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Antenna Array Weight Synthesis for Low Side Lobe Levels using Window Functions

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Abstract: ***A lot of research is being carried out to reduce side lobe levels (SSLs) in the radiation pattern of antenna arrays. A number of novel optimization techniques have been developed over the years and adapted for this purpose. In this paper, a number of window functions are applied to suppress the maximum side lobe level (MSLL) in linear antenna arrays. The window functions Bartlett, Taylor, Hanning, Barthann, Hamming, Gaussian, Blackman, Chebyshev, Blackman-Harris and Kaiser are considered in the simulation. The optimized pattern for a 10 element linear antenna array and corresponding normalized window tappers for every window are presented. Finally the efficiency of all windows is compared in terms of their computed parameters.***

Keywords: Chebyshev window, Gaussian window, linear antenna array, MSLL, Taylor window, window Tappers.

I. INTRODUCTION

The antenna arrays used at the transmitter side the main problem in the radiation pattern is high side lobe levels. This is a serious problem in most of the basic communication systems because it is completely wastage of power in directions of undesired signals. So the desired maximum SLL level maintained as low as possible which means low powers are radiated in the direction of interferers. In the field of radar engineering low side lobe powers are required to reduce the problem of false target identification through these side lobes. The low SLLs in antenna arrays can be achieved by varying the array elements number, the separation between the elements and window function coefficients [1].

In antenna arrays, a group of the antenna elements are located at different positions and are excited simultaneously to produce the desired radiation pattern. The antenna arrays perform better compared to single antennas by increase the signal strength in a particular direction along the main beam [2]. In antenna arrays, high gains are obtained by reducing the minor lobes power. Various fields of applications of the antenna arrays are radar systems, sonar systems, cellular communications, mobile communications and satellite communications.

In the presence of strong clusters (unwanted echoes from ground, water, living beings, and atmospheric disturbances) exact target detection is a complicated problem in radar systems [3]. In this case window functions or tappers are used to obtain the low SLLs in antenna arrays. The Window techniques are mainly suitable for uniform linear arrays with isotropic elements. Since every window has its own feature, a number of window functions are considered for simulation.

In this paper different window functions are applied to linear antenna array configurations to produce minimum side lobe patterns [4]. This paper is organized in the following sequence. The array pattern synthesis overview is discussed in section II. Different window functions used in the synthesis are presented in section III. Simulation results with minimum side lobe patterns are obtained in section IV and the conclusion is presented in section V.

II. ARRAY PATTERN SYNTHESIS

In antenna arrays obtaining the desired signal while filtering out the interfering signals and internal and external noise is known as array beamforming. Array beamforming can be divided into switched beamforming (array pattern synthesis) and adaptive beamforming. Adaptive antenna array systems provide better signal reception but are costly due to the use of fast computing digital processing systems. Because of the simplicity of system design switched beam systems can be considered in some in array synthesis problems as compared to fully adaptive antenna array systems. Switched beam (or array pattern) synthesis can be further classified into weight and geometry synthesis.

A. Array Weight Synthesis

In the array weight synthesis process the desired array pattern is obtained with fixed weights. These synthesis methods are most suitable for the design linear antenna arrays with isotropic antenna elements.

B. Array geometry synthesis

In array geometry synthesis process array element positions are adjusted to get required synthesized pattern. That is spacing between the elements is adjusted to achieve the optimized pattern.

The array response of N element linear antenna array with isotropic point sources based on element weights and element positions is given by

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$$AF = \sum_{n=1}^{N} W_n e^{j\Psi_n} \quad (1)$$

Where
W_n= Array element weights
Ψ_n= Progressive phase difference among the array elements
N= number of elements in the array antenna

III. WINDOWING FUNCTIONS

A window function is also known as the tapering function or weighting function is the mathematical function and exit within the specified interval and outside this, they do not exist. Therefore window functions [5-8] are used to reduce the SLLs in the antenna array synthesis.

