International Journal of Modern Engineering Research (IJMER)
www.ijmer.com Vol.1, Issue.2, pp-637-641 ISSN: 2249-6645

OPTIMIZATION OF LINEAR ARRAY ANTENNAS BY THE GRADIENT METHOD

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ABSTARCT

This paper mentions about how a linear array antenna can be optimized using different techniques to achieve the desired array characteristics mainly array factor. However this can be briefly discussed by linear array optimization using Chebyshev method and also how this optimization is more reliable in improving array factor by applying gradient algorithm. In this work, script for matlab was developed to optimize some radiation characteristics of the array factor using the method of the gradient. In order to improve some characteristics of the radiation pattern, an algorithm based on the gradient method has been included for optimization purposes. By this one can achieve sophisticated array characteristics by efficient side lobe reduction and by broadening the main lobe level.

Keywords: array factor, chebyshev method, optimization, gradient.

I.INTRODUCTION

A single antenna has a limited radiation pattern. But with the use of several antennas working together (array), it is possible to improve the radiation according to some specifications. In general the characteristics of the array are controlled by the proper choice of the element (dipole, horn, patch, etc.), the geometry of the array and the excitation (amplitude and phase) of each element.

The antenna arrays considered in this work are restricted to linear arrays where the radiated fields depend only on the θ coordinate. The electric field in far zone is represented by

$$E_\theta = E_{\theta 1}.AF \quad .... (1)$$

Where $E\theta 1$ is the electric field produced by the element at the origin of the coordinate system and AF is known as the array factor and is given by

$$AF = \sum_{k=1}^{n} a_k e^{j(kd_k \cos\theta + \beta_k)} \quad ...... (2)$$

ak , βk , and dk , represent; amplitude, phase and position of the k-th element respect to the origin.

The optimization is a procedure in which, the variables involved in the performance of a system are modified starting from a non optimum design, in such a way that one of several characteristics of the system are improved.

The purpose of this paper is to present an algorithm for the linear array optimization using chebyshev method and also gradient method is included to achieve efficient side lobe reduction by broadening the main lobe level. To apply gradient method we have included white Gaussian noise to the chebyshev array and we observed the number of iterations required to recover the original linear array.

II.METHODOLOGIES

A. Chebyshev method

You may have noticed that the antenna array factors for arrays with uniform weights have unequal sidelobe levels, Often it is desirable to lower the highest sidelobes, at the expense of raising the lower sidelobes. The optimal sidelobe level (for a given beamwidth) will occur when the sidelobes are all equal in magnitude.

This problem was solved by Dolph in 1946. He derives a method for obtaining weights for uniformly spaced linear arrays steered to broadside (θd =90 degrees). This is a popular weighting method because the sidelobe level can be specified, and the minimum possible null-null beamwidth is obtained. To understand this weighting scheme, we'll first look at a class of polynomials known as Chebyshev (also written Tschebyscheff) polynomials. These polynomials all have "equal ripples" of peak magnitude 1.0 in the range [-1, 1]

(See Figure 1 below). The polynomials are defined by a recursion relation:

$$T0(z) = 1 \ ...... (3)$$

$$T1 (z) = 1 \ ...... (4)$$

$$T_m(z) = 2zT_{m-1} - T_{m-2}(z), \text{ m=2, 3, } ...... (5)$$

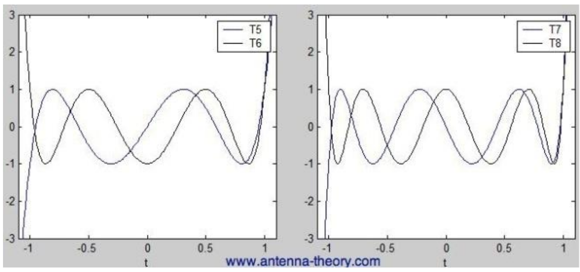

Fig.1. Examples of Chebyshev polynomials.

Observe that the oscillations within the range [-1, 1] are all equal in magnitude. The idea is to use these polynomials (with known coefficients) and match them somehow to the array factor (the unknown coefficients being the weights).

