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# UNMANNED SYSTEMS WEEK

## WELCOME TO
POSITIONING, NAVIGATION, AND GUIDANCE FOR UNMANNED SYSTEMS

**Monday, June 2, 2014**
11 am–12:30 PDT
Noon–1:30 pm Mountain
1 pm–2:30 pm Central
2 pm–3:30 pm Eastern

**Audio is available via landline or VoIP—For VoIP:** You will be connected to audio using your computer's speakers or headset. **For Landline:** Please select Use Audio Mode Use Telephone after joining the Webinar. **US/Canada attendees** dial +1 (516) 453-0031, Access 370-248-439

# WELCOME TO
## Positioning, Navigation, and Guidance for Unmanned Systems

**Sandy Kennedy**
Director of Core Cards
NovAtel Inc

**Andrey Soloviev**
Principal
QuNav

**Stephen Browne**
Executive Vice President
Veripos

**Co-Moderator: Lori Dearman, Sr. Webinar Producer**

# Who's In the Audience?

A diverse audience of professionals registered from 43 countries, 30 states and provinces representing the following industries:

21% GNSS Equipment Manufacturer

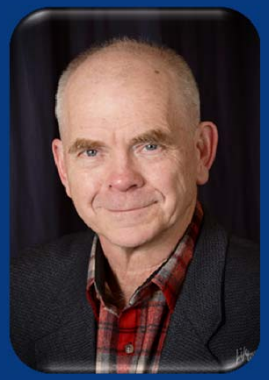
17% Professional User

17% System Integrator

17% Product/Application Designer

28% Other

# Welcome from *Inside GNSS*



**Glen Gibbons**

**Editor and Publisher**
***Inside GNSS***

# Positioning, Navigation, and Guidance for Unmanned Systems

**Demoz Gebre-Egziabher**
**Aerospace Engineer and Mechanics Faculty**
**University of Minnesota**

# Poll #1

***What application are you interested in using unmanned systems for?***
***(Select all that apply)***

- ***Air***
- ***Land***
- ***Marine***

# Overview of Unmanned System PNT Requirements

**Demoz Gebre-Egziabher**
**Aerospace Engineer and Mechanics Faculty**
**University of Minnesota**

# Unmanned Systems

Photo courtesy of FourthWing Sensors (Farm Intelligence[2])

- Vehicles without a human operator onboard
  - Unmanned Aerial Vehicles (UAV)
  - Unmanned Ground Vehicles (UGV)
  - Unmanned Marine Vehicles (UMV)
- Ideal for the **3-Ds** tasks: **Dangerous**, **Dirty** and **Dull**

Photos courtesy of Autonomous Surface Vessels Ltd. (ASV Unmanned Marine Systems)

# PNT Requirements

- Position, Navigation and Timing (PNT) performance metrics
  - Accuracy
  - Availability
  - Continuity
  - Integrity
- PNT Requirements depend on vehicle and operation
  - Example 1: UAV in Precision agriculture (Accuracy)
  - Example 2: Car platooning (Integrity)
- Can be as stringent as manned vehicle requirements

Photo courtesy of FourthWing Sensors (Farm Intelligence[2])

Photo courtesy of Road Safety GB.

# Performance Metrics

- **Availability**
  - Availability is defined (or computed) as the fraction of time a navigation system is providing position fixes to the specified level of accuracy, integrity and continuity.
- **Accuracy**
  - Accuracy or Navigation Sensor Error (**NSE**) is defined as the difference between the position estimated by the navigation sensor and the true position of the aircraft which is only exceeded 5% of the time in the absence of system failures.
- **Integrity**
  - Integrity risk is the likelihood of an undetected navigation error or failure that results in hazardously misleading information.
- **Continuity**
  - Continuity risk is the probability of a detected but unscheduled navigation function interruption after an operation has been initiated.

# Webinar Objectives

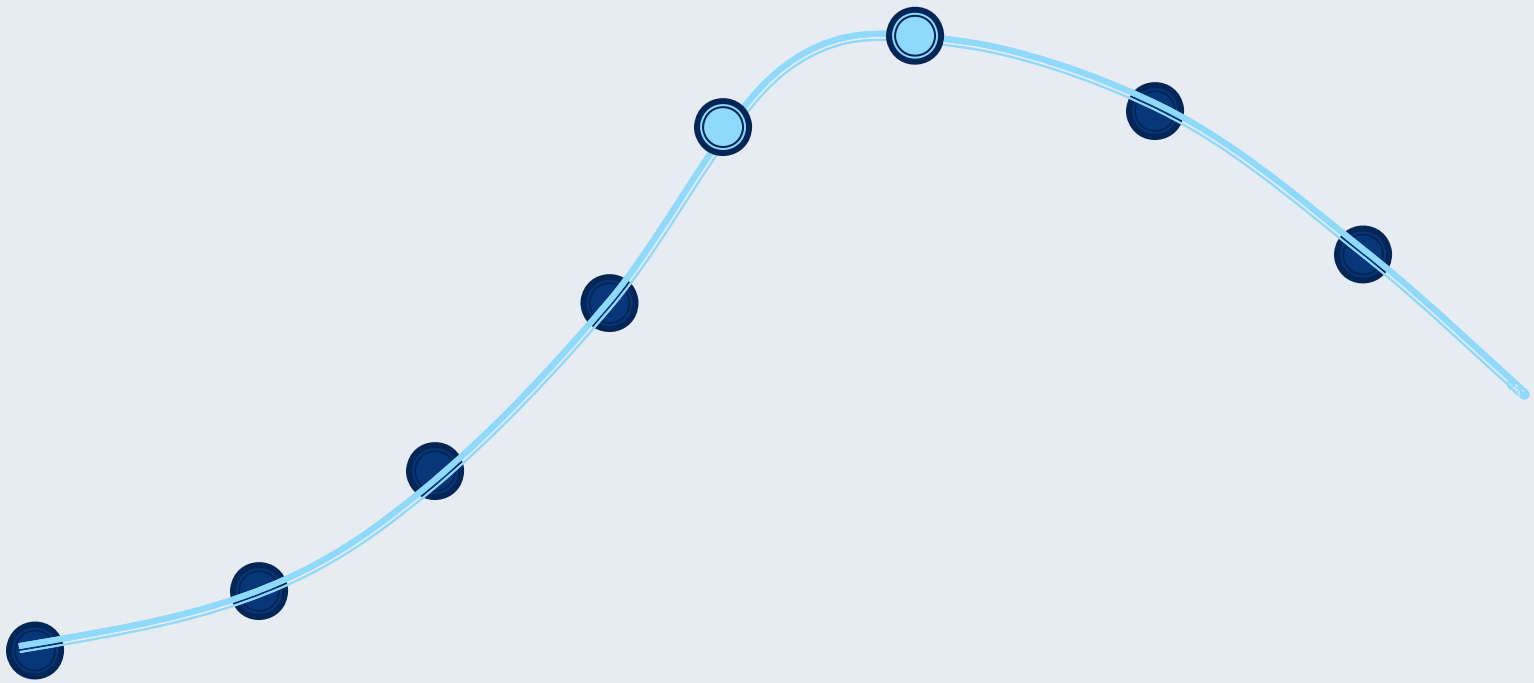
- What do these performance metrics mean?
- How are they measured?
- What are the software (algorithm) and hardware solutions to achieve these?
- How are the specific PNT requirements achieved in the air, land and marine domain?

