Millimeter Wave Radar using Stepped Multiple Frequency Complementary Phase Code Modulation

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ABSTRACT

Our research group has developed the millimeter wave radar using stepped multiple-frequency CPC (Complementary Phase Code) modulation. The millimeter wave radar system provides a high performance in spatial resolution in long range by narrowband receivers. In this paper, we explain the concept of the developed millimeter wave radar using stepped multiple frequency CPC modulation and then the configuration of the radar is illustrated. The results of fundamental experiments in anechoic chamber and field experiment, where the millimeter wave radar is equipped on the vehicle, in a multiple target situation are also presented to demonstrate its performance.

Keywords: Millimeter wave radar, Pulse compression

1. INTRODUCTION

In recent years, radar is expected to be utilized for the automotive safety applications. Automotive radar applications such as ACC (Autonomous Cruise Control), Collision Avoidance are required to provide a high performance in a long range and spatial resolution. FMCW (Frequency Modulation Continuous Wave) radar, which provides a high spatial resolution with comparatively low signal-processing load, is generally employed for current automotive radar. However, the pairing processes of the detected beat-frequency in the up and the down sweeps of FMCW cause some complicated problems under the multiple target situations [1]. The reflected waves from distant targets are superimposed by those from close targets and are also contaminated by the direct CWs from the transmitter. The reflected waves from the close targets and the direct CWs are considered to cause adverse effects on the estimation results.

We have proposed stepped multiple frequency CPC (Complementary Phase Code) modulation, which enable us to detect multiple targets in long range and have a high spatial resolution without pairing process [2]. In this paper, we explain the concept of the developed millimeter wave radar using stepped multiple frequency CPC modulation and then the configuration of the radar is illustrated. The results of fundamental experiments in anechoic chamber and field experiment are presented. The field experiment conducted in a multiple target situation that includes a moving vehicle, trees and buildings.

2. MILLIMETER WAVE RADAR USING STEPPED MULTIPLE FREQUENCY CPC

2.1 STEPPED MULTIPLE FREQUENCY CPC

The radar using stepped multiple frequency CPC sends and receives CPC pulses. As shown in Fig.1, the two pulses on the same frequency step are modulated by Code1 and Code2, which satisfy the complementary condition each other. The transmitted carrier frequencies are stepped N times in one sequence and the same sequences are repeated M times. As shown in Fig.2, Doppler frequencies, which correspond to the relative velocities of the targets, are estimated by FFT on the receiving signals for the same transmitted carrier frequencies. Then the target ranges for the corresponding velocities are calculated by using synthetic bandwidth processing [3], which uses the phase differences depending on their carrier frequencies. When we adopt three or more as N, which is the number of frequency steps in one sequence, it allows the range estimations of moving targets with same velocities. The range resolution depends on the bandwidth of transmit frequency. These signal processing makes it possible to distinguish the targets at same velocities and achieve a high spatial resolution by narrowband receivers.

