PERFORMANCE EVALUATION OF ARRAY ANTENNAS

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ABSTRACT

This paper will presents an optimization technique to reduce the side lobe level in the case of linear array antennas. There several methods are introduced for the side lobe reduction .But always the basic trade-off occur when implementing amplitude weighting functions is that a trade between low side lobe levels and a loss in main beam directivity always results . Here we made a comparison of three methods namely uniform illumination method , Taylor line source attenuation method and Taylor line source using redistribution method .The paper also presents different source distributions and their respective directivity patterns.

***Keywords*:** Amplitude weighing, uniform illumination, array antennas, normalization.

I.INTRODUCTION

Array antennas offer a wide range of opportunities in the variation of their directivity patterns through amplitude and phase control. Through the use of individual amplitude and phase control, array antennas offer a wide range of directivity pattern shape implementations to the antenna designer .Synthesis of linear array antennas has been extensively used in the last decades.[9]-[10] .Common optimization goals in array synthesis are the side lobe suppression and null control to reduce interference effects. 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.

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.

The purpose of the paper is to present a proper normalization technique to obtain a low side lobe level and to avoid loss in main lobe directivity.

II.METHODOLOGIES

A. Uniform Illumination method

Equal illumination at every element in an array referred to as uniform illumination, 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 a linear/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.

B. Directivity Pattern Calculations

The directivity pattern calculations given by Hansen [2] and Raffoul and Hilburn [4] are become confusing even though the calculations are not complex.

The below equation presents the calculation for the voltage directivity pattern for a linear array of N elements of isotropic radiators, where Δx is the inter-element spacing, and an is the amplitude of element n. Note that this equation is for the simplest array case of uniform phase for that of a broadside fixed beam array.

$$E(\theta)=\sum_{n=1}^{N} a_n \, e^{-j\left(\frac{2\Pi}{\lambda} n\Delta \text{ xsin } \theta\right)} \qquad (1)$$

The term uniform illumination is often used to describe the array amplitude distribution when the amplitude of all the elements is equal. If the voltage amplitudes all equal one Volt, the peak voltage E_{peak} , for the ideal linear array of isotropic elements occurs when θ is zero and has a value given by Equation

$$E_{peak} = \sum_{n=1}^{N} a_n$$

If a_n=1

$$E_{peak} = \sum_{n=1}^{N} 1 = N \qquad (2)$$

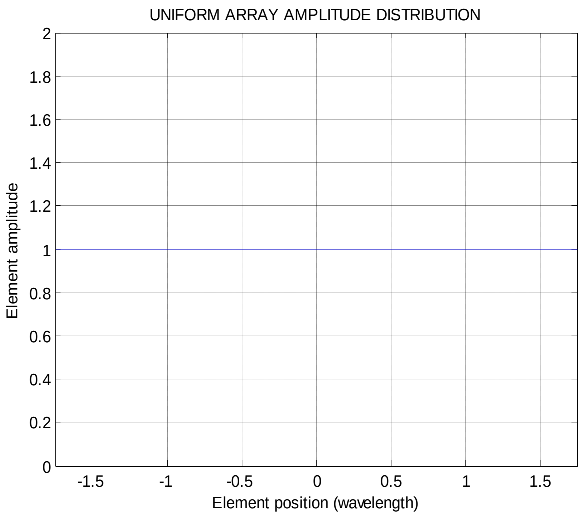

Figure 1.Plot of the uniform amplitude distribution for the eight element array

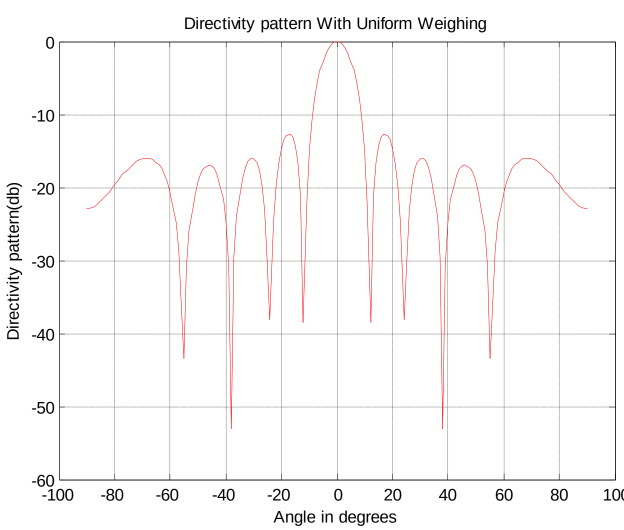

Figure 2.Directivity pattern of a linear array of eight elements with uniform amplitude using MATLAB software

