Evaluation of High-Speed FMCW Signal Generation and Processing for Optically-Connected Distributed-Type Millimeter-Wave Radar

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***Abstract*—The optically-connected distributed-type millimeter-wave radar system has been proposed and developed to detect small debris on the airport surface. The key concept of the radar system is the distributed architecture which consists of a single central unit and several antenna units, where both units are connected by radio-over-fiber technology. In this paper, the advantages of the architecture are experimentally evaluated using the prototype 96 GHz radar system. Firstly, a high-speed 12 GS/s arbitrary waveform generator-based frequency-modulated continuous wave signal generation is discussed. Then, the effects of the 10 kHz FM chirp rate is confirmed in a radar reflectors detection test at Sendai Airport.**

Keywords*— *distributed-type radar; foreign object debris; high-speed FMCW signal generation; millimeter-wave radar; radar signal processing; radio-over-fiber

I. INTRODUCTION

To detect and remove the small debris on the airport surface, the airport administrators often have to suspend the operation of aircraft. These downtimes are not negligible for the sufficient use of the runways, especially for the busy airports. However, the airport surface is required to leave nothing behind to ensure the safety and security operation of the aircraft [1]. Because of this, several detection systems of the foreign object debris (FOD) have been developed so far. We have been proposed and developed FOD detection millimeter-wave radar system based on the radio-over-fiber (RoF) technology [2], [3]. The radar system employs the distributed-type architecture based on the frequency-modulated continuous wave (FMCW) ranging method. In this paper, the advantages of the proposed architecture, which is enabled by the high-speed arbitrary waveform generator (AWG)-based FMCW signal generation and signal processing, are confirmed by the measurement results of the prototype radar system.

II. OPTICALLY-CONNECTED DISTRIBUTED-TYPE RADAR

Fig. 1 shows the block diagram of the optically-connected distributed-type 96 GHz millimeter-wave radar for the FOD detection on the airport surface. The key architecture is the radar system consisting of the several antenna units and a single central unit. The radar FMCW signal generator and the signal processing unit is only located in the central unit. On the other hand, the antenna units have only RF circuits and optical converters. This construction enables concentration of the cost resource for the one central unit. By using the FMCW signal generator based on the 12 GS/s arbitrary waveform generator (Keysight Technologies M8190A) and the signal processing circuit based on the FPGA (National Instruments PXIe-7965R), the real-time radar signal generation and processing of up to a 10 kHz chirp rate is achieved. Table I shows the specifications of the two antenna units for the evaluation. The high-power antenna unit and wide-bandwidth antenna unit are constructed to validate the feasibility of the

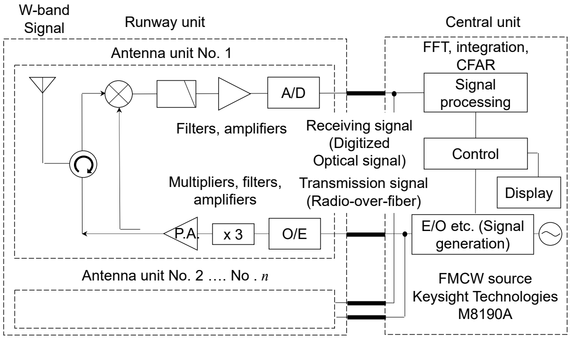

Fig. 1: Block diagram of the optically-connected distributed-type 96 GHz millimeter-wave radar system.

TABLE I. SPECIFICATIONS OF 96 GHZ OPTICALLY-CONNECTED RADAR

Antenna unit type	High-power	Wide-bandwidth
Frequency band (GHz)	95.5 – 96.5	92 - 100
Bandwidth (GHz)	1	8
Transmitting power (dBm)	26	17
Ranging method	FMCW	
Frequency modulation method	Linear triangle	
Frequency modulation chirp rate (kHz)	10 kHz	2 kHz
Antenna gain (dBi)	42 dBi	

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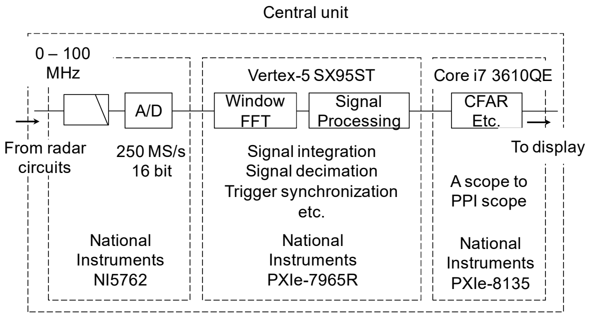


Fig. 3: Block diagram of high-speed radar receiving signal processing circuits, which are based on FPGA at the central unit.

