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The Radiation Pattern for Uniform Array Antennas

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Abstract – In this paper are studied the radiation pattern of the uniform linear array antenna and the uniform planar array antenna respectively. Thus, have been modified the phase of the currents injected into the elements of linear array and planar array, and the number of elements of planar array respectively. All these changes are made in a program implemented on Matlab. Simulation results using different phases of the currents injected into antennas and different numbers of antenna elements are provided.
Keywords: dipole antenna, uniform linear array antenna, planar array antenna

I. INTRODUCTION

To obtain high directivity, narrow beams, low side lobes, steerable beams, particular pattern characteristics, etc., commonly a group of antenna elements, called an array antenna, or simply array, is used. The design of an array involves mainly first the selection of elements and array geometry, and then the determination of the element excitations required for achieving a particular performance, sometimes under a given constraint.

The realization of the desired excitation requires a detailed knowledge of element input impedance characteristics as well as the mutual impedance between any two elements in the given array environment. In general, this is a difficult problem which may be solved approximately for large arrays with an infinite array model and for small arrays in a two-element environment model.

There is no reason why all elements in an array must be of the same type other than simplicity in fabrication and analysis. Furthermore, even with the same type of elements, the shape of current or aperture field distribution of the element near the edge of the array can be different from that of the element in the central portion of the array, depending on the array geometry, element spacing and orientation, and, of course, the element type. Generally such a difference may not cause a serious deterioration in the array performance in some applications[1].

Dipole, monopole and loop antennas and their associated arrays are the most common antenna used for communication systems, broadcasting and measurement of electric and magnetic fields[2].

Linear arrays occupy a unique position in array theory and have received great attention. This is probably because for uniformly spaced elements the pattern function can simply be expressed in terms of a polynomial for which the analytic tool is well-known[1].

II. PROBLEM FORMULATION

A. *Dipole antenna*

The simplest type of wire antenna is the dipole antenna. The dipole antenna is one of the most important and commonly used types of radio-frequency antenna. It is widely used on its own, and it is also incorporated into many other radio-frequency antenna designs where it forms the radiating or driven element for the antenna.

A dipole antenna is most commonly a linear metallic wire or rod with a feed point at the center as shown in Fig.1.

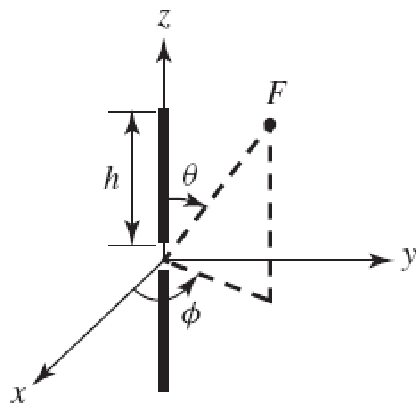

Fig. 1. Dipole antenna

As the name suggests the dipole antenna consists of two terminals or „poles” into which radio-frequency current flows. This current and the associated voltage causes and electromagnetic or radio signal to be radiated. Being more specific, a dipole is generally taken to be an antenna that consists of a resonant length of conductor cut to enable it to be connected to the feeder. For resonance, the conductor

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is an odd number of half wavelengths long. In most cases a single half wavelength is used, although three, five, etc. Wavelength antennas are equally valid.

The polar diagram of a half wave dipole antenna that the direction of maximum sensitivity or radiation is at right angles to the axis of the radio-frequency antenna. The radiation falls to zero along the axis of the dipole antenna as might be expected. The radiation pattern of the dipole antenna is shown in Fig.2.

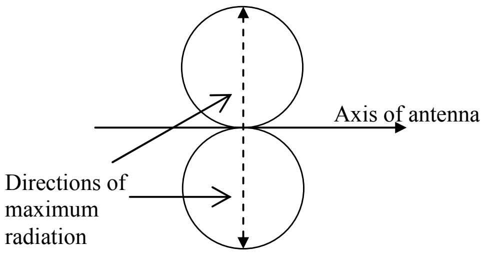


Fig. 2. The radiation pattern of the dipole antenna

Because of the symmetry of dipole relative to the *xOy* plane containing the feed point, the resultant radiation is independent of ϕ (rotationally symmetric about the *z*-axis)[3].