To begin to see how this is achieved, let's assume we have a symmetric antenna array for every antenna element at location dn there is an antenna element at location -dn, both multiplied by the same weight wn. We'll further assume the array lies along the z-axis, is centered at z=0, and has a uniform spacing equal to d. Then the array factor will be of the form given by:

$$AF = \sum_{n=1}^{M} Wne^{-jk\,(2n-1)d/2\cos\theta} + \sum_{n=-M}^{-1} Wne^{-jk\,(2n-1)d/2\cos\theta}$$

…… (6) For even array

$$\sum_{n=-M}^{M} Wne^{-jknd\ \cos\theta}$$

…… (7) For odd array

The array is even if there are an even number of elements (no element at the origin), or odd if there are an odd number of elements (an element at the origin). Using the complex-exponential formula for the cosine function:

$$\cos(x) = \frac{e^{jx} + e^{-jx}}{2}$$

The array factors can be rewritten as:

$$AF = \sum_{n=1}^{M} Wn\cos[(2n-1)u] \text{ …… (8)}$$

For even array

$$AF = \sum_{n=0}^{M} Wn\cos(2nu) \text{ …… (9)}$$

For odd array

Recall that we want to somehow match this expression to the above Tschebyscheff polynomials in order to obtain an equil-sidelobe design. To do this, we'll recall some trigonometry which states relations between cosine functions:

$$\cos(2u) = 2\cos^{2}u - 1$$

$$\cos(3u) = 4\cos^{3}u\text{-}3\cos\ u$$

$$\cos(4u) = 8\cos^{4}u\text{ - }8\cos^{2}u\text{+}1$$

…… (10)

If we substitute these expressions into the Antenna Array Factors given in equations (8) and (9), and introduce a substition:

$$\cos u(t0) = t \text{ …… (11)}$$

We will end up with an AF that is a polynomial. We can now match this polynomial to the corresponding Tschebyshef polynomial (of the same order), and determine the corresponding weights,W_n.

The parameter t_0 is used to determine the sidelobe level. Suppose there are N elements in the array, and the sidelobes are to be a level of S below the peak of the main beam in linear units (note, that if S is given in dB (decibels), it should be converted back to linear units SdB=20*log(S), where the log is base-10). The parameter $t_0$can be determined simply from:

$$t_0 = \cosh[\tfrac{\cosh^{-1}(s)}{N-1}] \text{ …… (12)}$$

The resulting Array Factor (AF) will have the minimum null-null beamwidth for the specified sidelobe level, and the sidelobes will all be equal in magnitude.

Consider array of 8 elements and construct the chebyshev array for which we add the white Gaussian noise. By using method of gradient we observe the number of iterations needed to get the optimum value.

B. White Gaussian noise

White noise is a random signal (or process) with a flat power spectral density. In other words, the signal contains equal power within a fixed bandwidth at any center frequency. White noise draws its name from white light in which the power spectral density of the light is distributed over the visible band in such a way that the eye's three color receptors (cones) are approximately equally stimulated.

In statistical sense, a time series r_t is characterized as having weak white noise if $\{r_t\}$ is a sequence of serially uncorrelated random variables with zero mean and finite variance. Strong white noise also has the quality of being independent and identically distributed, which implies no autocorrelation. In particular, if r_t is normally distributed with mean zero and standard deviation σ, the series is called a Gaussian white noise.

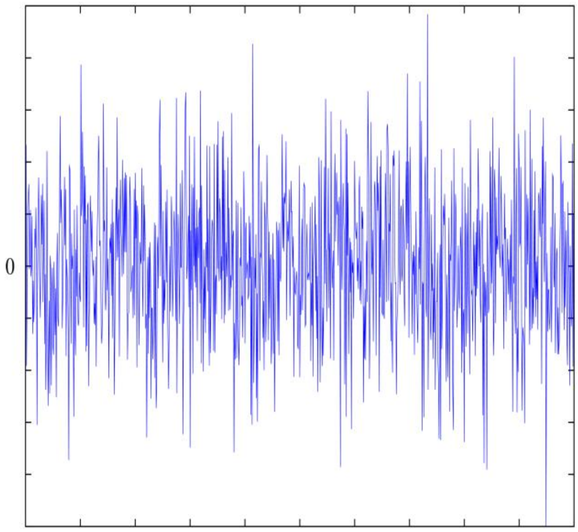

Fig.2. White noise

An infinite-bandwidth white noise signal is a purely theoretical construction. The bandwidth of white noise is limited in practice by the mechanism of noise generation, by the transmission medium and by finite observation capabilities. A random signal is considered "white noise" if it is observed to have a flat spectrum over a medium's widest possible bandwidth. While it is usually applied in the context of frequency domain signals, the term white noise is also commonly applied to a noise signal in the spatial domain.

