Swarm Communications Using a Sparse Array of Small Antennas

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Overview and Motivation for MIIMIO

- Microsats have a small power budget, which intrinsically limits downlink transmitter power and data capacity
  - Microsats may collect more data than they can downlink
  - Large downlink bandwidth requires a large receiving aperture on the ground
  - Microsat swarms compound the downlink problem
- The Multiple Independent Inputs, Multiple Independent Outputs (MIIMIO) sparse ground receive array concept provides microsat swarm downlink advantages
  - Provides large receive aperture, to enable wideband downlinks with low transmitter power
  - Enables simultaneous downlinks from all microsats in the swarm, using same frequency
  - Microsats transmit independently, without coordination
  - Low cost ground antennas point open loop, providing the field of regard and total aperture gain

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MIIMIO Downlink Overview System Drawing

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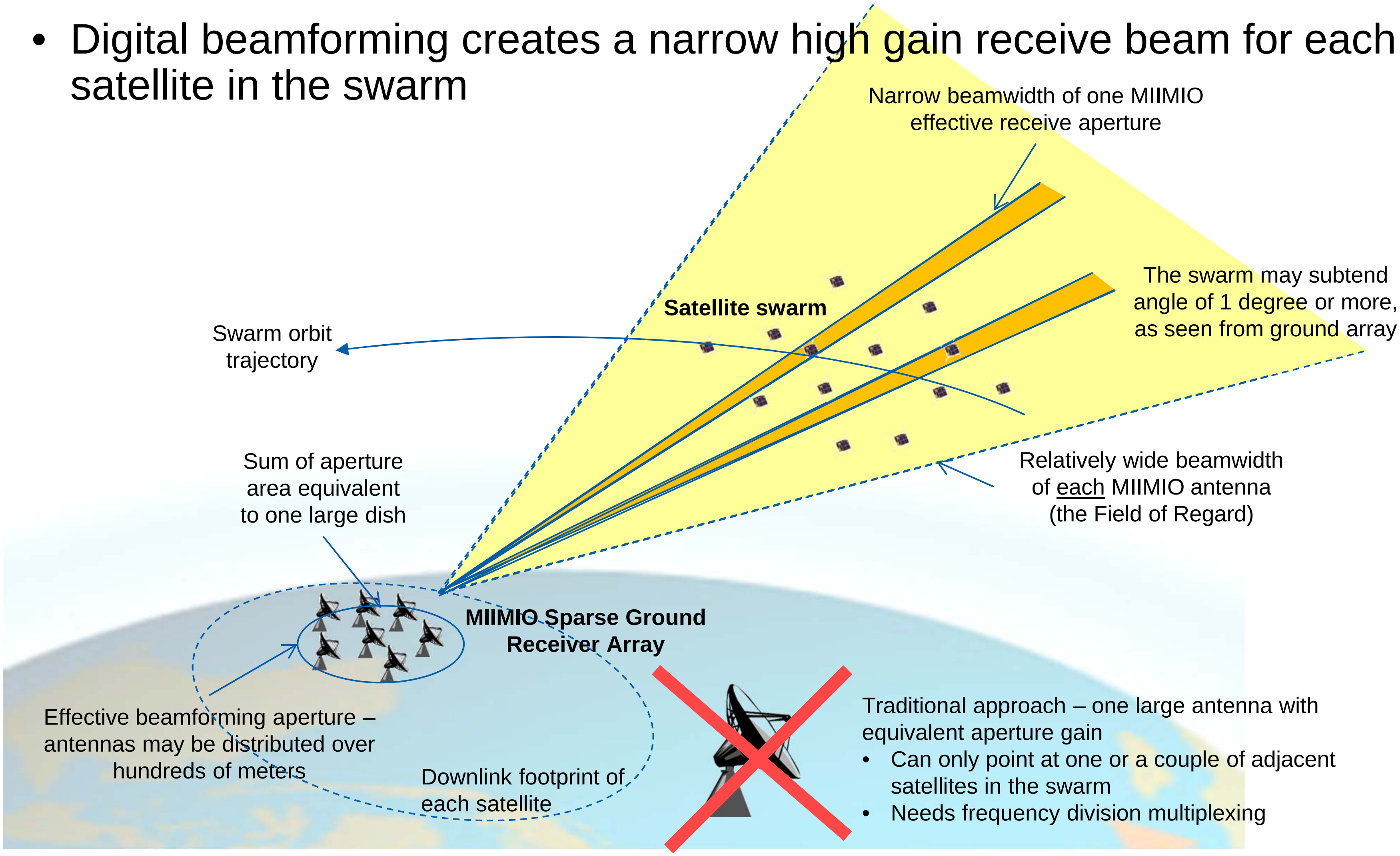
- Digital beamforming creates a narrow high gain receive beam for each satellite in the swarm