3.1 Different Window Functions:

3.1.1 Bartlett Window or Triangular Window:

The coefficients of N point (N is even) Triangular window are defined as

$$w(n) = \begin{cases} \dfrac{2n-1}{N} & 1 \le n \le \dfrac{N}{2} \\ 2 - \dfrac{(2n-1)}{N} & \dfrac{N}{2}+1 \le n \le N \end{cases} \quad (2)$$

3.1.2 Taylor Window:

The Fourier Transform of the Taylor window taper function is defined as

$$w(n) = \mathrm{sinc}(n) + \sum_{m=1}^{(\bar{n}-1)} F_m(\mathrm{sinc}(n-m) + \mathrm{sinc}(n+m)) \quad (3)$$

Where $\bar{n}$ is the distance between the main lobe and the constant sidelobes and F_m defines window coefficients.

3.1.3 Hann (Hanning) Window:

The coefficients of N point Hanning window are defined as

$$w(n) = 0.5\left(1 - \cos\left(2\pi \frac{n}{N-1}\right)\right); \; 0 \le n \le N-1 \quad (4)$$

3.1.4 Barthann (Modified Bartlett-Hann) window:

The coefficients of N point Barthann window are defined as

$$w(n) = 0.62 - 0.48\left|\left(\frac{n}{N-1} - 0.5\right)\right| + 0.38 \cos\left(2\pi\left(\frac{n}{N-1} - 0.5\right)\right)$$
$$for\; 0 \le n \le N-1 \quad (5)$$

3.1.5 Hamming Window:

The coefficients of N point Hamming window are defined as

$$w(n) = 0.54 - 0.46 \cos\left(2\pi \frac{n}{N-1}\right); \; 0 \le n \le N-1 \quad (6)$$

3.1.6 Gaussian Window:

The coefficients of N point Gaussian window are defined as

$$w(n) = e^{-n^2/2\sigma^2}; \quad -\frac{(N-1)}{2} \le n \le \frac{N-1}{2} \quad (7)$$

Where, σ is the standard deviation of a Gaussian random variable.

3.1.7 Blackman Window:

The coefficients of N point (N is even) Blackman window are defined as

$$w(n) = 0.42 - 0.5\cos\left(\frac{2\pi n}{N-1}\right) + 0.08\cos\left(\frac{4\pi n}{N-1}\right);$$
$$for\; 0 \le n \le \frac{N}{2} - 1 \quad (8)$$

3.1.8 Chebyshev Window:

The Fourier Transform of the Chebyshev window taper function is defined as

$$w(n) = \frac{\psi(n,N)\cos\left(\pi\sqrt{n^2 - A^2}\right)}{\cos \pi\sqrt{-A^2}} \quad (9)$$

Where

$$A = \frac{\ln\left(\eta + \sqrt{\eta^2 - 1}\right)}{\cos \pi\sqrt{-A^2}}$$

$$\eta = 10^{-S/20}$$

And S is side lobe level and ψ defines the sign of the expression.

3.1.9 Blackman-Harris Window:

The coefficients of N point Blackman-Harris Window are defined as

$$w(x) = a_0 + a_1\cos\left(\frac{2\pi n}{N-1}\right) + a_2\cos\left(\frac{4\pi n}{N-1}\right) - a_2\cos\left(\frac{6\pi n}{N-1}\right)$$
$$for\; 0 \le n \le N-1 \quad (10)$$

Wher the coefficients a_0=0.35875, a_1=0.48829, a_2=0.14128, a_3=0.01168.

3.1.10 Kaiser Window:

The coefficients of N point Kaiser Window are defined as

$$w(n) = \frac{I_0\left(\beta\sqrt{1 - \left(\frac{n-(N-1/2)}{(N-1/2)}\right)^2}\right)}{I_0(\beta)}; \; 0 \le n \le N-1 \quad (11)$$

Where I_0 presented in the equation is the zeroth-order modified Bessel function of the first kind. The parameter $\beta = \pi\alpha$ and α determines the shape of the window.

