Adaptive Beamforming with Low Sidelobe in Fundamental Component of 4-D Antenna Arrays

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***Abstract*—In this paper, adaptive beamforming with low sidelobe and deep null in fundamental component of four dimensional (4-D) antenna arrays is realized by using an improved switch structure and optimizing time sequences with wolf pack algorithm. First, adaptive beamforming in fundamental component is realized with amplitude modulation and phase modulation by time modulation based on the improved switch structure. Then, wolf pack algorithm is used to optimize time sequences to suppress sidelobe of adaptive beam. This method not only realizes adaptive beamforming in fundamental component, but also realizes low sidelobe optimization based on achieving main beam to target direction and nulls to interference direction, and suppresses strong clutter interference on sidelobe direction effectively.**

Key words—4-D antenna arrays, fundamental component, adaptive beamforming, optimization of low sidelobe

I. INTRODUCTION

In the 1950s, H. E. Shanks proposed concept of 4-D antenna arrays [1] firstly. Compared with phased array, 4-D antenna array can replace static amplitude and phase weighting by time weighting. When realizing broadband, high gain, ultra-low sidelobe and multi beam requirements, it can reduce feeding difficulty of array antenna, and save antenna cost at the same time [2]. In addition, due to introduction of time, design freedom of antenna array has also been greatly increased.

Adaptive beamforming with low sidelobe can get main beam in target direction and null in interference direction, but also suppress strong sidelobe clutter interference [3-5]. Adaptive beamforming of 4-D antenna arrays mainly uses time weighting instead of complex weighting of traditional adaptive beamforming to realize adaptive beamforming in harmonic components [6-7]. The adaptive digital beam forming in 4-D antenna arrays uses harmonic components with lower gain to achieve adaptive beamforming. But this paper uses fundamental component with higher gain to get adaptive beamforming. And it will suppress sidelobe to make antenna arrays work stably in strong sidelobe clutter interference.

II. THEOREM

A. Improved Switch Structure in 4-D Antenna Arrays

Adaptive beamforming can be realized in fundamental component with an improved switch structure [6].

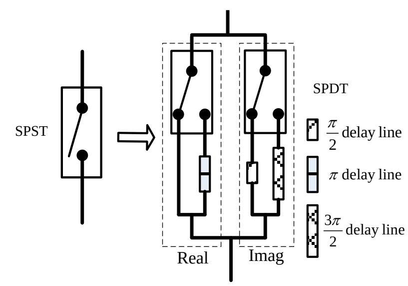

Fig. 1. The improved switch structure

Switching functions are shown in Figure 2, and switching functions expressions are in (1) and (2).

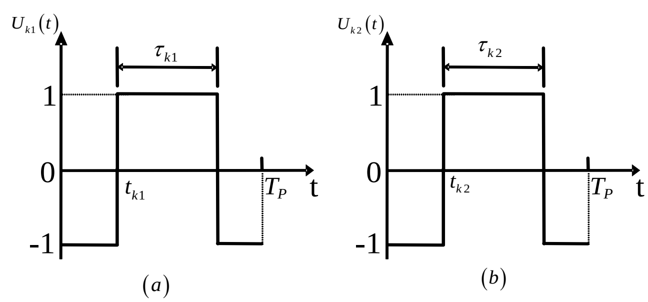

Fig. 2. Real and imaginary switching function

$$U_{k1}(t)=\begin{cases}1, & t_{k1}\le t\le t_{k1}+\tau_{k1}\\ -1, & otherwise\end{cases} \tag{1}$$

$$U_{k2}(t)=\begin{cases}1, & t_{k2}\le t\le t_{k2}+\tau_{k2}\\ -1, & otherwise\end{cases} \tag{2}$$

Array factor of 4-D antenna arrays based on improved switch structure is:

$$F_n(\theta,t) = e^{j2\pi(f_0+nf_P)t}\sum_{k=1}^{N} a_{nk}\cdot e^{j(k-1)\beta d\sin\theta} \tag{3}$$

We make $v_{k1} = t_{k1}/T_P$, $\mu_{k1} = \tau_{k1}/T_P$, $v_{k2} = t_{k2}/T_P$ and $\mu_{k2} = \tau_{k2}/T_P$. Fundamental component is as follow:

$$F_0(\theta,t) = e^{j2\pi f_0 t}\sum_{k=1}^{N}\left[(2\mu_{k1}-1)+j(2\mu_{k2}-1)\right]\cdot e^{j(k-1)\beta d\sin\theta} \tag{4}$$

B. *Optimization of Time Modulated Sequence*

In this paper, wolf pack algorithm [8] is used to optimize real and imaginary part time sequence of fundamental component. The fitness function is as follows:

$$f = \frac{\delta_1 P_0}{\delta_2\sum_{i=1}^{M}P_i + \delta_3 P_N + \delta_4 P_{SL} + \delta_5 P_{MSL}} \tag{5}$$

where P_0 is energy in desired direction, $P_i\,(i=1,2\cdots,M)$ is energy in ith interference direction, P_N is energy of noise, P_{SL} is energy of sidelobe, P_{MSL} is energy of highest sidelobe. $\delta_1,\delta_2,\delta_3,\delta_4$ are weight factors.

