InsideGNSS

GPS | GALILEO | GLONASS | BEIDOU

Thursday, May 2, 2013

9 am – 10:30 am PDT
10:00 am– 11:30 am MDT
11:00 am – 12:30 pm CDT
Noon– 1:30 pm EDT

GNSS-DENIED ENVIRONMENTS

LIVING IN A VULNERABLE WORLD

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US/Canada attendees dial +1 (646) 558-2121

- **Access Code** 689-191-370

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WELCOME TO:

GNSS-Denied Environments

Living in a Vulnerable World

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Logan Scott
Principal Consultant
LS Consulting

George Shaw
Principal Development Engineer
Research & Radionavigation
Directorate of the General
Lighthouse Authorities of the
UK and Ireland

Sherman Lo
Senior Research
Engineer
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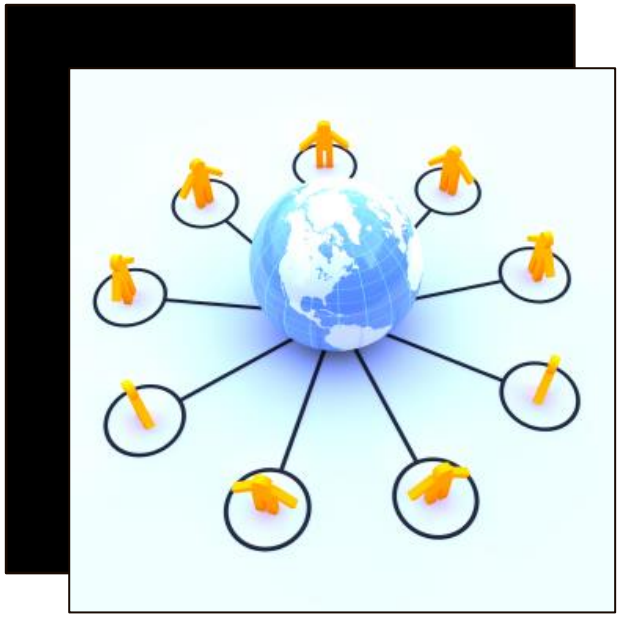
Moderator: Demoz Gebre-Egziabher, Aerospace Engineer and Mechanics Faculty at University of Minnesota

Co-Moderator: Lori Dearman, Sr. Webinar Producer

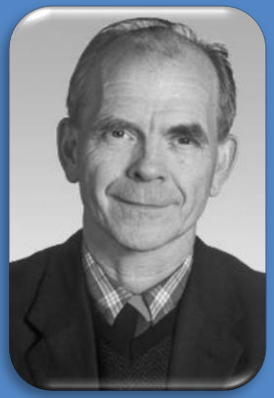
Who's In the Audience?

A diverse audience of over 650 professionals registered from 57 countries, 33 states and provinces representing the following roles:

- **22%** Product / Application Designer
- **18%** System Integrator
- **16%** Professional User
- **14%** GNSS Equipment Manufacturer
- **30%** Other



Welcome from *Inside GNSS*



Glen Gibbons

Editor and Publisher
Inside GNSS

A word from the sponsor

Neil Gerein
Aerospace & Defense
Product Manager
NovAtel

GNSS-Denied Environments
Living in a Vulnerable World

Demoz Gebre-Egziabher

Aerospace Engineer and
Mechanics Faculty,
University of Minnesota

Poll #1

Looking forward 5 to 10 years, do you think jamming and/or spoofing will impact operational use of GNSS? (please select one)

1. ***Yes, widely occurring***
2. ***Yes, occasionally occurring***
3. ***No because there will be redundant GNSSs operating***

Logan Scott, President, LS Consulting

GPS Denied Environments: Origins, Effects and Mitigations

loganscott53@gmail.com
http://logan.scott.home.comcast.net/~logan.scott/

2 May 2013

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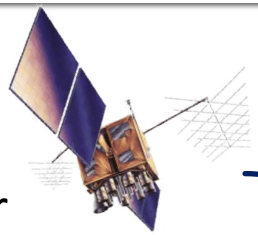
Why Is GPS So Sensitive to Jamming?



- The L1 C/A Signal
  - A 25 Watt Transmitter
  - Fed into a 13 dBiC (x 20) Antenna
  - At a Range of 20,200 km (12,550 miles)

Nominally; About the Same Parameters as a Cellular Basestation Transmitter Channel

5.45x DC to LA

Travel map from Washington, DC to Los Angeles, CA

- **Received L1 C/A Signal is Weak!**

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Why Would Someone Do That?

Motivation Oftentimes Indicates Likelihood and Method

- GPS Jamming and Spoofing (Military)
  - Denial of Navigation to Opposing Forces
  - Create Confusion / Lessen Effectiveness
- GPS Jamming and Spoofing (Civil)
  - Accidental
  - Deliberate
    - Financial Motivation (More Likely Reason)
    - Terroristic Exploit (Less Likely Reason)

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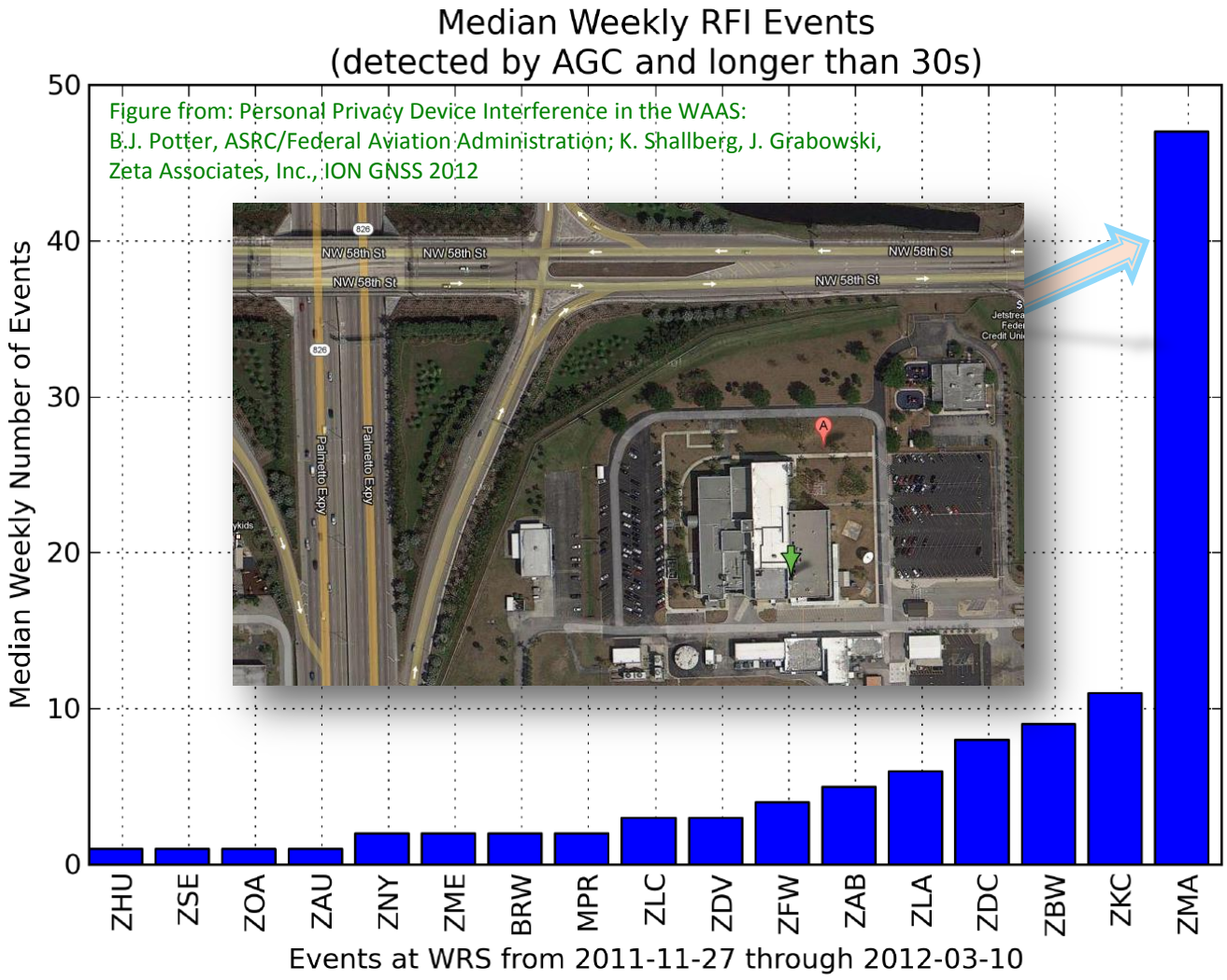
WAAS Reference Stations are Seeing Numerous RFI Events



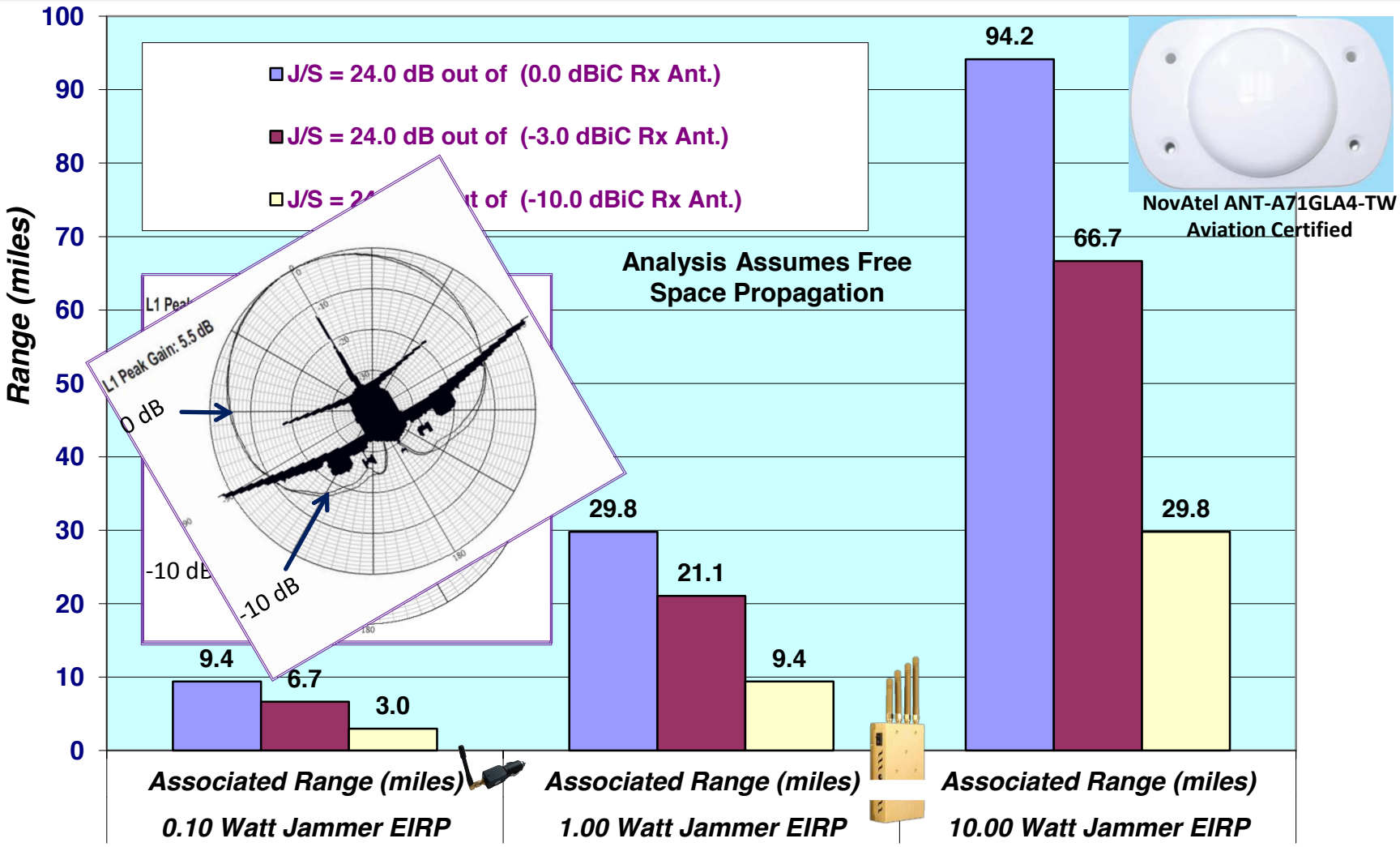
- Isoz et. al. report average of 117 events/day at Kaohsiung International Airport - Taiwan

Isoz et al., Assessment of GPS L1/Galileo E1 Interference Monitoring System for the Airport Environment, ION GNSS 2011

Civil Jamming Doesn't Require High Power to Be Damaging to Aircraft At Long Ranges

Earth Obscuration Limits Range

Nominal GPS Signal: -157 dBW into +3 dBiC



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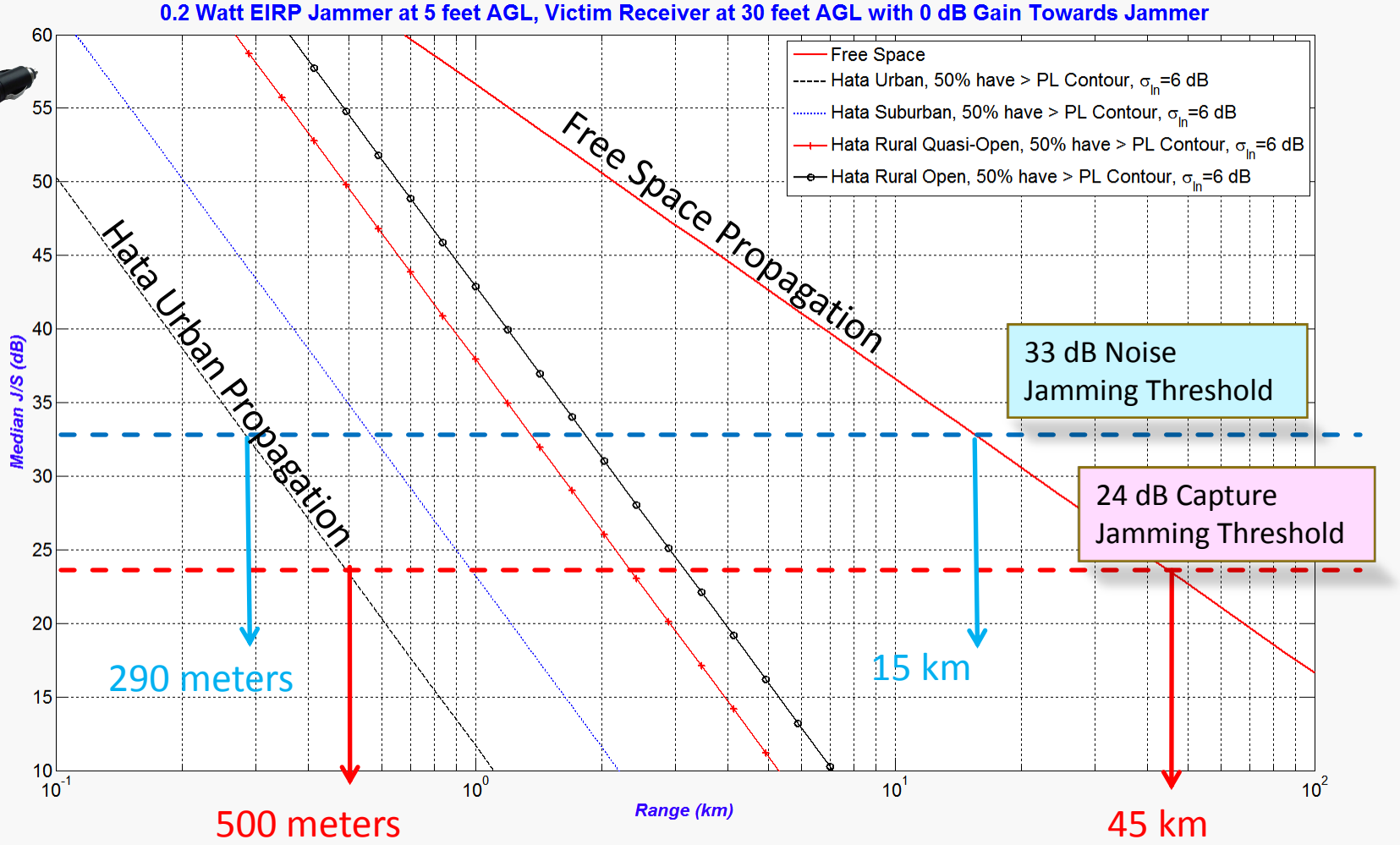
The Effective Range Of a Jammer Varies Widely Depending on Propagation

Can Also Make Jammers Hard to Find



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Compounding the Problem, People Use the "Best" Tools Available

Non-Approved Devices Are In Widespread Use Because They Are Often Easier to Use

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The Risk

Widely Used Ground Navigation Devices

"Updated" Aircraft Cockpits

Screenshot from Android Marine Navigation App

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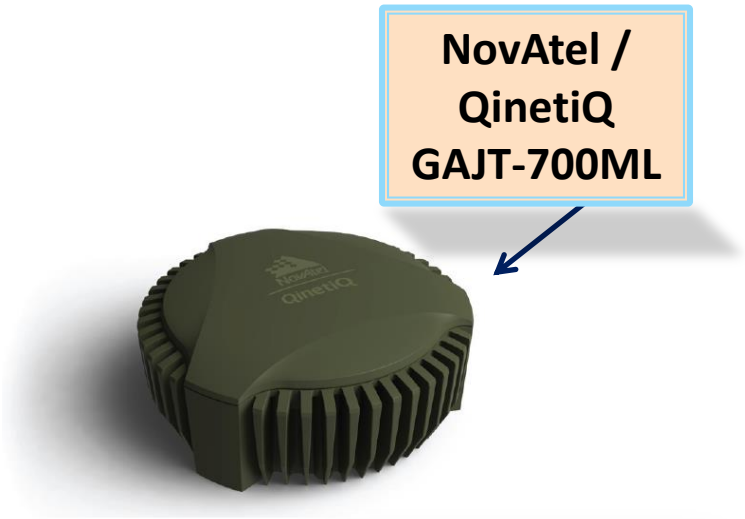
What Can We Learn From Military Signal Protection Methods?

