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THE ROLE OF GNSS ANTENNAS
IN MITIGATING JAMMING AND INTERFERENCE





Thursday, December 5, 2013

11 am–12:30 pm Pacific
Noon–1:30 pm Mountain
1 pm–2:30 pm Central
2 pm–3:30 pm Eastern

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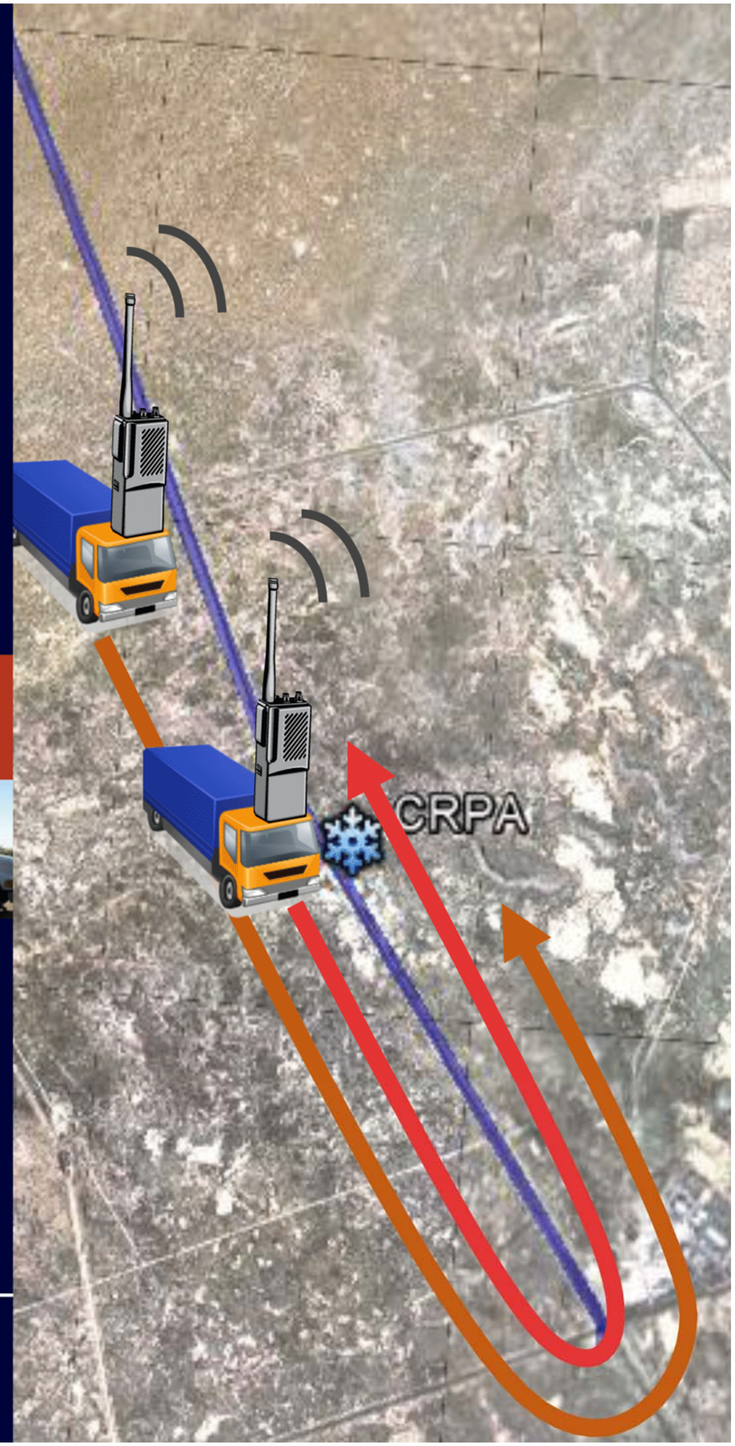

WELCOME TO
The Role of GNSS Antennas in Mitigating Jamming and Interference

Dr. David S. De Lorenzo
Principal Research Engineer
Polaris Wireless

Dr. Inder (Jiti) Gupta
Research Professor
The Ohio State University

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Co-Moderator: Lori Dearman, Sr. Webinar Producer

Who's In the Audience?

A diverse audience of over 500 professionals registered from 53 countries, 30 states and provinces representing the following industries:

21% GNSS Equipment Manufacturer

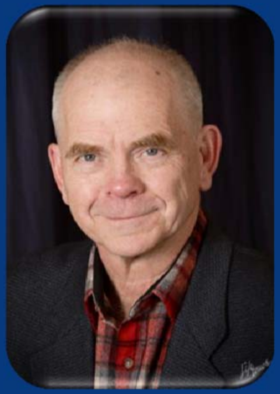
17% Professional User

17% System Integrator

17% Product/Application Designer

28% Other

Welcome from *Inside GNSS*



Glen Gibbons

Editor and Publisher
Inside GNSS

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Neil Gerein
Defense
Product Manager
NovAtel

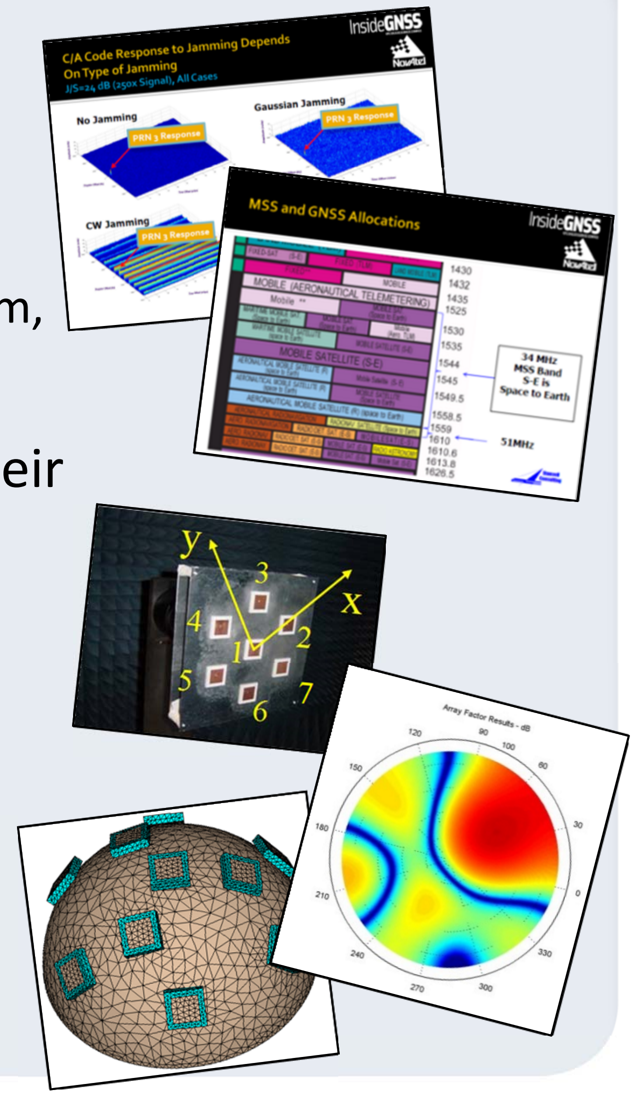
The Role of GNSS Antennas in Mitigating Jamming and Interference

Mark Petovello
Geomatics Engineering
University of Calgary
Contributing Editor
Inside GNSS

Interference Webinar Series to Date

- August 2012: Tom Stansell and Logan Scott
  - Types of jamming and spoofing as well as possible sources
  - Discussed several means of addressing the problem, one of which was multiple antennas

- Today the focus is entirely on antennas and their role in jamming and interference mitigation
  - Look at different types of antenna and receiver configurations
  - Practical considerations for antenna selection/design
  - Testing results
  - Outlook



Past webinars available at: http://insidegnss.com/webinars

Poll #1

Are you aware of ever having your GNSS receiver jammed?

1. *Yes*
2. *No*
3. *I have suspected it but cannot be sure*

Part I: Adaptive Beamforming/Nullsteering Antennas for GPS Receivers

Author photo

David S. De Lorenzo
with contributions from many, including Sherman Lo, Yu-Hsuan Chen, Dennis Akos, Per Enge, and others

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Outline

- Overview of signal processing for adaptive antenna systems
- Integrating beamsteering antennas with GPS receivers
- Taking it live: Testing adaptive antenna arrays, including over-the-air jamming trials
- Practical considerations and the civil outlook going forward

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- **Overview of signal processing for adaptive antenna systems**
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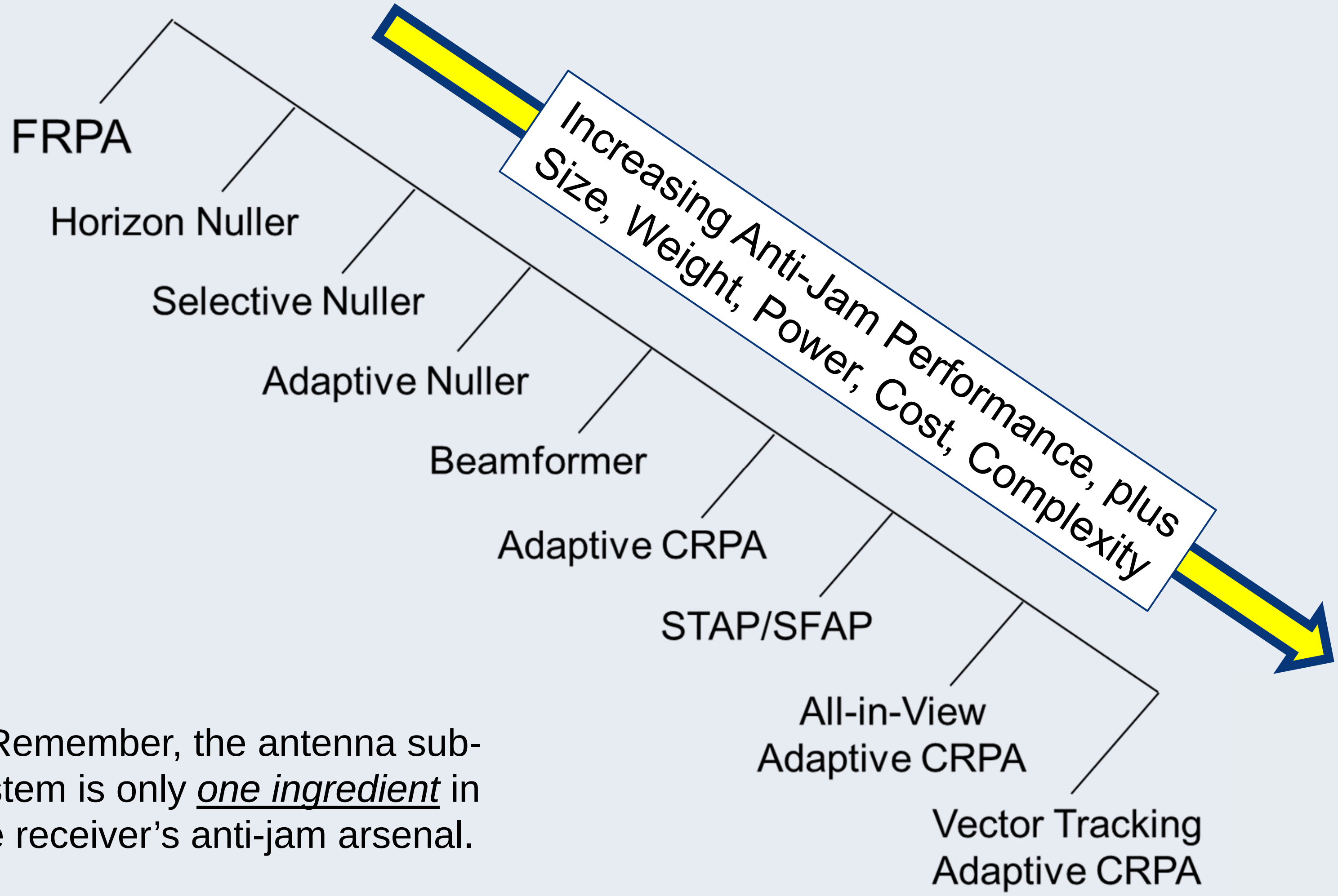
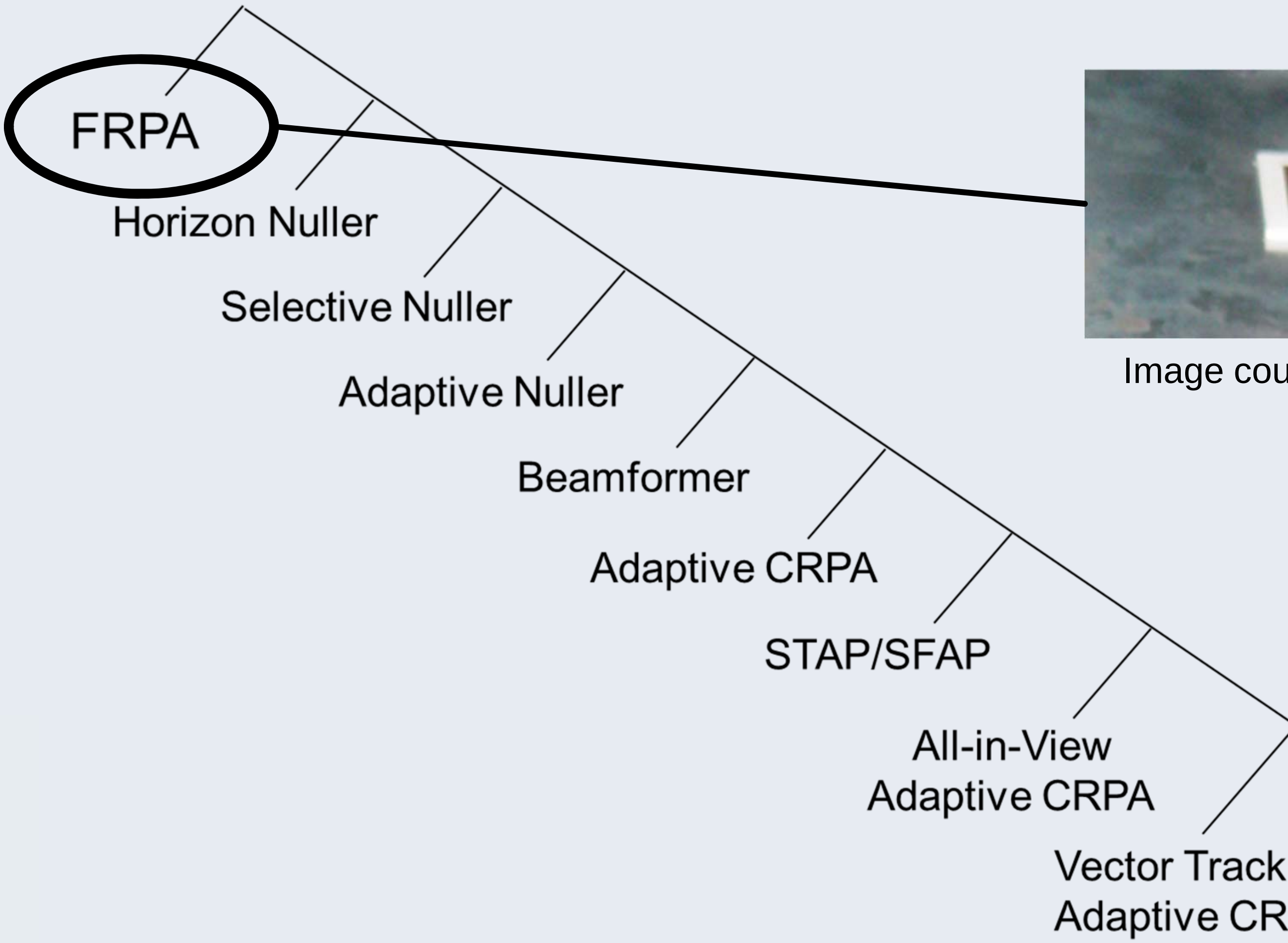
Basic Classes of GPS Receive Antennas



** Remember, the antenna sub-system is only _one ingredient_ in the receiver's anti-jam arsenal.

The Fixed Reception Pattern Antenna or "FRPA"



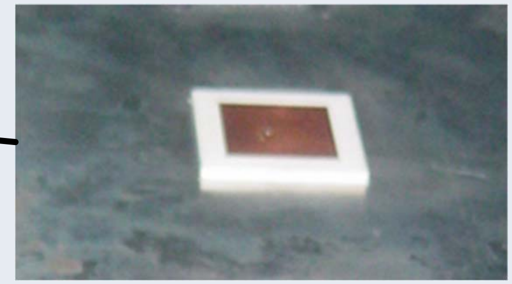


Image courtesy U-S. Kim

The Multipath-limiting Antenna or Horizon Nuller

FRPA
Horizon Nuller
Selective Nuller
Adaptive Nuller
Beamformer
Adaptive CRPA
STAP/SFAP
All-in-View
Adaptive CRPA
Vector Tracking
Adaptive CRPA

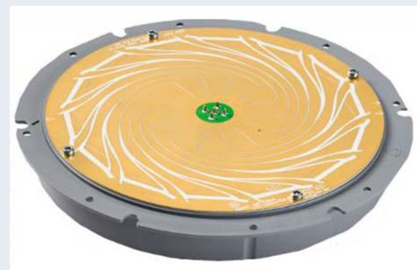


Image from NovAtel, Canada

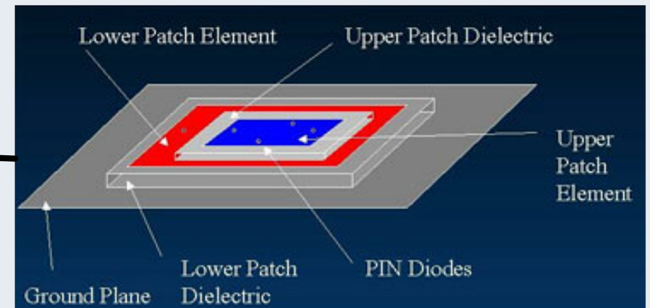
Image from Leica Geosystems

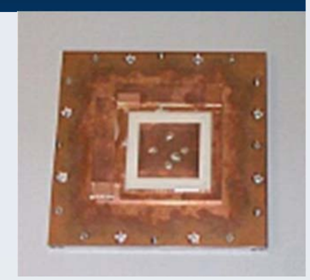
Image from Trimble Navigation

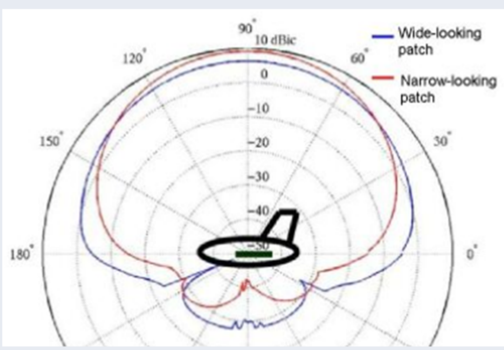
The Stacked-patch Selective Nuller

Images from F. Bauregger et al., "A Novel Dual-Patch Anti-Jam GPS Anrtenna, 2002.

