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RESEARCH PAPER

Synthesis of randomness in the radiated fields of antenna array

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An alternative approach is based on statistically computed signal analysis technique for the design of antenna array exhibiting lower side lobes in their radiation pattern. New and generalized expressions for the array factor of all physically realizable linear antenna arrays are introduced. An algorithm based on the statistically computed signal analysis is designed. By considering the random elements, distance between the sensors, their mean, variance, average amplitude pattern and correlation of the amplitude between the two angles, some mathematical formulations have been done and shown with the help of MATLAB. Based on these generalized expressions, a new way of synthesizing arrays with reduced side lobes is available. It applies to end fire antenna array, which may have either even or odd numbers of sensors with restricted elements spacing. Final expressions shown are a clear relationship between elements excitation and null location in the radiation patterns.

Keywords: Dipole, Array factor, Correlation, Amplitude, Statistics, Signal analysis

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I. INTRODUCTION

The study on the radiation pattern of linear dipole antenna arrays, especially the far-field pattern, is discussed in this note. To design a linear array, the far-field pattern and its formulation should be synthesized. The pattern of an array can be expressed as

$$E_{total} = E_{single\ element} \times Array\ factor.$$

This is a general rule in array patterns. As per this rule, simple dipoles placed in some geometry can form an arbitrary pattern. Hence, a desired pattern can be achieved by placing these elements in a proper geometry and feeding them with required current. The array factor depends on the current feed of elements and also the way in which these dipoles have been placed together. To achieve the desired pattern with a phased array, the array factor should be properly chosen. Tapering the excitation amplitude in antenna arrays is known to reduce the lobes' level especially those adjacent to the main beam. Suppressing the side lobes saves power in undesired directions on the expense of broadening the main beam, i.e., less directive radiation. A formulation, which makes no direct use of these polynomials, was given in [1]. During the design it should be taken into account that the main lobe should have maximum power and there must be a minimum number of side lobes with minimum radiation power. The relation between the array factor and designing parameters like spacing, geometry is discussed in the following sections and it will be shown how these parameters can affect the entire pattern.

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II. SIGNAL ANALYSIS AND ITS APPLICATION TO ANTENNA ARRAYS

A) Current source in array elements

Let us, for a linear array, assume that the array elements are located on the $x-y$ plane (at the points md_x, nd_y), $m = 0, 1, 2\ldots, M-1$ and $n = 0, 1, 2\ldots, N-1$. Let the current source in the array elements have the separable form $I(m, n) = I_1(m), I_2(n)$. The array amplitude pattern is given by (m and n are points of $x-y$ plane)

$$\begin{aligned} A(\theta, \Phi) &= \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} I(m,\ n)\exp(jk(md_x\cos(\Phi)\sin(\theta)) \\ &\quad + nd_y\sin(\theta)\sin(\Phi) \\ &= A_1(\theta,\Phi)A_2(\theta,\Phi), \end{aligned}$$

where

$$\begin{aligned} A_1(\theta,\Phi) &= \sum I_1(m)\exp(jk(md_x\cos(\Phi)\sin(\theta))), \\ &\quad m = 0 \text{ to } M-1, \\ A_2(\theta,\Phi) &= \sum I_2(n)\exp(jk(md_y\sin(\Phi)\sin(\theta))), \\ &\quad n = 0 \text{ to } N-1. \end{aligned}$$

We assume that

$$I_1(m) = |I_1(m)| \exp(jm\psi_x) \quad \text{and}$$
$$I_2(n) = |I_2(n)| \exp(jm\psi_y).$$

Then we conclude that max occurs when

$$kd_x \cos(\Phi)\sin(\theta) + \psi_x = 0 \quad \text{and}$$
$$kd_y \sin(\Phi)\sin(\theta) + \psi_y = 0.$$

These two equations can be solved for θ and Φ. Now assume that $|I_1(n)|$ and $|I_2(m)|$ are constants, say unity; then

$$A_1(\theta, \Phi) = \sum \exp(j\,k\,m\,d_x \cos(\Phi)\sin(\theta))$$
$$= \sin(k\,m\,d_x \cos(\Phi)\sin(\theta)/2),$$
$$\text{for } m = 0 \text{ to } M-1.$$