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MIIMIO Features

- Transmitters on the microsats are independent – no coordination required among them
- The initial MIIMIO application is for reception of separate, re-used frequency downlinks, from a swarm of closely-spaced microsats
- Sparse array of receiving antennas on the ground
  - Similar to high resolution sparse array interferometers in radio astronomy
  - Ground antenna elements are typically 100 to 1,000 wavelengths apart
  - Compute very narrow beams to isolate each downlink
  - Total receiving area (antenna aperture x number of array elements) sets link budget
  - Each microsat can downlink a large bandwidth
- This is -not- MIMO; no need for channel modeling

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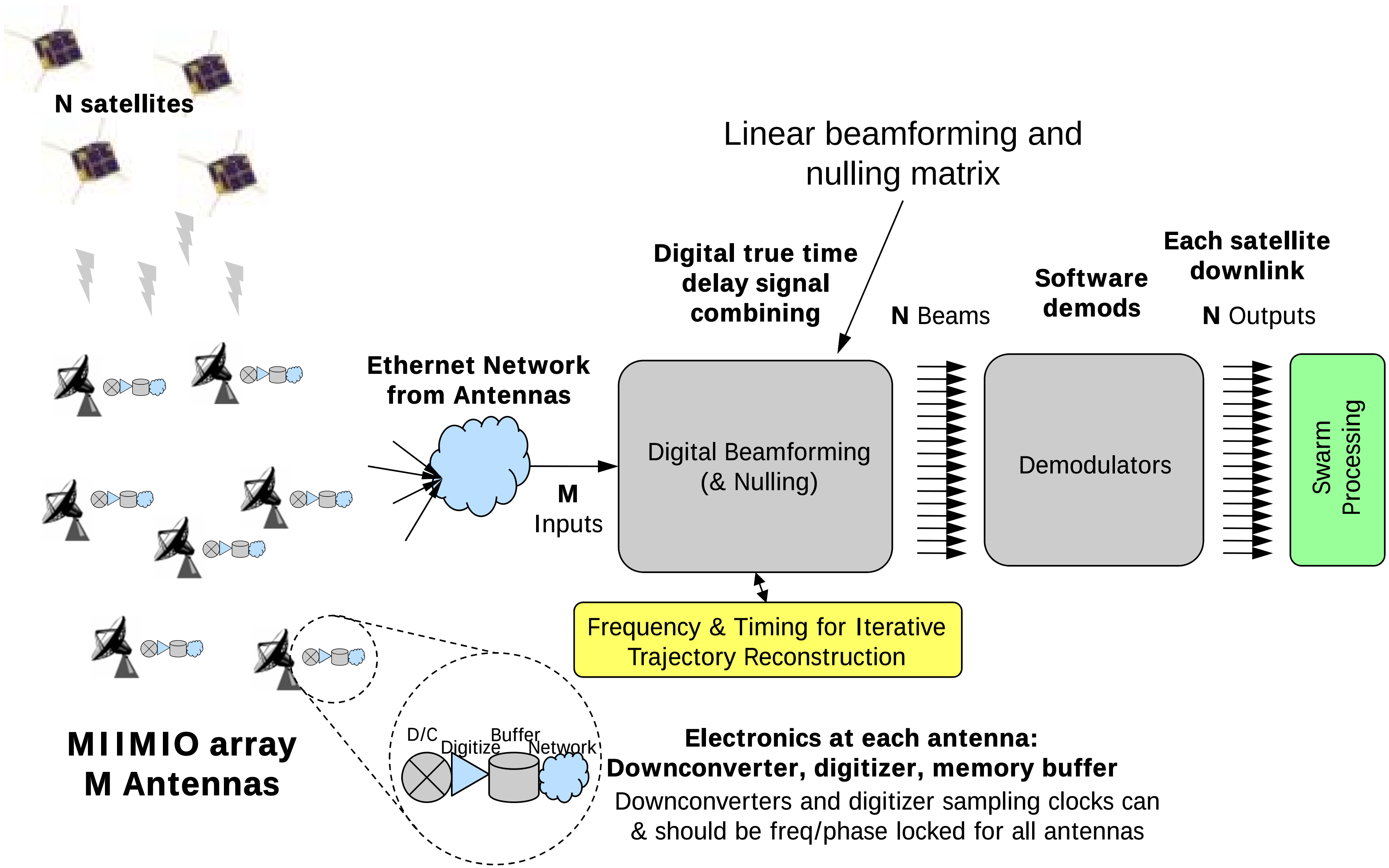
Sparse Aperture Digital Receive Beamforming Details



