URSI GASS 2023, Sapporo, Japan, 19 – 26 August 2023

FMCW Proximity sensor that minimizes the influence of leakage signals

Han-Sol Kim* [(1)], Dong-Sik Ko[(2)], Ju-Hye Kim[(2)] and Seong-Ook Park[(1)]
(1) Dept. of Electrical Engineering KAIST, DaeJeon, Republic of Korea; e-mail: gksthf30638@kaist.ac.kr, soparky@kaist.ac.kr
(2) Poongsan Defense R&D Institute, DaeJeon, Republic of Korea; e-mail: abito99@poongsan.co.kr, jukim@poongsan.co.kr

Abstract

The proximity fuze is a fuze developed to inflict damage by detecting a target and detonating the warhead when it approaches the target. The latest proximity fuze adopts Frequency Modulated Continuous Wave (FMCW) sensors to improve separation distance accuracy and self-destruction time precision. However, the FMCW radar has a chronic problem in that leakage signals are generated by various causes, such as antenna mismatch of the transmission signal, crosstalk between antennas, and leakage on the substrate. Leakage signals lower the target signal to noise (SNR) by raising the noise floor over the frequency. This paper presents an improvement of SNR through attenuation of leakage signal by tracking the leakage signal. We mathematically prove that the target SNR can be increased by leakage signal attenuation. By solving the undetectable problem, it was verified that the proposed signal processing technique is effective in reducing the malfunction probability of the proximity fuze sensor.

1 Introduction

Missiles and fighter jets cause massive damage to a country's assets. Therefore, it is important to defend against attack from the air. Since it is not easy to precisely hit a target in the air, a proximity fuze sensor is used in the missile. The proximity fuze sensor helps to detonate the missile in the vicinity of the target. The FMCW type proximity fuze sensor is attracting attention because it can accurately measure the distance of a target in the air. However, the FMCW radar has a chronic problem in that leakage signals occur through various paths such as antenna mismatch of the transmitted signal, crosstalk between antennas, and leakage on the board. Furthermore, since the space inside the missile is very small, the size of the FMCW type radar is inevitably reduced thereby exacerbating leakage signal. Due to these leakage signal, a low frequency component or a direct current (DC) component of an Intermediate Frequency (IF) band similar to an actual target is generated. In addition, leakage signals through various paths raise the noise floor across the frequency domain in the power spectrum result, thereby seriously lowering the SNR of the target signal. In other words, the FMCW type proximity fuze misjudge the distance information of the target signal and may malfunction against its intended purpose. But the target detection performance is improved by lowering the power of the leakage signal while leaving the power of the target signal. We suppose a P-type MOSFET (P-MOS) switch for synchronization of the generating a Linear-Frequency-Modulation (LFM) signal in Phase-Locked Loop (PLL) chip and converting analog signal to digital signal in Micro Control Unit (MCU) chip and radiating a Radio Frequency (RF) signal in transceiver chip. The voltage values of the leakage signal's In-phase and Quadrature-phase (I/Q) for each chirp become almost similar. Therefore, we can reduce the power of the leakage signal by subtracting the voltage value of the leakage signal. However, the phases of the leakage signal's IQ for each chirp are different because of phase noise in FMCW sensor system so the impact of leakage signal remained. We propose a leakage signal phase tracking technique to minimize the influence of the remaining leakage signal. In chapter 2, we will discuss the overall configuration and analysis of the K-band radar system. In chapter 3, we will show that the target recognition probability is increased by minimizing the impact of leakage signal. In chapter 4, we proved proposed algorithm is feasible with the purpose of proximity sensor system.

2 K-band FMCW Proximity Sensor

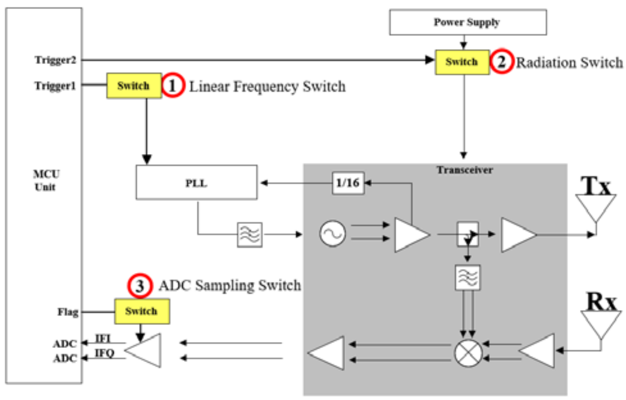

Figure 1. K-Band FMCW proximity fuze sensor system with switch synchronized.

The radar module is powered over USB through multiple low noise voltage regulators. The radar main board contains four important sections: an RF Part, an analog amplifier part, frequency control part and a digital part. Written data to be applied to PLL and transceiver registers are stored in non-volatile memory of Field Programmable Gate Array (FPGA). After that, when the power of radar is connected, the data stored in the memory of the FPGA is written to the PLL and Transceiver based on SPI. A signal can be created so that the final transceiver's output bandwidth is 300Mhz.