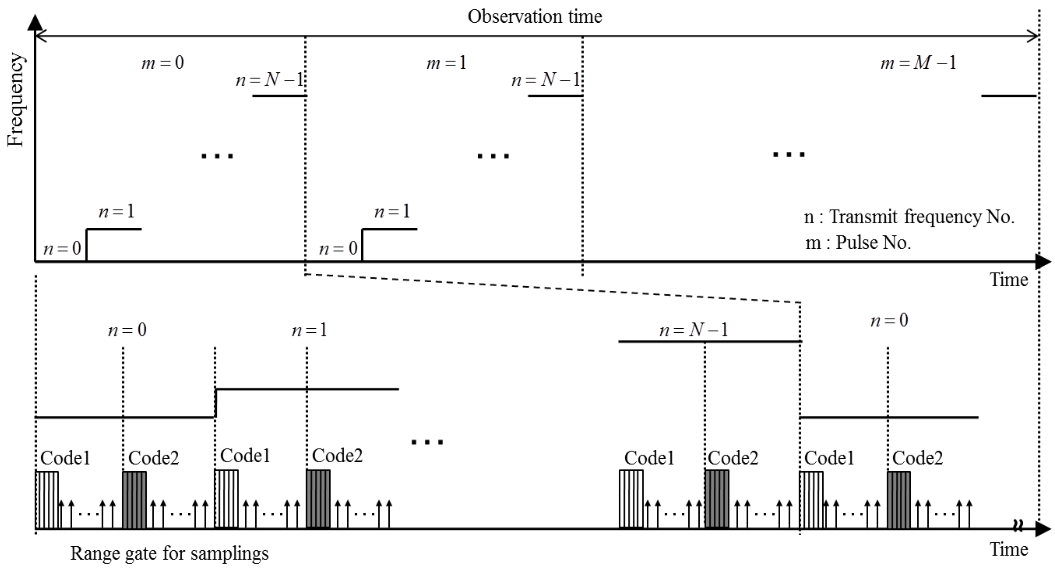

Figure 1. Frequency sequence of stepped multiple-frequency CPC

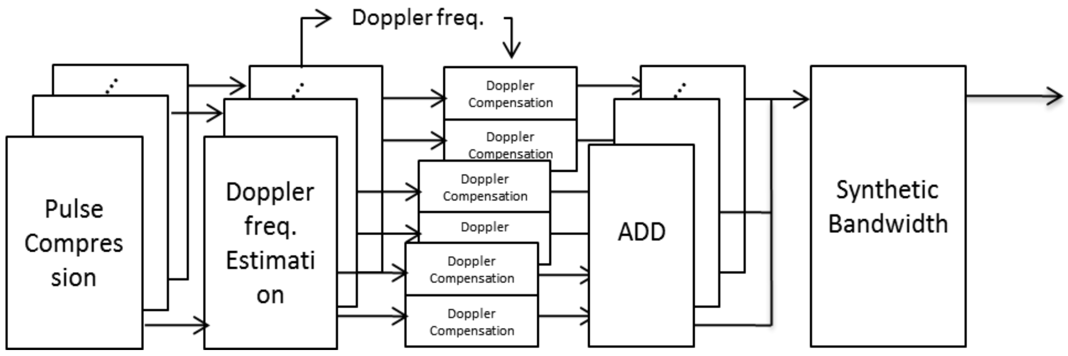

Figure 2. Schematic diagram of range/relative velocity estimation

2.2 CONFIGURATION DIAGRAM OF MILLIMETER WAVE RADAR USING STEPPED MULTIPLE FREQUENCY COMPLEMENTARY PHASE CODE

The developed millimeter wave radar shown in Fig.3 consists of IF unit, RF unit, and signal processing unit which can provide the observation results in real time.

The RF unit is composed of a transmitting antenna (slot antenna), receiving antennas (slot antennas), and transmitting and receiving circuits. This radar is based on specified low-power radio station of the millimeter wave (within of 500MHz, transmit power 10mW) [4] [5]. The transmitting antenna has an azimuth beam width of 22.5 degrees and an elevation beam width of 3.0 degrees with a gain of 22 dBi. The receiving antenna has an azimuth beam width of 60.0 degrees and an elevation beam width of 2.0 degrees with a gain of 22 dBi. The radar system has 4 receivers for 4 antennas, since the system adopts DBF (Digital Beam Forming) [6] and mono-pulse measurement processing. The IF unit has PLLs to switch the transmit frequency of the stepped multiple frequency CPC sequence and has a DAC (digital to analog converter) to produce the CPC pulses, which are baseband signals. The signal processing unit equips 8 ADC (analog to digital converter), 4 FPGA, and an interface board for communication with a control device for signal processing. As shown in Fig.4, the target range and relative velocity is calculated by FPGA. DBF and mono-pulse measurement functions are implemented on the control device. The precision of angular estimation should be enhanced, because in the calculation procedure the angular estimation is executed after distinguishing the targets by their relative velocities and ranges. The millimeter wave radar can switch the carrier frequency in step of 60MHz every 7.0 us and transmit CPC pulses with 80MHz bandwidth at 3.5 us intervals. The specification is described in Table 1. The received baseband signals (I/Q) are sampled by ADC at 160MHz sampling rate. The estimated target ranges, relative velocities and angles are displayed on the monitor of the control device in real time.

