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Invention of segment beams from arrays of wire antennas

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ABSTRACT

Array patterns depends on type of elements, spacing between the elements and length of the array etc., conventionally elements are spaced at λ/2 in an array. However, in this paper we are made to generate the normalized radiation patterns for different spacing and different types of elements. It has been possible to control the radiation pattern by controlling the spacing between the elements. The arrays considered contain non-identical elements with non-uniform spacing. The results are useful for design of arrays to produce low side lobes for EMI suppression.

Introduction

Wire antennas are often used for radio communication purposes from the days of discovery of Electromagnetic radiation. The term wire here represents a metallic highly conducting structure. The wire structure can be constructed from a given number of wire segments and the segments may in principle be straight or curved.

It is well known that the current distribution in the dipoles of length less than λ/4 can be approximated by triangular current distribution. When the length of the dipole is much less than 'λ', the constant current distribution is found to be valid.

For the dipoles of lengths of the order of 'λ', the sinusoidal current distribution is reasonably good approximation. When the straight wire antenna is terminated in a resistance, the current distribution is approximated as a travelling wave. In fact, V-antennas can also be converted to a travelling wave antenna by terminating each arm with a matched resistance.

Radiation Pattern of Wire Antennas

Consider a thin wire antenna located in free space. To obtain far-field pattern, the distance **r** should be much greater than wavelength. Consider typical antenna geometry as shown in Fig.1

Let **E** be the electric field and **r** is the radius vector. Then the electric field is in the form of

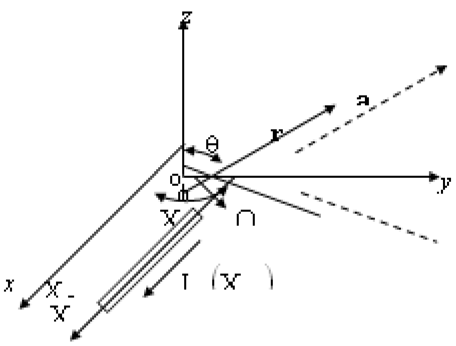

Fig 1. Geometry of wire and its coordinate system

$$\mathbf{E}(\mathbf{r}) = j\omega \mathbf{a}_r \times [\mathbf{a}_r \times \mathbf{A}(\mathbf{r})] \qquad (1)$$

Here, $\mathbf{a}_r$ is the unit vector from the origin towards the point of interest.

The computed magnetic field vector is given by

$$\mathbf{H}(\mathbf{r}) = \frac{1}{\eta_0} \mathbf{a}_r \times \mathbf{E}(\mathbf{r}) \qquad (2)$$

Here, η_0 is intrinsic impedance of free space.

As the dimensions of the wire cross-section is much smaller than wavelength, the current in the wire can be assumed to be along its axis.

As a result, the vector magnetic potential in the far-field zone is approximately written in the form of

$$\mathbf{A}(\mathbf{r}) = \mu G(r) \sum_{m=1}^{N} \int_{X_{1m}}^{X_{2m}} \mathbf{a}_{Xm} I_m(X_m) e^{(jk\mathbf{r}.\mathbf{a}_r)} dX_m \qquad (3)$$

Here, $G(r)$ is Green's function

$\mathbf{a}_{Xm}$ is unit vector tangential to wire axis

r is the distance from origin to element dX_m

N is number of segments

If the wire segments are straight

$$\mathbf{r} = \mathbf{r}_{Xm} + S_m \mathbf{a}_{Xm}$$

From the above equations, Electric field is given by

$$\mathbf{E}(r) = -jk\eta G(r) \sum_{m=1}^{N} [\mathbf{a}_\theta (\mathbf{a}_\theta . \mathbf{a}_{Xm}) + \mathbf{a}_\phi (\mathbf{a}_\phi . \mathbf{a}_{Xm})] \qquad (4)$$

Here, $\mathbf{a}_\theta$ and $\mathbf{a}_\phi$ are the unit vectors of the spherical coordinate system.

In the above expressions

$I_m(X_m)$ is given by the polynomial

$$I_m(X_m) = \sum_{i=0}^{n_m} I_{mi} X_m^i, \quad m = 1, 2, \ldots\ldots, N \qquad (5)$$

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Here, n_m is the desired degree of polynomial.

