PERFORMANCE ANALYSIS OF LINEAR ARRAY ANTENNA IN RADAR SYSTEM THROUGH ANALYTICAL METHOD AND COMPUTATION METHOD VIA DFT

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ABSTRACT

It is important to design RADAR antennas with more energy radiated in some particular directions and less in other directions. Different types of antennas and their radiation patterns are evaluated. This is tantamount to requiring that the radiation pattern should be concentrated in the actual direction of interest. This is hardly achievable with a single RADAR antenna which has a specific radiation pattern. But with the use of the several antennas working together, it is possible to improve the radiation according to suit some specific requirements. In this study we have dealed with the most common linear array antenna. The equation of the electric field radiation pattern is derived with detail discussion on array tapering. Simulation result shows the radiation pattern in one direction with lowered side lobes, indicates the improvement of the wave propagation through the RADAR antenna.

KEYWORDS: Array Factor (AF), Discrete Fourier Transform (DFT), Radiation Pattern, Main Beam, Side Lobe.

1.0 INTRODUCTION

An antenna array is a group of two or more isotropic radiators such that the currents running through them are of different amplitudes and phases. Each radiator is denoted as an element. The elements forming an array could be dipoles dish reflectors, slots in a waveguide or any other type of radiator. Array antennas synthesize narrow directive beams that may be steered mechanically or electronically in many directions. The antenna consists of lines whose elements are fed about a common phase shifter. The antenna which is formed by these numbers of vertically mounted lines is called Linear Array Antenna.

In this paper we evaluate the electric field and the gain of the radiation pattern from the approximation of the geometric criterion from both the analytical method and the computation method of DFT. This analysis shows the relationship among the main lobes, grating lobes and side lobes. All the behavioral changes observed are illustrated in the subsequent sections.

The fact of the transmission of more power to the distinct direction by the array tapering has also been introduced. Array tapering controls the side lobes and forced to lower the levels of the side lobes at the expense of lower aperture efficiency and larger bandwidth.

2.0 DERIVATION OF ELECTRIC FIELD AND GAIN OF RADIATION PATTERN

A linear array antenna consisting of N identical elements spaced by d (normally measured in wavelength units). Let

element #1 serves as a phase reference for the array. From the geometry, it is clear that an outgoing wave at the nth element leads the phase at the (n+1) the element by kdsin?, where k = 2p/λ the combined phase at the far field observation point P is independent of f is computed as -

E (p) = E (one element) (array factor)

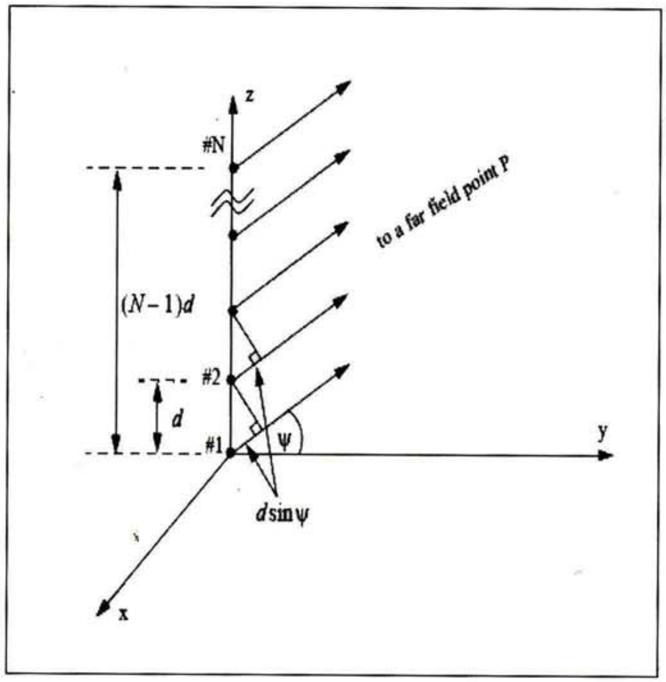

Figure-1: Linear array of equally spaced elements

The array factor is a general function of the number of elements, their spacing and their relative phases and magnitudes.

