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A Simple Design of Alternating Polarized Array Antenna with Anti-Interference Ability

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Abstract: We present a simple and novel design for alternating polarized array (APA) antenna which process anti-interference ability. The APA received signal model is established. By utilizing the different polarization property of target and the interference, the interference effect on desired signal detection will be eliminated through adaptive polarization filter technique. The predicted results are verified with simulation test and the pattern synthesis of APA is given. The anti-interference performance is indicated. The APA can reduce the complexity of the communication system which has good application prospect in the future.

Keywords: Polarized array; Simple design; Anti-interference

1 Introduction

Modern radar and communication system has not only responsible for guiding, but also for tracking, signal detection and estimation [1]. As a result, it has to overcome the effect of complex electromagnetic environment on the target detection. Traditional radar and communication system is single polarized which not fully utilized the polarization feature of target signal and interference signal. Polarization sensitive arrays have some inherent advantages over traditional antenna arrays [2-3] since they have the capability of separating signals based on their polarization characteristics, as well as spatial diversity. Intuitively, polarization sensitive antenna arrays will provide significant improvements for signals which have different polarization characteristics.

Polarization sensitive arrays are used widely in the communication, radio and navigation [4]. However, since each array element is composed of two polarized antennas and the two way polarized channel, it made radar system's structure to be complex, and the price of realization to be soaring. In order to solve this problem, a simple and novel type of anti-interference array named Alternating Polarized Array (APA) is advanced in this paper. Based on the polarization signal and processing model, adaptive polarization filter can be applied in APA which made it own interference suppression ability in polarization area [5]. Due to the simple design of this polarization diversity array, the system development expenditure is reduced, which will be widely used in the near future.

2 Alternating Polarized Array Model

An important factor that affects the communication system is the polarization. Polarization of an antenna in a given direction is defined as the polarization of the wave transmitted by the antenna. All transverse electromagnetic (TEM) waves have electric (E) and magnetic (H) fields components that are perpendicular to each other in the direction of propagation. The structure of alternating polarized array (APA) is shown in Fig.1. It can be seen that the polarization orientation of adjacent element is orthogonal .Assume the array is position in the origin of coordinates. The desired signal is complete polarized and the direction of arrival is (θ,φ). The polarization parameter is (γ,η), the complex baseband signal that carrying information is $s(t)$

The N array element is linear arranged. N is even number. Let the odd number position array element to be horizontally polarized which polarization vector is

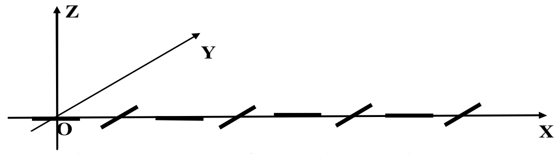

Figure 1 Structure of alternating polarized array

$$\mathbf{s}_{P1} = E_X = [-\sin\varphi \quad \cos\theta\cos\varphi]\begin{bmatrix}\cos\gamma \\ \sin\gamma e^{j\eta}\end{bmatrix} \tag{2.1}$$

Its received signal can be expressed as $\mathbf{s}_{P1}\cdot s(t)$. Let the even number position array element is vertical polarized which polarization vector can be written as followed

$$\mathbf{s}_{P2} = E_Y = [\cos\varphi \quad \cos\theta\sin\varphi]\begin{bmatrix}\cos\gamma \\ \sin\gamma e^{j\eta}\end{bmatrix} \tag{2.2}$$

Its received signal is $\mathbf{s}_{P2}\cdot s(t)$. The array gathered data contains spatial information and polarization information of signal, the n th element received signal is $\mathbf{Z}_n(t) = \mathbf{s}_P(t)e^{j\phi_n}$ .In which that $\mathbf{s}_P(t) = \mathbf{s}_{P1}\cdot s(t)$ when n is odd, and $\mathbf{s}_P(t) = \mathbf{s}_{P2}\cdot s(t)$ when n is even. Detailed, the received signal of the whole array can be written as followed.

