ANALYSIS OF DIFFERENT TAPERING TECHNIQUES FOR EFFICIENT RADIATION PATTERN

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Abstract
Array antennas offer a wide range of opportunities in the variation of their directivity patterns through amplitude and phase control. Peak side lobe levels may be reduced via amplitude control or weighting across the array aperture. Several authors have made significant contributions in detailing processes for synthesizing these aperture amplitude distributions for the purpose of side lobe level control. One of the basic trades-offs when implementing amplitude weighting functions is that a trade between low side lobe levels and a loss in main beam directivity always results. In this paper we are implemented and compare the Binomial array, Dolph-Tchebyscheff array and Taylor-Line Source array antennas. Descriptions of the amplitude tapers and their utility will be presented.

Keywords: Tapering, Binomial array, Dolph-Tchebyscheff array, Taylor-Line Source array, Side lobe level.

1. Introduction

Through the use of individual amplitude and phase control, array antennas offer a wide range of directivity pattern shape implementations to the antenna designer. High directivity antennas have defined main beams whose widths are inversely proportional to their aperture extents. High directivity antennas also have side lobes, which are often undesirable as they may permit reception of energy from undesired directions. The energy from the undesired directions may contain interfering sources such as multipath or even deliberate jammers.

Techniques for reducing the levels of the peak side lobes(those near the main lobe) are well understood. Near-inside lobes may be reduced relative to the peak of the main beam by simply tailoring the amplitude distribution across the array aperture. The amplitude distribution is often referred to as the amplitude weighting. The following section will present a review of techniques for synthesizing amplitude weighting functions to achieve varied levels of side lobe reduction. Use of these amplitude weighting functions have a well-known effect on the peak of the main beam of the directivity pattern. The amplitude tapering for side lobe reduction reduces the spatial efficiency (or aperture efficiency) of the antenna. Along with the reduction of peak directivity, amplitude tapering also results in a broadening of the main beam. Although not the focus of this discussion, the resultant change in beam width should be taken into consideration in the design process. While reduced side lobes are usually desirable, reduced peak directivity is usually not, therefore an accurate understanding of the aperture efficiency is a valuable design tool.

2. UNIFORMAMPLITUDE WEIGHTING FUNCTIONS

Equal illumination at every element in an array, referred to as uniform illumination as shown in Figure 1, results in directivity patterns with three distinct features. Firstly, uniform illumination gives the highest aperture efficiency possible of 100% or 0 dB, for any given aperture area. Secondly, the first side lobes for alinear/rectangular aperture have peaks of approximately –13.1 dB relative to the main beam peak; and the first side lobes for a circular aperture have peaks of approximately –17.6 dB relative to the main beam peak. Thirdly, uniform weighting results in a directivity pattern with the familiar sinc(x) or sin(x)/x where x=sin(θ) angular distribution, as shown in Figure 2.

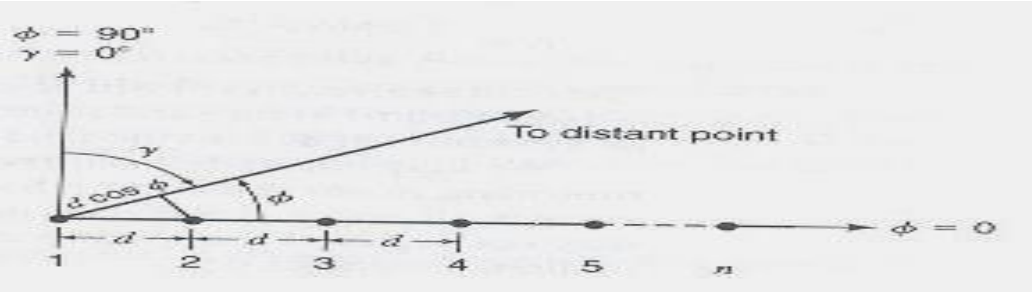


Figure 1: Linear array with n isotropic point sources with equal amplitude and spicing.

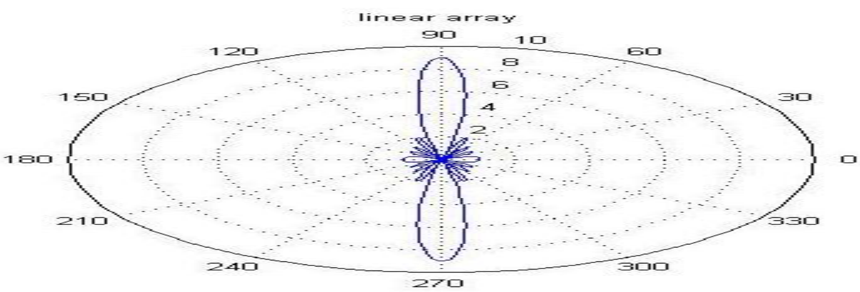


Figure 2: Radiation pattern forlinear array with n isotropic point sources with equal amplitude and spicing

