

# Range-Doppler Radar Signal Processing with Spectral Holography

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**Abstract:** Spectral holographic crystals can record the cross-power spectrum of RF signals modulated onto optical carriers and perform range-Doppler processing of gigahertz radar signals, resolving Doppler shifts up to 100 kilohertz with ~130 Hertz resolution.

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It has been shown that spectral holographic techniques can be used for signal processing of high time-bandwidth product multi-GHz radar signals [1,2]. The spectral holographic material records the cross power spectrum of an optical pulse sequence, here representing the known (transmitted) reference and the (received) radar return(s) with unknown delays and Doppler shifts. Each shot of a transmit/receive pulse-pair is modulated onto a stable optical carrier. Integration of multiple such shots over the material transition lifetime increases both the signal-to-noise ratio and the resolution of Doppler shifts on the return signal(s).

Figure 1 shows a schematic of the experimental demonstrator. A pulse pattern generator (PPG), signal generator, and mixer were used to emulate the radar transmit signal; identical equipment mimicked the radar return signal with an RF Doppler shift  $v_D$ . Coded patterns at 1.0 Gbps were modulated onto a 1.9 GHz RF carrier. Each pattern consisted of a pseudo-random noise (PRN) code of 512 bi-phase modulated bits. Transmit/receive pairs were created at a pulse repetition frequency of 100 kHz over a 7.45 ms integration time (745 shots).

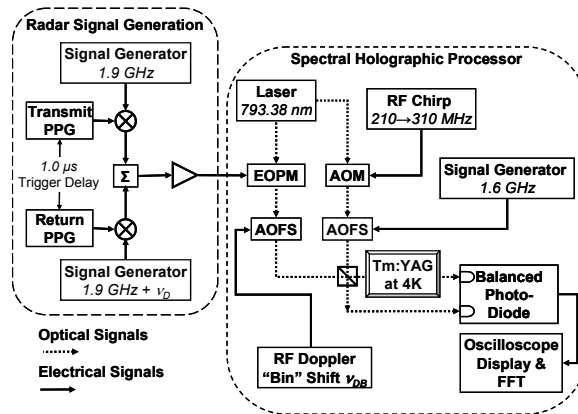


Fig. 1. Block diagram of demonstration platform for range-Doppler radar signal processing using spectral holography.

A delay of  $1.0 \mu\text{s}$  was set between the reference pulse and its return pulse. A stabilized optical carrier at 793.38 nm [3] was modulated by an electro-optic phase modulator (EOPM). The modulated light illuminated the Tm:YAG crystal for processing. Doppler compensation was performed optically with an

acousto-optic frequency shifter (AOFS), shifting the reference signal frequency by  $\nu_{DB}$  with respect to the return signal. In this single spatial channel demonstration, frequency shifts were applied to the AOFS serially to simulate multiple Doppler processing “bins”. A multiple channel implementation would utilize parallel optical beams, each with a unique frequency shift corresponding to a Doppler bin.

A 200-MHz portion of the resultant processing spectrum was read out using a frequency chirped optical pulse of 50  $\mu\text{s}$  duration. This pulse was created with a double passed acousto-optic modulator (AOM) and subsequently shifted by 1.6 GHz with an AOFS. The resulting transmitted optical pulse has intensity variations due to its interaction with the spectral grating [2], creating a temporal map of the spectral features. A noise canceling photodiode pair detected these intensity modulations referenced to the input waveform. The resulting low bandwidth (4 MHz) electrical signals were digitized and post-processed by an FFT algorithm to display the resolved time delay profiles for each Doppler bin.

Figure 2 shows typical experimental results displayed as a range-Doppler ambiguity function for a return signal with a 1 kHz Doppler shift and a delay of 1.0  $\mu\text{s}$ . This surface is compiled from separate experimental traces with Doppler compensation tones applied from 850-1150 Hz in 25 Hz increments, and shows a 3 dB Doppler resolution of  $\sim 130$  Hz. A Doppler profile at a delay of 1.0  $\mu\text{s}$  and a range profile from the 1 kHz Doppler bin are also shown.

