Development of Real-time LCA System based on Automotive Radar

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***ABSTRACT*— In this paper, we developed a real-time lane change assist (LCA) system based on automotive radar. The existing blind spot detection system only makes detection in a very limited zone up to about 5m, thus responding more slowly to vehicles approaching at faster speeds. In order to overcome this limitation, a radar-based LCA system was developed to provide information before vehicles enter the blind spot detection (BSD) and LCA zone. The performance of the developed LCA system was verified in an anechoic chamber and driving environments.**

Keywords- ***LCA*; *BSD*; *Intelligent Vehicle*; *Automotive Radar*; *Active Safety system*.**

I. INTRODUCTION

Recently, many vehicles have been equipped with driver assisting systems to assist drivers in their judgement and to prevent preventable accidents. Statistics show that most car accidents are caused by carelessness or misjudgment on the part of the driver. As such, the United States and Europe have enforced regulations on the installation of driver assistance systems and safety devices.

Among the many safety systems, Blind Spot Detection (BSD) alerts the driver of possible collisions by detecting vehicles in the blind spot. The detection zone of the BSD system is shown in ISO 17387, which is presented in Figure 1 [1]. When a car approaches rapidly from behind while the driver is attempting to change lanes, the driver may not receive sufficient information in a short BSD zone [2]. A Lane Change Assist (LCA) system that provides information on target vehicles from longer distances is needed to alert the driver of vehicles approaching from behind.

Previously, BSD and LCA systems include infrared, vision, and ultrasonic sensors. However, these sensors are very sensitive to weather or have shorter detection distances. For vision sensor and ultrasonic sensors, the detectable ranges are about within 30m and 12m, respectively. Recently, to overcome these limitations, Radar based BSD and LCA systems is being developed having less sensitive to weather and with longer detection distances [3].

And, the main contribution is to extend the maximum detectable range up to 80m comparable to the conventional radar based LCA system. To do this, we enhanced SNR performance by accumulating the received beat signals using multiple chirp signals.

In this paper, we developed a real-time radar based automotive LCA system. Here, a real-time means the system operates the LCA algorithm fully every 200ms time according to the standard 17387. Then, developed LCA System is verified in a chamber and various driving test sites.

The rest of this paper is organized. In section II, we will illustrate development of a radar based automotive LCA system. In section III, to verify the feasibility of our developed LCA system, the environment of measurement and experimental results will be shown. Section IV concludes this paper.

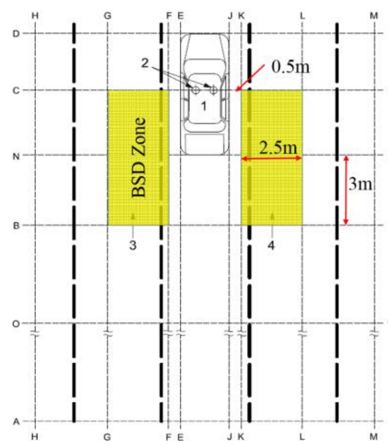

Figure 1. BSD detection zone [1]

II. DEVELOPMENT OF A RADAR BASED AUTOMOTIVE LCA SYSTEM

A. System parameter

In this section, we show the parameter of our considered LCA system in Table I. As shown in Table I, the center frequency is set to 24GHz, and the bandwidth is set to 200MHz. The Pulse Repetition Interval (PRI) is set to 80 μs, and 400 samples per PRI are sampled at a rate of 5MHz.

TABLE I. THE SPECIFICATIONS OF LCA SYSTEM

Parameter	Value
Center Frequency	24GHz
Bandwith	200MHz
Pulse Repetition Interval (PRI)	80 μs
Sampling Rate	5MHz

B. Front-End Module

We show the functional block diagram of the front end module (FEM) in Figure 2. The developed FEM operates for

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a frequency modulated continuous wave (FMCW) radar [4] that outputs signals of 200 MHz in the range of 24.05GHz ~ 24.25GHz at 10dBm power in the transmitter.

Figure 3 shows the picture of antenna patterns in our developed LCA system. The transmission antenna is composed of 5 antenna element arrays. The transmission antenna arrays make beam shape cover the BSD and LCA zones simultaneously. There are two Rx channels having only output real signals for LCA detection, and a channel having I and Q output signals for BSD detection.

