Simulation and Analysis of Influence of Group Delay Distortion on Performance of DBF System

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Abstract—**Group delay distortion between channels is one of the most important factors which affect the BER (bit error rate) performance of DBF (digital beam forming) System. The basic principles of DBF and the concept of group delay are first introduced, and a linear group delay filter is designed based on the relationship between the minimum phase system and the cepstral coefficients. And then a multi-channel group delay distortion model for simulation in MATLAB software is established. A QPSK system is simulated in multi-channel group delay. Simulation results show that the degradation of BER performance is caused by group delay distortion, and the more serious distortion of group delay, the greater deterioration of BER performance.**

Keywords-DBF; multi-channel; group delay distortion; BER; simulation

I. INTRODUCTION

Digital beam forming (DBF) is a beam forming technology which is achieved by digital methods. It has many advantages, such as the adaptive interference is set to zero automatically, the super-resolution is used for the direction of resolution, and the antenna is automatic calibration and ultralow side lobe is also used. Therefore, DBF is widely used in radar [1] [2] [3], navigation [4] [5], communication [6] and so on. And DBF is used in both the transmission and the receiving channels of the array.

The channels mainly include high frequency amplifier, mixer, intermediate frequency amplifier and A/D devices in the processing of array. Because of those analog devices and the active circuit which composed by them inevitably exist amplitude and phase difference, it makes the amplitude and the phase are not the same between transmission and receiving channels. When signals go through the respective channels, the group delay distortion may inconsistent with each signal [7] [8], which leads the waveform of each signal not to match between the rising edge and falling edge, so it has a great effect on DBF. Therefore, it has a very important significance to study the influence of the group delay distortion for DBF error performance.

There are many methods to design group delay filter. In this paper, a linear group delay filter is designed based on the relationship between the minimum phase system and the cepstral coefficients. In order to obtain a better group delay characteristics, and ensure that amplitude characteristic is not distortion at the same time, a kind of all-pass filter is designed

as a group delay filter to simulate the characteristic of the linear group delay distortion channel. This method is based on the relation between the minimum phase system and cepstral coefficient to solve the denominator coefficients of all-pass filter, so it is very easy to realize for only once inverse Fourier transform.

II. BASIC PRINCIPLES OF DBF AND CONCEPT OF GROUP DELAY

A. Basic Principles of DBF

Beam forming is a spatial filtering processing system, which can form the main beam in a specific direction to receive desired signal, and can restrain the interference signal from other direction.

Assuming that receiving antenna is a uniform linear array of N element, θ is the incidence angle of the wave, θ_k is the beam direction at time k, d is the distance of each adjacent array elements, λ is the wavelength of signals, and each array element is isotropic, where $\mathbf{W}_{ik} = [w_{1k}, w_{2k}, L, w_{Nk}]^{\mathrm{T}}$ is the weight vector at time k and the symbol "T" denotes the transposition operator. Simply, digital beam former is a multiply-accumulator, which is shown in Fig.1.
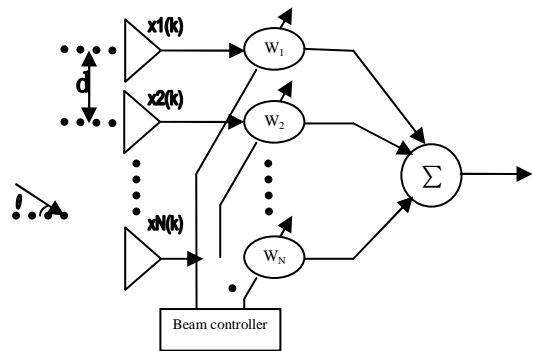

Fig 1 Principle diagram of DBF

The signal x_i denotes the complex digital signal which is obtained from the receiving signal after A/D and digital orthogonal transformation, where $w_{ik} = a_i \exp(-j\Delta\phi_k)$ are the

channel tap weights, $\Delta\phi_k = \dfrac{2\pi}{\lambda} d \sin\theta_k$ is the phase compensation value, a_i is the amplitude weighted coefficient to reduce the antenna side lobe. After compensating the phase and amplitude, the beam synthetic signal can be obtained which is formulated by

$$y_k = \sum_{i=0}^{N-1} w_{ik} x_i \tag{1}$$

So the function of antenna pattern can acquire by modulus (1). Due to the antenna pattern is not the only one, it can change the weight factors to obtain any form of beam. And the signal-to-noise ratio of the output signal can be greatly improved after the digital beam has been synthetic.