The Bunker Defense

- Electronic Countermeasures (ECM)
  - Strong Out of Band Signal Rejection
  - Maintain Situational Awareness
  - Avoid Relying on Civil Signals
  - Tightly Coupled IMU Aiding
    - Vector Tracking
  - **Adaptive Arrays**



- Most ECM Techniques Degrade Accuracy
  - RTK is Especially Sensitive to Applied ECM
- Encourage Jammers to Cease & Desist Using Kinetic Methods
  - BUT: Jammers are Inexpensive

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Array Antennas Are Physically Large

But If You Can Fit One In, They Offer The Biggest AJ Bang for the Buck By a Wide Margin

c.a. 1990

GAS-1 CHARACTERISTICS

ANTENNA ELECTRONICS

- SIZE: 12" X 8" X 2.27"
- WEIGHT: <9 lbs
- POWER: 115 Vac, 400Hz
  162 Vdc
  <38 W

CRPA

- NO. ELEMENTS: 7 (1 Ref/6 Aux)
- SIZE: 14.1" Diam 2.0" H
- WEIGHT: <8 lbs
- POLARIZATION: RHCP (All Elements)

Much Smaller / Higher Performance Now

Still The Same Size

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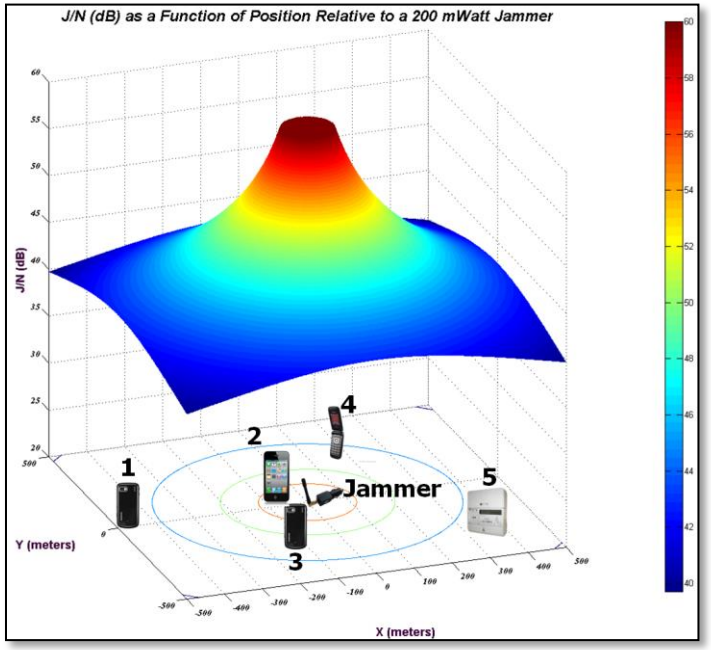
Situational Awareness Is Key!
Intelligent Receivers Look for Problems

- **Report Interference to Users**
  - **User Can Take Action (e.g. Body Shielding)**
  - **Less Time Debugging Dependent Systems**
- **Can Protect Against Generating Hazardously Misleading Information (HMI)**
- **Jammer Signature Information Improves Interference Detection & Monitoring (IDM) System Performance**
  - **Can Crowdsource To Locate Jammers ("J911")**
  - **Can Associate Jammer Reports from Multiple Sites Into Track Files**



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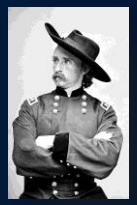

The Receiver is The First Line of Defense
Knowing You Are Jammed Is the First Step

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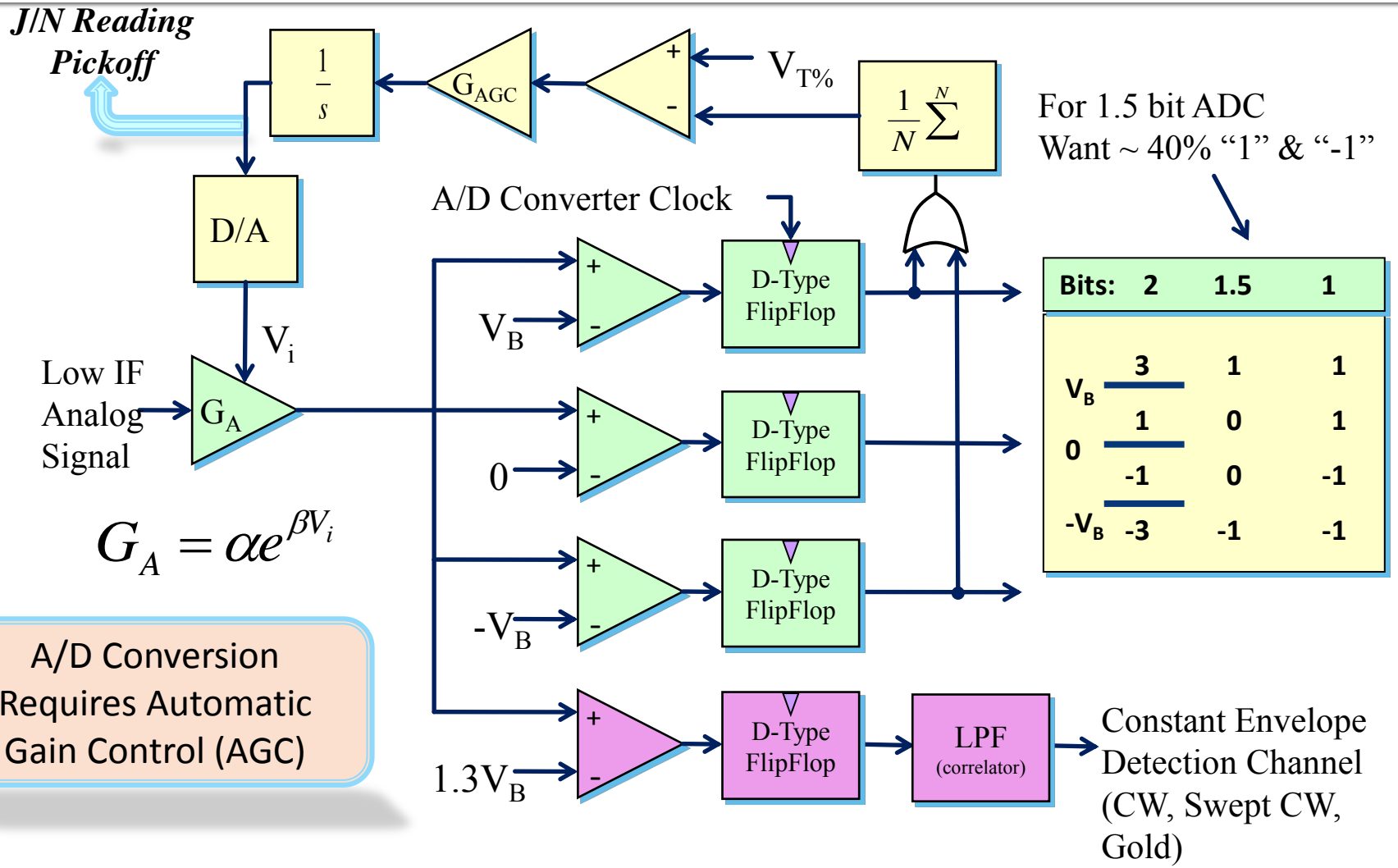

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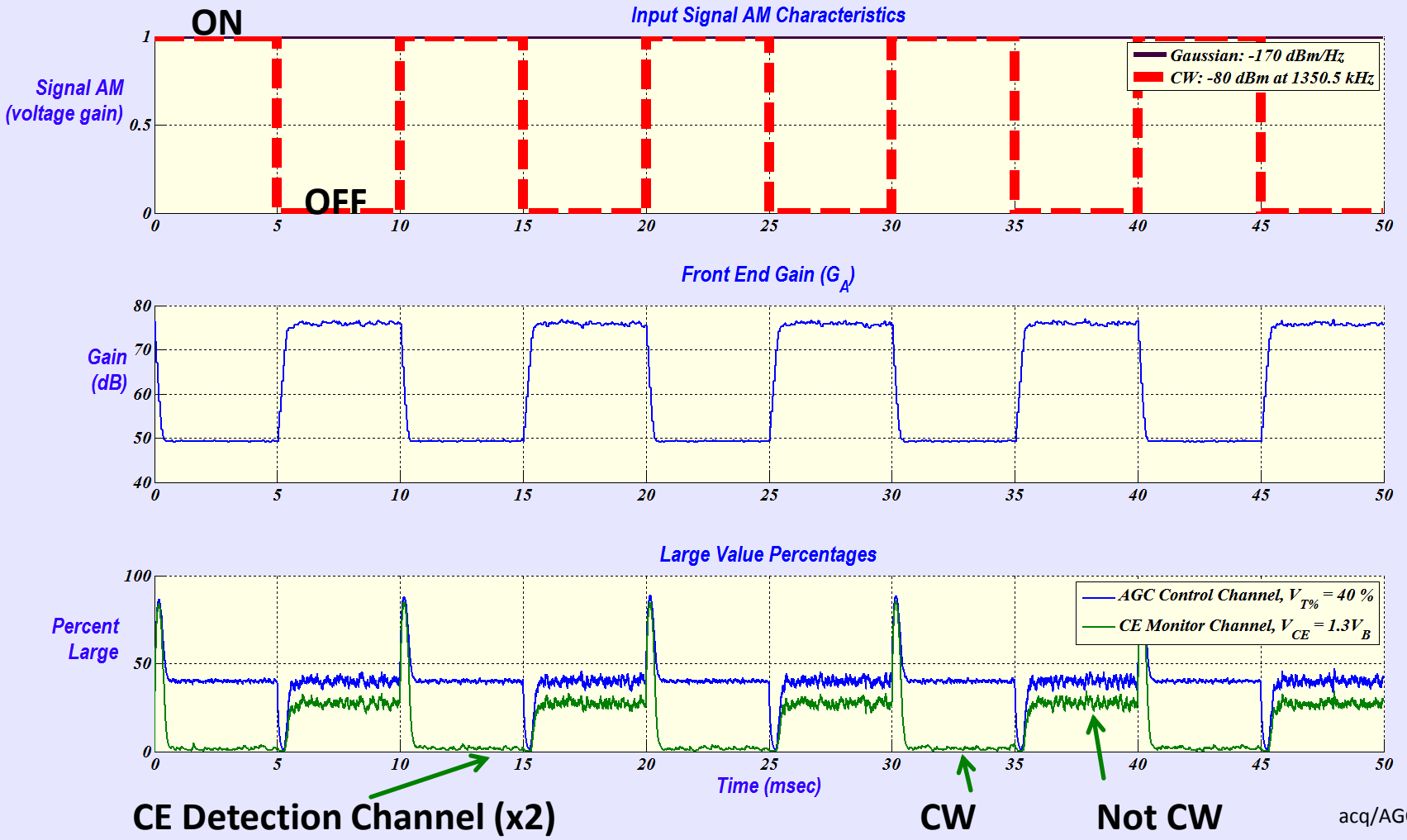
A/D Conversion Process Can Measure J/N, Pulse Rate & Jammer Type

Pulsed CW at 30 dB J/N (50 dB J/S), 100 Hz PRF



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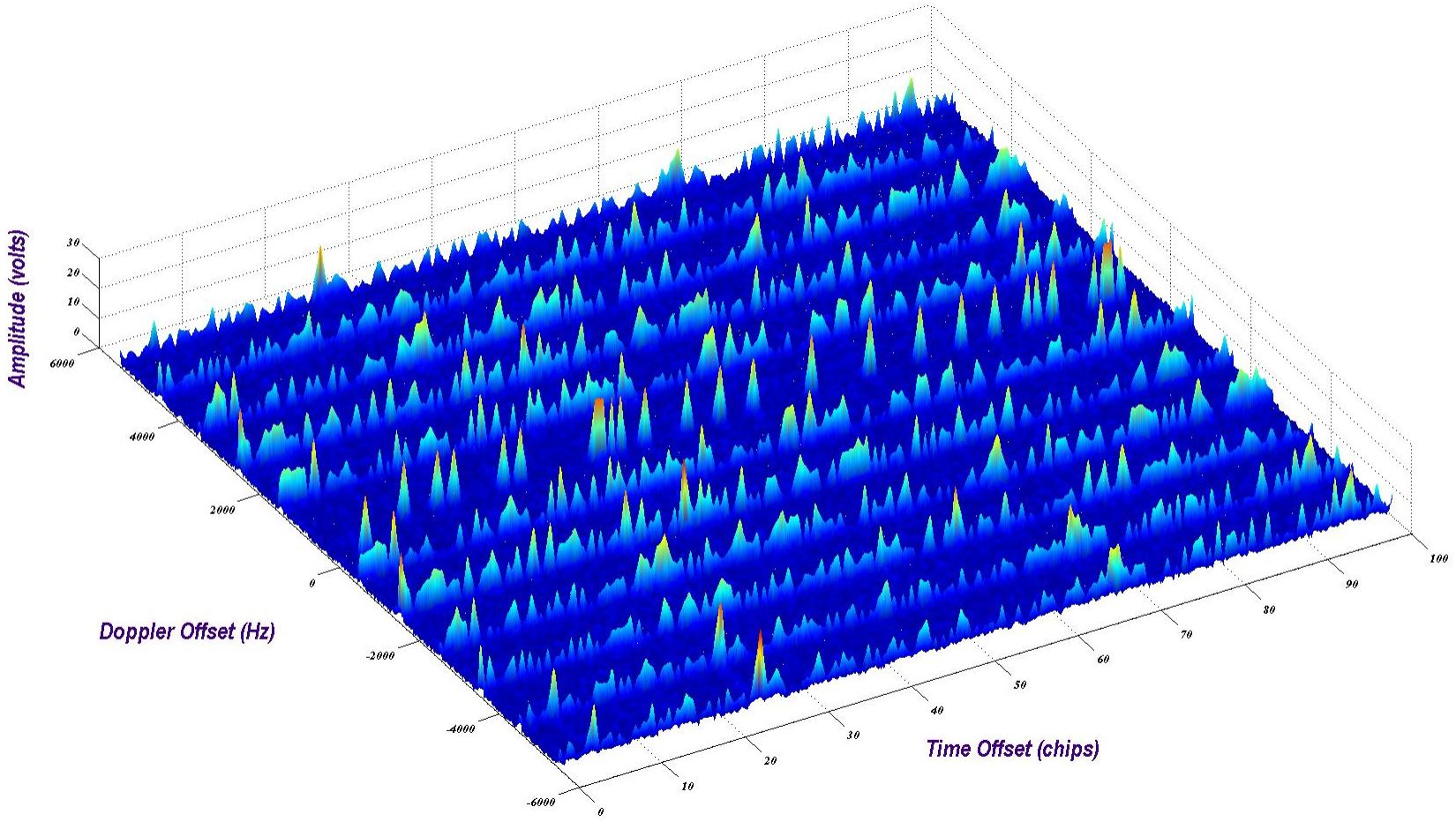
If Your Received Signal Looks Like This, How Reliable Is Your Position Estimate?