Radiation Pattern of Wire Antenna Placed above the Earth.

Consider a long horizontal wire at a height H above the earth fed at one end with respect to ground and other end terminated with matched load as shown in Fig. 2. Such a wire antenna will have the image. The wire and its image form an efficient radiating system. The current distribution on such a structure is an outward travelling damped wave. As the earth is conductive, the image current lies at a distance of H below the xy plane as the earth surface is found to be in z=0 plane.

The current on the image is an outward travelling wave and 180^0 out of phase with respect to the current in the wire. The pattern of such a wire structure is obtained by the product of the element pattern of the wire and the array factor.

The current distribution along the wire can be assumed in the form of

$$A(x) = A_0 . e^{-\gamma x} \quad (6)$$

Here, γ = propagation constant

For the above current distribution, the radiation pattern of the wire antenna is given by

$$E_\psi = \frac{j k_0 I_0 z_0}{4\pi r} \sin\psi \, e^{-j k_0 r} \int_0^L e^{-j k_0 x (1-\cos\psi)} dx \quad (7)$$

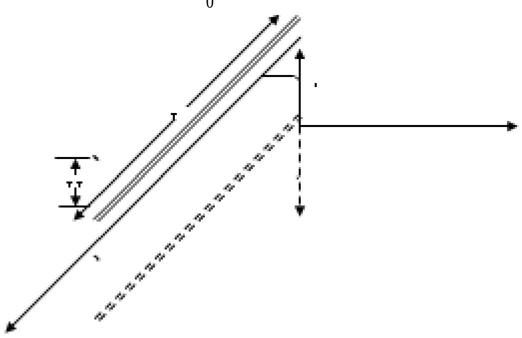

Fig 2. Horizontal wire antenna

Here, Ψ represents an angle between the two straight wire antennas as shown in the Fig. 3.

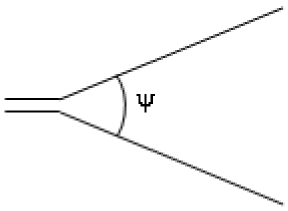

Fig.3. Geometry of V-antenna

The above equation can be simplified as follows.

$$= \frac{j k_0 I_0 z_0}{4\pi r} \sin\psi \, e^{-j k_0 r} \left[\frac{e^{-j k_0 x (1-\cos\psi)}}{-j k_0 (1-\cos\psi)} \right]_0^L$$

$$= \frac{j k_0 I_0 z_0}{4\pi r} \sin\psi \, e^{-j k_0 r} \left[\frac{e^{-j k_0 L (1-\cos\psi)} - 1}{-j k_0 (1-\cos\psi)} \right]$$

$$= \frac{j k_0 I_0 z_0}{4\pi r} \frac{\sin\psi}{\sin^2 \psi/2} \frac{1}{-2 j k_0} \left[e^{-j k_0 (r + L(1-\cos\psi))} - e^{-j k_0 r} \right]$$

$$= \frac{j I_0 z_0}{4\pi r} \frac{\sin\psi}{\sin^2 \psi/2} \left[\frac{e^{-j k_0 (r + L(1-\cos\psi))} - e^{-j k_0 r}}{-2j} \right]$$

$$= \frac{j I_0 z_0}{4\pi r} \frac{\sin\psi}{\sin^2 \psi/2} e^{-j k_0 r} \left[e^{-jk_0 \frac{L}{2}(1-\cos\psi)} . e^{-jk_0 \frac{L}{2}(1-\cos\psi)} - e^{-jk_0 \frac{L}{2}(1-\cos\psi)} . e^{jk_0 \frac{L}{2}(1-\cos\psi)} \right]$$

$$= \frac{j I_0 z_0}{4\pi r} \frac{\sin\psi}{\sin^2 \psi/2} e^{-jk_0\left(r + \left(\frac{L}{2}\right)(1-\cos\psi)\right)} \sin\left(\frac{k_0 L}{2}(1-\cos\psi)\right)$$

$$= \frac{j I_0 z_0}{4\pi r} \frac{\sin\psi}{\sin^2 \psi/2} e^{-jk_0\left(r + \left(\frac{L}{2}\right)(1-\cos\psi)\right)} \sin\left(\frac{k_0 L}{2} 2\sin^2 \psi/2\right)$$

$$E(\psi) = \frac{j I_0 z_0}{4\pi r} e^{-jk_0\left(r + \left(\frac{L}{2}\right)(1-\cos\psi)\right)} \sin\psi \frac{\sin\left(k_0 L \sin^2 \psi/2\right)}{\sin^2 \psi/2} \quad (8)$$

