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
Manager New York Yankees Baseball Team
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

12/3/2008
A Fundamental Change in Warfare

UFO Communication Satellite Controlled via AFSCN

Improved Battlefield Situational Awareness

Enable Precision, All-Weather Operations

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

CAOC directs aircraft

F-16 Drops GPS Guided JDAM

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 100,000 km 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
Launch 2009
Three Frequency L1 C/A, L2C, & L5

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

New!

L5

L2

L1C

L1

L2C

M

P(Y)

C/A

ARNS/RNSS Band

RNSS Band

ARNS/RNSS Band

L5

L5

L5

12/3/2008
ICG3 Talk
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Coming: a Plethora of Signals
New Systems: Can’t we just get along?

• Degrees of “Getting Along”
  – Compatible
    • Let's not hurt each other
  – Interoperable
    • I’ll try yours, you can try mine
  – Interchangeable
    • Any four will do
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

Autonomous Model Helicopter
GPS Position, Velocity and Attitude

Blind Landing Tests – 110 straight successes with one go around

Note four antennas to provide 0.1° Attitude

Tracking Test @ 5 m/s – worst error ~ 3 inches!

Stanford Robot Tractor

“Stanley” Vehicle the Winner
Stanford-Berkeley
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
GPtS Issue #1 - (Sustainment) Constellation Availability

- Average GPS on-orbit life 8.9 years
- First IIF currently available for launch: January 2009
- First GPS III currently available for Operations - April 2014
- When will Galileo be “certifiable”?

It is imperative the we avoid “GPtS 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/funding
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 - including all details
  - Seamless WAAS/EGNOS/+ ?
  - True clock Synchronization (Common Clock) and common grid

- **Payoff** - Availability, Accuracy and Robustness for Worldwide Users
The Burden for the GPsS Community

As *providers* of GPsS
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

*Accuracy vs. Mask Angle (degrees)*

*Monthly Availability of 24 sats 92 to 100%*
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
   - 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
The Five Biggest Development Challenges for GPS

1. Selection and detailed design of the GPS CDMA (code-division, multiple-access) signal

2. Developing and verifying space-hardened (upper Van-Allen belt qualified) atomic clocks

3. Developing techniques for orbit prediction to a few meters (URE) in 20,000 miles of travel (this includes prediction of the clock behavior)

4. Designing and building spacecraft that lasted about ten years (cost of ownership issue)

5. Designing and demonstrating user equipment that could eventually be miniaturized and produced at low cost.