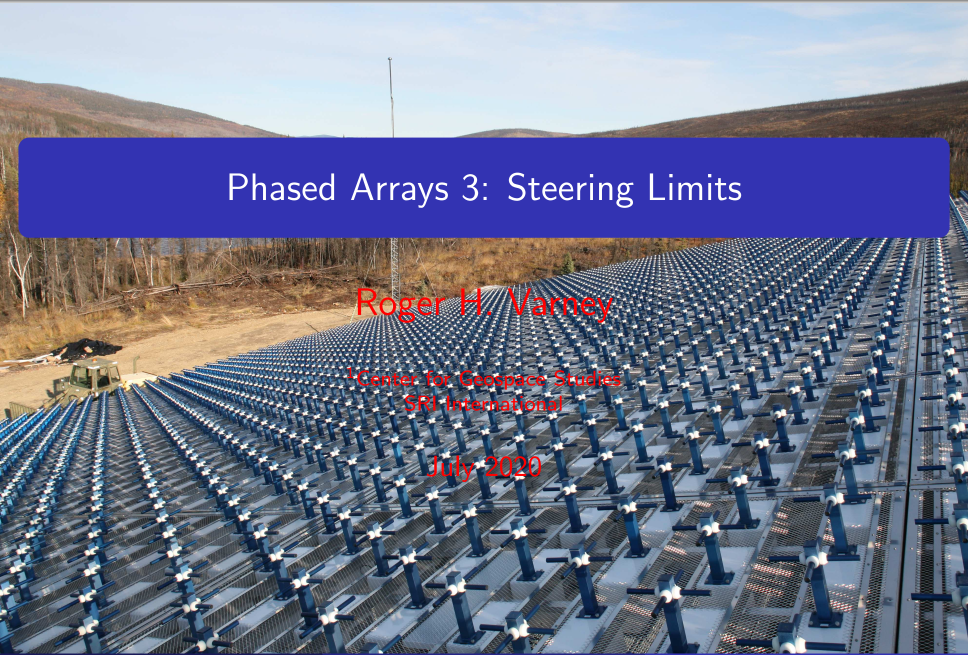

Phased Arrays 3: Steering Limits

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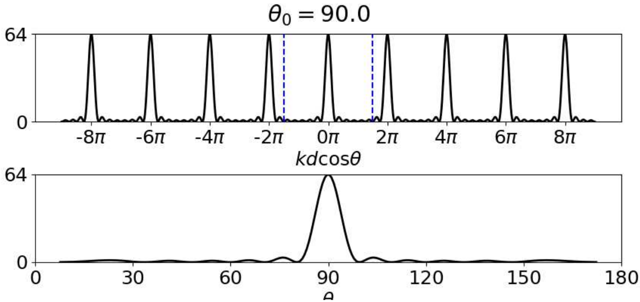
Visible Region

$$|F|^2 = \frac{\sin^2\left[\frac{N}{2}\left(kd\cos\theta + \alpha\right)\right]}{\sin^2\left[\frac{1}{2}\left(kd\cos\theta + \alpha\right)\right]}$$



Peak appears when $kd\cos\theta = -\alpha \rightarrow \alpha = -kd\cos\theta_0$

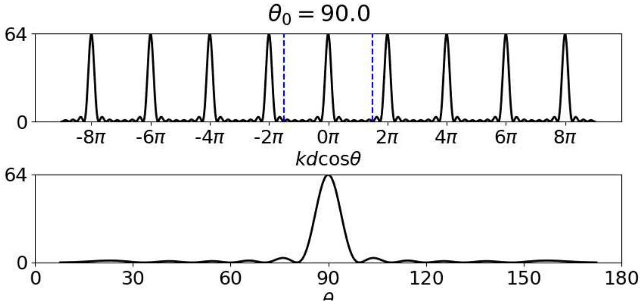
Additional peaks could appear when $kd\cos\theta = -\alpha + 2\pi m$ (Grating Lobes)

Visible Region: $0 < \theta < \pi \rightarrow -kd < kd\cos\theta < kd$

Grating Lobes

- $d < \lambda/2 \rightarrow kd < \pi$: No grating lobes will ever appear
- $\lambda/2 < kd < \lambda \rightarrow \pi < kd < 2\pi$: Grating lobes will only appear at some steering angles
- $d > \lambda \rightarrow kd > 2\pi$: Grating lobes will always appear

