Chirp Classification Architecture for High Sampling Efficient Multiband FMCW Radar

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A. Introduction

FMCW radar continuously transmits while mixing received echoes with a local replica to obtain a low-frequency beat signal.[1] Owing to its simplicity and effective use of wide bandwidth, it is widely employed in near- and far-range sensing. In Pol-SAR and Earth-observation applications, however, multiband operation is required due to frequency-dependent penetration depth and scattering mechanisms, which increases the maximum beat frequency and IF bandwidth and thus elevates ADC sampling requirements. To mitigate this limitation, this paper proposes a sampling-efficient multiband FMCW architecture that employs multi-slope chirp classification.

B. Multi-Band Multi-Slope Radar System and Classification Technique

Starting from a conventional FMCW radar architecture, three bands (X, Ku, K) are implemented. In the transmitter of Fig. 1, a chirp generator continuously produces the signal, which is then passed through a frequency multiplier to create three signals with different slopes These signals are split into separate up-conversion paths, amplified by power amplifiers, and radiated by the antenna. On the receiver side, down-conversion is performed with respect to each up-conversion reference to recover baseband chirp signals. These are finally mixed with a single reference chirp, resulting in an aligned beat-frequency signal and two chirp signals, as shown in Fig. 2. [2]

$$S_{TX1} = A_{TX1}\,exp\left(j2\pi\left(f_{c1}t + \frac{1}{2}K_r t^2\right)\right)S_{TX2} = A_{TX2}\,exp\left(j2\pi\left(f_{c2}t + \frac{1}{2}(K_r \cdot N_1)t^2\right)\right)S_{TX3} = A_{TX3}\,exp\left(j2\pi\left(f_{c3}t + \frac{1}{2}(K_r \cdot N_2)t^2\right)\right) \quad (1)$$

$$f_{b1} = K_r\tau, f_{b2} = K_r[(N_1-1)t - N_1\tau], f_{b3} = K_r[(N_2-1)t - N_2\tau] \quad (2)$$

$$f_{b2} - K_r[N_1-1]t = K_r N_1 \tau, \qquad f_{b3} - K_r[N_2-1]t = K_r N_2 \tau \quad (3)$$

The signal is ultimately represented by the frequency component in (2)[3]. In Cases 2 and 3, a time-varying residual chirp remains due to the slope mismatch; using the known ratios N1, N2 to the reference slope, we apply the quadratic-phase compensation (slope-matched filter) in (3) to cancel the residual chirp for each band. We then perform per-band FFT for component estimation and detection.

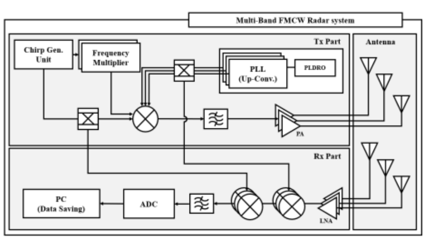

Fig. 1. Proposed FMCW Radar System

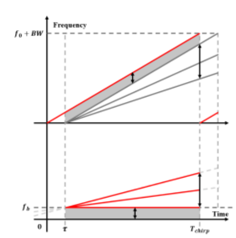

Fig. 2. Ref./Rx Signal Graph

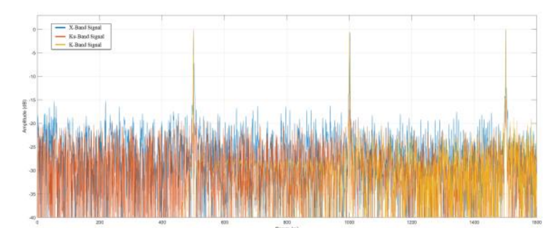

Fig. 3. Proposed Matched Filtered Range FFT Result

After applying the phase-compensation–based chirp discrimination, the range-FFT (Fig. 3) shows that the X/Ku/K-band returns are separated without mutual interference and co-registered at the same range bin. This indicates that inter-slope residual chirps are effectively canceled and per-band beat terms are restored to stationary tones, consistent with the design goal of improving sampling efficiency under equal-resolution conditions.

C. Conclusion

We demonstrated a multiband, multi-slope chirp-classification method with quadratic-phase compensation. Range-FFT results show separated, co-registered X/Ku/K returns, evidencing residual-chirp cancellation and resolution preservation under equal-resolution conditions while lowering ADC sampling rate. Future work will validate with real data and assess robustness to Doppler, slope-ratio uncertainty, and timing/phase misalignment.

References

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[3] P. You, H. Wang, Z. Xu, and J. Yang, “Dechirp-receiving radar target detection based on time–frequency analysis,” *IET Radar, Sonar & Navigation*, vol. 15, no. 11, pp. 1308–1321, 2021.