Signal Processing to Suppress Multi-Reflection for Level Sensing Using NRD Guide Pulse Radar at 60 GHz

#Futoshi KUROKI [1], Takeshi IZUHO [1], Tsukasa YONEYAMA [2]
[1]*Department of Electrical Engineering, Kure National College of Technology*
2-2-11 Aga-Minami, Kure 737-8506, Hiroshima, Japan
[2]*Department of Environmental Information Engineering, Tohoku Institute of Technology*
Futatsuzawa 6, Taihaku-Ku Sendai 982-0831, Japan
E-mail: [1]kuroki@kure-nct.ac.jp, [2]yoneyama@tohtech.ac.jp

Abstract

A pulse radar front-end using an NRD-guide technology was fabricated as a radar system for a millimeter wave level sensor, and then range finding was performed by using it. Multi-reflection however occurred between a target and a planar antenna due to a pencil beam radiation of our developing planar antenna, so that a precise distance could not be calculated for short range detection. In this paper, an FPGA-based signal processor was devised in order to eliminate such multi-reflection, and experimental errors of less than 30 cm could be achieved for the distance range from 2 m to 20 m under the multi-reflection environment.

1. INTRODUCTION

Research and development of pulse radar systems have been promoted for some applications such as car warning radar systems and tank level estimation systems [1], [2]. We developed a pulse radar front-end by using the non-radiative dielectric waveguide (NRD-guide) technology at 60 GHz [3], [4], [5], [6], but multi-reflection occurred between a target and a planar antenna due to a pencil beam radiation of our developing planar antenna. Thus the radar system suffered from difficulty to calculate distance to the target precisely.
In this paper, we devised a signal processor to overcome such difficulty, and the range finding was successfully performed by using it.

2. OVERVIEW OF PULSE RADAR SYSTEM

Figure 1 shows a configuration of a pulse radar system proposed in this paper. This pulse radar consists of a signal processor to generate a pulse and to calculate a distance, a duplexer, a planar antenna for transmission and reception, a down-converter for a heterodyne detection, and a demodulator. At first, the signal processor generates a pulse train with a pulse width of 495 nsec and a repetition frequency of 2 MHz. This pulse train was inputted into the ASK-modulator. A pulse wave reflected from the target was received at a planar antenna, and then it was down-converted to an intermediate frequency band. The intermediate frequency was selected at 1 GHz because the frequency spectrum spread of the pulse train was about 400 MHz. A demodulated pulse was inputted into the signal processor, and the distance to the target was finally calculated.
Figure 2 shows a photograph of the planar antenna. This antenna consists of a high e LSE-NRD guide radiator [7] located at a focal point of a 2-dimensional parabolic reflector in an oversized waveguide. The top metal plate is a metallized dielectric substrate, on which twenty seven slots are etched, and is exited by the oversized waveguide. The length of the slot was set to be 126 mm, and the total aperture area was found to be 126 mm × 111.1 mm. The radiation patterns in the E- and H- planes are shown in Fig. 3. Good pencil beam pattern having the half power beam widths of 2.8° in the E-plane and 3° in the H-plane was obtained. This performance could avoid influence of the multi-reflection under demonstration environment. The performance of the NRD guide pulse radar is summarized in the Table 1.

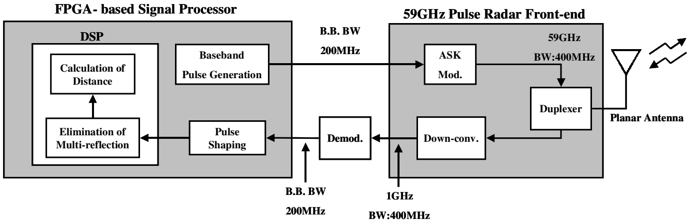


Fig. 1: Configuration of pulse radar system

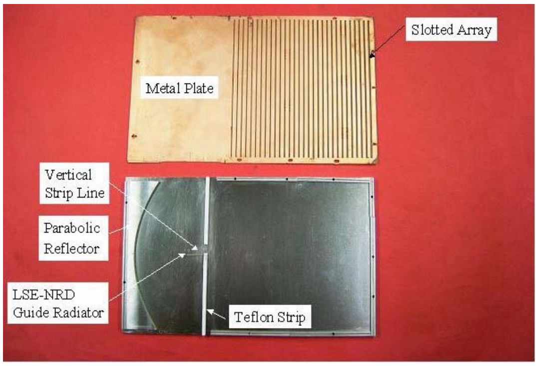
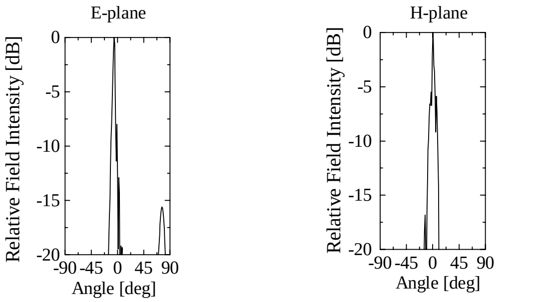