Example of linear array with $d = 3\lambda/4$ spacing

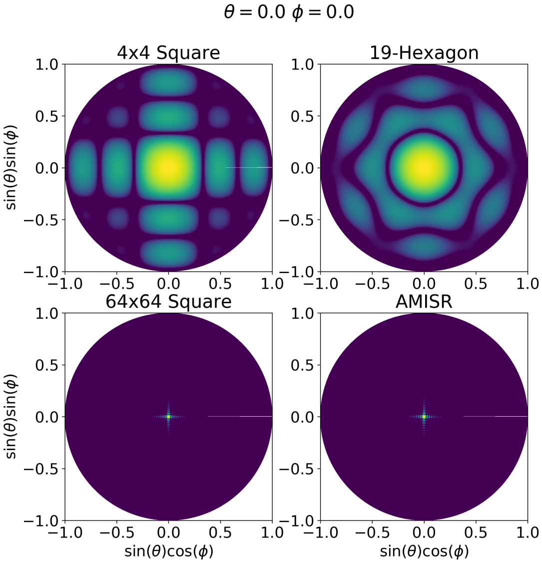


- Maximum steering angle (for a linear array): $\Delta\theta_{\max} = \left|\sin^{-1}\left(1 - \frac{2\pi}{kd}\right)\right|$

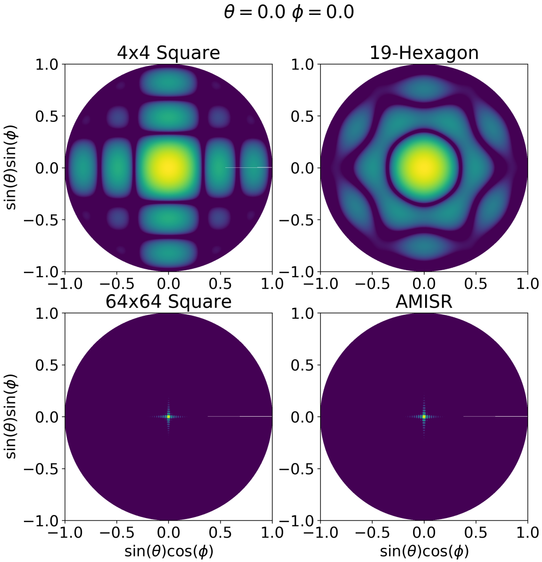
Issues Affecting Antenna Spacing

- Mutual Coupling Between Antennas
  - The true element factor for antennas in an array is different from the same type of antennas in isolation
    - Scattering off of neighboring antennas
    - Inductive coupling involving antenna near-fields
  - Impedance of an antenna in an array is different from the impedance of that antenna in isolation
- Cost
  - Antenna gain is determined by the area of the array
  - Larger distance between antennas $\rightarrow$ fewer elements to fill a given area

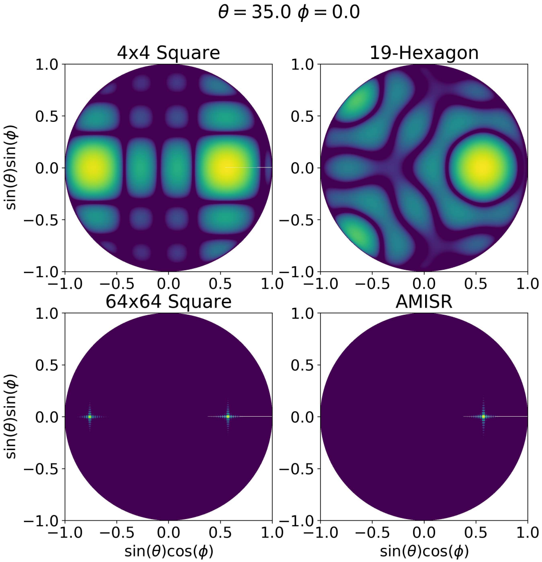
Examples Steering 2-D Arrays ($d = 3\lambda/4$)