Equations (1) to (8) are presented in order to bring out the element pattern of the wire antennas.

Generation of sector beams from array of wire antenna

Consider the array of geometry shown in Fig.4

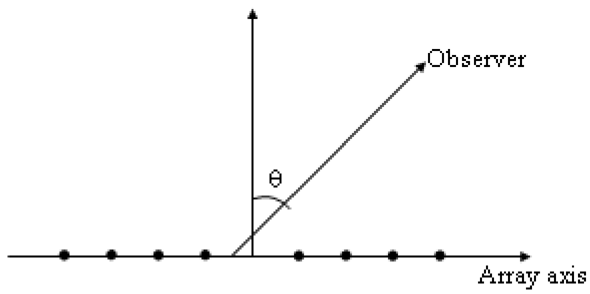

Fig.4. Array geometry

'θ' represent angle between line of observer and broadside. When the radiating elements are isotropic in nature, the array factor without additional excitation phase is given by

$$E(u) = \sum_{n=1}^{N} A(x_n) e^{j \frac{2\pi L}{\lambda} u x_n} \quad (9)$$

Here, u = sinθ

$\frac{2L}{\lambda}$ Is normalized array length

N is number of elements in the array

In this paper we are interest to consider array of discrete radiators but not line sources. However, the Taylor amplitude distribution for a continuous line source is made

Use of to extend it for the case of discrete arrays. In most of the works reported in the literature, discrete amplitude distributions are exclusively determined for discrete arrays. But in the present work, the amplitude distribution for discrete arrays is obtained from that of continuous line sources directly.

Results and Discussions

The radiation patterns are numerically computed for the following parameters.

N = 20, 50, 100, 200

$\bar{n}$ = 5

Here, $\bar{n}$ is a parameter in the Taylor's distribution for continuous line source and it is an integer which divides the radiation pattern into uniform side lobe region surrounding the main beam and the region of decaying side lobes.

$$\frac{2L}{\lambda} = 10, 25, 50, 100$$

The results are presented in Fig. (5 - 8)

As the results are the field strength patterns plotted in logarithmic scale, they are not compared with another pattern.

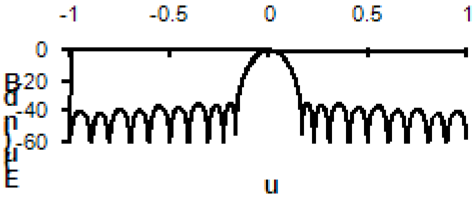

Fig 5. Normalized Radiation Pattern for side lobe level= -35 dB, array length = 10, Number of elements = 20

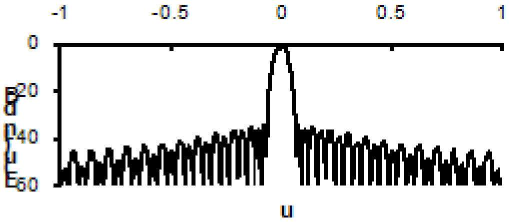

Fig 6. Normalized Radiation Pattern for side lobe level= -35 dB, array length = 25, Number of elements = 50

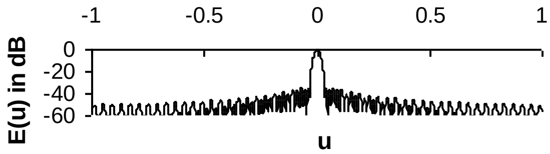

Fig 7. Normalized Radiation Pattern for Side lobe level = -35 dB,array length = 50, Number of elements = 100

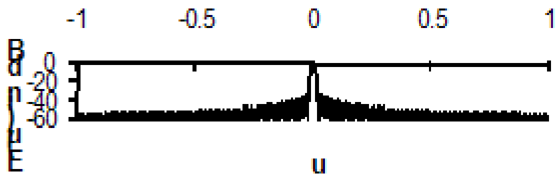

Fig 8. Normalized Radiation Pattern for side lobe level = -35 dB,array length = 100, Number of elements = 200

The patterns so obtained are converted into sector beams by introducing an additional phase distribution presented in the preceding chapter for desired beam widths of 0.4, 0.5, 0.6 and 0.8.

