SIDE LOBE REDUCTION OF CIRCULAR ARRAY USING TAYLOR DISTRIBUTION FUNCTION IN RADAR APPLICATIONS

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ABSTRACT  
The VHF/UHF band radar that using circular array antennas is a novel kind of radar, whose performances, such as angular accuracy, angular resolution, anti-jamming and low-altitude coverage capabilities are better than the conventional VHF/UHF band radar. On one hand, we focus on how the directivity of array element will influence upon the array pattern. The performance characteristics of the single microstrip patch antenna can be further enhanced by using microstrip patch antenna array. On the other hand, in order to lower the side lobe level (SLL) of circular array antennas, we investigate the effectiveness of amplitude-weighted methods including Taylor Window and Gaussian Window.

Key words: Radar, Circular array, Antenna pattern

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1. INTRODUCTION

The VHF/UHF band radar has excellent characters in some fields, such as the long range, low cost, anti-stealth, anti-ARM, etc. Since the conventional VHF/UHF band radar mostly adopted linear array antennas that using mechanical scanning, some disadvantages occur in some aspects, such as the angular resolution, angular accuracy, anti-jamming, low-altitude coverage and so on. These problems restrict the application of VHF/UHF band radar in the complicated and threatening modern war environment. The advancement in the antenna technology in the microstrip patch antenna and its array varies up to wide range of design methodologies and these has also accelerated the development in the modern communication system. The requirements in the modern communication system are low profile, simple planar structure antenna and hence cost-effective to manufacture and these all characteristics are satisfied by the microstrip patch antenna. Hence, microstrip patch antennas are used in the field of cellular communication, satellite communication, airborne and spacecraft applications. The various ways to improve the performance of the microstrip patch antenna is the comparative analysis by changing the shape of the patch, substrate material and using different feeding methodologies. The performance of the microstrip patch antenna can be further enhanced by designing the array structure of the microstrip patch antenna. The microstrip patch antenna has some of the disadvantages like low efficiency, narrow bandwidth, low power operation and spurious feed radiation. The various ways to improve the bandwidth of the microstrip patch antenna are:

- Increasing thickness of substrate
- Proper impedance matching
- Using substrates with less value of effective permittivity
- By multiple frequency operation

For antennas operating at frequencies less than 10 GHz, the substrates with less thickness and low relative permittivity should be used. For the microstrip patch antenna with thicker substrates when coaxial feed is used, feed length required is more and hence it causes matching problems as it makes the input impedance more inductive. The aperture coupled feed can be used for more bandwidth requirement. The aperture-coupling when used with crossed slots or off-centred coupling, circular polarization is obtained with more axial bandwidth. The fractal geometry was used in one of the proposed antenna which can be used for multiband applications like Wi-Fi and provides an increase in directivity with reduction in the dimension of the patch. In other proposed antenna, a comparative analysis of dual band dissimilar patch array of two, four, eight and sixteen elements was presented which shows improved performance in terms of gain and bandwidth with increase in array elements. The fixed circular array is made of multi elements which distributed on the same circle. In fact, the circular arrays can be regarded as a typical conformal array. As compared to traditional fixed linear arrays, the circular arrays has many merits. Firstly, it has the 360 degrees azimuth coverage. By Circulative change the working elements, the beam forming scan can be realized easily. Secondly, the antenna gain and beamwidth will not change with the changing of scan angle. Thirdly, the anti-jamming capability is strong and LPI capacity is satisfactory. Finally, it should be noted that circular array antennas can get far-field mode independent of frequency. Using wideband or ultra-wideband transmitted signal, we can achieve high range resolution. Therefore, it is significant that VHF/UHF band radar and circular array antennas can merge their
merits and develop a novel type of VHF/UHF band radar. As compared to linear arrays, circular arrays have a relatively high side-lobe level (SLL). This is the shortcoming of circular arrays. Some excellent techniques can help to lower the SLL. In this paper, we investigate the main performances of VHF/UHF band radar using circular arrays, such as antenna gain, beam width, SLL, etc. The emphasis is how to lower SLL using amplitude-weighted methods.