# Availability Requirements

**Sandy Kennedy**
Director of Core Cards
NovAtel Inc

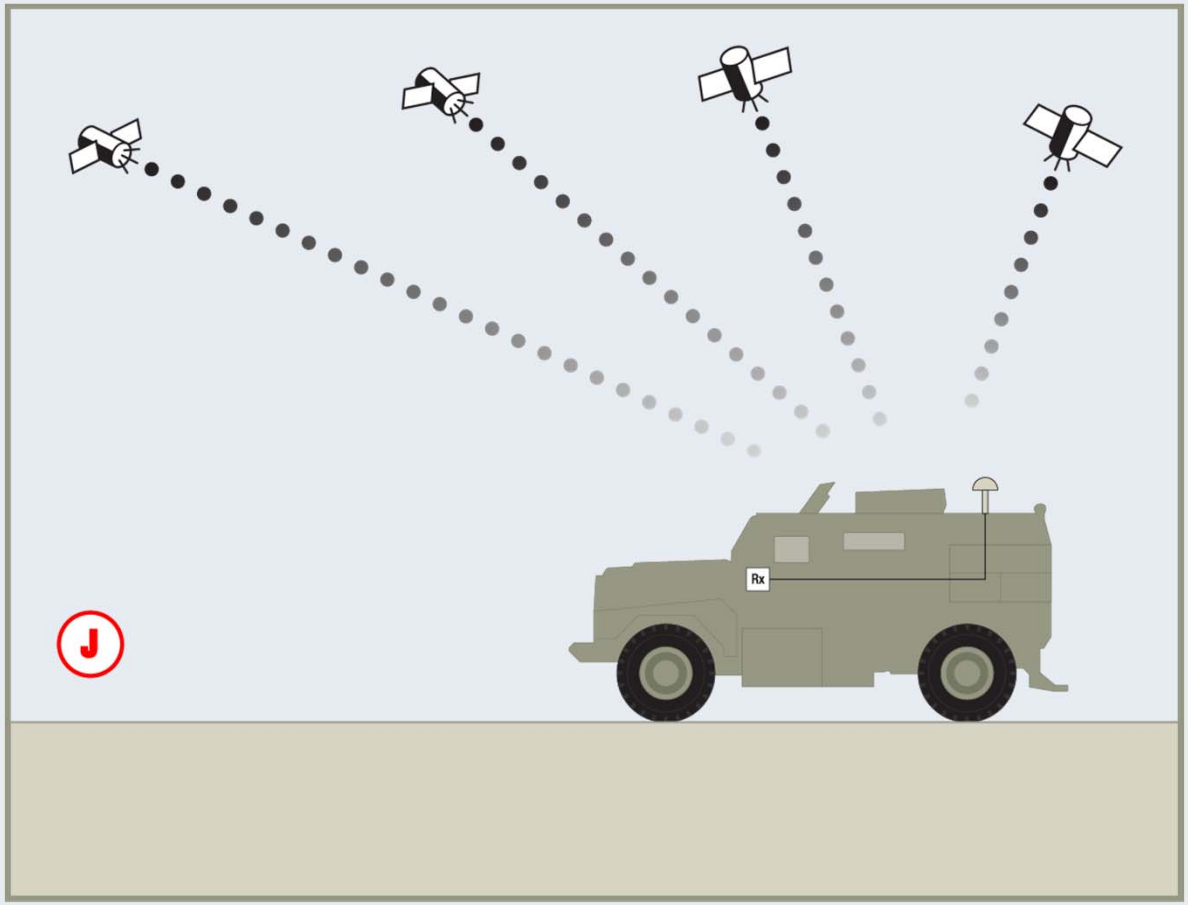
# Solution Availability

- Defined as how often a position, velocity and time solution is available
- For an Unmanned System (US), the requirement is typically ***always available in real-time***



# GNSS Solution Availability

- GNSS solution availability is governed by:
  - View of the sky
  - Signal quality

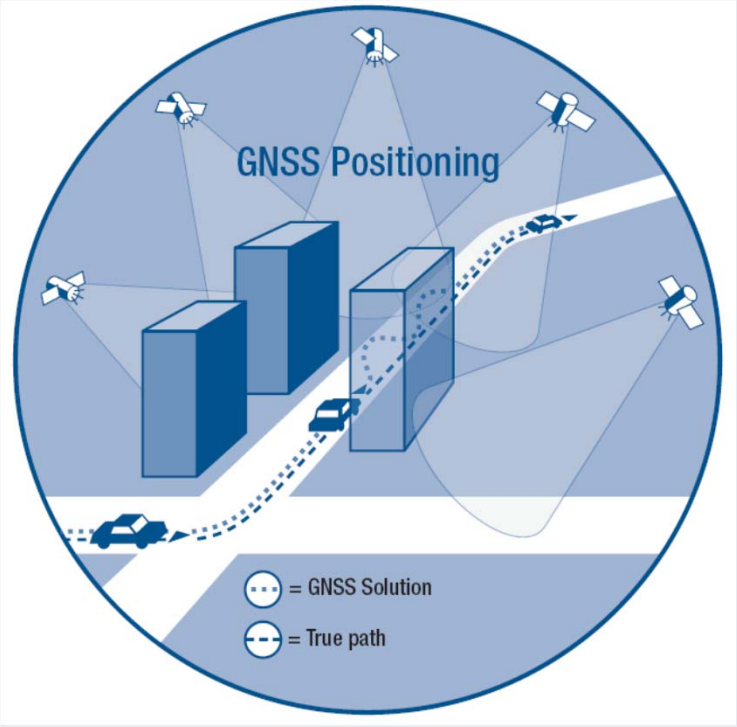


# Maximizing Satellites in View

- Multi-Constellation Support
  - Tracking everything up there is the simplest approach to being able to maximize the number of epochs with a position solution
- In an airborne situation, GPS alone may be sufficient
  - But perhaps not if significant banking occurs
- GNSS not just GPS
  - Include GLONASS, Beidou, Galileo
- By 2020, both Beidou and Galileo are expected to be fully operational

