Full Field-of-View Imaging for SuperDARN Radars

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1. INTRODUCTION

Conventional SuperDARN scanning limitations:
- Only one beam direction sampled at a time
- Beams stepped through one by one over 1-2 minutes
- Beams in a scan are sampled at different times

Why?
- Original radar design used analog phasing matrices to beamform
- Computing storage and processing speed limited data throughput

What's changed?
- SuperDARN Canada has developed a software-defined radio (SDR) system (McWilliams et al., 2023) for SuperDARN radars which can digitize a high throughput of data in real time

2. OBJECTIVES

- Transmit a wide beam that covers the FOV
- Investigate impact on data quality due to transmitted power reduction
- Investigate wide beam transmission with subset of transmitting antennas

3. METHODS

SuperDARN uses linear, equally-spaced transmitting array of 16 antennas. Narrow beams are generated with a linear phase progression across the antennas – previously done with analog phasing matrix, now done digitally.

Synthesizing desired far-field pattern is not straightforward – tradeoffs are required.

Optimal solution has:
- Minimal sidelobes
- Minimal ripple within FOV
- Minimal transition width (high roll-off)

Problem is also frequency-dependent, so solutions must be found for all common operating frequencies.

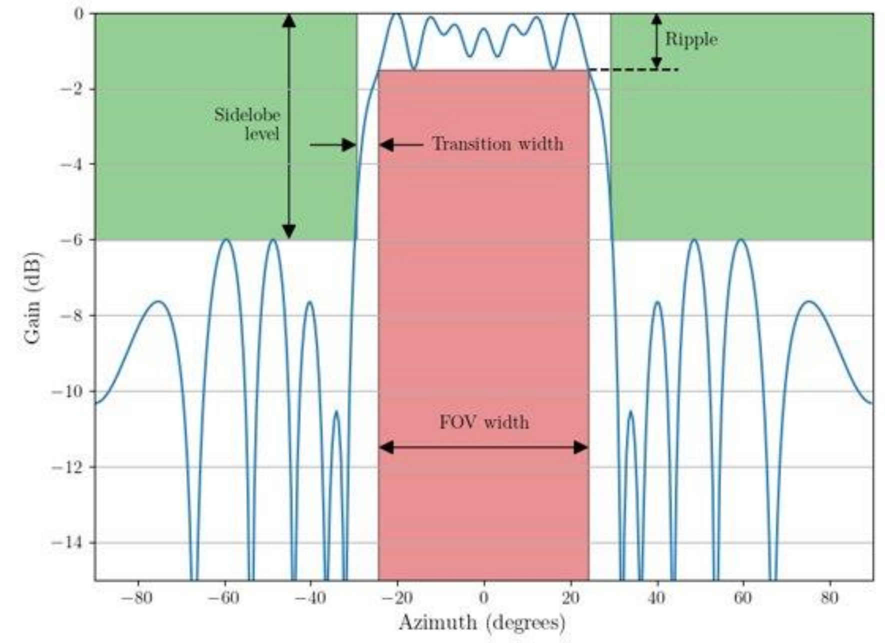


***Figure 1**: Gain vs azimuthal direction for far-field array factor. The blue line is an example array factor which satisfies constraints, i.e. does not enter the forbidden (shaded) regions.*

Genetic algorithm (Boeringer et al., 2005) used to find the signal to transmit from each antenna.

Simplifications:
- Can only **modulate phase offset** of each antenna
- Phase offsets lie between $0 \leq \varphi_k < 2\pi$
- Phase offsets must be **evenly symmetric** about array middle, $\varphi_k = \varphi_{N-k-1}$
- Outermost antennas used as reference phase, $\varphi_0 = \varphi_{N-1} = 0$

These reduce parameter space from N to $\left\lceil \frac{N}{2} \right\rceil$ elements. For each frequency, genetic algorithm run for different combinations of main lobe ripple, sidelobe level, transition width, and number of transmitting antennas.