So the electric field at a far field observation point with direction-sine equal to sin? (assuming isotropic elements) is

$$E(\sin\psi) = \sum_{n=1}^{N} e^{j(n-1)kd\sin\psi} \quad \text{.......} (1)$$

and expanding this equation,

$$E(\sin\psi) = 1+e^{jkd\sin\psi} + \cdots\cdots + e^{j(n-1)kd\sin\psi} \quad \text{.......} (2)$$

The right-hand side of Eq-2 is a geometric series which can be expressed in the form

$$1+a+a^2+a^3+\cdots\cdots+a^{(n-1)} = \frac{1-a^N}{1-a} \quad \text{.......} (3)$$

Replacing a by $e^{jkd\sin\psi}$ yields,

$$|E(\sin\psi)| = \frac{1-e^{jNkd\sin\psi}}{1-e^{jNkd\sin\psi}}$$

$$= \frac{1-(\cos Nkd\sin\psi) - j(\sin Nkd\sin\psi)}{1-(\cos kd\sin\psi) - j(\sin kd\sin\psi)} \quad \text{......} \quad (4)$$

The far field array intensity pattern is then given by

$$|E(\sin\psi)| = \sqrt{E(\sin\psi) \times E^*(\sin\psi)} \quad \text{......} \quad (5)$$

Substituting Eq-4 into Eq-5

$$|E(\sin\psi)| = \sqrt{\frac{(1-\cos Nkd\sin\psi)^2+(1-\sin Nkd\sin\psi)^2}{(1-\cos kd\sin\psi)^2+(1-\sin Nkd\sin\psi)^2}}$$

$$= \sqrt{\frac{(1-\cos Nkd\sin\psi)}{(1-\cos kd\sin\psi)}} \quad \text{......} \quad (6)$$

And using the trigonometric identity, $1-\cos\theta = 2\left(\frac{\sin\theta}{2}\right)^2$ yields

$$|E(\sin\psi)| = \left|\frac{\sin(Nkd\sin\psi/2)}{\sin(kd\sin\psi)/2}\right| \quad \text{......} \quad (7)$$

Which is a periodic function of $kd\sin\psi$, with a period equal to 2π.
The maximum value $|E(\sin\psi)|$ of which occurs at $\psi = 0$, is equal to N. It follows that the normalized intensity pattern is equal to

$$|E(\sin\psi)| = \frac{1}{N}\left|\frac{\sin(Nkd\sin\psi/2)}{\sin(kd\sin\psi/2)}\right| \quad \text{......} \quad (8)$$

The normalized two way array pattern (radiation pattern) is given by

$$G(\sin\psi) = |E(\sin\psi)|^2$$

$$= \frac{1}{N^2}\left(\frac{\sin(Nkd\sin\psi/2)}{\sin(kd\sin\psi)/2}\right)^2 \quad \text{......} \quad (9)$$

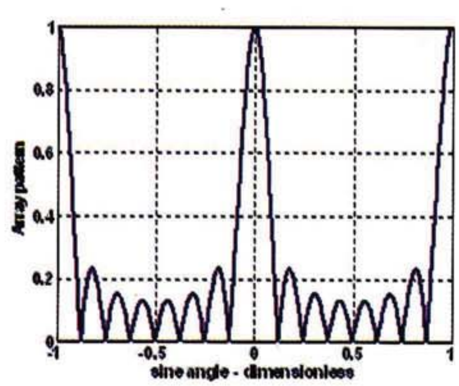

Figure- 2a: Normalized radiation pattern for linear array.