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Numerical Example

- X-band downlink, 9 GHz
- 36 antennas, 1.8 meter diameter, open loop pointing
  - Half-power beamwidth (HPBW) provides 1.2° field of regard
- Equivalent single dish collection area = 10 meter diameter
  - Total RX gain = 56 dB
- Sparse array distributed over 150 meters diameter
  - Each formed beam HPBW = 0.015°
  - On average, only one satellite in the swarm will be in the full-gain boresight
- Nulls can be computed to further reduce co-channel interference in sidelobes and grating lobes

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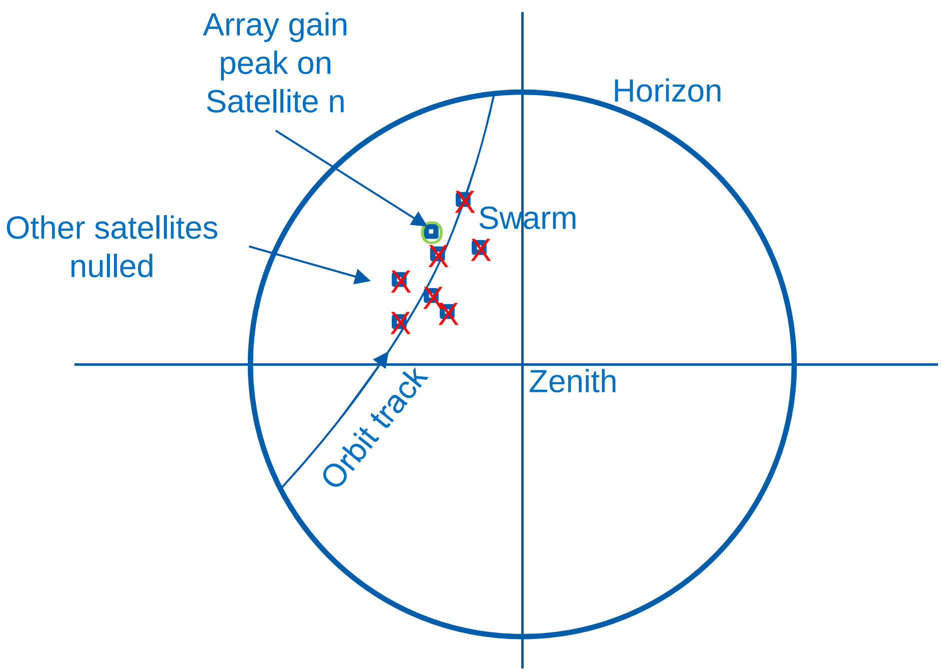
Notional Nulling in Swarm

- Can use traditional receive beamforming to accomplish reduction of interferers by nulling



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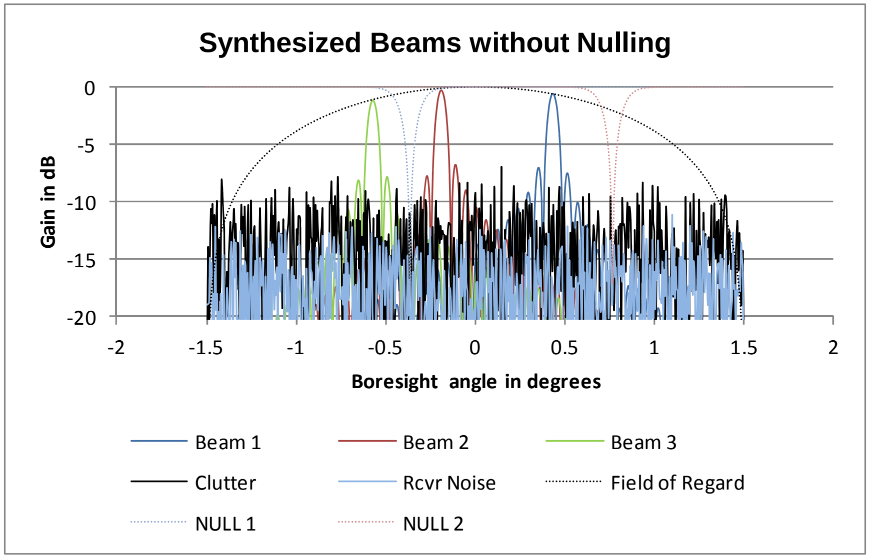
Notional Simulation - Beamforming Plus Multiple Nulls

