Sensors & Transducers, Vol. 163 , Issue 1, January 2014, pp. 9-14

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Sensors & Transducers

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Curtain Antenna Array Simulation Research Based on MATLAB

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Received: 5 November 2013 /Accepted: 9 January 2014 /Published: 31 January 2014

Abstract: For the radiating capacity of curtain antenna array, this paper constructs a three-line-four-column curtain antenna array using cage antenna as the antenna array element and obtains a normalizing 3D radiation patterns through conducting simulation with MATLAB. Meanwhile, the relationships between the antenna spacing and the largest directivity coefficient, as well as the communication frequency and largest directivity coefficient are analyzed in this paper. It turns out that the max value will generate when the antenna spacing is around 18 m and the best communication effect will be achieved when the communication frequency is about 12.4 MHz. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Curtain antenna, Antenna array, Intelligent antenna, MATLAB, Cage antenna.

1. Introduction

Antenna array is a specialized antenna that is made up of more than two antenna units through regular or random permutation and with proper stimulus to get the predetermined radiation characteristic. The transmission and receiving of antenna array is regarded as the linear synthesis of all transmission and receiving antenna elements. As for transmitting antenna, some simple radiant points like point source, symmetrical dipole source are common radiant points constructing antenna array. In order to obtain the best directionality of radiant energy, they constitute the array based on some small parameters like wireless feed current, spacing and electrical length in the format of a straight line or other more complex format. The antenna array can adjust radiation and receiving direction according to requirements, which is the charming of the antenna array.

Thus, adaptive antenna array in radar and intelligent array used in modern mobile communication are produced.

Compared to traditional single antenna, antenna array boosts lots of advantages, such as more flexible beam control, stronger interference rejection capability and higher spatial resolving power. As the rapid development of super-large scale, high speed integrated circuit and monolithic microwave integrated circuits, various kinds of advanced array signal processing system can be realized to provide a project implementation platform for array signal processing and theory.

2. Basic Theory

2.1. Finite Dipole

Since finite dipole can be regarded as a cascade of countless small dipoles, superposition principle can be employed to evaluate. Using the countless small dipoles whose superposition length of is dz' as the integration, the result is:

$$E_\theta = \frac{jk\eta I_0 L\sin\theta}{4\pi r} e^{-jkr} \int_{-L/2}^{L/2} I(z) e^{-jkz'\cos\theta} dz' \quad (1)$$

The dipole is center-fed and the current must stop on both sides, so dipole current can be well represented by normal line selection approximation, as the expansion of the existing transmission-line current.

Therefore, the expression of current is

$$I(z') = \begin{cases} I_0 \sin\left[k\left(\frac{L}{2} - z'\right)\right], 0 \le z' \le L/2 \\ I_0 \sin\left[k\left(\frac{L}{2} + z'\right)\right], -L/2 \le z' \le 0 \end{cases} \quad (2)$$

When the current value is submitted into the formula, the approximate far electronic field is:

$$E_\theta = \frac{j\eta I_0 e^{-jkr}}{2\pi r}\left[\frac{\cos\left(\frac{kL}{2}\cos\theta\right) - \cos\left(\frac{kL}{2}\right)}{\sin\theta}\right] \quad (3)$$

$$I(z') = \begin{cases} I_0 \sin\left[k\left(\frac{L}{2} - z'\right)\right], 0 \le z' \le L/2 \\ I_0 \sin\left[k\left(\frac{L}{2} + z'\right)\right], -L/2 \le z' \le 0 \end{cases} \quad (4)$$

2.2. Basic Theory of Antenna

The binary array is the most basic antenna array, easy to be analyzed. Similar with other larger antenna arrays, binary array also owns the general performance, which is the basis to understand the phase relation of two adjacent antenna arrays at the same time. The spacing of two vertical polarization infinitesimal dipoles placed along the y axis is d; the distance between the field point and the origin is r, accordance with $r \gg d$. Assumption can be made that the distance vector $r1$, r and $r2$ is almost parallel to each other.