B) Array synthesis

Consider an array with an odd number of elements. The amplitude pattern is given by

$$AF(\theta) = \sum a(m)\exp(jm\,\psi),$$
$$\psi = kd\cos(\theta) + \beta, \quad m = -M \text{ to } M.$$

From this equation we obtain

$$a(m) = \frac{1}{2}\pi \int AF(\Psi)\exp(-jm\Psi)d\Psi, \quad \text{limits} - \pi \text{ to } \pi$$

Let the amplitude pattern be specified over the range $\theta \in [\theta_1, \theta_2]$. We assume that $kd(\cos(\theta_1) - \cos(\theta_2)) \leq 2\pi$.

Then setting $\Psi_i = kd\cos(\theta_i) + \beta$, $i = 1, 2, 3 \ldots$.

For the current weights,

$$a(m) = \frac{1}{2}\pi \int AF(\Psi)\exp(-jm\,\Psi)d\,\Psi, \quad \text{limits } \Psi_1 \text{ to } \Psi_2,$$

where $AF(\Psi)$ is obtained by replacing θ in AF with

$$\cos^{-1}((\Psi - \beta)/kd).$$

C) Width of the main lobe of a uniform linear array

The width of the main lobe of a uniform linear array that has N elements can be determined using

$$A(\theta) = \sum \exp(jknd\cos(\theta))$$
$$= (\exp(jkNd\cos(\theta)) - 1)/(\exp(jkd\cos(\theta)) - 1)$$
$$\text{for } n = 0 \text{ to } N-1,$$
$$|A(\theta)| = |\sin(kNd\cos(\theta)/2)|/|\sin(kd\cos(\theta)/2)|.$$

The maximum occurs when $\theta = \pi/2$, and the first minimum occurs when

$$kNd\cos(\theta)/2 = \pi$$

or equivalent, when $\cos(\theta) = \lambda/Nd$ or

$$\theta = \cos^{-1}(\lambda/Nd)$$

or

$$\theta = \frac{\pi}{2} - \sin^{-1}(\lambda/Nd).$$

Width of the main lobe, i.e. angle between the first two nulls on either side of the max is given by

$$2\sin^{-1}(\lambda/Nd).$$

To design a three-element linear array with non-uniform excitation, so that the nulls of the array occur at $\theta = \theta_i$, $i = 1, 2, 3, \ldots$ assume that inter-element space is d.

The array factor can be written as

$$A(\theta) = I_0 + I_1\exp(jkd\cos(\theta)) + I_2\exp(j2kd\cos(\theta)),$$
$$z_i = \exp(jkd\cos(\theta_i)), \quad i = 1, 2, 3, \ldots.$$

Setting $u = I_1/I_0$ and $v = I_2/I_0$.

Then the following equation can be solved for the above design:

$$1 + uz_i + vz_i^2 = 0, \; i = 1, 2.$$

D) Correlation between the amplitude patterns

Consider a linear array with a sensor located on the z-axis at a distance d_n, $n = 1, 2, 3, \ldots, N$ from the origin. Let d_n be a random with mean $d_n o$ and variance σ_n^2 small. If we determine the average amplitude pattern and power pattern as well as the correlation between the amplitude patterns along two different directions. And, if this theory is applied to the analysis of dipole antenna. It has been observed that, if we make small variance and the correlation is expected to be nearly 1. The side lobes of the radiation pattern will be reduced to a great extent:

$$A(\theta) = \sum I_n\exp(jkd_n\cos(\theta)), \quad n = 1 \text{ to } N.$$

Let

$$\Phi_n(\xi) = \dot{E}\exp(j\xi d_n),$$

the characteristic function of d_n. Note that

$$\Phi_n(\xi) \approx 1 + j\,\xi\,d_n o - \xi^2(\sigma_n^2 + d_n o^2)/2.$$

The average amplitude pattern is given by

$$\langle A(\theta)\rangle = \sum I_n\Phi_n(k.\cos(\theta)), \quad n = 1 \text{ to } N.$$