2. PERFORMANCES OF UNIFORM DISTRIBUTED CIRCULAR ARRAYS MADE UP OF OMNIDIRECTIONAL ELEMENTS

In order to identify and verify the enhancement of the performance of patch antenna on EBG substrates, designed a conventional antenna and the proposed antennas. The width, W of the rectangular patch antenna is usually chosen to be larger than the length of the patch, L to get higher bandwidth. The resonant frequency of the antenna is 10 GHz. In this paper, we use Neltec dielectric material as patch substrates whose dielectric constant is 2.45 that is low dielectric constant, in low dielectric constant surface wave losses are more severe and dielectric and conductor losses are less severe. By using EBG substrates, surface wave loss can be reduced easily. The antenna is excited by a microstrip transmission line feed. The point of excitation is adjustable to control the impedance match between feed and antenna, polarization, mode of operation and excitation frequency. Table1 shows the important parameters for the geometrical configuration of the patch antenna.

3. THE PATTERN FUNCTION

As shown in Figure 1, N isotropic elements on a circle with radius R, constitute a uniformly spaced circular arrays The centre of the circle is at origin. The direction along the line joining the element n and origin has an angle $\phi_n=2\pi n/N$ relative to axis x. The wave number is $k=2\pi/\lambda$ ($\lambda$ is wavelength. In this paper, assume $\lambda=1$ meter.)

Suppose a narrowband incidence plane wave

![Figure 1 Uniform spaced circular arrays.](image)

The pattern of above circular arrays is

$$F(\phi, \theta) = \sum_{n=0}^{N-1} A_n e^{j[(\varphi_n - \cos(\phi_n)) \sin \theta]}$$
where $A_n e^{i\alpha_n}$ is complex form of weight factor of element n. In order to make the main beam along the direction. we can get the phase of the weight factor of element n as follows:

$$\alpha_n = \kappa R \cos(\phi_0 - \phi_n) \sin \theta_0$$  \hspace{1cm} (2)

and the corresponding circular arrays pattern function is

$$F(\phi, \theta; \phi_0, \theta_0) = \sum_{n=0}^{N-1} A_n e^{j\kappa R [(\cos(\phi - \phi_n) \sin \theta - \cos(\phi - \phi_n) \sin \theta)]}$$  \hspace{1cm} (3)

If we only care about the pattern in the xoy plane

$$F(\phi_0) = \sum_{n=0}^{N-1} A_n e^{j\kappa R [(\cos(\phi_0 - \phi_n) \sin \theta_0 - \cos(\phi_0 - \phi_n) \sin \theta_0)]}$$  \hspace{1cm} (4)

4. PATTERN CHARACTERS

For example, the amplitude weight factors are equal in a circular arrays made up of 60 elements and the uniform space inter-element distance is 0.5$\lambda$. The radius of the circular arrays is about 5 meters. The pattern (assume $\phi_0=0$) is shown as Figure 2 ($\alpha$ is azimuth angle).

![Figure 2](image)

**Figure 2** The pattern of uniform distributed circular arrays made up of omnidirectional elements.

The first SLL is -7.9dB and the beam width of main-lobe is 6.40. For a linear array with the same conditions, The first SLL is -13.4dB, which is better than that of circular arrays. If the element with directivity is adopted, the SLL can be lowered efficiently.
5. THE PERFORMANCE OF CIRCULAR ARRAYS WITH DIRECTIVITY ELEMENTS

Generally, the design of radiation directivity of the circular arrays should be the outer and radial, directional element and the coverage domain is from -90° to +90° to the center element with metal reflecting net is often used, whose pattern function can be described as

\[ f(\phi) = \frac{\cos(\frac{\pi}{2} \cos \phi)}{\sin \phi} \sin(\frac{\pi}{2} \sin \phi) \]