So the approximation is:

$$r_1 \approx r + \frac{d}{2}\sin\theta \quad (5)$$

$$r_2 \approx r - \frac{d}{2}\sin\theta \quad (6)$$

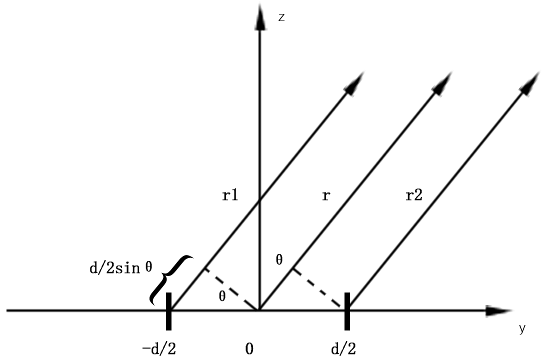

Fig. 1. Two vertical polarization infinitesimal dipoles.

Continuing to assume: the phase of array element $r1$ is $-\delta/2$, which means its phase current is $I_0 e^{-j\frac{\delta}{2}}$; the phase of array element is $+\delta/2$, which, in other words, indicates its phase current is $I_0 e^{j\frac{\delta}{2}}$. Far field can be achieved after the superposition of the array elements of these two dipoles.

$$E_\theta = \frac{jk\eta I_0 e^{-j\frac{\delta}{2}} L\sin\theta}{4\pi r_1} e^{-jkr_1} + \frac{jk\eta I_0 e^{j\frac{\delta}{2}} L\sin\theta}{4\pi r_2} e^{-jkr_2} \quad (7)$$

Of the above formula, δ represents the phase difference of two adjacent phase elements; L is the length of dipole; θ means the angle from z axis measurement in spherical coordinate; d is the element spacing.

Further simplifying the formula (7):

$$E_\theta = \underbrace{\frac{jk\eta I_0 L e^{-jkr}}{4\pi r}\sin\theta}_{\text{Array Element Factor}} \bullet \underbrace{\left(2\cos\left(\frac{kd\sin\theta + \delta}{2}\right)\right)}_{\text{Array Factor}} \quad (8)$$

E_θ can be divided into two parts. Element factor is the far field equation of a dipole antenna, and meanwhile, array factor is the pattern function related to array geometry.

The far distance of antenna array consisting of same elements can always be decomposed into the product of Element Factor and Array Factor. Multiplying EF by AF shows that antenna pattern possesses multiplicative property. Thereupon, the far field direction of any antenna array can be expressed as (AF)×(EF). AF is determined by element geometry, element spacing and the phase of each element.

Radiation intensity can be regarded as power density after distance normalization and be expressed as:

$$U(\theta,\phi)=\frac{r^2}{2\eta}\left|E_s(r,\theta,\phi)\right|^2 =\frac{\eta r^2}{2}\left|H_s(r,\theta,\phi)\right|^2 \quad (9)$$

The normalization radiation intensity can be obtained after plunging formula (8) into formula (9):

$$U_n(\theta)=[\sin\theta]^2\left[\cos\left(\frac{kd\sin\theta+\delta}{2}\right)\right]^2 =[\sin\theta]^2\left[\cos\left(\frac{\pi d}{\lambda}\sin\theta+\frac{\delta}{2}\right)\right]^2 \quad (10)$$

When $d/\lambda=0.5,\delta=0$, formula (10) construction can be adopted to explain the product of radiation pattern. As it is shown in Fig. 2(a) is the power radiation pattern of a single dipole array element; Fig. 2(b) refers to the power radiation pattern of a single array factor; Fig. 2(c) means the product of the both.