4. SIMULATIONS

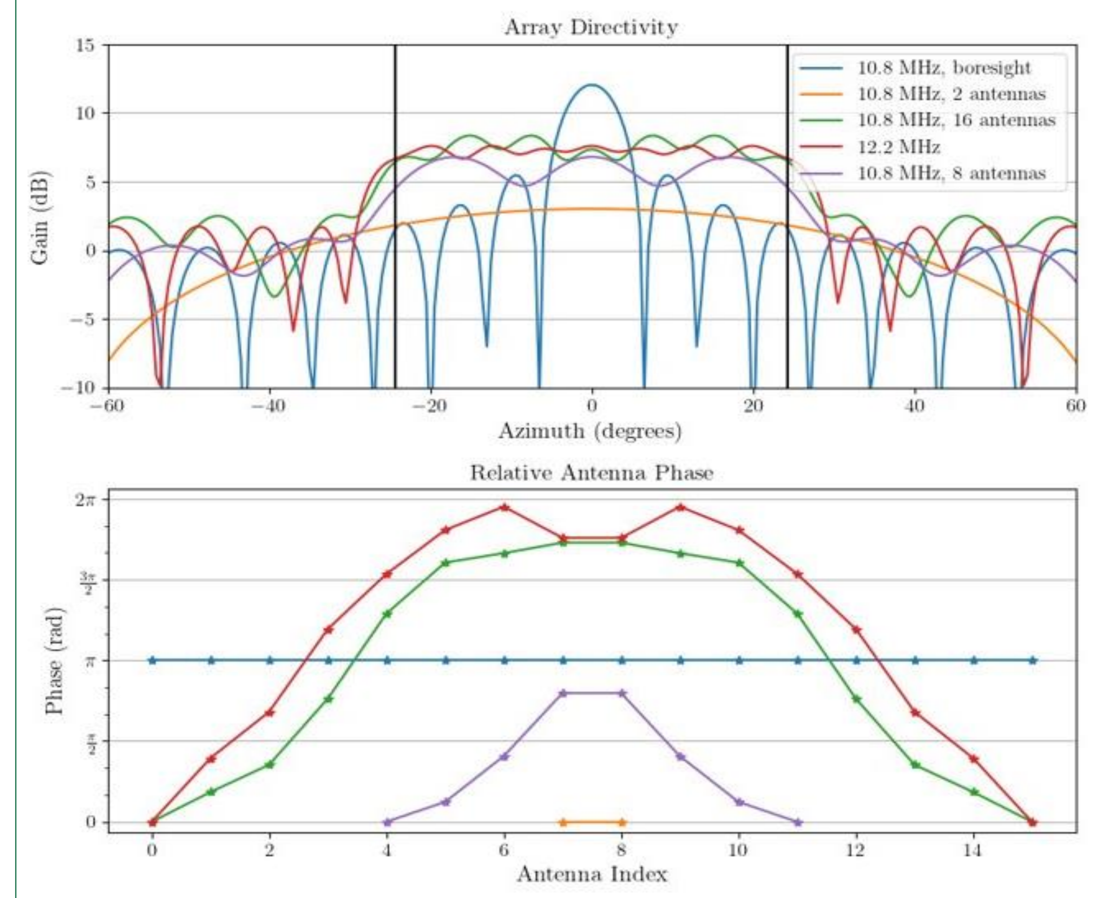


***Figure 2**: Gain vs. azimuthal deviation from boresight at zero elevation (top) and corresponding antenna phase offsets (bottom) for standard narrow beams and wide beams with different frequencies and number of transmit antennas (see legend).*