Figure-2a shows a plot of Eq-7 versus sin angle for N = 8. The radiation pattern G (sin ψ) has cylindrical symmetry about its axis (sin ψ = 0) and is independent of the azimuth angle. Thus it is completely determined by its values within the interval ($0 < \psi < \pi$) -

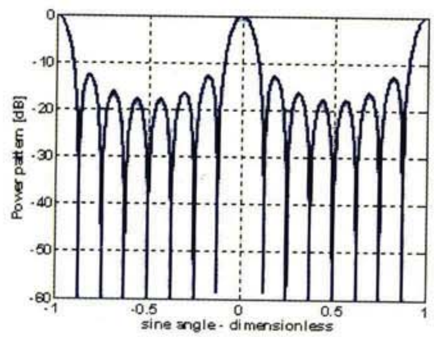

Figure-2b: Normalized power pattern

The main beam of an array can be steered electronically by varying the phase of the current applied to each array element. Steering the main beam into the direction-sine $\sin y_0$ is accomplished by making the phase difference between any two adjacent elements equal to $kd \sin y_0$. In this case the normalized radiation pattern is-

$$G(\sin\psi) = \frac{1}{N^2}\left(\frac{\sin\left[\left(\frac{Nkd}{2}\right)(\sin\psi - \sin\psi_o)\right]}{\sin\left[\left(\frac{kd}{2}\right)(\sin\psi - \sin\psi_o)\right]}\right)^2 \quad \text{..........} (10)$$

If $\psi_0 = 0$, then the main beam is perpendicular to the array axis and the array is said to be a broadside array. Alternatively, the array is called endfire array when the main beam points along the array axis.

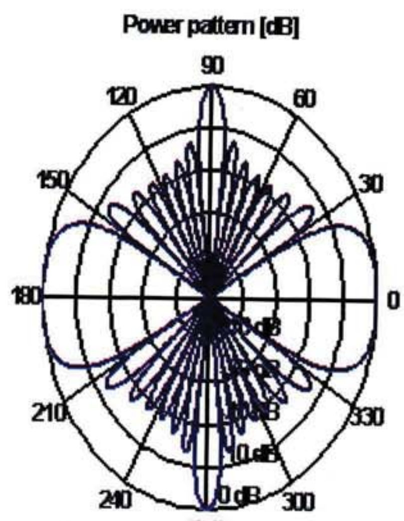

Figure-2c: Polar plot of power pattern

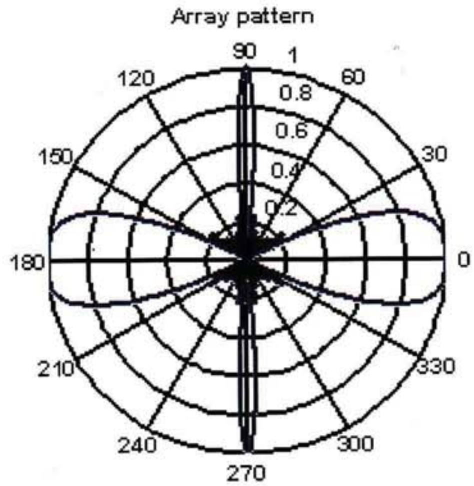

Figure-2d: Polar plot of array pattern.

The radiation pattern maxima are computed using L'Hospital's rule when both the denominator and numerator of Eq-9 are zeros. More precisely,

$$\frac{kd\sin\psi}{2} = \pm m\pi; \qquad m = 0,1,2,3\text{..........etc.} \qquad (11)$$

Solving ψ yields,

$$\psi_m = \operatorname{asin}\left(\pm\frac{\lambda m}{2}\right)$$

Where the subscript m is used as a maxima indicator. The first maxima occurs at $\psi_0 = 0$, known as main beam and the other maxima occurring at $|m| \geq 1$, known as grating lobes which are undesirable and must be suppressed. The grating lobes occur at,

$$|\sin\psi - \sin\psi_o| = \pm\frac{\lambda m}{d}; \qquad n = 1,2,3\text{..........etc.} \qquad (12)$$

Thus in order to prevent the grating lobes from occurring between ± 90, the element spacing should be $d < \lambda/2$.
Instead of $d < \lambda$. By this the directionality of the RADAR antenna will be improved.