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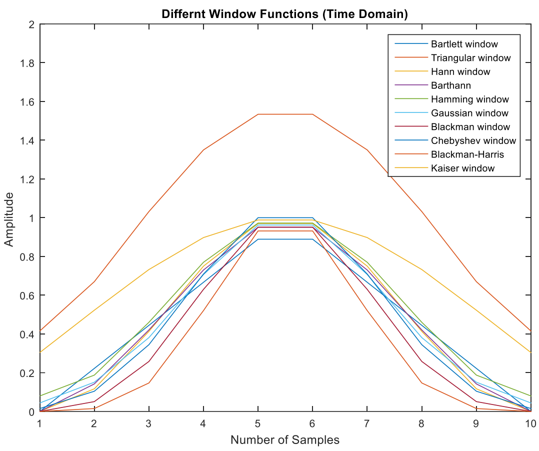

Figure 1: Different Window functions in Time Domain

The time domain response of different window functions used in the simulation is shown in figure 1 and their equivalent noise bandwidth (ENBW) is tabulated in table 1. The ENBW of a window function is defined by the width of a rectangle that holds the same amount of window power.

Table 1: Equivalent Noise bandwidth for different window function

S.NO.	Window Function	Equivalent Noise Bandwidth (Hz)
1	Bartlett Window	1.5
2	Taylor Window	1.171
3	Hann Window	1.666
4	Barthann Window	1.622
5	Hamming Window	1.468
6	Gaussian Window	1.582
7	Blackman Window	1.918
8	Chebyshev Window	1.728
9	Blackman-Harris Window	2.227
10	Kaiser Window	1.005

IV. RESULT AND DISCUSSION

The weight synthesis of a 10 element uniform linear array for minimum side lobe levels with 10 mostly used window functions is presented in this paper. The resultant maximum side lobe levels and first null beam widths are tabulated in table 2. In all the figures the desired pattern is compared with the synthesized pattern after optimization.

Table 2: Pattern synthesis of uniform linear array with different window function weights

S.NO.	Window Function	Maximum Side Lobe Level (MSLL) dB	First Null Beam Width (FNBW) Degrees
1	Bartlett Window	-25.77	48
2	Taylor Window	-29.79	34
3	Hann Window	-31.83	52
4	Barthann Window	-34.83	62
5	Hamming Window	-35.83	52
6	Gaussian Window	-49.10	80
7	Blackman Window	-64.62	84
8	Chebyshev Window	-100.8	86
9	Blackman-Harris Window	-108.2	134
10	Kaiser Window with β = 0.5	-13.42	24
11	Kaiser Window with β = 2.5	-23.36	32

Example1: Array pattern synthesis with Bartlett window:

A 10 Bartlett window tapered linear antenna array is used for synthesis. The Maximum side lobe level is reduced for -13dB as with conventional array to -25.77dB and the FNBW of 48^0. It is also observed that the 1^{st} side lobe level is reduced to -37.26 as shown in figure 2 and the normalized window tappers for the optimized pattern is shown in figure 3.

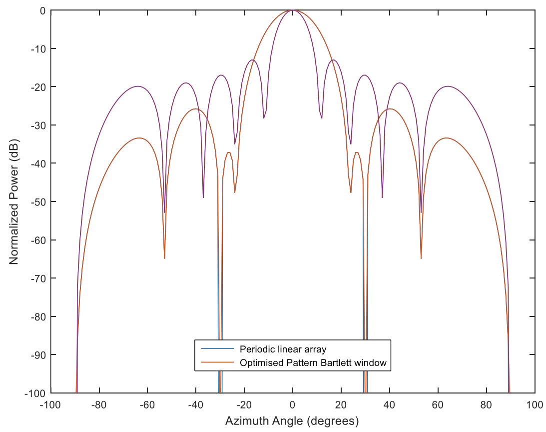

Figure 2: Optimized Pattern with Bartlett Window

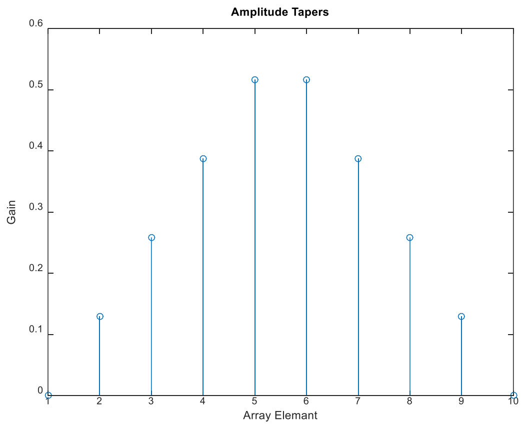

Figure 3: Normalized Taylor Window Tappers for Optimized Pattern

Example 2: Array pattern synthesis with Taylor window:

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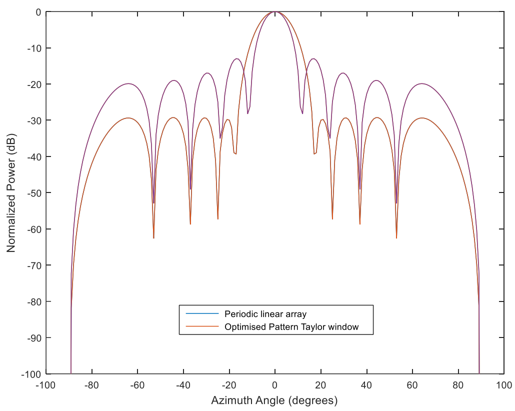

Figure 4: Optimized Pattern with Taylor Window

In this example 2 a Taylor with 4 side lobe levels -30dB is considered for simulation. The FNBW of 34^0 is observed and is the minimum one compared to the remaining windows listed in table 2. The figures 4 and 5 show the optimized pattern and corresponding normalized tappers for the Taylor window.

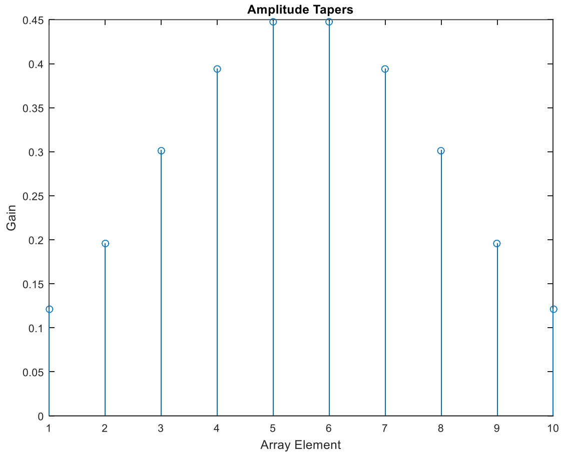

Figure 5: Normalized Taylor Window Tappers for Optimized Pattern

Example 3: Array pattern synthesis with Hann window:

This window is also known as the von Hann window or raised-cosine window.

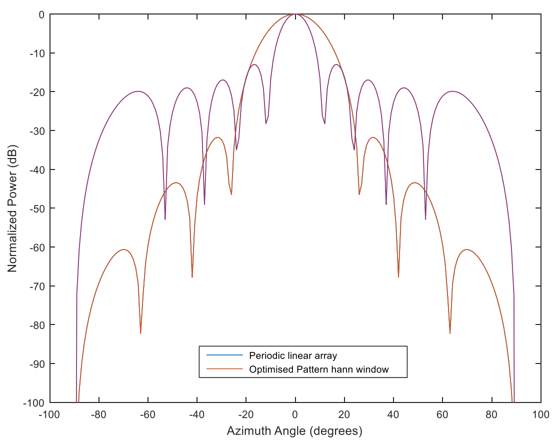

Figure 6: Optimized Pattern with Hann Window

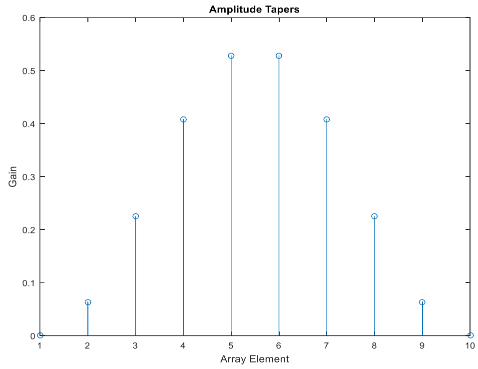

Figure 7: Normalized Hann Window Tappers for Optimized Pattern

The MSLL level of -31.83dB and FNBW of 52^0 is obtained with Hanning window. The synthesized pattern and normalized Hann window weights are shown in figures 6 and 7 respectively.

