

BEAMSPACE MUSIC DOA SYSTEM USING PHASE SHIFTER

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1 INTRODUCTION

This paper proposes a DOA(Direction Of Arrival) estimation system using chip sized phase shifters and a single ADC(Analogue to Digital Converter) and Rx(Receiver) module under the antenna elements[1]. The proposed system is only controlled by the phase of antenna to find the DOA of target. To obtain the low cost and portable DOA system[2] used as surveillance system in outdoor, we propose a modified beamspace MUSIC(Multiple Signal Classification) using a quasi-orthogonal multi-beam instead of DFT processing. The proposed multi-beam is easily obtained by changing a phase of a single element among array. We demonstrate the proposed system using 4-element microstrip array and chip sized phase shifters. The DOA experiment in anechoic chamber confirms the proposed system performance.

2 THE BEAM-SPACE MUSIC BY QUASI-ORTHOGONAL MULTI-BEAM

We consider an M-element linear array with an element interval of d and the output signal can be expressed by

$$X(t) = \sum_{i=1}^D s_i(t) e^{-j2\pi t d_i} + n(t) \quad (1)$$

where D is number of signal, $s_i(t)$ is the array input signal source, $n(t)$ is vector of white noise and $e^{-j2\pi t d_i}$ is source direction vector source, respectively.

In beam-space MUSIC algorithm, we can choose the beams containing desired and interference signal components in the first step and obtain the signal direction with high accuracy in the second stage. Considering $M \times M$ beamforming matrix composed of $M \times$ DFT (Discrete Fourier Transform), beamforming vectors are written as

$$W_R^{(all)} = \frac{1}{\sqrt{M}} \left[v_M(0), v_M\left(\frac{2}{M}\right) \cdots v_M\left(\left(M-1\right)\frac{2}{M}\right) \right] \quad (2)$$

The above equation is given by M point DFT of $X(t)$. The absolute values of the elements of $Y_{bs}^H(t)$ whose main beams contain DOAs are larger than the others. Here, we choose B of M beams in descending order. Defining the $M \times B$ DFT beamforming matrix as W_R whose B columns are columns of W_R as,

$$Y_{bs}(t) = W_R^H X(t) \quad (3)$$

Then the beam-space correlation matrix R_{bs} is expressed as follows.

$$R_{bs}(t) = W_R^H R_{xx} W_R \quad (4)$$

By applying beam-space transformation, the dimension of the correlation matrix becomes lower from R_{xx} to R_{bs} . It reduces computational cost of EVD (Eigenvalue Decomposition) and beam-space MUSIC spectrum is given as follows [3].

$$y = \frac{\left[W_R^H a(\theta) \right]^H \left[W_R^H a(\theta) \right]}{\left[W_R^H a(\theta) \right]^H E_{BN} E_{BN}^H \left[W_R^H a(\theta) \right]} \quad (5)$$

The DFT processing carried out in the baseband requires to receive RF signal from each antenna element independently, however proposed system has only a single receiver and can not provide multi-beam by DFT.

In this paper, we use a quasi-orthogonal multi-beam in the first step. In order to use phase shifter, the beam formation weight matrix is given in the following [4].

$$W = \begin{bmatrix} e^{-j\theta_1\pi/180^\circ} & 1 & \cdots & 1 \\ 1 & e^{-j\theta_2\pi/180^\circ} & \ddots & 1 \\ \vdots & \vdots & \ddots & \vdots \\ 1 & 1 & \cdots & e^{-j\theta_M\pi/180^\circ} \end{bmatrix} \quad (6)$$

In this matrix, the $\theta_1, \theta_2, \dots, \theta_M$ means the phase value of the phase shifter attached to antenna element. For the simplicity of the system, we use the same phase for all the element. We take several snap shots by setting only one phase shifter to be θ_M and 0 for other elements. For example, in the 4-element array, we take snap shots 4 times by setting the phase of each element in the above procedure.