3.0 RADIATION PATTERN BY COMPUTATION METHOD VIA DFT

Figure-3 shows a linear array of size N element spacing d and wavelength λ. The radiators are circular dishes of diameter d. Let w(n) and $\phi(n)$ denotes the tapering and phase shifting sequences. The normalized electric field at a far field point in the direction-sine sin? is -

$$E(\sin\psi) = \sum_{n=0}^{N-1} w(n) e^{j\triangle\phi\left(n - \left(\frac{n-1}{2}\right)\right)} \qquad (13)$$

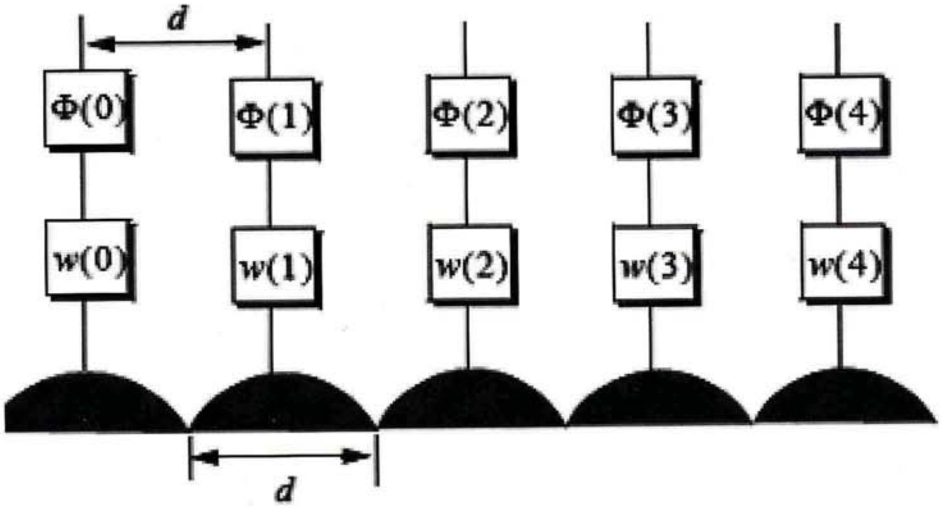

Figure-3: Linear array of size 5 with phase shifting hardware

Where in this case the phase reference is taken as the physical center of the array and

$$\triangle\varphi = \frac{2\pi d}{\lambda}\sin\psi$$

Expanding and factoring Eq-13 we get,

$$E(\sin\psi) = ej\varphi_o\{w(n-1)\, e^{-j\triangle\varphi(n-1)} + w(N-2)\, e^{-j\triangle\varphi(n-2)} + \ldots\ldots\ldots\ldots + w(0) \qquad \ldots\ldots\ldots \quad (14)$$

The discrete fourier transform of the sequence w(n) is defined as

$$W(q) = \sum_{n=0}^{N-1} w(n)e^{\frac{j2\pi nq}{N}} \qquad ; q = 0,1\ldots\ldots\ldots N \qquad \ldots\ldots\ldots\ldots (15)$$

The set of $\{\sin\psi_q\}$ which makes

$$\sin\psi_q = \frac{\lambda q}{Nd} \ldots\ldots\ldots\ldots \qquad \ldots\ldots\ldots\ldots (16)$$

So from Eq-15 & Eq-16

$$E(\sin\psi) = e^{j\varphi_o}\, W(q) \ \ldots\ldots\ldots \qquad \ldots\ldots\ldots\ldots (17)$$