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The amplitude correlation is

$$\langle A(\theta_1)A^*(\theta_2)\rangle = \sum I_n^2 \Phi_n(k(\cos(\theta_1) - \cos(\theta_2))) + \sum I_n I_m \Phi_n(k\cos(\theta_1))\Phi_m^*(k\cos(\theta_2)).$$

The multiple correlations may also be evaluated. In particular, the average power pattern is given by

$$\langle |A(\theta)|^2\rangle = \sum I_n^2 + \sum I_n I_m \Phi_n(k\cos(\theta))\Phi_m^*(k\cos(\theta)).$$

III. EXPERIMENTS

To examine the effects of the randomness in an antenna array, two programs in MATLAB have been written, one for using the conventional method and other in which the effect of the randomness has been studied. Few assumptions are considered as:

1) Uniform current distribution is assumed to be 1 A.
2) There is no mutual coupling effect.
3) Operating frequency for antenna is about 300 MHz.
4) $\eta = 120\pi$.

Conventional plots are represented using red and random plots are represented using blue.

A) Experiment 1

During the first experiment a program is written in MATLAB to verify the characteristics (current distribution, linear, and polar plot of dipole antenna array) of the antenna, such that the effect of randomness can be added further and can be visualized.

For value of length of antenna (in terms of wavelength) 0.5, 0.75, 1.00, 1.25, 1.50, 1.75, current distribution is as shown below (Figs. 1–3).

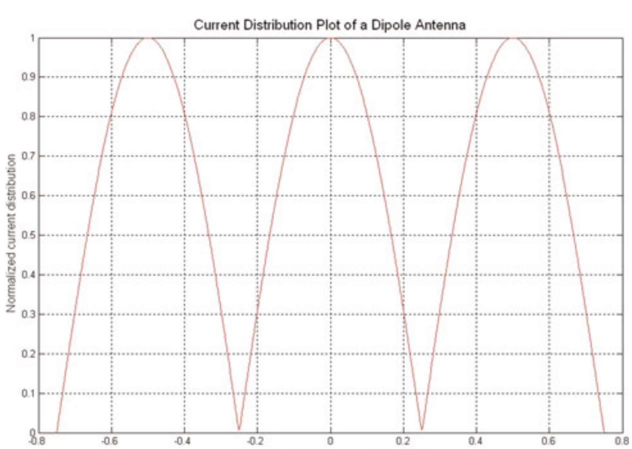

Fig. 1. Current Distribution (in terms of wavelength) 0.5, 0.75, 1.00, 1.25, 1.50, 1.75

As per the [2] for array factor, different plot will satisfy the equation with MATALB program.

B) Experiment 2

Some experimental results are shown for the conventional dipole antenna design.

Finally in the synthesis, it has been assumed that the sensors are placed randomly over the distance d_n (distance 0.20–0.40, in terms of wavelength). With their mean $d_n o$ and variance σ_n^2, it has to be taken care that the value of variance σ_n^2 is very small. As per the amplitude correlation [3] equation, if we **KEEP THE** value of correlation coefficient is always near to unity, then following results are obtained (Figs 4 and 5).

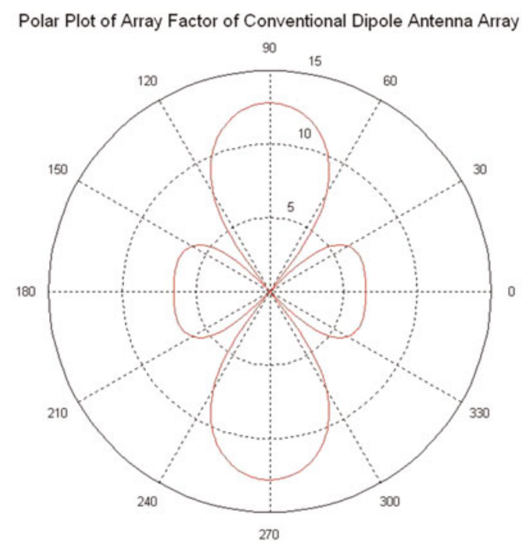

Fig. 2. Array factor of conventional dipole antenna (wavelength): 0.5, value of d (dipole spacing in meters): 0.25 and value of beta (phase shift, 0 or 180). $N = 4$.