Smart Receivers Also Look at Range/Doppler Maps Too



acq/stage1i.m

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Civil Defenses Emphasize Situational Awareness, Uncorrelated Vulnerabilities, and Agility
The Whack a Mole Defense

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Look for Consistency!

- Sanity Checks and Signal Authentication to Discard Jammed/Spoofed Signals
- Global SatNav Systems
  - GPS L1/L2/L5 (31 SV)
  - GLONASS (23 SV)
  - COMPASS (16 SV)
  - GALILEO (4 SV)
- Regional SatNav Systems

Uncorrelated Vulnerabilities

: Typical Smart Phone Capability

- Other Navigation Sensors
  - WiFi
  - Cellular TOA/TDOA
  - RF Fingerprinting
  - IMU ($3.35 in iPhone4)
  - Magnetic Compass
  - Point Space Database
  - Barometric Altimeter
  - SAR
  - eLORAN
- Size, Weight, Power, Cost & Export (ITAR) Considerations are Paramount

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Many Devices Use Multiple Signal Sources To Derive Location and Could Be More Robust In Partially Denied Civil Environments

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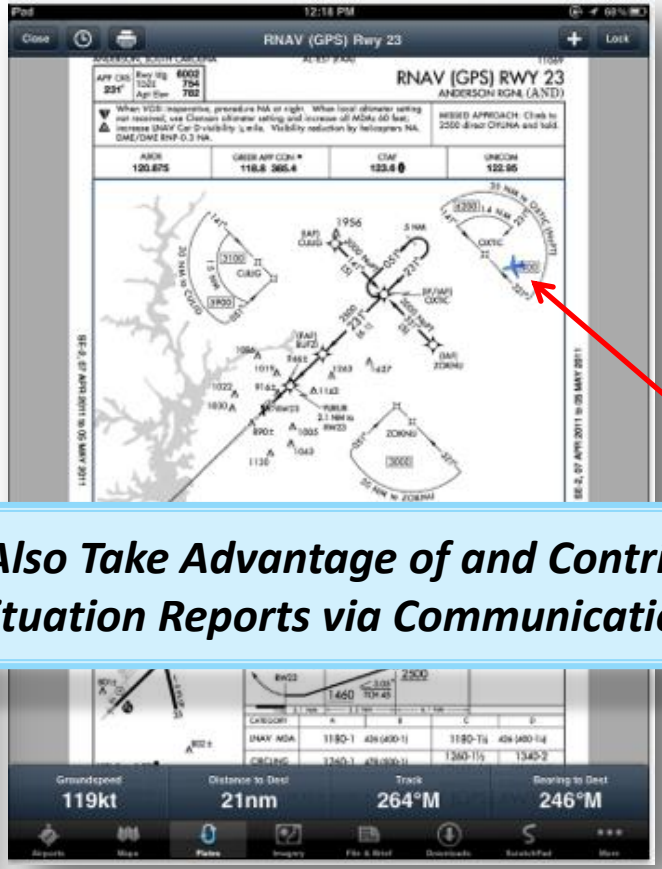
The Opportunity

Widely Used Ground Navigation Device

Screenshot from iPad Aviation App



Screenshot from Android Marine Navigation App

Can Also Take Advantage of and Contribute to External Situation Reports via Communications Channels

© Logan Scott / LS Consulting

Urgent need for Resilient PNT to protect safety of mariners

Risks to Maritime Safety of Navigation caused by GNSS denial must be mitigated by Resilient PNT solutions within e-Navigation

George Shaw
General Lighthouse Authorities of UK and Ireland
Principal Development Engineer

General Lighthouse Authorities of the United Kingdom & Ireland (GLAs)

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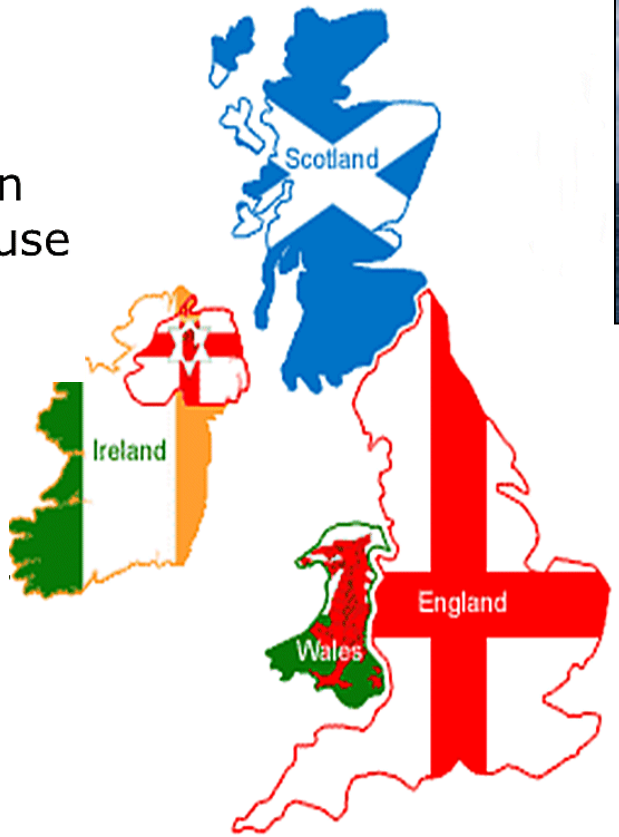
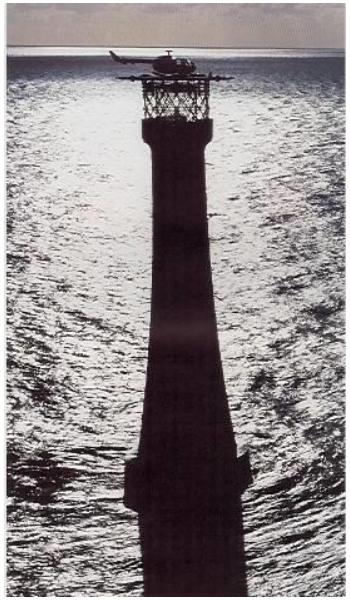
Northern Lighthouse Board





Commissioners of Irish Lights

Trinity House

Dover Strait – gateway to Europe & the world's busiest shipping area

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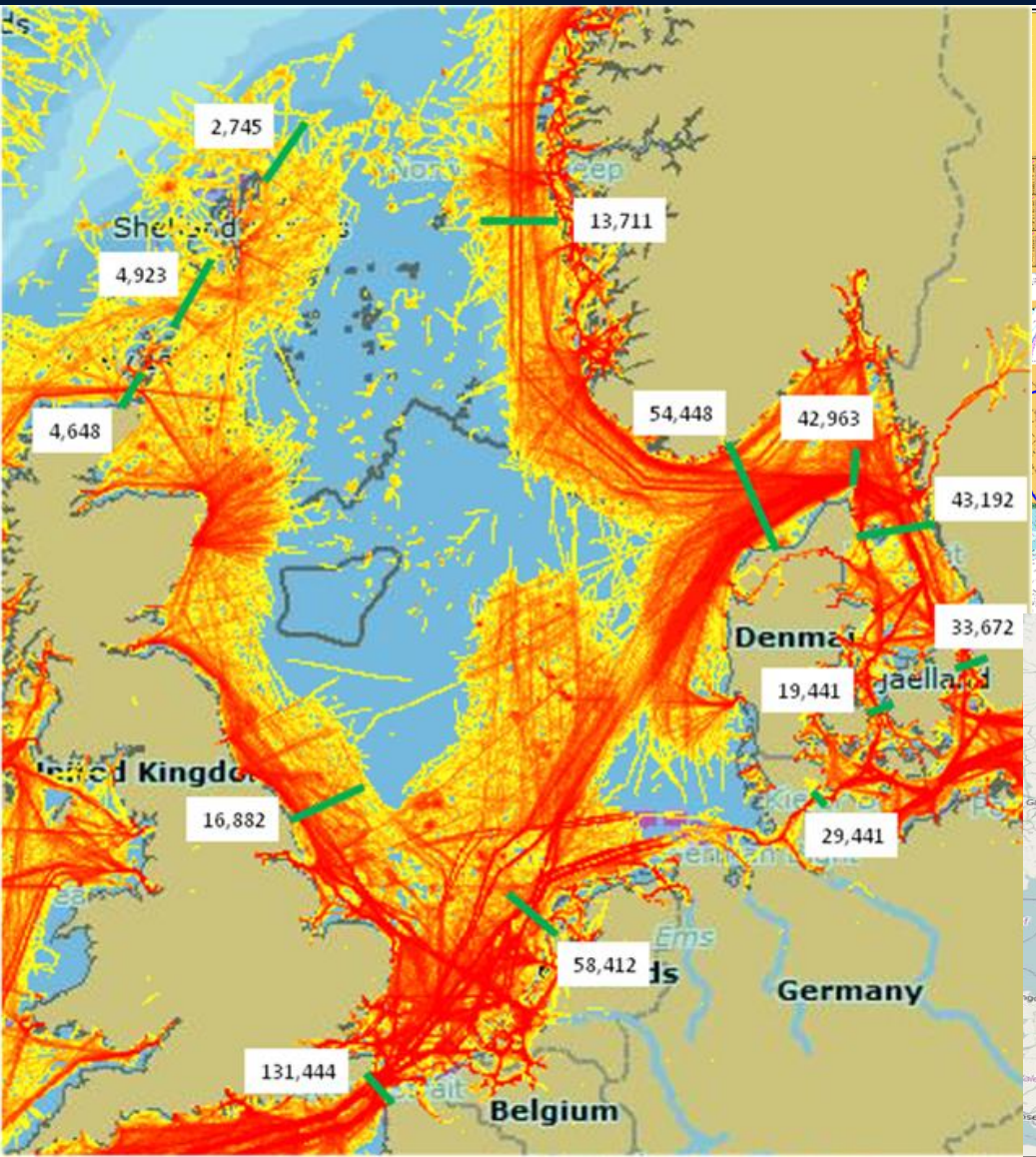
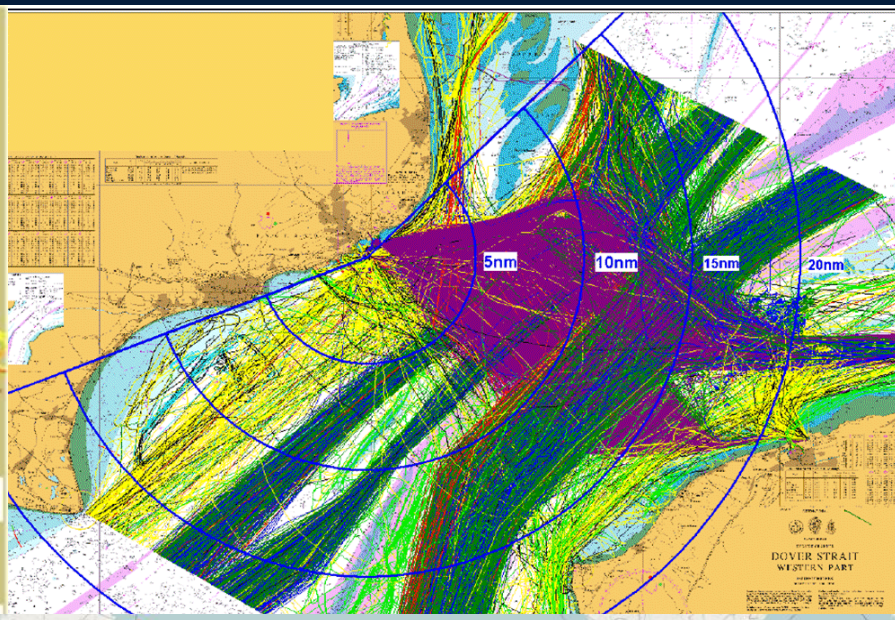
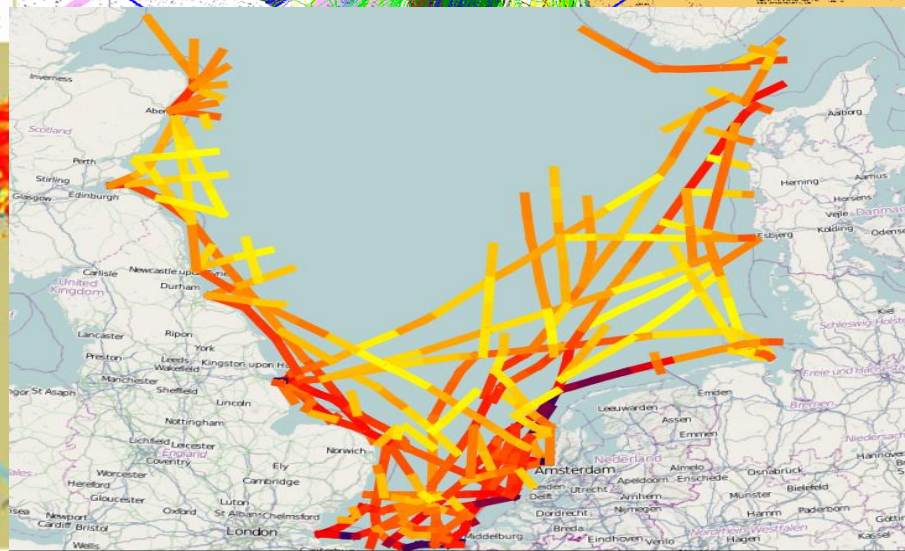
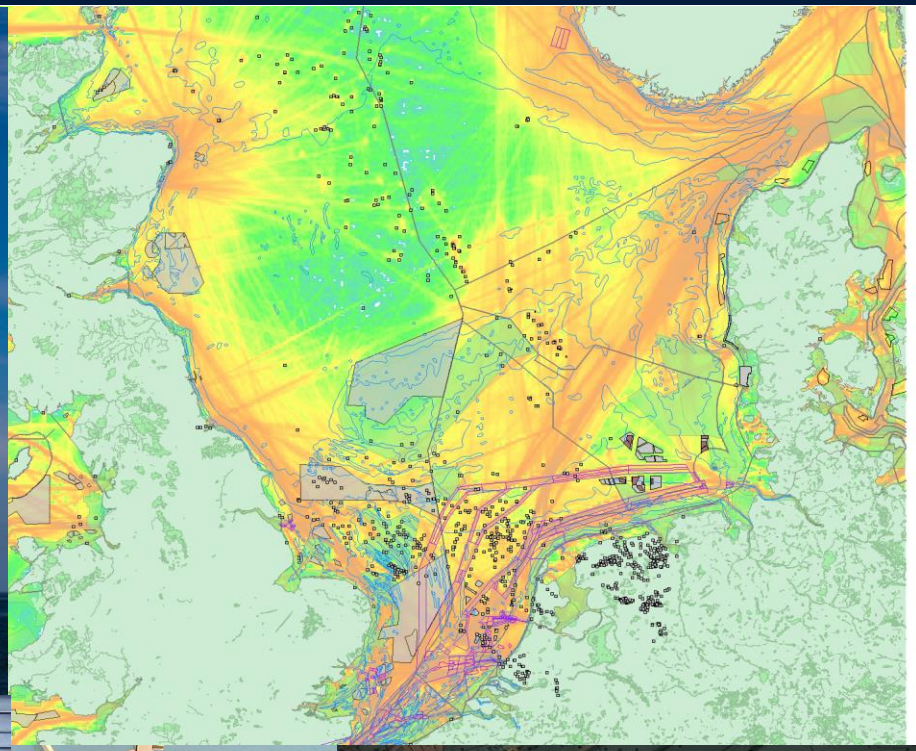
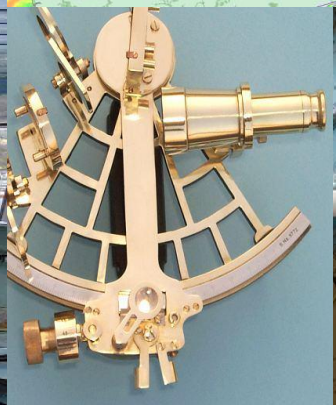




