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Wednesday, November 13, 2013

11 am – 12:30 pm PST
Noon – 1:30 pm MST
1:00 pm – 2:30 pm CST
2 pm – 3:30 pm EST

UNMANNED SYSTEMS:

NAVIGATION, GUIDANCE, AND INTEGRITY FOR AUTONOMOUS GROUND AND AIR VEHICLES

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WELCOME TO:

Unmanned Systems: Navigation, Guidance, and Integrity for Autonomous Ground and Air Vehicles

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Dr. Steven Heppe
Principal
Telenergy, Inc

Chris Wilson
CEO
Vehicle Data Science

Todd Colten
Principal
Aero/Systems Engineer
UTC Aerospace Systems

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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 500 professionals registered from 45 countries, 38 states and provinces representing the following operational domains:

- **55%** Air
- **32%** Land
- **6%** Marine
- **7%** Other

Welcome from *Inside GNSS*

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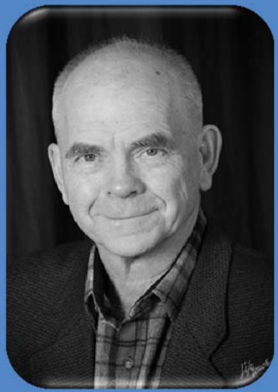

Glen Gibbons

Editor and Publisher
Inside GNSS

Unmanned Systems: Navigation, Guidance, and Integrity for Autonomous Ground and Air Vehicles

Demoz Gebre-Egziabher

Aerospace Engineer and Mechanics Faculty, University of Minnesota

Poll #1

Regulatory issues aside, what is the major (Guidance, Navigation control) or GNC obstacle to the widespread use of unmanned vehicles today? (please select one)

1. ***Reliability and performance of existing (GNC) technology*** **44%**
2. ***Cost of existing GNC technology*** **11%**
3. ***Lack of standards for certifying GNC technology*** **45%**

GNSS and Integrity of PNT in Unmanned Aerial Vehicles

Dr. Stephen Heppe
Principal
Telenergy, Inc

Unmanned Aerial vehicles

- Unmanned aerial vehicles (UAV)
  - autonomous flight, sometimes landings, DGPS, integrated nav sensors; autopilot (algorithms)


Raven
AeroVironment


Fire Scout
Northrop Grumman

Predator
General Atomics


Vireo-X
UTC Aerospace Systems


Hummingbird
DARPA


ScanEagle
Insitu/Boeing

Insitu / Boeing ScanEagle

PERFORMANCE

- Max Horizontal Speed 75 kt
- Cruise Speed 48 kt
- Ceiling 19,500 ft
- Endurance 20+ hours

APPROXIMATE DIMENSIONS

- Wing Span 3 m (10 ft)
- Length 1.5 m(5 ft)

APPROXIMATE WEIGHTS

- Empty Structure Weight 13 kg (28 lb)
- Max Takeoff Weight 20 kg (44 lb)

Insitu / Boeing ScanEagle

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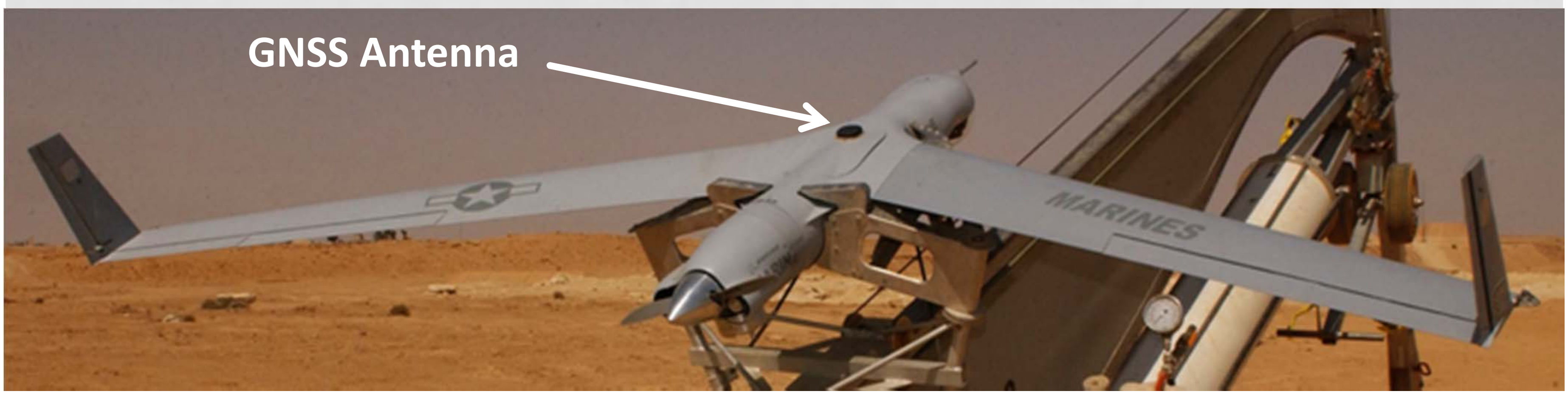