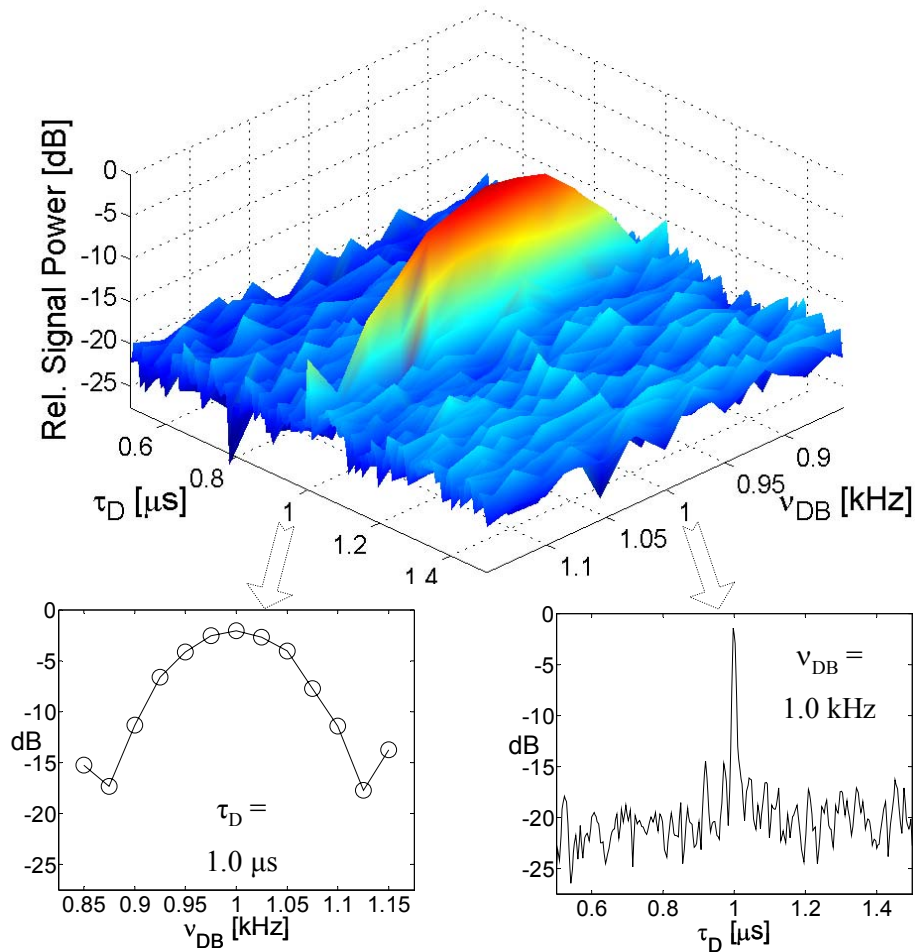


Fig. 2. Measured range-Doppler radar ambiguity function for 1 kHz Doppler shift on a 1.0  $\mu\text{s}$  delayed return signal. Expected Doppler resolution of  $\sim 130$  Hz due to the 7.45 ms integration time is observed.

Figure 3 shows the compiled Doppler ambiguity functions of four return Doppler shifts at a return delay of 1  $\mu$ s. Each shift is resolved over a 300 Hz frequency region, similar to Figure 2. Main peaks are observed as expected at the actual Doppler shifts. Expected aliasing of the 100 kHz Doppler shifted return at 0 Hz and of the 100 Hz Doppler shifted return at 100.1 kHz is also observed.

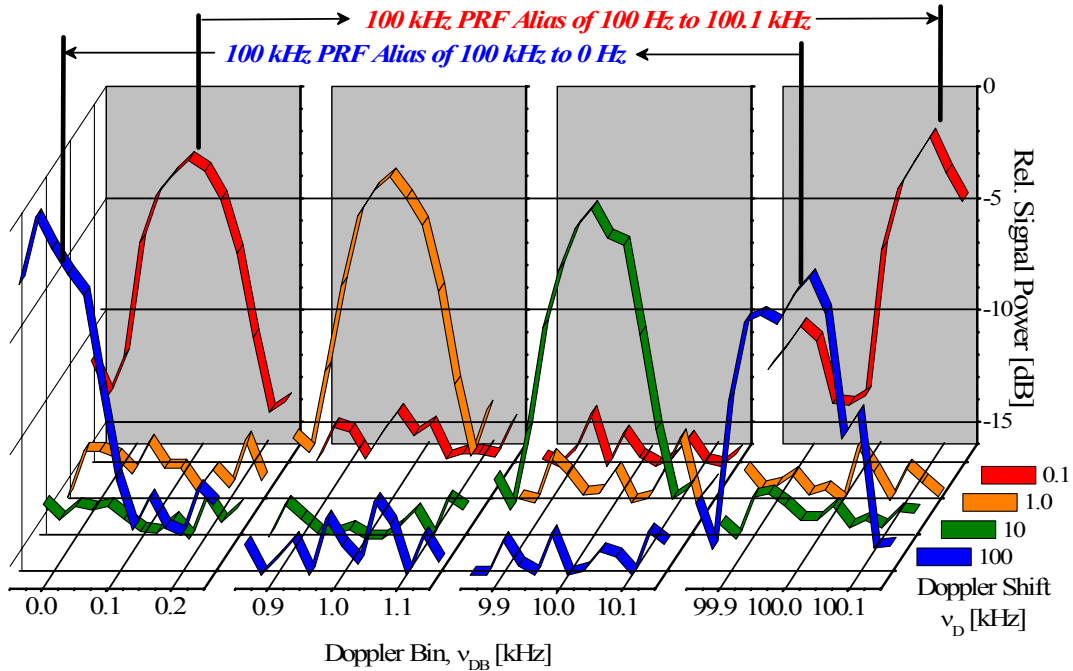


Fig. 3. Measured Doppler ambiguity profiles for 0.1 Hz, 1 kHz, 10 kHz and 100 kHz shifts.

## References

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