If the length of the dipole antenna is changed then the radiation pattern is altered. As the length of the antenna is extended, it can be seen that the familiar figure of „eight" pattern changes to give main lobes and a few side lobes. The main lobes move progressively towards the axis of the antenna as the length increases.

B. *Linear array*

Linear antenna arrays constitute an excellent starting point to array theory because of the insights of they lend into beamforming and the relationship between the array excitation functions and the resulting radiation patterns. It is considered an array where the excitation currents for all antenna elements are the same, and the interelement spacing is constant.

The field of an isotropic radiator located at the origin of the linear array may be written as (assuming θ-polarization)[4]:

$$E_\theta = I_0 \frac{e^{-jkr}}{4\pi r}. \qquad (1)$$

where:
I_0 – the complex excitation of the isotropic radiator
k – the free space wave number
r – distance of the observation point from the origin.

I assume that the N elements of the array are uniformly – spaced with a separation distance d. A linear array antenna uniformly – spaced is presented in Fig. 3.

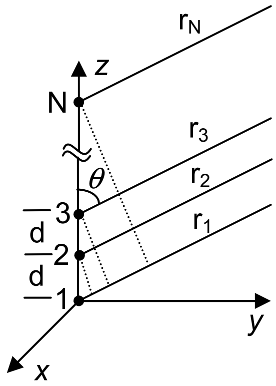


Fig. 3. Uniform linear array antenna

The current magnitudes of the array elements are assumed to be equal and the current on the array element located at the origin is used as the phase reference (zero phase).

$$I_1 = I_0 \quad I_2 = I_0 e^{j\phi_2} \quad \cdots \quad I_N = I_0 e^{j\phi_N}. \qquad (2)$$

The far fields of the individual array elements are:

$$\begin{aligned} E_{\theta_1} &\approx I_0 \frac{e^{-jkr}}{4\pi r} = E_0 \\ E_{\theta_2} &\approx I_0 e^{j\phi_2} \frac{e^{-jk(r-d\cos\theta)}}{4\pi r} = E_0 e^{j(\phi_2+kd\cos\theta)} \\ E_{\theta_3} &\approx I_0 e^{j\phi_3} \frac{e^{-jk(r-2d\cos\theta)}}{4\pi r} = E_0 e^{j(\phi_3+2kd\cos\theta)} \\ &\vdots \\ E_{\theta_N} &\approx I_0 e^{j\phi_N} \frac{e^{-jk[r-(N-1)d\cos\theta]}}{4\pi r} \\ &= E_0 e^{j[\phi_N+(N-1)kd\cos\theta]} \end{aligned} \qquad (3)$$

The overall array far field is found using superposition:

$$\begin{aligned} E_\theta &= E_{\theta_1} + E_{\theta_2} + E_{\theta_3} + \ldots + E_{\theta_N} \\ &= E_0\left[1 + e^{j(\phi_2+kd\cos\theta)} + \ldots + e^{j[\phi_N+(N-1)kd\cos\theta]}\right] \\ &= E_0[AF] \end{aligned} \qquad (4)$$

The array factor (AF) is independent of the antenna type, assuming all of the elements are identical. The array factor for a uniformly – spaced *N* – element linear array is:

$$AF = \left[1 + e^{j(\phi_2+kd\cos\theta)} + \ldots + e^{j[\phi_N+(N-1)kd\cos\theta]}\right]. \qquad (5)$$

A uniform array is defined by uniformly – spaced identical elements of equal magnitude with a linearly progressive phase from element to element:

$$\phi_1 = 0 \quad \phi_2 = \alpha \quad \phi_3 = 2\alpha \cdots \phi_N = (N-1)\alpha . \quad (6)$$

In this case, the array factor can be write as:

$$AF = e^{j(N-1)\frac{(\alpha + kd\cos\theta)}{2}} \frac{\sin\left(\frac{N(\alpha + kd\cos\theta)}{2}\right)}{\sin\left(\frac{(\alpha + kd\cos\theta)}{2}\right)} . \quad (7)$$