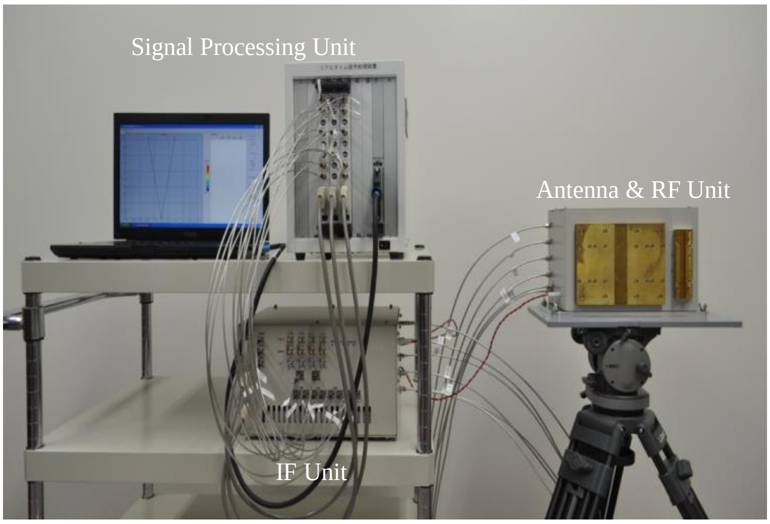

Figure 3. Millimeter wave radar using stepped multiple frequency CPC

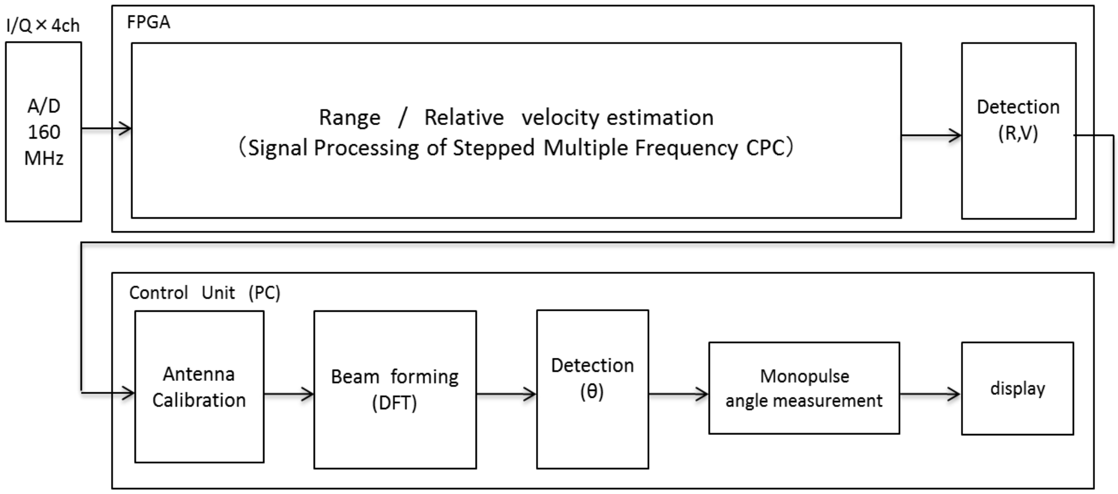

Figure 4. The configuration of the signal processing unit of millimeter wave radar using stepped multiple frequency CPC

Table 1. The radar parameter

Parameters	Specifications
Transmit frequency	60.25-60.75GHz
Pulse bandwidth	80MHz
Pulse width	0.2μsec (30m)
Code length	16
PRI	3.5μsec
Pulse number: M	512
Frequency step width	60MHz
Frequency step number:N	8
Transmission bandwidth	500MHz
Observation time	29msec
A/D sampling frequency	160MHz

3. MEASUREMENT RESULTS

3.1 Fundamental experiment in anechoic chamber

A corner reflector with 18 dB of RCS fixed on an actuator is used for a moving target on the experiment. The actuator is able to be reciprocated at ±4km/h from the range of 3.2m to 4.8m. Fig.5 shows the result on the case of one moving target. Fig.5 (a), (b) and (c) show Doppler frequency estimation, pulse compression result at the peak frequency shown in Fig.5 (a) and the range profile after synthetic bandwidth processing. In Fig.5 (a), one peak can be identified at the velocity of 4km/h. Fig.5 (b) indicates that the method proposed in this paper using stepped multiple frequency CPC suppresses the side lobe level less than -60dB from the range of 20m to 200m despite we adopt relatively short code length of 16. Here, we want to note that it takes 2047 code length to achieve the comparable side lobe level by M-sequence (Maximum length sequence), which is too long to satisfy the time resolution required in automotive radar. We can also identify the target at 4.1 m without range ambiguity in Fig.5(c).