After evaluating the input correlation matrix R_{xx} , the eigen value decomposition to obtain MUSIC spectrum as follows.

$$Y(t) = W_R^H X(t) \quad (7)$$

$$R_{xx} = APA^H + \sigma^2 I \quad (8)$$

3 PROTOTYPE SYSTEM AND MEASUREMENT

To verify the performance of our proposed system, we build up a prototype system using a chip-sized phase shifter. The proposed system is shown in Fig. 1. A 4-element patch array shown in Fig. 2 is fed by a 4-port power divider and chip sized phase shifters. The insertion loss of the phase shifter is about 1[dB] at 2[GHz] and its variable phase range 0 to 120 degree as shown in Fig. 3.

The DOA angle is set to be $\theta = -30^\circ$ in anechoic chamber. The evaluation parameters are summarized in Table 1. An optimum multi-beam pattern of the patch array is shown in Fig. 4 and its phase is 120 degree. When we do not know an optimum phase in advance, the MUSIC spectrum does not have a sharp peak as shown in Fig. 5. These results obtained by using the prototype model, which shows that our proposed system is effective for DOA. The maximum coverage angle limited by variable phase range is also presented in Table 2.

4 CONCLUSION

In this paper, we proposed a new algorithm for practical application with the diagonal phase of weight matrix using phase shifter, which provides quasi-orthogonal multi-beam for beamspace MUSIC algorithm. The experiment results by the prototype model verified the effectiveness of our proposed system.

References

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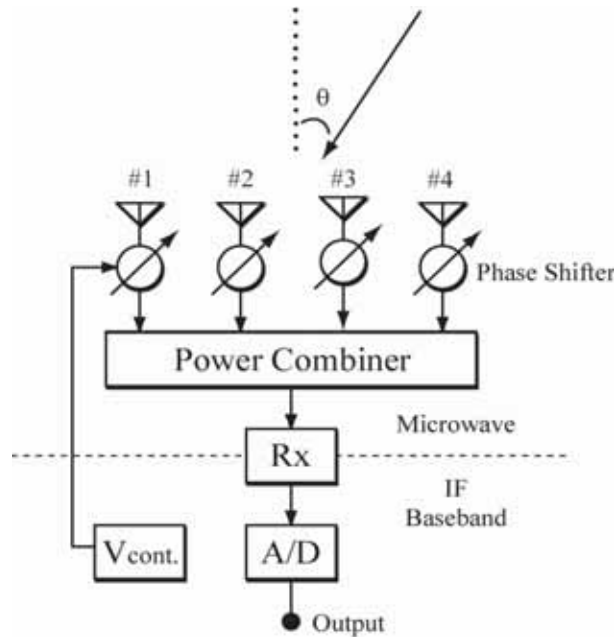


Fig. 1: DOA system using phase shifter

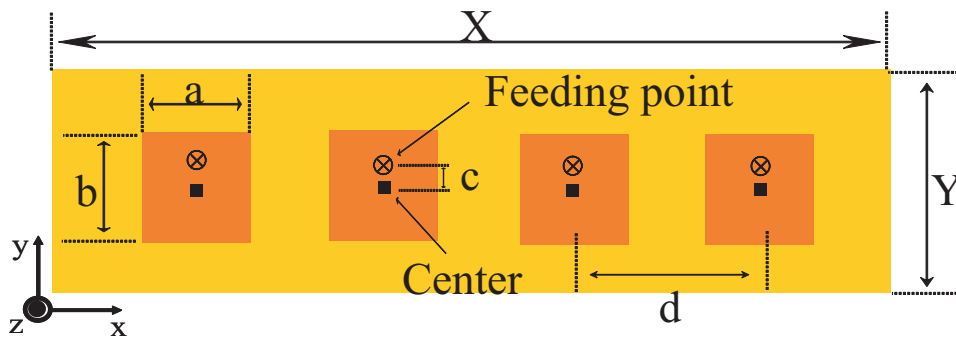


Fig. 2: Antenna configuration for experiment
 $\epsilon_r=2.6$, $a=b=46.4$, $c=6$, $d=75$, $X=305$, $Y=105$, Substrate thickness $t=1.6$ (mm)