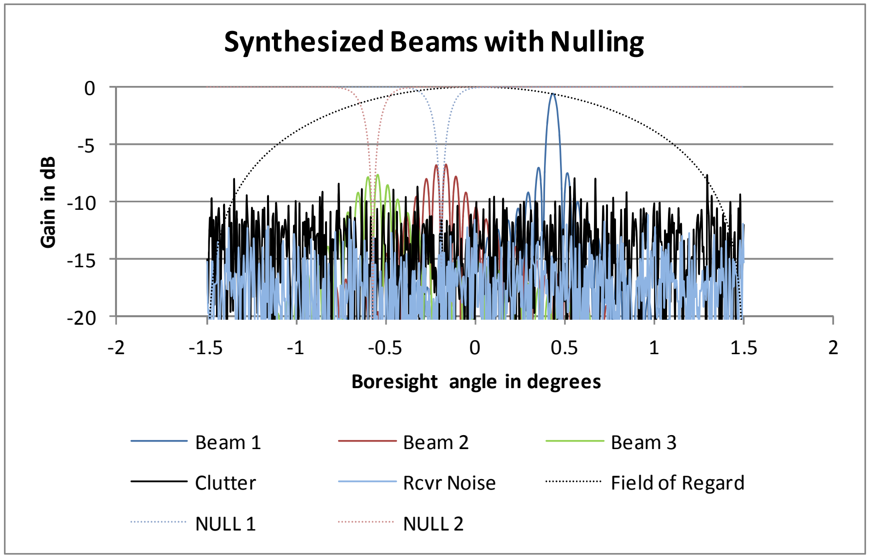
- Sharp nulls can be computed for each beam, to null some or all of the other satellite downlinks in the swarm to further reduce the cross-channel interference

- A number of well-formed nulls can be multiplied with little reduction of main beam gain, while providing significant reduction of interferers

Nulls not adaptively centered; have little effect on beam gain



Nulls centered on beams not of interest; suppression of >15 dB



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Simulation - Comparison of Transmitted Signal vs. Recovered Signal

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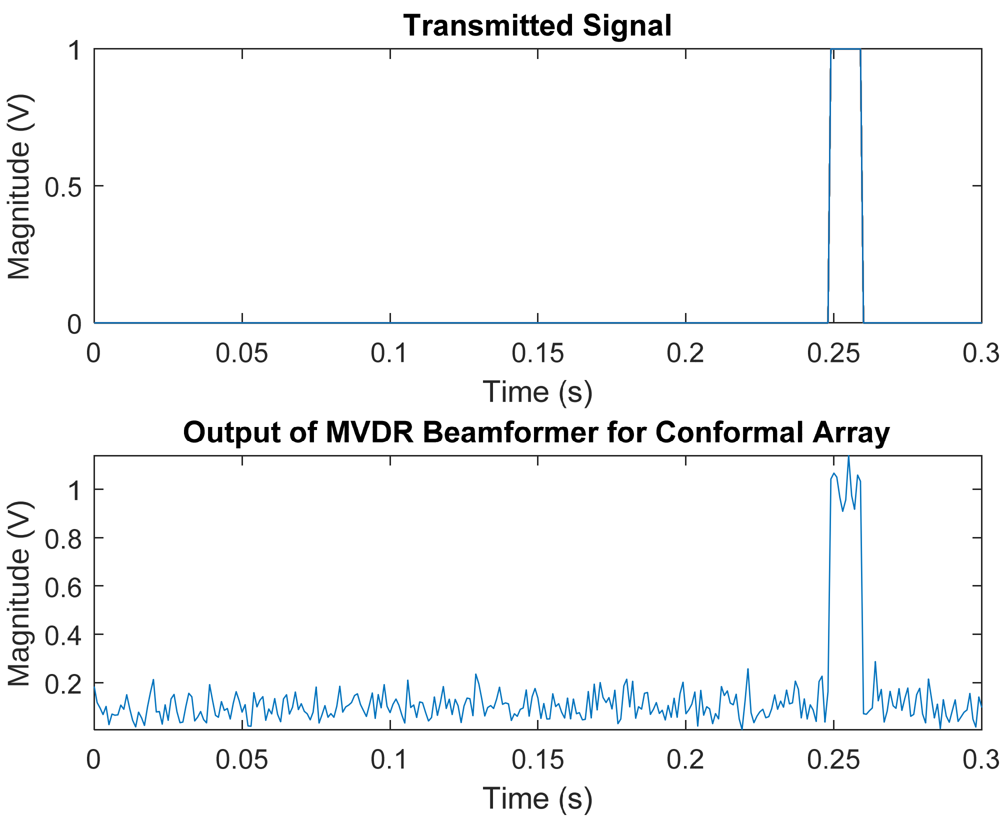
- In simulation, use time domain (burst transmissions) to show received signals relative to interference and noise



