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A Synthesis Design of Linear Array Antenna with Chosen Nulls Directions in Searching Systems

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***Abstract* – This paper presents a synthesizing design of a linear antenna array by adapting the Schelkunoff method. The idea behind this type of design is to produce nulls in radiation pattern of a structure without any notable effects on the main lobe. This design has been undertaken around 9 GHz, where both theoretical and simulation results are achieved and will be the target of this work. X-band searching radar system is considered where single and multi-target scenario is postulated in the design examlpes.**

Keywords - Linear arrays; Pattern synthesis; Schelkunoff's method; Null; Array polynomial.

I. INTRODUCTION

During the reception, the antenna receives desired and unwanted signal. The role of the processing is to enlarge the former and suppress the later. In signaling terminology this may be translated by the signal-to-noise ratio (S/N) should be as sufficient as possible to be adequate enough to form a strong (S/N) to interference ratio. Furthermore, as antenna terminology to reduce interference exported signal from the interferer a null in the direction has to be created in the radiation pattern to reduce or eliminate any Echo from that interferer. When this is achieved the signal-to-noise ratio will be improved and pay back. Although, that there are more than one approach to form a suitable polynomial for any desired array element number, (N-1) nulls can be formed from N element array using what is known as Schelkunoff polynomial. This has been adopted to be a the designing tool in this work.

II. DESIGN AND SYNTHESIS

The Schelkunoff method, used for the array takes input as required number of nulls and their positions and hence derives the required array elements number. Antenna synthesis is usually refers to antenna pattern synthesis, which usually requires that first approximate an analytical model is chosen to represent, either exactly or approximately, the desired pattern. The second step to match the analytical model to a physical antenna model.

The synthesis methods will be utilized to design a line-sources and linear array whose space factors and array factors will yield desired far-field radiation patterns. In general; pattern synthesis is applied to: *Continuous line source* and *Discretization of continuous line sources*.[1]

a) Continuous Line Source

Continuous lion source distributions all functions of only one coordinate, and they can be used to approximate linear arrays of discrete elements and vice versa.

The array factor of a discrete-element array, placed along the z-axis is given by [6]

$$AF = \sum_{n=1}^{N} a_n e^{j(n-1)(kd\,cos\gamma+\beta\,)} = \sum_{n=1}^{N} a_n e^{j(n-1)\psi} \quad (1)$$

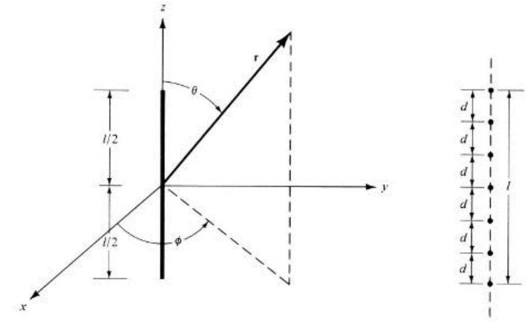
$$\psi = (kd\,cos\gamma + \beta\,) \qquad \gamma = \theta \quad (1a)$$

where the a_n and γ are amplitude excitation coefficients and angle of antenna and radial vector respectively. On the other hand, the array factor in this respect is named as *space factor* due to the relationship between the nature of pattern forming and target space covered by the radiation pattern and designed nulls. Thus, space factor (SF) is shown as in Figure 1(a) for a line source and expressed by

$$SF(\theta) = \int_{-l/2}^{l/2} I_n(z')e^{j[kz'\,cos\theta+\phi_n(z')]}dz' \quad (2)$$

Where $I_n(z')$ and $\phi_n(z')$ represent the amplitude and phase distributions, respectively, along with the source. For a uniform phase distribution $\phi_n(z') = 0$.

For a continuous source distribution, the total field as given by the product of the *element* and the *space* factor. It is



analogous to pattern multiplication of arrays.