Examples Steering 2-D Arrays ($d = 3\lambda/4$): Elevation Scan

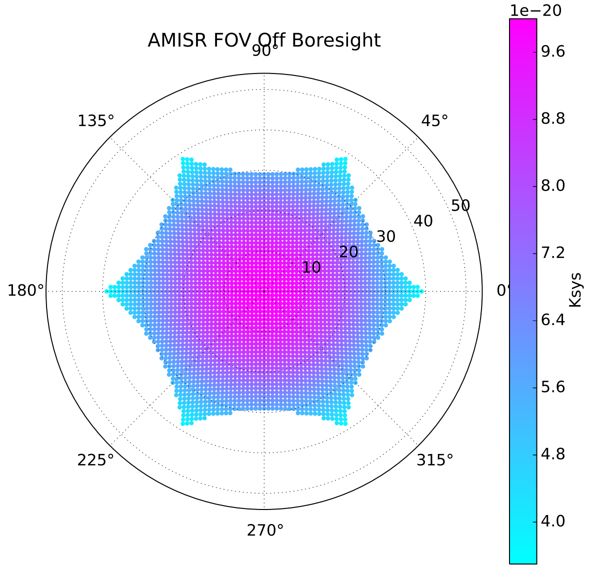


Examples Steering 2-D Arrays ($d = 3\lambda/4$): Azimuth Scan



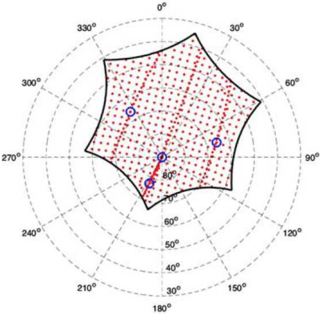
AMISR Antenna Properties

- Hexagonal spacing with $d \approx 3\lambda/4$
- FOV limited by grating lobe limit $\sim 30^\circ - 40^\circ$
- Antenna gain decreases with steering angle off of boresight
- Antenna works best within $\sim 25^\circ$ off of boresight



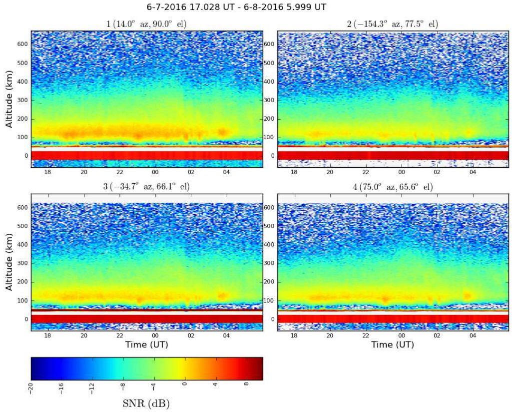
The PFISR Up-B Compromise

IPY Beam Pattern



The Up-B beam is close to the grating lobe limit, and therefore has reduced sensitivity.

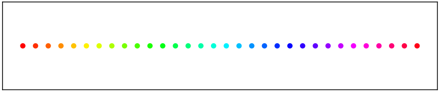
Reduced SNR in Up-B (Beam 2)



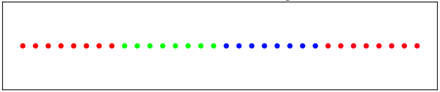
Phasing Subarrays

What if you can only control phases on subarrays instead of every individual antenna?

Phase Each Antenna



Phase Subarrays

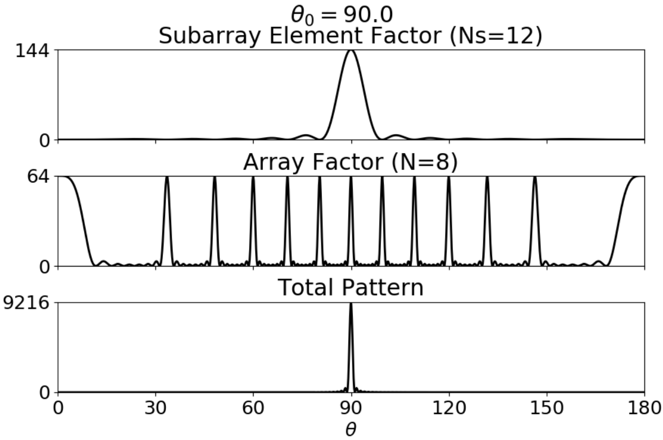


View the whole array as an array of subarrays, and use the subarray pattern as the "element factor."

Jicamarca Example:

- CoCo antennas spaced by $\lambda/2$
- 18,432 dipoles (9216 per polarization)
- 96×96 square array
- Only able to control phases on 64^{ths} of the array
- 8×8 array of subarrays
- Each subarray is 12×12

Steering Subarrays



Phased Array Steering Summary

- Limitations on phased array steering are determined by
  - Inter-element spacing
  - Pattern of elements (e.g. rectangular vs hexagonal)
  - Granularity of phase control (individual elements vs subarrays)
- In general phased arrays lose antenna gain as they are steered further from boresight

Practical results for ISR users

- Explains 6-pointed star patterns for AMISR FOV
- Explains why Jicamarca can only steer $\pm 3^\circ$