In Praise of Geometry

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The Most Important Ingredient

- Only Navigation by Satellite can provide **excellent Geometry**
  - *Continuous, worldwide, four dimensional, with excellent accuracy*
  - *GDOP, Geometric Dilution of Precision, and its important children:*
    - PDOP, HDOP, VDOP, and TDOP
  - *Although the satellite signals may be weak, the geometry is strong*
- No <u>terrestrial</u> navigation aid delivers “the most important ingredient”
- Do users need better geometry than GPS alone can provide?
- The answer is a definite “YES” as demonstrated by:
  - *Widespread use of GLONASS in products from consumer mobile phones to commercial survey and machine control products*
    - In spite of the difficulty of using GLONASS FDMA with GPS CDMA
  - *Plus widespread development of receivers to use <u>all</u> available GNSS*
- Aircraft at altitude and ships at sea may not <u>need</u> more than GPS
  - *But integrity by A-RAIM requires many more satellites*
- Users subject to signal blockage or outage do need more satellites
- Thus, the second most important ingredient is signal interoperability
  - *<u>Enabling</u> the best geometry by using every interoperable satellite signal*

Interoperability Regrets

- Soon there will be many signals with common center frequencies and a common spectrum
  - *These are the most important interoperability parameters*
- There remain many signal differences, including:
  - *Spreading codes, code lengths, data rates, forward error correction methods, message structures, etc.*
  - *GNSS receivers will carry the burden of these differences and provide what users will perceive as a seamless, fully interoperable GNSS*
- Little progress has been made toward providing a common “GNSS time reference” against which each system can reference itself
- Little progress has been made toward formulating a common “performance standard” for all systems
- There is not a common “middle frequency” signal to better enable interoperable, wide area, 10-cm navigation by tri-laning
  - *GPS has L2, BeiDou has B3, and Galileo has E6 (best of the three)*

Predicting the Future

- If there are three global interoperable GNSS constellations in 2020
  - *GPS, Galileo, and BeiDou, with a total of 72 to 90 operational satellites*

1. Use of GLONASS FDMA will fade away
   - *The current demand for more satellites will be satisfied by interoperable CDMA signals, leaving little demand for the more difficult FDMA signals*
2. Users will not say "this is my GNSS" or "this is my Galileo"
   - *There will be few <u>if any</u> GPS-only or Galileo-only receivers*
   - *Users won't know and they won't care where the signals originate*
   - *They will just enjoy the better performance provided by better geometry*
   - *And they probably will continue to call their device a "GPS" (sorry!)*
3. Special, unique, or "orphan" signals will be little used
   - *Use of GPS L2C will decline because no other GNSS provides it*
   - *The standard dual-frequency pair will become 1575.42 and 1176.45 MHz*
   - *E5b and B2b will be little used whereas E5a and B2a will be widely used*
     - A lively discussion topic!
4. If and when E6 becomes free, it will be used extensively for tri-laning

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Growth Continues and Should Accelerate

- Application growth is fueled primarily by the private sector
  - *Heavily regulated products, e.g., for aviation and the military, are slow to change and generally lag in innovation (sad but true)*
- Factors that encourage innovation and application growth:
  - *Competition, Moore's law, opportunity, fear, and the profit motive*
- What in the future will stimulate growth:
  - *Much better GNSS geometry improves availability, continuity, integrity, and accuracy, especially in difficult environments*
    - Urban canyons, real canyons, open pit mining, even aviation
  - *A-RAIM will become practical and begin to displace SBAS use*
  - *Ambiguity resolution for Real Time Kinematic (RTK) in survey and machine control will become almost instantaneous and more reliable*
    - Improved vertical accuracy will displace some laser plane requirements
  - *With free E6/B3 10 cm tri-laning could become a consumer application*
    - Car navigation lane-keeping, personal survey products, unmanned aircraft vehicles (UAV), unmanned lawnmowers, etc.
- Alternate means to communicate message parameters will promote "instant navigation" for all applications (push to navigate)

Backup Slides

Ionospheric Refraction Calculations

For L1 = 1575.42 MHZ and L2 = 1227.6 MHz

$$PR = (PR_{L1} \cdot 77^2 - PR_{L2} \cdot 60^2) / (77^2 - 60^2)$$

$$PR \approx 2.55 PR_{L1} - 1.55 PR_{L2}$$

For L1 = 1575.42 MHZ and L5 = 1176.45 MHz

$$PR = (PR_{L1} \cdot 154^2 - PR_{L5} \cdot 115^2) / (154^2 - 115^2)$$

$$PR \approx 2.26 PR_{L1} - 1.26 PR_{L5}$$

For L1 = 1575.42 MHZ and L5+ = 1191.795 MHz

$$PR = (PR_{L1} \cdot 154^2 - PR_{L5+} \cdot 116.5^2) / (154^2 - 116.5^2)$$

$$PR \approx 2.34 PR_{L1} - 1.34 PR_{L5+}$$

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Impact of Less Error Tracking L5+

For 1575.42 and 1227.6 MHz

$$\sqrt{2.55^2 + 1.55^2} \sim 2.98$$

For 1575.42 and 1176.45 MHz

$$\sqrt{2.26^2 + 1.26^2} \sim 2.59$$

For 1575.42 and 1191.795 MHz

$$\sqrt{2.34^2 + 1.34^2} \sim 2.69$$

For 1575.42 and 1191.795 MHz

$$\sqrt{2.34^2 + 0^2} \sim 2.34$$

Even if the pseudorange error tracking E5a+E5b were zero, the ionosphere corrected pseudorange error would be 90.35% of the error tracking only E5a

$$2.34 / 2.59 \sim 0.9035$$

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