III. TAYLOR SYNTHESIS

Since the 1940s, numerous researchers have contributed varying approaches for synthesizing amplitude distributions for the purpose of side lobe reduction. For this discussion, we will use the Taylor distributions as they are arguably more commonly used for array antenna pattern synthesis The Taylor yields an optimum compromise between beam width and side lode level .The Technique introduced by Taylor to pattern whose first few main lobes(closest to main lobe) are maintained at an equal level .The remaining side lobe levels monotonically decreases [5].The details of the analytical formulation are complex .They are presented in the literature [2][6]. Taylor published his synthesis technique for linear/rectangular [2] and circular [1] apertures in 1955 and 1960, respectively. This method also presents the same directivity pattern as that of Figure in uniform case , except that a Taylor amplitude weighting has been employed to reduce the near in side lobes . The $\bar{n}$ parameter is used to define how many near-in side lobes are held constant at the desired amplitude level. For further detail on this parameter refer to Taylor [1-2].

The Normalized line source which yields the desired pattern is given by

$$I(z') = \frac{\lambda}{l}\left[1 + 2\sum_{p=1}^{\bar{n}-1} SF(p, A, \bar{n}) \cos\left(2\Pi p \frac{z'}{l}\right)\right] \qquad (3)$$

The coefficients SF (p,A,$\bar{n}$) represent samples for Taylor pattern and the can be obtained by

$$SF(p, A, \bar{n}) = \begin{cases} \dfrac{[(\bar{n}-1)!]^2}{(n-1+p)!\,(\bar{n}-1-p)!} \displaystyle\prod_{m=1}^{\bar{n}-1}\left[1 - \left(\frac{\Pi p}{u_m}\right)^2\right] & |p| < \bar{n} \\ 0 & |p| \geq \bar{n} \end{cases}$$

The Taylor space factor is given by

$$SF(u, A, \bar{n}) = \frac{\sin u}{u} \frac{\prod_{n=1}^{\bar{n}-1}\left[1 - \left(\frac{u}{u_n}\right)^2\right]}{\prod_{n=1}^{\bar{n}-1}\left[1 - \left(\frac{u}{n\Pi}\right)^2\right]} \qquad (4)$$

Where $u = \Pi v = \Pi \frac{l}{\lambda} \cos\theta$

$$u_n = \Pi v_n = \Pi \frac{l}{\lambda} \cos\theta_n$$

Where θ_n represents the locatons of the nulls. From the Figures 2 to 4, the directivity patterns of both are normalized to zero dB. As these patterns are not normalized to a consistent peak, this is limited to no value in assessing the efficiency loss trade-off with side lobe reduction levels.

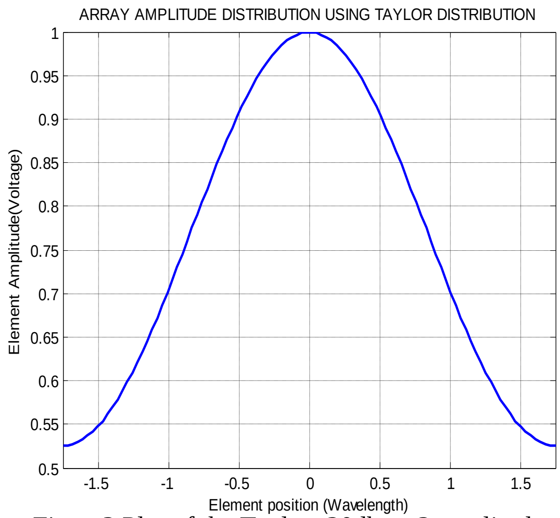

Figure3.Plot of the Taylor -20db $\bar{n}$=3 amplitude distribution.

