Implementing Spectrally-Sparse, Wideband Waveforms in Multi-Channel Software-Defined Radios for High-Accuracy Ranging

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Wireless applications generally benefit from the use of wideband waveforms, however it is often challenging to implement wireless hardware systems with wide instantaneous bandwidths. Particularly for radar ranging applications, the use of wideband waveforms is beneficial for high-resolution and high-accuracy measurements. Whereas achieving high range resolution generally requires the use of waveforms with continuous or near-continuous bandwidths over a wide band, high range accuracy measurements can be achieved using spectrally sparse waveforms. In particular, it has been shown that a two-tone ranging waveform has a the highest possible accuracy (J. E. Hodkin et al., "Microwave and millimeter-wave ranging for coherent distributed RF systems," 2015 IEEE Aerospace Conference, Big Sky, MT, 2015, pp. 1-7), which can be seen from the Cramer Rao Lower Bound (CRLB)

$$\sigma_R \geq \frac{c}{2\beta_{rms}\sqrt{2E_s/N_o}} \tag{1}$$

where β_{rms} is the root mean square bandwidth and E_s/N_o is the energy to noise ratio. To minimize measurement standard deviation for a given signal to noise ratio (SNR), the root mean bandwidth needs to be maximized. This is accomplished by concentrating the signal energy into the ends of the operational bandwidth; thus for a two-tone waveform $\beta_{rms} = \pi\delta f$ where $\delta f = f_2 - f_1$ is the waveform tone separation. In this manner, a signal with a wide operational bandwidth that consists of two instantaneously narrow-band signals can be used for high-accuracy ranging.

Software-defined radios (SDRs) have been gaining considerable interest for wireless applications such as communication and radar due to their ability to produce waveforms that are user defined. SDRs are a perfect example of a device that has a wide operational frequency band but low instantaneous bandwidth due to sampling limitations, thereby limiting the ability to implement wideband waveforms. In this work, the use of a multi-channel SDR for implementing spectrally-sparse, wideband signals is explored. Using an Ettus X310 SDRs, which contains two transceivers, the two frequencies of the two-tone signal described above can be implemented. The two transceivers on the X310 have operational bandwidths of nearly 6 GHz, but are limited to instantaneous bandwidths of 160 MHz. However, by transmitting the two tones from each of the two transmitters, a wideband waveform with tone separation up to nearly 6 GHz can be synthesized. After capturing the two tones, the signals are downconverted to baseband and sampled. After digitization, the two tones are digitally upconverted to the carrier frequencies, and the delay is estimated using matched filter processing. It is demonstrated that high-accuracy ranging can be achieved that is on the order of the accuracy obtained when using an instantaneously wideband two-tone signal.