B. Concept of Group Delay

The frequency response function is defined as

$$H(e^{j\omega}) = A(\omega) e^{j\theta(\omega)} \tag{2}$$

Where $A(\omega)$ is the amplitude-frequency characteristic function, $\theta(\omega)$ is the phase-frequency characteristic function.

The $\tau(\omega)$ is the group delay characteristic function which is defined by

$$\tau(\omega) = -\frac{d\theta(\omega)}{d\omega} \tag{3}$$

While $\tau(\omega)$ is a constant, $\theta(\omega)$ is a linear function (for $\theta(\omega) = \omega\tau_0$), the different frequency components of the signal may have the same group delay. Therefore it will not produce waveform distortion when the signal goes through the channel; otherwise it will cause waveform distortion, and produce the inter-symbol interference, which can lead to the system error performance deteriorative. In addition to the influence of Gaussian noise, the group delay distortion has further deterioration to BER performance in the system.

III. DESIGN OF GROUP DELAY FILTER

A. Principle of All-Pass Filter

Frequency characteristic function is defined as

$$H(e^{j\omega}) = \frac{N(j\omega)}{D(j\omega)} = \frac{\sum_{m=0}^{M} a_{M-m} e^{-j\omega m}}{\sum_{m=0}^{M} a_m e^{-j\omega m}} = e^{-j\omega M} \frac{\sum_{m=0}^{M} a_m e^{j\omega m}}{\sum_{m=0}^{M} a_m e^{-j\omega m}} \tag{4}$$

Where $a_0 = 1$ is the initial value, from (4), the phase frequency response of filter is obtained by

$$\theta(\omega) = \theta_N(\omega) - \theta_D(\omega) = -M\omega - 2\theta_D(\omega) \tag{5}$$

Where $\theta_N(\omega)$ is the phase frequency response of the molecular polynomial for system function, while $\theta_D(\omega)$ is the denominator polynomial's.

The group delay is acquired as

$$\tau(\omega) = -\frac{d\theta(\omega)}{d\omega} = M + 2\frac{d\theta_D(\omega)}{d\omega} = M - 2\tau_D(\omega) \tag{6}$$

And the relationship between $\tau(\omega)$ and $\tau_D(\omega)$ can be written as

$$\tau_D(\omega) = \frac{M - \tau(\omega)}{2} \tag{7}$$

B. Design of All-Pass Filter

Where $\tau(\omega)$ is given firstly, and $\tau_D(\omega)$ is calculated by (7), then in order to determine the whole filter transfer function, it should calculate the denominator coefficient a_m.

Denominator characteristic function is defined as

$$D(\omega) = |D(\omega)| e^{j\theta_D(\omega)} \tag{8}$$

And then equation (8) is taken the natural logarithm as

$$\ln D(\omega) = \ln|D(\omega)| + j\theta_D(\omega) \tag{9}$$

Because of $D(\omega)$ is a stable minimum phase system, $b(n)$ is its cepstral which is the causal system. So

$$\ln D(\omega) = \frac{b(0)}{2} + \sum_{n=1}^{\infty} b(n) e^{-j\omega n} = \frac{b(0)}{2} + \sum_{n=1}^{\infty} b(n)\cos(\omega n) - j\sum_{n=1}^{\infty} b(n)\sin(\omega n) \tag{10}$$

Comparing (9) to (10), we get the following equation,

$$\theta_D(\omega) = -\sum_{n=1}^{\infty} b(n)\sin(\omega n) + 2k\pi, k = 0, \pm1, \pm2\cdots \tag{11}$$