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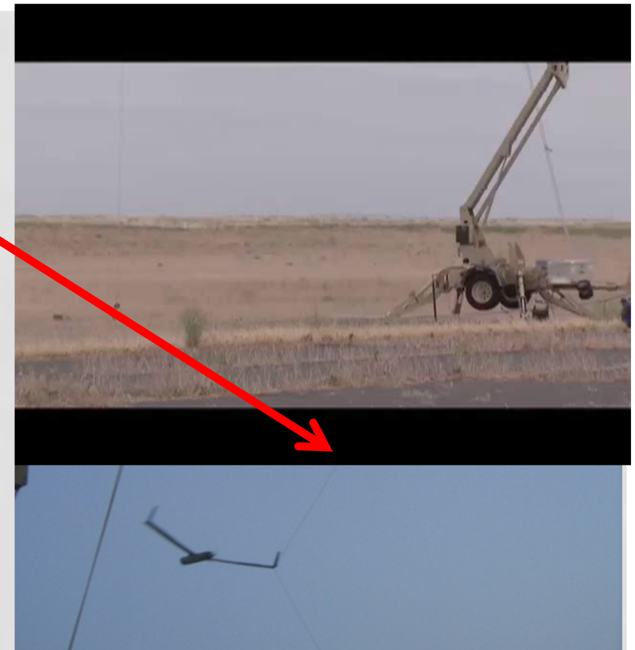
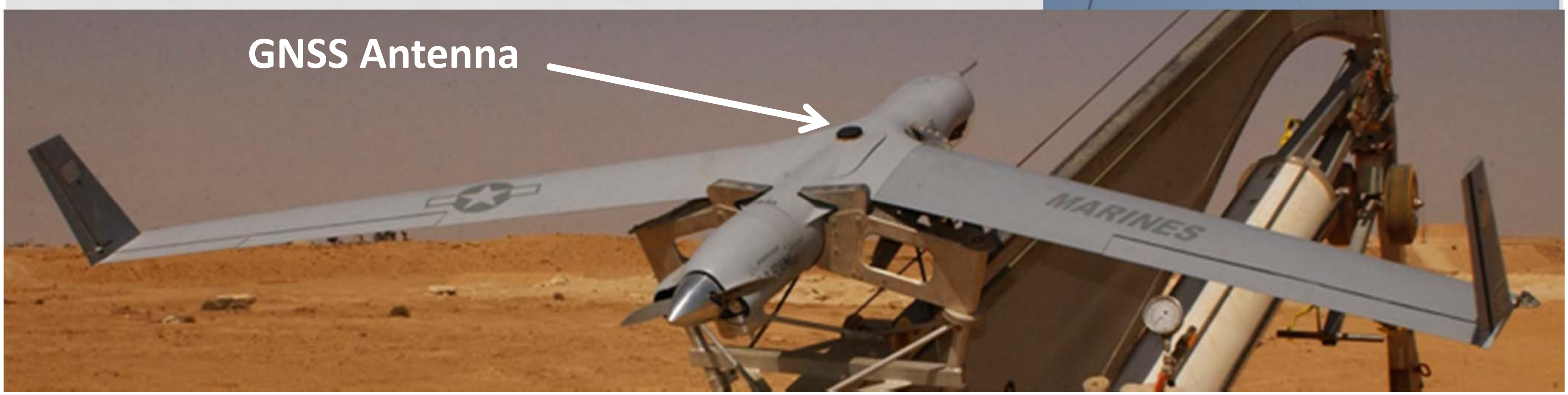
Unique Recovery System: Snag A Vertical Cable

RTK -- 1 cm





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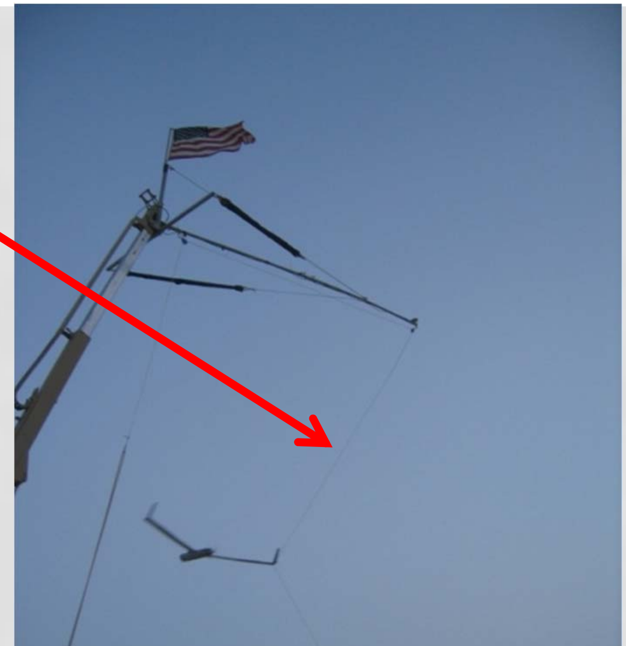
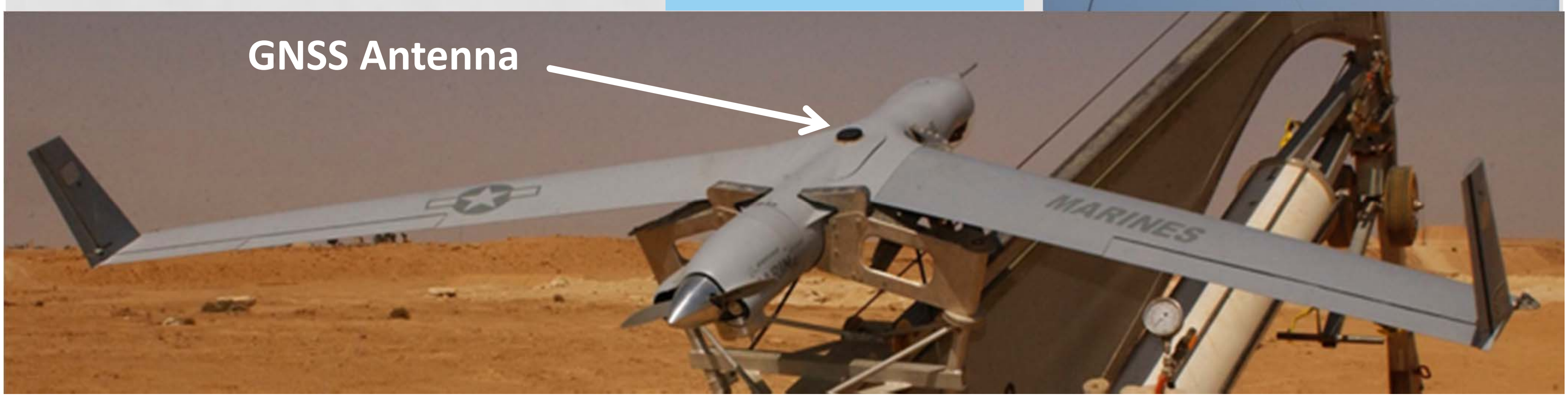
Required Nav. Perf.