The pattern maximum value of main lobe of element \( n \) is \( \phi_n = 2\pi n/N \) at and the normalized pattern is

\[ f(\phi, \phi_n) = \frac{\cos(\frac{\pi}{2} \cos(\phi + \frac{\pi}{2} - \phi_n))}{\sin(\phi + \frac{\pi}{2} - \phi_n)} \sin\left(\frac{\pi}{2} \sin(\phi + \frac{\pi}{2} - \phi_n)\right). \]

6. PATTERN CHARACTERS

In the xoy plane, \( \phi_0 \) is the direction of the maximum values of main lobes. According to pattern product theorem, the real pattern of circular arrays with directivity elements is

\[ F_n(\phi, \phi_n) = F(\phi; \phi_0) \cdot f(\phi, \phi_n) \]

7 WEIGHTING FACTOR TO IMPROVE THE DIRECTIVITY OF CIRCULAR ARRAYS

a) Gaussian Window Function as Weighting Factor

The expression of Gaussian Window is

\[ W(k + 1) = e^{-\frac{1}{2}(a(k - (N/2)))^2} \]

where \( 0 \leq k \leq N \), and \( a \geq 2 \) (a is the inverse of standard variance) When the number of elements is 60, the uniform space of elements is 0.5\( \lambda \), and \( a \) equals 2.5, we can obtain the pattern of this circular arrays as shown in Figure 3. The first SLL is -24.9dB and the width of main beam is 7.3 respectively.

b) Taylor Distribution Function as Weighting Factor

Taylor distribution function can be written as

\[ f(\xi) = 1 + 2\sum_{m=1}^{\bar{n}-1} g(m, A, \bar{n}) \cos m\xi \]
The pattern of uniform distributed circular arrays made up of directional elements with Gaussian Window function as weighting factor.

where \( \xi = 2\pi x/L \) (L is the aperture length of array); the coefficient \( g(m, A, \bar{n}) \) is

\[
g(m, A, \bar{n}) = \frac{\left[(n-1)\right]^2}{(n-1+m)(n-1-m)} \prod_{i=1}^{\bar{n}} \left|1 - \frac{m^2}{\sigma^2[A^2 + (k-\bar{n})^2]} \right|
\]

where \( A \) is determined by \( \eta \) (the ratio of main beam level and SLL):

\[ A = \frac{1}{\pi} \text{arch}\eta \quad \text{and} \quad \sigma \text{ is determined as follows.} \]

\[
\sigma = \sqrt{\frac{\bar{n}}{[A^2 + (\bar{n} - \frac{1}{2})^2]^{1/2}}}
\]

For Taylor distribution, generally, \( \bar{n} \) can be set as 5 to keep the SLL between -20 to -30dB and set as 7 to keep the SLL between -30 to -40dB. The Taylor distribution function has three prominent merits: the relatively small length of aperture of array with coordinate half-power beamwidth; SLL included in the design; definite engineering feasibility. When the number of elements is 60, the uniform space of elements is 0.5\( \lambda \), modified Taylor weighting factor in order to keep the SLL under -30dB. The simulation results are shown in Figure 4.
Side Lobe Reduction of Circular Array Using Taylor Distribution Function In Radar Applications

![Graph showing pattern of uniform distributed circular arrays made up of directional elements with Taylor distribution function as weighting factor]

Figure 4 The pattern of uniform distributed circular arrays made up of directional elements with Taylor distribution function as weighting factor.

The first SLL is -28.7dB and the width of main-beam is 73 degrees. To sum up, Taylor distribution weighting can help to lower SLL obviously, and the main beam at the cost of a little expanding of main beam width. In engineering, we can improve the angle resolution by enlarging the radius of circular arrays.

8. CONCLUSION

The circular arrays are key factors which have an influence on the performance of radar. Circular arrays have a relatively high SLL and we prove that the SLL can be lowered by weighting on array elements. Recently, the measurement of circular arrays is under investigation. With the development of digital beam forming, the circular arrays will show a great prospect.

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