Then two corner reflectors with 18 dB of RCS fixed on actuators separated by 30cm are used for moving targets. The actuators are reciprocated at ±4km/h as in the case with one moving target situation. Fig.6 shows the result of CPC pulse compression and range profile after synthetic bandwidth processing. We can identify 2 peaks in the same range gate in Fig.6. This result indicates that synthetic bandwidth processing make it possible to detect two moving targets with same speeds. The result also indicates that the radar system proposed in this paper achieve the high range resolution of 30cm, which is equivalent to the bandwidth of 500MHz, by the sampling rate of 160MHz.

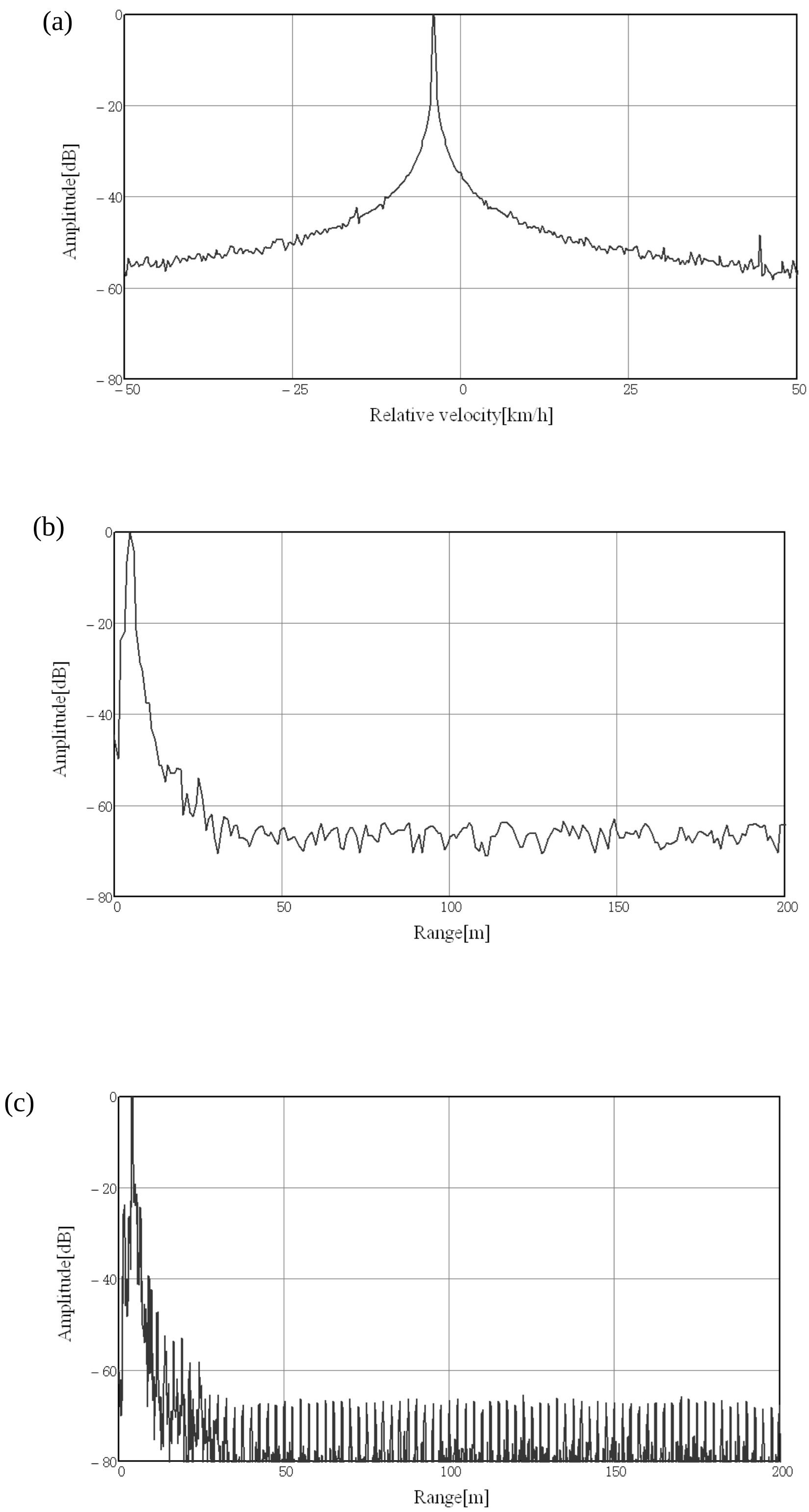

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Figure.5 Experimental results in single target situation in anechoic chamber ((a) Outputs Doppler freq. estimation (n=0), (b) Compressed CPC pulse associated with the estimated target velocity (n=0), and (c) Range profile associated with the estimated target velocity)

