Analysis of Phase Code Modulation on Optimizing Data Resolution at the Blackstone SuperDARN Site

Pitzl, A.P. [1], Sterne, K.T. [1], Thomas, E.G. [2], Ruohoniemi, J.M. [1]

[1] Virginia Tech, VA; [2] Dartmouth College, NH

ABSTRACT

In March 2024, the Blackstone (BKS) radar was upgraded to operate digitally using software defined radios. Using digital signal processing enables greater flexibility in the types of transmit waveforms. This work investigates phase code modulation (PCM) as a pulse compression technique. Pulse compression improves range resolution by subdividing pulses with coded sequences, with the added benefit of increasing signal to noise ratio (SNR). Barker codes are unique bit sequences that possess the quality of being easily correlated at the receiver. A comparative analysis was done using different baud Barker codes to see which ones are most applicable for SuperDARN radars, and the possibility of using polyphase PCM with Frank codes in the future.

INTRODUCTION

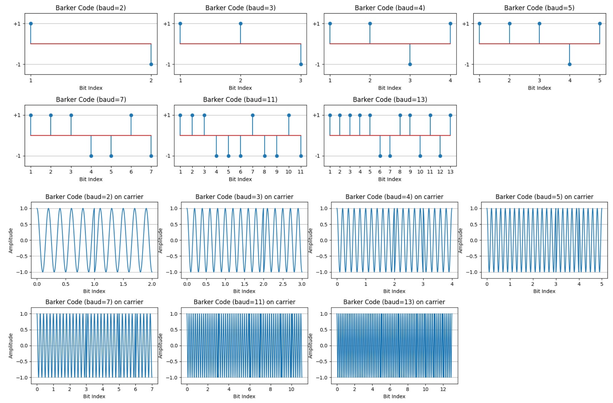
This work builds on phase coding developed by Bill Bristow's group at the University of Alaska Fairbanks, and the pcodescan code included in RST-ROS.

Pulse compression is a technique that simulates the benefits of using a longer pulse (high energy transmitted) and short pulse (minimized range ambiguity) simultaneously. It involves transmitting a long pulse but modulating it and using matched filtering (or correlation) at the receiver for compression.

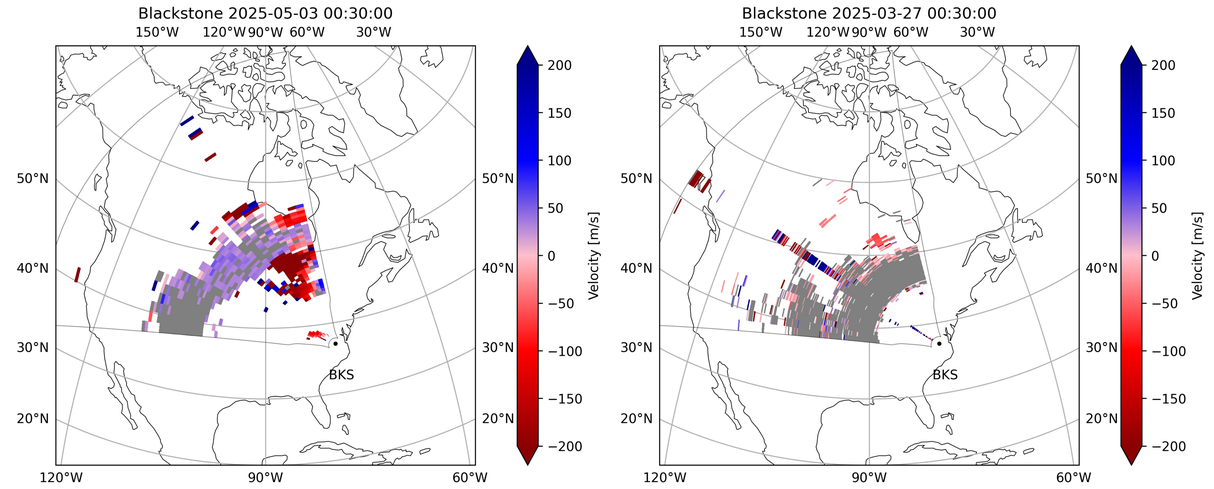
The SuperDARN radars transmit single frequency pulses, so pulse compression can only occur with phase modulation. In this instance the phase is biphase, 0° or 180°.

The code used for phase modulation is integral to how well it matches at the receiver. Barker codes are chosen because of their ideal correlation properties.

There are a limited number of bauds corresponding to the length of the Barker sequence; 2, 3, 4, 5, 7, 11, and 13. As the baud increases the level of the sidelobe compared to the peak lobe decreases, indicating better target discernibility.