FRPA
Horizon Nuller
Selective Nuller
Adaptive Nuller
Beamformer
Adaptive CRPA
STAP/SFAP
All-in-View Adaptive CRPA
Vector Tracking Adaptive CRPA







Elevation radiation pattern.

The Multi-element Adaptive Nuller

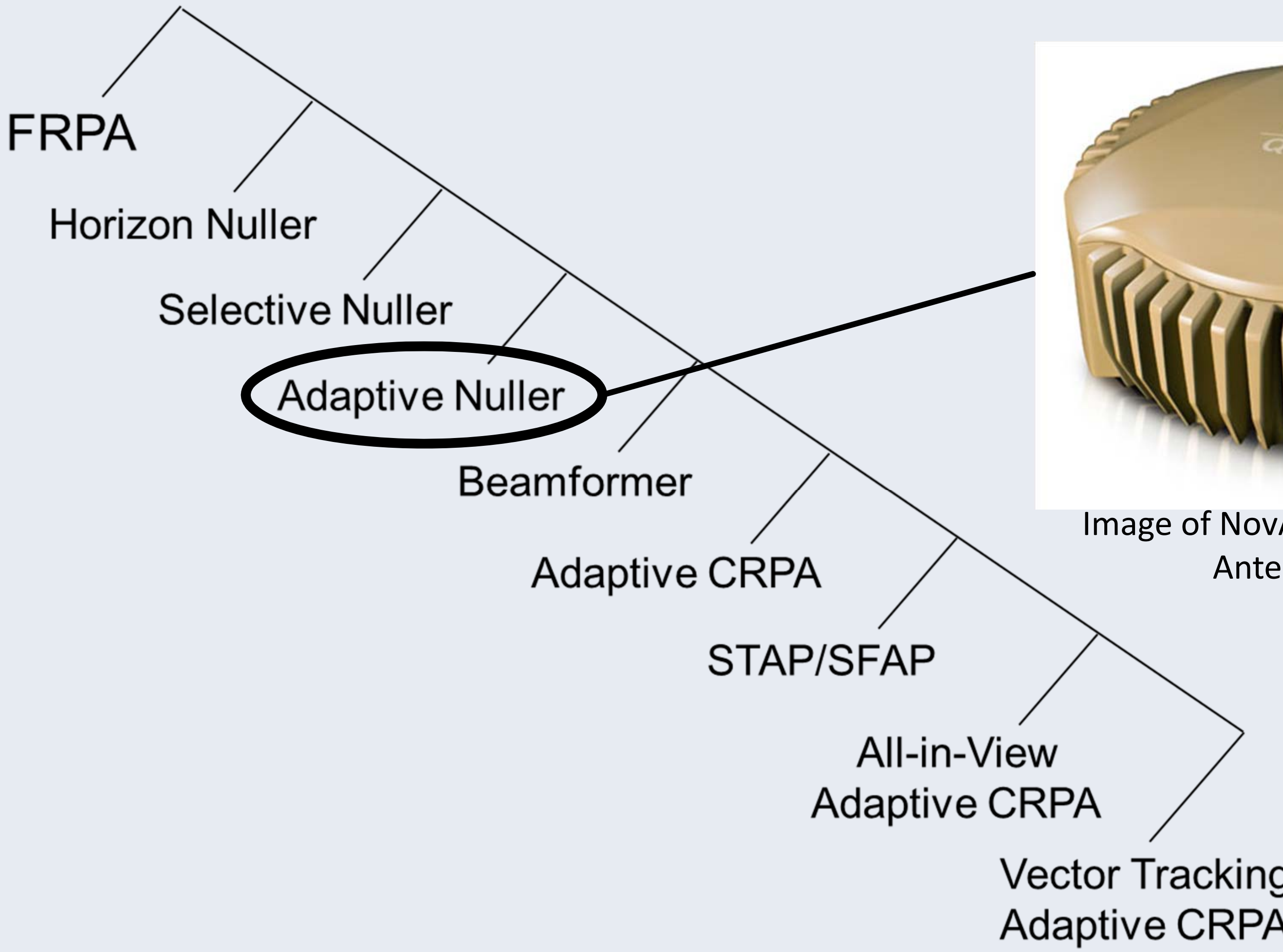
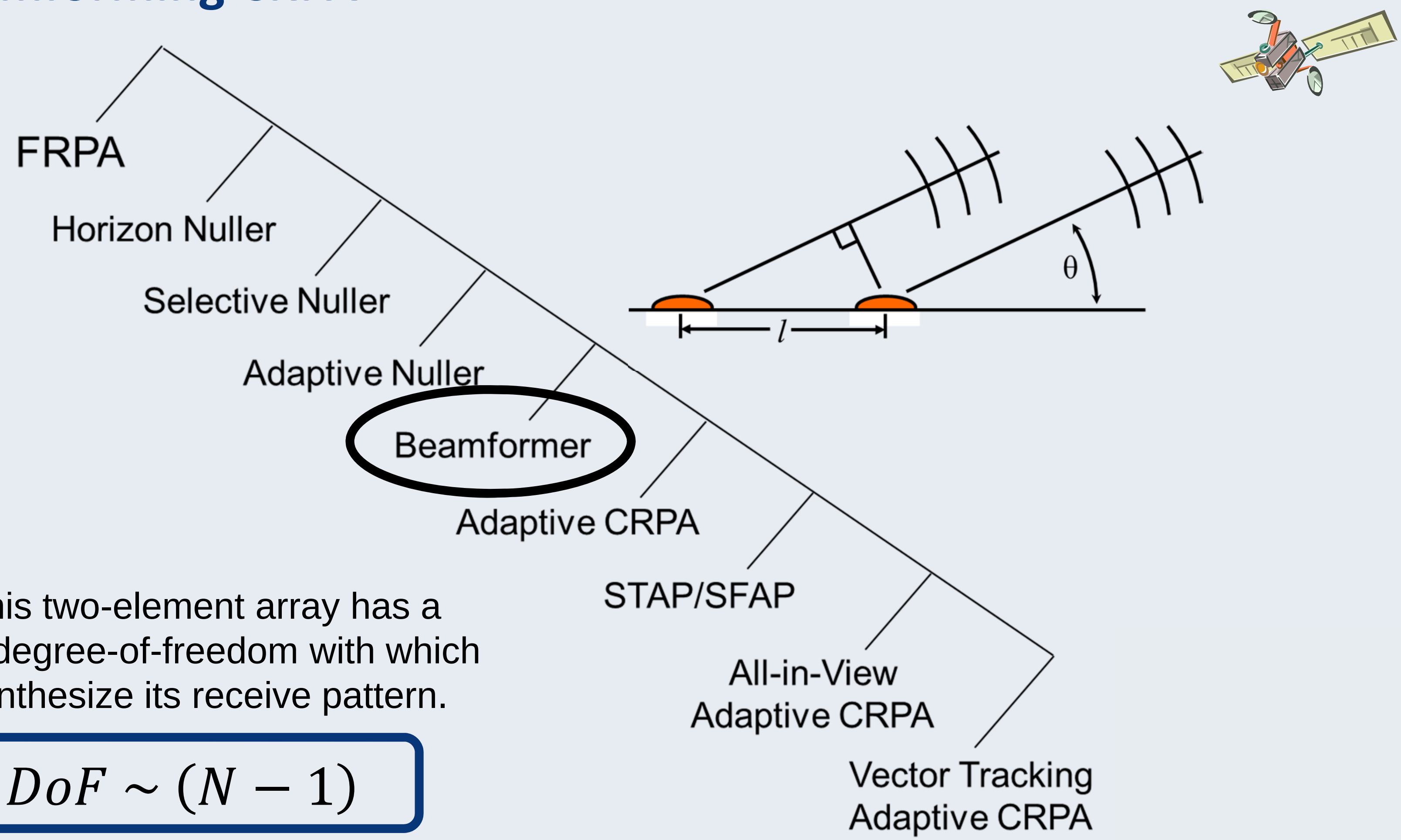


Image of NovAtel GAJT™ Anti-Jam Antenna System

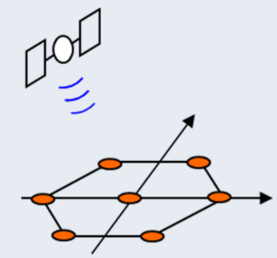
The Controlled Reception Pattern Antenna or "Beamforming CRPA"



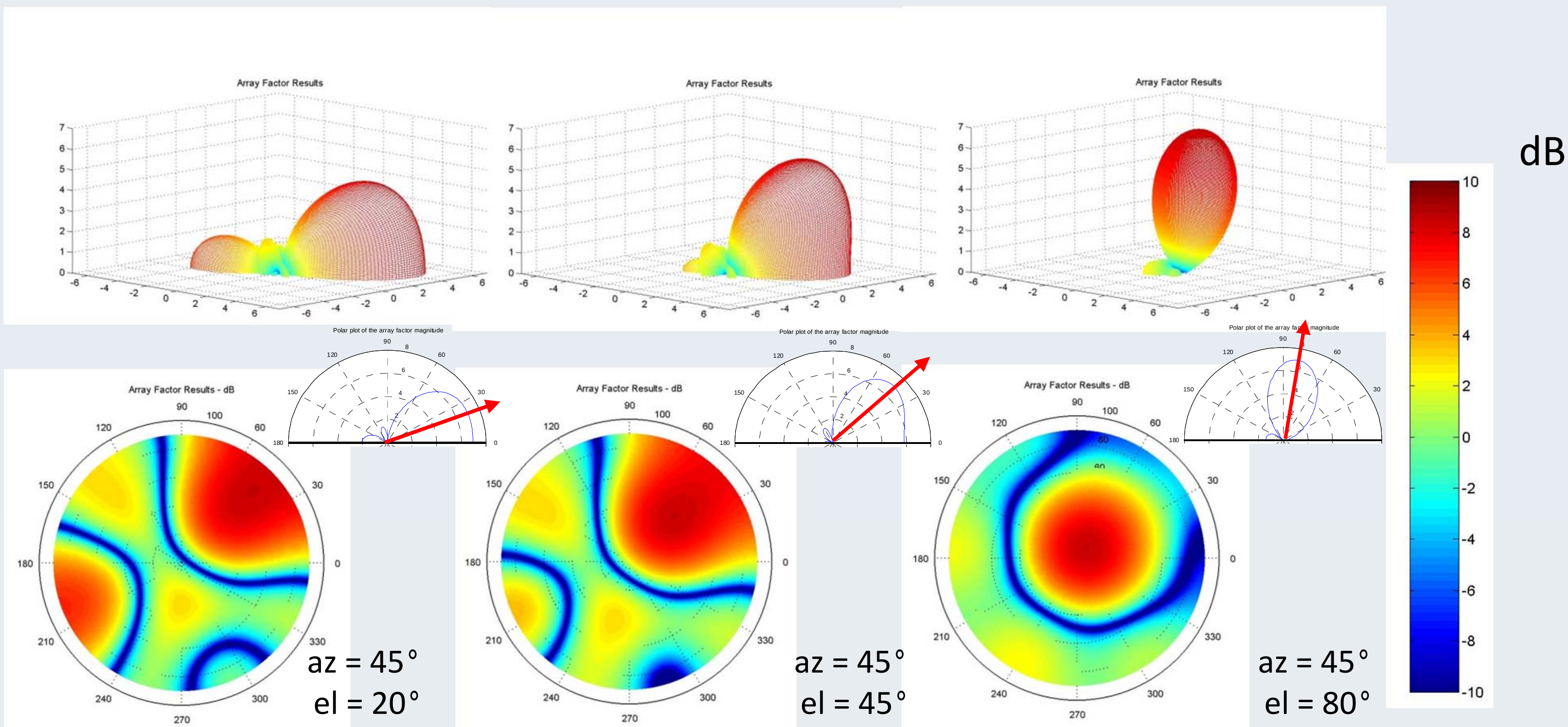
** This two-element array has a single degree-of-freedom with which to synthesize its receive pattern.

$$DoF \sim (N-1)$$

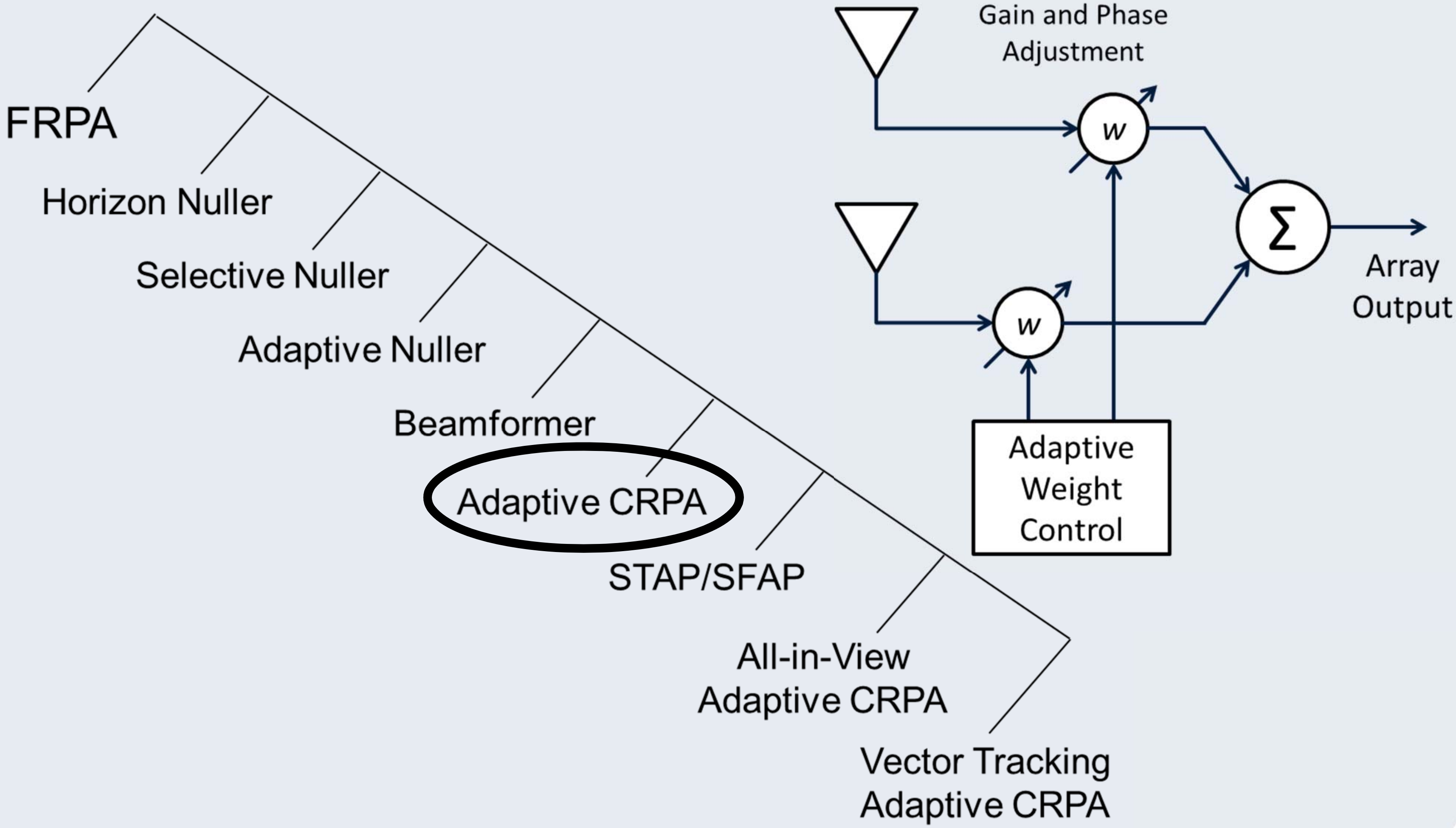
The Controlled Reception Pattern Antenna or "Beamforming CRPA"