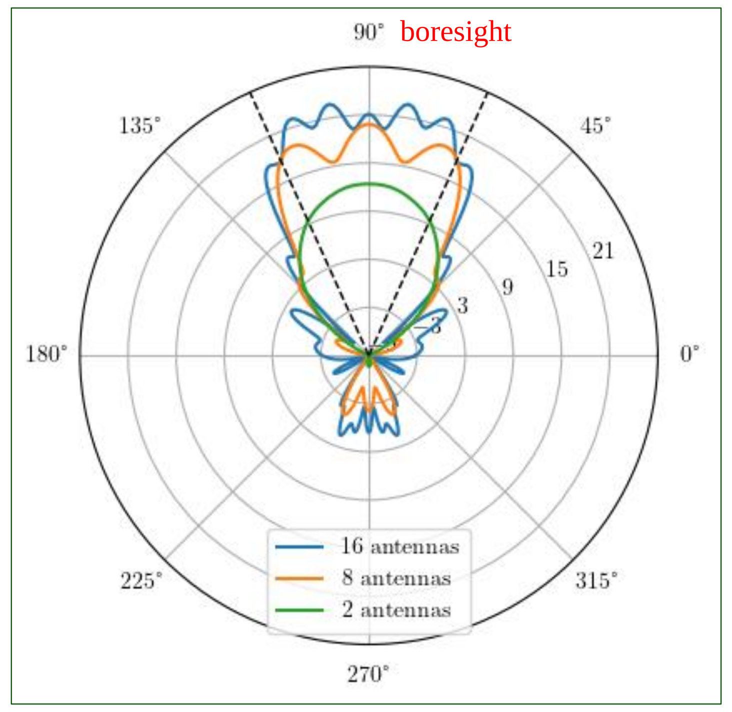
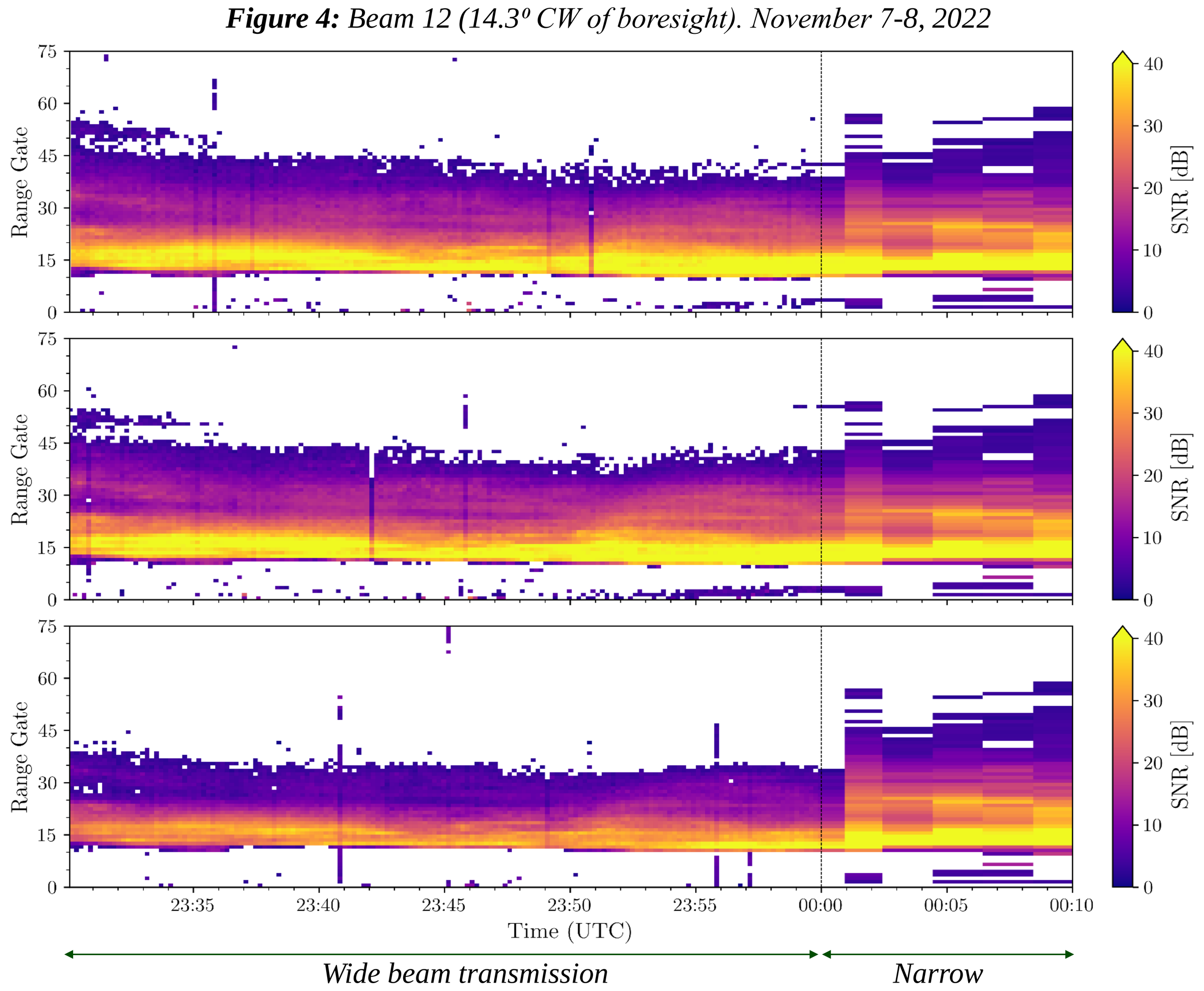