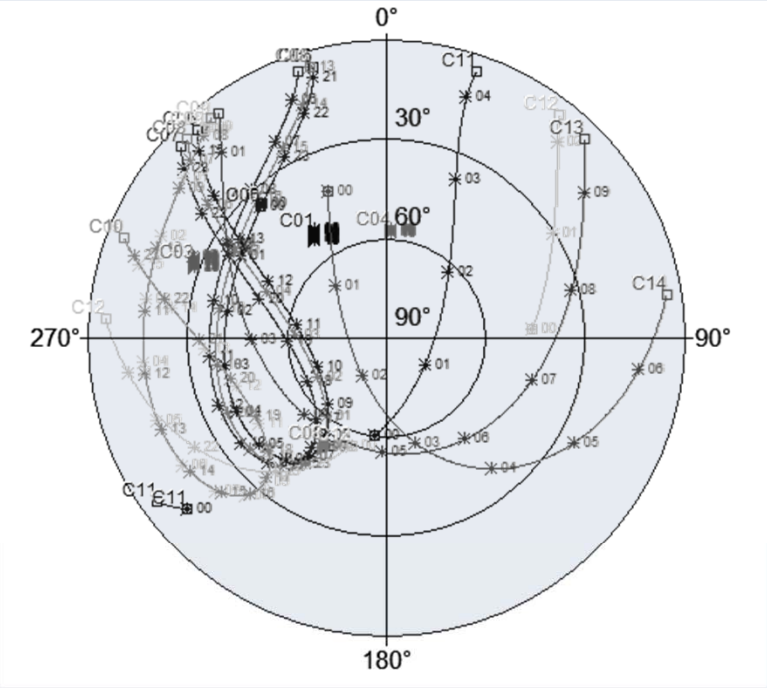
# Urban Canyon in North America = GPS + GLO

- In an urban canyon, the addition of GLONASS can enable a position to be computed when GPS alone would not
  - Doesn't provide ideal positioning geometry, but any position is often better than no position



# Urban Canyon in Asia = GPS + BDS

- Today in Asia, Beidou coverage is currently quite good, with the high elevation geostationary satellites being especially valuable.




*Beidou Visibility – Gold Coast, Australia*

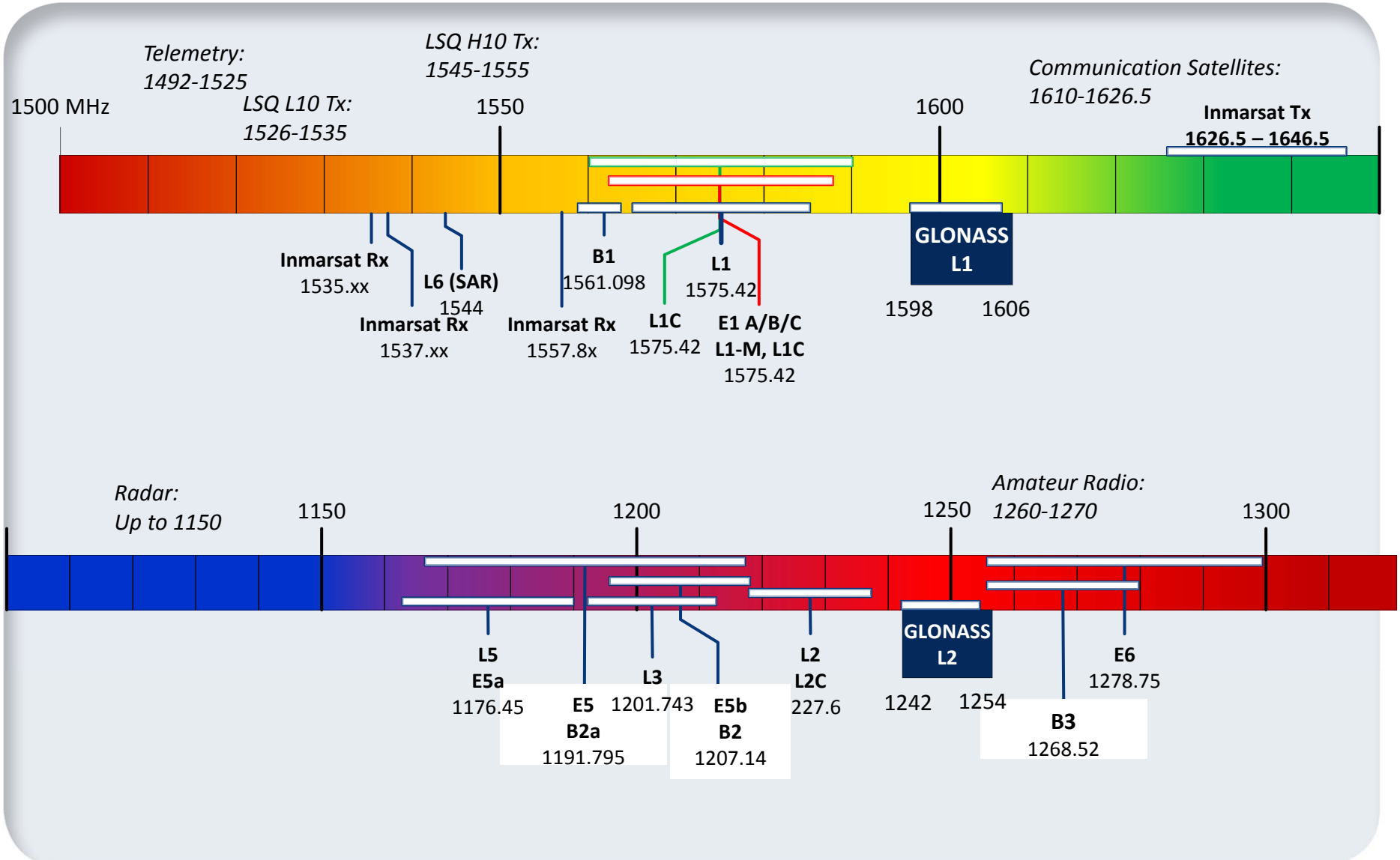
# Multi-Constellation Support = Choice

- If there is a failure in one constellation, you have others to rely on.
- For each constellation, supporting dual or triple frequency increases the number of measurements available
  - Also provides opportunity for higher accuracy solutions by removing ionospheric errors
- More measurements also means you can be more selective in choosing which ones contribute to the solution
  - More statistical analysis of “good” and “bad” measurements