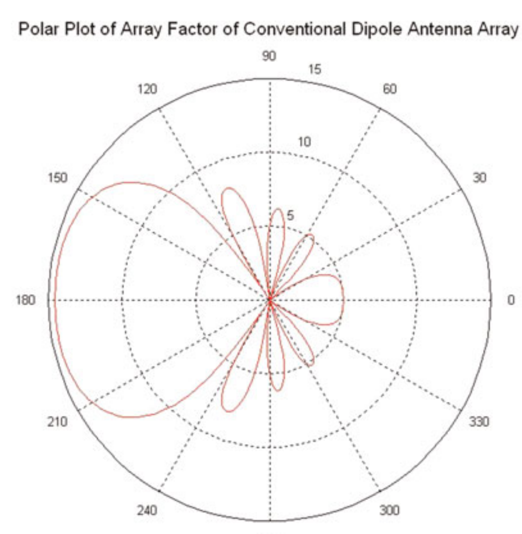

Fig. 3. Array factor of conventional dipole antenna (wavelength): 0.5, value of d (dipole spacing in meters): 0.25 and value of beta (phase shift, ±90). 90, $N = 4$.

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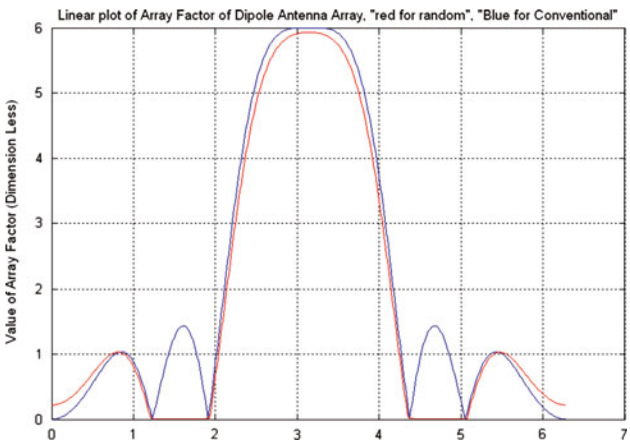

Fig. 4. Conventional and random array factor with $N = 4$.

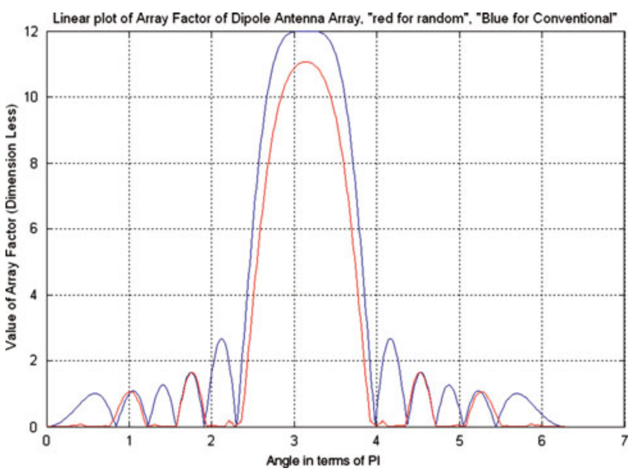

Fig. 5. Conventional and random array factor with $N = 12$.

IV. RESULTS

A procedure for reducing the level of the side lobes of large array antennas made of equal contiguous sub-arrays has been presented. Statistically computed theory of the variation of side-lobe level with range has been designed for long-distance end fire antenna arrays. The purpose of the note is to show that the main characteristics of polar diagrams of long-distance end fire arrays may be inferred from amplitude radiation patterns and the correlation coefficient taken in the Fresnel region.

V. CONCLUSION

The objective of the note is to provide an explanation of the differences of the conventional and random data input behavior of a dipole antenna array. An algorithm that efficiently determines the node coordination of sensors topology has been successfully designed with the help of statistically computed signal analysis. The array geometry that has been considered is a linear node array. Using statistically computed signal analysis in synthesizing array factors results in a lower side lobe level. In order to prove this hypothesis, graphical results are presented. Results for randomly synthesized array factors having suppressed alternate side lobes are compared with those of the conventional array (in number of elements, frequency, and spacing) [4]. An approximate theory of the variation of the side lobe level was developed for end fire antenna arrays.

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