***Figure 3**: Gain vs. azimuth at elevation of peak gain (~30º). NEC2 engine used with twin-terminated folded dipole (Sterne et al. 2011) SuperDARN antennas. Reflector fence provides ~20 dB front-to-back ratio.*

- Strong rolloff outside of FOV
- More ripple with 8 antennas than 16 antennas within FOV
- 16 antenna mode ~3 dB stronger than 8 antenna mode on average
- 8 antenna mode ~6 dB stronger than 2 antenna mode on average

5. EXPERIMENTAL RESULTS

***Figure 4**: Beam 12 (14.3º CW of boresight). November 7-8, 2022*



- Discontinuity in power for 2-antenna transmission at 00:00
- Temporal resolution 11.1 seconds before 00:00, 2 minutes afterwards
  - Could be 3x better before 00:00 if not switching between wide beam modes

5. EXPERIMENTAL RESULTS (continued)

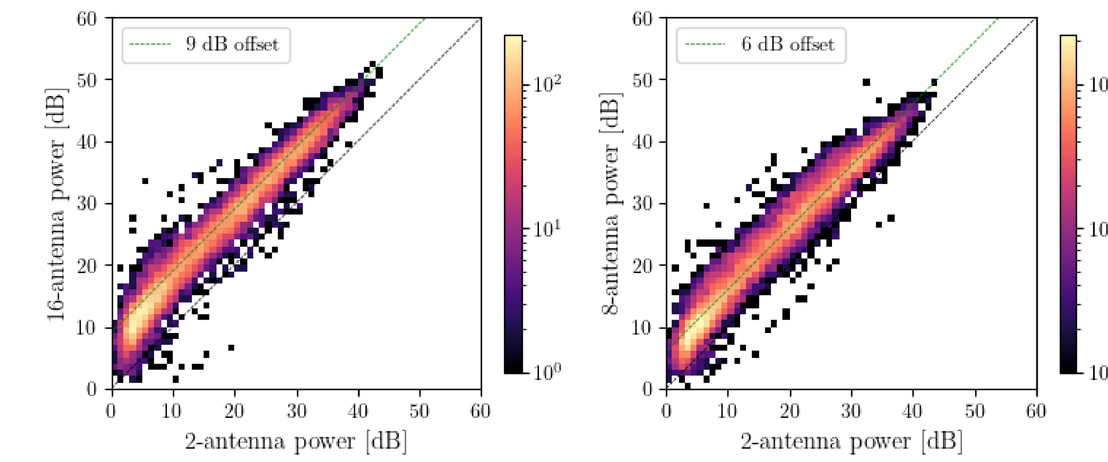


***Figure 5**: Histograms of power along beam 12 for scatter observed over a 2-hour period on November 7, 2022. Only scatter from matching ranges and beams for adjacent sampling times of both modes were selected.*

