DOA Estimation with Super Resolution Capabilities Using a Multi-beam Antenna of the Dielectric Lens

Tomoaki Ide[1], Yoshihiko Kuwahara[1], Hiroyuki Kamo[2], Junji Kanamoto [2]

[1] Graduate School of Engineering, Shizuoka University

3-5-1 Johoku Nakaku Hamamatsu 432-8561 Japan, tykuwab@ipc.shizuoka.ac.jp

[2] Honda elesys Co., Ltd.

134 Godo-cho Hodogayaku Yokohama 240-0005 Japan, Junji_Kanamoto@elesys.co.jp

Abstract

We have proposed a method of applying the MUSIC to a multi-beam antenna of the dielectric lens and have confirmed capabilities of super resolution by computer simulation. High resolution can be expected even if incident signals have low power because the gain is higher than that of the element space array.

Keywords: Dielectric lens antenna; Multi-beam antenna; DOA estimation, MUSIC

1. Introduction

Recently, the collision avoidance radar for the vehicle is advanced. The millimetre-wave is used to improve the azimuth resolution under the conditions of the limited aperture size. An active phased-array and a multi-beam antenna of the dielectric lens are used for the detection of plural vehicles in distance. In order to improve resolution radar that incorporates DOA estimation scheme with super resolution into an active phased-array has also examined [1].

The ordinary radar searches targets over a comparative narrow area in the horizontal plane in distance (100-150m). However, not only vehicles but also pedestrians or bicycles should be detected for the urban area. High gain and wide scanning range will be required, because the radar cross section is small and they exist in the vicinity of the vehicle.

The angular resolution of the super resolution scheme depends on SNR of incident waves. DOA estimation in the element space has disadvantageous on SNR, because the element gain is small. Though SNR is improved by the beam space techniques, the hardware becomes complicate.

This paper presents a method of applying the MUSIC [2] to outputs of the multi-beam antenna of dielectric lens, which has high gain. We can improve SNR and the angular resolution by the proposed method. Dielectric lens antenna has a simple structure compared with the beam space array, and the feed loss is small.
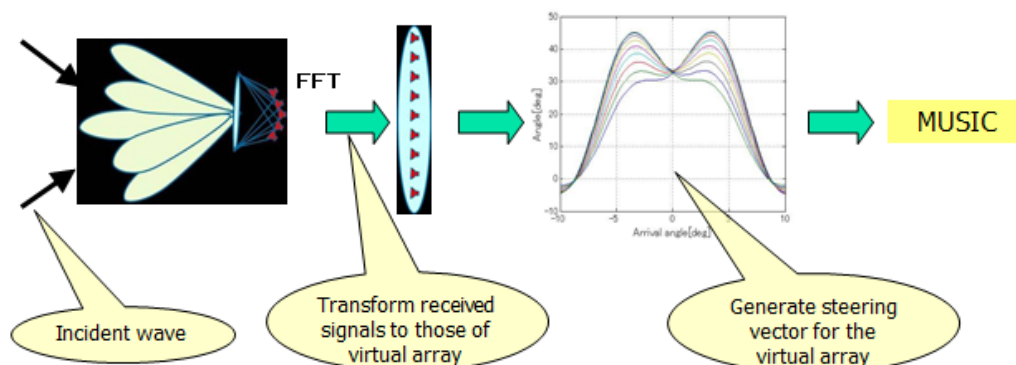
2. Proposed Method

Fig.1 Proposed Method

Figure 1 shows the principle of the proposed scheme. Multi-beams in the horizontal plane were formed by a dielectric-lens antenna. There is a relation of Fourier transform between the radiation pattern and the current distribution on the aperture. An aperture of the virtual array antenna is set in front of the lens. The discrete current distribution Y(n) on the virtual array is expressed by

$$Y(n) = \frac{1}{2\pi} \sum_{m=1}^{M} y(m) e^{-ju(m)v(n)} \qquad (1)$$

Here, n is a number of the elements on the virtual array, M is a number of the multi-beam, y(m) is a signal received by the multi-beam antenna, $u(m) = 2\pi \sin\theta_m$, θ_m is direction of m-th beam, and v(n) is a position of element on the virtual array. Also, an element of the steering vector a(θ, n) is expressed by

$$a(\theta, n) = \frac{1}{2\pi} \sum_{m=1}^{M} y(m, \theta) e^{-ju(m)v(n)} \qquad (2)$$

Here, y(m, θ) is a complex response of m-th multi-beam for incident DOA θ. Then, a covariance matrix for the received signals of the virtual array are estimated. It is decomposed, and the incident signal number is estimated by MDL [3]. Then, DOA is estimated by the MUSIC.

