

PROPOSAL OF MILLIMETER-WAVE HOLOGRAPHIC RADAR WITH ANTENNA SWITCHING

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ABSTRACT

This paper proposes a millimeter-wave holographic radar with a simple structure for automotive applications. The simplicity can be realized by switching both transmitting antennas and receiving antennas. Also, a super resolution technique is introduced for the detection of angular positions in the proposed radar. The radar developed experimentally has accomplished an azimuthal angular resolution of less than 2 degrees and an azimuthal field of view (FoV) of more than 20 degrees simultaneously.

INTRODUCTION

Millimeter-wave automotive radars with electrically switched beam antennas have been developed as forward-looking sensors for adaptive cruise control (ACC) and other systems [1]. DaimlerChrysler already has been launching 'Distronic' system, which is an ACC system with the millimeter-wave automotive radar, since June 1999 [2]. Other passenger vehicle manufacturers also will put the same systems on the market within a few years admittedly. However, for collision avoidance system and stop & go system used in urban areas, further reduction of the detection losses is indispensable.

The improvement of an azimuthal angular resolution of the radar sensor is particularly effective for the reduction of the detection losses presumably. The resolution of less than 2 degrees has to be acquired empirically. Moreover, a size is restricted by limitation of installation area and a simple structure that leads to the cost reduction is also required. An automotive radar attaining the resolution of less than 2 degrees under these conditions has never been reported yet.

This paper proposes a millimeter-wave automotive radar that can accomplish high resolution of less than 2 degrees and that can fulfill the above conditions. Furthermore, the validity of the proposed radar is discussed on the basis of the experimental results.

SOLUTION FOR IMPROVEMENT OF AZIMUTHAL ANGULAR RESOLUTION

A solution for obtaining the azimuthal angular resolution of less than 2 degrees is discussed under the condition that the width of the radar sensor must be less than 100 millimeters. This value is reasonable as a width of an onboard sensor.

A super resolution technique [3] is introduced to find a solution. Fig.1 shows the fundamental holographic radar

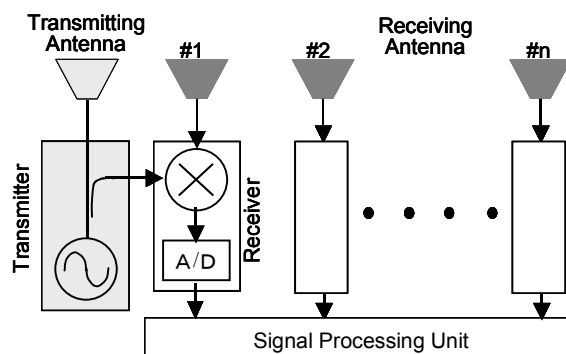


Fig. 1. Configuration of fundamental holographic radar for applying super resolution technique to detection of the angular position.

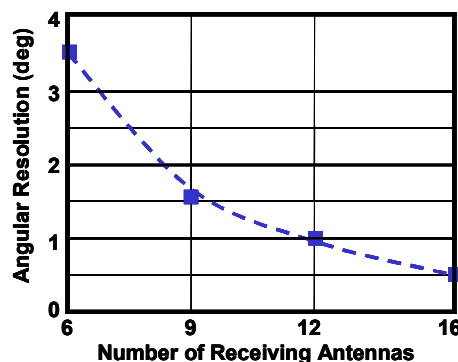


Fig. 2. Variation of angular resolution with number of receiving antennas. Interval of receiving antennas and beam width of receiving antenna are assumed to be 1.5 wavelengths and 26 degrees, respectively.

for applying the super resolution technique to the detection of the angular position. The resolution depends on the number of the receiving antennas (receivers). Fig.2 shows the variation of the resolution with the number of antennas in Fig.1. The variation is estimated with MARPET (Millimeter-wave Automotive Radar Performance Evaluation Tool), which is a simulation software developed by TOYOTA R&D Center [4]. In the estimation, the beam width of every receiving antenna and every interval of the receiving antennas are assumed to be 26 degrees and 1.5 wavelengths, respectively. Also, ESPRIT [5] is used as a super resolution technique here. Fig. 2 represents that the resolution of less than 2 degrees can be obtained with nine receiving antennas. Then, the width of the radar sensor certainly becomes less than 100 millimeters including the transmitting antenna.