Example 4: Array pattern synthesis with Barthann window:

The Barthann window is a combination of Bartlett window and Hann window. Compare to these both windows the barthann window produces lower SLLs. Here the FNBW of 52^0 is the same as the Hann window but the side lobe power is reduced to -34.76dB as shown in figure 8. Hence for low side lobe levels, Barthann is preferred compared to the Hann window. The normalized Barthann window tappers are shown in figure 9.

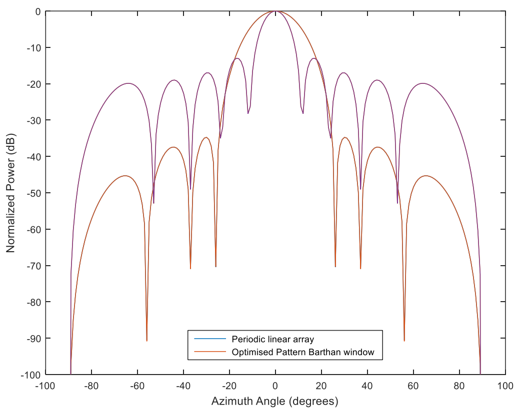

Figure 8: Optimized Pattern with Bathan Window

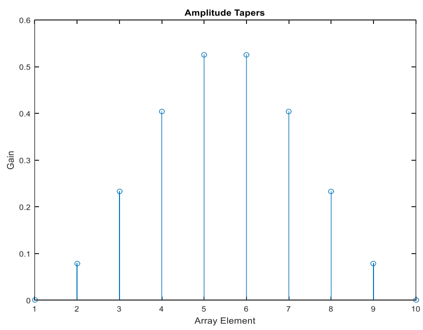

Figure 9: Normalized Bathan Window Tappers for Optimized Pattern

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Example 5: Array pattern synthesis with Hamming window:

The Hamming window is considered as optimized form the Hanning window. The minimum first side lobe level (FSLL) can be obtained with the coefficients of this window. A 10 point hamming window is used for the low side lobe levels. As shown in figure 10 the side lobe level is reduced from -13dB of uniform linear to -35.83dB. But it is achieved with the increase of FNBW for 24^0 to 62^0. The normalized window tappers for the optimized pattern are shown in figure 11.

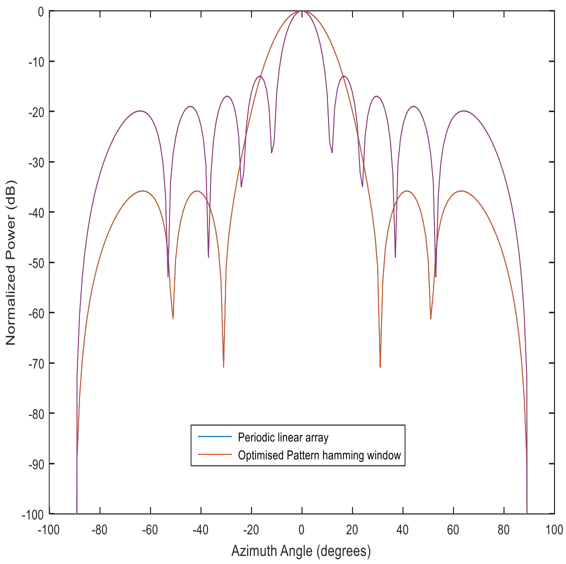

Figure 10: Optimized Pattern with Hamming Window

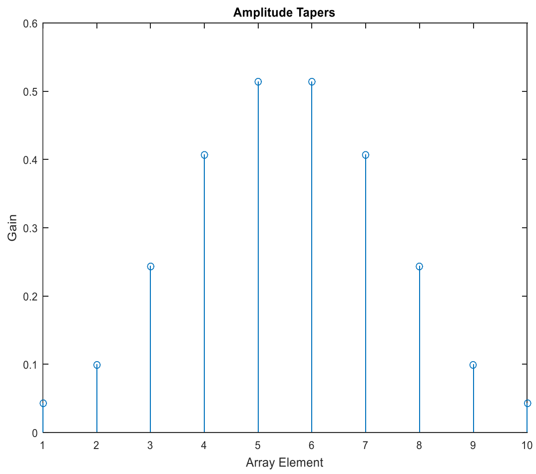

Figure 11: Normalized Hamming Window Tappers for Optimized Pattern

Example 6: Array pattern synthesis with Gaussian window:

A Gaussian window with a zero mean and 0.4 standard deviation is considered for simulation. With the Gaussian window, the side lobe levels as low as -49.10dB is obtained with the expanse of increased FNBW of 80^0. The normalized Gaussian Window Tappers for Optimized Pattern are shown in figure 13.