# Interference

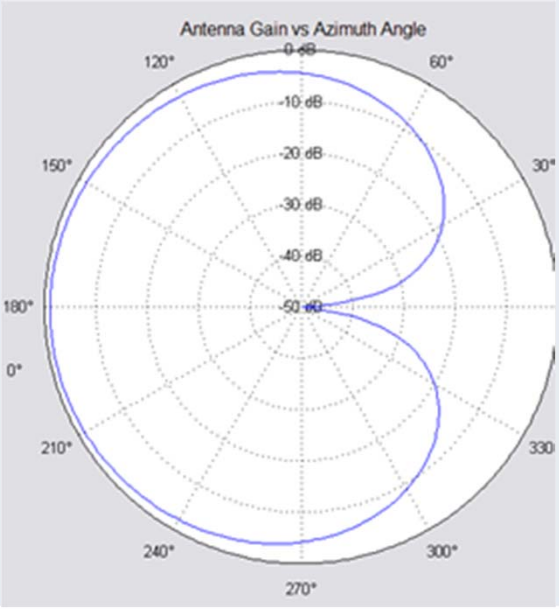
- Even with line of sight to a sufficient number of satellites, interference can render the signals in space inaccessible or useless
- The flip side of multi-constellation and multi-frequency support can be interference susceptibility
  - Depends on how the receiver is designed
  - How wide are the paths? Does GPS L1 share a path with GLO L1, or is GLO L1 separate?
  - Depends on the antenna used
  - If you aren't using all the frequencies, do not use a wide band antenna.
- Interference conditions on a UAV can be especially challenging
  - Lots of electronics packed into a small area
  - Other sensors onboard, like radar, can be interference sources
  - Telemetry systems

# Frequencies of Interest



# Unavoidable Interference: Intentional Jamming

- Anti-Jam Antenna: Null Steering
- A Controlled Reception Pattern Antenna (CRPA) is multiple antenna elements that are used to exploit spatial diversity
- Digital spatial processing is used to modify the apparent gain and phase of the antenna elements to create a new adaptively changing antenna pattern that creates nulls in the direction of the interfering signal
- N-1 degrees of freedom, where N is the number of antenna elements



*NovAtel's GAJT (N = 7)*

# Receiver Design for Interference Robustness

- Some applications cannot bear the size or weight of an anti-jam antenna
- Need to rely on receiver design only then
- Mitigation techniques on the receiver, for example:
  - Digital filtering? (provided you are not saturated)
  - Narrow band design and independent signal tracking – let's you "turn off" problem frequencies

# Solution Availability vs Accuracy: Multipath Effects

- Multipath is often a dominant error source
  - Especially in urban areas
  - With vehicles approaching large installations or buildings
    - Refueling a small craft from a large tanker
    - Mining vehicle close to a pit wall
  - Especially an issue with high sensitivity receivers
- With GNSS only, it can be difficult to identify and remove or adequately de-weight multipath-ed measurements
- The correlator used in the receiver is a key defense against multipath
- Direct reflected signals hard to detect
- Antenna design also key to multipath performance

# GNSS Solution Availability Strategies

- Track the signals that are valuable to you!
- Protect those signals
  - Shielding
  - Receiver RF design
  - Antenna design

# Ask the Experts – Part 1

**Sandy Kennedy**
Director of Core Cards
NovAtel Inc

**Andrey Soloviev**
Principal
QuNav

**Stephen Browne**
Executive Vice President
Veripos

## Poll #2

*In which of the following unmanned system operating domains are the PNT requirements most stringent? (Please select one)*

- *Air*
- *Land*
- *Marine*
- *It depends on the operation*

# Accuracy Requirements

**Andrey Soloviev**
**Principal**
**QuNav**

# Accuracy Requirements

- There are ***no general requirements***, accuracy is defined by a *specific application*

Precision agriculture

***Centimeter-level accuracy***

Autonomous driving

***Decimeter-level accuracy***

UAVs

***Meter-level accuracy***

Autonomous marine vessels

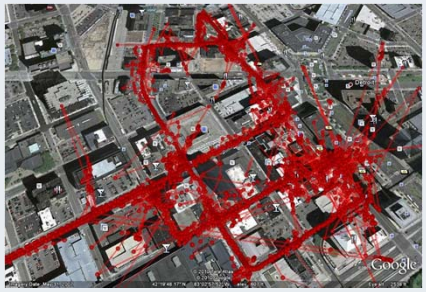
***0.1-2 meters***

# GNSS Positioning Techniques

| Positioning Technique | Typical Accuracies |
|---|---|
| Stand-alone solution | ~ 10 meters |
| Satellite-Based Augmentation Systems (SBAS) | Meter-level |
| Precise Point Positioning (PPP) | Decimeter - Sub-meter |
| Real-Time Kinematic (RTK) solution | Centimeter-level |

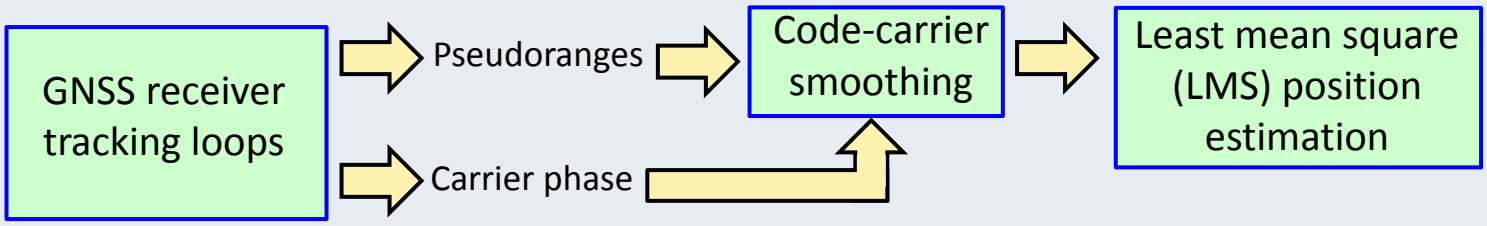
- GNSS can generally meet accuracy requirements when adequate satellite geometry is available (open-sky, suburban areas);

- Otherwise, *augmentation with other sensors* is required (tree-covered applications, dense urban areas, indoors, underwater)