Thus the one way array pattern is computed as the modulus of Eq-17. It follows that the radiation pattern becomes

$$G(\sin\psi) = G_e\ |W(q) \ \ldots\ldots\ldots \qquad \ldots\ldots\ldots\ldots (18)$$

Where G_e is element pattern

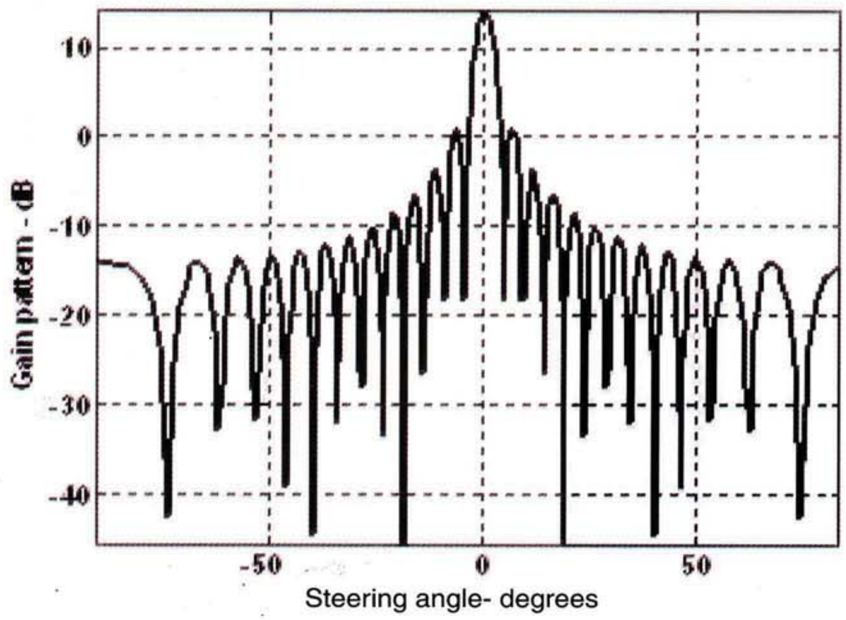

Figure-4a: Array gain pattern for steering angle = 0 and win = none.

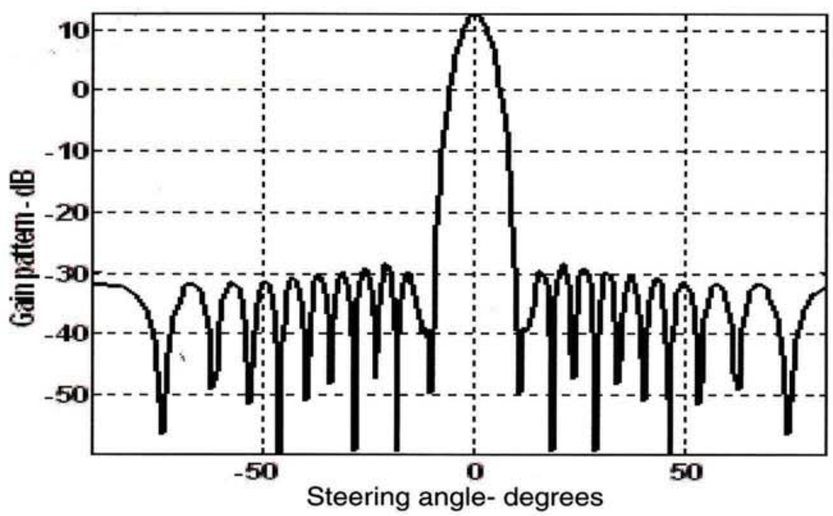

Figure-4b: Array gain pattern for steering angle = 0 and win=Hamming.