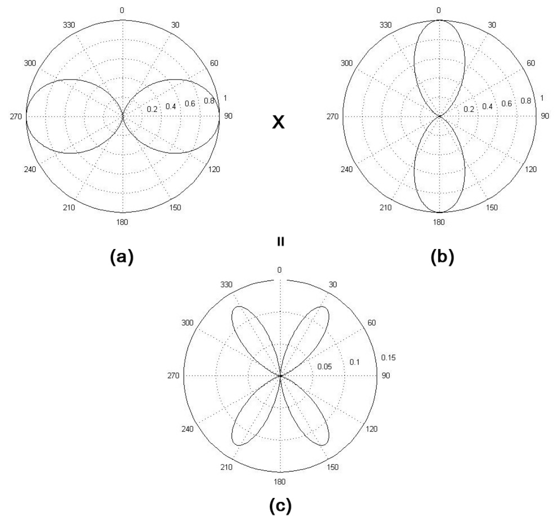

Fig. 2. (a) Power radiation pattern of dipole; (b) Power radiation pattern of array factor; (c) General radiation pattern.

The most important theory that binary array tries to prove is: one array factor can be separated from another; as long as all array elements are the same, the array factor of all array can be calculated individually, and is irrelevant to the chose array element.

3. Curtain Antenna Array Model

3.1. Cage Antenna

Curtain antenna array uses cage antenna as the array element. A hollow cylinder is made with multi-conductors to replace the antenna of a single conductor with making, as it is shown in Fig. 3. Its directivity is similar to symmetrical dipole of a general conductor, which can be treated as an equal part of dipole antenna.

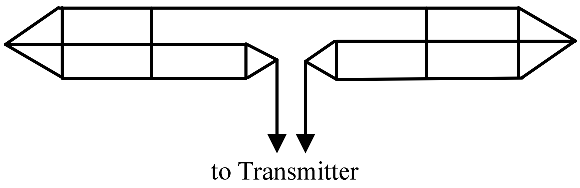

Fig. 3. Schematic figure of cage antenna.

3.2. Curtain Array Factor

Fig. 4 is a schematic figure of curtain array in the y-z plane. If there are N and M elements respectively on z axis and y axis, a curtain array of $N\times M$ is thus formed.

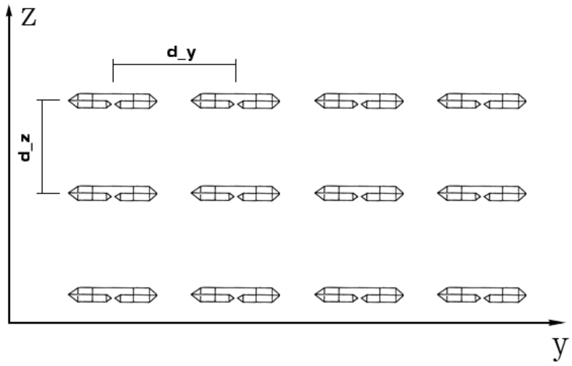

Fig. 4. Structure model of curtain array.

The following curtain antenna array factor can be realized with the radiation pattern multiplication principle:

$$AF = AF_z \bullet AF_y =\sum_{n=1}^{N} e^{-j(n-1)(kd_z\cos\theta+\beta_z)}\sum_{m=1}^{M} e^{-j(m-1)(kd_y\sin\theta\sin\phi+\beta_y)} \quad (11)$$

Among it, β_x, β_y is the delay of beam transferring to phase, which can be presented as following:

$$\beta_z=-kd_z\cos\theta_0,\beta_y=-kd_y\sin\theta_0\sin\phi_0 \quad (12)$$

The array factor that normalizes AF can be re-expressed as:

$$AF_{NM} = \frac{1}{NM}\sum_{n=1}^{N} e^{-j(n-1)(kd_z\cos\theta+\beta_z)} \bullet \sum_{m=1}^{M} e^{-j(m-1)(kd_y\sin\theta\sin\phi+\beta_y)} \quad (13)$$

3.3. Power Density and Radiation Intensity

The far field radiation intensity of curtain array is:

$$E(r,\theta,\phi) = EF\times AF = \frac{jk\eta I_0 L e^{-jkr}}{4\pi r}\sin\theta \bullet \sum_{n=1}^{N} e^{-j(n-1)(kd_z\cos\theta+\beta_z)} \sum_{m=1}^{M} e^{-j(m-1)(kd_y\sin\theta\sin\phi+\beta_y)} \quad (14)$$

