

Microwave Photonics for Ranging and Filtering Applications

Abstract

Radio detection and ranging (Radar) is a key enabling technology for sensing, navigation, and situational awareness, facilitating target detection, ranging, and velocity estimation in applications that span air and maritime surveillance, self-driving cars, satellite navigation, remote sensing, and imaging. Modern radars demand high range and velocity resolution, multi-function operation over multiple frequency bands, and higher carrier frequencies. Conventional electronic radar architecture faces bottlenecks in waveform generation and processing of ultra-high time-bandwidth product waveforms. Conventional radars are susceptible to electromagnetic interference and are limited due to bandwidth availability, high jitter, and slow processing speeds. Microwave photonics offer unique characteristics by leveraging the large bandwidth availability by encoding microwave signals into the optical frequency band. MWP enables the generation of large bandwidth waveforms, signal processing such as filtering, phase shifting, and antenna remoting with low-loss optical fiber, immunity from EMI, and compatibility with radio-over-fiber for high-speed data transmission. The primary objective of using this technology is to architect a photonic based, highly reconfigurable radar with tunable frequency and bandwidth, along with highly reconfigurable signal processing, such as filtering in the optical domain, which is difficult to achieve in the RF frequency domain.

The primary focus of this thesis is to address the growing application of microwave photonics (MWP) in radar technology. The thesis examines various aspects of a microwave photonic radar, including the generation of reconfigurable radar waveforms, simultaneous ranging and velocity detection of moving targets, and signal processing for radar applications. A highly frequency-agile dual-chirp waveform generation is demonstrated using a simple, low-bandwidth MZM modulator. A novel multiband complementary waveform for simultaneous range and velocity estimation is also demonstrated, with experimental validation using a moving toy car in a laboratory environment. Modern radars require operation in multiple frequency bands with different bandwidths to detect targets of varying sizes and velocities. This requires a real-time tunable filter in the microwave frequency band to change the filter's frequency response, bandwidth, or to switch between transmission and rejection filters. A SBS based electromagnetically induced transmission (EIT) analogue and electromagnetically induced absorption (EIA) analogue filters with tunability in frequency and bandwidth are experimentally validated. The thesis also explored chromatic dispersion compensation in a phase-modulated link demodulated with an MZI using stimulated Brillouin scattering. This improved the operational bandwidth of the phase-modulated link for antenna remoting in radar and radio-over-fiber applications. Moreover, the thesis discusses the limitations of the proposed microwave photonic radar and proposes a future research direction for further enhancement.