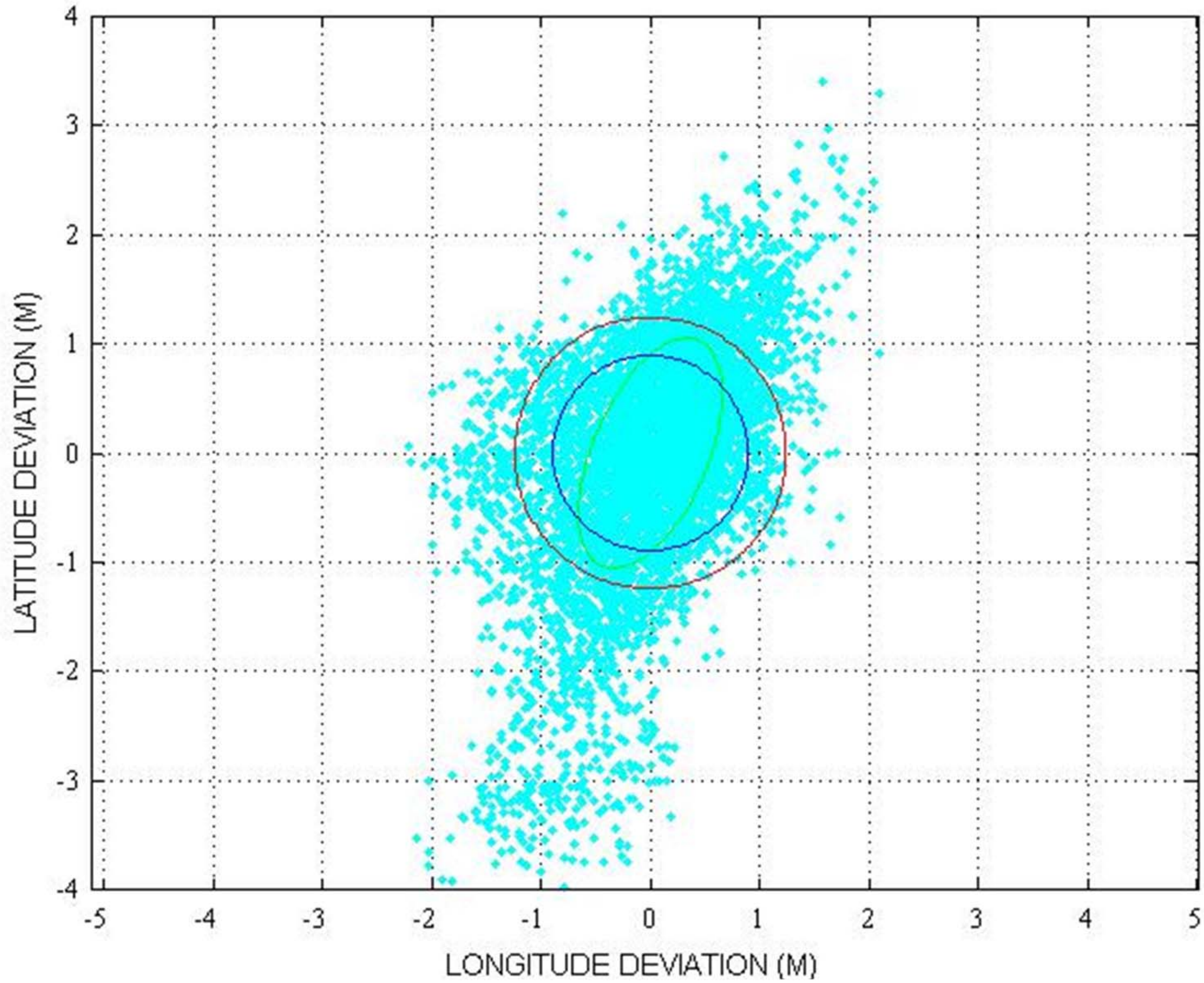
- **Accuracy**
- **Availability**
- **Continuity**
- **Integrity**





Elements of Required Navigation Performance (RNP)

- ***Accuracy***
  - **Where Am I?**



Elements of Required Navigation Performance (RNP)

- ***Accuracy***
  - Where Am I?
- ***Availability***
  - Can I Start The Mission?

Are the GNSS Signals There?

Are The Differential And Integrity Signals There?

Usually, Today, This Is Not A Problem!!

Elements of Required Navigation Performance (RNP)

- ***<u>Accuracy</u>***
  - **Where Am I?**
- ***<u>Availability</u>***
  - **Can I Start The Mission?**
- ***<u>Continuity</u>***
  - **Can I Continue The Mission?**
  - **Are The Satellites Blocked? Are They Jammed?**

RFI

Elements of Required Navigation Performance (RNP)

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- ***Accuracy***
  - **Where Am I?**
- ***Availability***
  - **Can I Start The Mission?**
- ***Continuity***
  - **Can I Continue The Mission?**
  - **Are The Satellites Blocked? Are They Jammed?**
- ***Integrity***
  - **Can I Trust My GNSS Receiver And Navigation System?**
  - **Can I Trust *Your* GNSS Receiver And Navigation System?**

Elements of Required Navigation Performance (RNP)

- ***Accuracy***
  - W Am I?
- ***Availa***
  - Can I C
- ***C***
  - Can I (
- ***Integrity***
  - Can I Trust My GNSS eiver A avigation Sy tem?
  - Can I Trust ***Your*** GNS eceiver And Navigation System?

Our Goal:

High Accuracy, All The Time,

With Integrity

Design Objectives (RNP)
High Accuracy, All The Time, With Integrity

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NOMINAL OPERATIONS

- Pilot is in control
- All systems working
- Mission being performed

High Performance, Trusted Navigation System Reduces Work Load And Enhances Mission Performance

Fisheries Management

Design Objectives (RNP)
High Accuracy, All The Time, With Integrity

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High Performance, Trusted Navigation System Reduces Work Load And Enhances Mission Performance

EMERGENCY OPERATIONS*

- Loss of command link
  - Aircraft must return to base, navigating autonomously
  - Reliable navigation is key!

* Situations we would like to avoid!

Design Objectives (RNP)
High Accuracy, All The Time, With Integrity

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- Loss of navigation (GNSS)
  - Pilot uses camera to navigate visually; guide UAV back to base
  - High stress; potential for failure even over land. Training is key!
  - More difficult over water, at night, in fog, etc

* Situations we would like to avoid!

Design Objectives (RNP)
High Accuracy, All The Time, With Integrity

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- Loss of CMD link + Loss of NAV

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Design Objectives (RNP) High Accuracy, All The Time, With Integrity

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UTC Aerospace Systems

Unmanned Aircraft Systems

Todd Colten
Principal
Aero/Systems Engineer
UTC Aerospace Systems

UAV or UAS or Drone?

- The media likes to use the term “Drone”
- The industry uses:
  - UAV: unmanned aerial vehicle
  - UAS: unmanned aircraft system
    - Sometimes unmanned aerial system
  - UA: FAA just uses unmanned aircraft
  - RPA: USAF has been using remote piloted aircraft
- “Drone” implies too much. RPA is most accurate.
  - There is always somebody operating the aircraft

Vireo™ UAS

1 meter wingspan
1.5 kg (3 lb)
Electric powered

UTC Aerospace Systems

Basic Architecture

Military Applications

Military UAS have become ubiquitous with applications ranging from:

- "over the hill/down the road"
- to broad area surveillance
- to weaponization




Emerging market for domestic UAVs

- FAA expected to allow commercial operations of small UAS in 2014/2015.