In this paper, we consider a radar for far, which searches targets in distance over the range of ±5° in the horizontal plane and a radar for the vicinity, which searches target of neighborhood over the range of ±40°.

3. Simulation

3.1 Design of multi-beam dielectric lens antenna

A radar for the vicinity has four multi-beams in the horizontal plane (±15°and ±30°). Radar for far has three multi-beams (0 and ±4°). When these patterns are overwritten in the horizontal plane, it is necessary not to see large nulls within the range of ±40°.

The dielectric-lens antenna was designed based on parato Genetic Algorithm [4]. The objectives are a) Minimum value of cross point level of the multi-beams in the horizontal plane, b) maximum sidelobe level in both of the horizontal and vertical plane, and c) difference from the set value (4°) of the vertical beamwidth. The lens shape and focus positions for feeds are decided so as to maximize a) and minimize b) and c). Figure 2 and Figure 3 show the designed lens antenna and
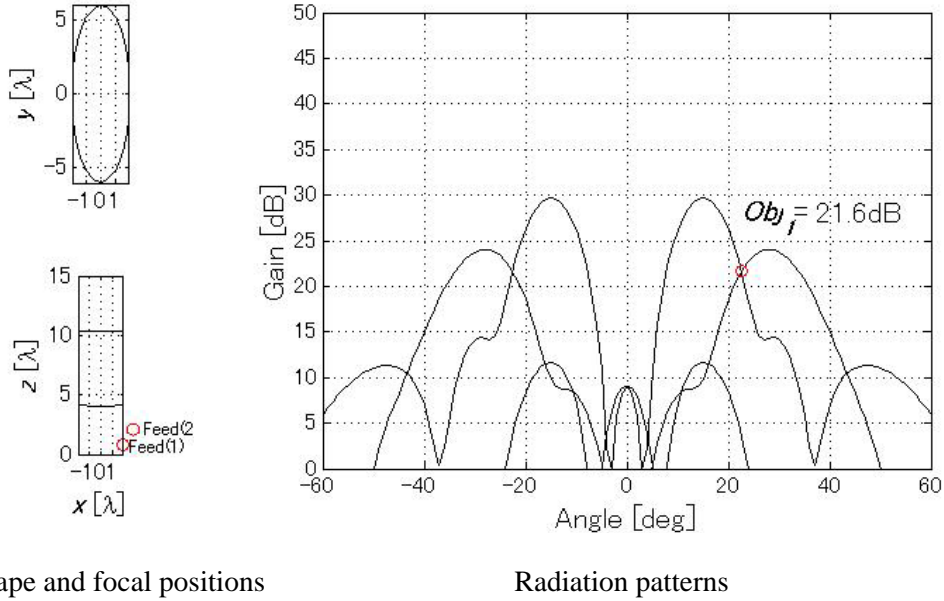