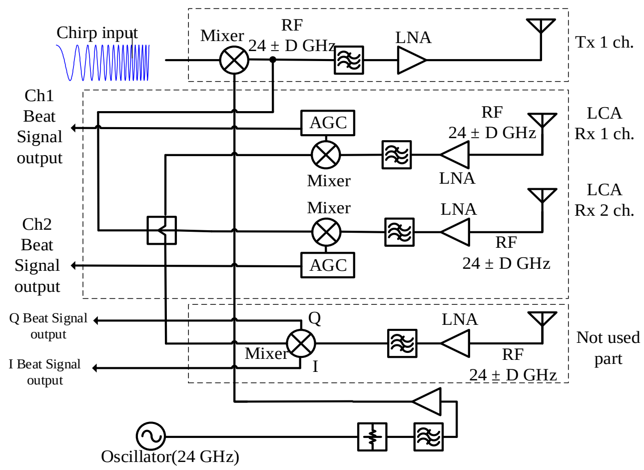

Figure 2. Fucntional block of FEM consisting of transmission antenna

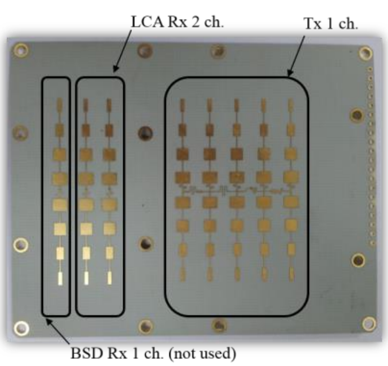

Figure 3. Antenna pattern

C. Back-End Module and Radar Signal Processing

We show the photo of back end module (BEM) in Figure 4. The BEM was developed on the TMS320 DSP processor that operates at a maximum of 150MHz. Because the DSP processor is a low-cost and high-efficiency processor, it makes our designed LCA system cost-effective. Also, it provides various interfaces, such as ADC, Direct Memory Access (DMA), and Controller Area Network (CAN), in addition to a high-performance signal processing library.

Figure 5 shows the block diagram of the developed LCA and BSD system. First, in the main task block of BEM, the RF_ON signal is transmitted to start the FEM. The FEM module receives the RF_ON signal to transmit FMCW radar signals, and outputs RF_Sync signals in a PRI period. The RF_Sync signals provide external interrupts to the BEM, which in turn leads to the external interrupt task and DMA interrupt task.

The external interrupt task triggers the ADC, and beat signals are converted into digitalized signals to be stored in the DMA buffer. The DMA interrupt task is synchronized with RF_Sync signals from the FEM, and stores the digitalized beat signals in the external RAM according to the predetermined size and number by the DMA buffer. Once storing signals is complete, the DMA interrupt task stops the external interrupt task and runs the main task. The main task runs the radar signal processing so-called detection and tracking algorithms.

Figure 6 presents the simplified radar algorithms of the radar signal processing in our developed system [6]. For distinguishing driving lane from another lane, digital beam forming [7] was applied to extract angles of target vehicles. The 2D-FFT algorithm was utilized to obtain the distances and velocities [7] and [8]. Due to the homodyne transceiver used for a cost-effective radar module, the DC–offset component is inherently included in the beat signals. For improving the performance of a near range detection, the DC offset was digitally calculated and removed. Next, a first FFT was processed the beat signals for range extraction, and a second FFT was processed the range bin in a PRI direction for Doppler extraction. Digital beam forming processing was performed the beat signals in an antenna direction for angle extraction. Finally, the target range, velocity, and angle were detected based on Constant False Alarm Rate (CFAR) and Peak Power Spectral Density (PSD) Detection. The final results provide various safety systems through a CAN communication. The total processing time of this system is within about 100ms.

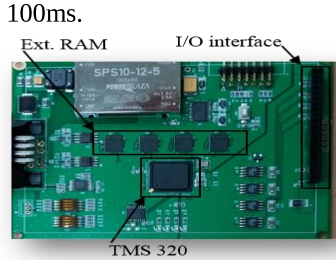

Figure 4. BEM consisting of a DSP processor

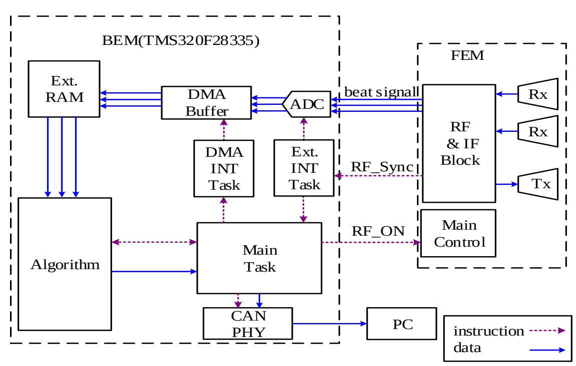

Figure 5. Entire functional block diagram of the developed LCA system

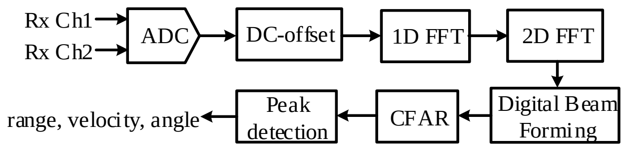

Figure 6. Simplified radar signal processing algorithm of the developed LCA and BSD system

III. MEASUREMENT RESULTS

This section illustrates the environment of measurement and measurement results. Figure 7 shows the experiment setup of our developed LCA system. The FEM and BEM are integrated using a single connection socket, and the signals are exchanged between the two. The output is 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.