In this case, it has an auto correlation which can be represented by a delta function over the relevant space dimensions. The signal is then "white" in the spatial frequency domain (this is equally true for signals in the angular frequency domain, e.g., the distribution of a signal across all angles in the night sky). Being uncorrelated in time does not restrict the values a signal can take.

Any distribution of values is possible (although it must have zero DC components). Even a binary signal which can only take on the values 1 or -1 will be white if the sequence is statistically uncorrelated. Noise having a continuous distribution, such as a normal distribution, can of course be white.

It is often incorrectly assumed that Gaussian noise (i.e., noise with a Gaussian amplitude distribution — see normal distribution) is necessarily white noise, yet neither property implies the other. Gaussianity refers to the probability distribution with respect to the value, in this context the probability of the signal reaching amplitude, while the term 'white' refers to the way the signal power is distributed over time or among frequencies.

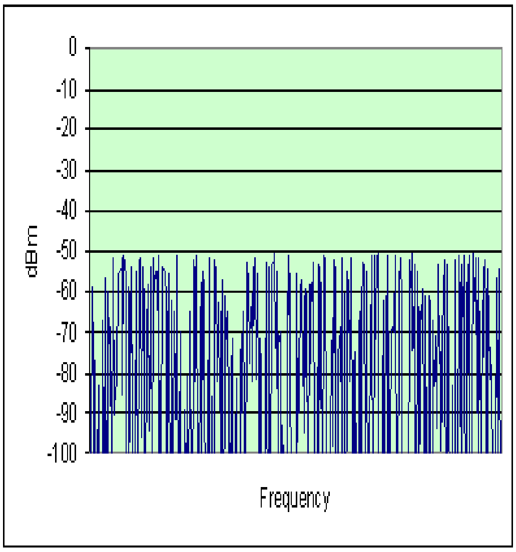

Fig.3. Gaussian noise

We can therefore find Gaussian white noise, but also Poisson, Cauchy, etc. white noises. Thus, the two words "Gaussian" and "white" are often both specified in mathematical models of systems. Gaussian white noise is a good approximation of many real-world situations and generates mathematically tractable models.

These models are used so frequently that the term additive white Gaussian noise has a standard abbreviation: AWGN. Gaussian white noise has the useful statistical property that its values are independent. Additive white Gaussian noise (AWGN) is a channel model in which the only impairment to communication is a linear addition of wideband or white noise with a constant spectral density and a Gaussian distribution of amplitude.

The model does not account for fading, frequency selectivity, interference, nonlinearity or dispersion. However, it produces simple and tractable mathematical models which are useful for gaining insight into the underlying behavior of a system before these other phenomena are considered. Wideband Gaussian noise comes from many natural sources, such as the thermal vibrations of atoms in conductors. The AWGN channel is a good model for many satellite and deep space communication links. It is not a good model for most terrestrial links because of multipath, terrain blocking, interference, etc. However, for terrestrial path modeling, AWGN is commonly used to simulate background noise of the channel under study, in addition to multipath, terrain blocking, interference, ground clutter and self interference that modern radio systems encounter in terrestrial operation.

C. Optimization by Gradient Method

An optimization algorithm is an algorithm for finding a value *x* such that *f(x)* is as small (or as large) as possible, for a given function *f*, possibly with some constraints on *x*.

In optimization, gradient method is an algorithm to solve problems of the form

$$\min_{x \in R^n} f(x) \;\ldots\ldots\; (13)$$

With the search directions defined by the gradient of the function at the current point, Code optimization involves the application of rules and algorithms to program code with the goal of making it faster, smaller, more efficient, and so on. Often these types of optimizations conflict with each other: for instance, faster code usually ends up larger, not smaller.

The function *f* is called, variously, an objective function, cost function, energy function, or energy functional. A feasible solution that minimizes (or maximizes, if that is the goal) the objective function is called an optimal solution.

Generally, when the feasible region or the objective function of the problem does not present convexity, there may be several local minima and maxima, where a local minimum x^* is defined as a point for which there exists some $\delta > 0$ so that for all x such that

$$\left|\left|x - x^*\right|\right| \leq \delta \;\ldots\ldots\; (14)$$

The optimization is a procedure in which, the variables involved in the performance of a system are modified starting from a non optimum design, in such a way that one of several characteristics of the system are improved .In this work a script for MATLAB was development to optimize some radiation characteristics of the array factor using the method of the gradient. Basically the process is a loop searching for an optimum point. The optimum value could be a maximum or a minimum depending of the specific characteristic.