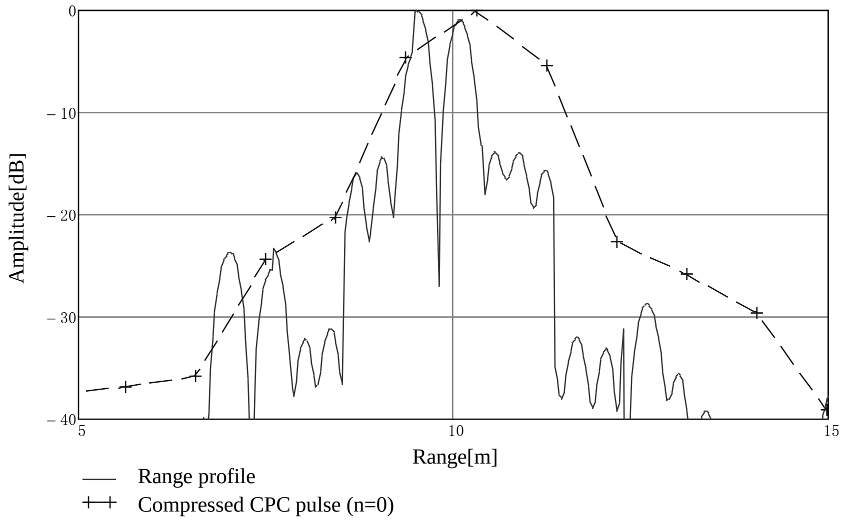

Figure 6. Results of CPC pulse compression and range profile in 2 targets situation in anechoic chamber.

3.2 Field Experiment

The vehicle with millimeter wave radar shown in Fig.7 (a) follows a vehicle moving in the same direction in a multiple target situation including the stationary objects such as trees and buildings as shown in Fig.7 (b). The vehicle equipped with the radar and the other vehicle run at a maximum speed of 30km/h and 20km/h, respectively. The measuring results on the distance, the relative velocity and the angle of the vehicle are obtained every 29 ms with a range resolution of 0.3m and a relative velocity resolution of 0.3 km/h.

Fig.8 shows the field experiment result of field experiment on which the tracking filter has been applied. In Fig.8 (b), a train of symbols around 5-10km/h indicate the front vehicle and other symbols correspond to stationary objects. In Fig.8 (a), we can identify a train of symbols which have the different slope of time versus range estimation from other groups. In Fig.8 (c), a train of symbols identified around 0 degrees corresponds to the front vehicle. As described above, we demonstrated the capability of the radar system proposed in this paper to distinguish the front vehicle and the stationary objects.

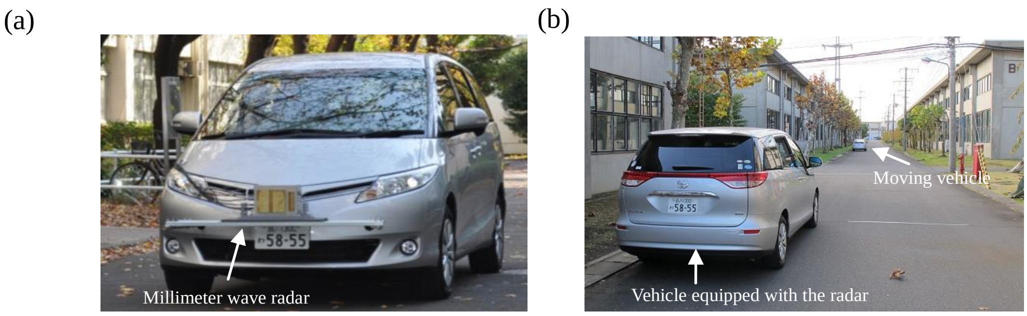

Figure 7. Experimental overview ((a) Millimeter wave radar equipped on vehicle and (b) Experiment environment)