Lens shape and focal positions   Radiation patterns

Fig.2 : Designed multi-beam lens antenna for the vicinity.
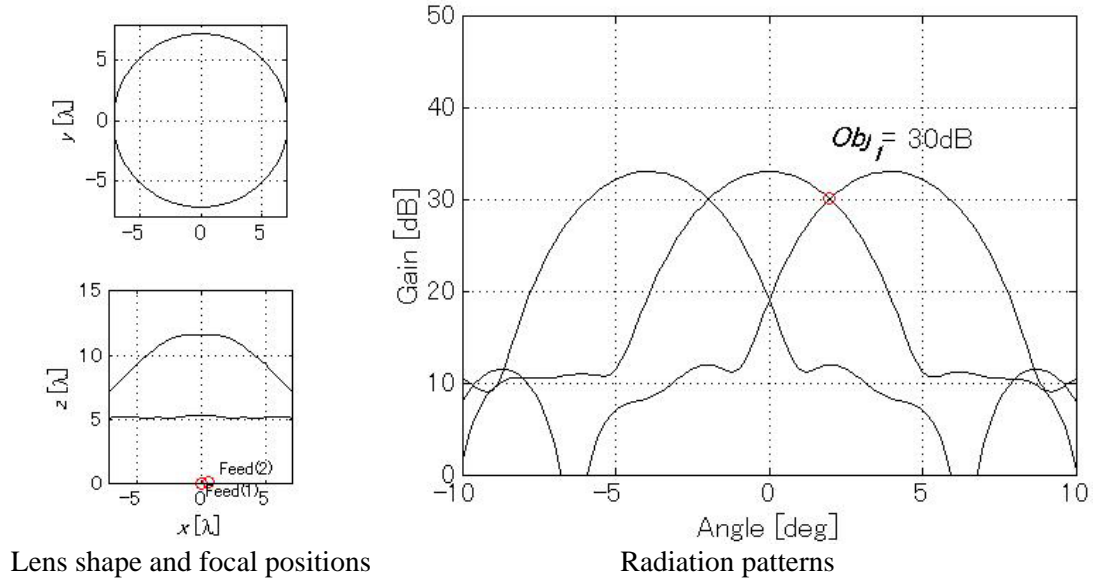
Lens shape and focal positions   Radiation patterns

Fig.3：Designed multi-beam lens antenna for far

horizontal radiation pattern. Minimum value of cross point level in the horizontal plane is more than 20dBi, maximum sidelobe level in both of the horizontal and vertical plane is less than -15dB, and the vertical beamwidth is 3.8° .

3.2 DOA estimation by MUSIC

We assumed that a number of elements for the virtual array antenna is nine of which aperture length is same as a diameter of the dielectric lens. The minimum resolvable angle of 2 incident signals for two types of radars (for far and for the vicinity) was examined using two non-correlated incident signals.

Figure 4 shows relations between resolution and SNR for various snapshots and DUR (Desired and Undesired Ratio) in case of radar for the vicinity. For DUR evaluation, the snapshot number is fixed to 100. Figure 5 also shows relations between resolution and SNR in case of radar for far. As the snapshots decreases, the resolution is deteriorated in both radars for the vicinity and far. If SNR is high, influence on the resolution is small when DUR is varied. Resolution has been greatly deteriorated for low SNR. Figure 6 shows examples of the MUSIC spectrum.
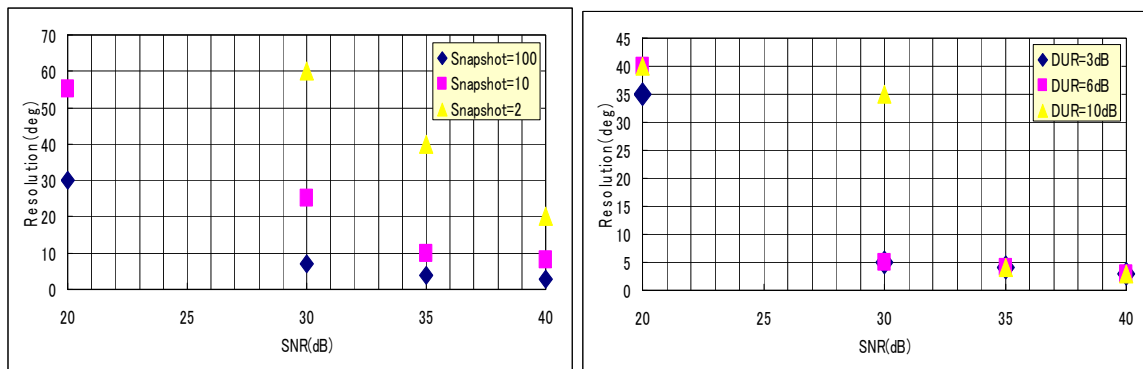