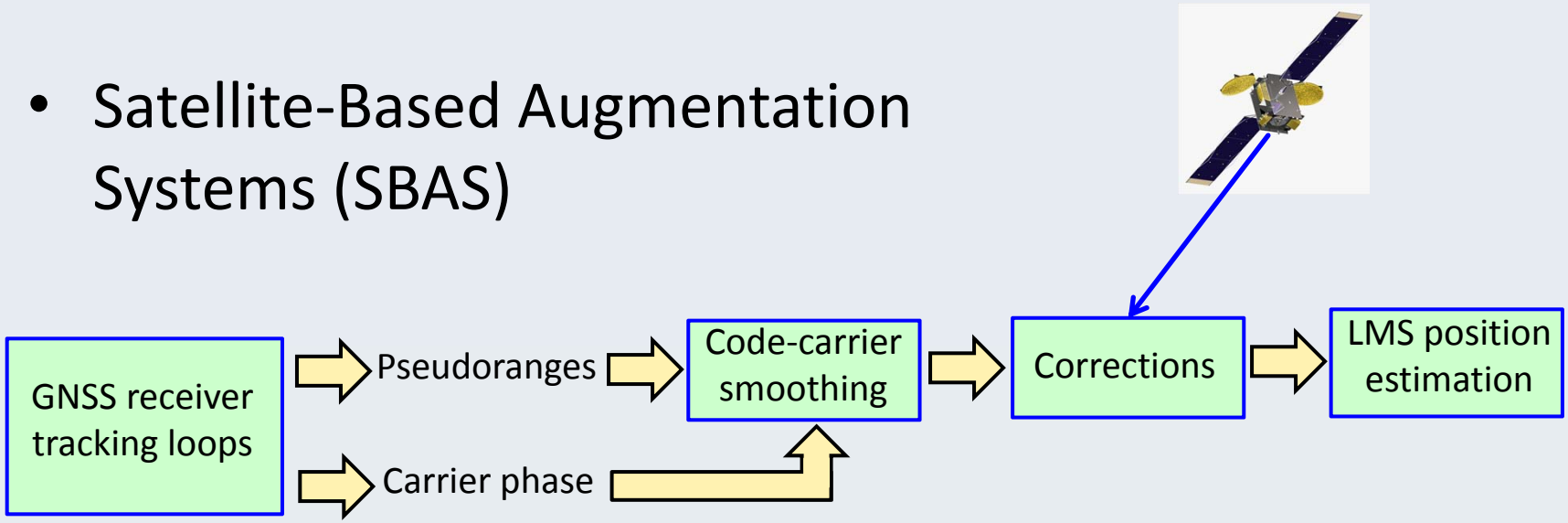


# Main Positioning Techniques

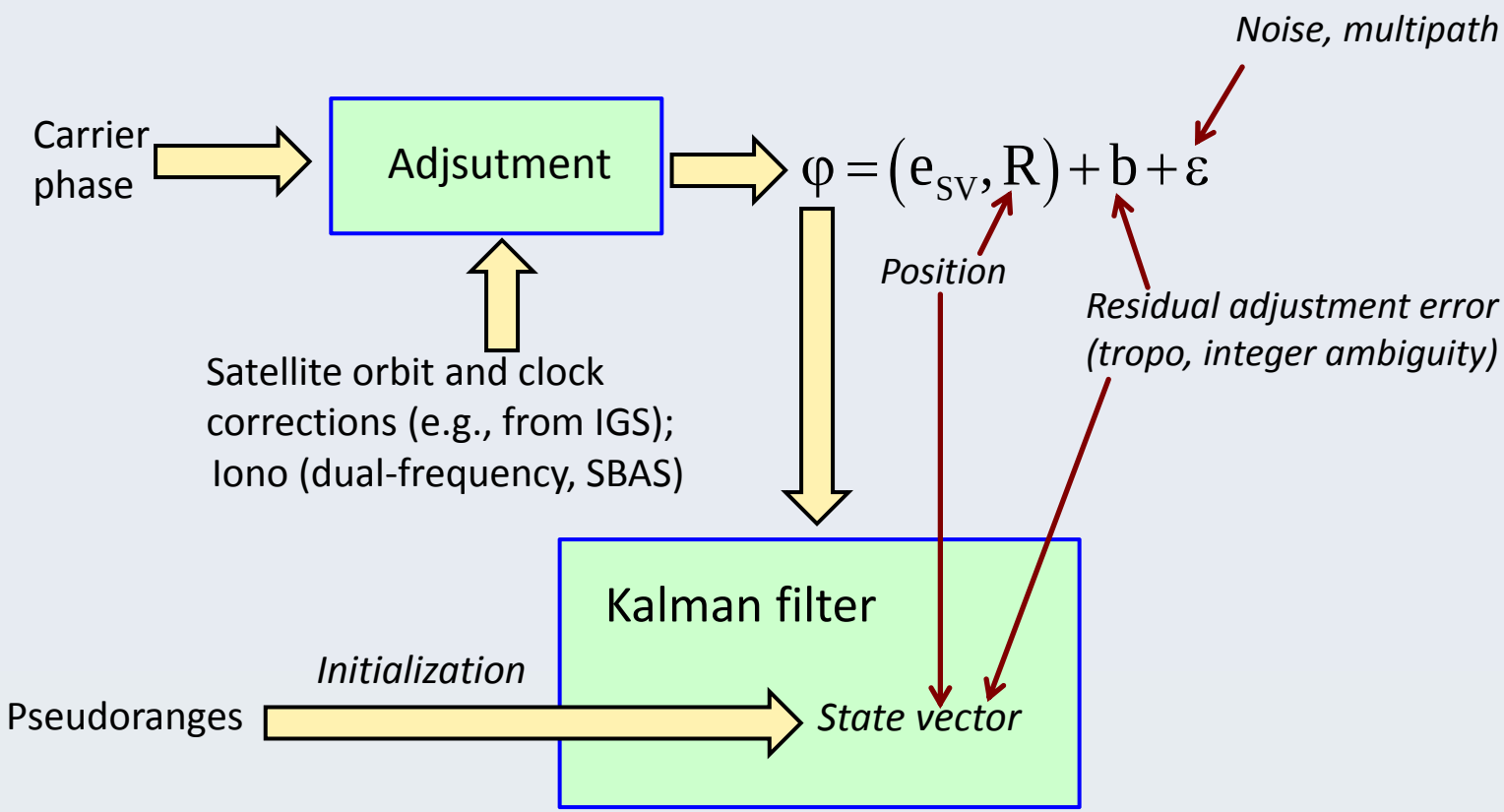
- Stand-alone solution



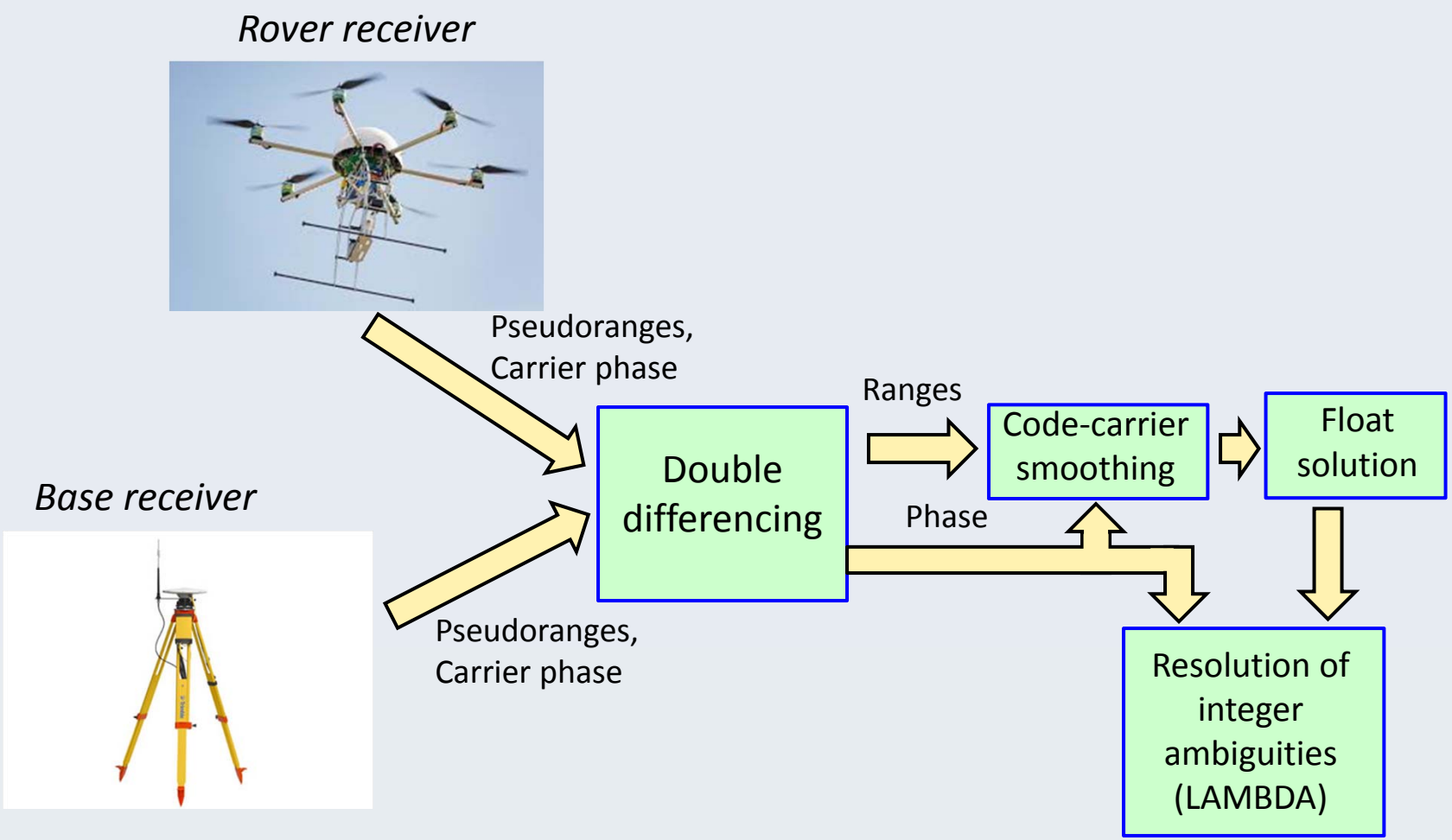

- Satellite-Based Augmentation Systems (SBAS)



- Precise Point Positioning (PPP)



- Real-Time Kinematic (RTK) solution



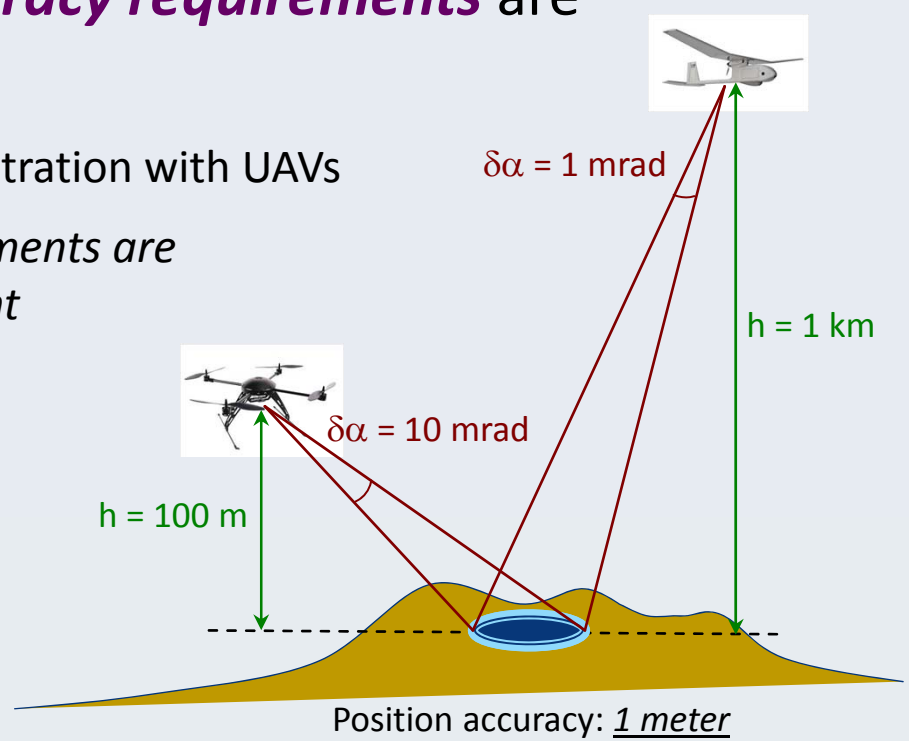
# It's not Just About Positioning!

- Other motion states have to be estimated for ***trajectory control*** and ***trajectory capture***:
  - Velocity, acceleration, attitude

- Similar to positioning, ***accuracy requirements*** are ***application specific***

Example: Geo-registration with UAVs

*Attitude requirements are height-dependent*