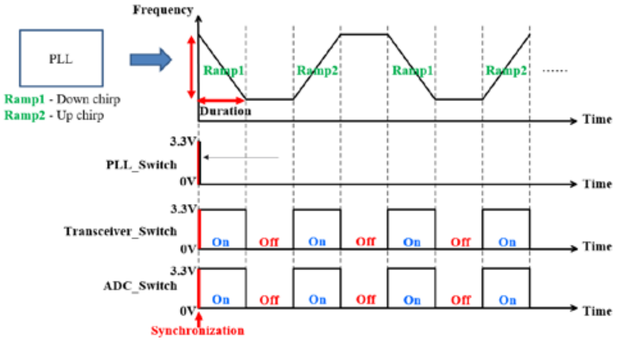

Figure 2. Timing diagram with synchronized switch.

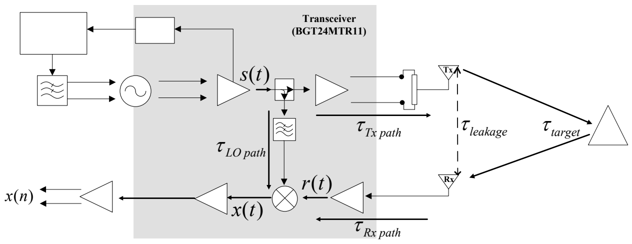

Figure 3. Signal expression in time domain with proximity fuze sensor system.

3 Result

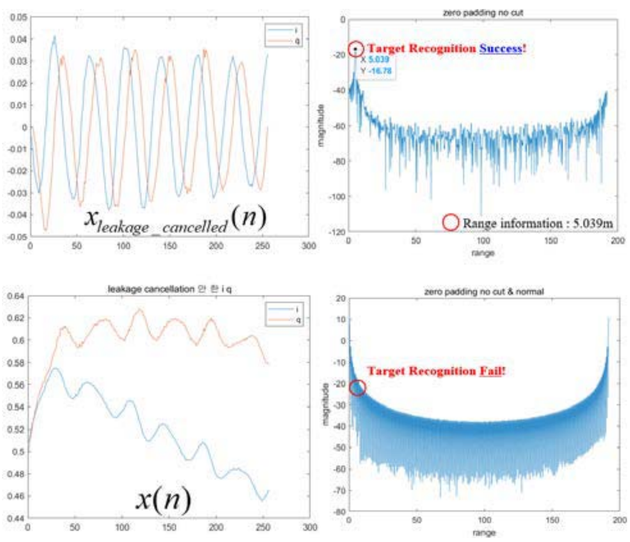

Figure 4. Experiment signal processing output using leakage cancellation method (up) and experiment signal processing output not using leakage cancellation method (down)

In order to experimentally prove the equations demonstrated in chapter 2, the leakage signals generated from the FMCW fuze sensor were collected and stored in the reverberation chamber. we compared the result of Fast-Fourier-Transformation (FFT) of the I/Q data obtained by operating the FMCW fuze sensor with the target with the result of FFT of the I/Q data which subtract the previously stored I/Q data without target. As a result, it was verified that the previously undetected target signal can be detected by improving the SNR of the target signal by applying the leakage signal substraction. We also proved that ths SNR increased by 24dB after applying leakage signal subtraction.

4 Conclusion

A method of securing a high SNR by lowering the noise and power of the leakage signal has been proposed. We demonstrated the feasibility of the proposed method mathematically and suggested the method to solve the problem of the FMCW radar sensor’s difficulty in detecting a target in short distance by increasing the SNR of the target at a short distance through an experiment in the field. Unlike most studies to reduce leakage signals, this method is very simple in signal processing operation and implementation without adding hardware. Therefore, the proposed method can have very high reliability when applied to sensors that must operate in real time. In addition, the proposed method is expected to contribute to detecting humans by increasing the possibility of identifying targets with low reflectivity.

Acknowledgements

This work was supported by a grant-in-aid of Poongsan Corporation Ltd.

References

[1] Park, Junhyeong, et al. "Leakage mitigation in heterodyne FMCW radar for small drone detection with stationary point concentration technique." IEEE Transactions on Microwave Theory and Techniques 67.3 (2019): 1221-1232.

[2] Park, Junhyeong, et al. "Advanced stationary point concentration technique for leakage mitigation and small drone detection with FMCW radar." IEEE Transactions on Microwave Theory and Techniques 69.3 (2021): 1791-1804.

[3] Hong, Sang-Geun, et al. "Development of Tracking Technique against FMCW Proximity Fuze." Journal of the Korea Institute of Military Science and Technology 13.5 (2010): 910-916.

[4] Choi, Jae-Hyun, et al. "A Direction Finding Proximity Fuze Sensor for Anti-air Missiles." Journal of the Korea Institute of Military Science and Technology 16.5 (2013): 613-621.