Equation (11) is derivative on both sides,

$$a_0 = 1\sum_{n=0}^{m} \frac{nb(0) = 0}{m} \tag{12}$$

Doing inverse Fourier transform in (12), we can get $b(n)$,

$$IDFT[\tau_D(\omega)] = \frac{nb(n)}{2} \tag{13}$$

Due to the cepstral theory, we get a_m by

$$a_m = \sum_{n=0}^{m} \frac{nb(n)}{m} a_{m-n}, m > 0 \tag{14}$$

While $b(0) = 0$ is the initial value. According to the method above, the linear group delay filter is designed by MATLAB software, and its amplitude characteristics, phase characteristics and the group delay characteristics curves respectively are shown in fig.2, fig.3 and fig.4.
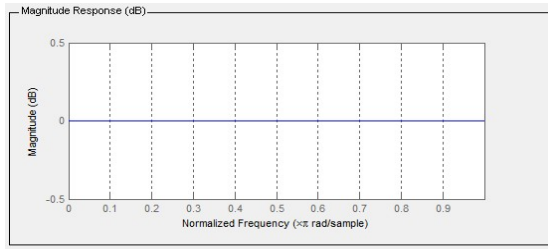
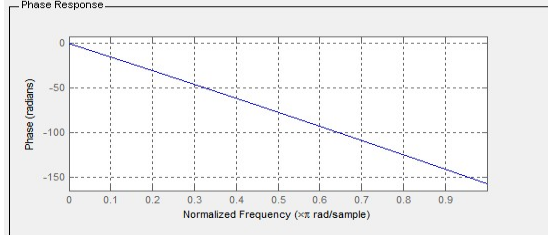Fig 2 Amplitude characteristic curve of linear group delay filter

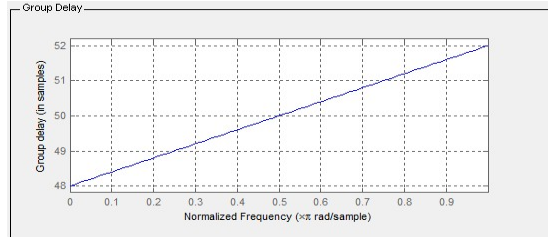Fig 3 Phase characteristic curve of linear group delay filter

Fig 4 Group delay characteristics curve of linear group delay filter

IV. SIMULATION MODEL AND RESULTS

It is difficult to use simple analytic expression to indicate the influence of group delay distortion on the system error performance, which brings a certain difficulties in quantitative analysis. So, it is difficult to analysis the influence in theory. But it is a relatively simple method to study this problem through the computer simulation.

Group delay distortion simulation diagram is given firstly in Fig.5, and then a multi-channel group delay distortion model for simulation in MATLAB software is established in Fig.6.
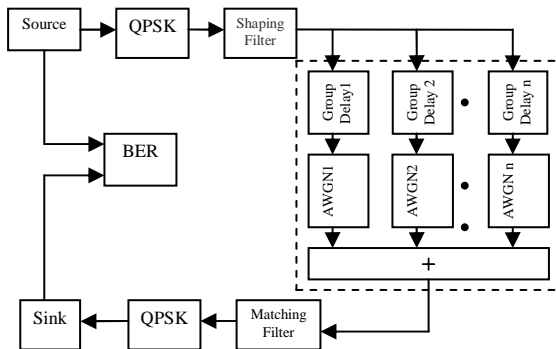
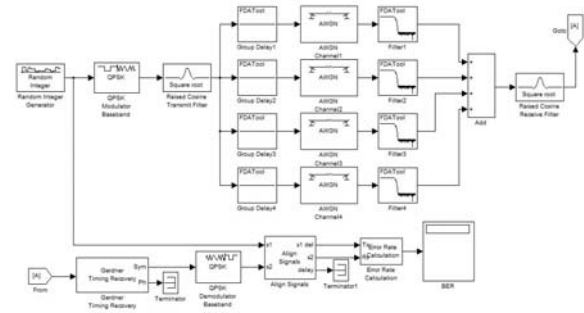

Fig 5 Group delay distortion simulation diagram

Fig 6 MATLAB simulation model

QPSK is used as a modulation method in system simulation, and the rate of source is 10Mb/s. The rise cosine square root filter is used in both the transmit side and the receive side with the roll-off coefficient equal to 0.6, and the filter interpolation is 8, and the group delay filter is a linear filter which is designed by FDA TOOL [10] in MATLAB software. Noise interference is the white Gaussian noise in the channel.

Ideally, the relationship between error performance and E_b / N_0 in the coherent demodulation QPSK system is defined as

$$P_e = \frac{1}{2} erfc \sqrt{\frac{E_b}{N_0}} \qquad (15)$$

Where E_b is the bit energy of the signal, N_0 is the power spectrum density of the noise, and $erfc(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$.