It is found from the above discussion that the holographic radar possessing nine sets of receiving antennas and receivers, together with the super resolution technique, has the capability to accomplish azimuthal angular resolution of less than 2 degrees. Moreover, the radar can fulfill the condition that the width of the radar sensor must be less than 100 millimeters. For the configuration of the radar, however, the large number of components is an obstacle to the cost reduction. Therefore, it is indispensable to design a novel holographic radar with a simple structure.

PROPOSAL OF MILLIMETER-WAVE HOLOGRAPHIC RADAR WITH SIMPLE STRUCTURE

The necessity of the holographic radar with nine sets of antennas and receivers has been described in the previous chapter. This chapter proposes a novel holographic radar with a simple structure.

Fig. 3 shows the structure of the novel holographic radar, that is the holographic radar with the antenna switching. In this radar, the switching of the transmitting and receiving antennas enables the big decrease in the number of the antennas and the receivers as compared with the

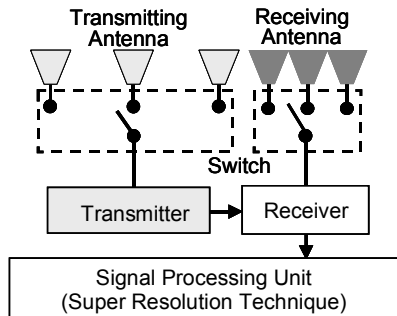


Fig. 3. Configuration of novel holographic radar with switching of transmitting and receiving antennas.

fundamental holographic radar. They are essentially equivalent in detecting the target direction, although the received signal corresponding to each receiving antenna is obtained in the time division manner. The radar operating in the time division manner is presumably applicable to automotive uses because automobiles generally move slower than airplanes.

Fig. 4 illustrates the phase differences among the transmitted signals and the received ones. In this figure, the target is located far away in the left side from the front by the angle θ . In addition, the phase differences among the received signals in the fundamental radar are illustrated. The fundamental radar possesses one transmitting antenna and nine receiving antennas arranged linearly with the intervals of d . Then, the phase $\phi_0(n)$ of the signal received with the n th antenna is given by Eq.(1) assuming that $\phi_0(1)$ is 0.

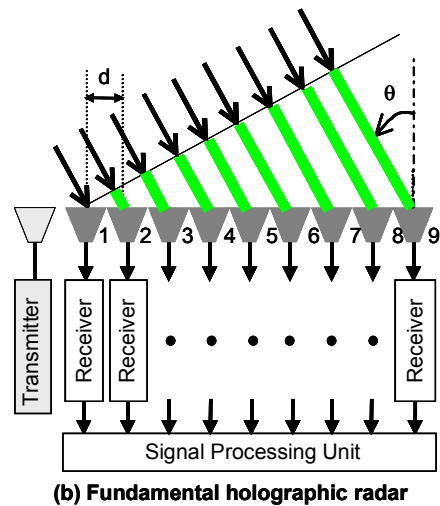
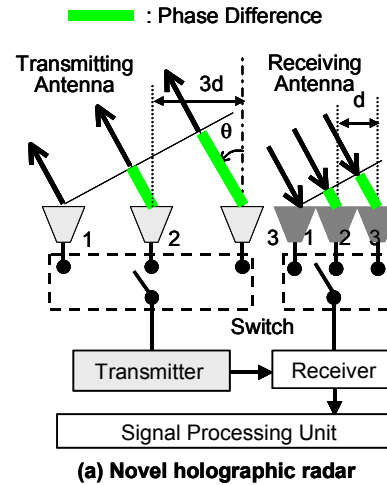


Fig. 4. Phase differences among transmitted and received signals in novel holographic radar (a) and among received signals in fundamental holographic radar (b).

$$\varphi_0(n) = 2\pi(n-1)d \sin\theta / \lambda \quad (1)$$

where λ is the wavelength. The phase of the signal received by each antenna varies with the direction of the target. Also, the phase changes for the position of each receiving antenna. On the basis of such variations in the received signal, the direction of the target can be detected.