3. NON- UNIFORMAMPLITUDE WEIGHTING FUNCTIONS

3.1 Binomial Arrays

So far, the discussion was limited to the linear arrays of n isotropic sources of equal amplitude but arrays of non- uniform amplitudes are also possible and binomial array is one of them. In this, the amplitudes of the radiating sources are arranged according to the coefficient of successive terms of the following binomial series and hence the name.

$$(a+b)^{n-1} = a^{n-1} + \frac{n-1}{1!} a^{n-2} b + \frac{(n-1)(n-2)}{2!} a^{n-3} b^2 + \frac{(n-1)(n-2)(n-3)}{3!} a^{n-4} b^3 \quad (1)$$

where n = number of radiating sources in the array

Here the secondary or side lobes in the linear broadside arrays are to be eliminated then the radiating sources must have current amplitudes proportional to the coefficient of the above binomial series. This work can be accomplished by arranging the arrays in such a way that radiating sources in the center of the broadside array radiated more strongly than the radiating sources at the edges. The secondary lobes can be eliminated entirely, if the following two conditions are satisfied.

(i) Spacing between the two consecutive radiating sources does not exceed $\lambda/2$, and
(ii) The current amplitudes in radiating sources (from outer, towards center source) are proportional to the coefficients of the successive terms of the binomial series.

These two conditions are necessarily satisfied in binomial arrays and the coefficients which correspond to amplitudes of the sources are obtained by substitute n = 1, 2..... In the eqn. (1), for example, relative amplitudes for the arrays of 1 to 5 radiating sources are as follows:

No. Of Sources	**Relative amplitudes**
n = 1	1
n = 2	1, 1
n = 3	1, 2, 1
n = 4	1, 3, 3, 1
n = 5	1, 4, 6, 4, 1etc

3.2. Dolph- Tchebyscheff or Chebyshev Arrays

In defining the Tchebyscheff polynomial the first latter **T** is used as a symbol, as Tschebyscheff being the older spelling. The Tschebyscheff polynomial is defined by eqn.

$$T_m(x) = \cos(m \cos^{-1} x) \quad \text{for } |x| < \pm 1$$

$$\text{and} \qquad T_m(x) = \cosh(m \cosh^{-1} x) \quad \text{If } |x| > \pm 1$$

where m is order of polynomial. For higher terms can be hadfrom the recursion formula

$$T_{m+1}(x) = 2\,x\,T_m(x) - T_{m-1}(x)$$

Steps to be followed while calculating Dolph- Tchebyscheffamplitude distribution

Step 1: Side lobe level below main lobe maximum in db = $20\log_{10} r$
where r = Main lobe maximum/side lobe level

Step 2: Now select the Tchebyscheffpolynomial $T_m(x)$ of the same degree as array polynomial. For, if m be the degree of Tchebyscheff polynomial then the degree of array polynomial would be (n-1), where n is number of antennas. Symbolically therefore

$$T_m(x_0) = T_{n-1}(x_0)$$

After having known the values of $T_m(x_0)$ and r, equate them and solve the equation

$$T_m(x_0) = T_{n-1}(x_0) = r, \text{ for } x_0$$

Step 3: Choose array polynomial E as n is even

$$E = \sum_{k=0}^{k=N-1} a_k \cos{(2k+1)\psi/2}$$

If n is odd

$$E = \sum_{k=0}^{k=N} a_k \cos{(2k\psi/2)}$$

where ψ = (ß d cos θ + α) radian.

Step 4: Finally, equate array polynomial E and Tchebyscheffpolynomial i.e.

$$E=T_{n-1}(x)$$

By solving the above equation the coefficient a_0, a_1, a_2.......etc are calculated which gives Dolph- Tchebyscheff optimum distribution for the specified side lobe level.

3.3. Taylor Line-Source (One-Parameter):

The Taylor design and its source distribution is given by

$$w(m) = Io(\alpha\surd(1-m^2/M^2)$$

where m = ±1,±2, . . . ,±M, orm = 0,±1,±2, . . . ,±M, for even or odd number of arrayelements, N = 2M or N = 2M + 1.