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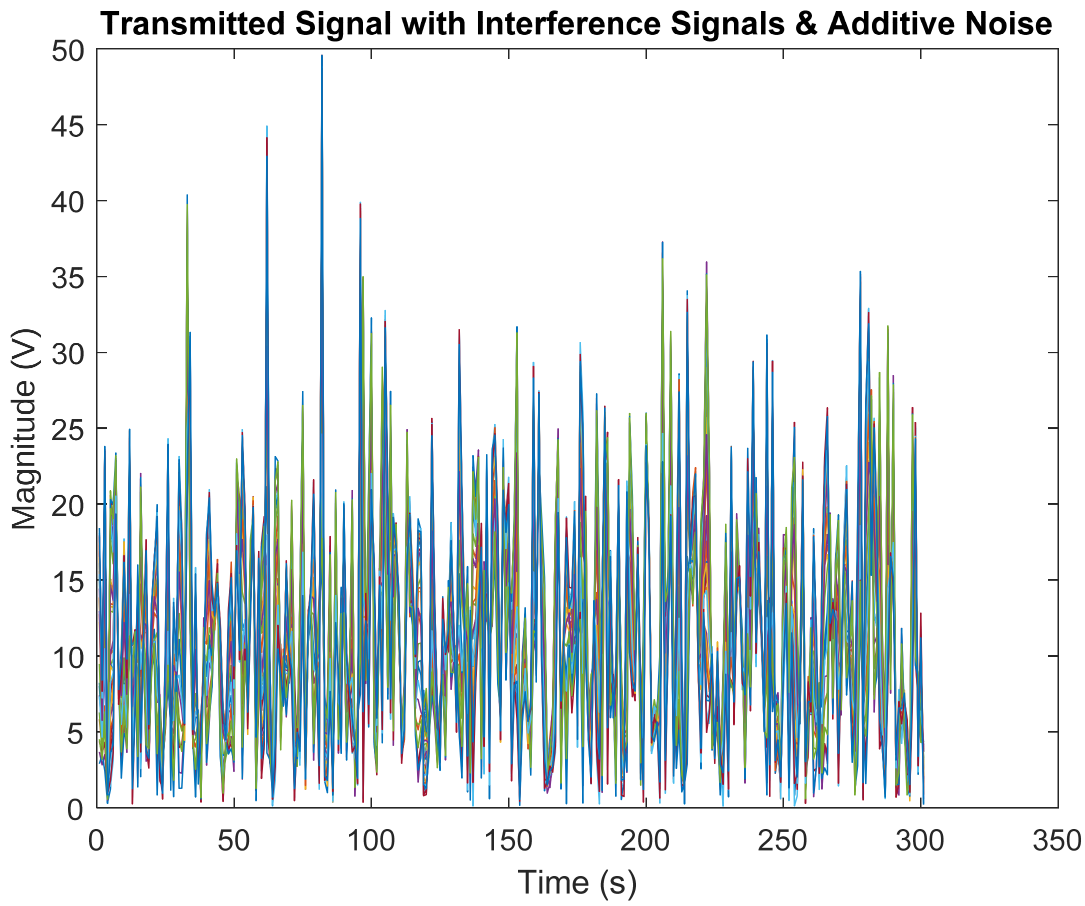
Simulation - Signals Received at Antenna Array