Fig. 2: Photograph of planar antenna fed by LSE-NRD guide radiator



(a) E-Plane (b) H-Plane

Fig. 3: Measured radiation patterns of planar antenna fed by LSE-NRD guide radiator

Table 1: Performance of NRD guide pulse radar front-end

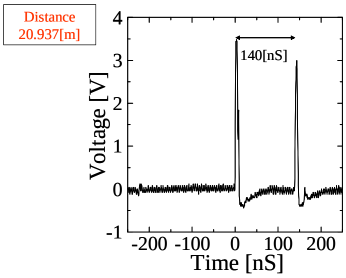
Oscillation Frequency	59 GHz
Oscillation Power	13 dBm
Phase Noise	< -95 dBc/Hz (100 kHz offset)
Temperature Coefficient	< -1.3 ppm / °C
PR Frequency	59 GHz
RF Power	7.5 dBm
Modulation Scheme	Direct ASK
LO Frequency	60 GHz
LO Power	- 4 dBm
Conversion Loss of Down Converter	7 dB
Antenna Gain	33 dBi

3. MEASURED PULSES REFLECTED FROM TARGET

Placing a metal plate with 80×90 cm in area in front of the fabricated radar, a pulse reflected from this metal plate was received and demodulated as a function of the distance between the radar and the metal plate. The results are shown in Fig. 4.

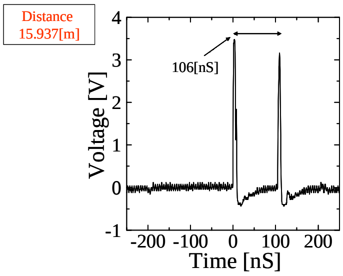
Figure 4 (a) shows the demodulated pulse when the distance to the metal plate was set at 21 m. The right pulse waveform corresponds to the reflection of the metal plate, while the left pulse waveform corresponds to leakage of the transmitting pulse wave through the duplexer. This right pulse waveform terms the reference pulse waveform because this pulse gives the reference position. The distance between to the metal plate can be estimated by counting an interval of both pulse positions. Unneeded reflection from a wall and a roof was not observed although the range finding was performed at a long corridor, having a width of 2 m, a height of 2.5 m, and a length of 40 m, in a concrete building.

Next, figure 4 (c) shows the demodulated pulse waveform when the distance between to the metal plate was set at about 8.5 m. Another pulse, whose peak voltage is lower than those of the left pulses, was observed on the right side as shown in Fig. 4 (c). The modulated pulse waveform is shown in Fig. 4 (d) when the distance was more shortened to be 2.4 m. In this case, the third pulse appeared and its peak voltage was close to those of the two left pulses. The reason is that the multi-reflection occurred between the antenna and metal plate due to a pencil beam pattern of the planar antenna. The third pulse is unneeded, and must be removed for the range finding.



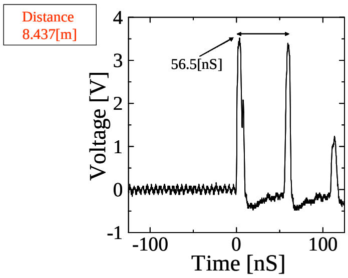
Measured Distance: 21[m]

(a)



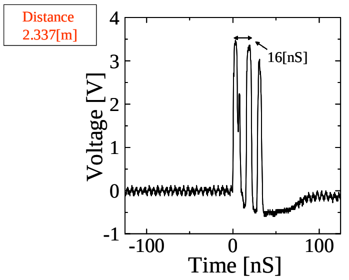
Measured Distance: 15.9[m]

(b)



Measured Distance: 8.475[m]

(c)



Measured Distance：2.4[m]
(d)

Fig. 4: Demodulated waveforms of pulse waves

4. Overview of FPGA-based signal processor

Main functions of our fabricating signal processor are generation of a pulse inputted into the ASK-modulator, pulse shaping, elimination of the multi-reflection, and calculation of the distance to the target as shown in Fig. 1.
At first, the modulated pulse waveform as shown in Fig. 4 (d) was pulse-shaped by the FPGA as shown in Fig. 5. Next, signal processing flow to eliminate the multi-reflection from the pulse-shaped waveform is described with a time chart as shown in Fig. 6. There are the reference pulse leaked through the duplexer, the pulse reflected from the target, and the multi-reflected pulses in the [Received Signal] as mentioned above. The [Sync Signal] synchronizes these pulses.
The [Number of Pulses] increases to ‘1’ when the reference pulse rises, and increases to ‘2’ when the pulse reflected from the target rises, and increases to ‘3’ and ‘4’ when every multi-reflected pulses rise, and is finally reset to be ‘0’ when the next [Sync Signal] rises. Time difference between the reference pulse and the pulse reflected from the target is counted in order to eliminate the multi-reflection while the [Number of Pulses] is just ‘1’.
From the [Received Signal] without the multi-reflection, the propagation time is counted every period of the pulse train, and then it is averaged by adding its count data. From the average, the CPU finally calculates the distance.