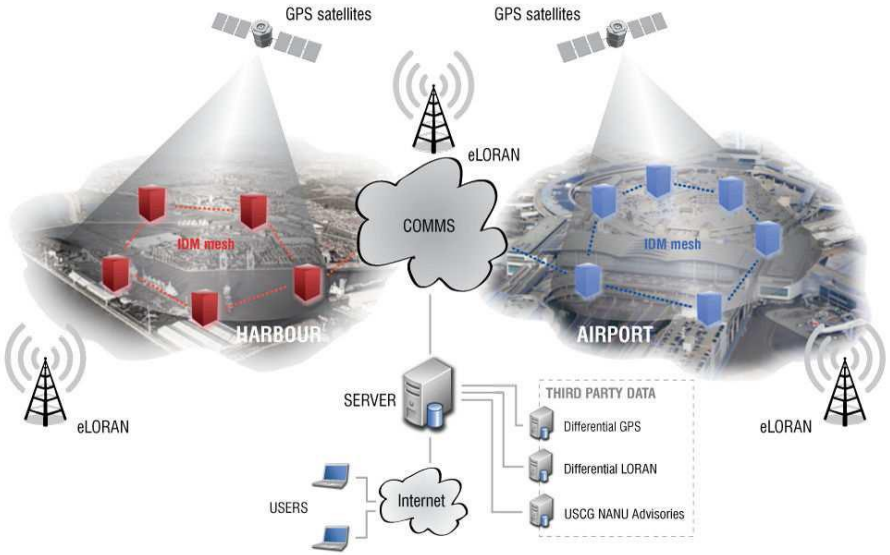


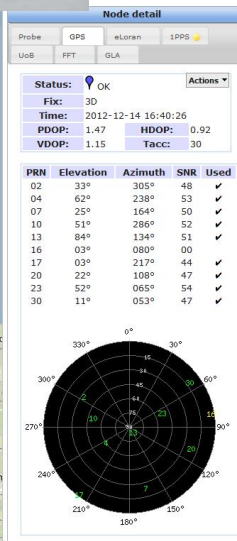
e-Navigation demands resilient PNT



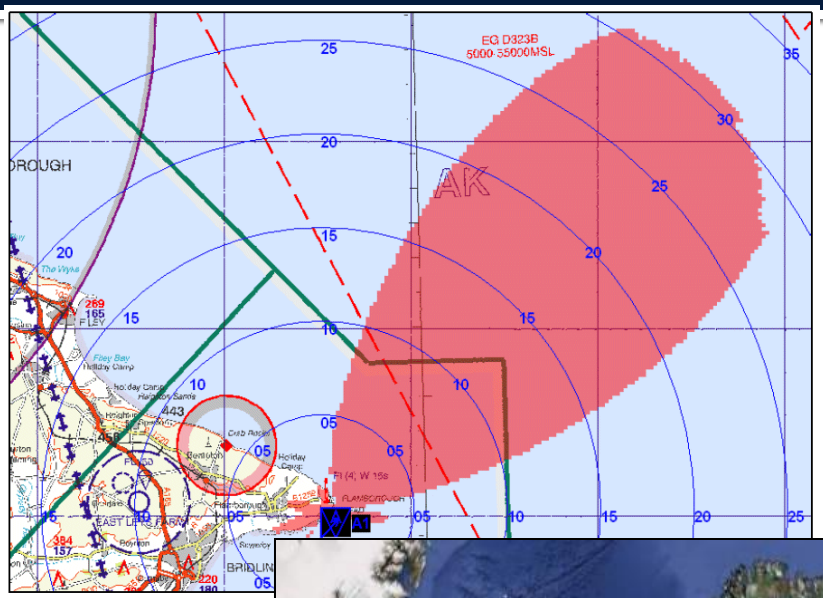


SENTINEL – detecting GPS jamming daily



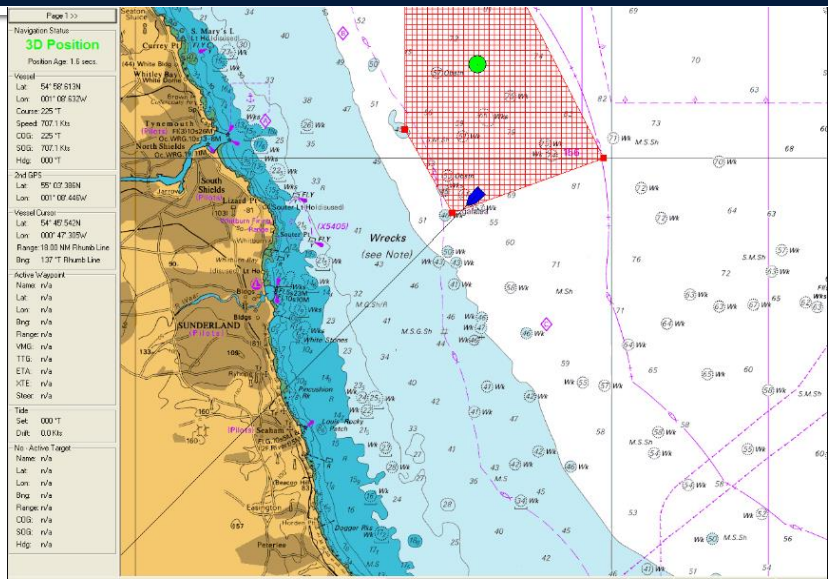


Ship trial – land based GPS jammer



Trial with GPS jammer onboard

With low power jammer on board...



Jammer of less than 1 milliWatt:

- **False positions, and velocities**
- **Autopilot may turn vessel**
- **But no alarms!**

Hazardously Misleading Information

With a little more jammer power:

- **Electronic Chart Displays**
- **Autopilot**
- **Automatic Identification System**
- **Differential GPS**
- **Satellite voice and data comms**
- **Maritime distress safety system**
- **Ship's radar & gyrocompass**

Resilient PNT for North Sea Shipping

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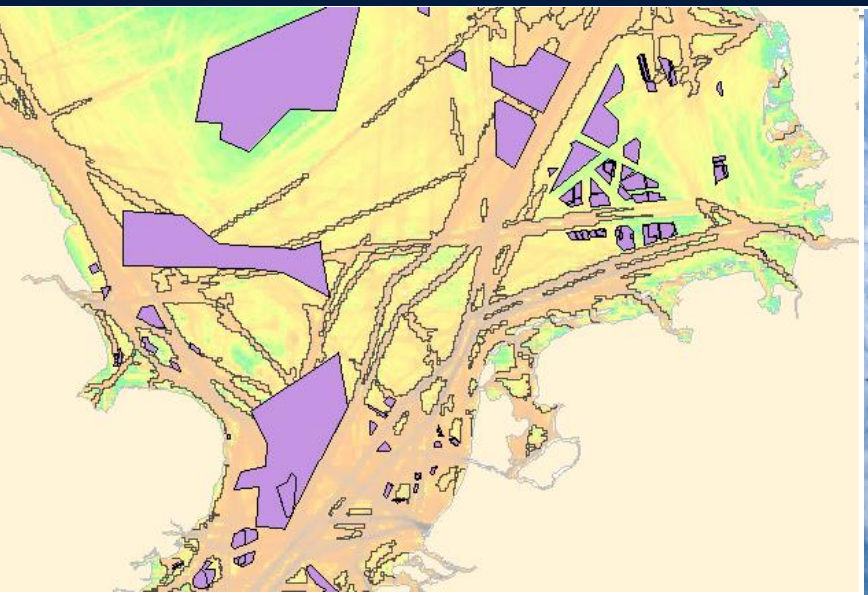
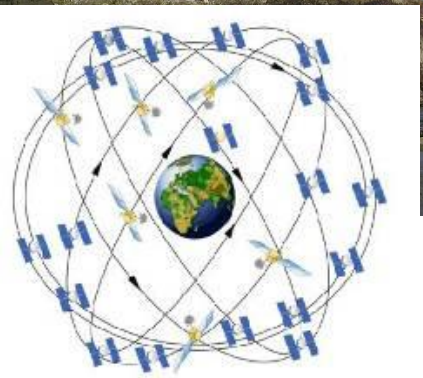




ACCSEAS

www.accseas.eu

The Interreg IVB North Sea Region Programme

Investing in the future by working together for a sustainable and competitive region

Maritime is leading cross-sector action

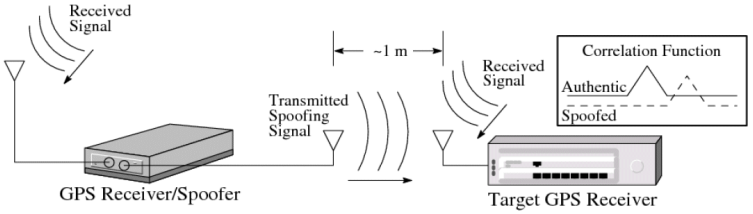
... with land mobile solutions under investigation

eLoran already delivering resilient timing across the UK ...

£6m lorry hijackings gang face ten years

Thursday 6th May 2010, 11:30AM BST.

The Most Likely Threat:
A Portable Receiver-Spoofer



The portable receiver-spoofer architecture simplifies a spoofing attack

Ask the Experts – Part 1

Logan Scott
Principal Consultant
LS Consulting

George Shaw
Principal Development Engineer
Research & Radionavigation
Directorate of the General
Lighthouse Authorities of the
UK and Ireland

Sherman Lo
Senior Research
Engineer
Stanford GPS
Laboratory

Peter Soar
NovAtel
Business Development
Manager
Military & Defence

Poll #2

In the future when several GNSS will be operational, the methods for dealing with jamming/interference will: (Select one)

1) ***Be standardized and uniform for all users***
2) ***Require different solutions for different applications***
3) ***I don't know***

eLoran for Robust Position and Timing

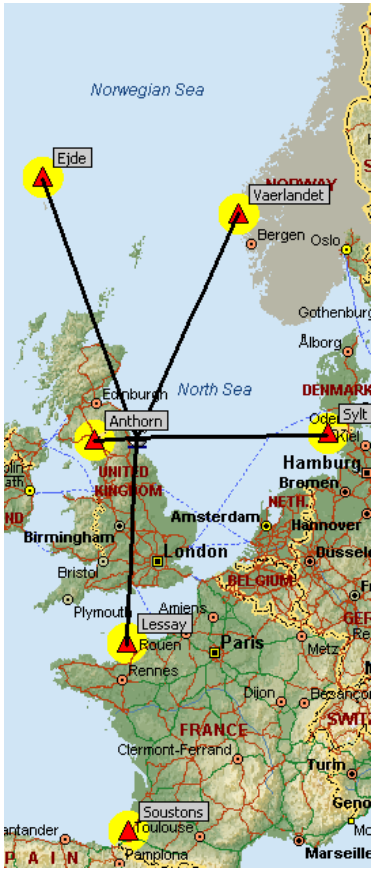
eLoran Initial Operational Capability in the UK - proven 'here-and-now' Resilient PNT has begun to safeguard shipping in the world's busiest channel

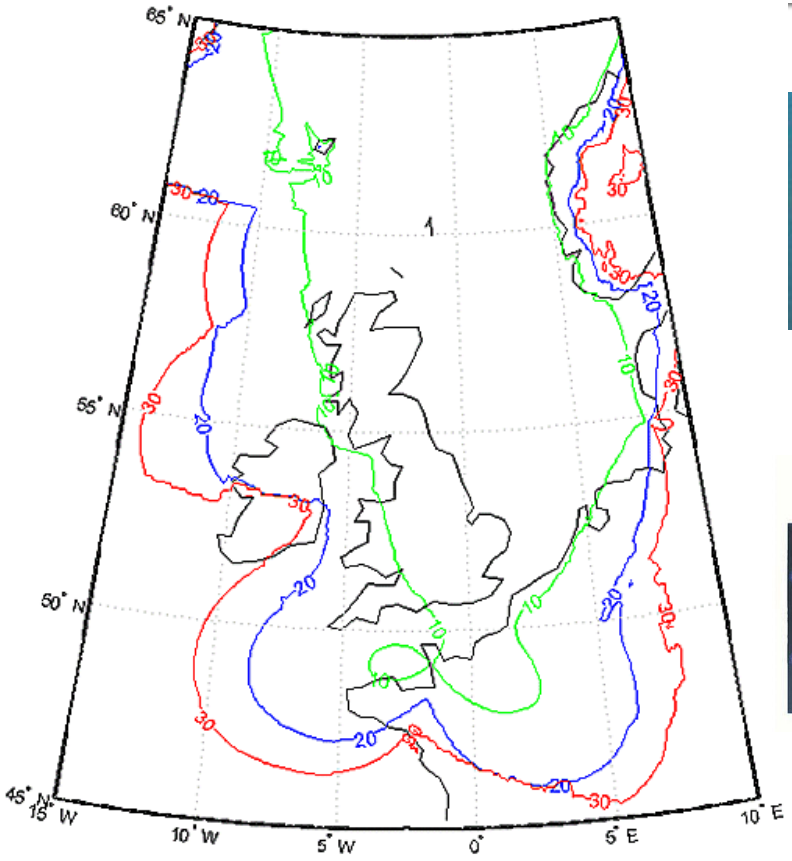
George Shaw
General Lighthouse Authorities of UK and Ireland
Principal Development Engineer

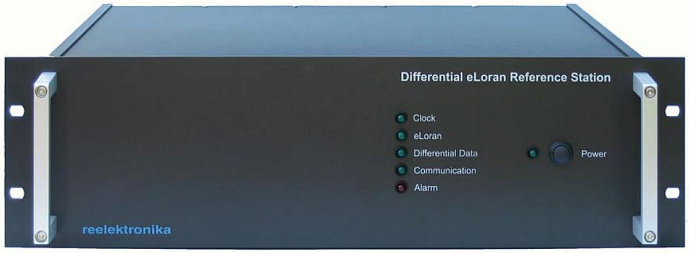
Approach: seamless PNT if GPS is denied

- Harden GPS systems, continue to develop radar positioning and inertial integration, but...
- Complementary navigation system now:
  - enhanced Loran (eLoran)
  - *independent of GNSS, but compatible*
  - Integrated Navigation System (INS)
  - multi-system receiver standards
- Extend coverage - new Tx, R-Mode.....
- Reduce costly lighthouses and buoys

GLAs' prototype eLoran system is on air



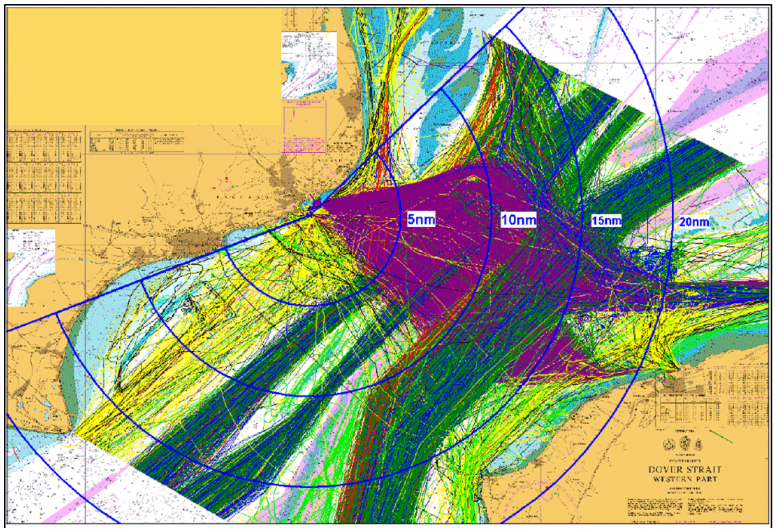


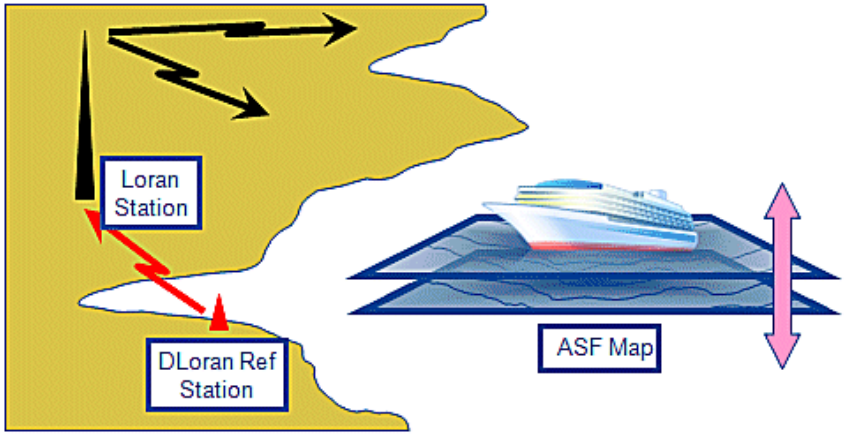


- **Runs continuously; available since May 2010;**
- **10-20m accuracy in ports with differential service (green area)**

First stage eLoran Initial Operational Capability (IOC)

- **serving the Port of Dover and the UK section of the Dover Strait**





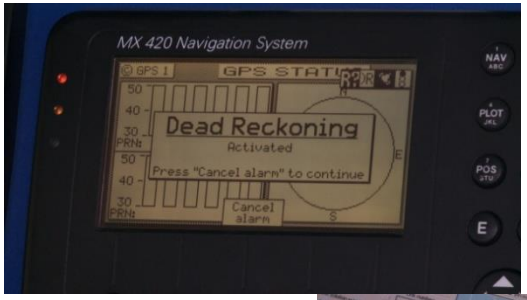
- Map ASFs
- Real-time differential corrections
- Corrections and integrity status via eLoran data channel

eLoran seamless integration works!