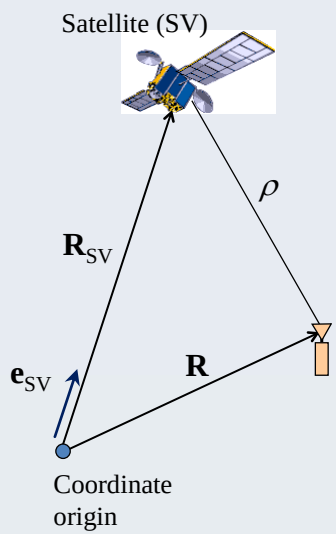


# GNSS Velocity Estimation

- Possible Approaches:
  - Position differencing
  - Use of Doppler frequency

  } *Sub-decimeter/second accuracy*
  - Estimation of velocity from temporal changes in carrier phase } *Sub-centimeter/second accuracy*

- Estimation of velocity from carrier phase




Carrier phase measurement

$$\varphi = \rho + \lambda N + \delta t_{rcvr} + \varepsilon + \eta$$

- $\lambda N$ → Ambiguity
- $\delta t_{rcvr}$ → Clock bias
- $\varepsilon$ → Atmospheric delays & SV clock
- $\eta$ → Noise & multipath

⇩

Temporal differencing

$$\Delta\varphi = -(\mathbf{e}_{SV,}\Delta\mathbf{R}) + \text{SV motion terms} + \Delta\delta t_{rcvr} + \Delta\varepsilon + \Delta\eta$$