This window is based on Taylor's one-parameter continuous line source, andis obtained by setting X_m = md with d = l/2M, so that $2X_m$ = m/M,

$$I(X_m) = Io\left\{\pi B\sqrt{1-\left(\frac{2X_m}{l}\right)^2}\right\} = Io\left\{\pi B\sqrt{1-\left(\frac{m}{M}\right)^2}\right\}$$

Thus, we note that the Kaiser Window shape parameter α is related to Taylor's parameterB by α = πB. The parameter B or α control the side lobe level. The continuousline pattern

$$F(u) = \frac{\sinh(\pi\sqrt{B^2-u^2}}{\pi\sqrt{B^2-u^2}} = \frac{\sin(\pi\sqrt{u^2-B^2}}{\pi\sqrt{u^2-B^2}}$$

has a first null at uo =$\sqrt{B^2+1}$, and therefore, the first sidelobe will occur for u >uo.For this range, we must use the sinc-form of F(u) and to find the maximum sidelobelevel, we must find the maximum of the sinc function. The side lobe level R_a (in absolute units) is defined as the ratio of the pattern at u = 0to the maximum sidelobe level r0, that is,

$$R_a = \frac{1}{r_0}\frac{\sinh(\pi B)}{\pi B}$$

and in dB, R = 20 $log_{10}(R_a)$

$$R = R_0 + log_{10}\frac{\sinh(\pi B)}{\pi B}$$

The 3-dBbeam width may be more accurately calculated by finding it in u-space, say Δu, and then transforming it to ψ-space, $\Delta\,\psi_{3dB} = \frac{2\pi\Delta u}{N}$. The width Δu is given by Δu = $2u_3$, where u_3 is the solution of the half-power condition

$$|F(u_3)|^2 = \frac{1}{2|F(0)|^2} => \frac{\sinh(\pi\sqrt{B^2-u_3{}^2})}{\pi\sqrt{B^2-u_3{}^2}} = \frac{1}{\sqrt{2}}\frac{\sinh(\pi B)}{\pi B}$$

For small values of B, the right-hand side becomes less than one, and we must switchthe left-hand side to its sinc form. This happens when B ≤ B_c, where

$$\frac{1}{\sqrt{2}}\frac{\sinh(\pi B_c)}{\pi B_c} = 1 \quad => B_c = 0.4747$$

The equation y = sinh(x)/x is solved for x by using the Taylor series expansion y = sinh(x)/x = 1 + x^2/6 + x^4/120 .for larger x, it is solved by the iteration sinh(x_n)/x_{n-1} = y, or, xn = asi nh(yx_{n-1}), for n = 1, 2, ...Once the B-parameter is determined, the array weights w(m) can be computed.In this case, to avoid grating lobes, the element spacing must be less than the maximum:

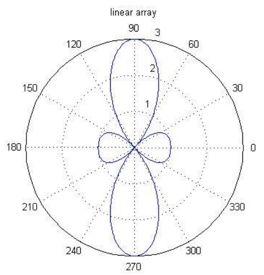
$$d_0 = \frac{\lambda}{1 + |\cos\varphi_0|}$$

in order for the visible region is ψ-space to cover at least one Nyquist period, the element spacing d must be in the range:

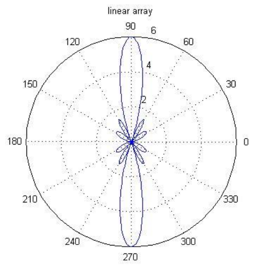
$$\frac{d_0}{2} < d < d_0$$

4. RESULTS

In this paper we simulated antenna radiation patterns and observe the side lobe variations in uniform amplitude distribution for linear arrays and non-uniform amplitude distribution for Binomials, Chebyshev and Taylor –Line Source Arrays.



(a)



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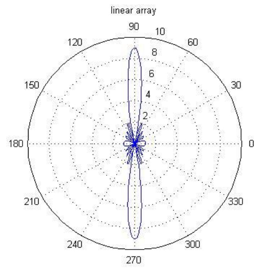
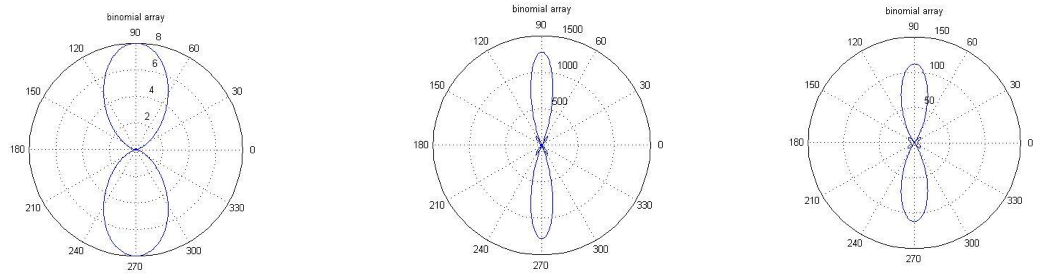


(c)