- **On 28 February 2013, the Trinity House Vessel *Galatea* reverted automatically to eLoran when GPS was jammed. Galatea continued seamlessly on track, reporting eLoran positions to nearby ships and the Vessel Traffic Service ashore.**

IOC extensively reported

MarineLink.com
Maritime Reporter and *MarineNews* magazines online



New Ship-based System Takes Out GPS Jamming Threat

PC Advisor — Monday, March 11, 2013

With GPS jamming a growing worry for UK shipping, a new device seamlessly switches systems to counter the navigational menace.

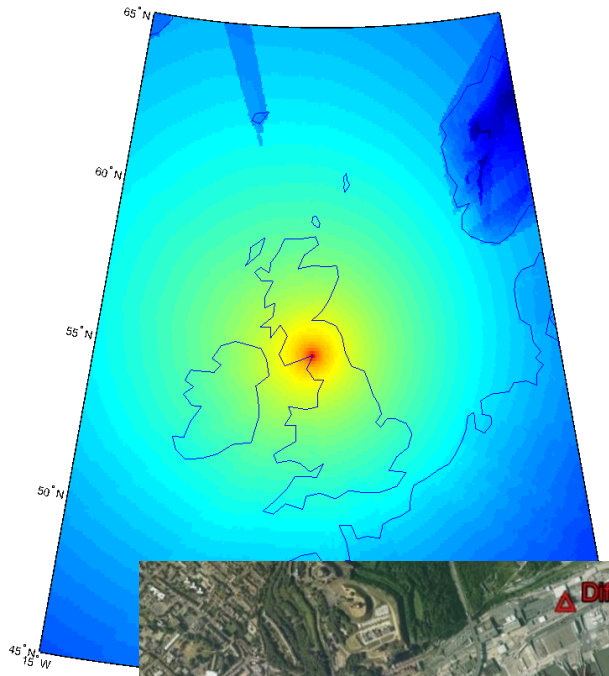
Digital Ship

Positional assistance for ships – eLoran rolls out over the English Channel

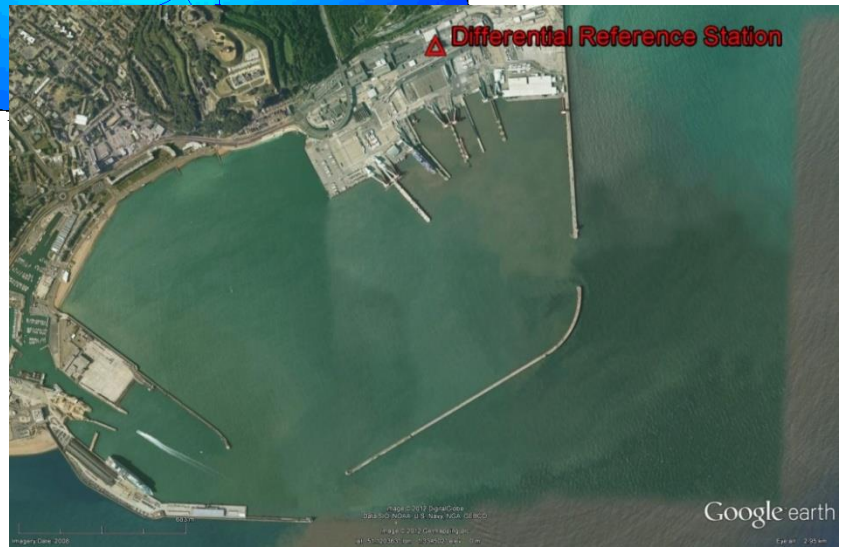
11 March 2013 Liam Stoker

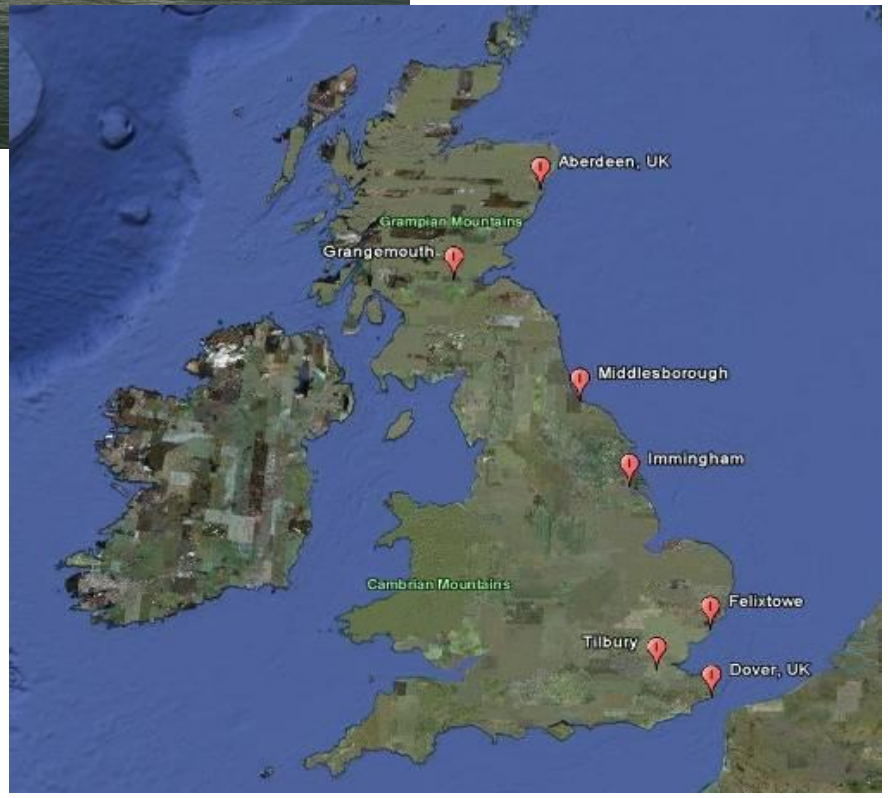
ship-technology.com
News, views and contacts from the global Ship industry

Further stages of eLoran IOC



P&O Ferries





Building on USCG Loran

Supported Application	USCG Loran-C	Modernised Loran-C	Prototype eLoran	eLoran
Resilient PNT				✓
Maritime: Ocean		✓	✓	✓
Maritime: Coastal & Harbour			✓	✓
Aviation: Non-Precision Approach				✓
Stratum 1 Frequency	✓	✓	✓	✓
UTC			✓	✓
Precise Timing				✓
Land Mobile			✓	✓
Interference Detection & Mitigation			✓	✓

- ***eLoran and eChayka offer:***
- **Compatibility between them to serve the high north**
- **Modern transmitting stations and procedures**
- **Advanced receivers that track all stations in view**
- **High precision in ports**
- **A data channel**

eLoran – the way forward

- Replace Loran-C with new eLoran
- Re-use Loran-C stations
- Serve shipping
- Serve telecomms timing
- Serve secure data
- Serve land transport
- Share costs
- Maximise Loran-C payback

RESEARCH & RADIONAVIGATION

United Kingdom eLoran Programme
- Report to FERNS Technical Working Group

Professor David Last, Dr Paul Williams, George Shaw
General Lighthouse Authorities of United Kingdom and Ireland (GLAs)

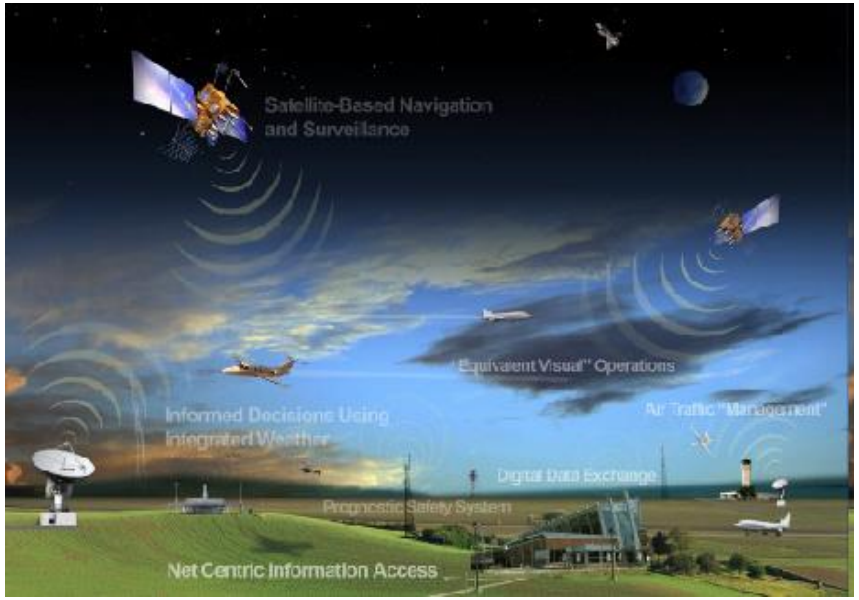
21st Session of the Council of the Far East Radionavigation Service (FERNS)
Moscow, 22-26 October 2012

Providing Aviation Navigation for Continued Operations in GNSS Degraded Environments

Sherman Lo
Stanford University GPS Laboratory

Aviation Relies on GNSS to Handle Future Needs

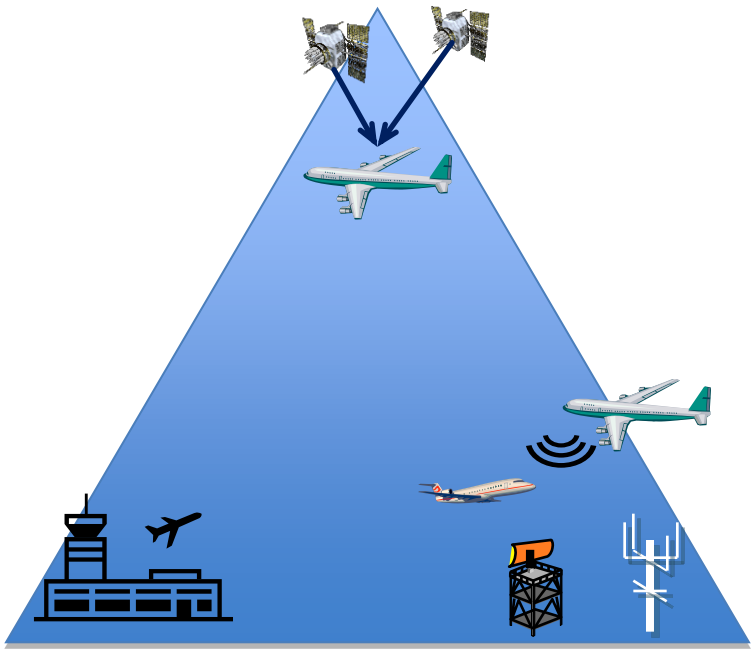
- Airspaces are modernizing
  - Handle 2-3 times current traffic level
  - More efficient flight operations
- GNSS is the key enabler
  - *“an evolution from a ground-based system of air traffic control to a satellite-based system of air traffic management.”*



NextGen (Next Generation Air Transportation System)

GNSS in the Airspace: Newark Arrival

GNSS in the Airspace: CNS – Building Blocks for Safety



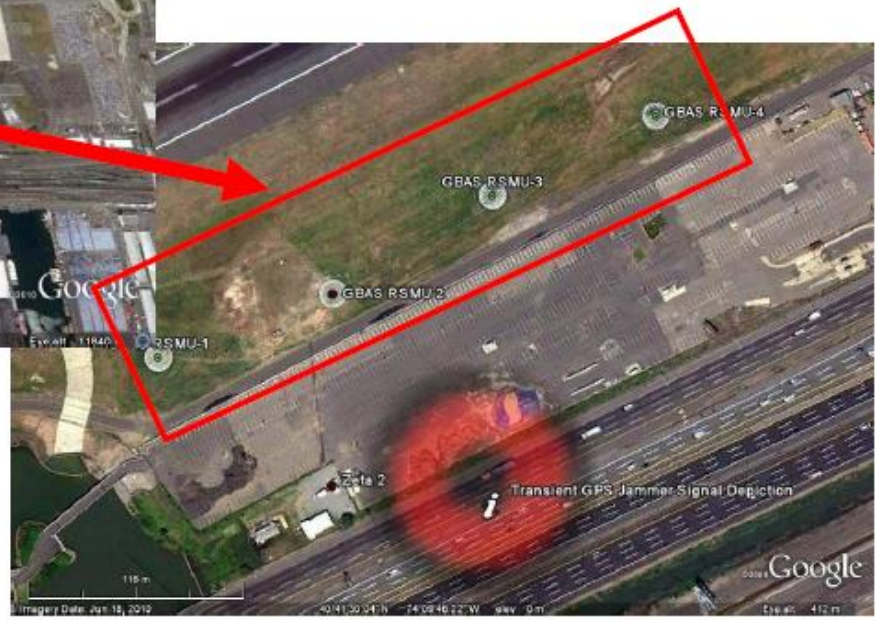
- Traditionally three separate systems
- Mutually supporting
  - Loss of one system is survivable
- GNSS will provide primary navigation, surveillance
  - Blurring separation between C-N-S

Responding to GNSS Degradation: A Multi-tiered Approach

- Degraded GNSS comes in many forms
- Hardened GNSS
  - Ground Based Augmentation System (GBAS), Wide Area Augmentation System (WAAS)
  - Receiver, systems redundancy, antenna
- GNSS Denied
  - Alternative Position Navigation & Timing (APNT)

Mitigating Personal Privacy Devices (PPD) for GBAS

•GBAS location and PPD Jammer example

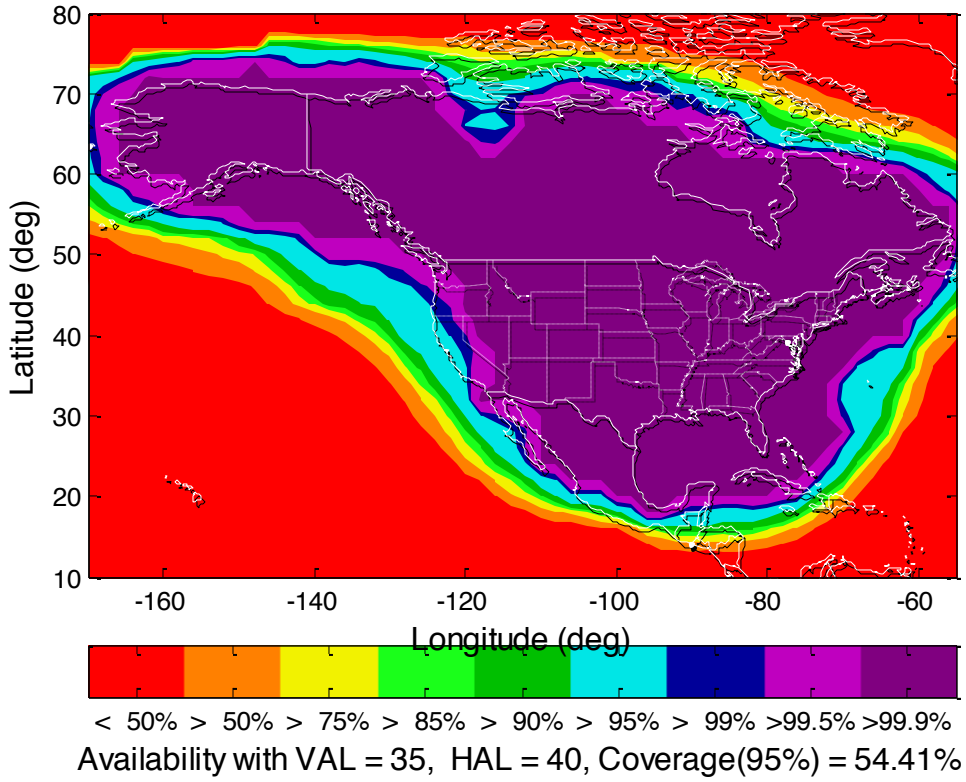


- Mitigations
  - Siting
  - SLS-4000 Block I
  - Masking off low elevation

Source: John Warburton, FAA GBAS: Program Status & Activity Summary Updates, RTCA March 2013

