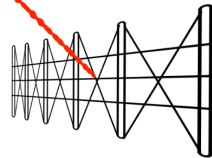
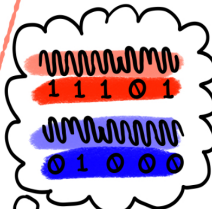
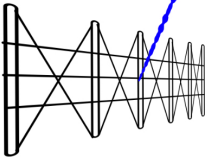


Phase Coding in Digital SuperDARN Radars to Observe Multistatic Propagation Modes

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Sterne, K, Ruohoniemi, M, Baker, J, Kunduri, B, Frissell, N

March 15, 2026



What is SuperDARN?

- Network of HF radars in the mid to high-latitude regions that observe space weather effects on the ionosphere and magnetosphere.
- TX: 8-20MHz (typically 10-14MHz).
- Single-frequency multi-pulse sequence, monostatic.
- Length of individual pulses varies, usually $300\mu\text{s}$ for 45km range bins, $100\mu\text{s}$ for 15km bins.
- Depending on bin size, $\sim 3375\text{km}$ radial extent of FOV.

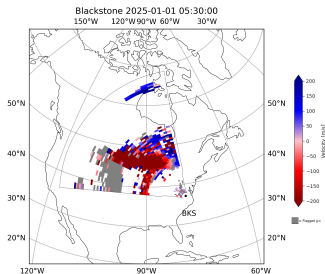
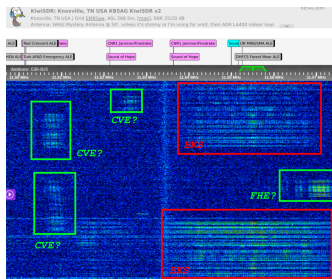


Figure: Image credit: <http://vt.superdarn.org/>

Who Can Hear SuperDARN?



*KB5AG KiwiSDR located in
Knoxville, TN receiving 2-3
SuperDARN radars*

<http://kb5ag.ddns.net:8074/>

- Hams and shortwave listeners have been receiving SuperDARN for decades, nicknamed *"The Grasshopper."*
- Listen anytime! WebSDR/KiwiSDR: Worldwide network of public, receive-only wideband SDRs run by the shortwave and ham community.
- WebSDRs stream audio only. USB SDRs with direct sampling on HF can be used to provide IQ data.
- But which SuperDARN radar are you hearing?



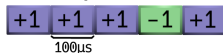
- Since 2024, some SuperDARN radars have been upgraded to SDR systems.
- Possible to flexibly modulate the TX pulse.
- Common operating mode is Pcodescan, phase modulating the pulse with the 5-baud Barker code.
- Bit length corresponds to a range bin of 15km, no compromise in transmit pulse length, increased SNR.

Process control program

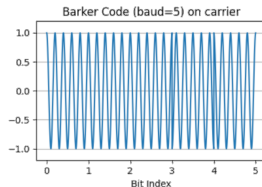


Pcodescan:
barker baud = 5
range separation = 15km

Lookup binary code,
translate bit length
to match range
separation



Multiply on carrier and transmit



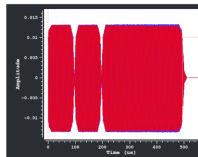
pcodeID:

stid = BKS

rsep = 15km



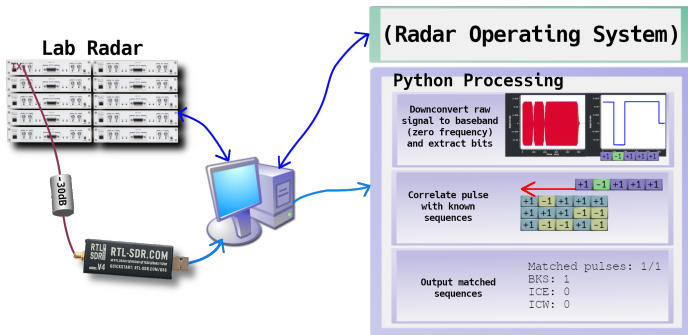
BKS	+1	-1	+1	+1	+1
ICE	+1	+1	+1	-1	-1
ICW	+1	-1	-1	+1	-1



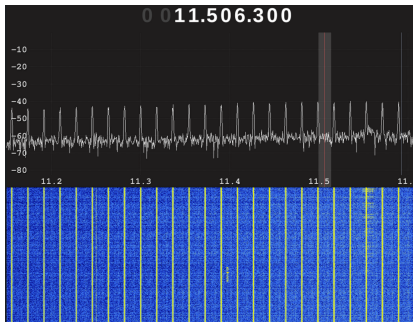
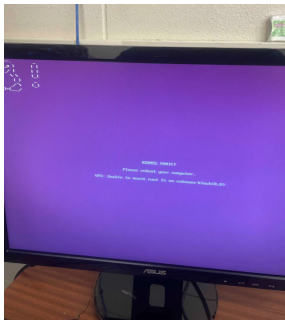
- pcodeID: a modified pcodescan mode that phase modulates each pulse with a unique 4-bit radar ID.
- Station ID is pulled from the schedule file and encoded into the pulse sequence at build time.
- First bit is a “pilot” — sets the phase reference for decoding. Only 4 bits carry the radar ID.