III. Numerical Results

This example will optimize low side lobe of the adaptive beam by wolf pack algorithm. Optimization variables are μ_{k1} and μ_{k2}. Optimized real and imaginary part time sequences are as shown in Figure 3. Contrast of adaptive beamforming in fundamental component is as shown in Figure 4.

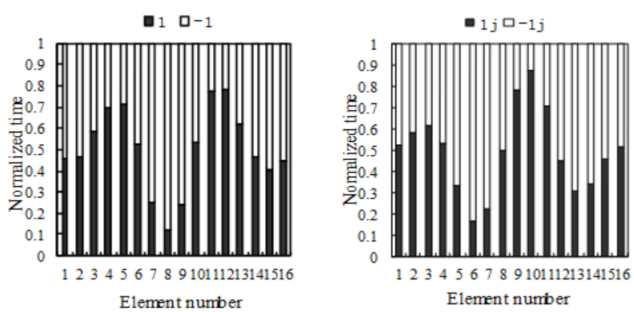

Fig. 3. Real and Imaginary part time sequences

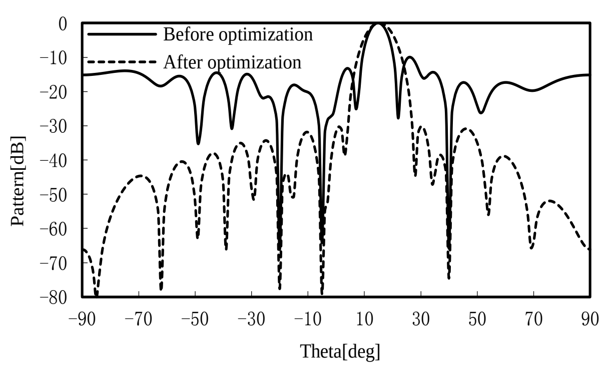

Fig. 4. Contrast of adaptive beamforming in fundamental component

By observing Figure 4, it is found that maximum sidelobe of fundamental component after optimization is -31dB approximately and suppress 21dB compare with before optimization. It can achieve main beam direction to 15° and nulls to -20°, -5° and 40° at the same time.

IV. Conclusion

In this paper, adaptive beamforming with low sidelobe in fundamental component of 4-D antenna arrays is studied. Based on improved switch structure and time series optimization by wolf pack algorithm, adaptive beamforming with low sidelobe in fundamental component is realized. This method not only realizes adaptive beamforming in fundamental component, but also optimizes low sidelobe based on main beam and nulls adaptive formed. It can also suppress sidelobe strong clutter interference effectively.

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References

[1] Shanks H E, Bickmore R W. Four-dimensional electromagnetic radiators [J]. Canadian Journal Of Physics, 1959, 37(3), 263-275.

[2] Li G, Yang S, Chen Y, et al. A Novel Electronic Beam Steering Technique in Time Modulated Antenna Array[J]. 97,(2009), 2009, 97: 391-405.

[3] Pei G E, Ming L I, Liu X. An Adaptive Beamforming Method at Subarray Level for Planar Array with Low Sidelobes[J]. Radar Science & Technology, 2012.

[4] Liu J, Gershman A B, Luo Z Q, et al. Adaptive beamforming with sidelobe control: a second-order cone programming approach[J]. Signal Processing Letters IEEE, 2003, 10(11): 331-334.

[5] Li J. Ultra-low sidelobe technique for large linear array adaptive digital beamforming[J]. Signal Processing, 2005.

[6] Gang Li, Shiwen Yang, Yikai Chen, et al. A Hybrid Analog-Digital Adaptive Beamforming in Time-Modulated Linear Arrays[J]. Electromagnetics, 2010, 30(4):356-364.

[7] Li G, Yang S, Chen Y, et al. An adaptive beamforming in time modulated antenna arrays[C]. International Symposium on Antennas, Propagation and Em Theory. IEEE, 2008:166-169.

[8] Hu-Sheng W U, Zhang F M, Lu-Shan W U. New swarm intelligence algorithm——wolf pack algorithm[J]. Journal of Systems Engineering & Electronics, 2013, 35(11).