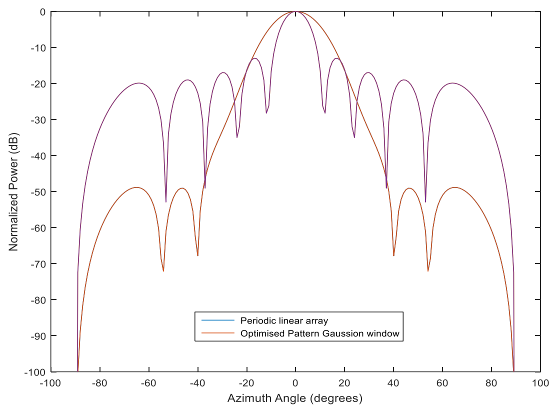

Figure 12: Optimized Pattern with Gaussian Window

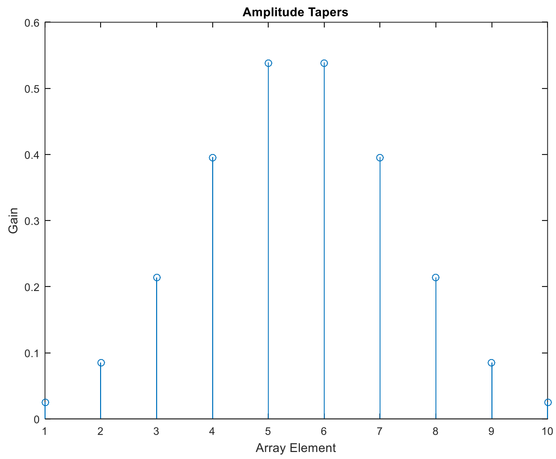

Figure 13: Normalized Gaussian Window Tappers for Optimized Pattern

Example 7: Array pattern synthesis with Blackman window

The FNBW of 84^0 and MSLL of -64.62dB are obtained with the Blackman window. The optimized pattern is shown in figure 14 and the normalized Blackman window weights are shown in figure 15.

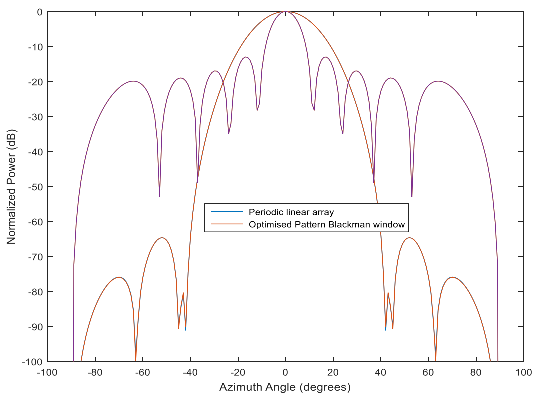

Figure 14: Optimized Pattern with Blackman Window

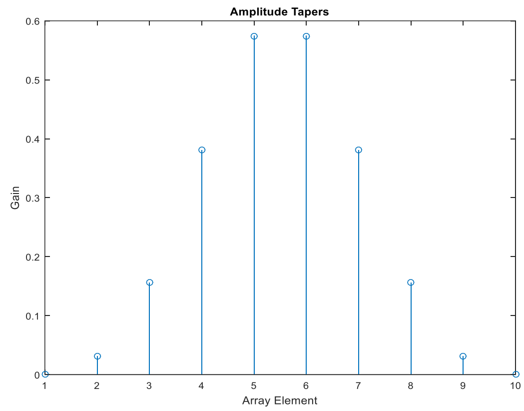

Figure 15: Normalized Blackman Window Tappers for Optimized Pattern

Example 8: Array pattern synthesis with Chebyshev window:

In this example, a 10 point Chebyshev window with side lobe magnitude of -100.8dB is considered for simulation. But the first null beam width is increased to 86^0 as shown in figure 16 and figure 17 presents corresponding Chebyshev window weights.