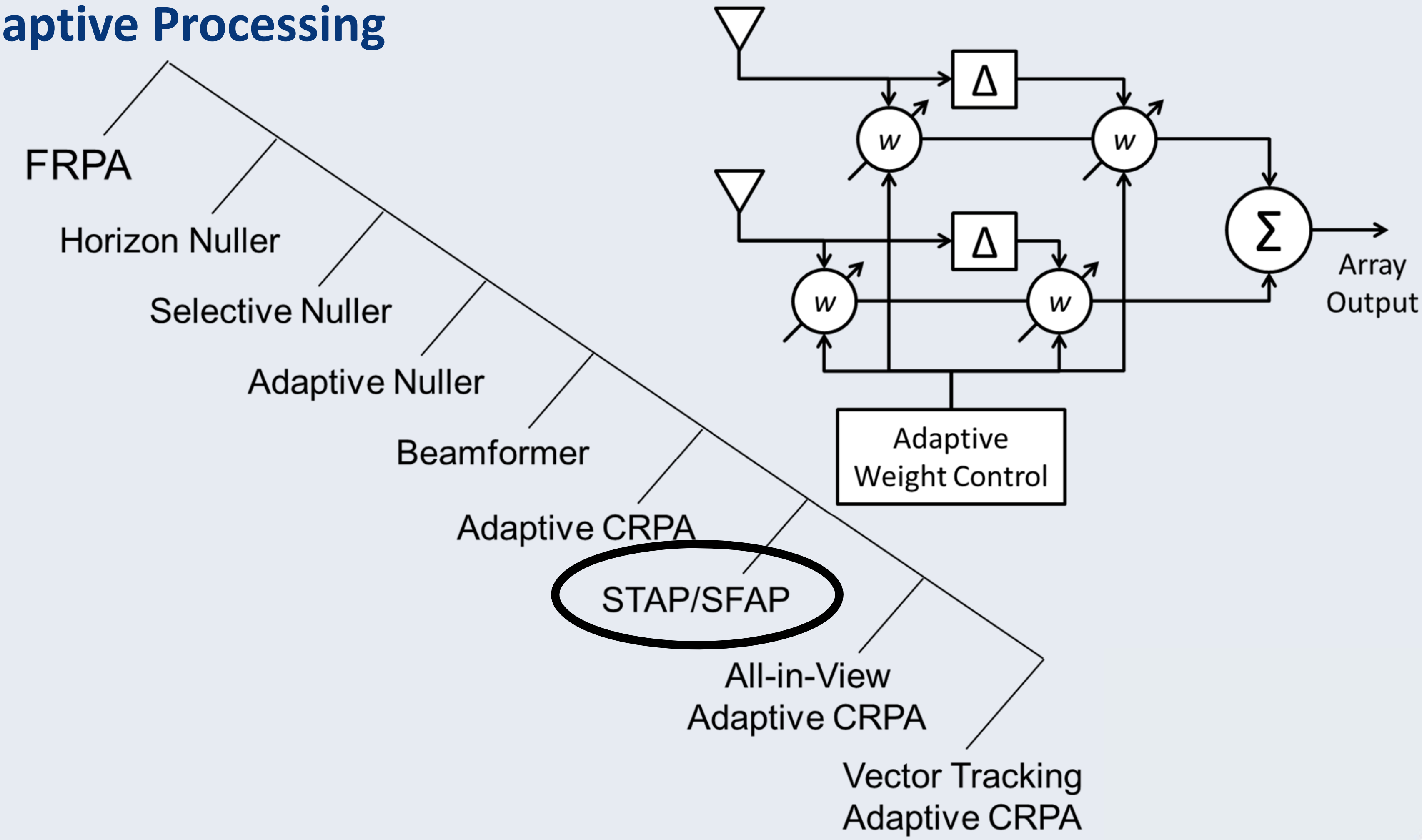
7-element isotropic planar array with λ/2 spacing



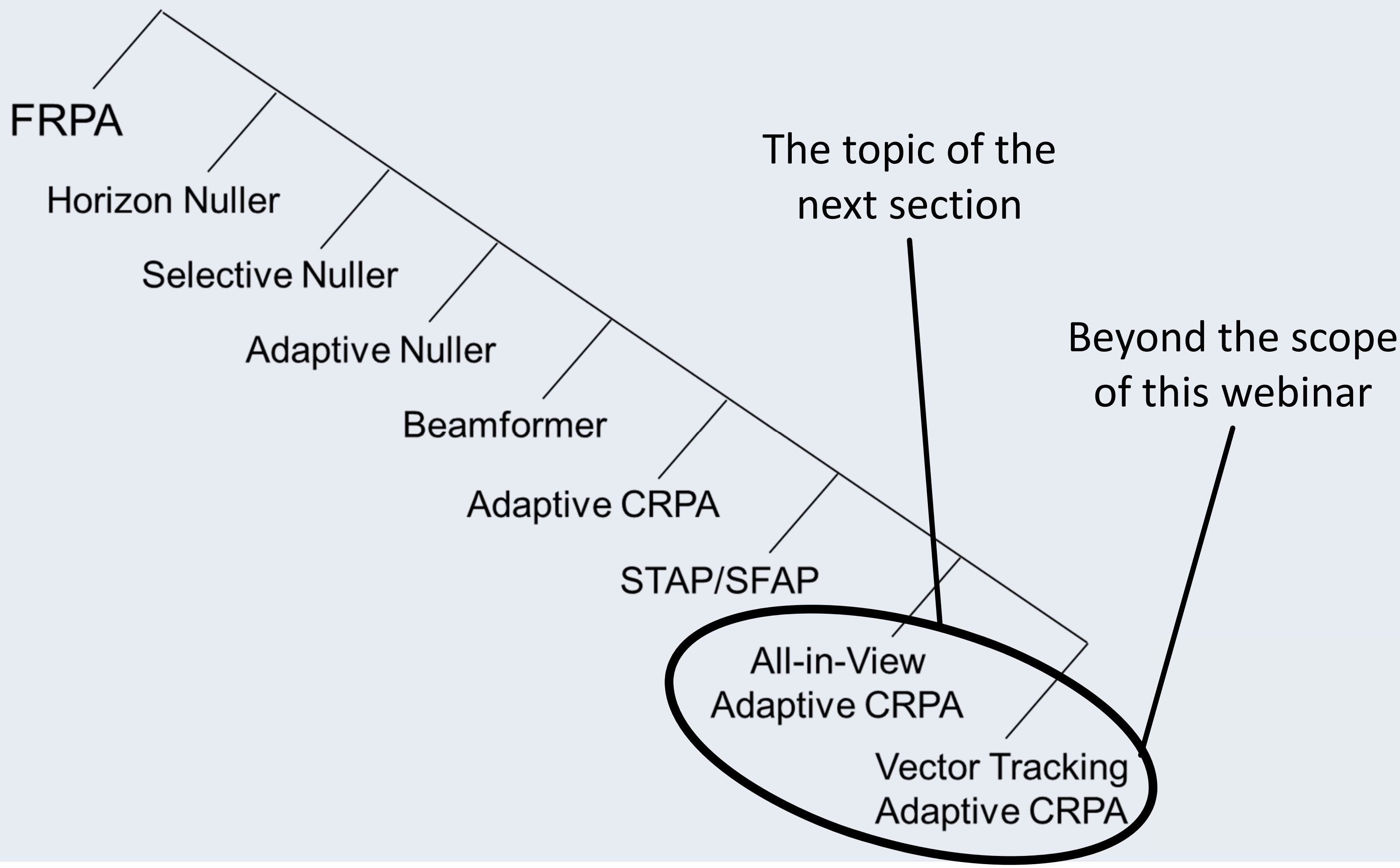
The Adaptive CRPA for Beamforming & Nullsteering



Space-Time Adaptive Processing & Space-Frequency Adaptive Processing



Advanced Classes of GPS Receive Antennas



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The Traditional GPS Receiver:
Showing One Satellite Tracking Channel

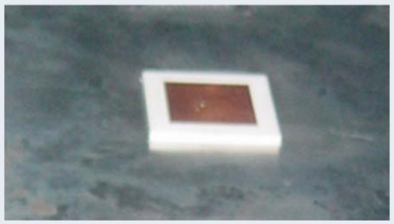
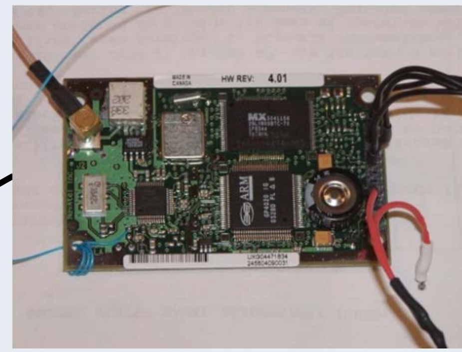
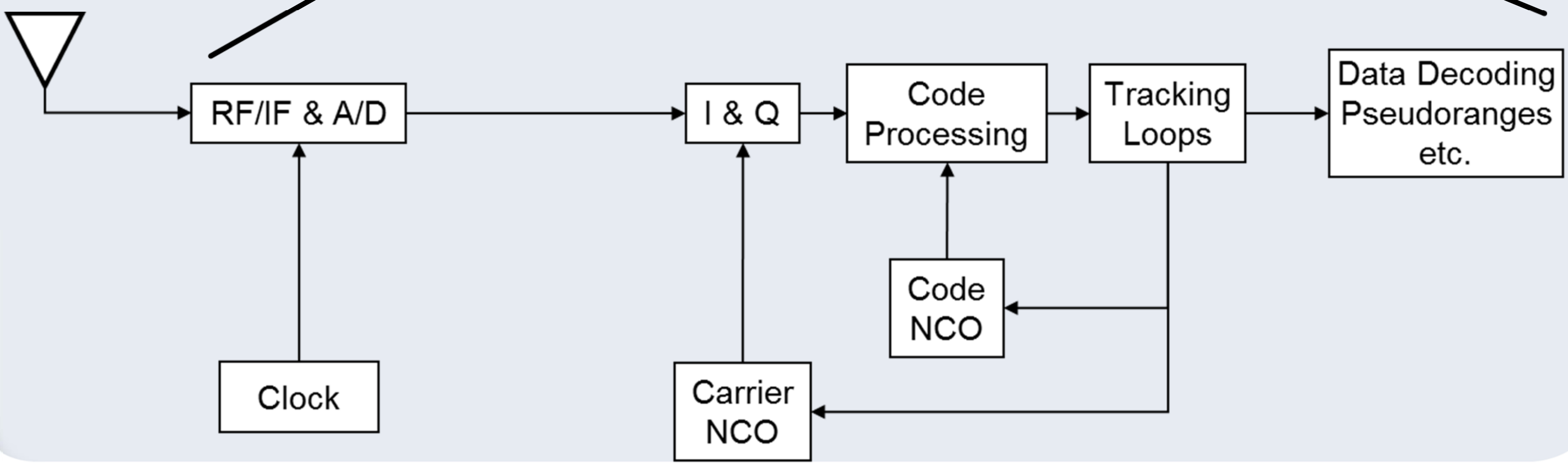