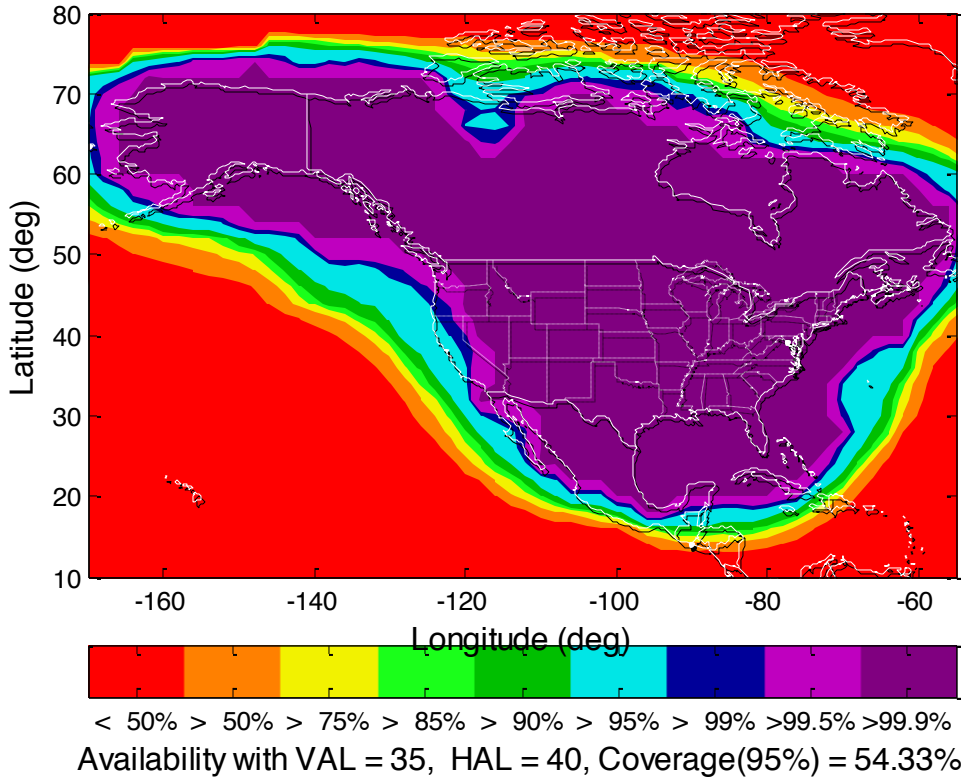
PPD Effect on WAAS: Nominal Case

Courtesy: Kazuma Gunning



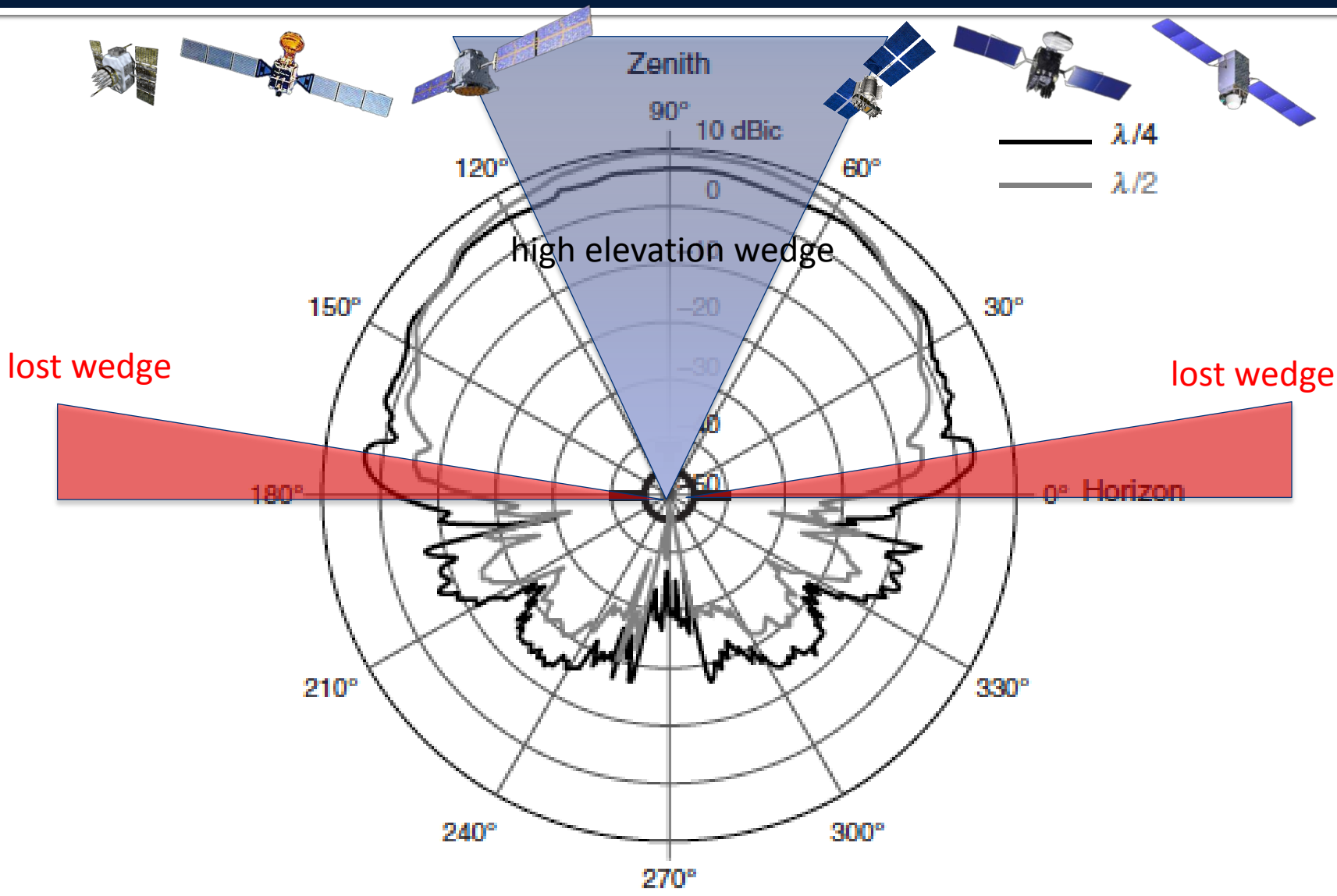
PPD Effect on WAAS: Average 10 outage case (Typical)

Courtesy: Kazuma Gunning



- Assumed PPD effect – loss of all sats below 35 degree elevation
- Over 1000 outages to have any noticeable effects

Higher Antenna Elevation Mask Angles



APNT for GNSS Denied Scenarios

- Alternative Position Navigation & Timing (APNT)
  - Improved terrestrial navigation
  - Robust navigation during GNSS degradation events
- Develop performance to provide many benefits gained from using GNSS
  - Continued operations while minimizing impact & workload on pilots, air traffic
- Terrestrial transmitter are more robust to jamming (Power & Proximity)

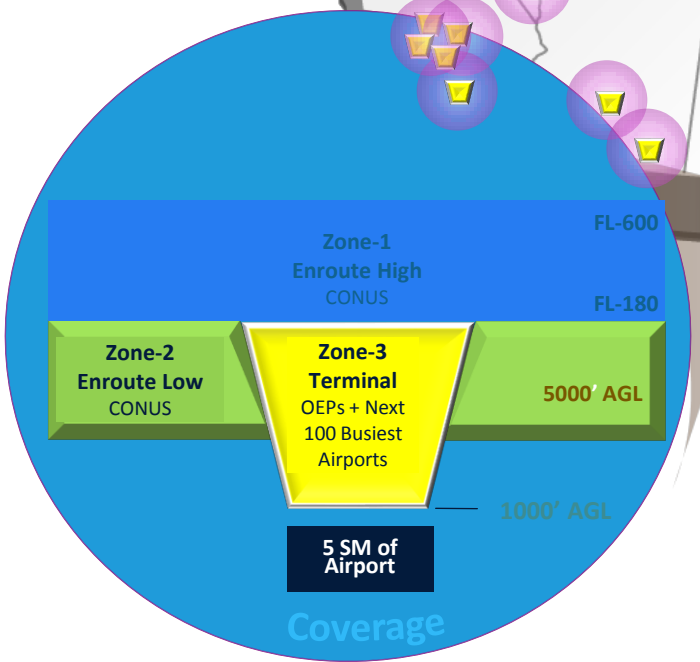
Image: wikipedia, ITT

APNT Coverage to Support Continued Operations without GNSS

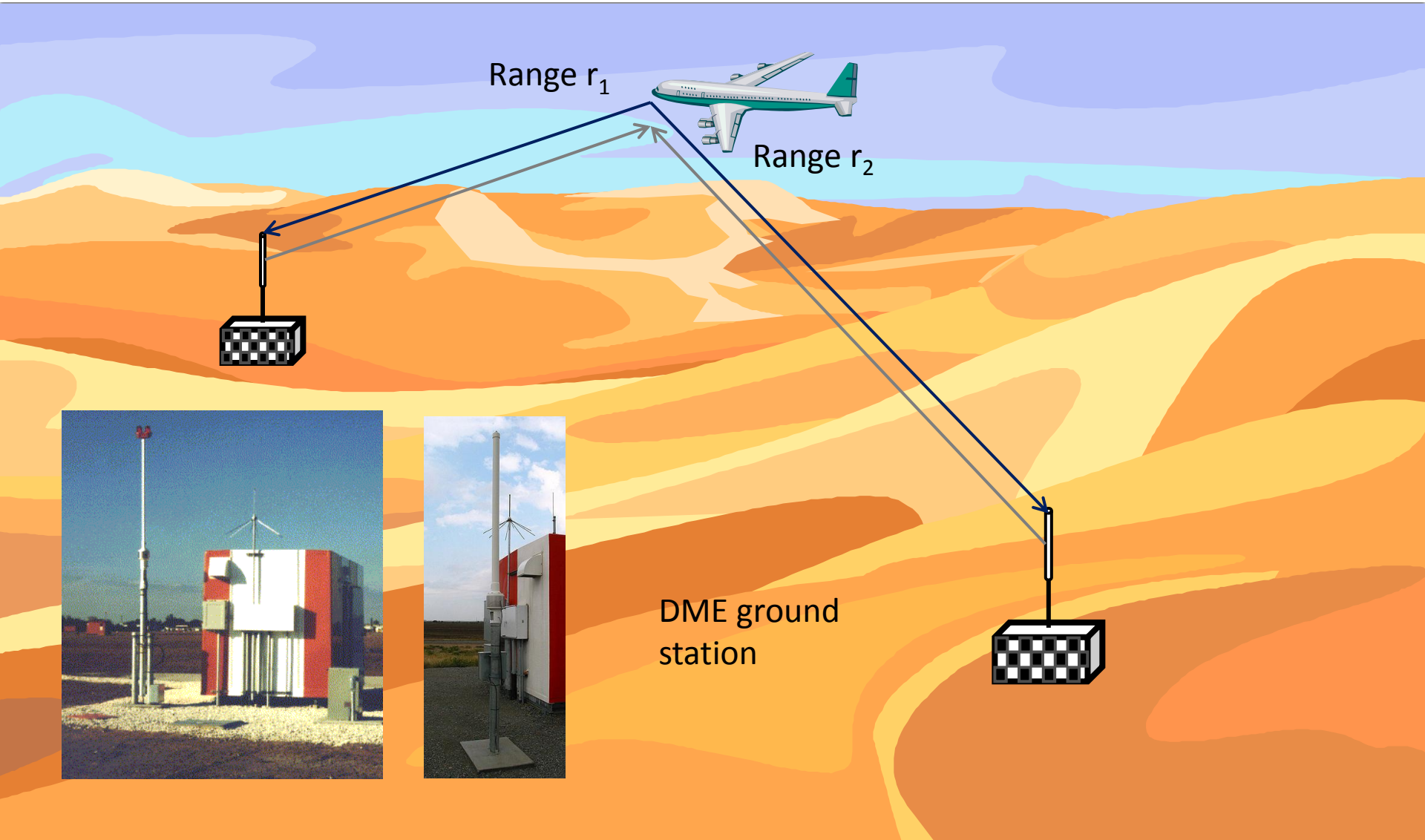
InsideGNSS
GPS | GALILEO | GLONASS | BEIDOU

NovAtel

Full coverage
Enroute & Top
135 airport
Terminal Area

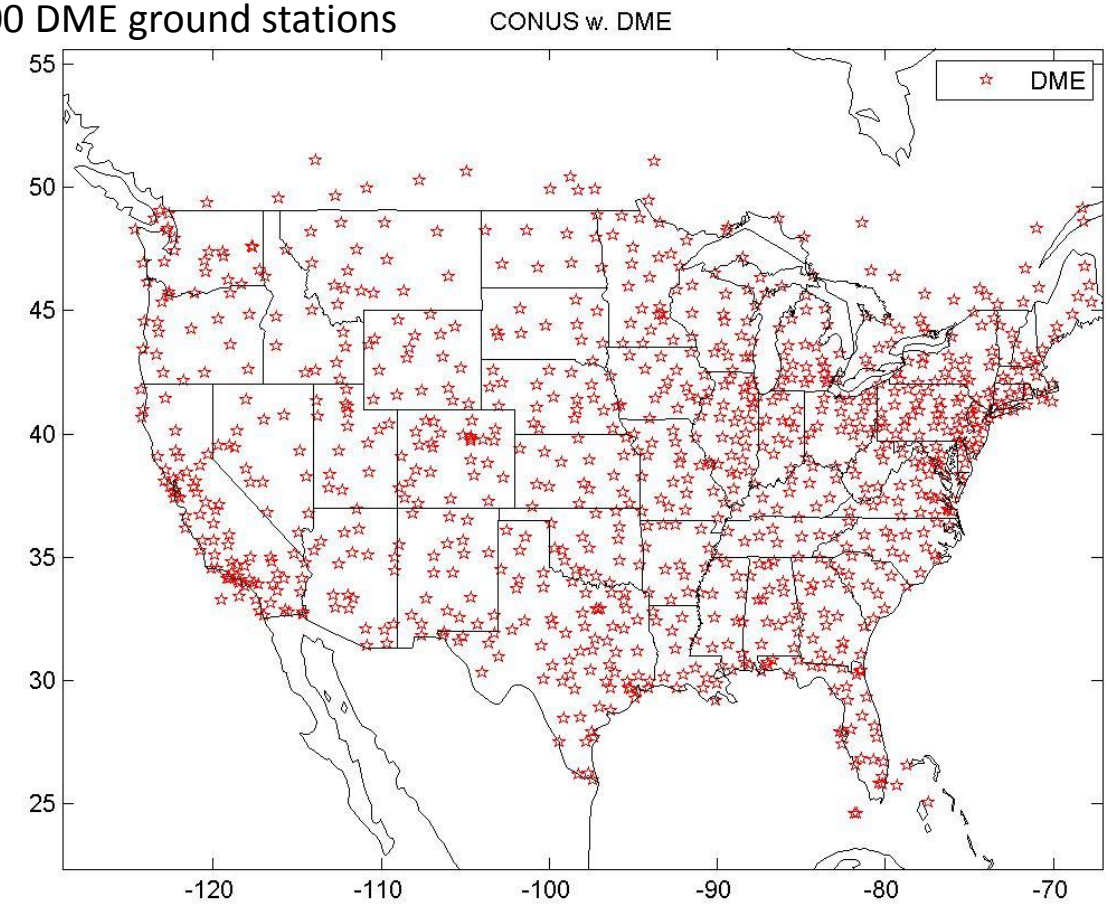


Distance Measuring Equipment (DME)