Power density is:

$$E(r,\theta,\phi) = EF\times AF = \frac{jk\eta I_0 L e^{-jkr}}{4\pi r}\sin\theta \bullet \sum_{n=1}^{N} e^{-j(n-1)(kd_z\cos\theta+\beta_z)} \sum_{m=1}^{M} e^{-j(m-1)(kd_y\sin\theta\sin\phi+\beta_y)} \quad (15)$$

Among it,

$$AF = \sum_{n=1}^{N} e^{-j(n-1)(kd_z\cos\theta+\beta_z)} \bullet \sum_{m=1}^{M} e^{-j(m-1)(kd_y\sin\theta\sin\phi+\beta_y)} \quad (16)$$

The power density $1/r2$ makes the far field radiation pattern is irrelevant to distance. After normalization, the normalized radiation intensity is:

$$U(\theta,\phi) = [\sin\theta]^2 |AF_{NM}|^2 \quad (17)$$

3.4. Directivity Factor

The directivity factor and the maximum directivity factor of curtain antenna array is:

$$D(\theta,\phi) = \frac{4\pi U(\theta,\phi)}{\int_0^{2\pi}\int_0^{\pi} U(\theta,\phi)\sin\theta d\theta d\phi} = \frac{4\pi[\sin\theta]^2 |AF_{NM}|^2}{\int_0^{2\pi}\int_0^{\pi} [\sin\theta]^3 |AF_{NM}|^2 d\theta d\phi} \quad (18)$$

Through working out the maximum value of directivity factor, the maximum directivity factor of curtain array can be obtained:

$$D_0 = \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi} \sin^3\theta |AF_{NM}|^2 d\theta d\phi} \quad (19)$$

4. Simulation Analysis

Simulation parameters are set as follows: communication frequency is 12.4 MHz; received power is 1 KW each feed point; the length of antenna is set as 20 m; and the antenna is in three-line-four-column array, with the line spacing of 10 m, turning to elevation angle 0° and azimuth angle 0°.

Parameter of measured point : testing elevation angle is 0° and the testing azimuth angle is 0°; the distance is 1000 m.

With simulations under the environment of MATLAB, the field strength of antenna array at the measured point can be obtained is 1.92206 V/m and power intensity is 0.004899 W/m2.

Using MATLAB, the three-dimensional radiation intensity figure of curtain antenna array is (see Fig. 5).

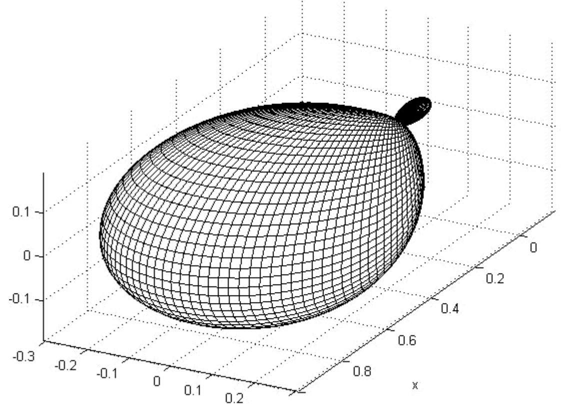

Fig. 5. Normalized 3D radiation pattern (0° elevation and 0° azimuth angle).

The rest of the parameters remain the same; the relation curve of the simulated curtain array antenna distance and its maximum directivity factor is shown in following Fig. 6:

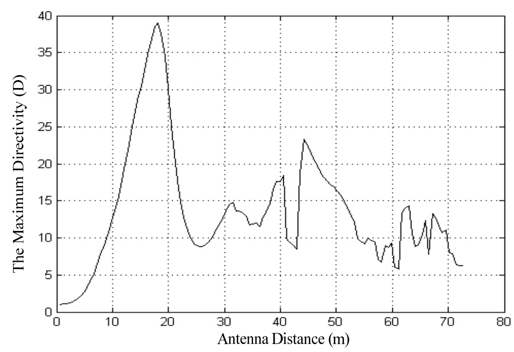

Fig. 6. Relation curve of antenna distance and the maximum directivity factor.