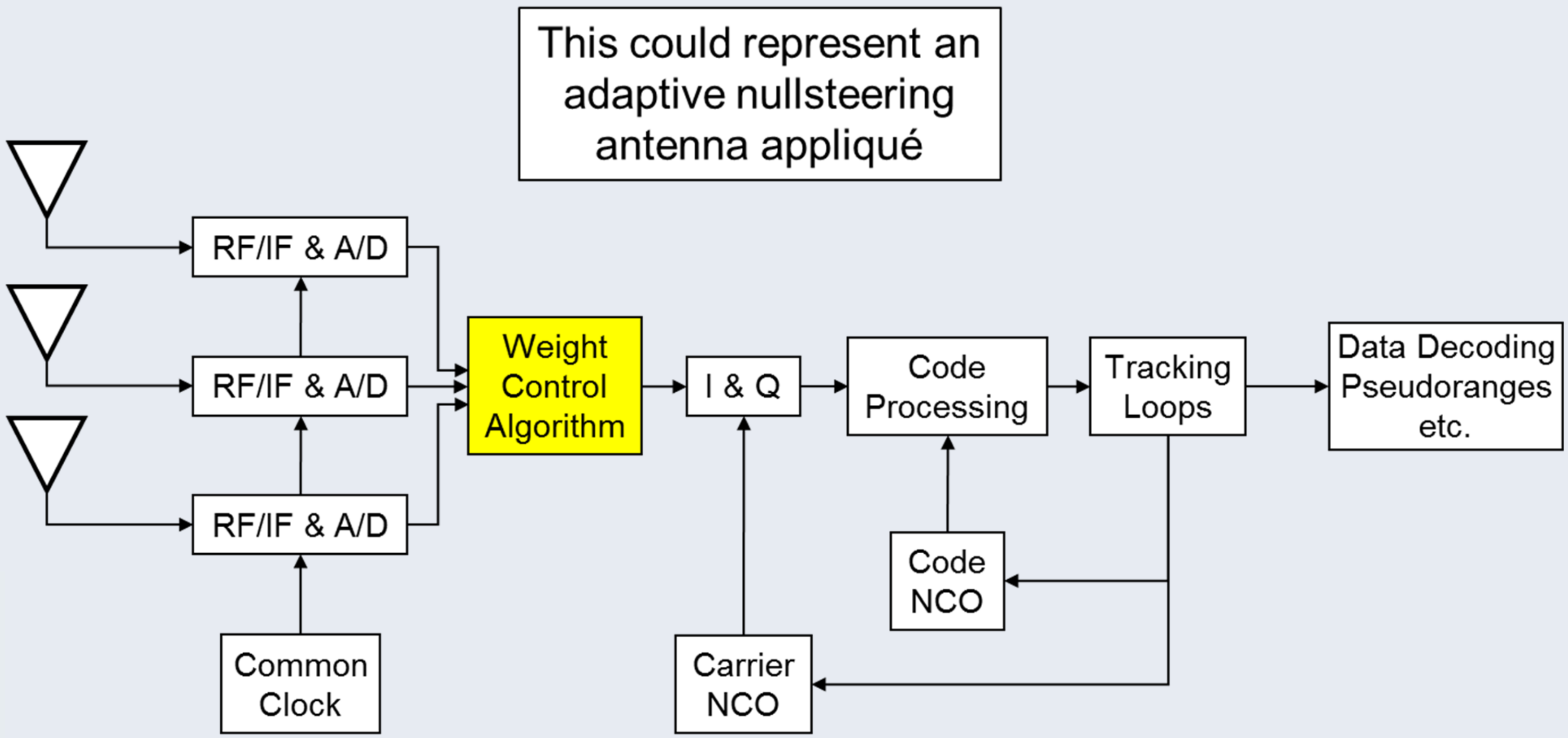
Image courtesy U-S. Kim



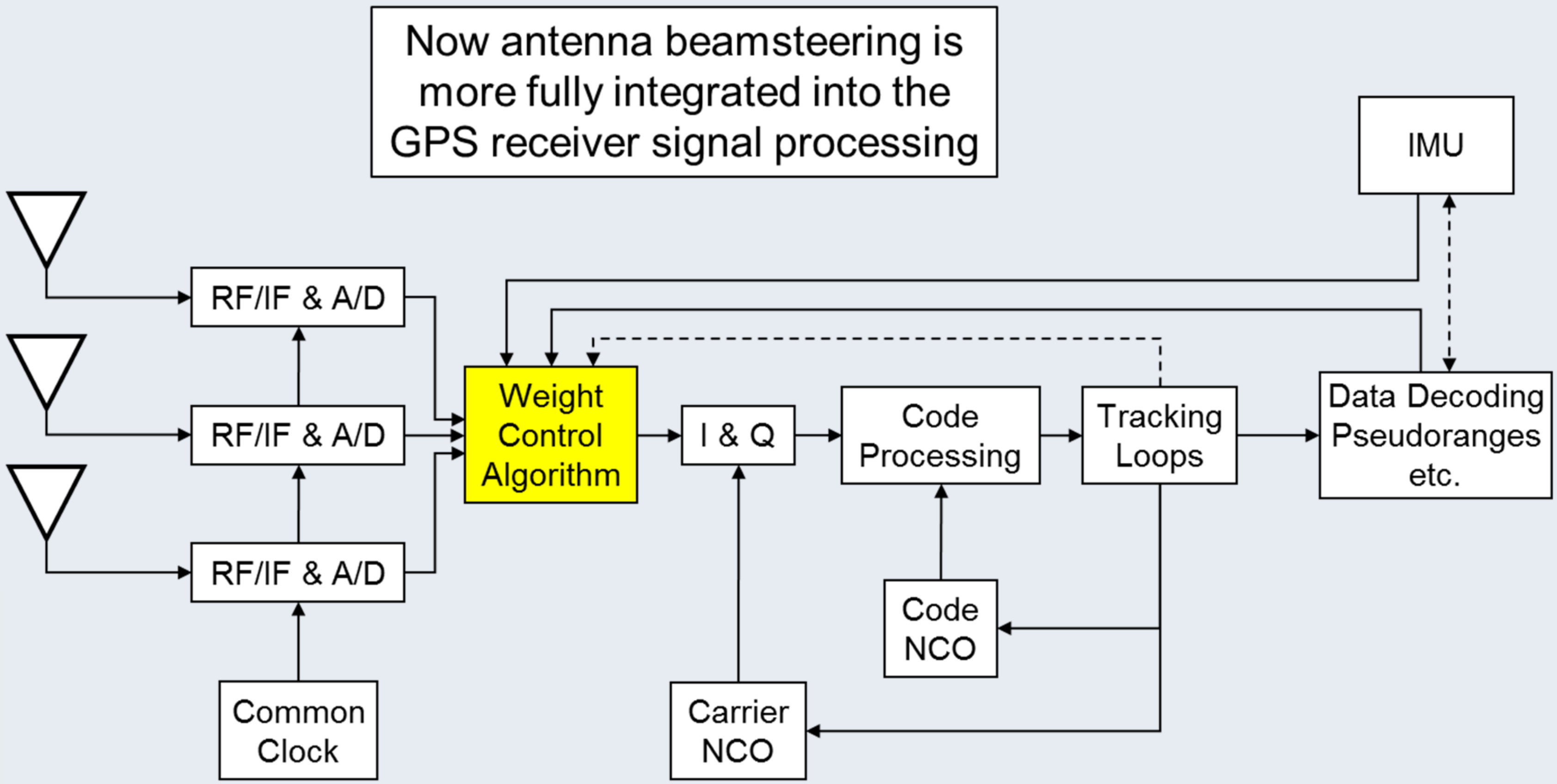
NovAtel SuperStar II
Author photo



The Beamsteering GPS Receiver:
Showing One Satellite Tracking Channel

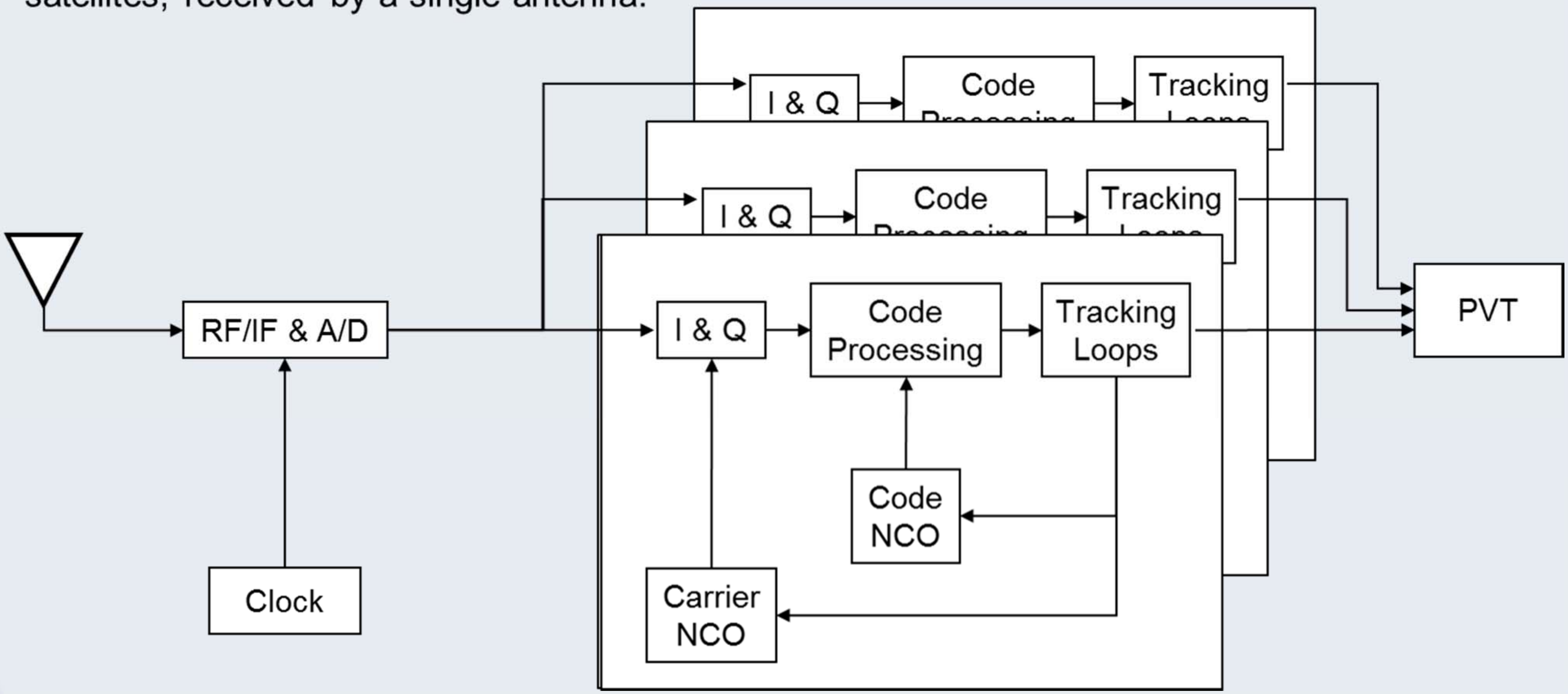


The Beamsteering GPS Receiver: Showing One Satellite Tracking Channel

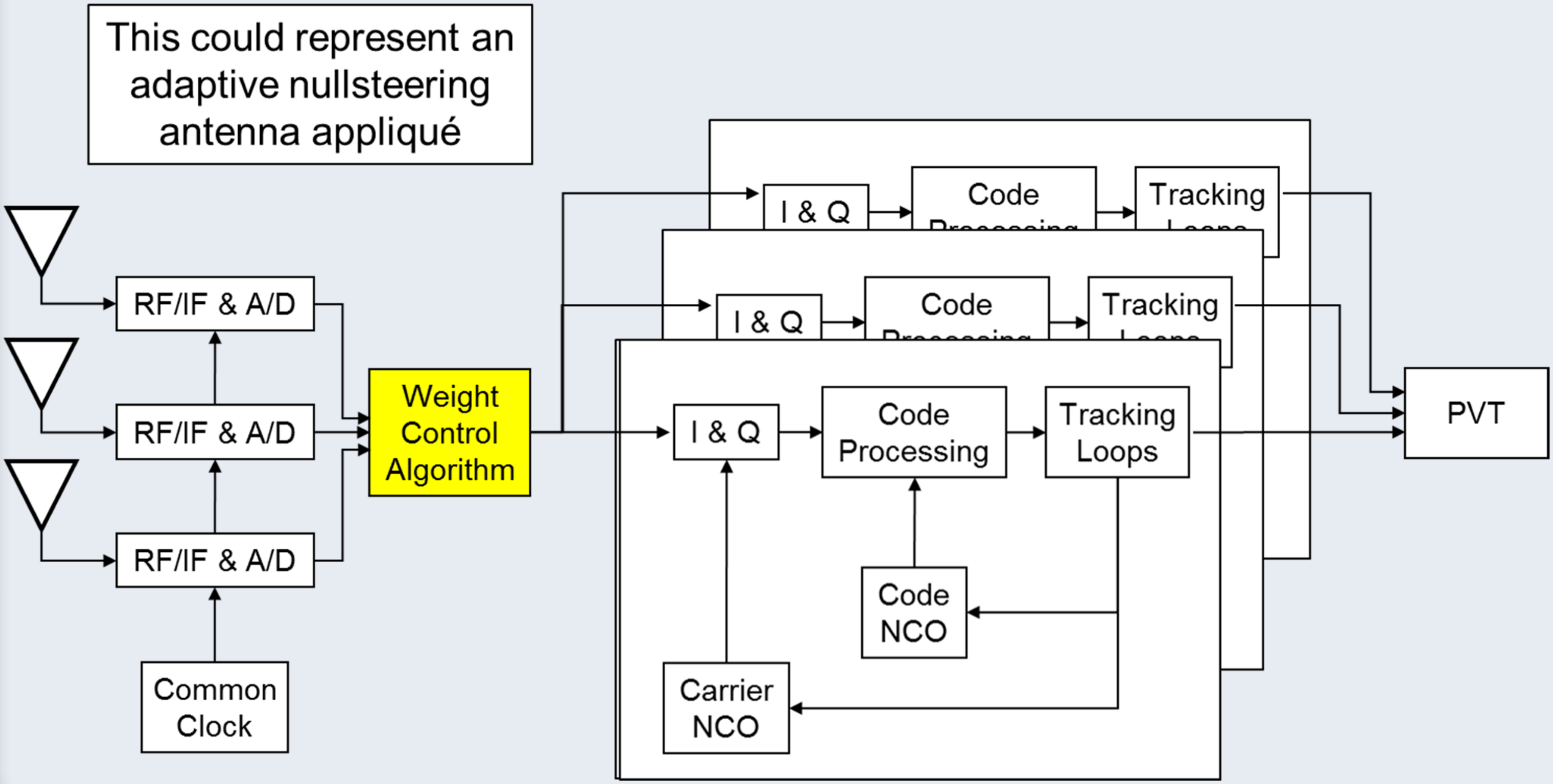


The Traditional GPS Receiver:
Showing Multiple Tracking Channels

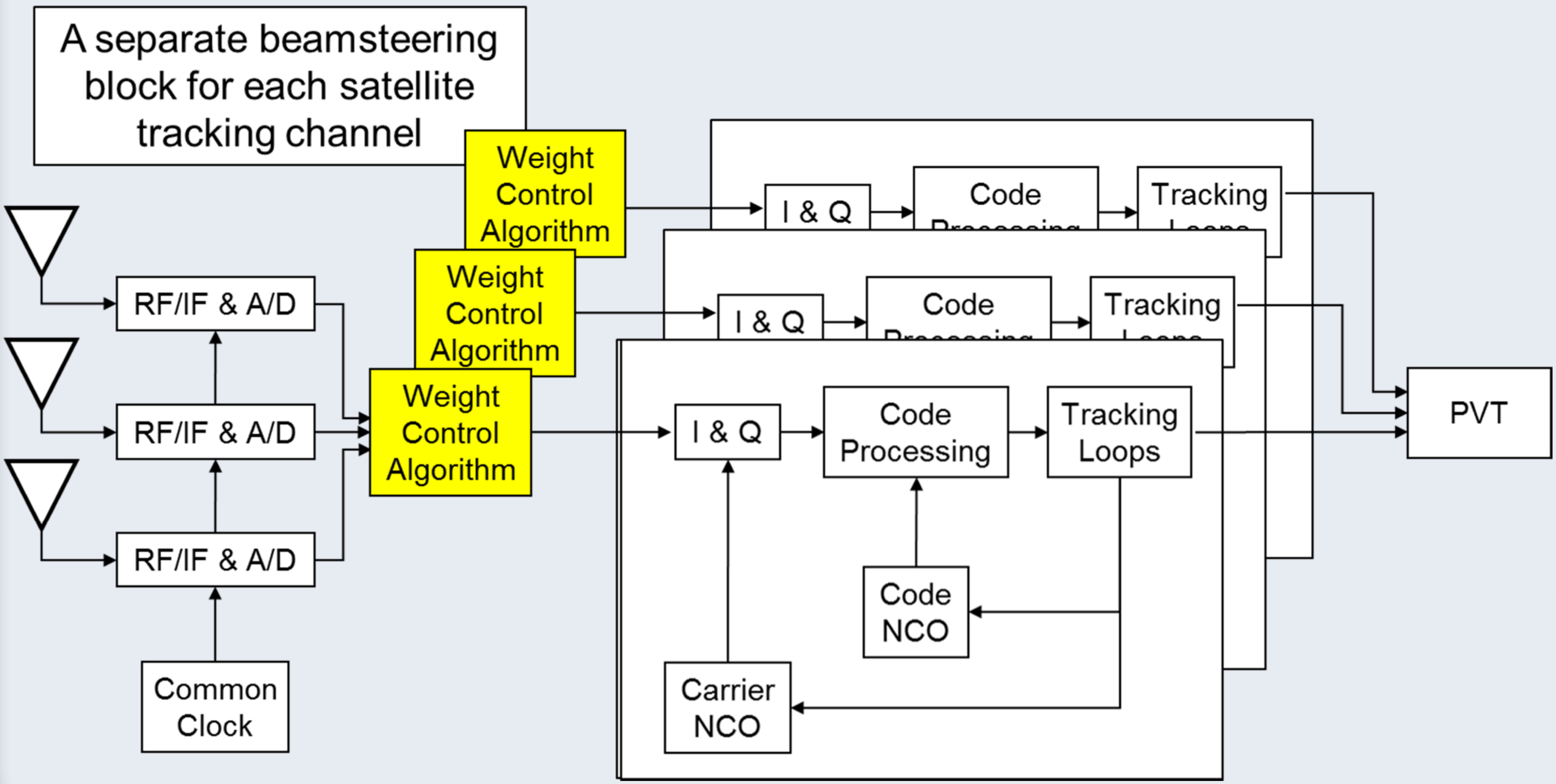
** Remember, the conventional receiver processes in parallel the signals from all satellites, received by a single antenna.



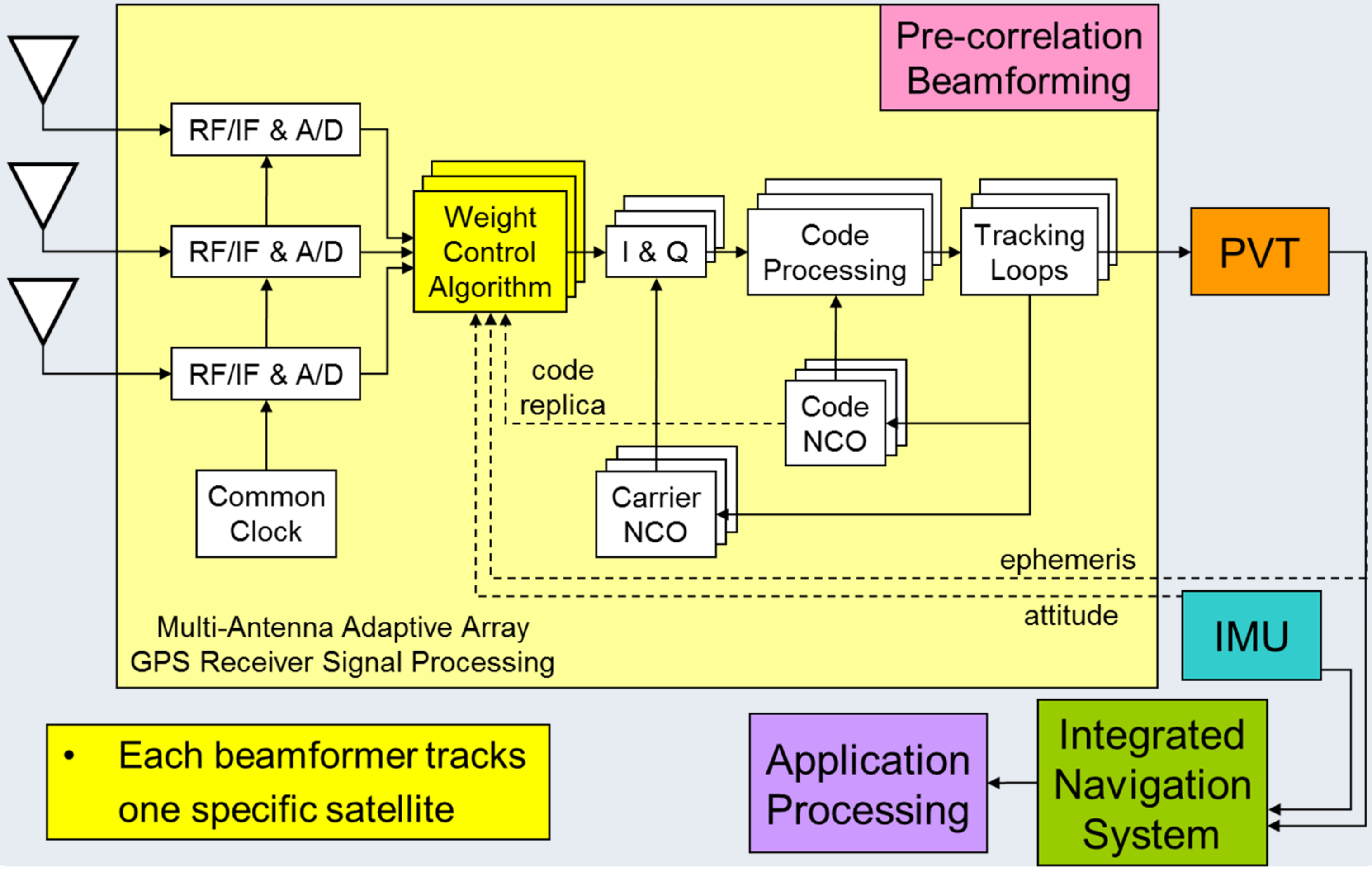
The Beamsteering GPS Receiver: Showing Multiple Tracking Channels