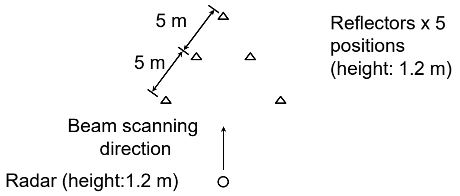


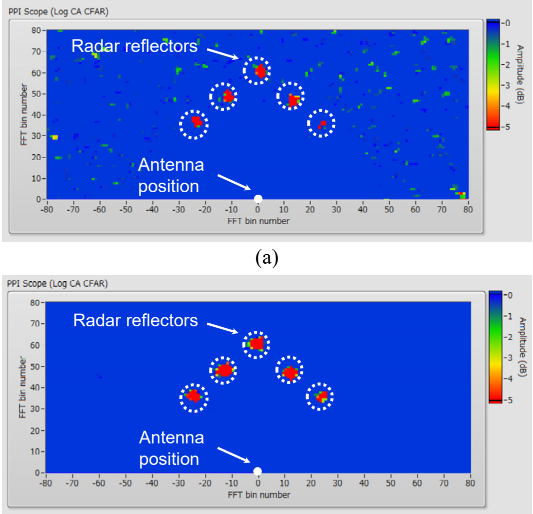
Fig. 4: Positions of the radar reflectors in the experiments at Sendai Airport.

proposed architecture. The effects of the high-speed AWG-based FMCW signal generation and processing is investigated using two antenna units which have different chirp rates.

III. HIGH-SPEED FMCW SIGNAL GENERATION AND PROCESSING

To confirm the advantages of the high-speed FMCW signal generation and signal processing, the fundamental evaluations are carried out on the airport surface. As described in the previous section, the W-band linear FMCW signal is generated using the AWG and frequency multipliers. In addition, Fig. 3 shows the block diagram of high-speed radar receiving signal processing circuits, which are based on FPGA in the central unit. The FPGA circuit enables signal processing such as signal integration, decimation, windowing and 8,192 point FFT up to more than the rate of 10 kHz. Fig. 4 shows the positions of the radar reflectors in the experiments. The received radar signals are displayed using the plan position indicator (PPI) scope after the non-coherent integration and constant false rate (CFAR) calculation. In the experiments, the antenna is rotated for the azimuth plane using the mechanically scanning parabolic reflector at 60 rpm [3].

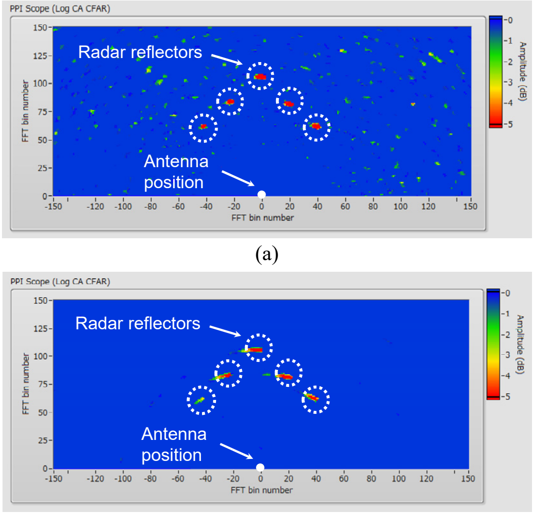
Then, the received signal of the 2 kHz and the 10 kHz FMCW chirp rate are compared to evaluate the effects of high-speed FMCW signal. Fig. 5 and Fig. 6 show the measured radar PPI scope of the high-power (FMCW chirp rate: 10 kHz) and the wide-bandwidth (FMCW chirp rate: 2 kHz) antenna unit, respectively. The log cell-averaging CFAR with the 3 dB threshold value is used to display the scope. The CFAR threshold detection, and the non-coherent signal integrations are usually employed to reduce the fluctuation of the noise floor. If there are no integrations in the receiving signals, false detections are observed such as in Fig.5 (a) and Fig. 6 (a). By comparing Fig. 5 (b) and Fig. 6 (b), it is obvious that the high-power antenna with high-speed 10 kHz chirp rate radar enables clear target detection with no distortions in the image of the radar scope.



(a)

(b)

Fig. 5: Measured PPI scope of the high-power antenna unit (FMCW chirp rate: 10 kHz) with (a) 4 times and (b) 16 times non-coherent integration.



(a)

(b)

Fig. 6: Measured PPI scope of the wide-bandwidth antenna unit (FMCW chirp rate: 2 kHz) with (a) 4 times and (b) 16 times non-coherent integration.

IV. CONCLUSIONS

The proposed distributed-type radar architecture has only one signal generation and processing unit. This construction enables concentrated investment of high performance for both units. The effect of the high-speed FMCW signal generation and processing were experimentally demonstrated.

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