Not all SBAS Are Equally Good: What Can be done by SBAS Providers to Assist in Machine Control Applications

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## Precision Agriculture and Construction Bring the Biggest Benefits from Use of GPS (~33.5%)

<table>
<thead>
<tr>
<th>Application Category</th>
<th>Range of Benefits ($billions)</th>
<th>Mid-range Benefits ($billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Precision Agriculture — grain*</td>
<td>10.0–17.7</td>
<td>13.7</td>
</tr>
<tr>
<td>A Construction — earthmoving with machine guidance*</td>
<td>2.2–7.7</td>
<td>5.0</td>
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<tr>
<td>A Surveying</td>
<td>9.8–13.4</td>
<td>11.6</td>
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<tr>
<td>A Air Transportation</td>
<td>0.119–0.168</td>
<td>0.1</td>
</tr>
<tr>
<td>C Rail Transportation — positive train control</td>
<td>0.010–0.100</td>
<td>0.1</td>
</tr>
<tr>
<td>C Maritime Transportation — private-sector use of nautical charts and related marine information*</td>
<td>0.106–0.263</td>
<td>0.2</td>
</tr>
<tr>
<td>A Fleet vehicle connected telematics*</td>
<td>7.6–16.3</td>
<td>11.9</td>
</tr>
<tr>
<td>A Timing — average of eLoran and GEOs estimates</td>
<td>0.025–0.050</td>
<td>0.1</td>
</tr>
<tr>
<td>A, B Consumer and Other Non-Fleet Vehicle — average of estimates based on willingness-to-pay and value of time*</td>
<td>7.3–18.9</td>
<td>13.1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>37.1–74.5</td>
<td>55.8</td>
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</tbody>
</table>

The Majority Of MC* and Precision Ag** Customers Require an Accuracy of 1-20 cm (~47%)

Source: “Machine Control, Precision Agriculture, Transportation: Half Want Under 5 cm”, GPS World, September 2015, p. 46

*MC – Machine Control
**Ag – Agriculture
Today customers, who want better accuracy and reliability may benefit from using range measurements of:

- GPS
- GLONASS
- Beidou
- QZSS
- …and SBAS

**SBAS Satellites Available (as of September 2015):**

- WAAS (3 NSV: PRN 133, 135, 138)
- EGNOS (2 NSV: PRN 120, 136)
- GAGAN (2 NSV: PRN 127, 128)
- MSAS (2 NSV: PRN 129, 137)
Roughly 80% of GNSS Equipment are SBAS-Capable

What Positioning Technologies are Used in MC and Precision AG Areas

- RTK – Real Time Kinematics
- Dead Reckoning with Carrier Phase Increments
- PPP – Precise Point Positioning

All above technologies may benefit from having more GNSS measurements including SBAS ranging data, except PPP (no precise ephemeris and clock data are available for SBAS)

However....
There is a patent:

“Method and System for GPS and WAAS Carrier Phase Measurements for Relative Positioning”

**Filed:** 2000  
**Granted:** 2002  
**Assignee:** CSI Wireless (now - Hemisphere GNSS)

So, nobody can use SBAS ranging data in RTK within commercial products?
How RTK Is Organized

GNSS Satellites

Correction Data

Rover

Positioning Results

Base
What Is RTK?

RTK – Real Time Kinematics:

A methodology to provide real time positioning with an accuracy at centimeter level with respect to a base station.

RTK Specifics:

- A need for static reference station called ‘base’
- A need for data link between base and a rover
- Carrier phase ambiguity resolution (AR) at rover side is a must in order to achieve centimeter level accuracy

When carrier phase ambiguities are resolved – output solution has status ‘fixed’ and accuracy of centimeter level
Dead Reckoning With Carrier Phase Increments

**Path-to-path accuracy is important**

Starting Point

GNSS Satellites

Rover
Dead Reckoning (DR) with Carrier Phase Increments:

Use of SBAS Ranging Data is not Covered with Patent

DR with Carrier Phase Increments:

A methodology to provide real time positioning with an accuracy at millimeter through decimeter level with respect to a starting point.

Specifics of DR with carrier phases:

- No base station is used
- No need for data link with a base station
- Accuracy degrades with time (~1 mm/s)
- In order to achieve the best positioning accuracy GNSS ephemeris and clock data shall be as precise as possible
- Satellite velocity component is of high importance
A Problem With Using SBAS in DR with Carrier Phase Increments:

**Insufficient Accuracy of GEO Ephemeris Data**

- WAAS – acceptable: URA = 2÷16 m
- MSAS – acceptable: URA = 16÷32 m
- GAGAN – acceptable: URA = ~4000÷6000 m, but in fact it is comparable with MSAS, i.e. much better than declared
- EGNOS – unacceptable! URA = 10000 m what is true!

**EGNOS transmits zero values for Z component of GEO satellite position and all velocity components, so the errors are on the order of kilometers and meters per second!**

**As result, EGNOS ranging data cannot be used in DR with carrier phases due to poor GEO velocity accuracy!**
Conclusions

- SBAS ranging data can be a good augmentation to GPS, GLONASS and Beidou, leading to higher positioning accuracy and availability (not only in MC and precision AG);

- SBAS ranging data can be a good augmentation to GPS, GLONASS and Beidou leading to more reliable RAIM;

- Use of SBAS ranging data in RTK is protected with a patent, what limits is use in MC and precision AG;

- Use of SBAS ranging data in dead reckoning with carrier phases is not protected with a patent and is possible (what is important in MC and precision AG);

- In order to be used in as an augmentation in all types of positioning algorithms and RAIM, GEO ephemeris accuracy shall be comparable with that of GPS, GLONASS and Beidou;

- All SBAS providers (esp. EGNOS) shall pay more attention to the accuracy ephemeris data for SBAS satellites. Many thanks to GAGAN providers who maintains GEO ephemeris accuracy at very good level, despite formal declarations.