On the other hand, the novel radar has three transmitting antennas with intervals of $3d$ and three receiving ones with interval of d . These antennas are arranged linearly. Then, the phase $\varphi(n_t, n_r)$ of the signal obtained by the n_t th transmitting antenna and the n_r th receiving antenna is given by Eq.(2) assuming that $\varphi(1,1)$ is 0.

$$\varphi(n_t, n_r) = 2\pi\{3(n_t-1)+(n_r-1)\}d \sin\theta / \lambda \quad (2)$$

The equation (2) represents that nine different phase values can be given according to the combinations of three transmitting antennas and three receiving antennas. Moreover, the following equation is derived from Eqs.(1) and (2).

TABLE I PRINCIPAL SPECIFICATIONS OF DEVELOPED EXPERIMENTAL RADAR SENSOR

Wave Form	FMCW
Beam Width of Transmitting Antenna	20 degrees in azimuth 4 degrees in elevation
Beam Width of Receiving Antenna	35 degrees in azimuth 4 degrees in elevation
Interval of Transmitting Antennas	4.5 wavelengths
Interval of Receiving Antennas	1.5 wavelengths
Polarization	45 degrees linear
Update Rate	10Hz

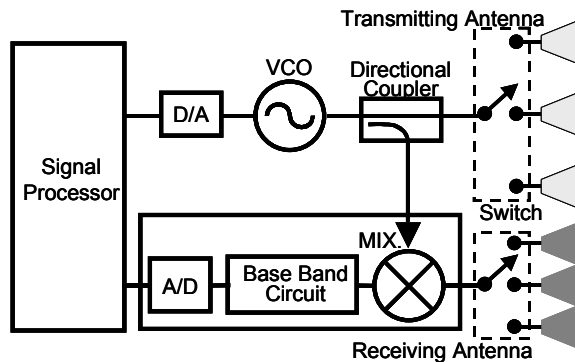


Fig. 5. Basic block diagram of developed holographic radar.

$$\varphi_0(3(n_t-1)+n_r) = \varphi(n_t, n_r) \quad (3)$$

Consequently, Eq.(3) represents that the phase value of each receiving antenna in the fundamental radar can be obtained with the certain combination of the transmitting antennas and the receiving antennas in the novel one. Therefore, they are shown to be equivalent in detecting the target direction. Moreover, the structure of the novel radar is said to be simple, which is advantageous to the cost reduction.

DISCUSSION ON VALIDITY OF NOVEL HOLOGRAPHIC RADAR

In the previous chapter, the holographic radar with the quite simple structure has been proposed. This chapter discusses the validity of this radar through experiments. The azimuthal angular resolution of less than 2 degrees is confirmed.

A. Experimental Radar For Evaluating Performance

The experimental radar sensor has been developed to evaluate the performance of the proposed radar. The principal specifications of the developed radar sensor are shown in TABLE I. The block diagram is shown in Fig. 5. A frequency-modulated continuous wave (FMCW) is transmitted with three antennas in the time division manner. Fig. 6 shows the switching signals of the transmitting and receiving antennas for a period of about 4.5msec corresponding to the up phase of FM signal. When the switching signal is high, the respective antenna is selected. For the period of the transmission from a certain selected antenna, three receiving antennas are switched in order. The transmitting and receiving antennas are switched successively with the respective fixed switching periods

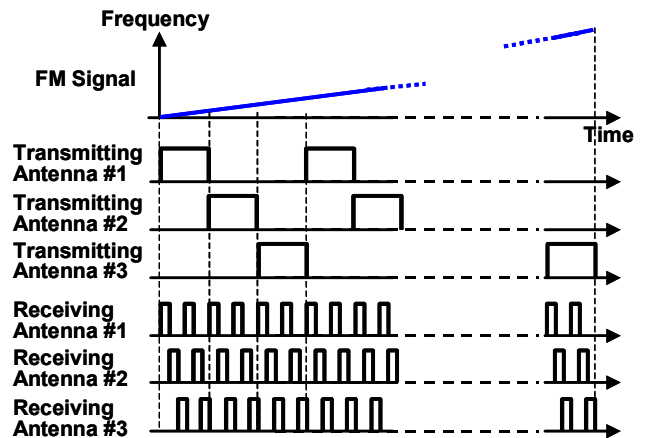


Fig. 6. Sequences of antenna switching signals for period of about 4.5msec corresponding to up phase of FM signal. Switching periods of transmitting and receiving antennas are 2.4μsec and 0.4μsec, respectively.