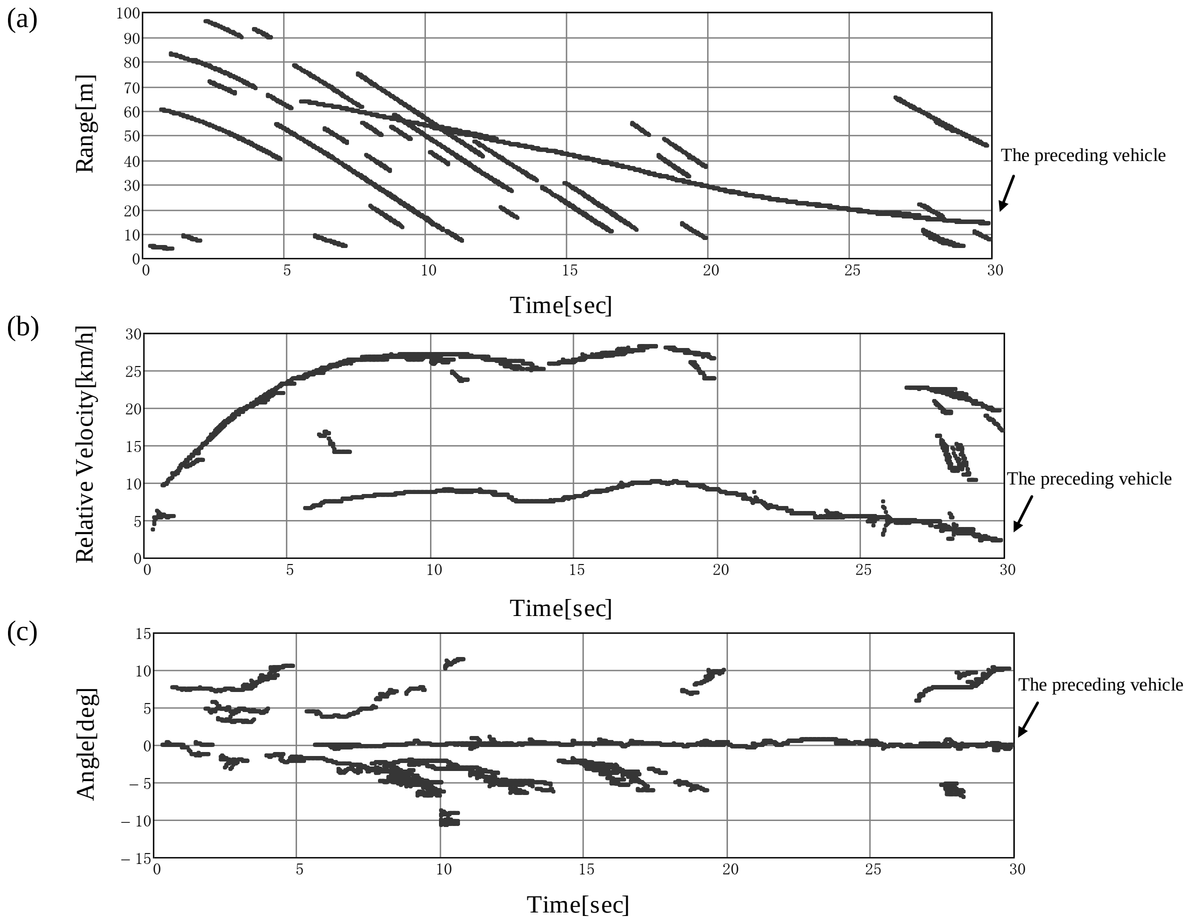

Figure 8. Measurement result applied tracking filter
((a) Range estimation, (b) Relative Velocity, and (c) Estimated angle)

4. CONCLUSION

In this paper, we explained the concept of the millimeter wave radar using stepped multiple frequency CPC modulation and then the configuration of the radar system is illustrated. One experimental result in anechoic chamber indicated that the radar system proposed in this paper suppressed the side lobe level less than -60dB from the range of 20m to 200m despite we adopted relatively short code length 16. The other experimental result in anechoic chamber also indicated that the radar system achieved the high range resolution of 30cm, which was equivalent to the bandwidth of 500MHz, by the sampling rate of 160MHz. We also showed the field experimental result in multiple target situations that contain the vehicle, trees and buildings. We demonstrated the capability of the radar system proposed in this paper to distinguish the vehicle and the stationary objects.

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