The Beamsteering GPS Receiver:
Showing All Satellite Tracking Channels



The Adaptive Beamforming GPS Receiver: Showing All Satellite Tracking Channels



- Each beamformer tracks one specific satellite

Part I: Adaptive Antennas for GPS Receivers

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Introduction

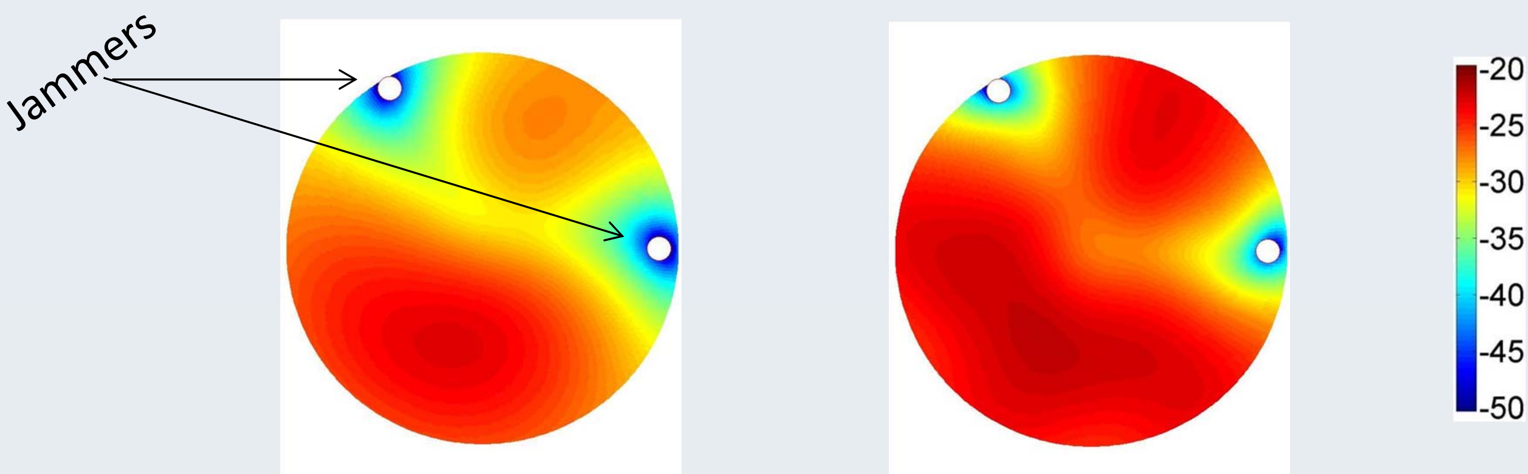
- Performance of adaptive antennas depends on the antenna array, weighting algorithm as well as on the interference environment.
- No amount of signal processing can make up for a poorly designed antenna array.
- In this part of the webinar, we will discuss guidelines for the physical antenna array design.

GNSS Antenna Arrays

- Aperture Size
- Number of elements and element distribution
- Planar or non-planar
- Individual elements

Aperture Size

- Antenna array should have the largest possible aperture.
- Large aperture leads to better resolution
  - One will be able to get out of a null faster.
- Fewer GNSS satellites will be lost due to spatial nulling

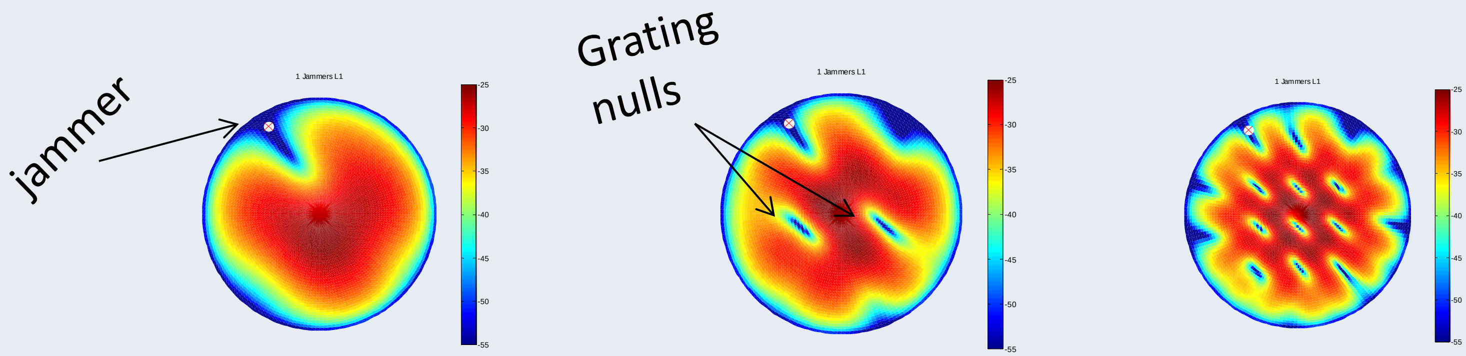


Small aperture

large aperture

Number of Elements and Distribution

- To avoid sympathetic (grating) nulls, Interelement spacing should be less than half a wavelength



- An antenna array with large aperture will have many antenna elements, and this in turn will increase the weight, power consumption and cost.
  - Thinned antenna array nay be needed
- A careful thinning of the antenna array should be carried out. Antenna literature is full of thinned antenna arrays
- Fortunately or unfortunately, GNSS antenna arrays, in general, have small aperture.

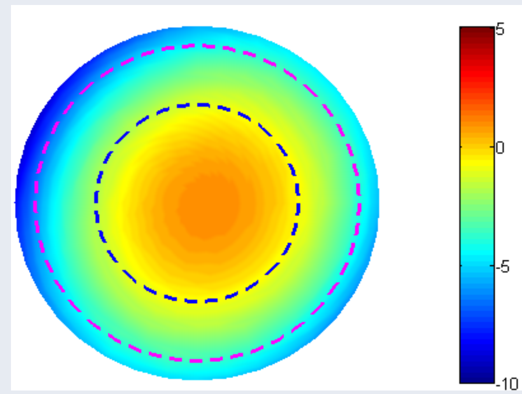
Number of Elements and Distribution

- Since GNSS antenna arrays have small aperture, one should densely (very small interelement spacing) pack the aperture
  - More degrees of freedom
- Increasing the number of elements in a given aperture
  - Will not increase the resolution
  - May lead to loss of upper hemispherical coverage from individual elements
  - Antenna induced biases will be affected

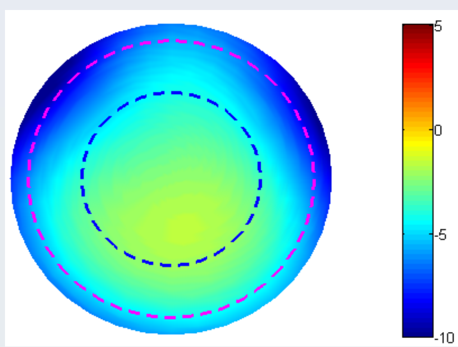
Number of Elements and Distribution

A small antenna Array

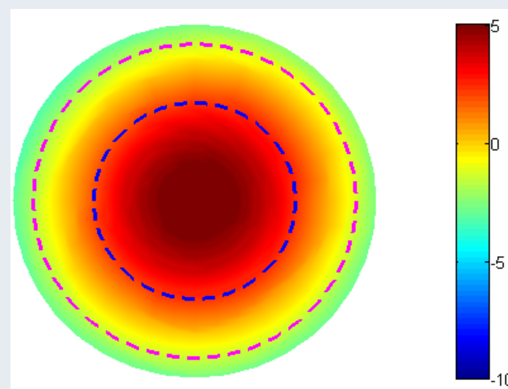
An element by itself



Element in array mode



Elements weighted to steer beam along zenith



Number of Elements and Distribution (cont.)

- Inter-element spacing should be around 0.4 wavelength to 0.45 wavelength.
- For fully filled aperture, the element distribution does not play a big part.
- individual antenna element size and PWC requirements dictate the maximum number of elements in GNSS antenna arrays.

Ask the Experts – Part 1

Dr. David S. De Lorenzo
Principal Research Engineer
Polaris Wireless

Dr. Inder (Jiti) Gupta
Research Professor
The Ohio State University

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Poll #2

Should a GNSS antenna be designed for smallest possible bandwidth to filter undesired signals?

1. *Yes*
2. *No*
3. *Don't know*

Part II: Adaptive Antennas for GPS Receivers

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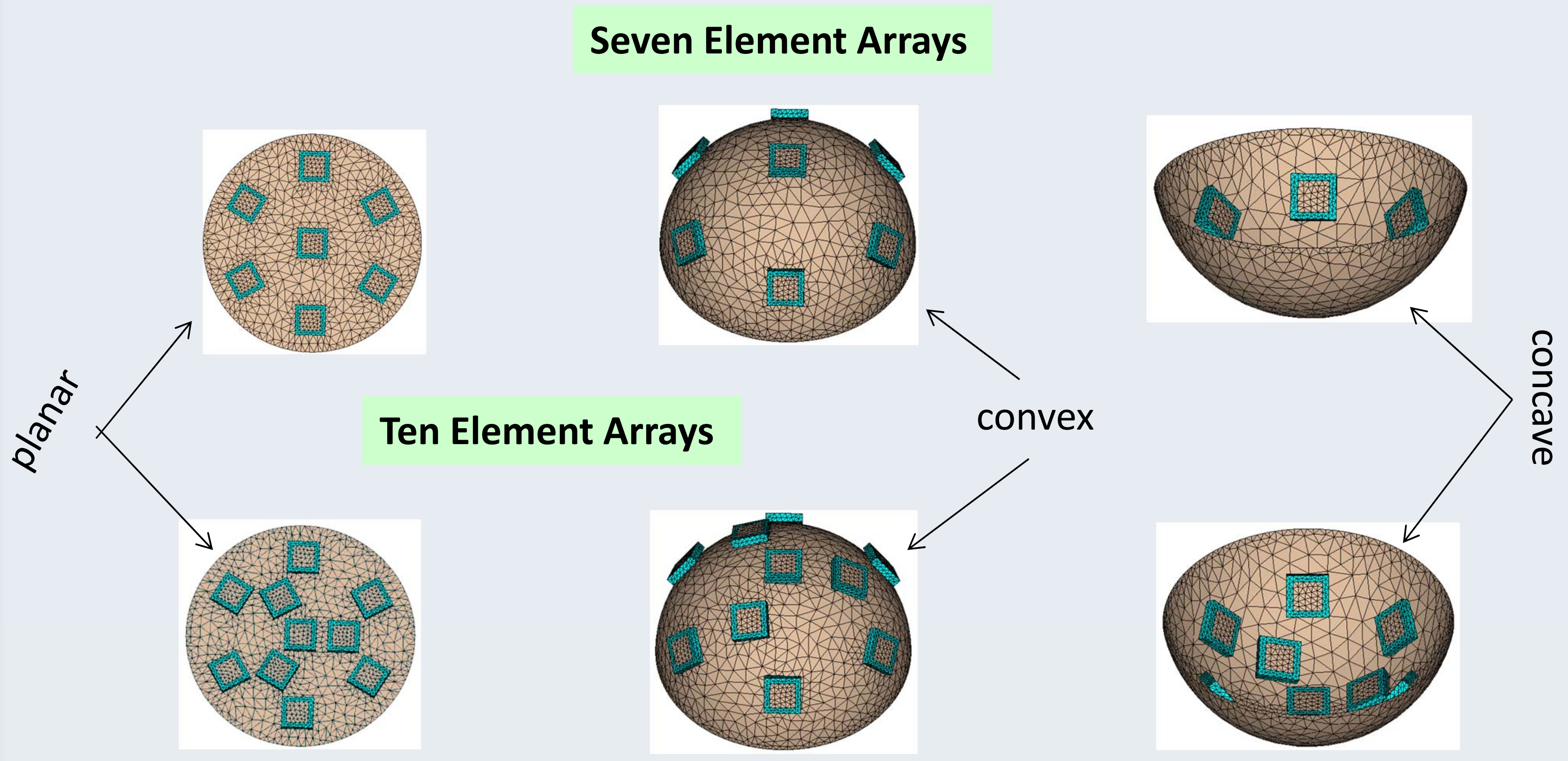
Planar vs. Non-Planar

- Currently, planar controlled reception pattern antennas (CRPAs) are used with GNSS receivers.
- For low elevation signals, planar CRPAs have limited resolution in the vertical direction
  - non-planar CRPAs would be a better choice.
- Convex non-planar CRPAs have the best performance.
- One can add more elements to the convex non-planar CRPAs to improve AJ performance.

Some Antenna Arrays Investigated



All antennas have approximately the same size foot print

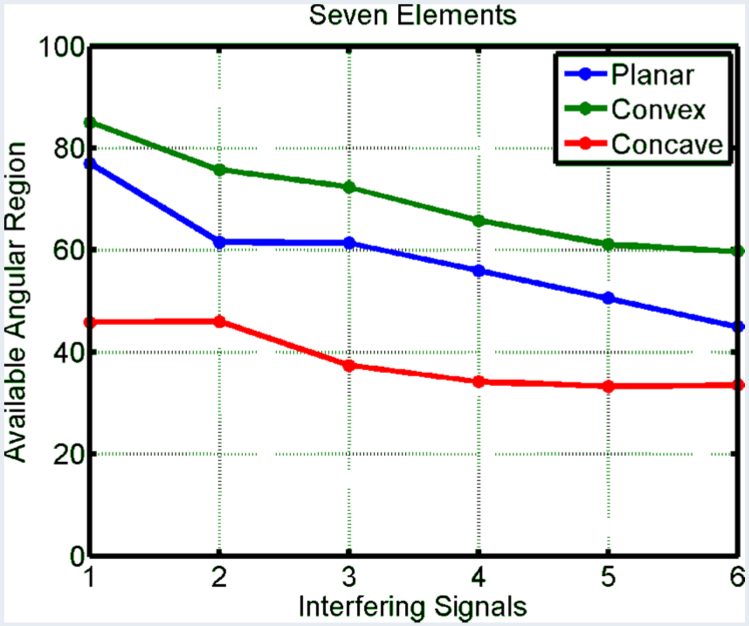
EM Analysis of Antennas

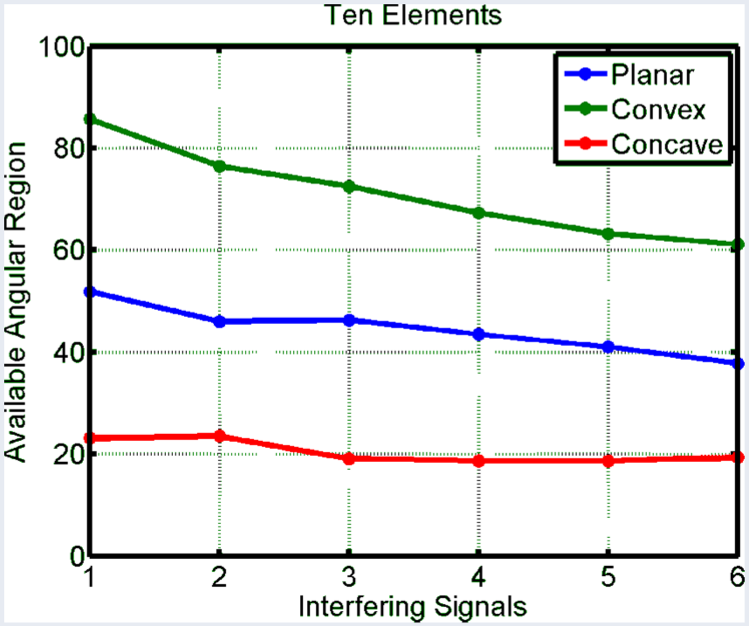
- A numerical EM (electromagnetic code), FEKO, is used to calculate *in situ* volumetric patterns of individual antenna elements.
- Patterns include mutual coupling as well as structure effects.