- Business models already proven on a small scale
  - Entertainment industry
  - Agriculture
  - Law enforcement, First Responders
  - Aerial photography (e.g. real estate)

Commercial Applications for Small UAVs

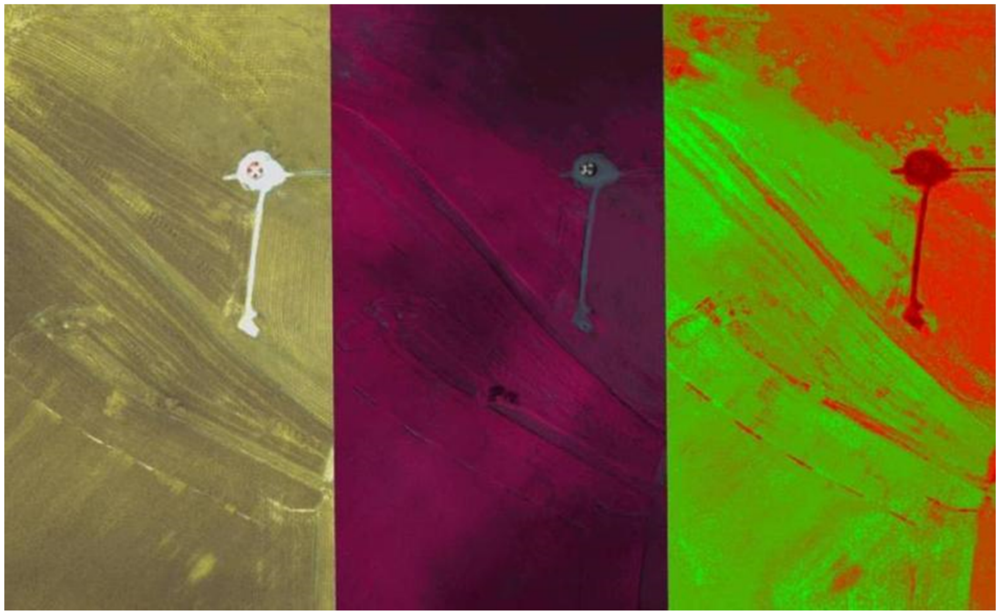
Small UAVs will be used in very high numbers in commercial applications

- Low altitude
- Low cost

Mobile phone miniaturization of sensors and processors is an huge enabler

Agriculture, aerial mapping, orthophotography, real-estate, infrastructure monitoring, security, wildlife and forestry management, movies, commercials, entertainment, etc.

Precision Agriculture, Aerial Mapping, Huge Potential



Color Near infrared NDVI

- Mosaics
- Geo registered
- Hi res color photos
- Multi-spectral
  - NDVI
- Infrared
- Data processing
  - Formats useful to different industries

Precision Navigation for commercial UAVs

Lots of overlap with military UAV needs, but a special focus on improving performance of small and low cost:

- How to ensure reliability and robustness with low cost/low performance sensors?
- Accurate landings, robust control
- Geo-registration of imagery / convert to useful data for commercial applications
- Payload and image stabilization
- Imagery enhancement (ERS wobbly video)
- Many others…

Ask the Experts – Part 1

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www.novatel.com

GNSS and Integrity of PNT in Unmanned Aerial Vehicles

Part II

Dr. Stephen Heppe
Principal
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Design Objectives (RNP)
High Accuracy, All The Time, With Integrity

- **All The Time**
  - **High Availability**
  - **Good Continuity**

RFI

Many Sources Of *Unintentional RF Interference (RFI)*

- VHF Narrowband Radio (Harmonics)
- Personal Electronic Devices (PEDs)
- Radio and TV Broadcast Towers
- Satcom Communications
- Broken Equipment

Design Objectives (RNP)

High Accuracy, All The Time, With Integrity

- All The Time
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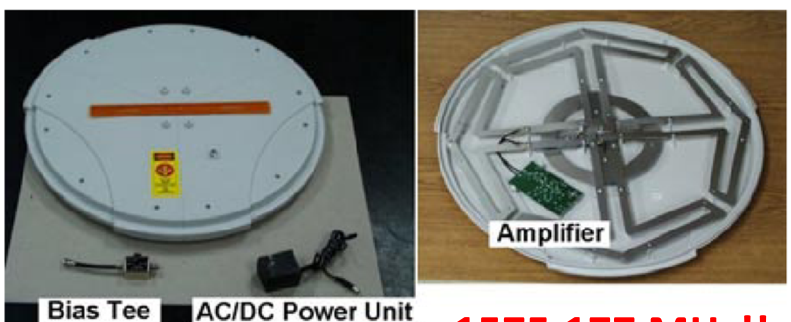
  - Good Continuity

In April of 2001, GPS Was Jammed In All Of Moss Landing & About 1 km Out To Sea



1575.177 MHz!!

Radio Shack 15-1624 VHF/UHF Antenna

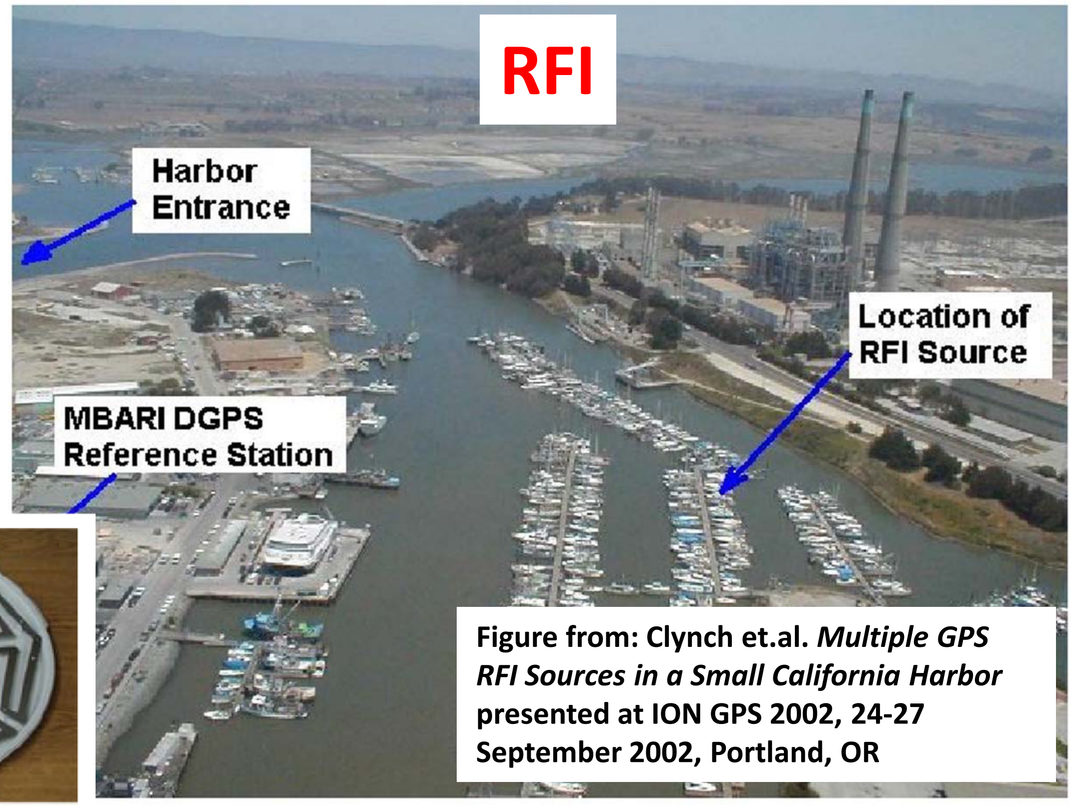


Figure from: Clynch et.al. *Multiple GPS RFI Sources in a Small California Harbor* presented at ION GPS 2002, 24-27 September 2002, Portland, OR