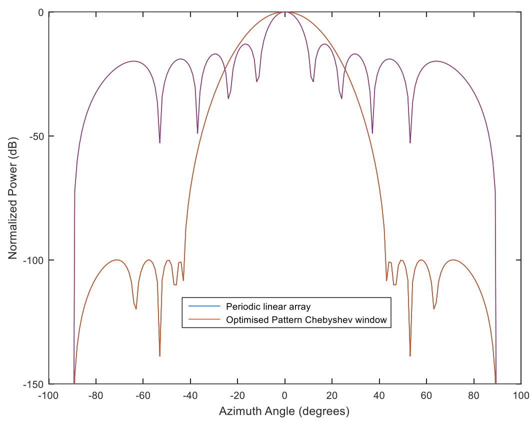

Figure 16: Optimized Pattern with Chebyshev Window

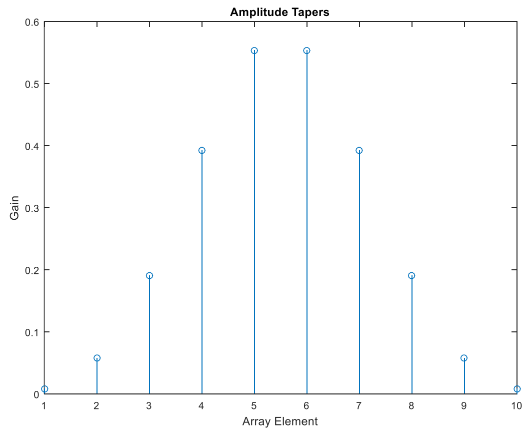

Figure 17: Normalized Chebyshev Window Tappers for Optimized Pattern

Example 9: Array pattern synthesis with Blackman-Harris window:

For comparing the listed windows in table 2 Blackman-Harris window produces the side lobe levels of -108.20dB but with the expense of FNBW of 1340 as shown in figure 17. The normalized weights are shown in figure 18.

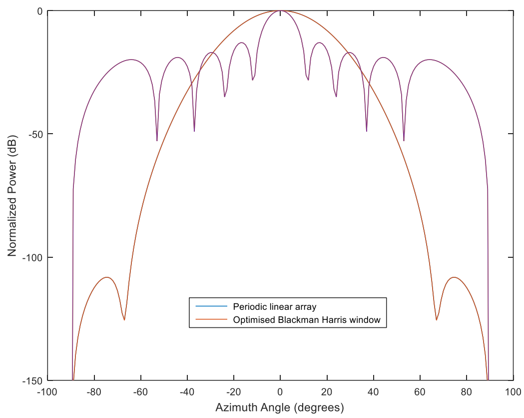

Figure 18: Optimized Pattern with Blackman-Harris Window

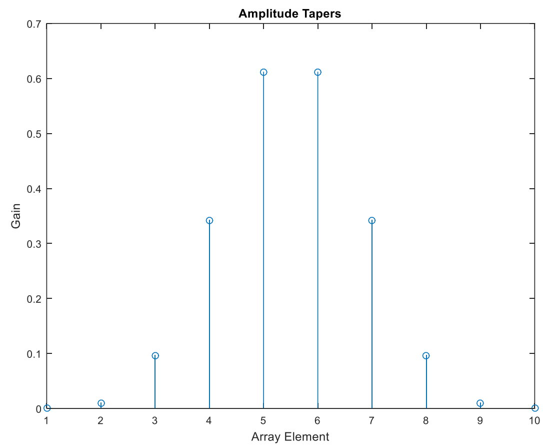

Figure 19: Normalized Blackman-Harris Window Tappers for Optimized Pattern

Example 10: Array pattern synthesis with Kaiser window for β = 0.5.

The 10 point Kaiser window for β = 0.5 reduces the side lobe level from -13dB to -13.42dB by maintaining the same FNBW. The synthesized pattern is shown in figure 20 and the window tappers are shown in figure 21.