4 paths channel is simulated as an example, and two ways are analyzed in the simulation which one has the same maximum group delay distortion and the other is different. Then the BER curves are shown in Fig.7 and Fig.8.
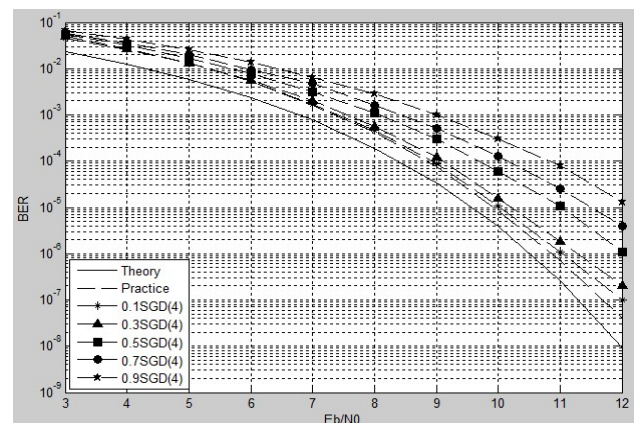

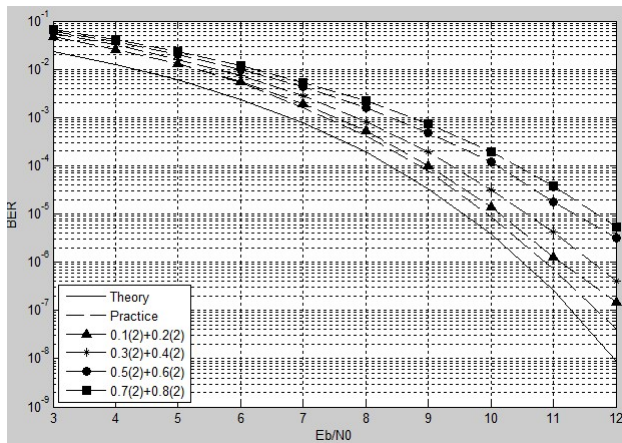Fig 7 BER curve with the same maximum group delay distortion

Fig 8 BER curve with the different maximum group delay distortion

In Fig.7, we can see that the bottom curve is the ideal BER curve in Gaussian channel, and the curves in turn up are BER curves with no group delay, and the maximum group delay distortion are respectively 0.1SGD, 0.3SGD, 0.5SGD, 0.7SGD and 0.9SGD. The SGD denotes the symbol number of group delay distortion. And 0.1SGD(4) denotes 4 paths channel which have the same group delay in each path and every path has 0.1 symbol distortion, the rest can be done in the same manner. When the BER is 10^{-5}, the E_b / N_0 of the ideal channel is 9.6dB, the no group delay channel is 9.9dB, and the others are 10.0dB, 10.3dB, 11.0dB,11.5dB and 12.2dB, which are respectively deteriorated 0.1dB, 0.4dB, 1.1dB, 1.6dB and 2.3dB according to the no group delay channel.

In Fig.8, 0.05(2)+0.1(2) denotes 4 paths which two of them have the same group delay who have 0.05 symbol distortion and the others have the same group delay who have 0.1 symbol distortion, the rest can be done in the same manner. When the BER is 10^{-5}, the E_b / N_0 in each of the channels are respectively 10.2dB, 10.6dB, 11.4dB and 11.7dB, which are respectively deteriorated 0.3dB, 0.7dB, 1.5dB and 1.8dB.

Simulation results show that:

When the group delay distortion is identical in each channel, the BER performance gradually becomes worse with the increasing of the symbols of group delay distortion. When the BER is 10^{-5}, the deterioration of E_b / N_0 is 0.1dB to 2.3dB when the deterioration of the symbol is 0.1SGD to 0.9SGD;

When it is different in each channel, the average group delay distortion is used as a standard, which is acquired by the total numbers of the distortion symbol divided by the total numbers of the channel. The deterioration of E_b / N_0 is 0.3dB to 1.8dB when the deterioration of the symbol is 0.15SGD ((0.1*2+0.2*2)/4) to 0.75SGD ((0.7*2+0.8*2)/4).

And it also shows that the result is the same as the results above if only the average of the group delay distortion is considered. That is the more serious distortion of group delay, the greater deterioration of BER performance. In order to facilitate analysis, the synthetic gain of DBF is not considered in simulation in this paper. There is 6dB to improve the synthesis gain for 4 paths channel in theory.

V. CONCLUSION

In this paper, we have designed a linear group delay filter which is satisfied with the requirements of simulations, and the filter has been realized based on the relationship between minimum phase system and the cepstral coefficients. The model for simulation has been established, and the simulation has been completed by MATLAB software. The simulation results show that the group delay distortion has a great effect on the BER performance. In order to eliminate the influence, a group delay equalizer should be properly added to ensure that the system can work normally in the actual engineering practice.

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