Simulation-based Evaluation of a De-ramping FMCW Radar System for Short-Range Detection Scenarios

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A. Introduction

Frequency-Modulated Continuous Wave (FMCW) radar is widely used in short-range detection for its high resolution with low sampling rate. Conventional direct mixing, however, processes only part of the received signal and is highly vulnerable to noise, degrading SNR. De-ramping overcomes these issues by mixing the entire signal with a reference, covering delayed echoes, suppressing high-frequency noise, and improving SNR for clearer range separation and reliable detection. In this work, a de-ramping based FMCW radar system is modeled and evaluated under short-range scenarios using MATLAB simulations. The transmitted signal is defined as

$$S_{TX} = A_{TX} \exp\left(j2\pi \left(f_0 t + \frac{1}{2} K_r t^2\right)\right) \qquad 0 \le t \le T_{chirp}$$

where f_0 is the carrier frequency and K is the chirp rate. The reference signal is expressed as

$$S_{REF} = A_{TX} \cdot A_{REF} \exp\left(j2\pi \left((f_0 + f_{REF})(t-\tau') + \frac{1}{2} K_r (t-\tau')^2\right)\right) \qquad \tau' \le t \le T_{chirp} \cdot \alpha + \tau'$$

Where τ denotes the round-trip delay related to target range, and τ' and α are introduced to extend the reference signal beyond the Tx interval, ensuring full coverage of the minimum and maximum frequencies of the delayed Rx. By mixing the Rx with this extended Ref, a stable beat frequency proportional to τ is obtained, which enables accurate range estimation and further validates the effectiveness of the de-ramping method.

B. System Solutions and Simulation Results

Figure 1 shows the time–frequency diagram of Tx, Rx, and Ref signals, where direct Tx–Rx mixing is limited to the transmission interval, while Ref–Rx mixing with a frequency offset ensures full echo coverage and stable beat frequencies proportional to target range. Figure 2 presents the de-ramping radar architecture: DDS #1 generates the Tx chirp, DDS #2 the reference, and the Rx is mixed, low-pass filtered, digitized, and synchronized via MCU and clock. Figure 3 compares spectra, demonstrating that de-ramping suppresses direct leakage, yields higher peak amplitudes, and narrows the –3 dB main lobe, thereby enhancing SNR, resolution, and target separation.

C. Conclusion

In this work, a de-ramping FMCW radar system for short-range detection was validated through simulation. Using a reference signal to cover delayed echoes enabled stable beat frequency extraction with clearer results than direct Tx-Rx mixing. Future work will focus on quantitative metrics and robustness under noise and interference for next-generation applications.

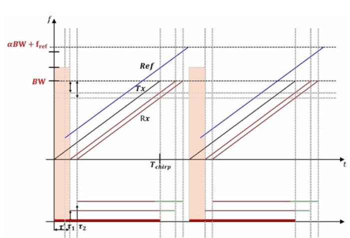

Fig. 1. Tx, Rx, Ref signal

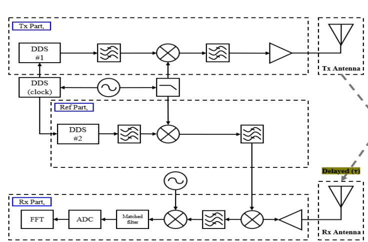

Fig. 2. Block diagram of de-ramping radar system

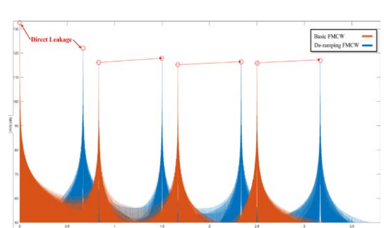

Fig. 3. FFT simulation

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