Moss Landing, CA Harbor
GPS RFI Source May 2001

Design Objectives (RNP)
High Accuracy, All The Time, With Integrity

- **All The Time**
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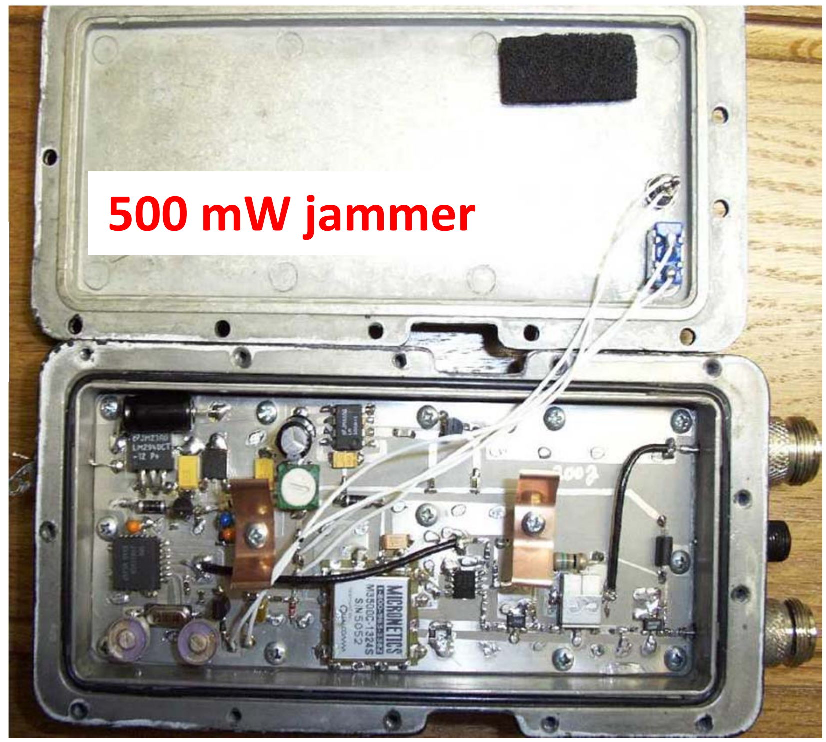
  - **Good Continuity**

"Personal Jammer"
for use in a car

Intentional Jamming



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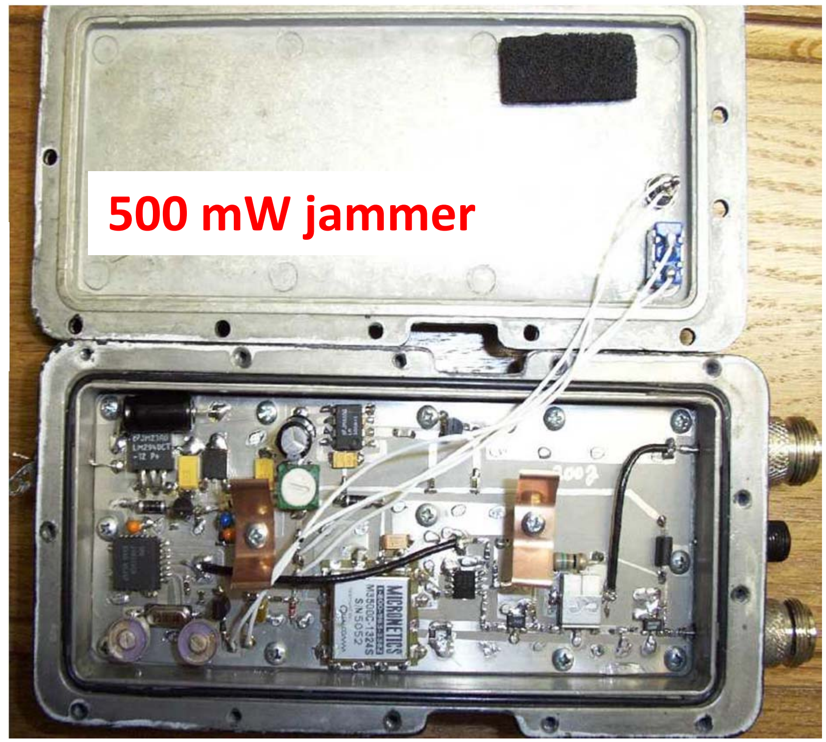
"Personal Jammer" for use in a car

Why Do They Do It?
- Privacy
- Terrorism
- Criminal Activity

Intentional Jamming



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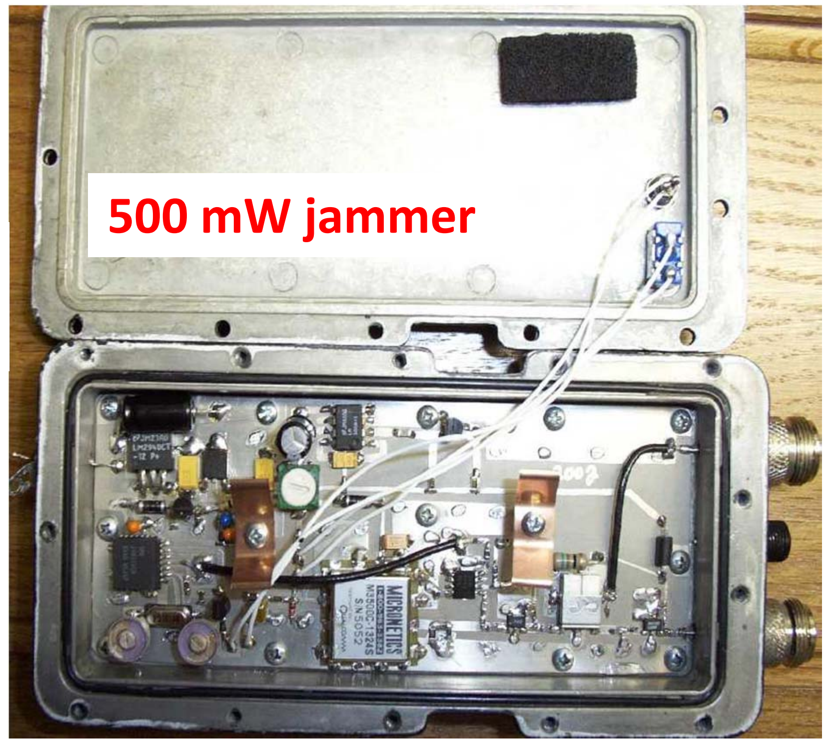

Design Objectives (RNP)
High Accuracy, All The Time, With Integrity

- **High Integrity**
  - **PNT Output Verified**

False Lock, Space Segment Error, And *Spoofing* (It Is A Reality!)

