	1	0.3286
48	1	1	0.3571
49	0	1	0.3857
50	1	1	0.4143
51	0	1	0.4429
52	1	1	0.4714
53	1	1	0.5000
54	0	1	0.5286
55	1	1	0.5571
56	1	1	0.5857
57	1	1	0.6143
58	0	1	0.6429
59	1	1	0.6714
60	0	1	0.7000
61	1	1	0.7286
62	1	1	0.7571
63	0	1	0.7857
64	1	1	0.8143
65	0	1	0.8429
66	1	1	0.8714
67	0	1	0.9000
68	1	1	0.9286
69	0	1,1	0.9571,0.965
70	1	1	0.9857

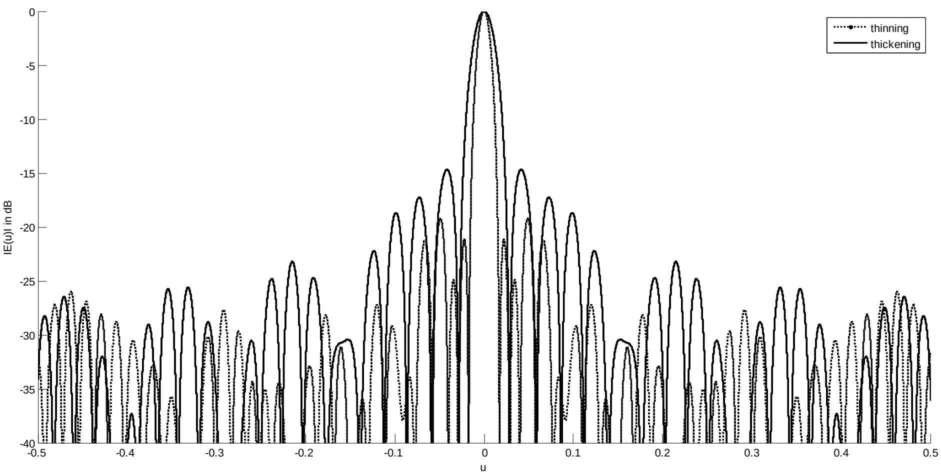


Fig5: Radiation pattern for thinned and thicked array for N=70

Table 7: Amplitude and spacing values for thinned and thicked arrays for N=90

S.NO	Amplitude distribution for thinning	Amplitude distribution for thickening	Spacing
1	1	1	-0.9889
2	1,1	1	-0.9667,-0.977
3	1	1	-0.9444
4	1	1	-0.9222
5	1	1	-0.9000
6	1	1	-0.8778
7	1	1	-0.8556
8	1	1	-0.8333
9	0	1	-0.8111
10	1	1	-0.7889

11	1	1	-0.7667
12	1	1	-0.7444
13	1	1	-0.7222
14	1	1	-0.7000
15	1	1	-0.6778
16	1	1	-0.6556
17	1	1	-0.6333
18	1	1	-0.6111
19	1	1	-0.5889
20	1	1	-0.5667
21	1	1	-0.5444
22	1	1	-0.5222
23	1	1	-0.5000
24	1	1	-0.4778
25	1	1	-0.4556
26	1	1	-0.4333
27	1	1	-0.4111
28	1	1	-0.3889
29	1	1	-0.3667
30	1	1	-0.3444
31	1	1	-0.3222
32	1	1	-0.3000
33	1	1	-0.2778
34	1	1	-0.2556
35	1	1	-0.2333
36	1	1	-0.2111
37	1	1	-0.1889
38	1	1	-0.1667
39	1	1	-0.1444
40	1	1	-0.1222
41	1	1	-0.1000
42	1	1	-0.0778
43	1	1	-0.0556
44	1	1	-0.0333
45	1	1	-0.0111
46	1	1	0.0111
47	1	1	0.0333
48	0	1	0.0556
49	1	1	0.0778
50	1	1	0.1000
51	0	1	0.1222
52	1	1	0.1444
53	1	1	0.1667
54	0	1	0.1889
55	1	1	0.2111
56	1	1	0.2333
57	1	1	0.2556
58	1	1	0.2778
59	0	1	0.3000
60	1	1	0.3222
61	1	1	0.3444
62	0	1	0.3667
63	1	1	0.3889
64	1	1	0.4111
65	0	1	0.4333
66	0	1	0.4556
67	1	1	0.4778
68	1	1	0.5000
69	0	1	0.5222
70	1	1	0.5444
71	1	1	0.5667
72	0	1	0.5889
73	1	1	0.6111
74	1	1	0.6333
75	0	1	0.6556
76	1	1	0.6778
77	1	1	0.7000
78	0	1	0.7222
79	0	1	0.7444
80	0	1	0.7667

81	1	1	0.7889
82	1	1	0.8111
83	0	1	0.8333
84	1	1	0.8556
85	0	1	0.8778
86	1	1	0.9000
87	0	1	0.9222
88	1	1	0.9444
89	1	1,1	0.9667,0.977
90	0	1	0.9889

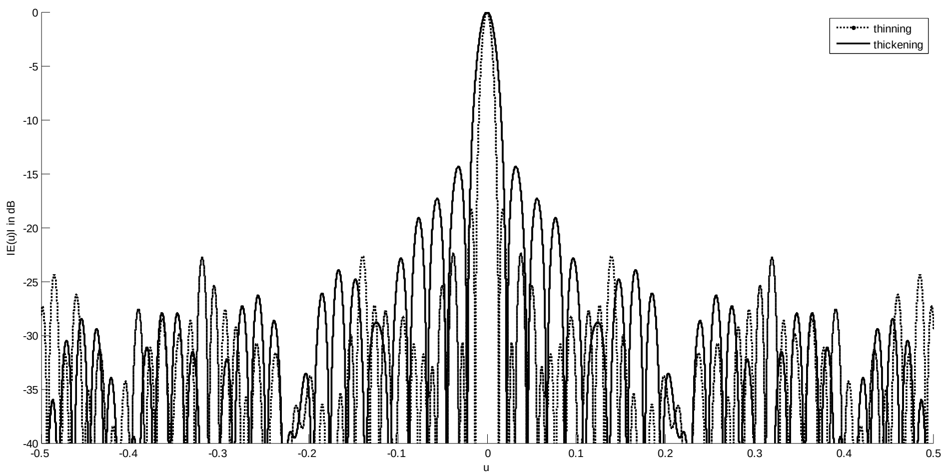


Fig 6: Radiation pattern for thinned and thicked array for N=90

IV. Conclusion

The work presents a new technique for designing a thinned and thicked linear antenna arrays with reduced close in sidelobe levels with fixing the percentage of thinning and thickening.

One of the objective is less beam width is achieved for ishmaru spacing and low sidelobe level is achieved for resonant spacing.

Results for a thinned and thicked linear isotropic antenna array have illustrated the performance of this proposed technique. This method is very simple and can be used in practice to synthesise thinned and thicked arrays.The patterns are very useful for radar applications and by using thinning power can be saved.

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