(a) Continuous sources (b) Discrete sources

Figure 1: Continuous and discrete linear sources. [6]

b) *Discretization of continuous sources*

With proper design of element spacing discrete array elements with suitable spacing can be used as approximation of the continuous sources. Radiation pattern of discrete array. This is illustrated in Figure 1(b) whereby spacing *d* is chosen between elements to be distributed along the line of continuous source.

III. ARRAY SYNTHESIS USING SCHELKUNOFF POLYNOMIAL METHOD

Schelkunoff' s method is a powerful tool used for the synthesis of antenna array with a radiation pattern specified by several nulls. It is used to place nulls at undesired signal directions. Array factor is viewed as a polynomial with roots that are located on the Schelkunoff's unit circle [1].

Let us consider the following relation (Euler's relation):

$$z = x + jy = e^{j\psi} = e^{j(kd\,cos\gamma+\beta\,)} \tag{3}$$

Then we can rewrite (1) as

$$AF = \sum_{n=1}^{N} a_n z^{(n-1)} = a_1 + a_2 z + a_3 z^2 + \cdots + a_N z^{N-1} \tag{4}$$

From the fundamental theorem of Algebra and complex variables, for an N element array, the array factor can be viewed as polynomial of degree (N-1) and can be expressed as a product of (N-1) linear terms which represents (N-1) roots,

$$AF = a_n(z - z_1)(z - z_2)(z - z_3) \ldots (z - z_{N-1}) \tag{5}$$

The magnitude of the polynomial can be expressed as (in general the zi roots may be complex)

$$|AF| = |a_n||z - z_1||z - z_2||z - z_3| \ldots |(z - z_{N-1})| \tag{6}$$

where z_1, z_2, z_3, ----- $z_{(N-1)}$ are the roots of the polynomial. The position of the nulls can be changed by varying the position of the roots z_n. The roots of z_n that lie on the unit circle contribute to the nulls in the radiation pattern. We can also rewrite the complex variable z as

$$z = |z|\, e^{j\psi} = |z| \angle\psi = 1\angle\psi \tag{7}$$

As the roots are unity in magnitude then only (*N-1*) roots are to be determined for certain array pattern. One way is based on M nulls specified by the user, M out of (*N-1*) roots are fixed over the unit circle at fixed positions. Another way, by selecting θ and d, the required β and the radiation pattern can be synthesized.

IV. DESIGN EXAMPLE 1

To demonstrate this technique for pattern synthesis, a linear array with an element spacing $d = \frac{3\lambda}{8}$ and β = 0 such that it has zeroes at θ = 0, $\theta = \frac{\pi}{2}$, and θ = π are chosen to determine the required number of elements and their coefficients (amplitude & phase), as well as finding the range of progressive phase shifts β such that the null at $\theta = \frac{\pi}{2}$ no longer lies within the visible range, and hence no radiation pattern null occurs in this direction.

In this case, $\psi = \frac{3\pi}{4} cos\theta$ and the visible range spans the arc, $-3\pi/4 \le \psi \le 3\pi/4$. The desired nulls occur in the directions

$$\psi_1 = \frac{3\pi}{4};\ \psi_2 = 0\ ;\ \psi_3 = \frac{-3\pi}{4}$$

These zeroes have the complex representation on the unit circle,

$$z_1 = e^{3j\pi/4};\ z_2 = 1;\ z_3 = e^{-3j\pi/4}$$

It follows that

$$AF = (z-1)(z- e^{3j\pi/4})(z- e^{-3j\pi/4}) = (z-1)(z^2- e^{3j\pi/2}) = z^3 - z^2 + jz - j$$

So, four (N = 4) elements are required and the excitation coefficients are equal to

$a_1 = -j$, $a_2 = j$, $a_3 = -1$, and $a_4 = 1$.