2.4 μ sec and 0.4 μ sec. Thus, the received signal is obtained in the time division manner. The base-band signal obtained in the receiver is digitized. On the basis of the digitized signal fed to the signal processor unit, the range, the relative velocity and the azimuthal direction of each target are obtained with the signal processing including the fast Fourier transform and the super resolution technique.

B. Experiments To Evaluate Angular Resolution and FoV

Fig. 7 shows the experimental result of the azimuthal angular resolution. In this figure, the arrangement of standard reflectors used in the experiment is also depicted. The azimuthal direction for each reflector is precisely detected in the region that the set angular difference between two reflectors is more than 1.6 degrees. This result represents that the azimuthal angular resolution of less than 2 degrees has been accomplished. Also, Fig. 8 shows the experimental result of the azimuthal FoV. The reflector set within the azimuthal region of 15 degrees in both right and left sides can be detected with the accuracy of less than 0.2 degrees. Consequently, the developed radar accomplishes less than 2 degrees in azimuthal angular resolution and more than 20 degrees in azimuthal field of view simultaneously.

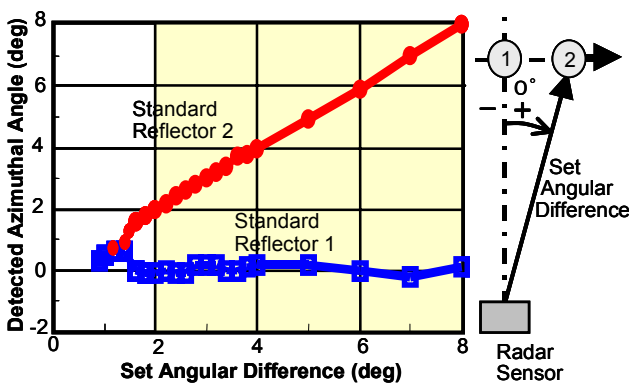


Fig. 7. Experimental result of azimuthal angular resolution.

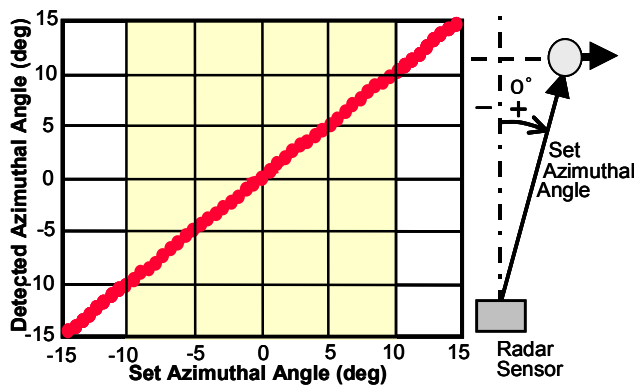


Fig. 8. Experimental result of azimuthal FoV.

CONCLUSION

The novel holographic radar, that is the holographic radar with antenna switching, has been proposed. The switching of the transmitting and receiving antennas enables the big decrease in the numbers of the antennas and the receivers as compared with the fundamental holographic radar. No difference can be seen between on the radar operation for detecting the target direction, except for the time-division reception of the signal corresponding to each receiving antenna. The novel radar possessing three transmitting antennas and three receiving ones, together with the super resolution technique, has the capability to accomplish azimuthal angular resolution of less than 2 degrees. Simultaneously, the radar is capable of fulfilling the conditions that the width of the radar sensor must be less than 100 millimeters due to the limitation of installation area and that the radar must be realized with the simple structure for the cost reduction.

The further improvements of the azimuthal angular resolution and the azimuthal FoV are the future investigations for realizing advanced intelligent-vehicle systems, such as collision avoidance system and stop & go system.

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