Looking Ahead for GPS ---

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"You've got to be very careful if you don't know where you are going, because you might not get there." — Yogi Berra

GPtS – the Stealth Utility

- The Future
- Challenges

Note: t = TIME
Today, GPS Serves over 300 Million Users
(from the FAA & C. Moon, AMTI)
GPS Applications have Proliferated

• Civil
  - Transportation
    • Aviation
    • Automobile
    • Maritime
    • Rail Control
  - Public Services
  - Timing & Frequency
  - Surveying
  - Surveillance
  - Other

• Military
A Fundamental Change in Warfare

Improved Battlefield Situational Awareness

Enable Precision, All-Weather Operations

UFO Communication Satellite Controlled via AFSCN

E-3 AWACS

F-16 Drops GPS Guided JDAM

10th Mountain Division Soldiers requesting close air support with satellite radios
Operation ANAconda, March 2002

CAOC directs aircraft

al-Qaeda Target Destroyed
What’s Next?
PNT to Explode with Opportunities

The Five Design Keys (& Barriers to Entry)

1. The CDMA signal (PRN or Spread spectrum)
2. Van-Allen qualified atomic clocks
3. Orbit prediction to a few meters (URE) in 20,000 miles of travel
4. Spacecraft that lasted about ten years (cost of ownership)
5. User Equipment that could (eventually) be miniaturized (<$)
New Signals are On the Way
Summary - Spectrum of Modernized GPS Signals

Earlier GPS
Dual Frequency w/ Semi-codeless P(Y)

Block IIR-M
Launch 2005
Dual Frequency L1 C/A & L2C

Block IIF/IIR-M+
Launch 2008
Three Frequency L1 C/A, L2C, & L5

Block III
Launch 2013
L1C, L2C, L5, & L1 C/A Code

L5 ARNS/RNSS Band

L2 RNSS Band

L1 ARNS/RNSS Band

New!
Coming: a Plethora of Signals
So what are the major new (or expanded) applications going to be?

"Predicting the future is easy. It's trying to figure out what's going on now that's hard." - Fritz R. S. Dressler

- Expanded Crustal Tracking
- Precision Tracking and Reporting (Air Traffic ADS-B)
- Cell/GPS explosion - where will this go?
Robotic or “Assisted” Control already a Major Application of GPS
New Systems: Robotic Use Of GPS at Stanford

Typical Accuracy - Four Inches

Blind Landing Tests – 110 straight successes with one go around

Autonomous Model Helicopter
GPS Position, Velocity and Attitude

“Stanley” Vehicle the Winner
Stanford-Berkeley

Stanford Robot Tractor

Note four antennas to provide 0.1° Attitude

Tracking Test @ 5 m/s – worst error ~ 3 inches!
A Future **System**: Auto-guided Automobiles and Freeway Automatic Traffic Control

- Use all International Position Signals
- Vector Kinematic Receivers (10 cm or better)
- MEMS/IMU/CSAC
- Radars
- Cooperative Tracking of other vehicles

**ADS-B for Highways?**
A Caution: Three Critical Issues for GPs
We are Victims of our success:

**GPS Enormous Capability**

Worldwide Dependency

What must we do to **insure** that the Trust in GPS is not misplaced?
The Three Issues

• Sustainment
• Robustness
• Interchangeability
GPS Issue #1 - (Availability) Constellation Sustainment

• Average on-orbit life 8.9 years
• First IIF currently available for launch: January 2009
• First GPS III currently available for Operations - April 2014

It is imperative the we avoid “GPS Brownouts”

Needed: Sustained, high-level support for earlier GPS III delivery and availability
GPS Issue #2 - GPS Robustness (Deterrence)

- Constellation size of 30+X for users in impaired environments (the GDOP imperative)
  Need: Full, urgent **Commitment** by US

- Affordable GPS Receiver Interference Rejection Technology (inertial integration and digital beam steering technology)
  Needs full development

- GPS Backup - eLoran?
  Needs decisions
GPS Issue #3 - GPS and Galileo - True, Total **Interoperability**

• **Real Measure:** *Interchangeability* “Mix and Match” with the same ranging accuracy
  - L1C defined, implemented, and operable
  - Seamless WAAS/EGNOS/+ ?
  - True clock Synchronization (*Common Clock*) **and** common grid

• **Payoff** - Availability, Accuracy and Robustness for *Worldwide Users*
As providers of GPtS, we must insure the Service is Always Available - To meet: the Safety, Economic, and Convenience Needs of the World And the Defense of Freedom
Thanks for your Attention - Questions?
Backups
Illustrating why current number of Satellites is Minimal (Courtesy GPS World and John Lavrakas)

- Accuracy is strongly driven by Masking Angle and number of satellites (the impaired user’s problem)
- Above 10°, less than 30 satellites destroys accuracy and availability

Monthly Availability of 24 sats 92 to 100%

Accuracy vs. Mask Angle (degrees)
THE "Big Five" Civil Goals for GPS

1. Assured Availability of GPS signals-Including impaired situations (mountains, urban areas, foliage, etc.)
   - Number of GPS Satellites/Geometry
   - Interoperability and Standardization with Galileo et al
2. Resistance to Interference (RFI)
   - Additional Satellite RF power and Frequency Diversity
   - More jam resistant GPS receivers
3. Accuracy
   - Require Prediction Accuracy (Satellite Clocks and Age of Update)
   - Improved Satellite Geometry is essential
   - Augmentations: WAAS, LAAS, EGNOS, MSAS, NDGPS, PLs
4. Bounded Inaccuracy to limit wild points
   - Concerned with the 1% or less "wild data points"
   - Good Satellite Geometry Coverage is Imperative
5. Integrity
   - WAAS
   - RAIM

Three of top four Goals are driven by the number of satellites – hence DSB & IRT
30+X satellite recommendation