As is shown in the above figure: the relation curve between antenna distance and the maximum directivity factor is nonlinear, but in a very complex curve. However, it is obvious in the figure that when the antenna distance is around 18 m, the maximum value of relation curve will arise.

By referring to Fig. 7, after changing the antenna distance to 18 m, then the following 3D radiation intensity figure will be achieved:

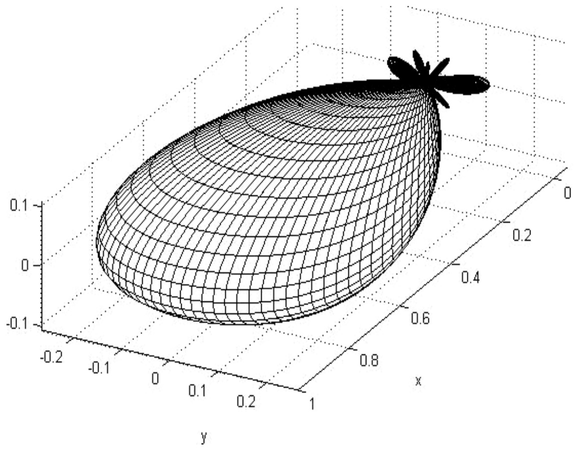

Fig. 7. Curtain array normalized 3D radiation pattern (18 m as the distance).

With the parameters of the antenna and antenna array (18 m) unchanged, the following waveform is obtained by using MATLAB simulation to analyze the directivity of each communication frequency.

From the Fig. 8, it is apparent that different frequencies have divergent communication. With the current set parameters, the best communication effect can be achieved at about 12.4 MHz.

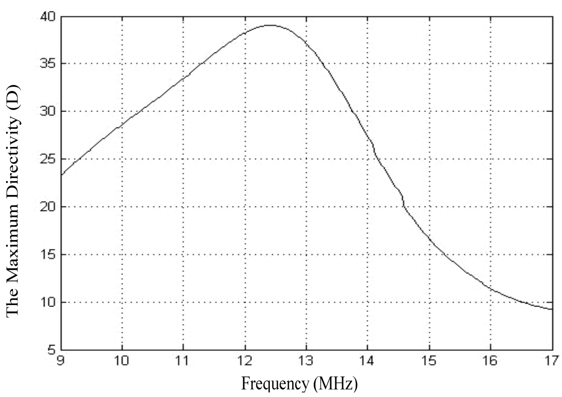

Fig. 8. Relation curve between communication frequency and the maximum directivity factor.

As the antenna can adjust the direction, the Fig. 9 after setting the elevation to 45° and azimuth angle 0° will be realized. Obviously, the antenna main lobe is changed to point at the turning location.

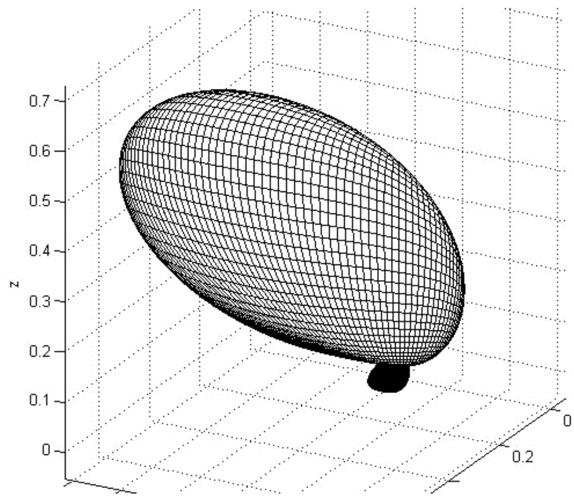

Fig. 9. Normalized 3D radiation pattern (45° elevation and 0° azimuth angle).

5. Conclusions

This paper researches on curtain antenna array through modeling the array signal and analyzes the influences of antenna array distance, communication frequency on array signal via simulation. As it only conducts some superficial researches, further researches should be carried out to address some relative complex problems, such as the mutual couplings between antennas, other types of antenna arrays, influences of communication channel, etc.

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