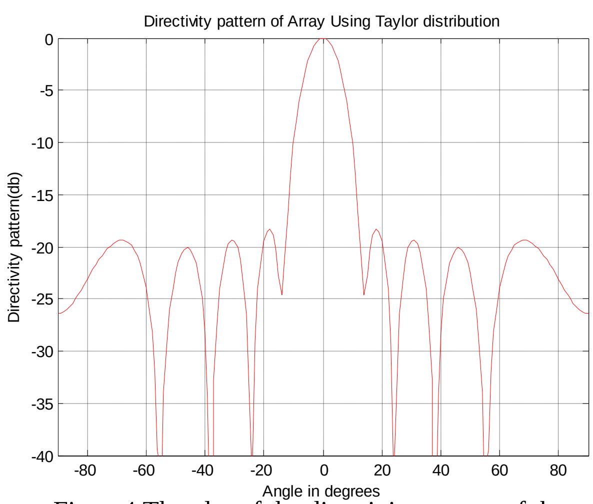

Figure4.The plot of the directivity pattern of the linear array using Taylor -20db $\bar{n}$=3amplitude for near inside lobe reduction.

IV.NORMALIZATIONS

There are two physical methods for generating amplitude distributions for array antennas. Amplitude tapers can be created by either redistributing the power among the elements or by attenuating the power for the outer elements. With the attenuated method, power removed at the outer elements is attenuated in ohmic losses.

A. Attenuation Method

The attenuation method is analogous to achieving the amplitude taper by increasingly resistively attenuating the field energy for radiators toward the periphery of the array to achieve Voltages less than 1. But, this method is the least efficient, and the main beam gain loss is the greatest. Consider the example of a linear array of eight elements having element patterns and an inter-element spacing of 0.695 λ.

The following series of plots were calculated using Equation1, using software written in MATLAB. Routines written to calculate the amplitude weighting coefficients for array side lobe reduction usually provide a_n for each element in Voltage form. Not always, but often, the routines are written to provide a maximum value of 1, The Taylor Voltages calculated for this amplitude illumination function are (from the outer elements to the center) 0.5828,0.7283,0.9147,1 from the figure 3.Where as in the case of uniform illumination every element have the amplitude is equal to 1V.

This approach is further illustrated in Figures 5,6 where the amplitude distributions and resulting directivity patterns are presented for the range of Taylor weightings from –20 to –65 dB. The attenuation method predicts very significant main beam pattern losses

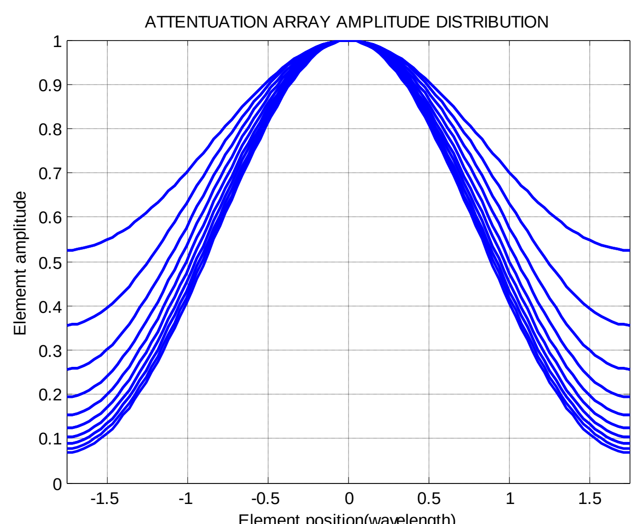

Figure 5.Plot of amplitude distributions for Taylor functions of -20db to -65db using the attenuation normalization.

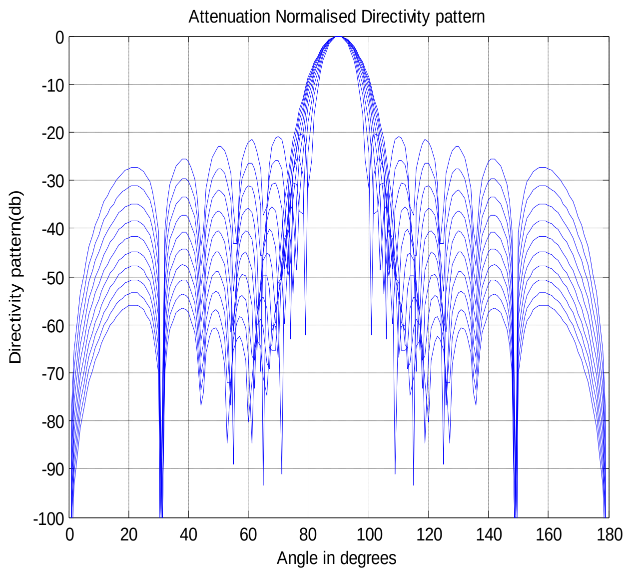

Figure 6.Plot of directivity patterns with amplitude distributions for Taylor functions of -20db to-65db using attenuation normalization