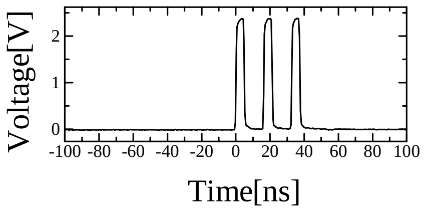


Fig. 5 Pulse-shaped waveform

5. Consideration on experimental error

The range finding was performed by changing the distance to the target. Figure 7 shows the experimental error versus the distance. The maximum error was about 30 cm.
The experimental error of our fabricating signal processor is significantly influenced by a period of a counting clock. In this system, the period of the counting clock was set to be 2.5 nsec, and thus a maximum experimental error was estimated to be 37.5 cm from this period. The reason why the experimental error is smaller than the theoretical one is due to the averaging.

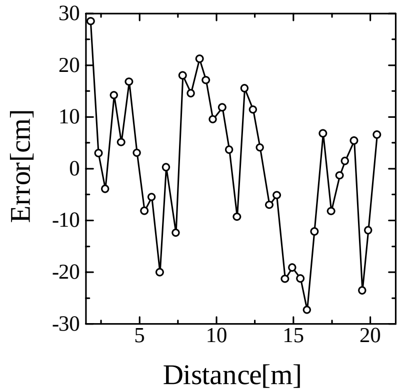


Fig. 7: Error versus distance

6. Conclusions

The FPGA-based signal processor was devised in order to eliminate the multi-reflection, and the experimental errors of less than 30 cm could be achieved for the distance range from 2 m to 20 m under the multi-reflection environment.

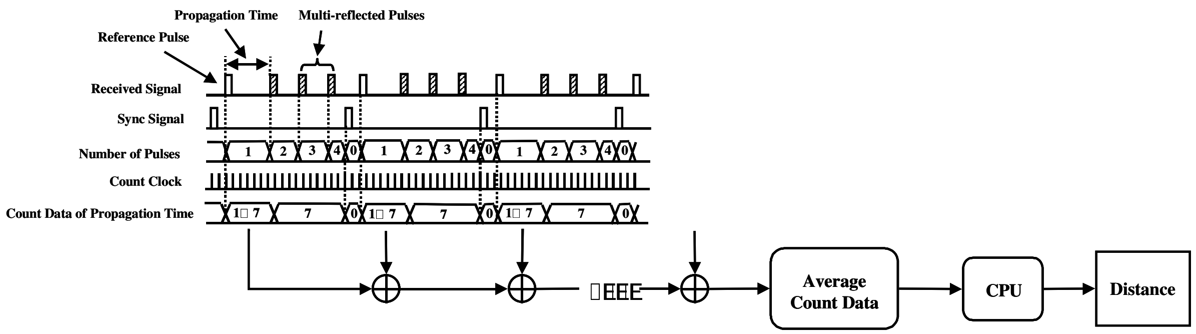


Fig. 6: Signal processing flow to eliminate the multi-reflection

REFERENCES

[1] H. H. Meinel, “Commercial Applications of Millimeterwaves, History, Present Status and Future Trends”, IEEE Trans. Microwave Theory Tech., Vol. 43, No.7, 1995

[2] N. C. Currie and C/ E/ Brown, “Principles and Applications of Millimeter-Wave Radar,” Artech House, Inc., Norwood, MA, 1987

[3] T. Yoneyama and S. Nishida, “Nonradiative Dielectric Waveguide for Millimeter-wave Integrated Circuits,” IEEE Trans., Microwave Theory and Tech. , Vol. MTT-29, No. 11, pp.1188-1192, (1981)

[4] F. Kuroki, M. Sugioka, S. Matsukawa, K. Ikeda and .T. Yoneyama, “High Speed ASK Transceiver Based on the NRD Guide Technology at 60GHz band,” IEEE Trans. Microwave Theory Tech., Vol. 46, No.6, pp.806-811, 1998

[5] F. Kuroki,, M. Yamaguchi, T. Araki, H. Sato, and T. Yoneyama, “Giga-bit Class Ultra High Speed Signal Wireless Distribution by Using NRD Guide Technology at 60GHz”, Proceedings of IEEE MTT-S Microwave Symp., pp.620-623 (June, 2003 in Philadelphia)

[6] F. Kuroki, K. Yamaoka, and T. Yoneyama, “NRD Guide Pulse Radar Front-End for Level Sensor Applications at 60 GHz” Proceedings of the 35th European Microwave Conference, pp. 1847-1850 (October, 2005 in Paris, France)

[7] F. Kuroki, M. Yamaguchi, Y. Wagatsuma, and T. Yoneyama, “NRD Guide Integrated Circuit-Compatible Folded Planar Antenna Fed by High Permittivity LSE-NRD Guide Radiator at 60 GHz ”, IEICE Trans. Vol.87-E, No.9, pp.1412-1417 (September, 2004)