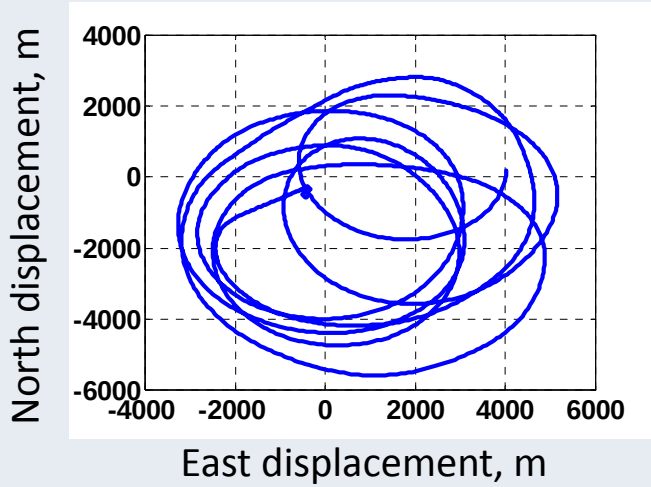
⇩

Velocity estimation

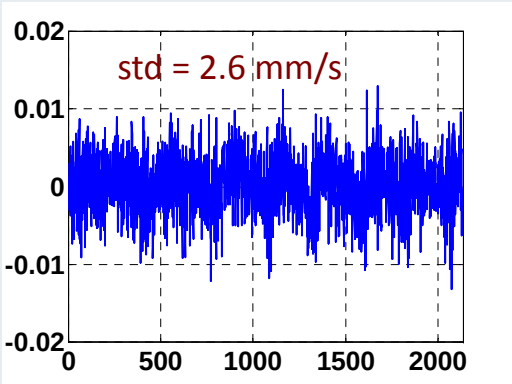
# GNSS Velocity Estimation (cont.)

- Example Test Results

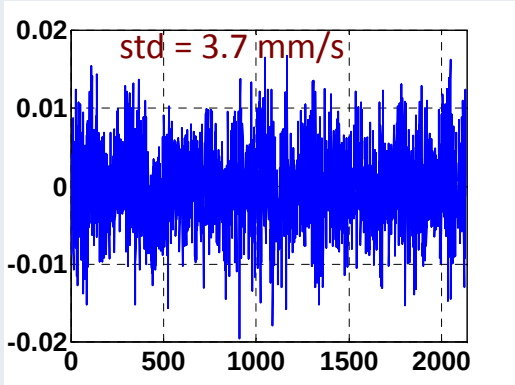
Flight trajectory




East velocity error, m/s

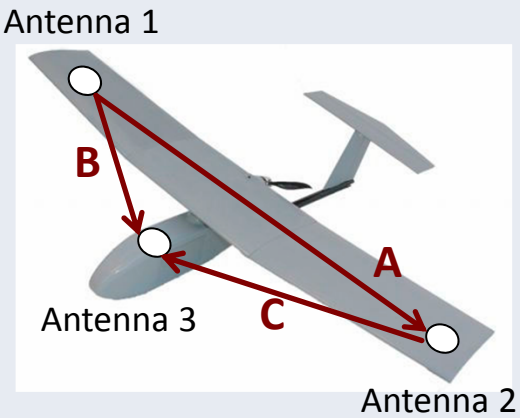



North velocity error, m/s



# GNSS Attitude

- Use of multiple antennas and carrier phase interferometry




Antenna 1 → Pseudoranges, Carrier phase
Antenna 2 → Pseudoranges, Carrier phase
→ Double differencing → Constrained ambiguity resolution (*known length of the baseline*)
→ **A** resolved in the navigation frame of reference

{**A**, **B**, **C**} *resoloved in the nav frame* →
{**A**, **B**, **C**} *resoloved in the body frame frame* (pre-measured) →
→ Attitude Estimation → {Roll, Pitch, Heading}

- Attitude accuracy:

  ~ 1 cm/(size of the multi-antenna system) ⇒ *Limited accuracy for small-size autonomous vehicles* (augmentation with inertial may be required)

# DGNSS for Unmanned Marine Vessels

**Stephen Browne**
**Executive Vice President**
**Veripos**

# Unmanned Marine Vessels (UMV)

- Limited number of production UMVs currently operating, and several prototype UMVs undergoing test and evaluation with other prototypes in the planning stages.
- UMV missions:
  - Military
  - Offshore Oil & Gas
  - Scientific
  - Cargo & Transportation

Photo courtesy of Liquid Robotics & Marinelink.com

Photo courtesy of Aeronautics Defense Systems Ltd.

Photo courtesy of Rolls Royce and Bloomberg Media

# The UMV DGNSS Requirement

- Robust, reliable and redundant DGNSS positioning system, most likely integrated with INS:
  - Designed to prevent single-point-failures
  - High-accuracy PPP DGNSS solution
  - Marine Environmental Considerations
  - Position Outputs
  - INS Integration
  - Heading Capability
  - Data logging

Photos courtesy of Autonomous Surface Vessels Ltd.
(ASV Unmanned Marine Systems)

# GNSS Challenges

- GNSS Issues & Challenges:
  - Multipath
  - Dynamic Motion
  - Antenna location and type
  - Interference
  - Physical system integrity
  - Position integrity, accuracy & repeatability
  - Antenna Blockage caused by platforms

Photo courtesy of Subsea 7

Photo courtesy of Textron Systems

# Multipath & Motion Issues

- Multipath issues:
  - Antenna height in relation to water surface
- Motion issues:
  - High dynamic range of motion in various sea states
  - Rapidly changing GNSS constellation elevations
  - Corrections links
- These issues make an argument for an integrated INS/DGNSS solution

Photo courtesy of Autonomous Surface Vessels Ltd.
(ASV Unmanned Marine Systems)

Photo courtesy of NovAtel Inc.

Photo courtesy of Veripos Ltd.

# Receiver & Antenna Considerations

- Receiver & Antenna Issues:
  - Small vessel design & mast
  - System physical integrity: Integrated Pod system or separate receivers & antenna
  - Receiver capability
  - Analysis and selection of antenna type
  - Interference rejection criteria

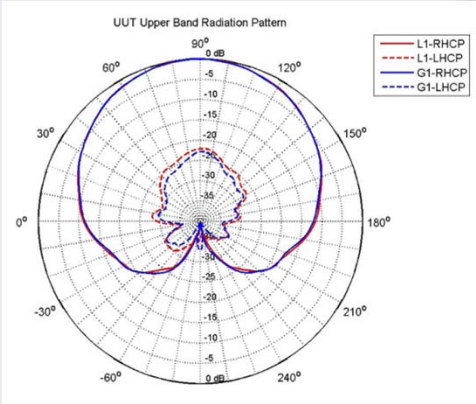



Photo & image courtesy of NovAtel Inc.