Gradient technique generally employees in giving the optimum value by the number of iterations in a given number of steps.

Algorithm:

- 0<phi<2*pi
- For lambda/2 spacing
- Chebyshev Window values
- E for different shi values
- Add white Gaussian noise to E
- Converting into dB scale
- Plot both signals

- Compute maximum level decomposition.
- Perform a wavelet decomposition of the signal
- Estimate the noise standard deviation from the detail coefficients at each level, using wnoisest.
- Use wbmpen for selecting global threshold
- For signal de-noising, using the tuning parameter.
- Use wdencmp for de-noising the signal using the above threshold with soft thresholding and approximation kept.
- Plot noisy and de-noised signals.

II. SIMULATION RESULTS

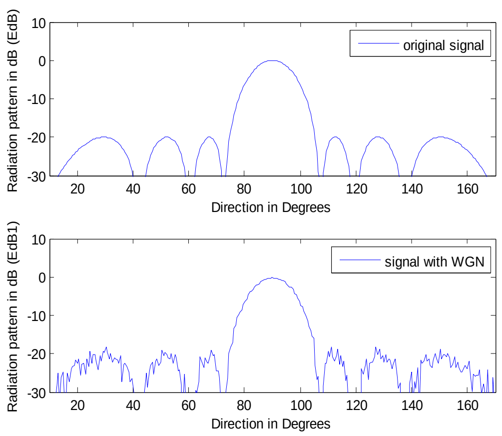

Fig.4. (a) Original signal (b) signal with White Guassian Noise

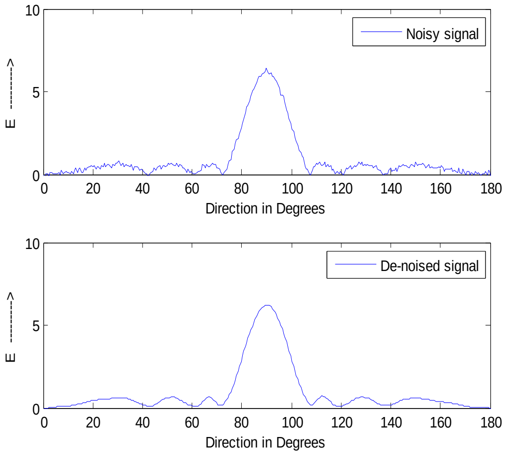

Fig.5. (a) Noisy signal (b) De-noised signal

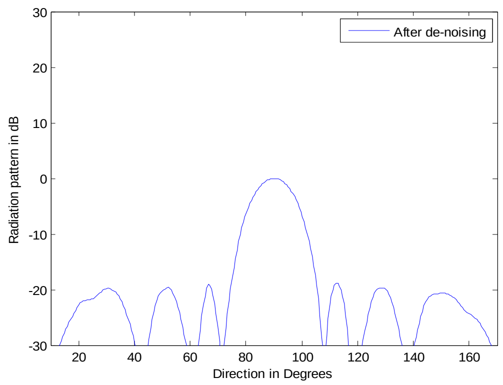

Fig.6. Regenerated signal after de-noising

III. CONCLUSION

The most relevant contribution in this work is the development of a specialized algorithm to design radiation pattern using antenna linear arrays since it can help researchers and teachers to test in a cheap and fast way their own ideas. At the moment to implement the algorithm the mathematical models were manipulated to get more convenient expressions and are written using MATLAB software.

The optimization routine is a widely known powerful tool. In this case we have used it successfully to antenna array optimization. However this can be briefly discussed by linear array optimization using Chebyshev method and also how this optimization is more reliable in improving array factor by applying gradient algorithm. By this one can achieve sophisticated array characteristics by efficient side lobe reduction and by broadening the main lobe level.

ACKNOWLEDGEMENTS

It plunges us in exhilaration in taking privilege in expressing our heartfelt gratitude to all those who helped, encouraged and foreseeing successful completion of our work. We take immense pleasure in thanking our KL University and our staff for their inspiring advice, immense help, whole hearted support and invariable encouragement throughout the tenure of this work.

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