Todd Humphreys Experiment At University of Texas

Hornet Mini. Extended Kalman Filter with altimeter; magnetometer; IMU; L1 C/A GPS receiver with RAIM

Design Objectives (RNP)

High Accuracy, All The Time, With Integrity

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NAV SIGNAL SPOOF

- Challenging and getting more harder all the time…
- But still feasible for a determined individual
- If the "victim" is complicit, this is easy (Limpet spoof)

DGNSS DATA LINK SPOOF

- Almost trivially easy if data link is not authenticated
  - Most are not!

Design Objectives (RNP)
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No Civilian GNSS Receiver I Am Familiar With Is Designed To Detect and Respond Correctly To These Threats.

The Moral Of The Story…

- Do Not Rely On Mother Nature, Or Government Regulations, To Protect You
- Be Cautious And Pro-Active
  - Expect The Worst!

Let's Look At Some Solutions

- High Integrity
  - PNT Output Verified

False Lock

False Lock And Other Receiver Problems

- Solutions Include Receiver Self-Checks, RAIM, Vector Tracking

Design Objectives (RNP)
High Accuracy, All The Time, With Integrity

False Lock, Space Segment Error

- High Integrity
  - PNT Output Verified

False Lock And Other Receiver Problems

- Sc…
  R…

Space Segment Error

- Rare, But Still A Possibility
- Solutions Include RAIM, Multi-GNSS, External Sensors

Design Objectives (RNP)
High Accuracy, All The Time, With Integrity

- High Integrity
  - PNT Output Verified

False Lock, Space Segment Error, Spoofing

False Lock And Other Receiver Problems

- Sc
  R

Space Segment Error

- R
- S

Navigation Signal Spoofing

- Solutions Include Vector Tracking; Authentication (Galileo); Syndrome Detection (SNR, Doppler, etc.); Cross-Checking With External Sensors

Design Objectives (RNP)

High Accuracy, All The Time, With Integrity

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False Lock, Space Segment Error, Spoofing

False Lock And Other Receiver Problems

- Sc
  R

Space Segment Error

- R
- S

Navi... Signal Spoofi...

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DGNSS/Command Link Spoof

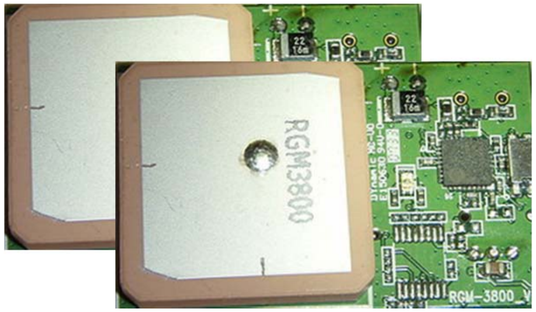
- Trivially Easy
- Best Solution Is Authentication

Solutions to Enhance Integrity

- **Rely on latest GNSS signal sets**
  - **Data-free signals can be tracked with very narrow filters**
  - **Galileo authenticated signals, if feasible for you application**
  - **Cross-constellation cross-checks (extended RAIM algorithms)**
- **Use existing receiver metrics to detect onset of spoofing**
  - **AGC output fluctuations, C/No, correlated Doppler**
- **Use external cross-checks if feasible – *do not assume the GNSS receiver is reliable when it reports great performance***
- **Push for vector tracking (technology roadmap issue)**
  - **A vector tracker is very difficult (impossible?) to subvert**
- **Test your autopilot's rules for merging navigation data**
- **Protect your DGNSS data link(s) and command links**
  - **Unprotected DGNSS data links are a hacker's back door!**

What Is The Ideal PNT System For UAVs?
(If Size, Weight, Power, and Cost Were Not Important)

- **Redundant GNSS Receivers To Overcome Hardware Failures**
  - **Rely On New GPS/GNSS Signals For Enhanced Robustness, Jamming Immunity, and Integrity**



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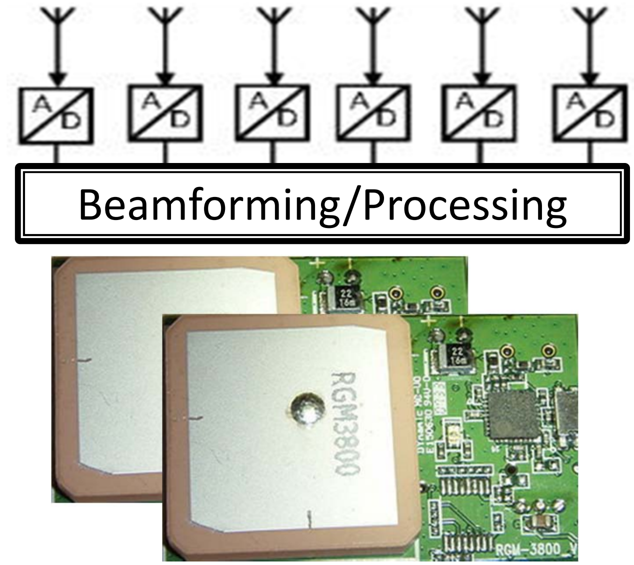

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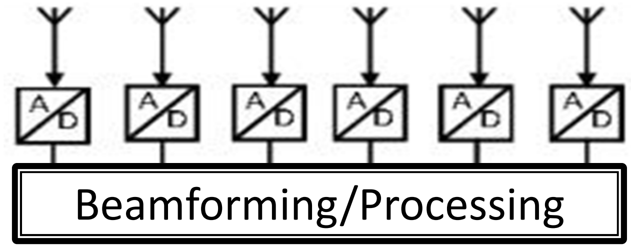
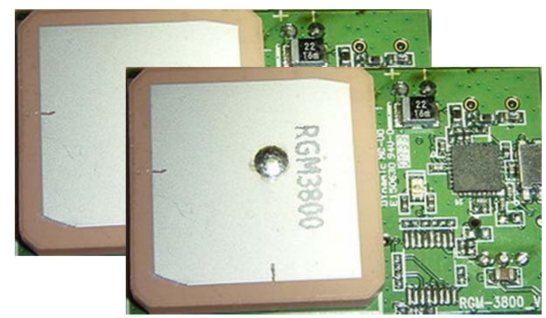
  - **Out-vote GNSS Rcvrs When They Are Spoofed**