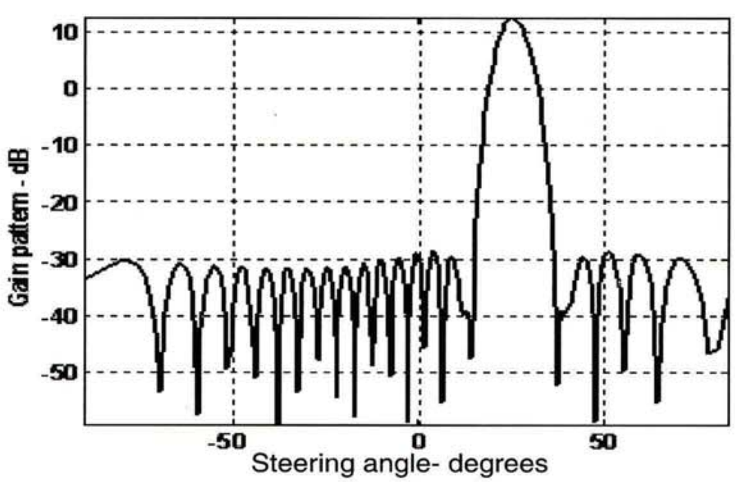

Figure-4c: Array gain pattern for steering angle = 25 and win=Hamming

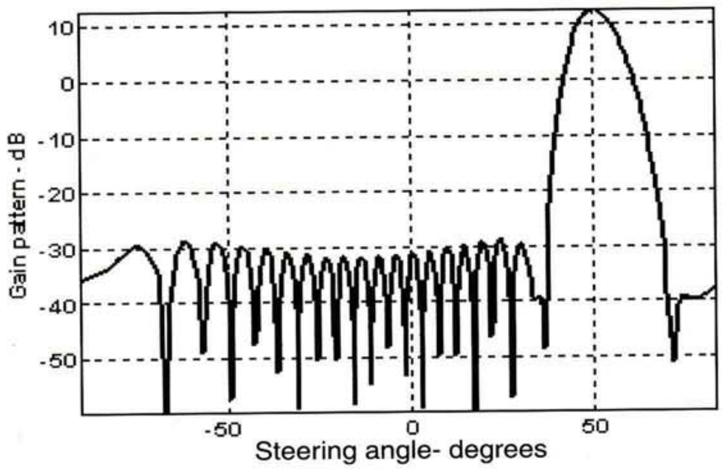

Figure-4d: Array gain pattern for steering angle = 50 and win = Hamming

The computer simulation of Eq-15 shows that with the increase of the steering angle (y) and the use of DFT through the various windows (such as - hamming, hanning, buttermouth etc) the main lobe level is increased lowering the sidelobes. At constant steering angle in Figure-4a there are increased level of the sidelobes while in Figure-4b with the use of the hamming windows the sidelobe levels are lowered. In Figure-4c and Figure-4d, it is shown that the more the steering angle with windows (hamming), the less the side lobe levels which increases the gain and the directivity of the RADAR antenna.

4.0 ARRAY TAPERING

Figure-2a shows the normalized radiation pattern of a uniformly excited linear array for element spacing d = $\lambda/2$. The first side lobe is about 13.46 db below the main lobe.

In order to reduce the side lobe levels, the array must be designed to radiate more power towards the centre and much less at the edge. Array tapering is nothing, simply the use of the windowing method used to reduce the side lobe levels at the expense of widening the main beam. Thus for a given radar application, the choice of the tapering sequence must be based on the trade off between side lobe reduction and main beam widening.

5.0 CONCLUSIONS

An analytical solution of the electric field and the radiation pattern with respect to the steering angle and the element spacing is being presented. Simulation result shows the method of reduction of the side lobe levels. It is estimated that the main beam becomes more directional with the optimized power gain as the aperture efficiency increases. So the approximate analysis presented here can be used to improve the directivity and the gain of RADAR antenna of linear array.

The further direction of this study can be to design the geometry of different types of the linear array for the high resolution RADAR system. In future it can be investigated to totally reduce the side lobes introducing sophisticated suppression technique. Array tapering method can be improved and used widely.

6.0 REFERENCES

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