The results are presented in fig. (9 – 24). Here also the amplitude distribution is fixed and the computed phase is made use of.

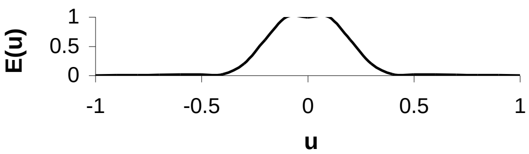

Fig 9. Normalized Radiation Pattern for Side lobe level = -35 dB,array length = 10, beam width = 0.4

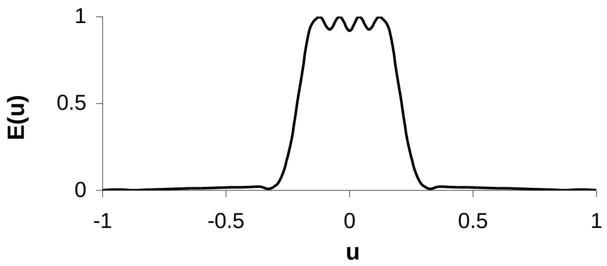

Fig 10. Normalized Radiation Pattern for Side lobe level = -35 dB,array length = 25, beam width = 0.4

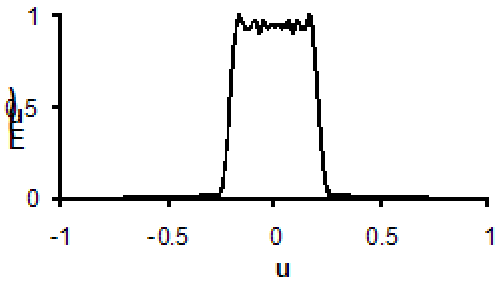

Fig 11. Normalized Radiation Pattern for Side lobe level = -35 dB,array length = 50, beam width = 0.4

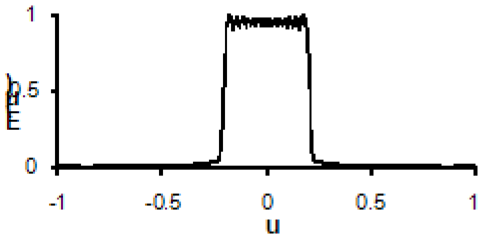

Fig 12. Normalized Radiation Pattern for Side lobe level = -35 dB,array length = 100, beam width = 0.4

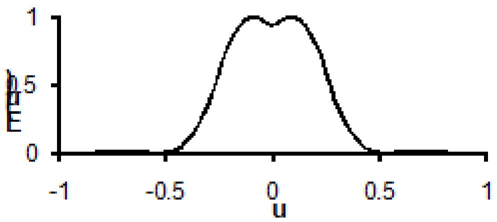

Fig 13. Normalized Radiation Pattern for Side lobe level = -35 dB,array length = 10, beam width = 0.5

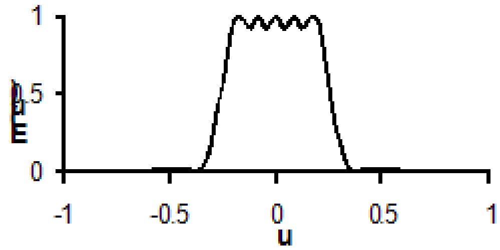

Fig 14. Normalized Radiation Pattern for Side lobe level = -35 dB,array length = 25, beam width = 0.5

Fig 15. Normalized Radiation Pattern for Side lobe level = -35 dB, array length =50, beam width = 0.5