The complex exponential term in expression (7) represents the phase shift of the array phase center relative to the origin. If the position of the array is shifted, so that the center of the array is located at the origin, this phase term goes away. The array factor then becomes:

$$AF = \frac{\sin\left(\frac{N\psi}{2}\right)}{\sin\left(\frac{\psi}{2}\right)} . \quad (8)$$

The array factor may be normalized so that the maximum value for any value of N is unitary. The normalized factor is:

$$AF = \frac{1}{N} \frac{\sin\left(\frac{N\psi}{2}\right)}{\sin\left(\frac{\psi}{2}\right)} . \quad (9)$$

C. *Planar array*

When a planar array has a separable excitation, an analysis can be made simply by regarding each row (or column) sub-array as a single element and then considering all rows (or columns) to form a „linear column" (or row) array. In so doing, the theory for linear array applies[1].

Unlike linear arrays that can only scan the main beam in one polar plane (θ - the elevation plane or ϕ - the azimuth plane), planar arrays scan the main beam along both θ and ϕ. Planar arrays offer more gain and lower sidelobes than linear arrays, at the expense of using more elements. The design principles for planar arrays are similar to those presented earlier for the linear arrays. Since the elements are placed in two dimensions (Fig. 4), the array factor of a planar array can be expressed as the multiplication of the array factors of two linear arrays: one along the x-axis and one along the y-axis[5].

$$AF_{planar} = AF_x * AF_y = \frac{\sin\left(\frac{N\psi_x}{2}\right)}{N\sin\left(\frac{\psi_x}{2}\right)} \frac{\sin\left(\frac{M\psi_y}{2}\right)}{M\sin\left(\frac{\psi_y}{2}\right)} . \quad (10)$$

where:

$$\begin{aligned} \psi_x &= kd_x \sin\theta\cos\phi + \alpha_x \\ \psi_y &= kd_y \sin\theta\sin\phi + \alpha_y \end{aligned} . \quad (11)$$

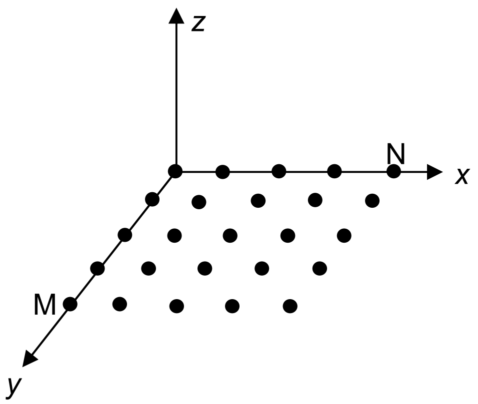


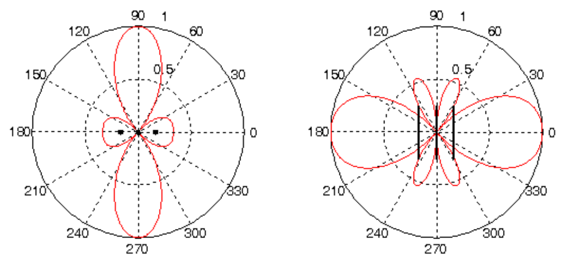
Fig. 4. Planar array antenna

III. SIMULATION RESULTS

In these simulations, it was considered a linear array antenna, and a planar array antenna respectively. The linear array antenna and planar array antenna are composed by the dipole antennas, which are evenly spaced with the distance of λ/2. By multiplying the linear array antenna system in *xOy* plane, the planar array antenna is obtained.

All these simulations are made in Matlab[6] and all results are normalized displayed.

