Advances in Engineering Research, volume 185
2nd International Conference on Electrical and Electronic Engineering (EEE 2019)

Research on the Optimizing Technology for Sparse Antenna Arrays Based on Aperture Function

Ling-li ZHAO
Electronic Engineering Institute of Beifang University of Nationalities, YinChuan NingXia, P. R. China 750021

Keywords: Sparse array, Aperture function, Reduce the sidelobe.

Abstract. In order to reduce the sidelobe level of antenna array, optimize the minimum element space spacing and element number of the antenna array, it is proposed optimizing technology for sparse antenna arrays design. The linear gradient aperture function and the stepped aperture function are used to select the position of the array elements appropriately, and the sparse array with fewer elements is obtained. The effective aperture is smoothed by controlling the shape of the transmitting and receiving aperture functions. The radiation patterns of a single antenna and a sparse array antenna are simulated and compared. The results show that the sidelobes are reduced in the radiation patterns of the receiving antenna, which provide alternative solutions to the optimization problems of sparse antenna arrays.

Introduction

Linear phase antenna arrays have been used in radar, sonar positioning, ultrasonic imaging and seismic signal processing. Sparse arrays eliminating some elements are economical and of great practical value. Several design algorithms for sparse arrays with specific beams are discussed in this paper.

Sparse Antenna Array Design

Consider a linear array with N isotropic equispaced elements, where the elements are spaced d, Fig. 1 is the array structure of linear array.

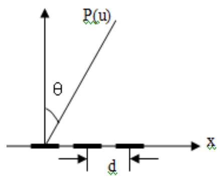

Figure 1. Array structure of linear array

$$p(u) = \sum_{n=0}^{N-1} w[n] e^{j[2\pi(u/\lambda)d]n} \quad . \tag{1}$$

In formula (1), w [n] is the weight of complex excitation or the nth element, λ is the wavelength, and $u = \sin\theta$. The function p(u) can therefore be regarded as a DTFT with a frequency variable w[n]. The array elements weighted by the function w [n] of element position are used as aperture functions. w[n] is a constant for arrays with balanced drive, if d≤λ/2, the grating lobes in the radiation pattern will be eliminated. Generally, d=λ/2, at this time, the range of u(-л, л). It can be seen from formula (1) that sparse arrays with fewer elements can be obtained by eliminating some elements to increase the spacing between pairs of continuous elements until it exceeds λ/2. Usually, this will lead to an increase in the sidelobe level and may lead to the appearance of grating lobes in the radiation pattern. However, these sidelobes can be significantly reduced by properly selecting the location of array elements. A two-way radiogram is generated by a transmitting array and a receiving array. The design of arrays can be viewed as the design of an effective aperture function $W_{eff}[n]$, it is a convolution operation of two functions, as shown in Formula 2[1]. Where $W_T[n]$ is the transmitting array aperture function, $W_R[n]$ is the receiving array aperture function. Therefore, the design is determine $W_T[n]$ and $W_R[n]$ according to expectations $W_{eff}[n]$.

$$w_{eff}[n] = w_T[n] \otimes w_R[n] \quad . \tag{2}$$

Aperture Function

Z-transformation of formula (2) is the formula (3). First, consider the uniform array $W_{eff}[n]=1$, when $N=2^K$, factorization $P_{eff}(z)$ such as formula (4).

$$P_{eff}(z) = P_T(z) P_R(z) \quad . \tag{3}$$

$$P_{eff}(z) = (1+z^{-1})(1+z^{-2})\cdots(1+z^{-N}) \quad . \tag{4}$$

Uniform Aperture Function Method

When N = 16, the design method of sparse antenna array using formula (4) is given:

$$P_{eff}(z) = (1+z^{-1})(1+z^{-2})(1+z^{-4})(1+z^{-8}) \quad . \tag{5}$$

Three possible options $P_T(z)$ and $P_R(z)$ are as follows:

Design 1:

$$P_T(z) = 1 \quad ,$$

$$P_R(z) = (1+Z^{-1})(1+Z^{-2})(1+Z^{-4})(1+Z^{-8}) \quad . \tag{6}$$

Design 2:

$$P_T(z) = 1 + z^{-1} ,$$

$$P_R(z) = (1+Z^{-2}+Z^{-4}+Z^{-6}+Z^{-8}+Z^{-10}+Z^{-12}+Z^{-14}) \quad . \tag{7}$$