Incident Signal Scenario

- A desired signal and multiple interfering signals.
- Desired signal has -30 dB SNR and its direction is varied to scan the upper hemisphere.
- Strong interfering signals with elevation angles of -10 to 20 degrees.
- Twenty five independent trials.
- Angles of arrival of the interfering signal is varied randomly from one trial to the next.
- All incident signals are narrow band signals
- Space only processing

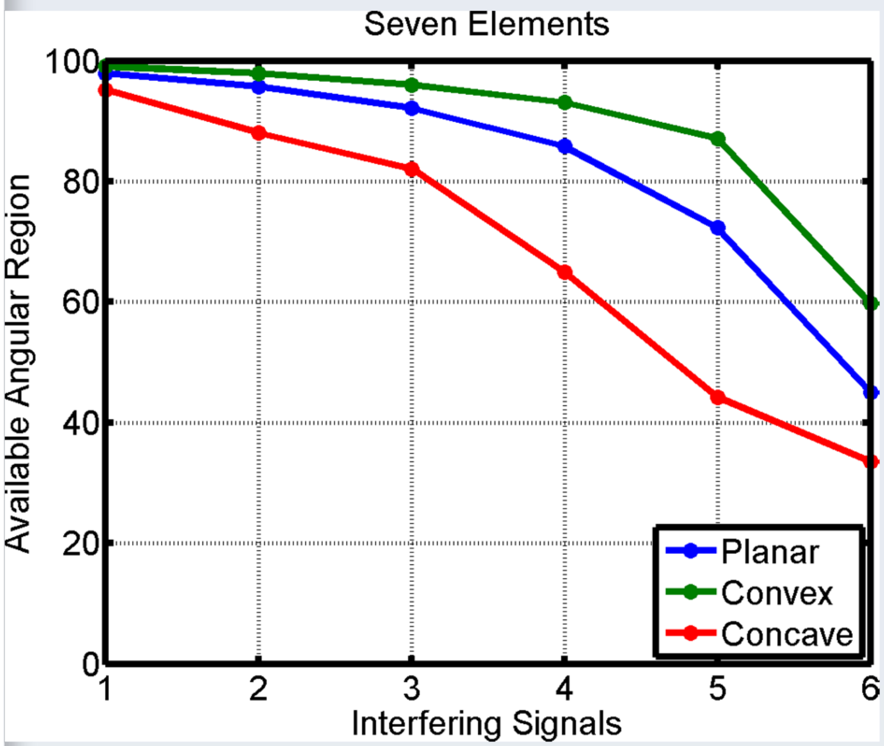
Available Angular Region (-35dB Threshold)

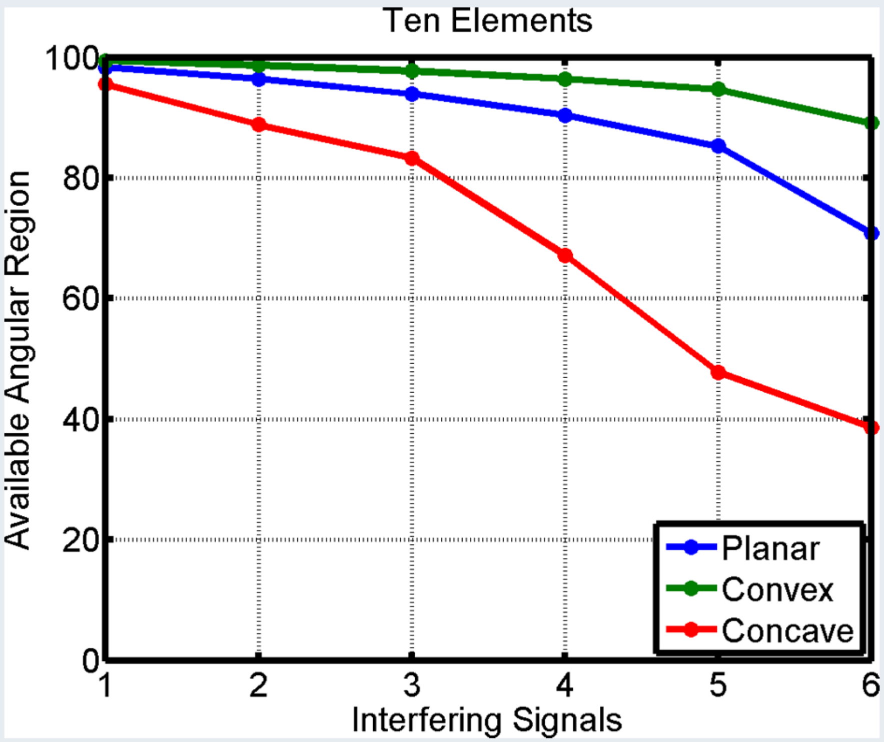




Simple null steering

Available Angular Region (-35 dB Threshold)





Unit Response in the Desired Signal Direction (beam steering and nulling)

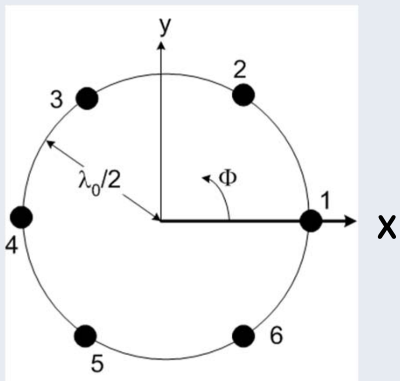
Antenna Elements

- Individual antenna elements dictates the performance of an array
- Individual antenna elements should be designed for
  - uniform coverage over the given field of view.
  - larger bandwidth than the bandwidth of interest.
    - Less distortion of the satellite signal
    - More stable phase center over the given field of view
    - Less strain on the antenna electronics.

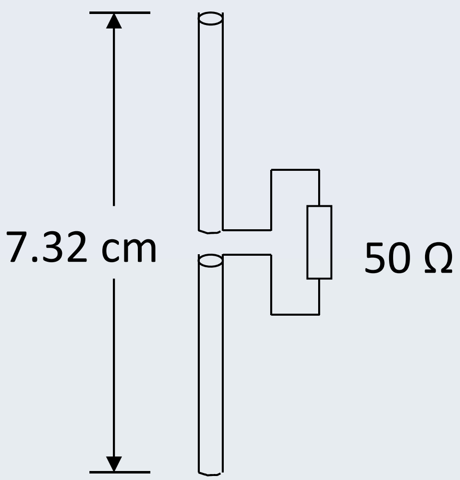
Dispersive antenna elements + Mutual Coupling → Dissimilar, Dispersive Antenna elements

Antenna Geometry

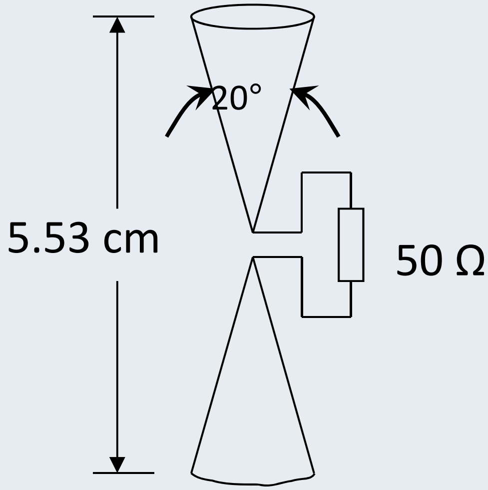
- Six antenna elements distributed uniformly on a circle.
- Elements are oriented along z.
- 2 GHz center frequency.
- Two different antenna elements.



Thin Dipole

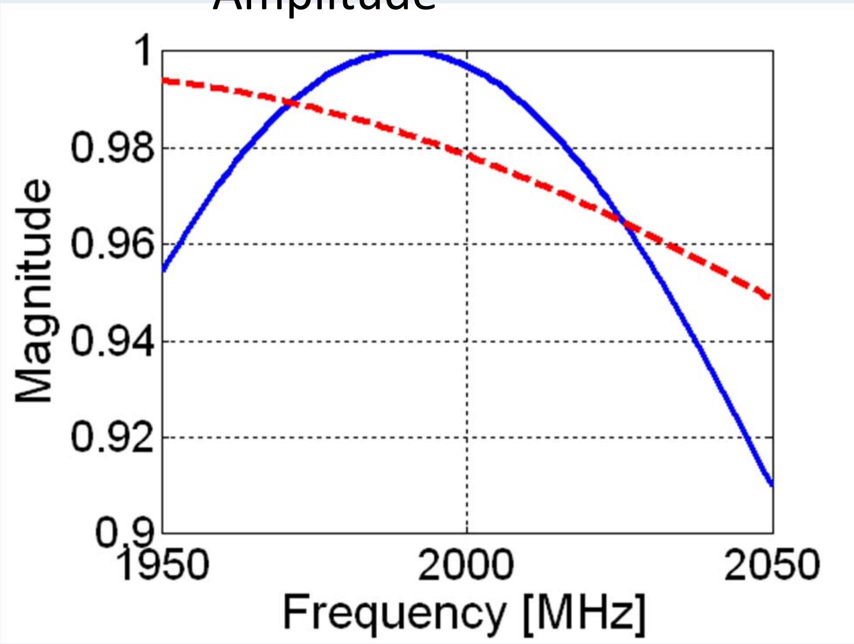


Biconical Antenna

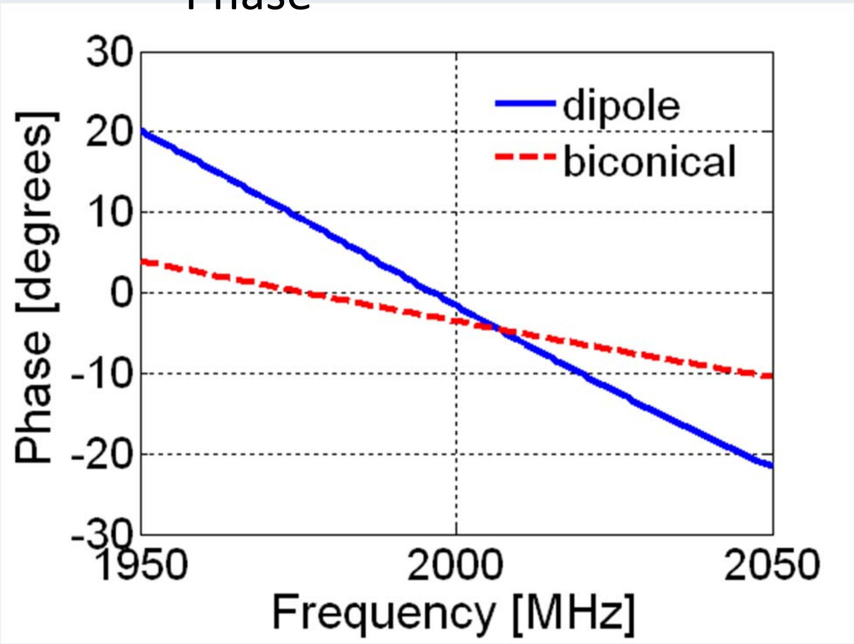


Response of a Single Element

Amplitude



Phase



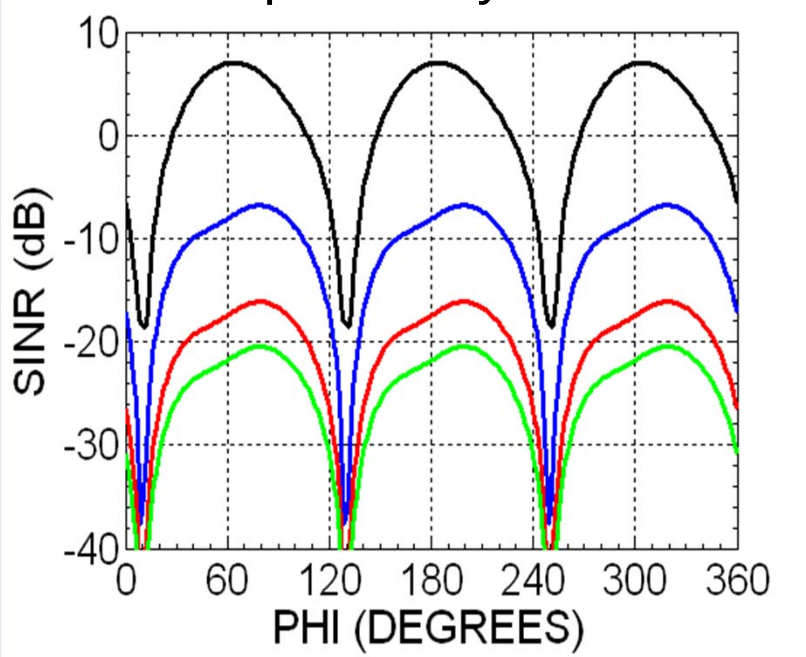
- Thin dipole has more variation with frequency and is more dispersive.

Signal Scenario

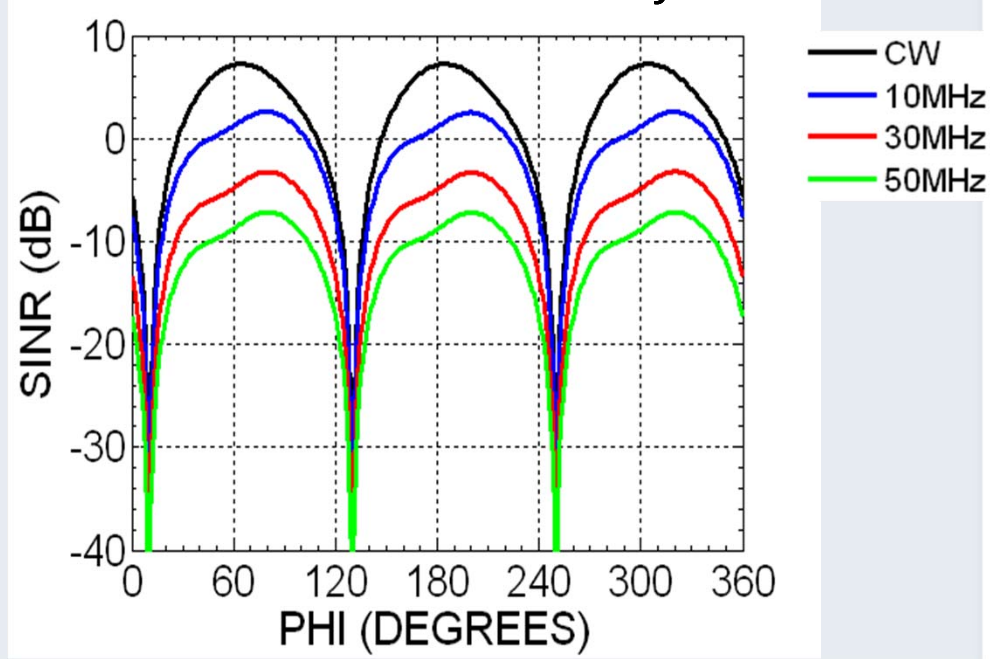
- All signals are incident in the x-y plane and have flat power spectral density.
- The desired signal has 50 MHz bandwidth and 0 dB SNR at an isolated element.
- All interfering have the same bandwidth and 50 dB INR at an isolated element.
- Mutual coupling between elements is included.

Output SINR in the presence of three Interference Signals at Φ=10°, 130° and 250°

Thin Dipole Array



Biconical Antenna Array



- For wideband signals, both arrays are fully constrained.
- Biconical antenna array is performing much better.

GNSS Adaptive Antenna Array

- Should have a large aperture
  - In general, platform size dictates the aperture
- Should be fully packed
  - Hardware cost and size of the individual elements dictates the number of elements
  - In any case, interelement spacing should be less than half a wavelength
- Elements, if possible, should be distributed on a convex surface. The larger the surface curvature the better.
- Individual antenna elements should cover the field of view and should be designed for larger bandwidth.