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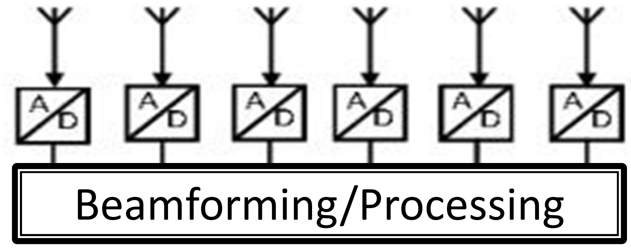
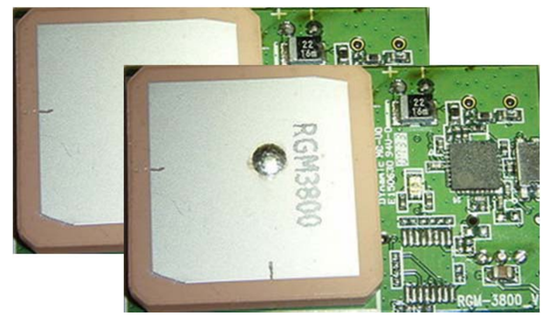
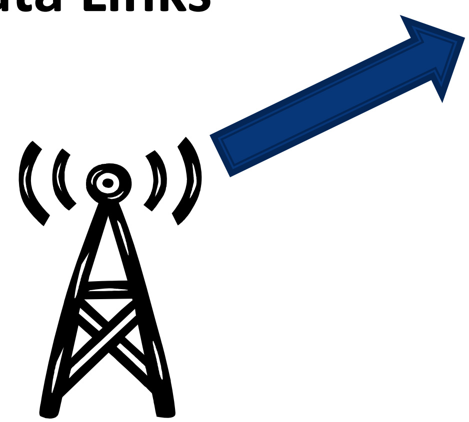
- **Authenticated DGNSS Data Links**







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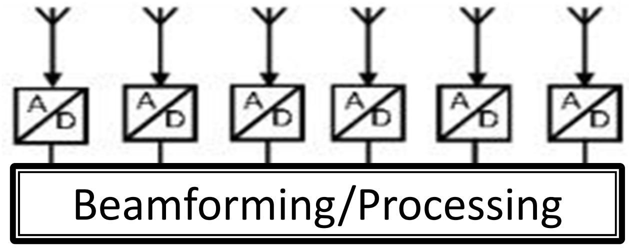
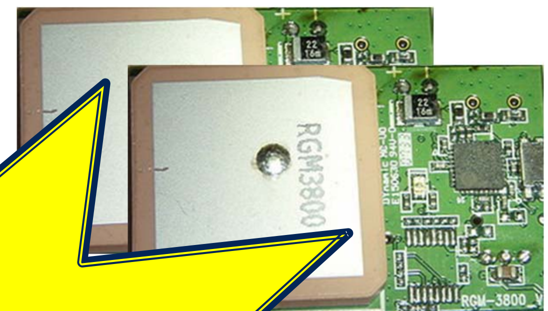
- **Redundant Ine… Navigation …stems To Overcome GNSS O… /Jam…**
  - **Out-vote GNSS R…**
- **Authenticated D…**





Of Course, This Is Completely Impractical For Most UAVs

What Is A *Realistic* PNT System For UAVs?

- **High-end GNSS receiver with latest signal sets**
- **Automotive (consumer-grade) IMU for short-term coasting**
- **Magnetic compass (can be p/o IMU) and baro altimeter**
  - **Can discipline the IMU to extend coasting time**
- **Authenticated DGNSS Data Links**
  - **Or authenticated/encrypted CMD links with DGNSS data verified at the ground control node prior to uplink to the UAV**

What Is A *Realistic* PNT System For UAVs?

- High-end GNSS receiver with latest signal sets
- Automotive (consumer-grade) IMU for short-term coasting
- Magnetic compass (can be p/o IMU) and baro altimeter
  - Can discipline the IMU to extend coasting time
- Authenticated DGNSS Data Links
  - Or authenticated/encrypted CMD links with DGNSS data verified at the ground control node prior to uplink to the UAV

This is what most of us fly with today.

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This is what most of us fly with today.
But let's talk about some embellishments.

Other Possible Enhancements For PNT

- **VOR/DME/eLoran**

- Suitable for rough emergency nav
- However,
  - -- Does Not Work Everywhere
  - -- Antenna and Electronics May Be Too Large For Some UAVs

Other Possible Enhancements For PNT

- **VOR/DME/eLoran**
- **Cell phone ranging/nav**

• Suitable for rough emergency nav

• Suitable for emergency nav; hardware is small and low-cost

• However,
 -- Does Not Work Everywhere
 -- Could Adversely Affect Cell Network (Work With Them!)

Other Possible Enhancements For PNT

InsideGNSS
GPS | GALILEO | GLONASS | BEIDOU
NovAtel

- **VOR/DME/eLoran**
- **Cell phone ranging/nav**
- **Camera-based solutions**

• Suitable for rough emergency nav

• Suitable for emergency nav;
hardware is small and low-cost

• Attractive Because Most UAVs Already Have A Camera

• However,
-- This Is A Challenging Problem
-- Does Not Work Everywhere
--- Over Oceans
--- At Night In Remote Areas
--- In Fog (Under Clouds)

Other Possible Enhancements For PNT

- VOR/DME/eLoran
- Cell phone ranging/nav
- Camera-based solutions
- Use your own data link

• Suitable for rough emergency nav

• Suitable for emergency nav; hardware is small and low-cost

• Attractive Because Most UAVs

• Attractive Because SWaP Impact On UAV Is Usually Close To Zero

• Monopulse (Phased Array) Angle Measurement Can Be Quite Accurate

• However,
  -- Requires Careful Design Of Data Link, And Careful Setup For OPS

Summary

- Think before you build
- Leverage the latest GNSS signal sets
  - The receivers are relatively low-cost and yield enormous benefits which reduce costs elsewhere
- Combine GNSS with reasonable and cost-effective external sensors
- Authenticate everything
- Test, test, test

Poll #2

The most demanding levels of integrity are associated with: (Select one)

1) *Unmanned aerial vehicles* **50%**
2) *Unmanned ground vehicles* **11%**
3) *Equally on aerial and ground vehicles* **37%**
4) *Neither since no one would use them in safety critical applications* **3%**

Positioning for Automated Ground Vehicles

Chris Wilson
CEO
Vehicle Data Science

Automated Vehicles- Overview

- Ground Vehicles
  - You and I might be driving in the next decade.
- Status
- Absolute positioning systems
- Relative positioning systems
- Contextual Information (map)
- Cooperative positioning (communications)