Design 3:

$$P_T(z) = (1+z^{-1})(1+z^{-8}) = 1+z^{-1}+z^{-8}+z^{-9} ,$$

$$P_R(z) = (1+z^{-2})(1+z^{-4}) = 1+z^{-2}+z^{-4}+z^{-6} . \tag{8}$$

Design 1 consists of a single element transmitting array and a 16 elements non-sparse receiving array, so the total 17 elements are required. Design 2 and 3 generate sparse transmit and receive arrays. The aperture function for transmitting and receiving of design 2 is given as follows (9).

$$w_T[n]=\{1\ 1\}, w_R[n]=\{1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\}. \tag{9}$$

Among $W_R[n]$, 0 is the missing element, and a total of only 10 elements are needed. Figure 2 shows the radiation pattern of a single antenna and two radiation patterns of a combined antenna. Figure 2 are the transmitting array (point Line) and receiving array (damaged line) radiogram and two-way radiogram (solid line).

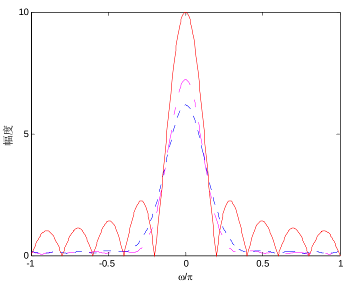

Figure 2. Antenna radiogram

As shown in figure 2, the derived lobe in the radiation pattern of the receiving antenna is suppressed by the radiation pattern of the transmitting array. Most practical 8-element sparse antenna arrays are designed using design 3, which requires total of 8 elements. For example, the aperture function for transmitting and receiving of design 3 is given as follows (10).

$$w_T[n]=\{1\ 1\ 0\ 0\ 0\ 0\ 0\ 0\ 1\ 1\},\quad w_R[n]=\{1\ 0\ 1\ 0\ 1\ 0\ 1\}. \tag{10}$$

Linear Gradient Aperture Function Method

The shape of the effective aperture function can be smoothed by controlling the shape of the transmitting and receiving aperture functions to reduce the sidelobe. The sparse antenna array is designed by choosing the linear gradient effective aperture function $P_{eff}(z)$, it can choose

$$P_{eff}(z) = P_1(z)P_2(z). \tag{11}$$

$$P_1(z)=\frac{1}{R}\sum_{n=0}^{R-1} z^{-n} \quad , \quad P_2(z)=\sum_{n=0}^{S-1} z^{-n}. \tag{12}$$

The total number of elements of the aperture function is N=R+S-1. Gradient element value is $\frac{1}{R},\frac{2}{R},\dots,\frac{R-1}{R}$. The parameter S must satisfy the condition S > R-1. For example, considering the design of linear gradient antenna arrays with R = 3 and S = 8, the effective aperture function is

$$W_{eff}[n]=\{\frac{1}{3}\ \ \frac{2}{3}\ \ 1\ 1\ 1\ 1\ 1\ 1\ \ \frac{2}{3}\ \ \frac{1}{3}\}, \tag{13}$$

A possible design of transmitting and receiving antenna array is given as follows (14), the corresponding proportional radiation diagram is given in figure.3.

$$w_T[n]=\{1\ 1\ 0\ 0\ 1\ 1\}, w_R[n]=\{\frac{1}{3}\ \ \frac{1}{3}\ \ \frac{2}{3}\ \ \frac{1}{3}\ \ \frac{1}{3}\}. \tag{14}$$

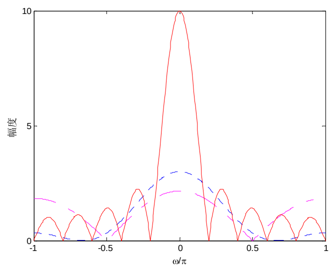

Figure 3. Radiogram of linear gradient transmitting and receiving antenna arrays

Stepped Aperture Function Method

When in the formula (11),

$$P_1(z) = \frac{1}{2l+1}\left[1 + z^{-k_1}(1 + z^{-k_2}(1 + \cdots z^{-k_l}\left(1 + \cdots z^{-k_2}(1 + z^{-k_1}) + \cdots\right)))\right] \tag{15}$$