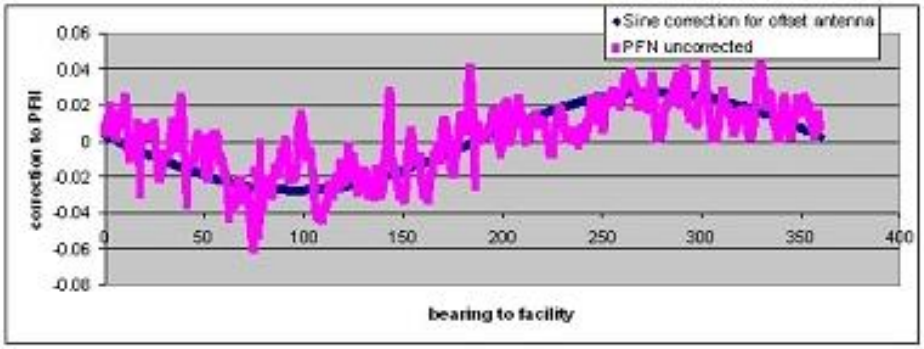
DME/DME Ground Infrastructure

> 1100 DME ground stations



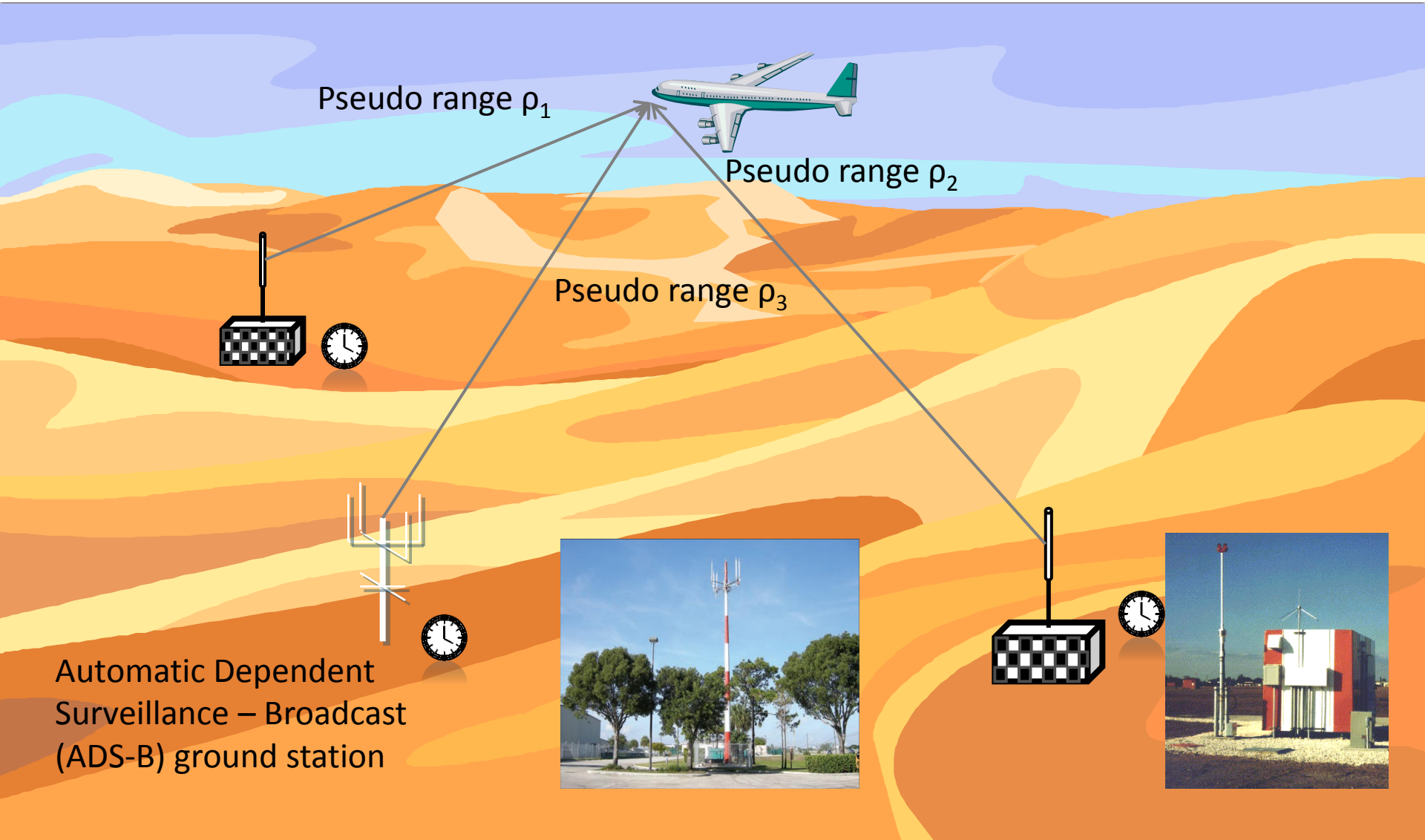
How do we get better DMEs?

- Credit for actual performance vs. specs
- Better surveys
- New avionics
- Improved signals & processing

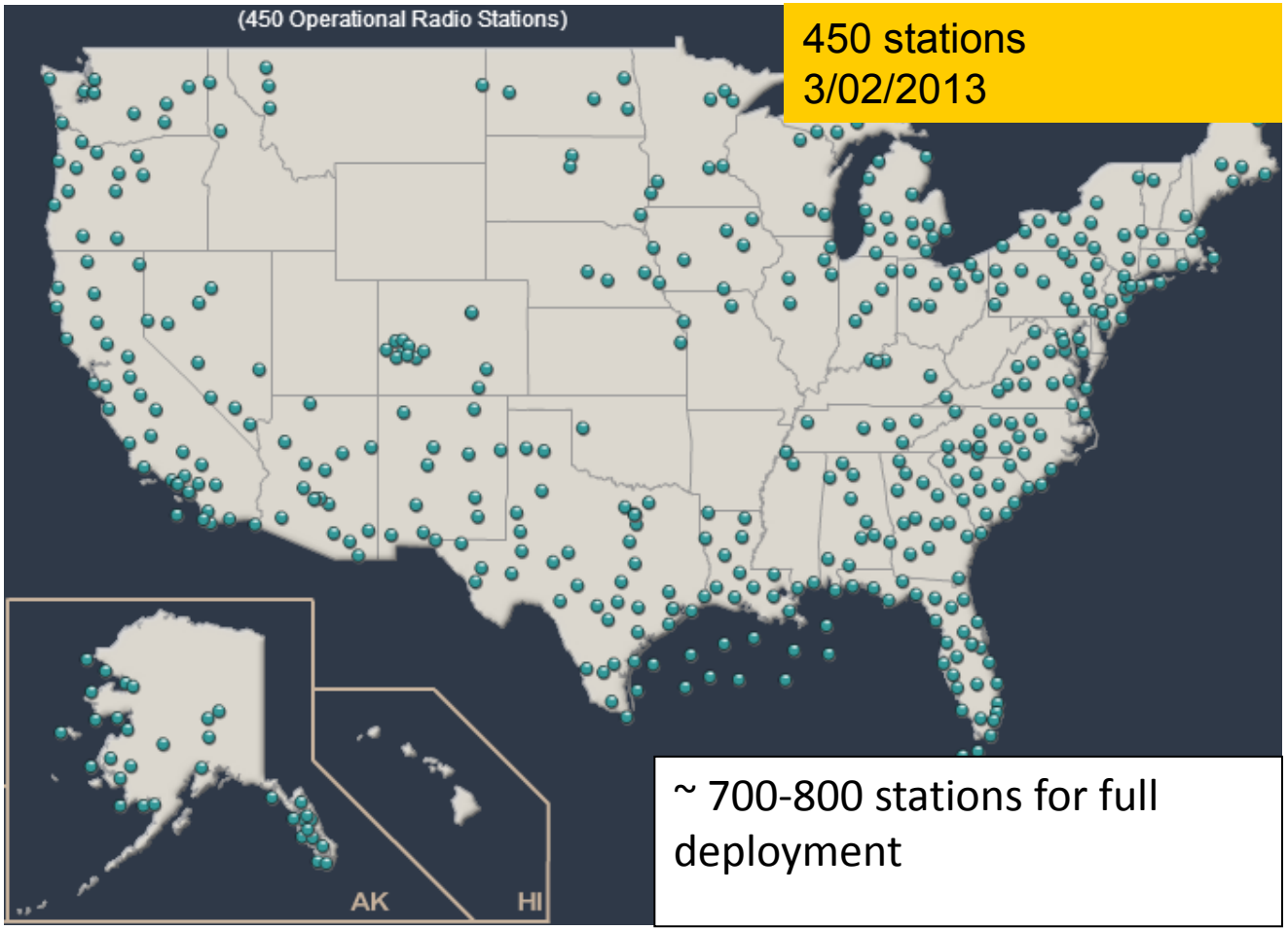


Source: R. Lilley, R. Erikson from flight inspection data

Passive Ranging/Pseudolite



Automatic Dependent Surveillance Broadcast (ADS-B) Ground Infrastructure



450 stations
3/02/2013

~ 700-800 stations for full deployment

~1100 DMEs

Combined Network of DME and ADS-B Ground stations

~700 ADS-B stations

Array Antenna Technology for Critical Timing

InsideGNSS
GPS | GALILEO | GLONASS | BEIDOU

NovAtel

0.5 W PPD (AA battery) jams GPS within ~100 m

~ 1 kW (Microwave Oven) jams GPS Array Antenna within ~ 100 m

FAA Anticipating Threats & Tracking Potential Solutions

- GNSS Intentional Interference & Spoofing Study Team (GIISST)
- Other technologies may be useful
  - Robustness: vector tracking, interference/spoof detection
  - Redundancy: microPNT, Low Frequency

Next Steps

For more information:

- Visit www.insidegnss.com/webinars for:
  - PDF of Presentation
  - List of resources provided

For more information on NovAtel

- Visit : www.NovAtel.com

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Poll #3

Which feature of a GNSS-based navigation system is important to your applications?
(Please select one)

1. ***Continuing to provide navigation during jamming/interference.***
2. ***Avoiding generating Hazardously Misleading Information (HMI)***
3. ***Providing a timely indication of possible interference.***

Ask the Experts – Part 2

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Principal Consultant
LS Consulting

George Shaw
Principal Development Engineer
Research & Radionavigation
Directorate of the General
Lighthouse Authorities of the
UK and Ireland

Sherman Lo
Senior Research
Engineer
Stanford GPS
Laboratory

Peter Soar
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Manager
Military & Defence

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A word from the sponsor

Neil Gerein
Aerospace & Defense
Product Manager
NovAtel

www.novatel.com

Backup

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Related Papers by Logan Scott

- **Policy Recommendations**
  1. **Towards a Sound National Policy for Civil Location and Time Assurance; Putting the Pieces Together, InsideGNSS Magazine, September/October 2012**

- **Cryptographic Signal Authentication**
  1. **Anti-Spoofing & Authenticated Signal Architectures for Civil Navigation Systems ION GPS/GNSS 2003**
  2. L1C Should Incorporate Cryptographic Authentication Features, May 2006 Comments on ICD-GPS-800
  3. Civilian GPS Signal in Space Enhancements for AntiSpoofing and Location Authentication, presented at JNC 2011, 28 June, 2011
  4. Location Signatures: Proving Location to Second Parties without Requiring Trust 12 June 2012, JNC 2012

- **Jammer Location "J911"**
  1. J911: The Case for Fast Jammer Detection and Location Using Crowdsourcing Approaches, paper presented at ION-GNSS-2011, September 20-23, 2011

- **Receiver Certification**
  1. Receiver Certification: Making the GNSS Environment Hostile to Jammers & Spoofers, presented Nov 9, 2011 to PNT EXCOM AB. Available at http://www.pnt.gov/advisory/2011/11/scott.pdf
  2. Level 1 Draft Specification posted at: http://logan.scott.home.comcast.net/~logan.scott/

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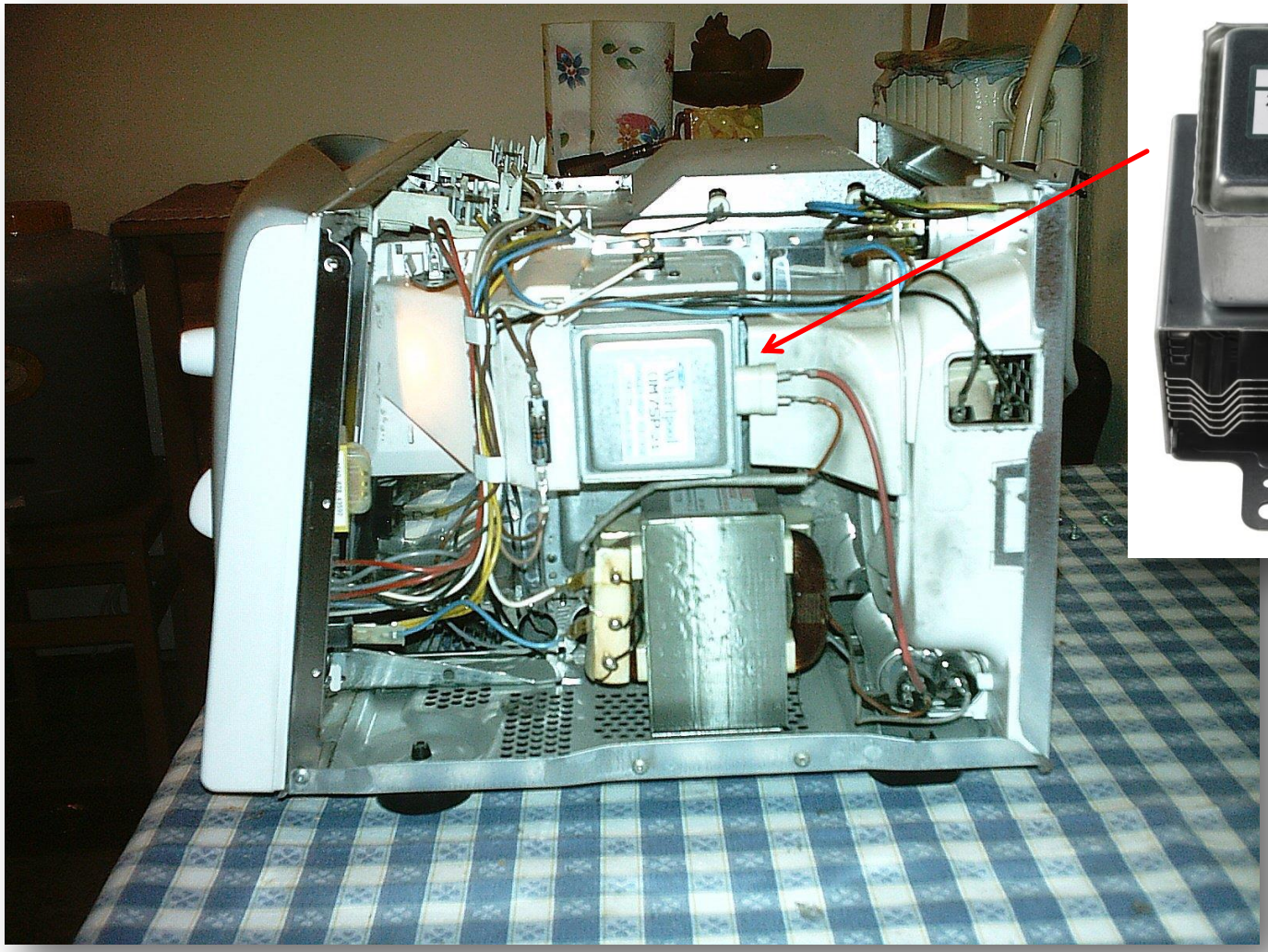
A 1000 Watt Jammer