- Interference Signals at [30, 45.5] & [31, 45.5] ([az,el])



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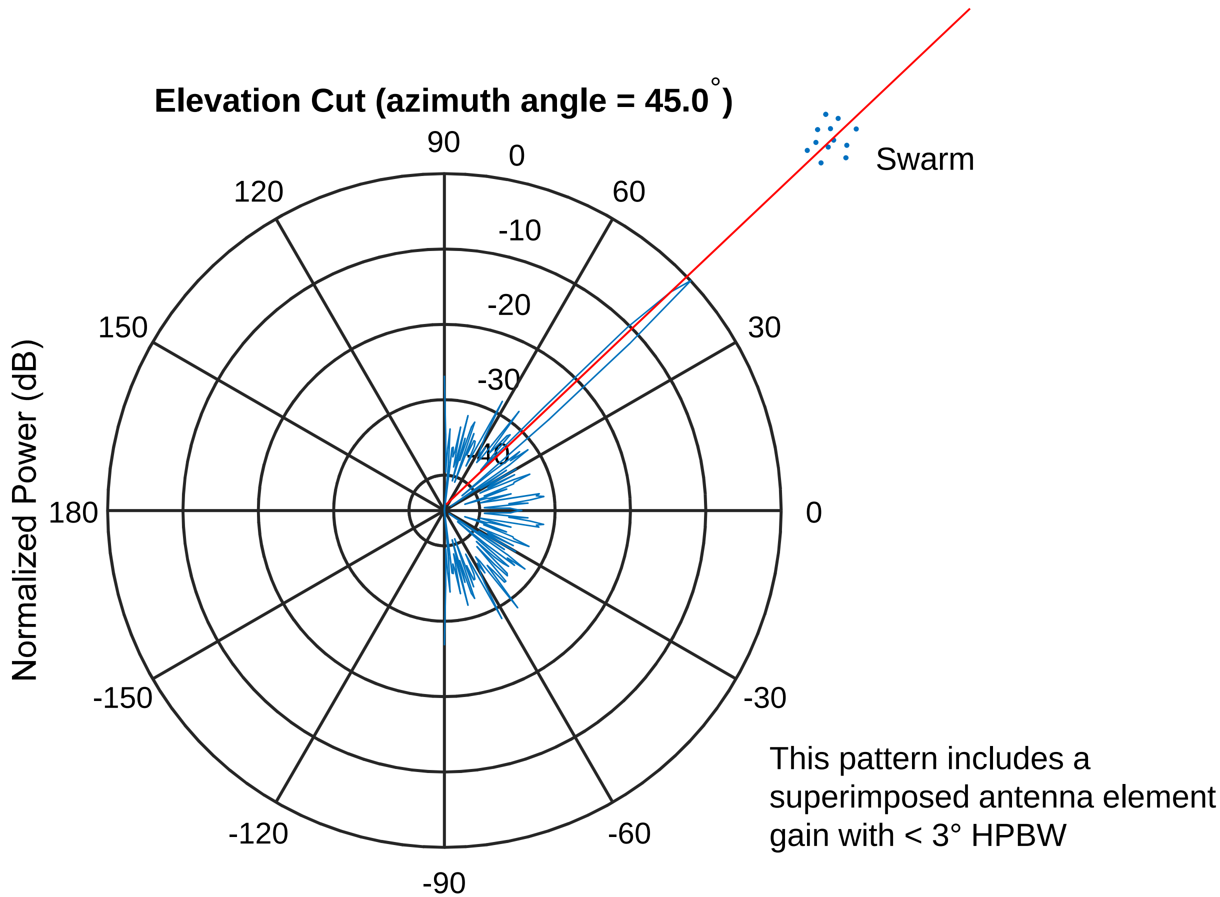
Simulation - Polar Radiation Plot of 36 Element Array and Parabolic Pattern Superimposed



Normalized Power (dB), Broadside at 0.00 degrees

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Conclusions

- Mature sparse array beamforming provides swarm support
- Microsats are independent and can be as simple as possible
  - No crosslinks needed for on-orbit coordination
- Beams can be computed after the LEO flyover
  - Iteratively optimize LEO tracking, formed beam gain, nulling and cross-channel cancellation across the flyover arc
- Low cost ground
  - Small antennas with open loop pointing
  - Commodity digitizers
  - Offline beam computing

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