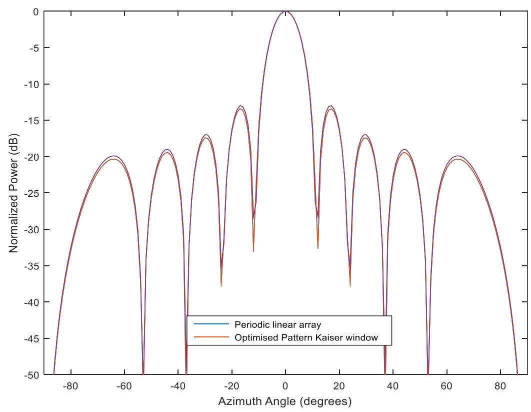

Figure 20: Optimized Pattern with Kaiser Window with β = 0.5

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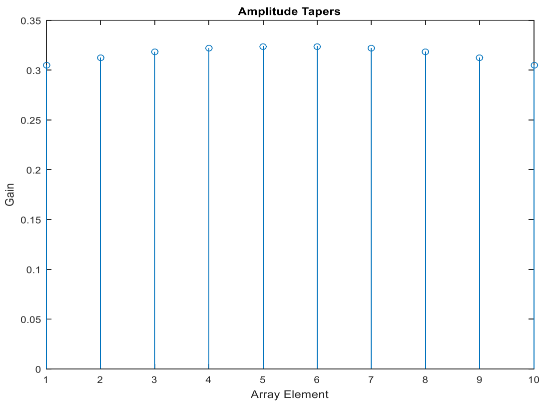

Figure 21: Normalized Kaiser Window Tappers for Optimized Pattern with β = 0.5

Example 11: Array pattern synthesis with Kaiser window with β = 2.5:

The parameter β in the Kiser window controls the relative side lobe levels in the synthesized pattern. With β = 2.5 the side lobe level is reduced to -23.36dB but with small increase in FNBW of 32^0.

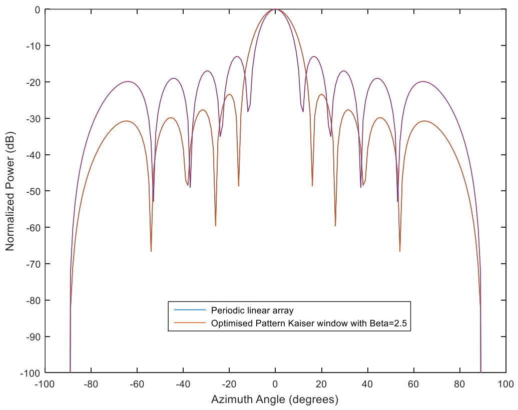

Figure 22: Optimized Pattern with Kaiser Window with β = 2.5

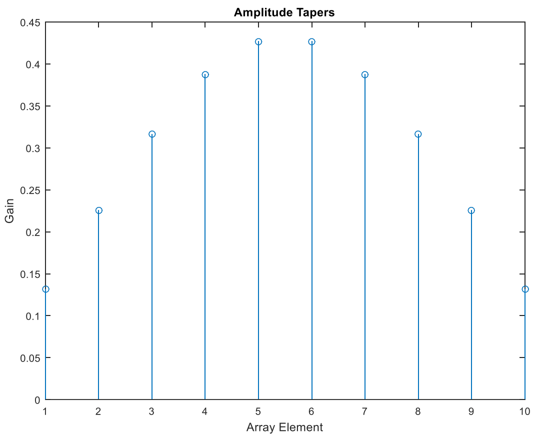

Figure 21: Normalized Kaiser Window Tappers for Optimized Pattern with β = 2.5

V. CONCLUSION

In this paper, a linear antenna array is analyzed to reduce side lobe levels with different window functions. Here different window function coefficients are applied on antenna arrays to achieve MSSL reduction. The Blackman-Harris and Chebyshev windows reduce the side lobe level to minimum value compared to other windows. For minimum FNBW levels the Taylor and Kaiser window shows the enhanced perform compared to other windows. The MATLAB simulations are presented for 10 elements linear antenna array pattern with isotropic elements. The window function fixed weights can also be used for difference element antenna array patterns.

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