Part II: Adaptive Beamforming/Nullsteering Antennas for GPS Receivers

Author photo

David S. De Lorenzo
with contributions from many, including Sherman Lo, Yu-Hsuan Chen, Dennis Akos, Per Enge, and others

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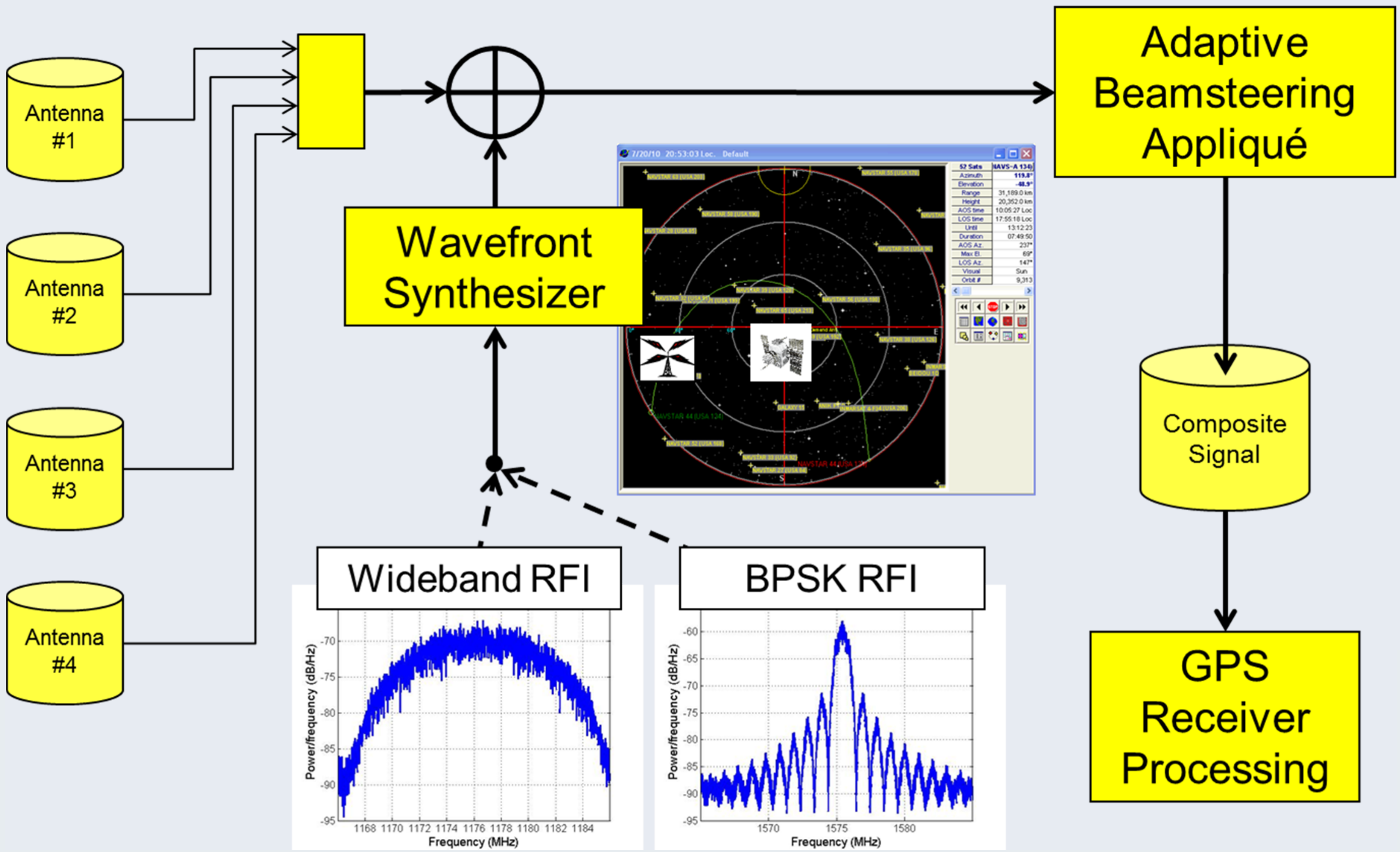
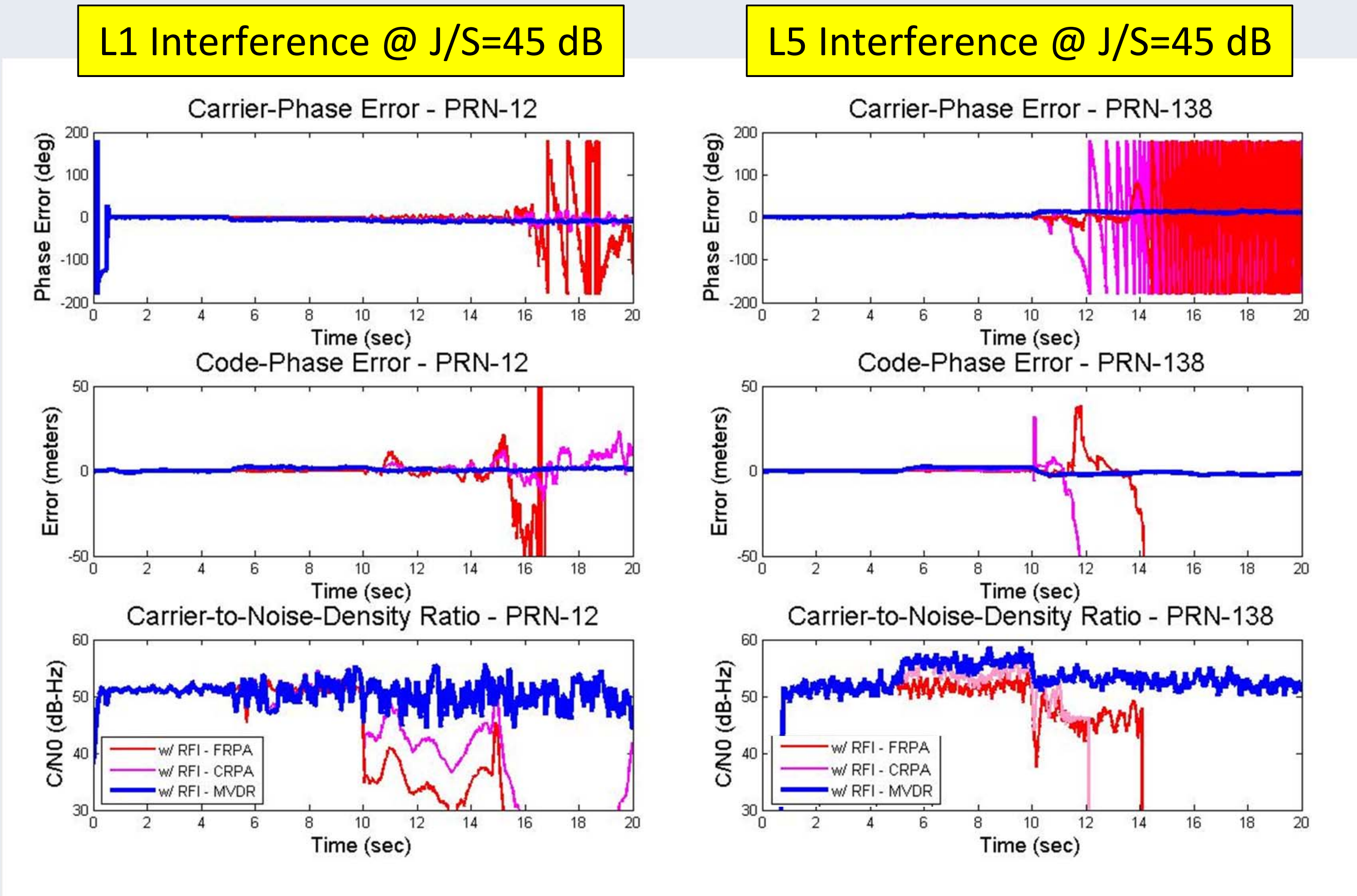
Recorded Signal Playback w/Synthetic RFI Overlay



Recorded Signal Playback w/Synthetic RFI Overlay



Signal Generator w/ Wavefront Synthesizer and Operational Hardware-in-the-loop

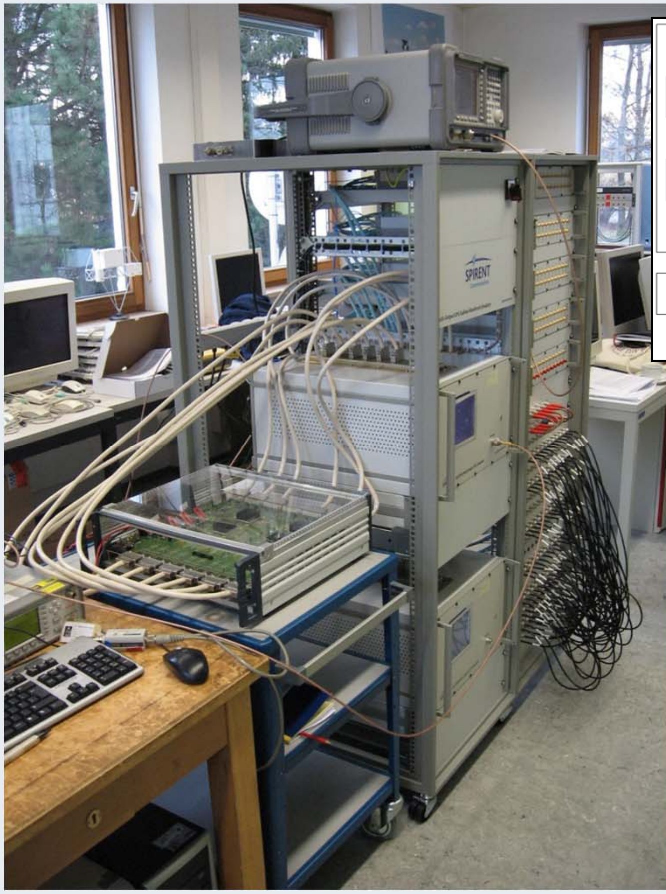
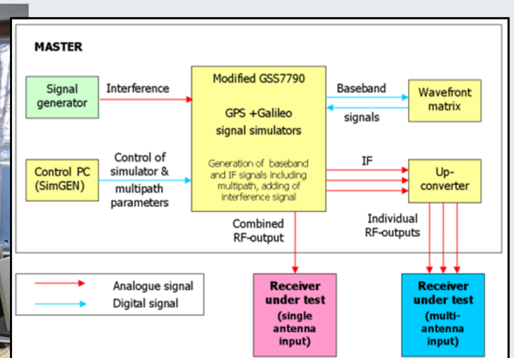
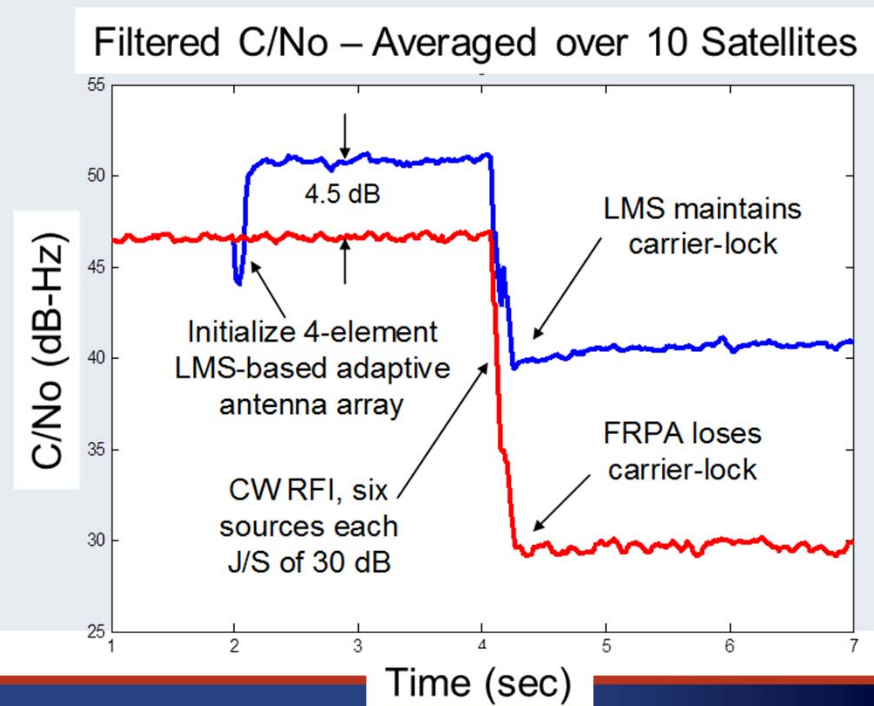


Image courtesy DLR Institute of Communications and Navigation, Dr. Felix Antreich and Dr.-Ing. Achim Hornbostel





Anechoic Chamber Testing w/ Operational Hardware-in-the-loop

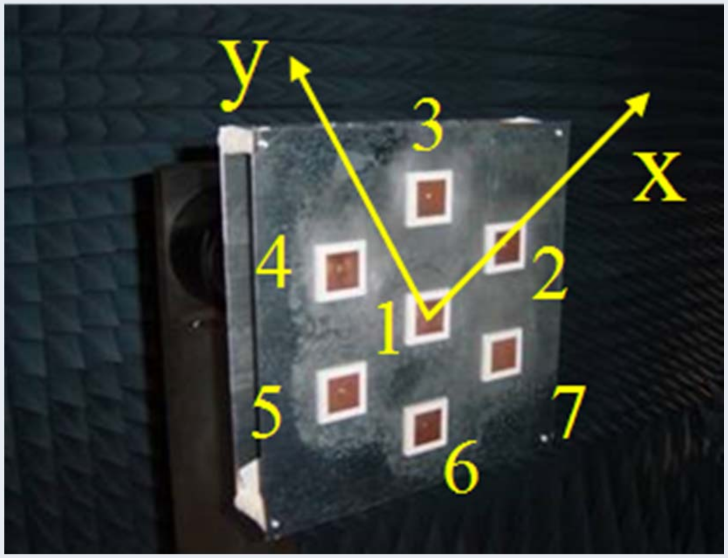


Image courtesy U-S. Kim

- Enables carefully controlled and highly repeatable test campaigns
- Expensive and specialized facilities are not easily available to all researchers

Image from Inside GNSS

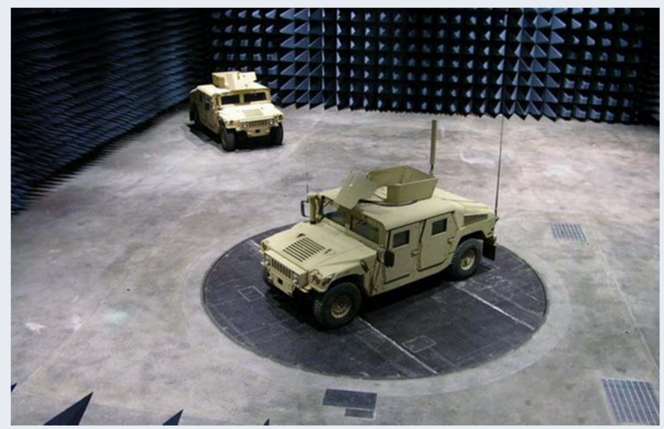


Image courtesy Army Research Lab

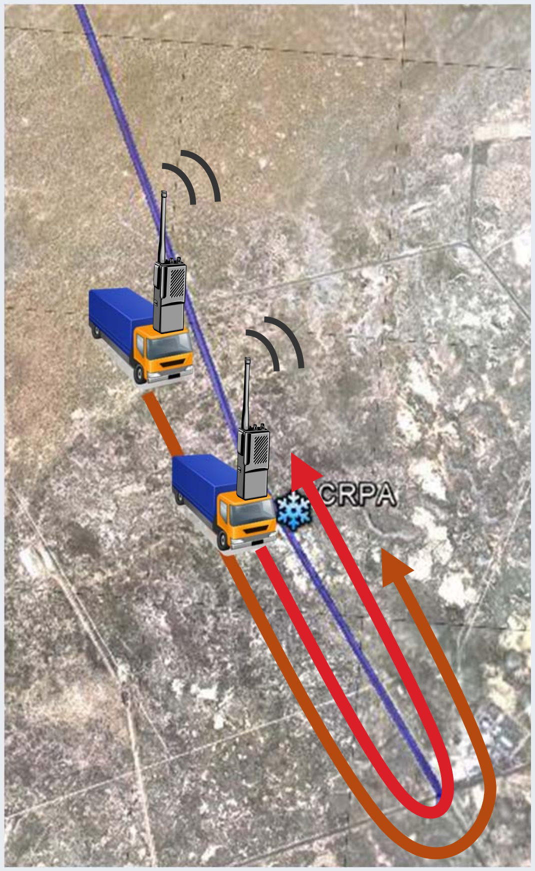
Over-the-air Jamming w/ Operational Hardware-in-the-loop