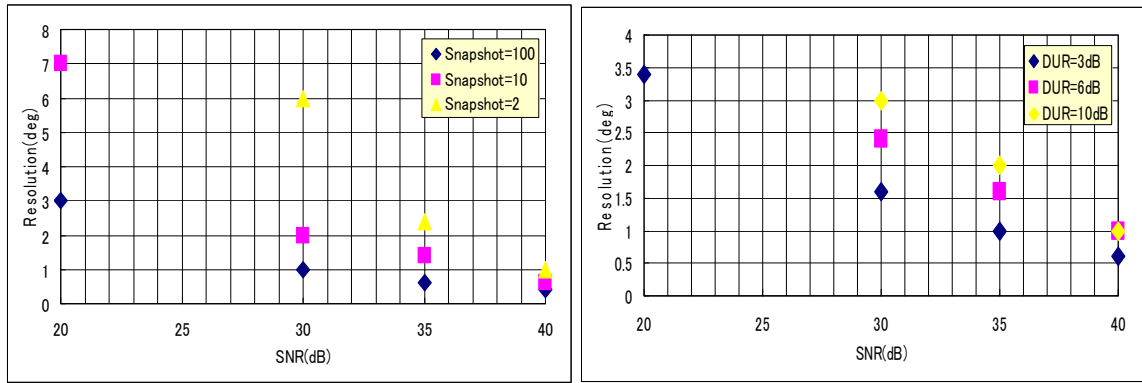Fig.4 Simulation results of radar for the vicinity
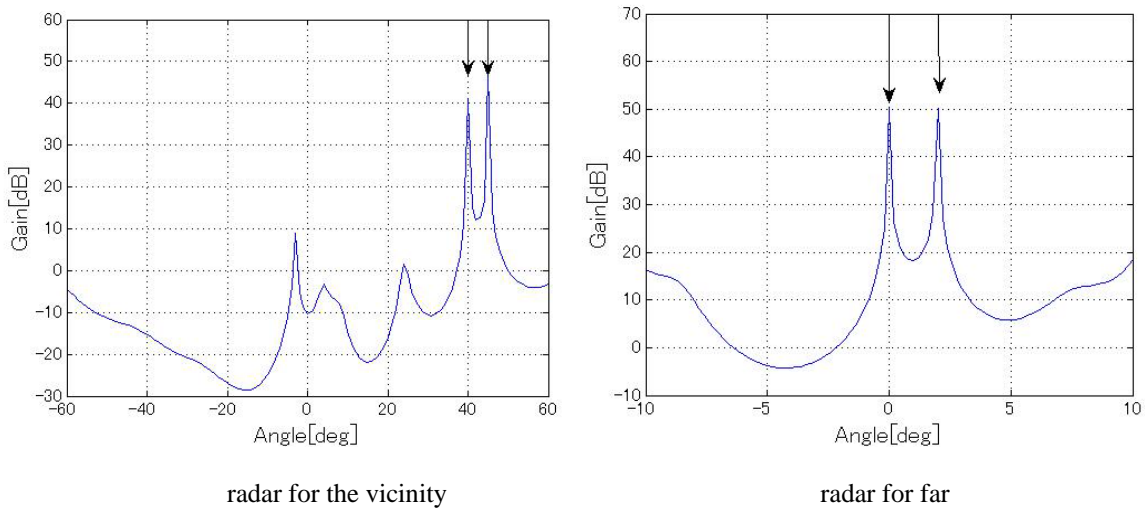
Fig.5 Simulation results of radar for far

radar for the vicinity   radar for far

Fig.6 MUSIC spectrum

4. Conclusions

We have proposed a DOA estimation which is applied MUSIC to a multi-beam antenna of the dielectric lens. The beam with a high directivity formed by the dielectric lens can be incorporated into MUSIC. DOA estimation with super resolution can be confirmed over the range of ±40° in the horizontal plane. Targets of small RCS such as pedestrians or bicycles should be detected and be resolved.

References

[1] PAT. No JP 4098311, 2008.
[2] R.O.Schmidt, Multiple emitter location and signal parameter estimation, IEEE Trans. Antennas and Propagat. Vol.34, no.3, pp.276-280, 1986.
[3] M. Wax and I. Zinkind, Detection of the number of coherent signals by the MDL principle, IEEE Trans. Acoust.,Speech and Signal Processing, Vol.37, no.8, pp1190-1196, 1989.
[4] T. Maruyama, K. Yamamori, *and* Y. Kuwahara, "Design of Multibeam Dielectric Lens Antennas by Multi-objective Optimization," IEEE Trans. Antennas and Propagat Vol.57, no.1, pp.57-63, 2009.