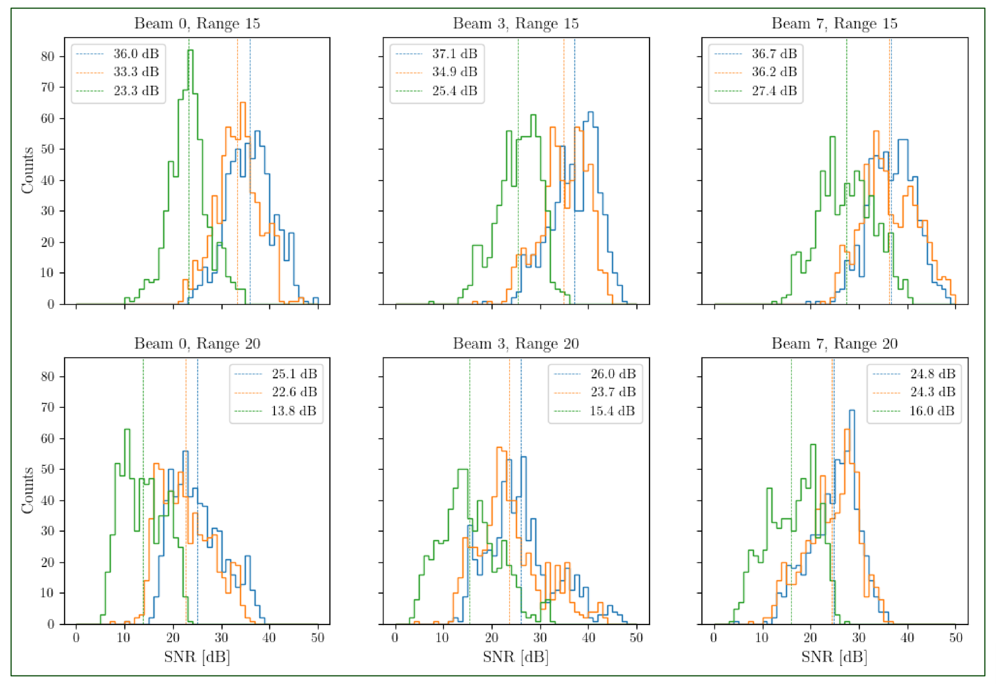


***Figure 6**: Histograms of SNR for assorted beams and ranges from same experiment. Means are denoted by vertical dashed lines. Higher power seen at closer range as expected. 8- and 16-antenna modes almost equal near boresight (beam 7) showing agreement with simulation (Figure 3).*

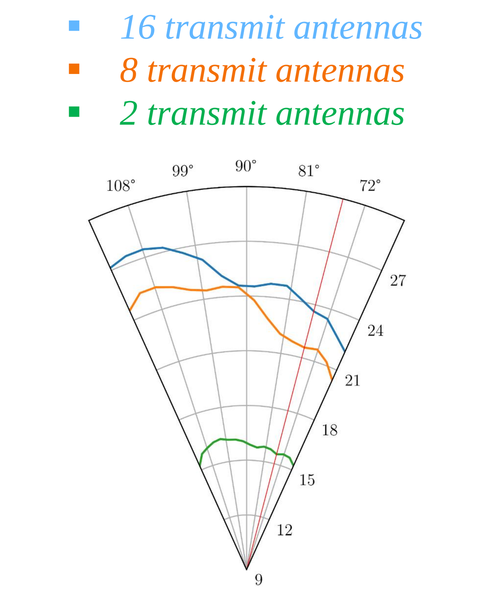


***Figure 7**: Average SNR across all ranges as a function of azimuthal direction. The red line denotes beam 12 (shown in Figure 4). Ionospheric conditions possibly responsible for deviation from Figure 3.*

6. CONCLUSIONS

- Wide transmit beams can be generated by SuperDARN to **radiate power over the entire field of view** simultaneously.
- Transmission with 8 or 16 antennas yields similar data quality to conventional narrow beams.
- A **16-fold increase in sampling rate** of the field of view can be achieved with wide beam transmission without increasing the variance of measurements.
- This advancement will enable higher volumes of data collection in the future and enable study of **short-lived large scale ionospheric phenomena**.

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