- Proof of concept: SDR test setup in the SuperDARN lab recording pcodeID from the test radar.
- In an isolated environment on RTL-SDR v4, correctly identifies ~80% of pulses on USRP, ~50% on RTL-SDR v4 on laptop; good enough given the large number of pulses per integration period?
- Tested on both RTL-SDR v4 and USRP x300, RTL-SDR requires digital filtering to produce usable data.



- Bad luck! Kernel panic during first PcodeID run. Managed to run it again, but receiver for IQ data was unavailable.
- Picked up BKS in the backyard though! But not over my neighbor's solar panel inverter.



Hardware Requirements

- Radar ID decoding requires wideband IQ data covering 8-20MHz.
- Doppler measurements additionally require frequency stability.

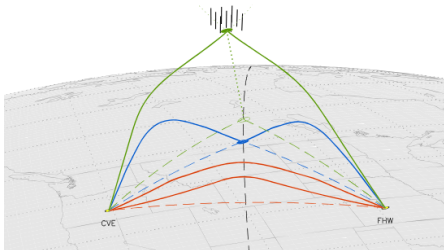
Device	Freq. Range	RX BW	External Clock?	Price
RTL-SDR V4	500 kHz–1.75 GHz	3.2 MHz	Modification (sketchy)	\$40
SDRplay RSPdx-R2	1 kHz–2 GHz	10 MHz	Yes	\$235
RX-888 MkII	1 kHz–1.8 GHz	64 MHz	Modification (\$30 kit)	\$150



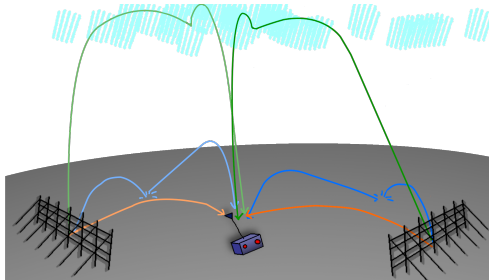
Scary external clock mod, credit Rig Expert:

https://rigexpert.com/files/product_documentation/gpsdo/TBR-AN-7.pdf

- In 2019-2020, bistatic observations were done with the Christmas Valley East (CVE) and Fort Hays West (FHW) radars.
- CVE was operated in RX-only mode.
- Demonstrated a straightforward way to gather data on the echoes undetectable with monostatic radar (Shepherd et al.).
- This method relies heavily on radar placement, and disrupts normal operation by forcing one to be receive-only.



- Ionospheric scatter mode
- Ground scatter mode
- Direct mode



- Measure true extent of SuperDARN propagation.
- Multistatic reception captures scatter monostatic radar geometrically cannot.
- Multiple observations of same ionospheric feature from different angles.
- For frequency stabilized receiver - resolve velocity vector in areas where two FOVs don't overlap.

- PcodeID extracts radarIDs in the lab on cheap hardware. The next step is field testing with channel effects.
- A distributed network of receivers at known locations could observe multistatic SuperDARN propagation modes that no fixed radar array can access completely passively.
- Velocity information is valuable. Using frequency-stabilized receivers, this data could be used for ionospheric science similar to the GRAPE project.



Questions?

Acknowledgments:

Thank you to Kevin Sterne, Dr. Ruohoniemi, Dr. Baker, and Dr. Kunduri for feedback and advice, and thanks to Dr. Frissell for inspiring this project.

Thank you to the Hamsci community!

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Range resolution is related to pulse length as:

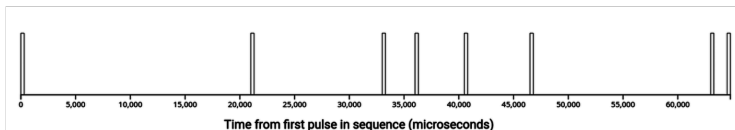
$$\Delta R \geq \frac{c\tau}{2} \quad (1)$$

where τ is length of the pulse, or length of bit in sequence.

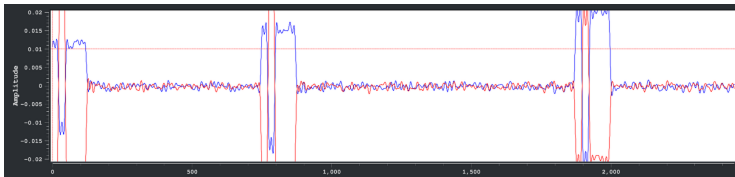
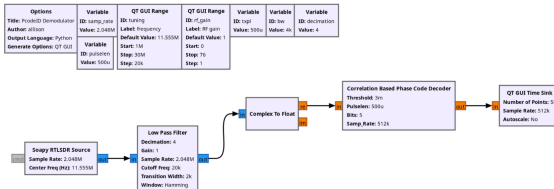
Using phase coding (or varying the pulse any other way over time) subdivides the pulse into “chips” that a matched filter at the receiver can use to determine the reflection moment with more certainty.



- Radars divide field of view in 16-24 beams (24 beams for Blackstone).
- Integration period on 24 beam radars are 2-3 seconds.
- The length of each individual pulse is hundreds of microseconds long, depending on modulation.
- Multi-pulse sequence designed so lag between pulses allows autocorrelation function (ACF) estimation. ACF extracts velocity, spectral width, and power from back scatter.



GNURadio Flowgraph



Shepherd, S G, et al. "Bistatic Observations with SuperDARN HF Radars: First Results." *Radio Science*, vol. 55, no. 8, 27 June 2020, <https://doi.org/10.1029/2020rs007121>.

