Design and Development of the 24 GHz FMCW Radar Sensor for Blind Spot Detection and Lane Change Assistance Systems

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***Abstract*— In this paper, we designed and implemented the automotive radar based on Frequency Modulated Continuous Wave method for Lane Change Assist and Blind Spot Detection radar system. We also developed digital signal processing module and a 24 GHz FMCW radar RF module composed of a single transmitter, a single transmitting antenna array of five elements and three receivers to measure range, velocity and angle for LCA and BSD. In order to verify the developed radar system, we conducted experiments to measure the detection rate and the range accuracy in the anechoic chamber and real road environment. The experimental results show that the developed radar is feasible for use in BSD/LCA systems for automotive.**

Keywords- FMCW Radar; Automotive Radar; BSD; Bind Spot Detection; LCA; Lane Change Assistance.

I. INTRODUCTION

Recently, the smart car for autonomous driving has functions such as lane keeping support, lane change support, inter-vehicle distance control, etc. This function is based on radar and vision sensor. It is a precise distance measurement technology for various obstacles and moving objects is required. Lane change assist (LCA) and Blind spot detection (BSD) radars should be able to detect objects approaching at a medium distance as well as at the rear of the near side. Because the LCA/BSD system must be able to detect where the moving target is on the left and right lanes of the vehicle in the rear of the vehicle and to be able to detect whether there is a moving target in the blind zone area, the signal processing technique is needed [1]-[3].

Frequency modulated continuous Wave (FMCW) radar has been popularly used in automotive radar. It can detect range and velocity of the moving target, simultaneously. To overcome ambiguities, the fast ramp based FMCW radar has been proposed [4][5].

In this paper, we developed an integrated medium - range radar system with dual function for blind spot detection and lane change support. To verify the developed radar, we tested in the anechoic chamber of high frequency band.

This paper is organized as follows. The system design of the BSD/LCA radar is presented in Section II. To validate developed systems, experimental results are provided in Section III. Finally, a conclusion is drawn in Section IV.

II. BSD/LCA RADAR SYSTEM DEGIGN

We implemented the FMCW LCA/BSD radar systems at 24 GHz, which has two receiving antennas and analog-to-digital converter (ADC) channels. The transmitter contains a voltage controlled oscillator (VCO), a frequency synthesizer, and a 26 MHz oscillator. To generate the FMCW source, a frequency synthesizer controls the input voltage of the VCO. The source sweeps over the range of 24.0-24.25 GHz.

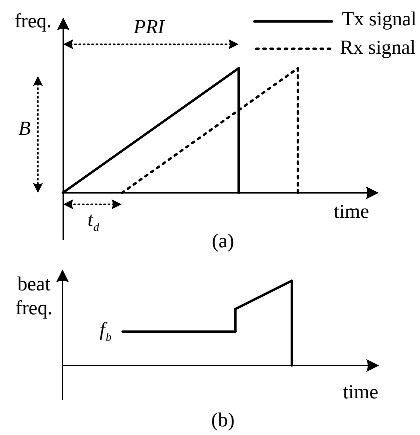


Figure 1. FMCW radar signal (a) the transmitted signal and received signal (b) beat signal.

Figure 2. Signal processing module and transceiver of the Developed BSD/LCA radar system

Figure 1 shows frequencies as a function of time in the transmitted signals and received signals for a stationary target. The range beat frequency can be obtained by signal processing, and then the range of the target can be estimated using (1).

$$R = (C \cdot PRI \cdot f_b)/(2 \cdot B) \tag{1}$$

where, C is light speed, B is the modulation bandwidth, and t_d is the delay time between transmitted and received signals. The PRI is Pulse Repetition Interval, which is a chirp period.

The signal processing module and the transceiver are shown in Figure 2. The detection algorithm based on 2D fast fourier transform (FFT) using fast ramp was implemented in the signal processing module. Transceiver consists of a transmit antenna with five arrays, a receive antenna with three channels, which has three receiving antennas and four ADC channels.

III. EXPERIMENTAL RESULTS

This section presents experimental results to demonstrate the performance of the developed BSD/LCA radar in the anechoic chamber and road environment.

We experimented in chamber with frequency band from 8GHz to 110GHz to obtain the accurate measurement results. As shown in Figure 3, the dimension is 10m (L) × 5m (W) × 4m (H).

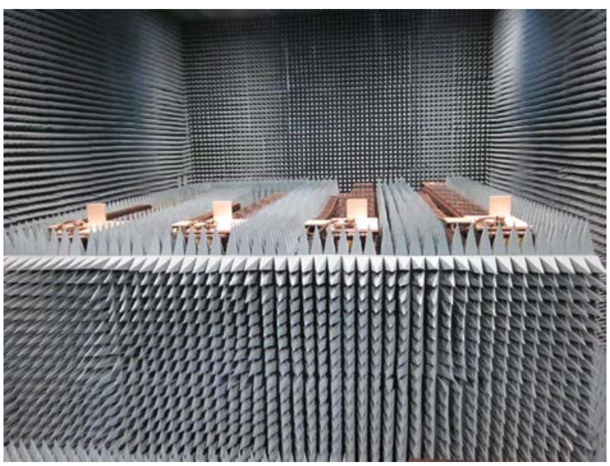


Figure 3. Photo of the anechoic chamber

In our chamber environment, we performed range accuracy experiments with multiple targets. Figure 2 shows the signal processing module and the radio frequency (RF) transceiver module of the developed LCA / BSD radar.