$$\mathbf{x}(t) = \begin{bmatrix}\mathbf{s}_{p1}s(t)e^{j\varphi_1} \\ \mathbf{s}_{p2}s(t)e^{j\varphi_2} \\ \mathbf{s}_{p1}s(t)e^{j\varphi_3} \\ \cdots \\ \mathbf{s}_{p2}s(t)e^{j\varphi_N}\end{bmatrix} = \sqrt{N}\mathbf{s}_{S1}\otimes\mathbf{s}_{P1}s(t) + \sqrt{N}\mathbf{s}_{S2}\otimes\mathbf{s}_{P2}s(t) \tag{2.3}$$

where the spatial normalized steering vector is defined as followed

$$\mathbf{s}_{S1} = \frac{1}{\sqrt{N}}\begin{bmatrix}e^{j\phi_1} & 0 & e^{j\phi_3} & 0 & \cdots & e^{j\phi_{N-1}} & 0\end{bmatrix}^T$$
$$\mathbf{s}_{S2} = \frac{1}{\sqrt{N}}\begin{bmatrix}0 & e^{j\phi_2} & 0 & e^{j\phi_4} & \cdots & 0 & e^{j\phi_N}\end{bmatrix}^T \tag{2.4}$$

If a uniform linear array is considered, and the element distance is d , then the phase lag item of the n th element can be expressed as

$$\phi_n = \frac{2\pi(n-1)d\sin\theta\sin\varphi}{\lambda} \tag{2.5}$$

3 Anti-interference performance analysis

Assume interference signal is existed in the received signal, the signal model is

$$\mathbf{x}(t) = \sqrt{N}\mathbf{s}\cdot s(t) + \mathbf{i}\cdot i(t) + \mathbf{n}(t) \tag{3.1}$$

where $\mathbf{s}$ and $\mathbf{i}$ is the steering vector in polarization-spatial joint domain of desired signal and interference signal respectively, $s(t)$ and $i(t)$ is the waveform of desired signal and interference signal, the covariance matrix of interference and noise is as followed

$$\mathbf{M} = \sigma^2\mathbf{E} + P_I\mathbf{i}\mathbf{i}^H \tag{3.2}$$

By using matrix inversion lemma

$$\mathbf{M}^{-1} = \frac{1}{\sigma^2}\left(\mathbf{E} - \frac{\mathrm{INR}\cdot\mathbf{i}\cdot\mathbf{i}^H}{1+\mathrm{INR}\cdot\|\mathbf{i}\|^2}\right) \tag{3.3}$$

The maximum SINR after adaptive polarization filter [6]-[7], can be obtained.

$$\begin{aligned}\mathrm{SINR}_{\max} &= P_S\mathbf{s}^{\mathrm{H}}\mathbf{M}^{-1}\mathbf{s} = \mathrm{SNR}\cdot\left(\|\mathbf{s}\|^2 - \frac{\mathrm{INR}\cdot\left|\mathbf{i}^{\mathrm{H}}\mathbf{s}\right|^2}{1+\mathrm{INR}\cdot\|\mathbf{i}\|^2}\right) = \\ &\mathrm{SNR}\cdot\|\mathbf{s}\|^2\left(1 - \frac{\mathrm{INR}\cdot\|\mathbf{i}\|^2}{1+\mathrm{INR}\cdot\|\mathbf{i}\|^2}\cdot\frac{\left|\mathbf{i}^{\mathrm{H}}\mathbf{s}\right|^2}{\|\mathbf{i}\|^2\cdot\|\mathbf{s}\|^2}\right)\end{aligned} \tag{3.4}$$

As $\mathrm{INR} >> 1$, then $\frac{\mathrm{INR}\cdot\|\mathbf{i}\|^2}{1+\mathrm{INR}\cdot\|\mathbf{i}\|^2} \approx 1$, and

$$\mathrm{SINR}_{\max} = \mathrm{SNR}\cdot\|\mathbf{s}\|^2\left(1 - \frac{\left|\mathbf{i}^{\mathrm{H}}\mathbf{s}\right|^2}{\|\mathbf{i}\|^2\cdot\|\mathbf{s}\|^2}\right) \tag{3.5}$$