2.45 GHz Center Frequency



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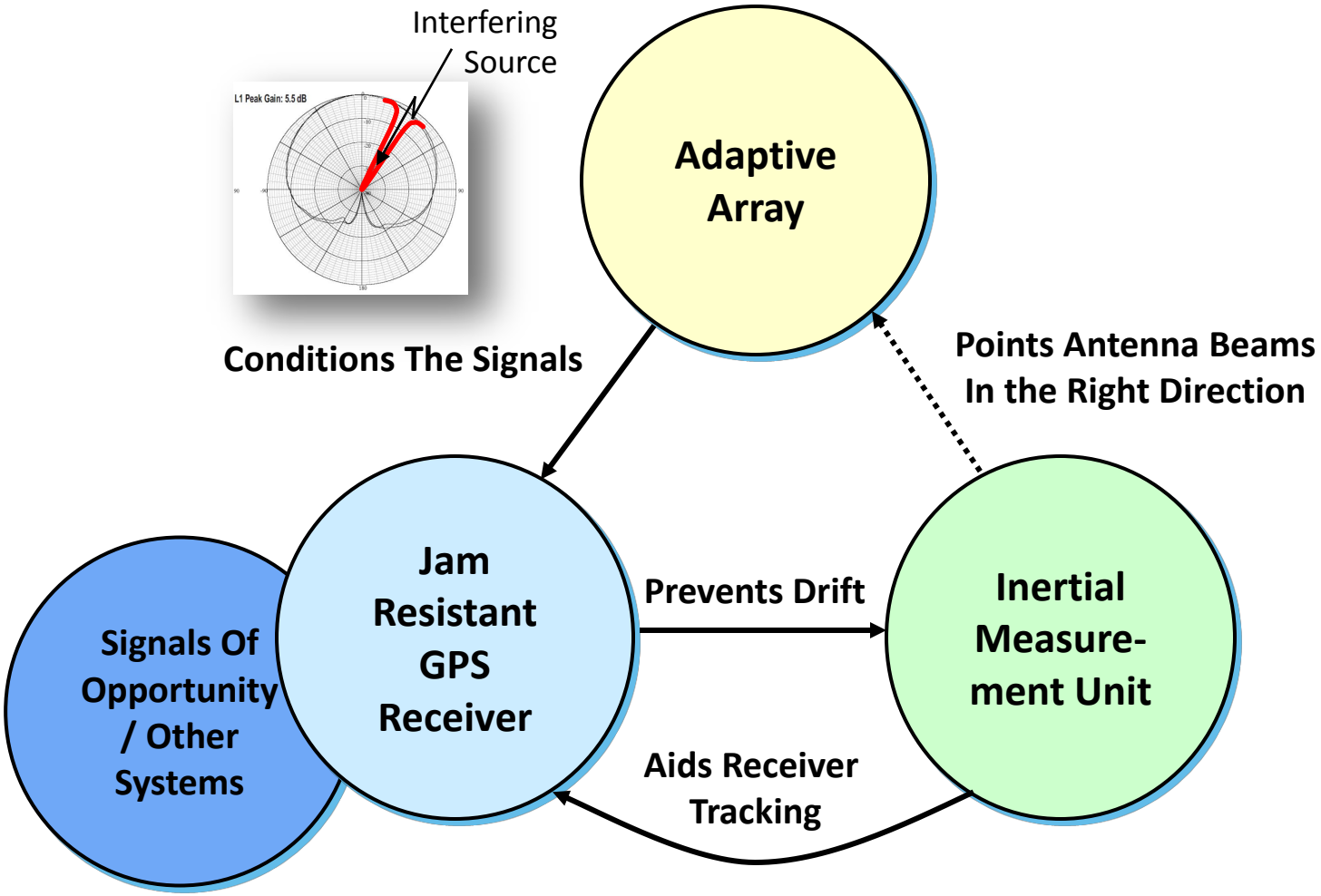
The Antijamming Triad



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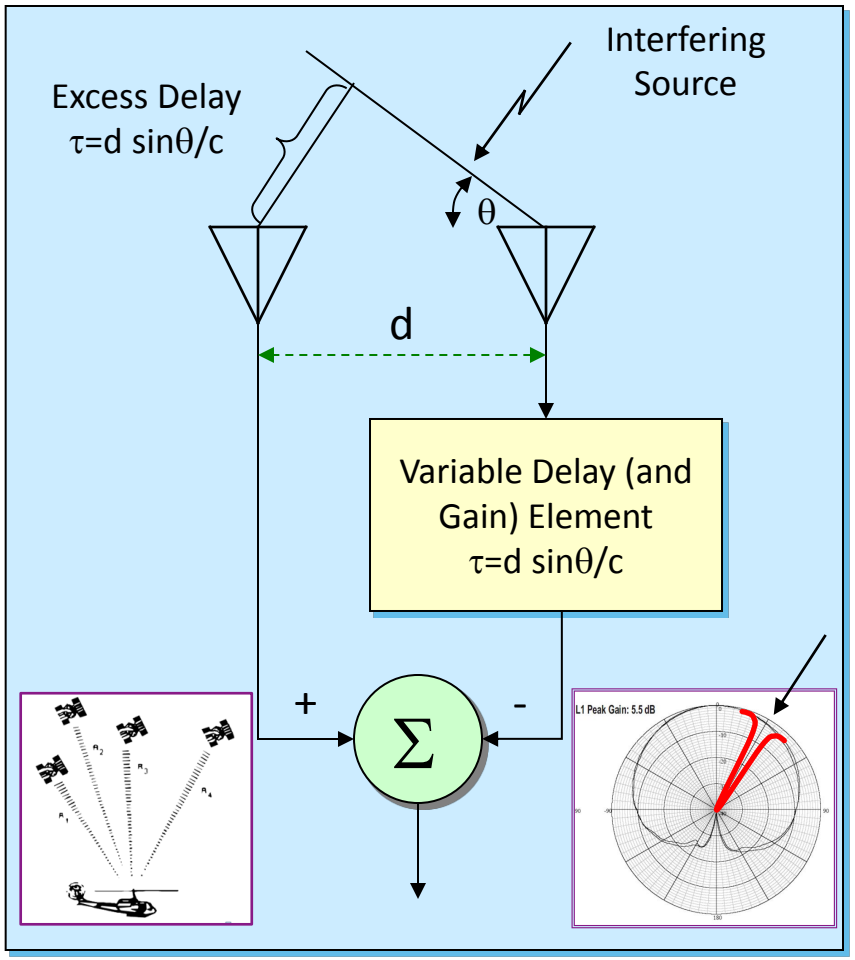
An Adaptive Nuller Seeks to Create Nulls In the Direction of Interferers



- N-1 Independently Steerable Spatial Nulls with N element array

- Wide Variety of Control Algorithms

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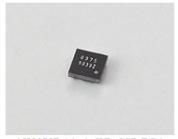
Significant AntiJam, AntiSpoof, & Anti HMI via Multisensor Integration Is Within Realm of Consumer Electronics

iPhone4 Also Uses WiFi & Cell Tower Positioning

iPhone4 Part	Price
STM LIS331DLH 3-axis Accelerometer	$ 0.65
STM L3G4200D 3-axis Gyro	$ 2.60
AKM AK8975B 3-axis Magnetometer	$ 0.70
Broadcom BCM4750 A-GPS	$ 1.75
Total	**$ 5.70**

AKM Semiconductor
AK8975B
$0.70



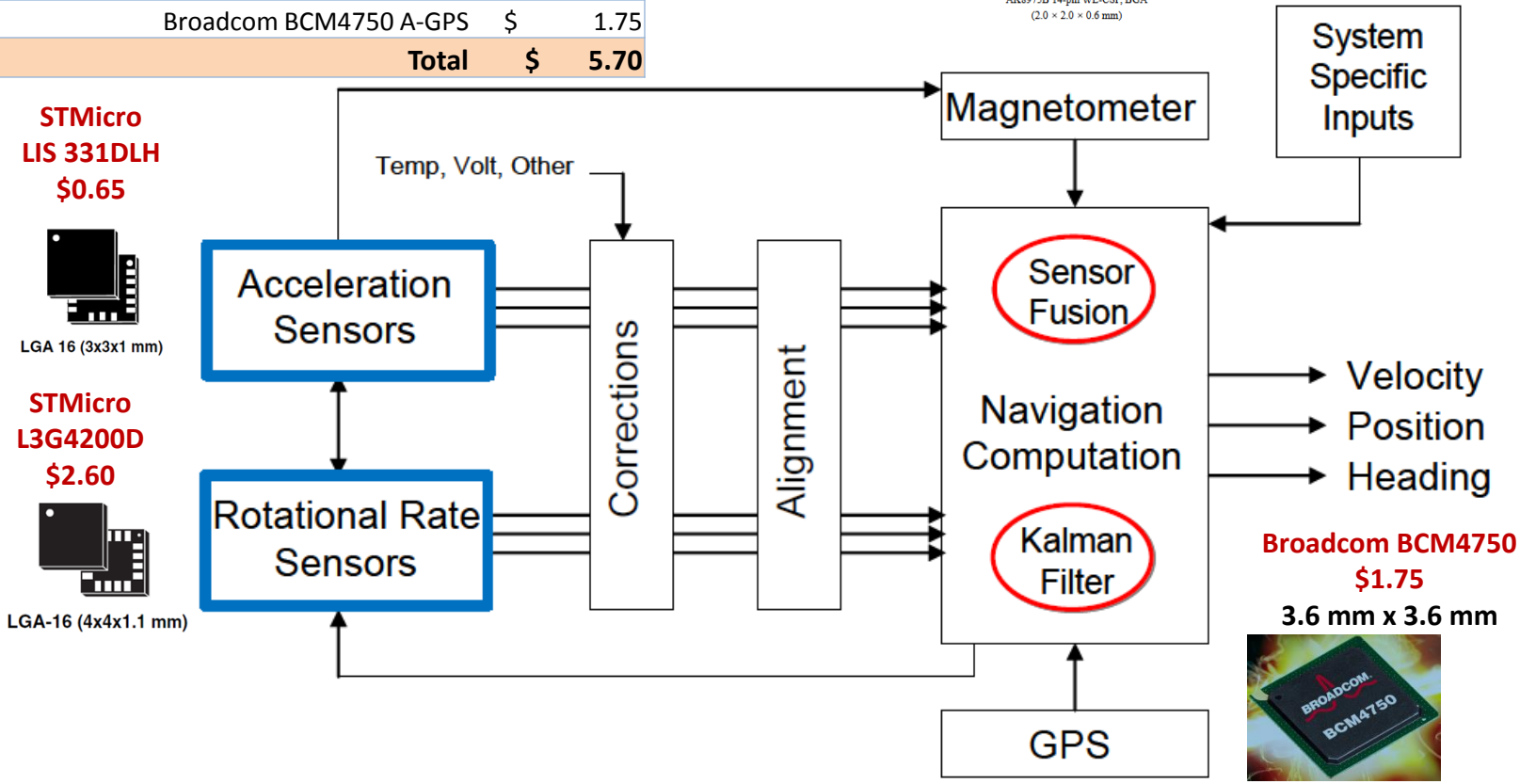
AK8975B 14-pin WL-CSP, BGA
(2.0 × 2.0 × 0.6 mm)

STMicro
LIS 331DLH
$0.65

LGA 16 (3x3x1 mm)

STMicro
L3G4200D
$2.60

LGA-16 (4x4x1.1 mm)



Broadcom BCM4750
$1.75
3.6 mm x 3.6 mm

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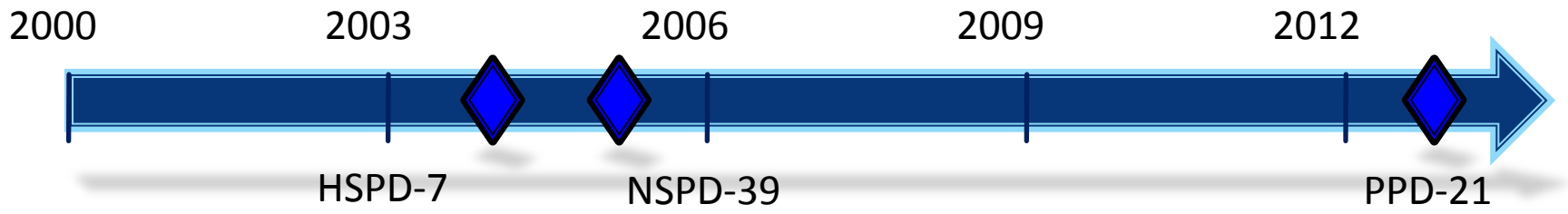
Positioning Using Point Space Databases

© Logan Scott / LS Consulting

Back Up & Additional Information

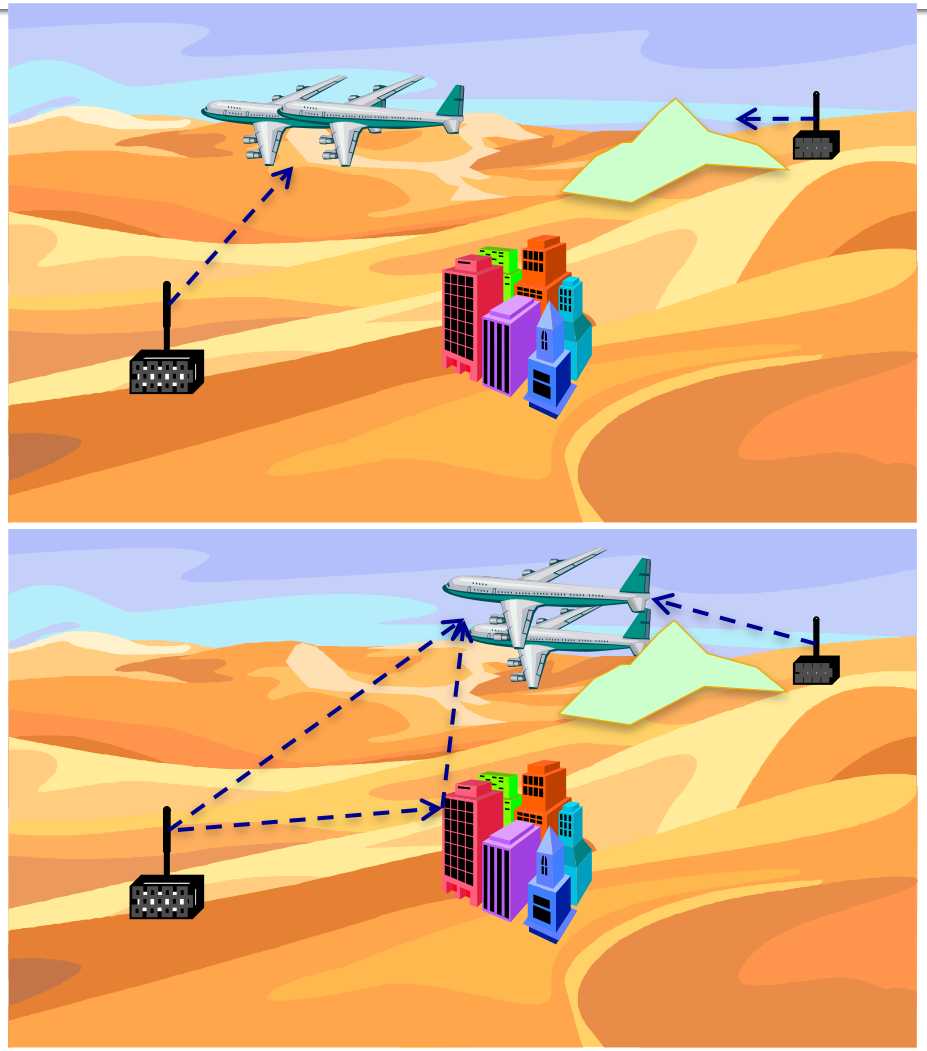
Sherman Lo
Stanford University GPS Laboratory

Protecting Critical Infrastructure Policy



"ensure that the US maintains space-based PNT services, augmentation, back-up, and service denial capabilities that: (1) provide uninterrupted availability of PNT services …" NSPD -39

"It is the policy of the United States to strengthen the security and resilience of its critical infrastructure against both physical and cyber threats."
PPD-21

Terrestrial Power Benefits Come at a Cost

- Not easy to meet APNT terminal area goals with (existing) ground stations
- Line of Sight Limitations
  - Fewer stations visible at low altitudes
- Ground Multipath
  - Buildings, ground (roads, runways) reflect signals