V.UNIFORM ILLUMINATION VS TAYLOR TECHNIQUE

Using Taylor line source (Tchebyshev error) Technique, we get the better side lobe reduction in directivity pattern of linear array but there is a loss in the main beam of the directivity pattern. So a trade is always observed in between low side lobe levels and a loss in main beam directivity always results. In this example the main lobe to first side lobe level in case of Taylor Technique is 18.36 db where as in the case of uniform illumination method is only 12.66db from the figure 7.But the main lobe peak value in the directivity pattern of seven element linear array is 10 db higher than that of Taylor Technique. By Using Taylor, Along with the reduction of peak directivity, amplitude tapering also results in a broadening of the main beam.

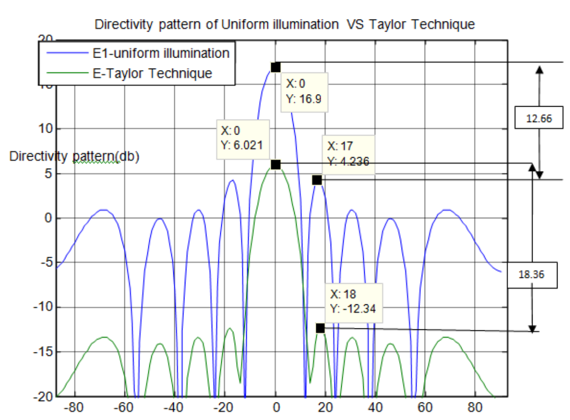

Figure 7.Comparision plot of the directivity patterns of uniform illumination and Taylor using attenuation method

A. Redistribution Method

In contrast to the attenuation method, significantly higher aperture efficiencies can be obtained by redistributing or renormalizing the energy within the amplitude distribution [8]. This can be thought of as conservation of energy as any Voltage removed from outer elements is reallocated to more central elements. The redistributed normalization process can be affected by simply translating the average of the amplitude weights back to one using Equation 5.

$$a_{n,redistributed\quad normalized} = \frac{a_n N}{\sum_{n=1}^{N} a_n} \quad (5)$$

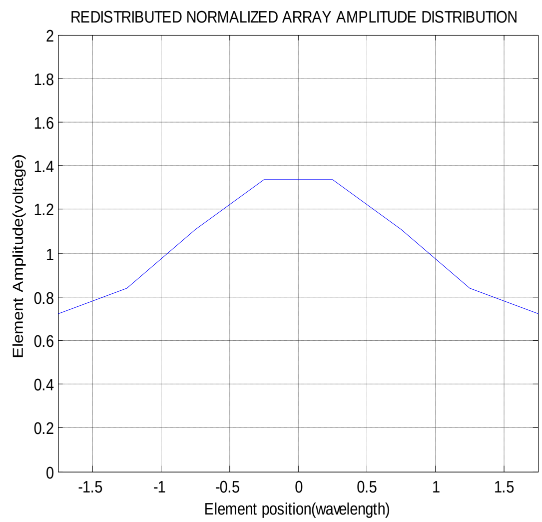

Figure 8.Amplitude Distribution of eight element linear array using taylor redistributded normalizations

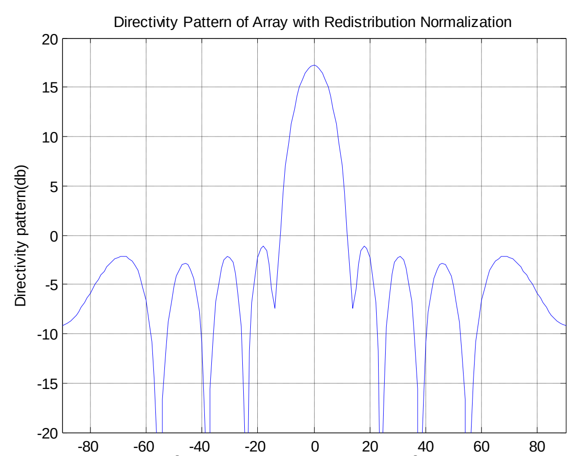

Figure 9. Plot of the directivity pattern of eight element linear array using Taylor with Redistribution normalization

VI.ATTENUATION METHOD VS REDSTRIBUTION

Figure 10 presents a comparison of the directivity patterns of the eight element linear array using Taylor attenuation and redistribution normalizations. Regarding the methods of achieving the tapers, both the methods have same level of reduction in first side lobes but the attenuated method discards the energy while the redistribution method does not lose any energy .There is no loss in the main beam peak value by using Taylor redistribution normalization.