Table 1: Experimental parameters

Frequency	2 [GHz]
SNR	20 [dB]
Snapshot	2000 [times]
Sampling rate	40 [MHz]
IF Frequency	11 [MHz]
ADC	14[Bit]

Table 2: Tracking possible range of phase shifter

Phase Scope	Tracking Possible Angle
0 – 30°	±63°
0 – 60°	±65°
0 – 90°	±70°
0 – 120°	±74°

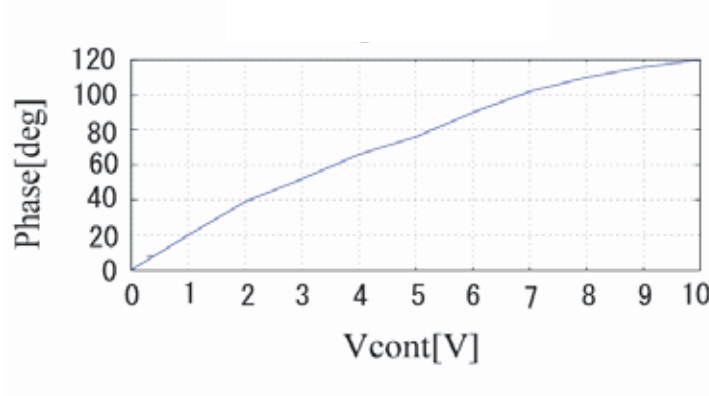


Fig. 3: Characteristic of phase shifter

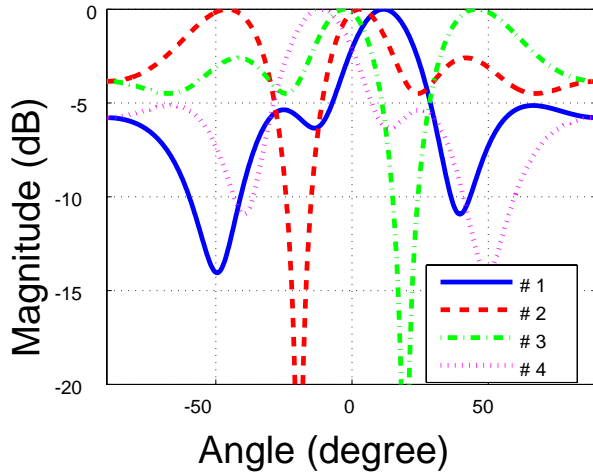


Fig. 4: Optimum beam pattern of patch array(
 $\theta_M = 120^\circ$)

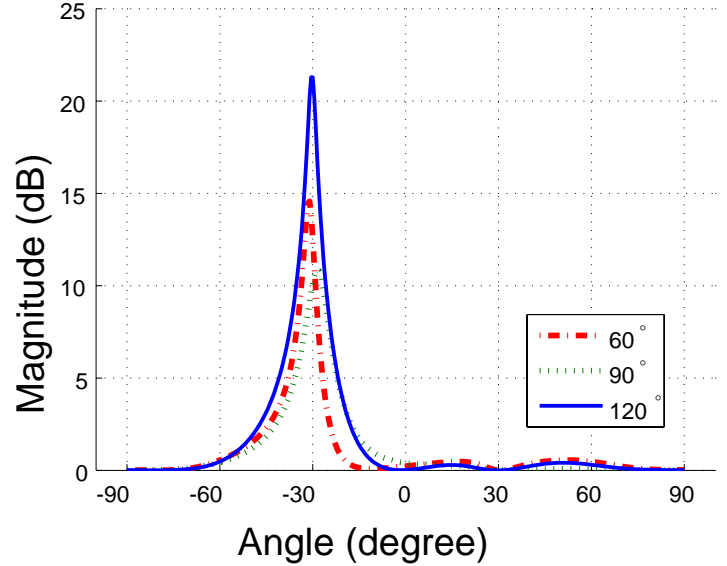


Fig. 5: Evaluated MUSIC spectrum by experiment