Further, we can obtained the following expression by using polarization array steering vector

$$\begin{aligned}\mathrm{SINR}_{\max} &= \mathrm{SNR}\cdot\|\mathbf{s}\|^2\left(1 - \frac{\left|\mathbf{i}_P^H\mathbf{s}_P\right|^2}{\|\mathbf{i}_P\|^2\cdot\|\mathbf{s}_P\|^2}\cdot\frac{\left|\mathbf{i}_S^H\mathbf{s}_S\right|^2}{\|\mathbf{i}_S\|^2\cdot\|\mathbf{s}_S\|^2}\right) \\ &= \mathrm{SNR}\cdot\|\mathbf{s}\|^2\left(1 - M_P\cdot M_S\right)\end{aligned} \tag{3.6}$$

where M_P and M_S is polarization matching coefficient and spatial matching coefficient respectively, $M_{\mathrm{P}}, M_{\mathrm{S}} \in [0,1]$. After polarization filtered, considered the signal power loss, the normalized SINR can be defined as

$$\mathrm{Loss} = \frac{\mathrm{SINR}_{\max}}{\mathrm{SNR}\cdot\|\mathbf{s}\|^2} = 1 - M_P\cdot M_S \tag{3.7}$$

When the included angle between target polarization and interference polarization is fixed, the variation of interference polarization will cause the desired signal energy loss, where $\mathrm{Loss} \in [1-M_{\mathrm{S}}, 1]$.

4 Pattern synthesis simulated results

Antenna radiation pattern is the directional function that characterizes the relative distribution of power radiated by an antenna. The size, type and design of the antenna as well as how the current is distributed on it determine the characteristics of the radiation pattern. The radiation power is usually plotted against the angle that is made with bore-sight direction.

The power at bore-sight, that is, at the position of maximum radiated power, is usually plotted at 0 dB, thus, the power at all other position appears as negative value. The radiation pattern can be plotted using rectangular or polar coordinates. The rectangular plots can be read more precisely but the polar plots offer a more pictorial representation and are thus easier to visualize.8 Rectangular plots are standard x-y plots where the axes are plotted at right angle to each other. Fig.2 shows a typical rectangular plot of an APA radiation pattern. In a polar plot, the angles are plotted radically from bore-sight and the power or intensity is plotted along the radius as illustrated in Fig.3.

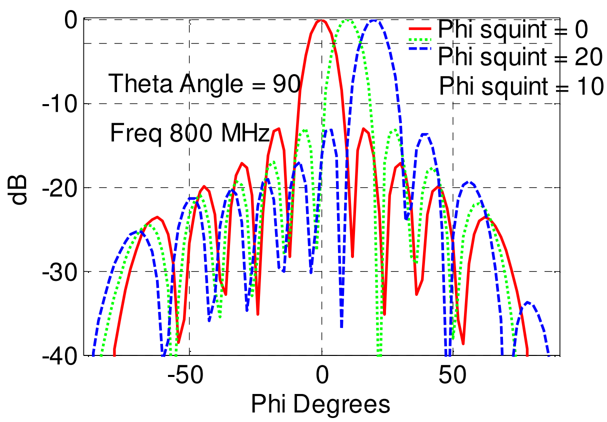

Figure 2. Rectangular plot of APA radication pattern

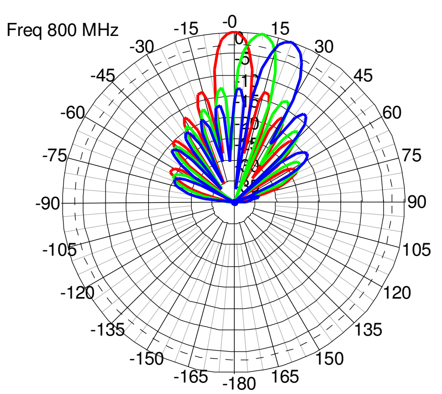

Figure 3. Polar plot of APA radiation pattern

5 Polarization anti-interference simulation

The anti-interference performance of polarization filter and spatial filter is analysis by simulation experiment by using APA as shown in Fig.4. Assume target is at the normal direction, the distance between radar and target is about 20km, and SNR is about 0dB. The interference source is at the main-lobe direction, INR is about 40dB. The polarization angle between target and interference is separately 0°, 1° and 3°. The anti-interference performance is given in Fig.5-Fig.7.