Figure 3.(a) Linear Arrays radiation pattern for n=3, (b) Linear Arrays radiation pattern for n=6, Linear Arrays radiation pattern for n=9

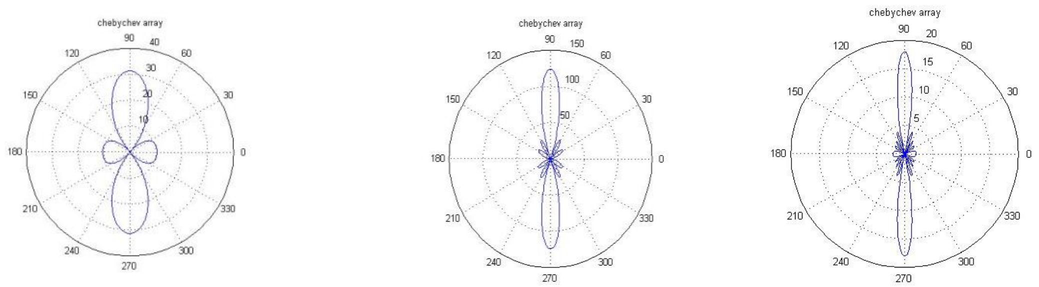
First we are increasing the n values, observe the radiation pattern and number of side lobes for uniform amplitude distribution as shown in Figures 3.(a),(b),(c). As for observation number of antennas n increasing the number of side lobes are also increasing. This is undesired.
In order to reduce the side lobes we are implemented another method is non-uniform amplitude distribution. In binomial array we observed as n values are increasing number of side lobes are decreasing but beam width is increasing with the cost of directivity. In binomial array main drawback is as n increasing, directivity is decreases as shown in Figures 4(a),(b),(c).

We are considered side lobe level ratio is -19.1db and implemented chebyshev arrays as n increasing corresponding beam width decreasing as shown in Figures 5(a),(b),(c).



(a) (b) (c)

Figure:4(a)Binomial array radiation pattern for n=3, (b)Binomial array radiation pattern for n=6, (c) Binomial array radiation pattern for n=9

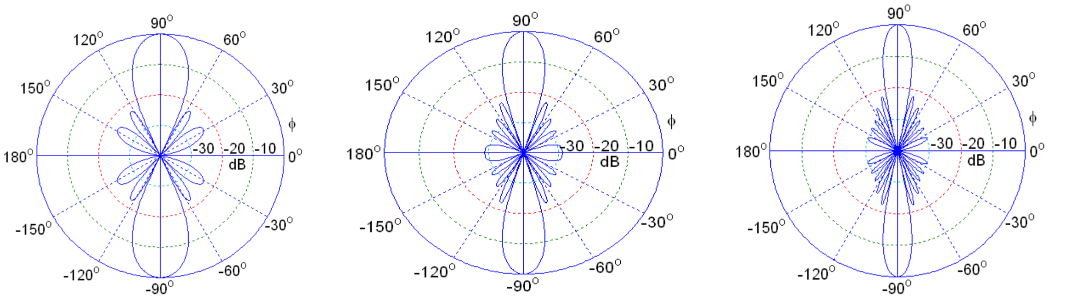


(a) (b) (c)

Figure:5(a) Chebyshev Arrays radiation pattern for n=3, (b) Chebyshev Arrays radiation pattern for n=6, (c) Chebyshev Arrays radiation pattern for n=9

The Dolph- Tchebyscheff array design yields minor lobes of equal intensity while the Taylor produces a pattern whose inner minor lobes are maintained at constant level and remaining ones decrease monotonically which is shown in Figures 6(a),(b),(c).

For some applications, such as radar and low-noise systems, it is desirable to sacrifice some beam width and low inner minor lobes to have all the minor lobes decay as the angle increases on either side of the main beam. In radar applications this is preferable because interfering signals would be reduced further when they try to enter through the decaying minor lobes



(a) (b) (c)

Figure:6 (a)Taylor-Line Source Arrays radiation pattern for n=6, (b) Taylor-Line Source Arrays radiation pattern for n=9, (c) Taylor-Line Source Arrays radiation pattern for n=12

5. Conclusion

By using Uniform arrays we get the desired radiation pattern by changing the phase, but we get the side lobes due to equal amplitudes. Where as in case of Binomial arrays, we can reduce or eliminate minor lobes by giving non uniform amplitudes to radiating sources but it leads to cost of directivity. Dolph – Tschebyshev array provides optimum beam width for a specified side lobe level but, it is efficient for limited number of elements only and it causes some errors in radar applications. Taylor produces a pattern whose inner minor lobes are maintained at constant level and remaining ones decrease monotonically which is preferable in radar applications by scarifying the beam width.

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