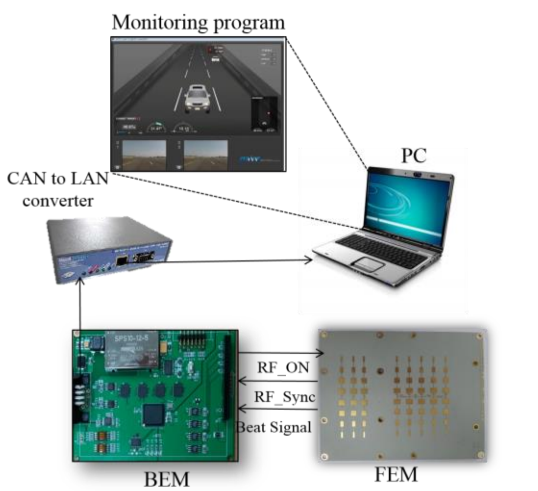

Figure 7. Verification Set-up of our developed LCA System

Table II shows the performance measurement of our developed LCA system. The 95% probability of detection is met to the OEM requirements and the range accuracy of 0.5m is good enough to meet the requirement according to the LCA standard ISO17387. The developed LCA system was evaluated in an anechoic chamber and real-road sites.

TABLE II. THE PERFORMANCE MEASUREMENTS OF OUR DEVELOPED LCA SYSTEM

Parameter	Our developed	Conventional
Maximum Detectable Range	< 80m	<50m
Probability of detection	< 95%	<95%
Range Accuracy	< 0.18m	<0.5m
Maximum Detectable Speed	250Km/h	250Km/h

Table III presents the used anechoic chamber for the performance measurement, which is a space with a length of 10m, a width of 5m, and a height of 4m. It is capable of measuring in a frequency range of 8GHz~110GHz, and has a shielding effectiveness of 60 dB at 8Ghz. Figure 8 shows the real picture of the used anechoic chamber.

TABLE III. THE USED ANECHOIC CHAMBER FOR THE PERFORMANCE MEASUREMENT

Chamber Spec.	Value
Chamber Style	Rectangular
Chamber Size	10m(L) × 5m(W) × 4m(H)
Shielding Effectiveness	60dB at 8GHz
Absorver Type	Microwave Absorber
Absorber Thickness	More than 8 inch
Absorber	More than -40dB at 8GHz

Figure 8. Used anechoic chamber for the performance measurement

First, the probability of detection and false alarm rate were verified. Measurements were taken in the chamber in cases of single and multiple targets. A total of 400 single targets were detected in 400 attempts, and 770 multiple targets were detected in 800 attempts. A detection rate of 97.5% was achieved over 1,200 attempts. Table IV shows the detection results.

TABLE IV. PROBABILITY OF DETECTION

	Target Number			
	Single Target	Multi Target	Total	percentage
Detection Number	400	770	1170	97.5%
Total	400	800	1200	

Range accuracy was measured 1000 times in the chamber with the target placed at a distance of 1m, 1.5m, 2m, and 2.5m. Table V shows the range accuracy. The range accuracy was 0.07 m at a measurement range of 1 m, 0.15 m at 1.5 m, 0.18 m at 2 m, and 0.14 m at 2.5 m. The minimum range accuracy is 0.18m.

TABLE V. RANGE ACCURACY

	Measurement Range			
	1 m	1.5 m	2 m	2.5 m
Average measurement	1.07 m	1.65 m	2.18 m	2.36 m

	Measurement Range			
	1 m	1.5 m	2 m	2.5 m
range				
Standard deviation	0 m	0.0001 m	0.05 m	0 m
Range accuracy	0.07 m	0.15 m	0.18 m	0.14 m

In order to evaluate the maximum detection performance, the developed LCA system was 20 times repeatedly tested on a moving target in a driving road site. The Figure 9 shows the experimental setup in the vehicle test site. Figure 9(a) shows the radar attached on the right side of the back bumper. A tilting device was installed to adjust the radar angle and direction. Figure 9(b) shows the radar-attached vehicle and the position of the target vehicle, which was set to move to the left of the radar. Figure 9(c) shows the scenario, while Figure 9(d) presents the GUI of the test results. The GUI outputs distance, velocity, angle, and camera images of the target vehicle. The target vehicle was detected at a maximum range of 80 m. The probability of detection was 97% measured.

Figure 9. Vehicle driving test site environment: (a) mount view, (b) vehicle position, (c) scenario, (d) result GUI

IV. CONCLUSIONS

In this paper, we developed a real-time radar-based automotive LCA system up to 80m without increasing output power. The system was based on a low-cost high-efficiency processor. The radar signal processing was carried out using 2D-FFT and digital beamforming algorithms. The radar was tested in an anechoic chamber and real driving road test site. Further tests will be conducted in various actual driving environments and road conditions.

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