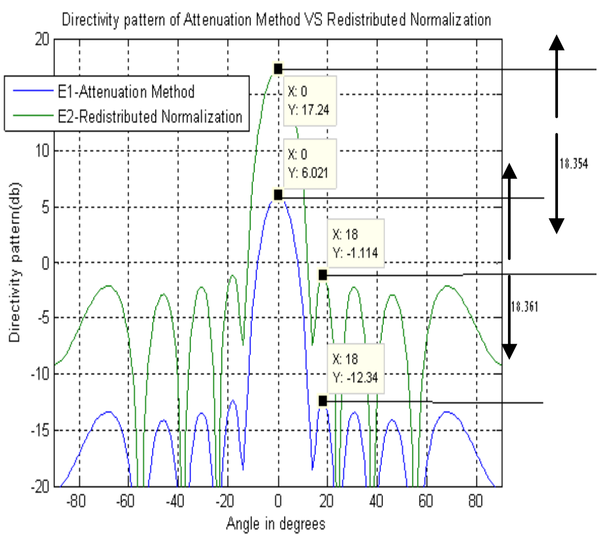

Figure 10.Comparision plot of directivity pattern of eight element linear array using Taylor attenuation and redistribution normalizations.

VII.COMPARISION OF THREE TECHNIQUES

Figure 11 gives the comparison of the three methods like uniform illumination and Taylor attenuation method and redistribution normalization technique.

In the previous section we have seen the comparison of the uniform illumination method and Taylor using attenuation normalization from figure 7and also the comparison of the attenuation and redistribution normalizations from the figure 10.By uniform illumination we get good main lobe directivity but the side lobe reduction is not good. The disadvantage of high side lobe in uniform illumination case is overcome by making use of Taylor attenuation method. Even though we have good reduction in side lobe value we are suffering with loss in main lobe peak value and also results in a broadening of the main Beam. The disadvantage of attenuation method i.e., main lobe loss in directivity pattern is overcome by the Taylor using redistribution normalization .From the figure 11 Even though we avoid the loss of ,main lobe peak in the directivity pattern of eight linear array ,we always suffer with a loss of aperture efficiency is always incurred with both the attenuation and redistribution methods of achieving amplitude tapers when compared to Uniform illumination method.

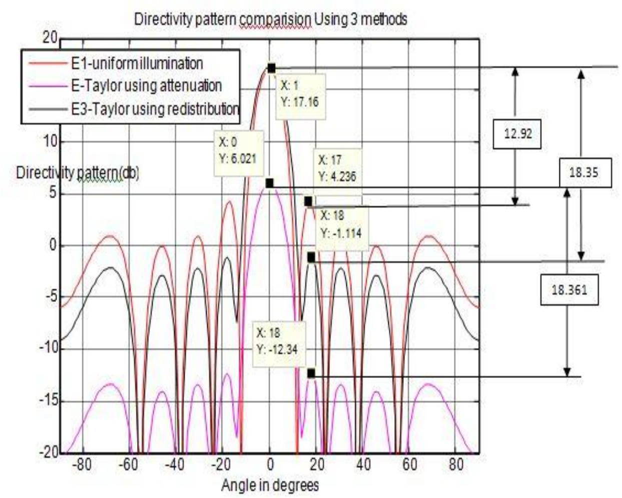

Figure11. Comparison plot of directivity patterns of uniform illumination method and Taylor using attenuation and redistribution normalizations.

VIII.CONCLUSION

This paper presented a discussion of methods used to Suppress the side lobe level of linear array antennas and made the comparisons of source distributions and the directivity patterns of three methods namely uniform illumination method, Taylor line source using attenuation method and redistributed normalization method. Equations to simulate basic array antenna patterns like source distribution and voltage calculations, spacefactor are discussed .The normalizations namely attenuated and redistributed methods were developed and the importance of normalization is discussed. All these are explained by taking example of eight element linear array and the simulations required for this discussion are done using MATLAB Software.

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