Photo: Volvo

The Vehicles

Automated vehicles are coming

The Law

- Several states allow testing driverless cars
- States developing licensing rules
- NHTSA is developing rules around levels of automation
  - 1- single system, as today
  - 2- integrated systems, but driver still needed
  - 3- systems where the driver is needed occasionally
  - 4- no driver required
- White house developing position

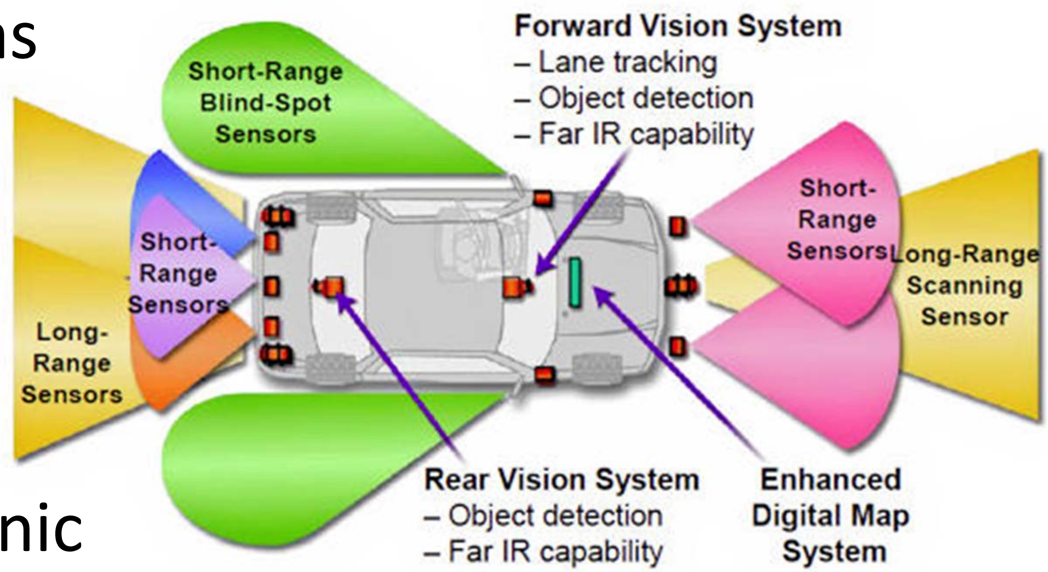
Path to Automation

- Automation started in the 70s (ABS).
- Complete automation is on the horizon
  - Google has said “5 years” (2017)
  - Nissan “all models in 2020”
- Automation within limited envelope available today.

- There is significant debate over the necessity or advisability of partial automation.

Automated Vehicle Sensors

- Sensors
  - Radars
  - Cameras
  - LIDAR
  - GPS
  - IMU
  - Map
  - Ultrasonic
  - Communications



Absolute Positioning

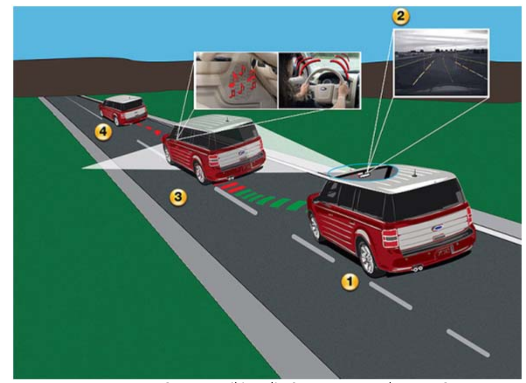
- Vehicles designed to follow a track
  - GNSS, IMU, map
- Issues similar to airborne

"Virtual tracks" connecting every driveway

- Problems:
  - Obstructions (tunnels, urban canyons, trucks)
  - Accuracy (road level, lane level, sub-lane)
  - Integrity
    - Millions of driving hours in a day.
  - Context (map)
  - Dynamic obstacles

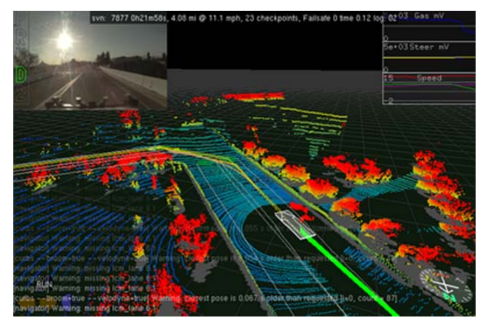
Relative Positioning

- Use the vehicle's sensors to detect landmarks.
- Feature search
  - There's a road around here somewhere…
    - Road markings
    - Specific infrastructure



Source: Wikimedia Commons; Ford Motor Company

- Scene matching
  - Model entire space and pre-compute a path
  - Landmark selection
    - Possibly no distinctive features
  - Requires extensive 'map' in vehicle



Source: MIT

Position context

- Maps (geographic database)
- Commensurate accuracy to position
  - Representation
  - Construction
  - Maintenance
  - Dissemination

Open issues.

Positioning method	Req. Position Accuracy	Req. Map Accuracy	Data Size	Robustness
Absolute Position	Very High	Very High	Med	Low
Feature Matching	Moderate	Moderate	Small	Med
Scene Matching	High	High	Huge	High

- Maps link absolute and relative position
  - Communication of relative position information
  - Enable best of both worlds

Vehicle-Vehicle Communications

- Major efforts underway worldwide
- Primary data is location

Correct Identification of Vehicle in Lane Ahead by Device (%)

Route:	Device Under Test (DUT)				
	ILV2	X1(VAD)	X2 (VAD)	Y (VAD)	Z (ASD)
Freeway	95	93	83	94	87
Local 1	94	97	93	88	77
Local 2	94	96	91	94	84

US DOT, Safety Pilot Model deployment

- Determining relative position is difficult with GNSS
  - Dependent on device and configuration
  - No ranging signal on communications
- Possibility for integrated “local dynamic map”

Integrity Awareness

Integrity of position data…
and the ability to communicate integrity

- Need a 'figure of merit'
  - DOP, IMU quality, track history, consistency across sensors…
- Correlation with sensor data
  - Model errors in sensor accuracy
- Collaboration among vehicles
  - Different perspectives
  - Different capabilities.
- Defend against active attacks

Source: DOT, RITA

Conclusion

- Multiple approaches to location
  - Solution is in fusion of absolute and relative position approaches
  - Map linking absolute and relative positions.
- Need for a better quality metric
  - And a way to communicate position quality

- Good enough for many advisory applications
- Still more work for full automation.

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

From what you have heard today, how do you plan to enhance the integrity of your unmanned system: (Please select all that apply)

1. *Increase number of redundant sensors* **47%**
2. *Increase quality/reliability of sensor* **49%**
3. *Use smarter/sophisticated algorithms (e.g. vector tracking)* **74%**

Ask the Experts – Part 2

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