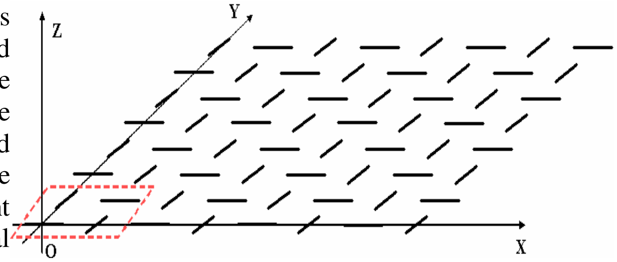

Figure 4. Alternating Polarized Array（APA）

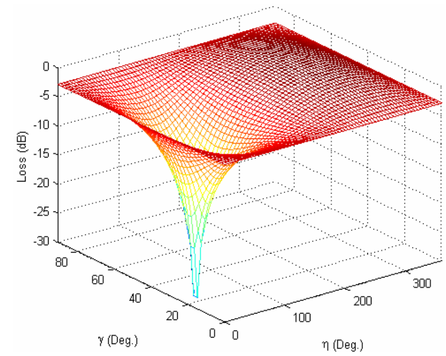

Figure 5. Anti-interference performance when polarization angle between the signal and interference equal to 0 deg

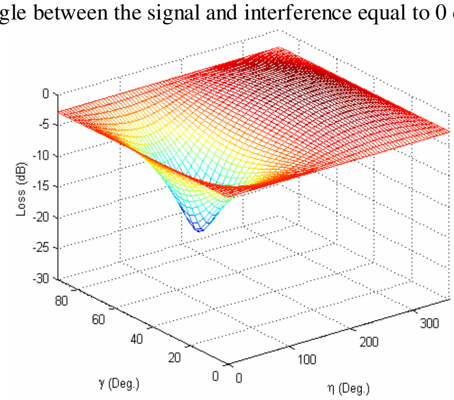

Figure 6. Anti-interference performance when polarization angle between the signal and interference equal to 1 deg

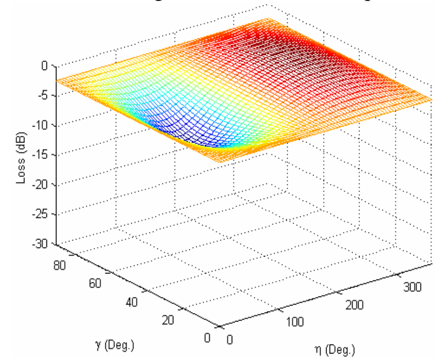

Figure 7. Anti-interference performance when polarization angle between the signal and interference equal to 2 deg.

When the target signal source and interference source in the same position, the conventional spatial filter technology can not cancel the interference. However, as the target polarization states are different from the interference, the interference effect will be eliminated through adaptive polarization filter technique. In this way, the proposed new concept of APA has good anti-interference performance, the simulation result verified the conclusion.

6 Conclusion

Polarization diversity antennas, as one of the most promising technologies in the cellular arena, are rapidly becoming an integral part of both analog and digital cellular networks. This situation has been the fundamental source of motivation for this thesis. In order to reduce system development cost and has better anti-interference performance, this thesis advanced a novel array architecture named Alternating Polarized Array(APA). Simulations have been carried out using APA for beam synthesis. Results have shown that good radiation pattern is obtainable using relatively less arrays than the traditional antennas. By utilizing the polarization difference between target and interference, the interference effect on desired signal detection will be eliminated through adaptive polarization filter of APA. When arrival direction of target and interference approached, the performance of anti-interference is more obvious. Simulation experiment and results indicated that this type of array not only has better anti-interference performance but also reduces the equipment quantity, which will be widely used in the future.

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