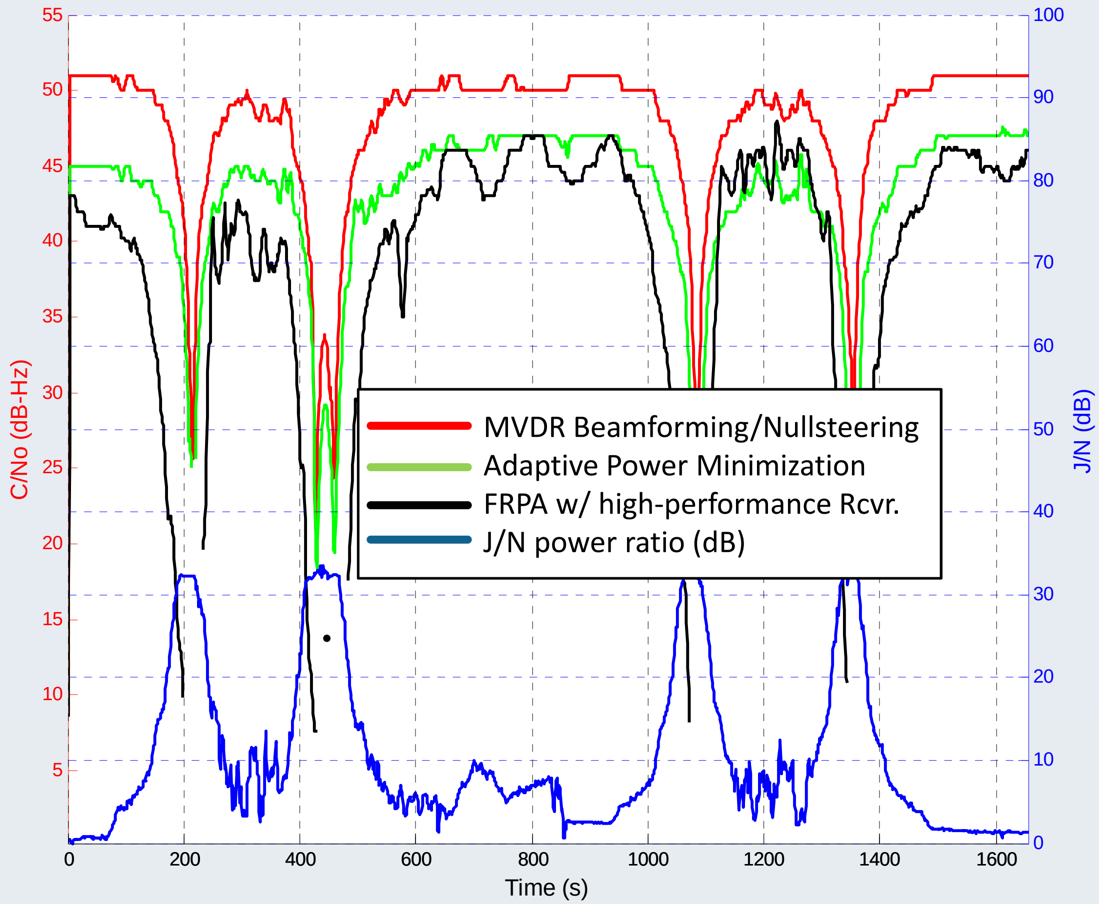
Images courtesy 746 Test Squadron

- The ultimate performance test prior to deployment or release-to-market
- These are *not* simple events
  - Wide-spread disruption of highly protected ARNS band for tens to hundreds of kilometers

Author photo

Over-the-air Jamming w/Operational Hardware-in-the-loop





Images courtesy Y-S. Chen

Outline

- Overview of signal processing for adaptive antenna systems
- Integrating beamsteering antennas with GPS receivers
- Taking it live: Testing adaptive antenna arrays, including over-the-air jamming trials
- **Practical considerations and the civil outlook going forward**

Interference Threats to GPS/GNSS

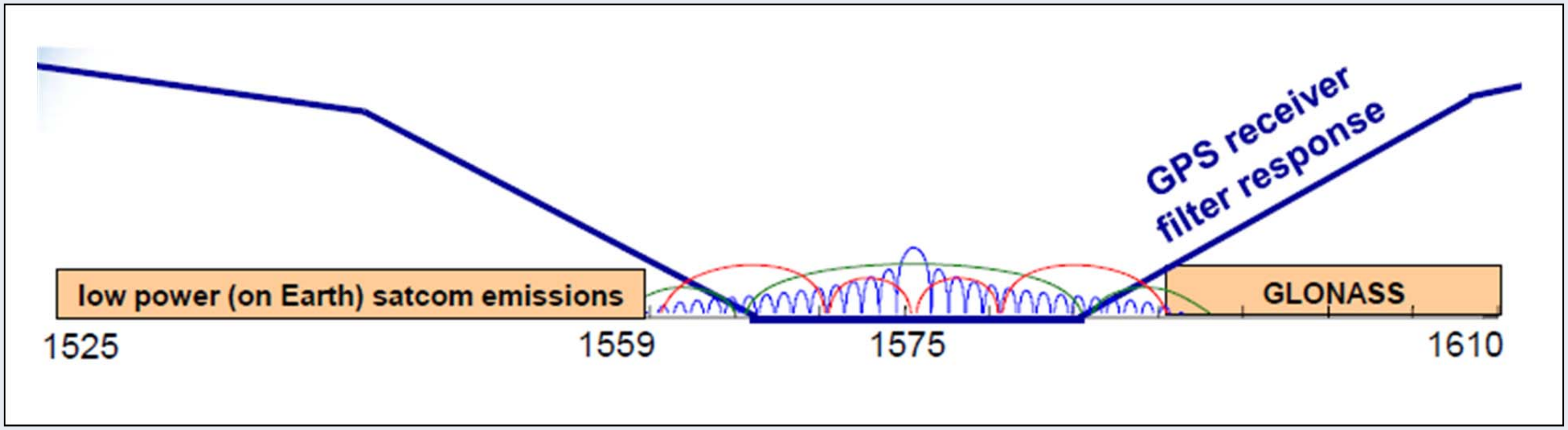


Image from C. Hegarty, "Spectrum Issues", 2011.

- GPS signals reach the receiver at low power, and RFI can come from many potential sources
  - High-power signals in nearby frequency bands
  - Accidental or unintentional in-band interference
  - Deliberate jamming, incl. wide-area denial of service

Interference Threats to GPS/GNSS

Scheduled Outages: DoD Testing & NOTAMs	Unintentional Outages: Anomalous Events
Short-range Jamming: Low-power GPS Jammers	Intentional Jamming: Deliberate GNSS Attack

Interference Threats to GPS/GNSS

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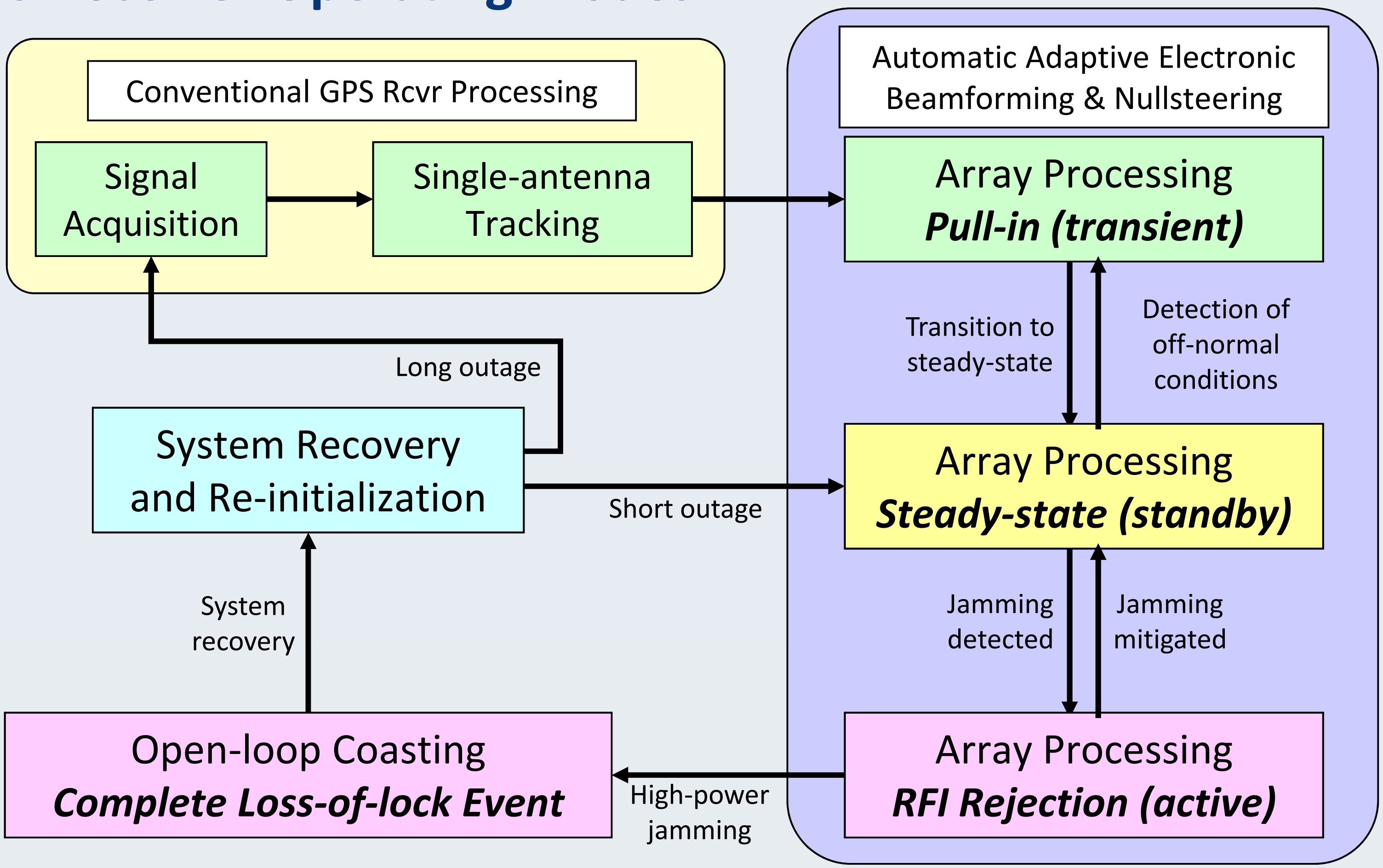
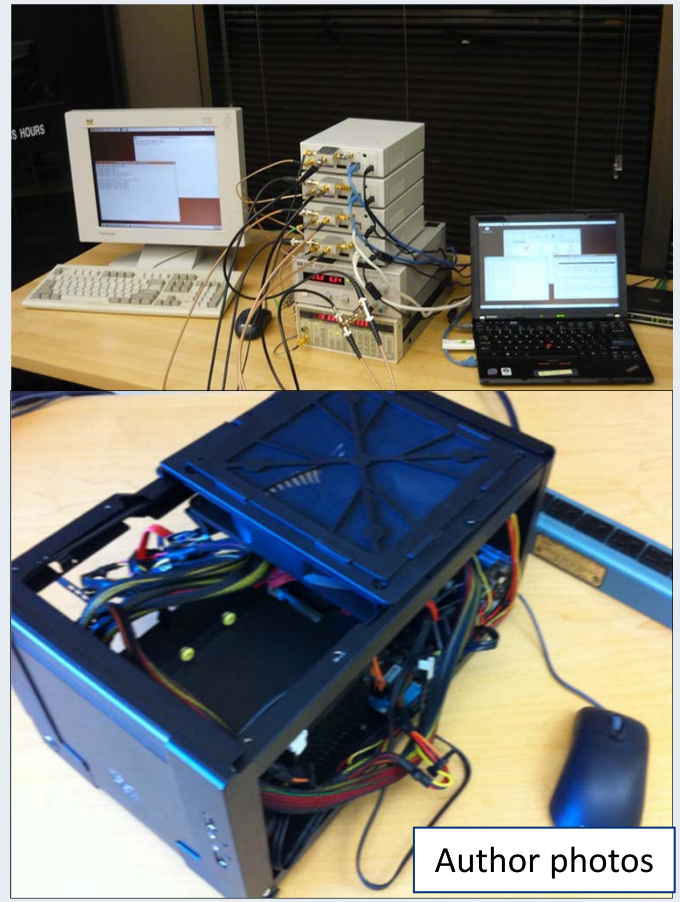
Adaptive Antenna Arrays & GNSS Receiver Operating Modes



Example of an All-in-view Adaptive Beamforming/Nullsteering GPS Receiver

- All-in-view real-time adaptive beamforming & nullsteering CRPA software receiver
  - 4 elements, 24+ channels, 4 MHz I/Q sampling, 14 bits ADC, online carrier-phase bias compensation
- Based on all COTS components
  - Patch antennas
  - SW programmable radio front-ends
  - Intel i7 workstation computer (*2012*)



Author photos

Example of an All-in-view Adaptive Beamforming/Nullsteering GPS Receiver

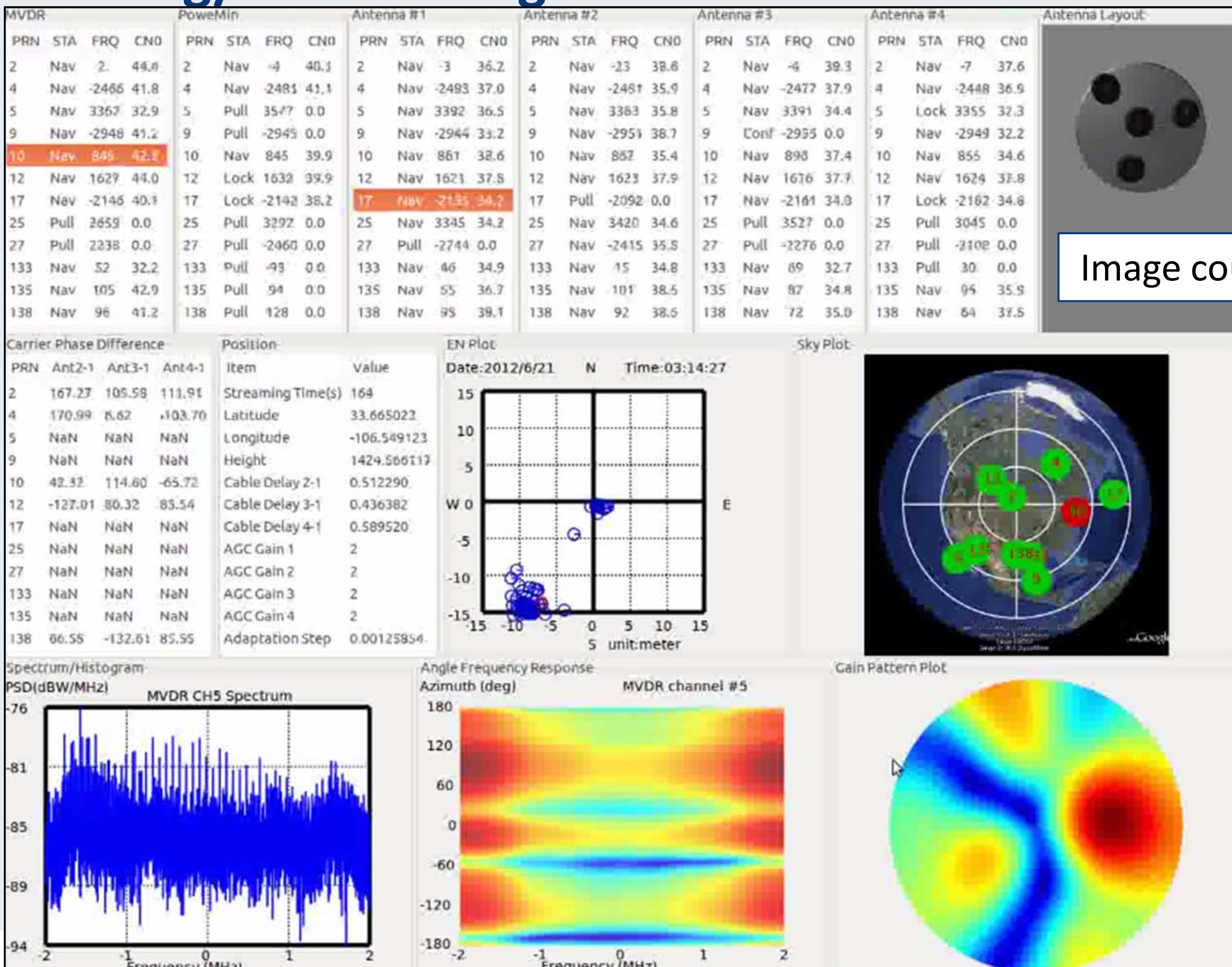


Image courtesy Y-S. Chen

Conclusions

- A number of anti-jam options are available to the GPS receiver designer – some more effective *and more expensive* than others – and no particular solution will work best in absolute isolation.
- Multi-element adaptive antennas are among the very strongest interference mitigation techniques that exist.
- The proper approach is to define the mission objectives, then evaluate vulnerabilities & threats, and finally develop an appropriate response.

Next Steps

Visit www.insidegnss.com/webinars for:

- PDF of Presentations (including additional slides)
- Bibliography

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Poll #3

What are your top 2 concerns regarding the use of a multi-antenna setup to mitigate jamming and interference? (Please select your top 2)

1. *Size/weight*
2. *Cost*
3. *Power consumption*
4. *Complexity*

Ask the Experts – Part 2

Dr. David S. De Lorenzo
Principal Research Engineer
Polaris Wireless

Dr. Inder (Jiti) Gupta
Research Professor
The Ohio State University

Neil Gerein
Defense Product Manager
NovAtel

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