Number R of elements in $P_1(z)$[2], $R = 2\sum_{i=1}^{\ell} k_i + 1$, the elements number S of $P_2(z)$ must satisfy the condition $S = 2\sum_{i=1}^{\ell} k_i$, at this point, the elements number of stepped aperture function is $2\sum_{i=1}^{\ell} k_i$, the value is $\frac{1}{2\ell+1},\frac{2}{2\ell+1},\dots,\frac{2\ell}{2\ell+1}$. For example, when k_1 = 1, l= 2, and S = 8, the design of the antenna array,

$$P_1(z) = \frac{1}{5}\,(1+Z^{-1}+Z^{-3}+Z^{-5}+Z^{-6}),$$

$$P_2(z) = (1+Z^{-1}+Z^{-2}+Z^{-3}+Z^{-4}+Z^{-5}+Z^{-6}+Z^{-7}). \tag{16}$$

The aperture function is:

$$w_{eff}[n] = \{0.2 \quad 0.4 \quad 0.4 \quad 0.6 \quad 0.6 \quad 0.8 \quad 1 \quad 1 \quad 0.8 \quad 0.6 \quad 0.6 \quad 0.4 \quad 0.4 \quad 0.2\}. \tag{17}$$

A possible design of transmitting and receiving antenna arrays:

$$w_T[n]=\{\frac{1}{5} \quad \frac{1}{5} \quad \frac{1}{5} \quad \frac{2}{5} \quad 0 \quad \frac{2}{5} \quad \frac{1}{5} \quad \frac{1}{5} \quad \frac{1}{5}\}, w_R[n]=\{1 \quad 1 \quad 0 \quad 0 \quad 1 \quad 1\}. \tag{18}$$

The corresponding proportional radiation diagram is given in figure.4.

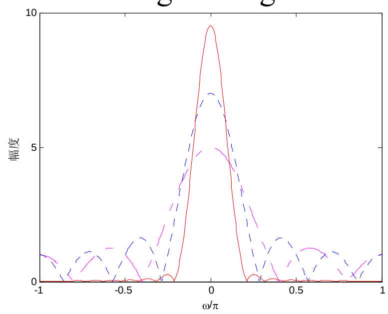

Figure 4. Radiogram of stepped transmitting and receiving antenna arrays

It can be seen from figure.3 and figure.4, using linear gradient and stepped aperture function, the position of the array element is taken as the optimization variable, and the effective aperture is smoothed by forming the transmitting and receiving aperture function, which reduce the derivative lobes and further suppresses the sidelobe level.

Conclusions

It is proposed a design of sparse antenna array based on aperture function algorithm in this paper. By using linear gradient aperture function and stepped aperture function, the sparse array with fewer elements can be obtained by properly choosing the position of array elements, which can reduce the volume, weight and number of receiving channels and save hardware costs. The effective aperture is smoothed by controlling the shape of the transmitting and receiving aperture functions to reduce the sidelobe level. The simulation results prove the validity of this method.

Acknowledgements

This work is supported by "Ningxia Natural Science Foundation(2019AAC03135)" and "the Fundamental Research Funds for the Central Universities", North Minzu University (2018XYZDX04).

References

[1] G.R. Lockwood, P-C.Li, M. O'Donnell, and F.S. Foster. Optimizing the radiation pattern of sparse periodic linear arrays. IEEE Trans. On Ultrasonics Ferroelectrics, and Frequency Control, 43:7-14, January 1996.

[2] S.K.Mitra, M.K. Tchobanou, and G. Jovanvic-Dolecek. A simple approach to the design of one-dimensional sparse antenna arrays. In Proc. IEEE Itternational Symposium on Circuits Systems, May 2004, pages 541-544, Vancouver, B.C, Canada

[3] Kaifas T N, Babas D G, Miaris G S, et al. A Stochastic Study of Large Arrays Related to the Number of Electrically Large Aperture Radiators [J]. IEEE Transactions on Antennas &

Propagation, 2014, 62(7): 3520-3533.

[4] Yepes L F, Covarrubias D H, Alonso M A, et al. Hybrid Sparse Linear Array Synthesis Applied to Phased Antenna Arrays [J]. IEEE Antennas & Wireless Propagation Letters, 2014, 13(13): 185-188.

[5] Yang S H, Kiang J F. Optimization of Sparse Linear Arrays Using Harmony Search Algorithms [J]. IEEE Transactions on Antennas & Propagation, 2015, 63(11):4732-4738.