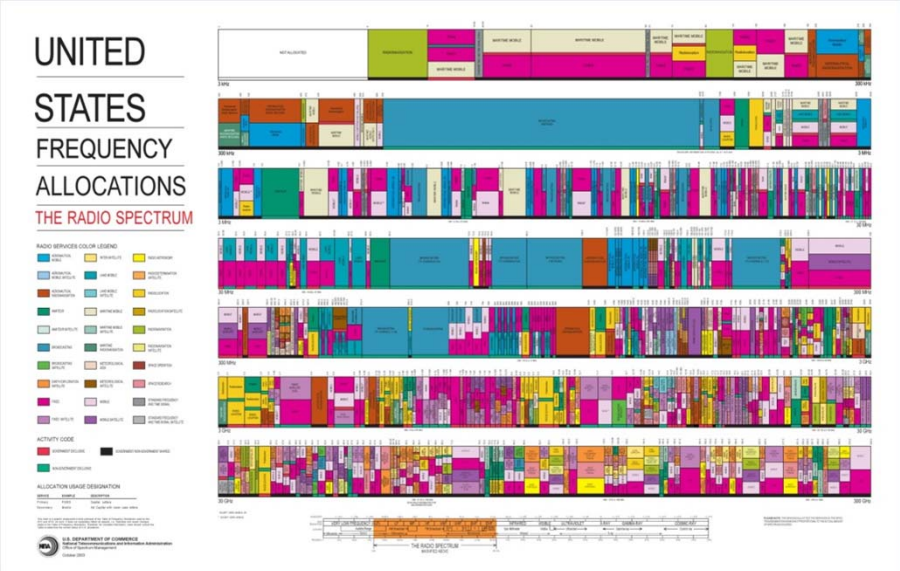
NovAtel GAJT Antenna

# Interference Issues

- Interference in the Marine Environment can generally be classed as in-band interference and out-band interference
  - Causes of In-band interference
  - Causes of Out-band interference
- Extra Consideration: Data-link systems
- Receiver technology, antenna type and mounting location (again)
- DGNSS & INS integration

Courtesy of Veripos Ltd.

Courtesy of the U.S. Department of Commerce



# Position Integrity

- The integrity of the DGNSS position will be influenced by the operational criteria of a specific mission type, for instance:
  - Operations requiring absolute accuracy
  - Operations requiring position stability robustness
  - Multi-mission configurable vessels will require both

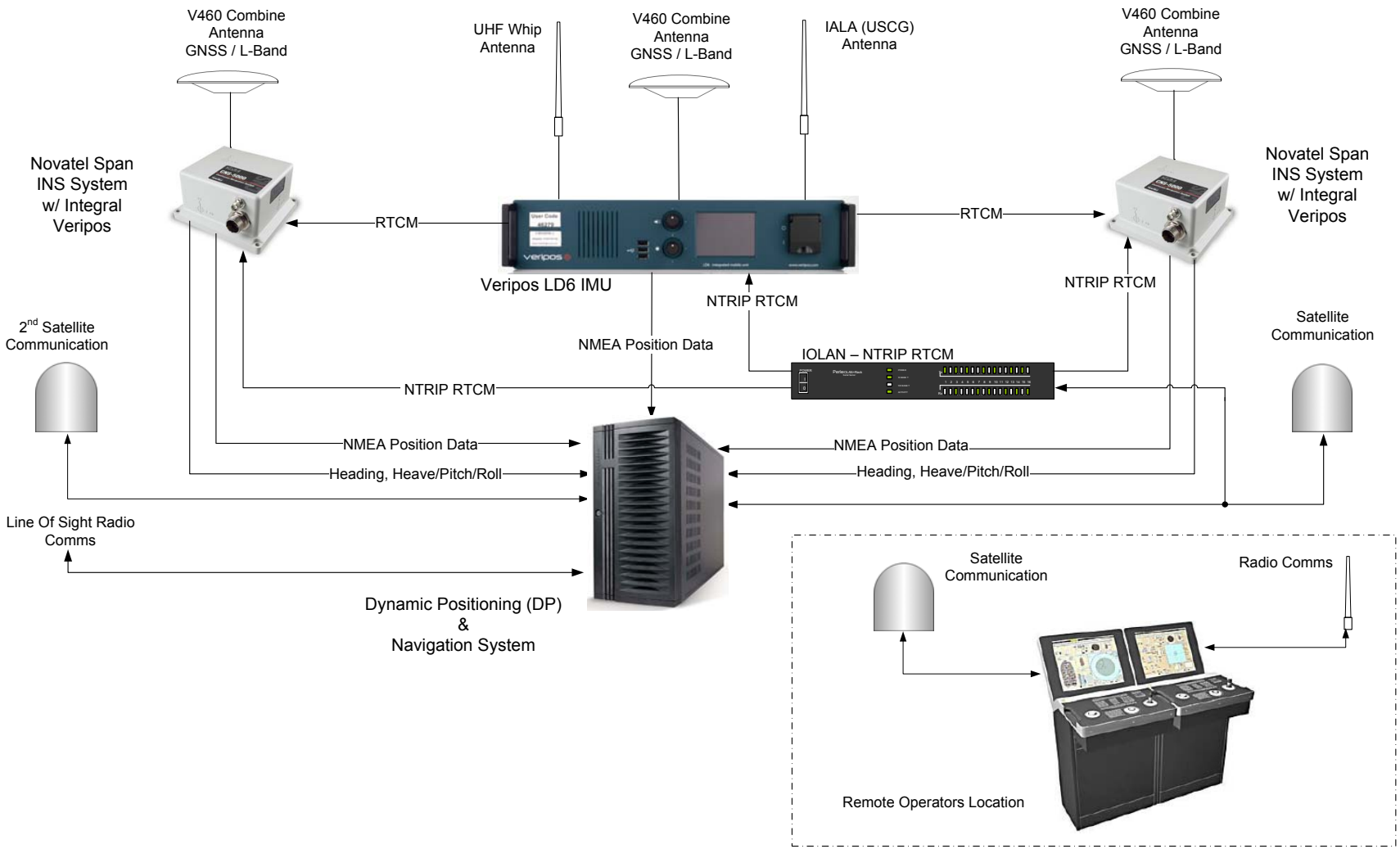
# The Prevention of Single Point Failures

- As with all marine DGNSS operations, the prevention of single point failures will be a key design criteria. There are several areas to be addressed, as follows:
  - Multi-constellation capability
  - Capable of utilizing multiple correction sources simultaneously
  - Integration of INS & DGNSS
  - Redundant  systems
  - Different and complimentary systems

Photo courtesy of Veripos Ltd.

Veripos LID6-GG2 IMU

# System Block Diagram – Example 1



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- Aeronautics Defense Systems Ltd.: www.aeronautics-sys.com
- Rolls Royce: www.rolls-royce.com & www.rolls-royce.com/marine
- Bloomberg Media: www.bloomberg.com & www.businessweek.com
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- Farm Intelligence$^2$: http://www.farmintelligence.com/
- Road Safety GB: http://www.roadsafetygb.org.uk/

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- Weds, June 4th : GNSS/Inertial + Integration for Unmanned Systems
- Fri, June 6th : Unmanned Solutions & Applications Day

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**•Andrey Soloviev – soloviev@qunav.com**
**•Stephen Browne – stephen.browne@veripos.com**

## Poll #3

*If all regulatory framework is in place, When do you see yourself using unmanned systems? Within: (Please select you one)*

- *1 year*
- *2 years*
- *3 years*
- *4 years*
- *5 years*

# Ask the Experts – Part 2

**Sandy Kennedy**
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