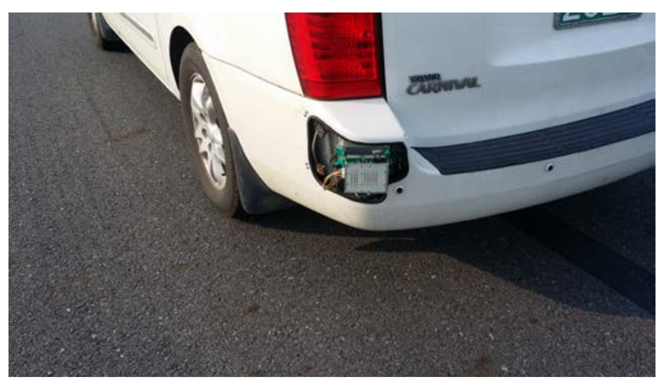
BSD/LCA radar algorithm is implemented in TI DSP TMS320F28335 as shown Figure 2. The MS320F28335 processor is a low cost, high efficiency processor that operates at 150MHz and provides interfaces and signal processing libraries such as ADC, direct memory access (DMA), and control area network (CAN). The RF transceiver module consists of a transmit antenna with five arrays, a receive antenna with three channels, and an RF module.

To verify the effectiveness of the proposed method, we tested the detection performance of the developed radar system using the two-channel FMCW RF module shown in Figure 2.

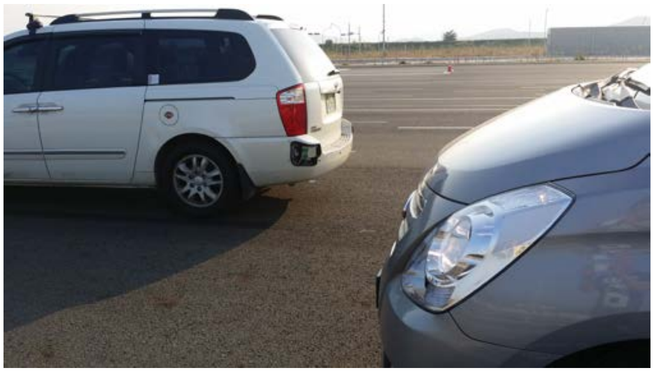
TABLE I. RANGE ACCURACY

	Range (m)						
	0.5	1	1.5	2	2.5	3	3.4
Measured average range	0.47	0.94	1.41	1.88	2.34	2.81	3.28
Range accuracy	0.03	0.06	0.09	0.12	0.16	0.19	0.12
	Range (m)						
	10	20	30	40	50	60	70
Measured average range	10.53	20.60	30.68	40.74	50.81	59.97	71.41
Range accuracy	0.53	0.60	0.68	0.74	0.81	0.03	1.41

By using the chamber environment, we can avoid the negative effect of the unknown echoes on the algorithm performance. We performed the range estimation of the developed 24 GHz FMCW BSD/LCA radar sensor for single target, placed at different location in chamber room. We have captured the beat signal through Ethernet using radar signal processing module. Range accuracy was measured 1,000 times in the anechoic chamber. The target is located 0.5m to 3m in intervals of 0.5m. We measured the range changing the distance in 10m intervals from 10m to 70m to demonstrate the performance of the maximum detection range. Table 1 shows the measurement results of the range accuracy. The experimental results show that the measured average distance accuracy is about 0.11m at distance between 0.5 m and 3.4 m and about 0.69m at distance between 10m to 70m respectively.



(a)



(b)

Figure 4. Experiment environments (a) radar setup (b) snapshot of the scenario

Figure 4 shows the experimental environment for the verification of the algorithm of the developed BSD/LCA radar in this paper. Figure 4 (a) shows that the developed radar for the experiment on an actual road environment is mounted on an experimental vehicle bumper. Figure 4 (b) shows an experiment in which the radar detects a moving target. The measured results of the developed radar system are passed through CAN, and the results are sent to a PC through a CAN to LAN convertor. The final results were displayed using a monitoring program as shown Figure 5 and Figure 6.

Figure 5. Experimental results of the LCA zone on urban road environment

Figure 6. Experimental results of the BSD zone on urban road environment

The experiments were performed to verify the developed radar could simultaneously detect the BSD and LCA zones on urban road environment. The purpose of this experiment is to verify that the BSD/LCA radar system gives warnings when required as the target vehicle overtakes the radar vehicle on real road environment.

Figure 5 shows the experimental results of the LCA zone of the developed radar on real road environment. The measured detection results of the LCA zone shows that developed radar can detect the target vehicle approaching the radar vehicle at high speed as shown Figure 5. Figure 6 shows the measured detection results of the BSD zone of the developed radar on real road environment. The detection results of the BSD zone show that developed radar can detect the target vehicle in the BSD area within 5m as shown Figure 6. Figure 5 and 6 show the range, velocity, and angel of the radar output.

IV. CONCLUSIONS

In this paper, the LCA/BSD radar system was presented. We developed the radar system to obtain high accuracy range and velocity for LCA/BSD. The LCA/BSD radar algorithm is implemented on DSP chip of the developed signal processing module. We verified the radar sensor connected with a 24 GHz front-end-module transceiver to obtain accurate measurement results in anechoic chamber. And we demonstrated that the developed radar has target detection capabilities of BSD area (within 5m) and LCA area (maximum 70m) for BSD/LCA application. Convincing results confirm the feasibility of the complete system and are encouraging for further research activities.

ACKNOWLEDGMENT

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