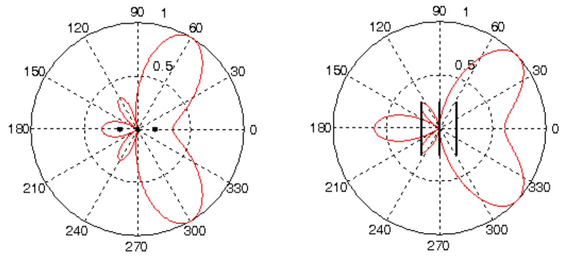
In the first case it was considered a linear array antenna composed by three elements, the phase of the currents injected into the antenna being zero. The radiation patterns obtained in *xOy* plane and *xOz* plane respectively, can be observed in fig. 5.



a) b)

Fig. 5. The radiation patterns for linear array antenna, zero phase: a) in *xOy* plane, b) in xOz plane

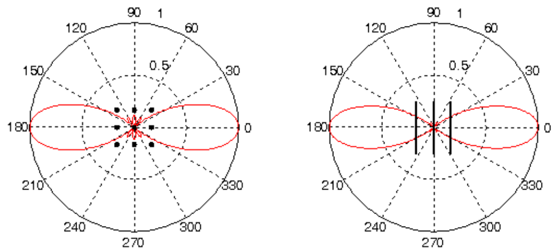
Modifying the phase of the currents injected into the antenna with 90º, were obtained the radiation patterns presented in fig. 6.



a) b)

Fig. 6. The radiation patterns for linear array antenna, 90º phase: a) in *xOy* plane, b) in *xOz* plane

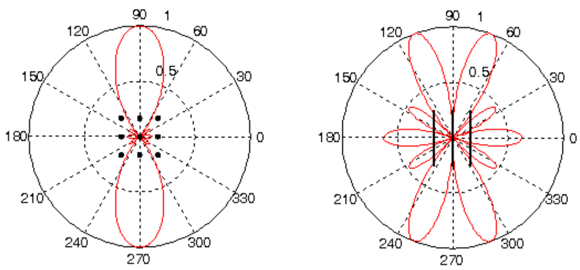
In the second case it was considered a planar array antenna, obtained by multiplying, in *xOy* plane, the linear array used in the previous case. For a zero phase of the currents injected into the system elements, the radiation patterns in *xOy* plane and *xOz* plane are obtained. (see fig. 7.)



a) b)

Fig. 7. The radiation patterns for 3x3 planar array antenna, zero phase: a) in *xOy* plane, b) in *xOz* plane

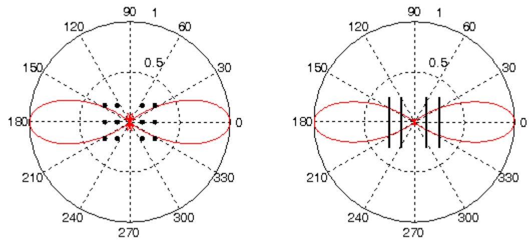
Fig. 8. presents the radiation patterns obtained for a planar array antenna composed by 3x3 elements, with 90º phase shift between the currents injected in two consecutive antennas.



a) b)

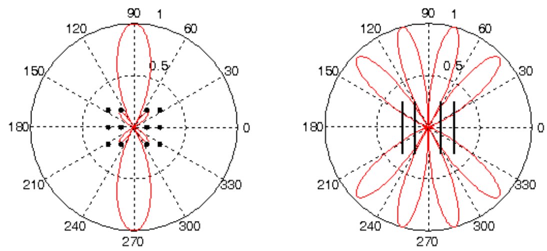
Fig. 8. The radiation patterns for 3x3 planar array antenna, 90º phase: a) in *xOy* plane, b) in *xOz* plane

In the last case it was considered a planar array antenna composed by 4x3 elements. The radiation patterns obtained for such system, for zero phase of the currents and 90º phase respectively, are presented in fig. 9. and in fig. 10. respectively.



a) b)

Fig. 9. The radiation patterns for 4x3 planar array antenna, zero phase: a) in *xOy* plane, b) in *xOz* plane



a) b)

Fig. 10. The radiation patterns for 4x3 planar array antenna, 90º phase: a) in *xOy* plane, b) in *xOz* plane

IV. CONCLUSIONS

In general, the dipole antennas are used for applications where the radiation is desired in the *xOy* plane of the antenna. The linear array controls the radiation pattern in one plane; it depends on the element pattern to control the beam in the other plane. Planar arrays can control the radiation pattern in both planes.

According to the radiation patterns obtained by my program in Matlab software, I conclude that it can achieved an electronic radiation in whole space (in *xOy* and *xOz* plans at the same time), by the variation of the excitation phase.

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