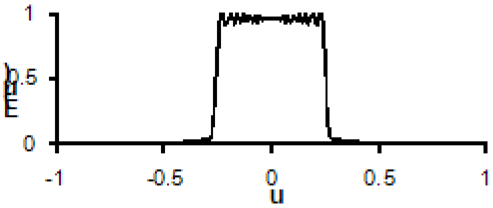

Fig 16. Normalized Radiation Pattern for Side lobe level = -35 dB, array length = 100, beam width = 0.5

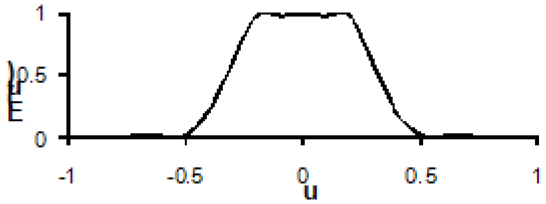

Fig 17. Normalized Radiation Pattern for Side lobe level = -35 dB, array length = 10, beam width = 0.6

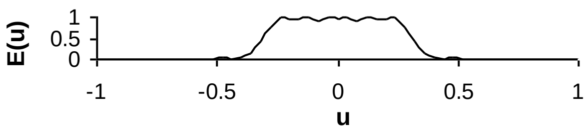

Fig 18. Normalized Radiation Pattern for Side lobe level = -35 dB,array length = 25, beam width = 0.6

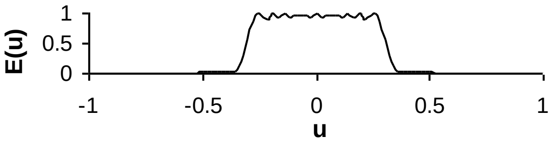

Fig 19. Normalized Radiation Pattern for Side lobe level = -35 dB,array length = 50, beam width = 0.6

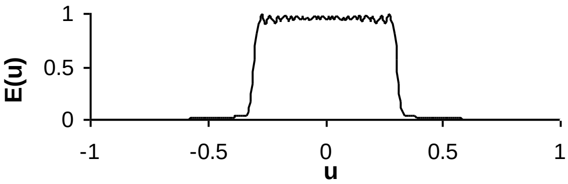

Fig 20. Normalized Radiation Pattern for Side lobe level = -35 dB,array length = 100, beam width = 0.6

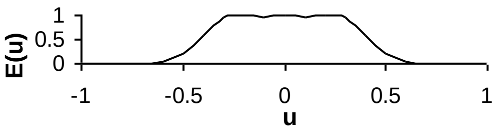

Fig 21. Normalized Radiation Pattern for Side lobe level = -35 dB, array length = 10, beam width = 0.8

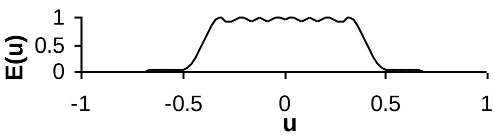

Fig 22. Normalized Radiation Pattern for Side lobe level = -35 dB, array length = 25, beam width = 0.8

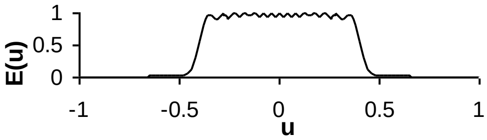

Fig 23. Normalized Radiation Pattern for Side lobe level = -35 dB, array length = 50, beam width = 0.8

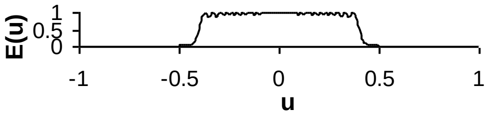

Fig 24. Normalized Radiation Pattern for Side lobe level = -35 dB, array length = 100, beam width = 0.8

The above sector beams are numerically computed for the arrays of wire antennas taking the element pattern into account.

Conclusion

It is evident from the results that the amplitude distribution obtained from Taylor's is reasonably tapered and it is practically realizable. The phase distribution used for the conversion of narrow beams into sector beams is found to be optimal, as the resultant patterns over the angular widths are very close to the specified ones. Moreover, the converted beams do not have any side lobes in the desired region. The beams are almost flat in the specified angular regions.

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