Since as β = 0, $-3\pi/4 \le \psi \le 3\pi/4$, it is clear that $\psi = 0$ falls outside the original visible range, provided that

$$|\beta| \ge 3\pi/4$$

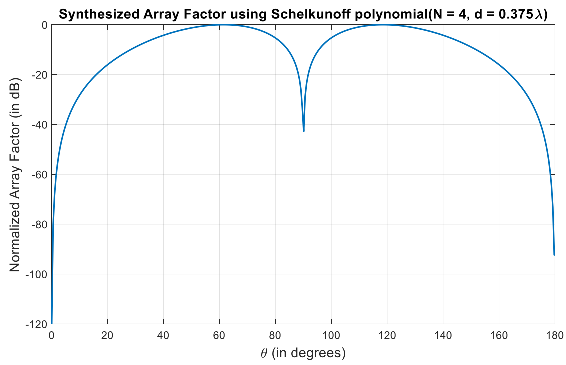


Figure 2: Synthesized array factor using Schelkunoff polynomial of a four-element array of isotropic sources with a spacing of 3 λ/8 between them, zero degrees progressive phase shift, and zeros at θ = 0◦, 90◦, and 180◦.

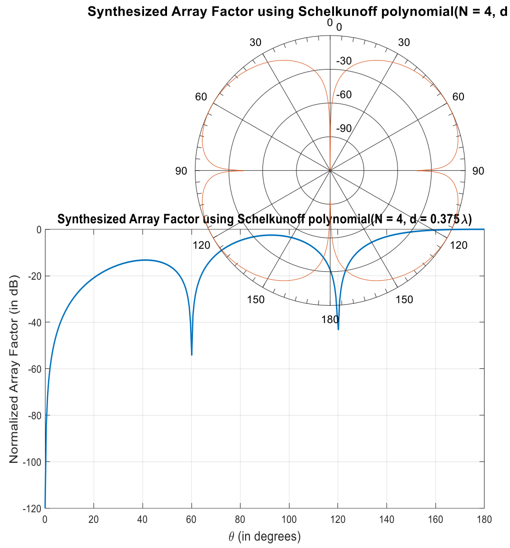
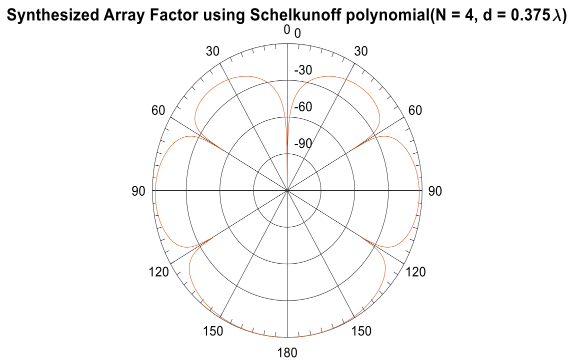


Figure 3: Amplitude radiation pattern of a four-element array of isotropic sources with a spacing of 3λ/8 between them, zero degrees progressive phase shift, and zeros at $\theta = 0°, 90°$, and $180°$.



V. DESIGN EXAMPLE 2

With similar procedure, one can show the design flexibility of polynomial consisting the array in hand, in that we can choose other direction for new nulls. In this example nulls are chosen to be at $\theta = 0$, $\theta = \frac{\pi}{3}$, and $\theta = \frac{2\pi}{3}$, as depicted in Figure 3 and Figure 4.

Figure 4: Synthesized array factor using Schelkunoff polynomial of a four-element array of isotropic sources with a spacing of 3λ/8 between them, zero degrees progressive phase shift, and zeros at $\theta = 0°, 60°$, and $120°$.

Figure 5: Amplitude radiation pattern of a four-element array of isotropic sources with a spacing of 3λ/8 between them, zero degrees progressive phase shift, and zeros at $\theta = 0°, 60°$, and $120°$.

VI. CONCLUSION

As a concluded outcomes from this paper one can surely have the flexibility of directing the nulls in the radiation pattern. Moreover, for complicated scenario where more than one interferer is present the radiation pattern may be more flexible to search multidirectional with suitable nulls locations on each searching angle.

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