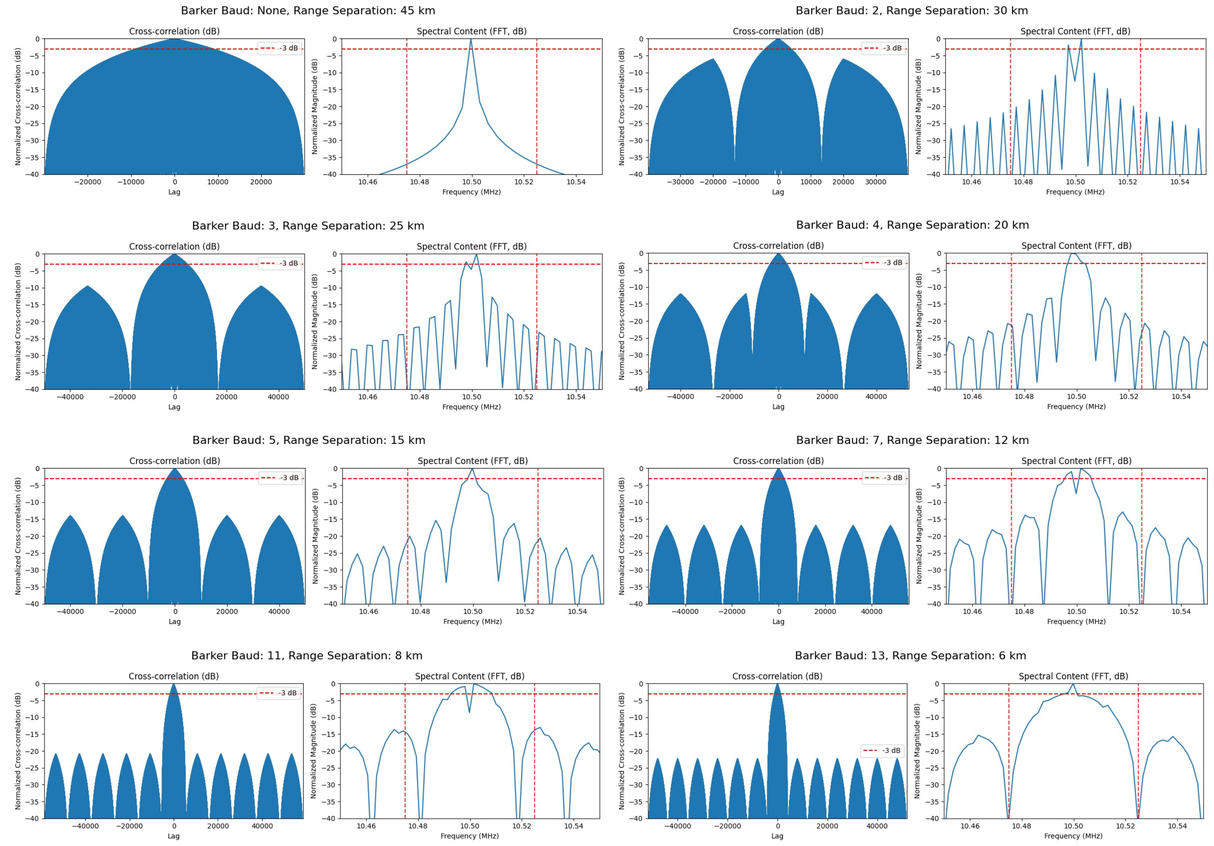


Existing Implementation at BKS



Fan plots displaying range gate differences between an unmodulated pulse (left, 45km range resolution)and a PCM pulse at 5-baud (right, 15km range resolution). Plots created using VT SuperDARN's online interactive fan plotting tool.

SIMULATION



CONSIDERATIONS

PCM is only possible with the upgrade to software defined radios. The USRP X300s used at the BKS site have a maximum sample rate of 200Mbps, which is a sample every 5ns. In current practice, the range separation is an input parameter and bit length is calculated from it. The pulse length is then a multiple of baud and bit length, or 300 microseconds for unmodulated. The modulated pulses are around 500 microseconds, which puts more strain on transmitter hardware.

Modulation introduces discontinuities, which increases spectral bandwidth. To comply with the FCC, the bandwidth must be <50kHz.

FURTHER RESEARCH

• The combination of range separation and bit length need to be chosen keeping hardware limitations and frequency allocation guidelines as priority.

• Only binary PCM was discussed, but it is possible to split the phase further and use quadrature phase shift keying (QPSK) with Frank codes as modulation waveforms. This would have the effect of making the correlation sidelobes smaller. With QPSK, there is risk of the pulse length being too long to accommodate the additional bits, and also adding to spectral bandwidth.

• The correlation simulations are done in Python on a single pulse. This is overly simplified, and not the output of the auto correlation software (ACF) used in radar data processing. To continue development, simulated data must be created to verify theory.

REFERENCES

This work was supported by NSF under award AGS-1935110.

The authors acknowledge the use of SuperDARN data. SuperDARN is a collection of radars funded by national scientific funding agencies of Australia, Canada, China, France, Italy, Japan, Norway, South Africa, United Kingdom, and the United States of America

M. A. Richards, J. Scheer, and W. A. Holm, "Chapter 20: Fundamentals of Pulse Compression Waveforms" in Principles of Modern Radar: Basic Principles. Raleigh: Scitech Publishing, 2010.

F. F. Kretschmer and K. R. Gerlach, “Low Sidelobe Pulse Compression Waveforms,” vol. 2, pp. 663-667, Aug. 2005, doi: https://doi.org/10.1109/acssc.1988.754633.

R. J. Barnes, E. G. Thomas, et al, "Radar Software Toolkit (RST)," Version 4.5, GitHub Repository, May 22, 2025. [Online]. Available: https://github.com/egthomas/rst-ros

E. G. Thomas, et al, "SuperDARN UHD Server," GitHub Repository, May 22, 2025. [Online]. Available: https://github.com/egthomas/SuperDARN_UHD_Server