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

Presenter: Sergey Averin, Mathematical Team Leader,
Topcon Technology Center,
Moscow, Russia

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

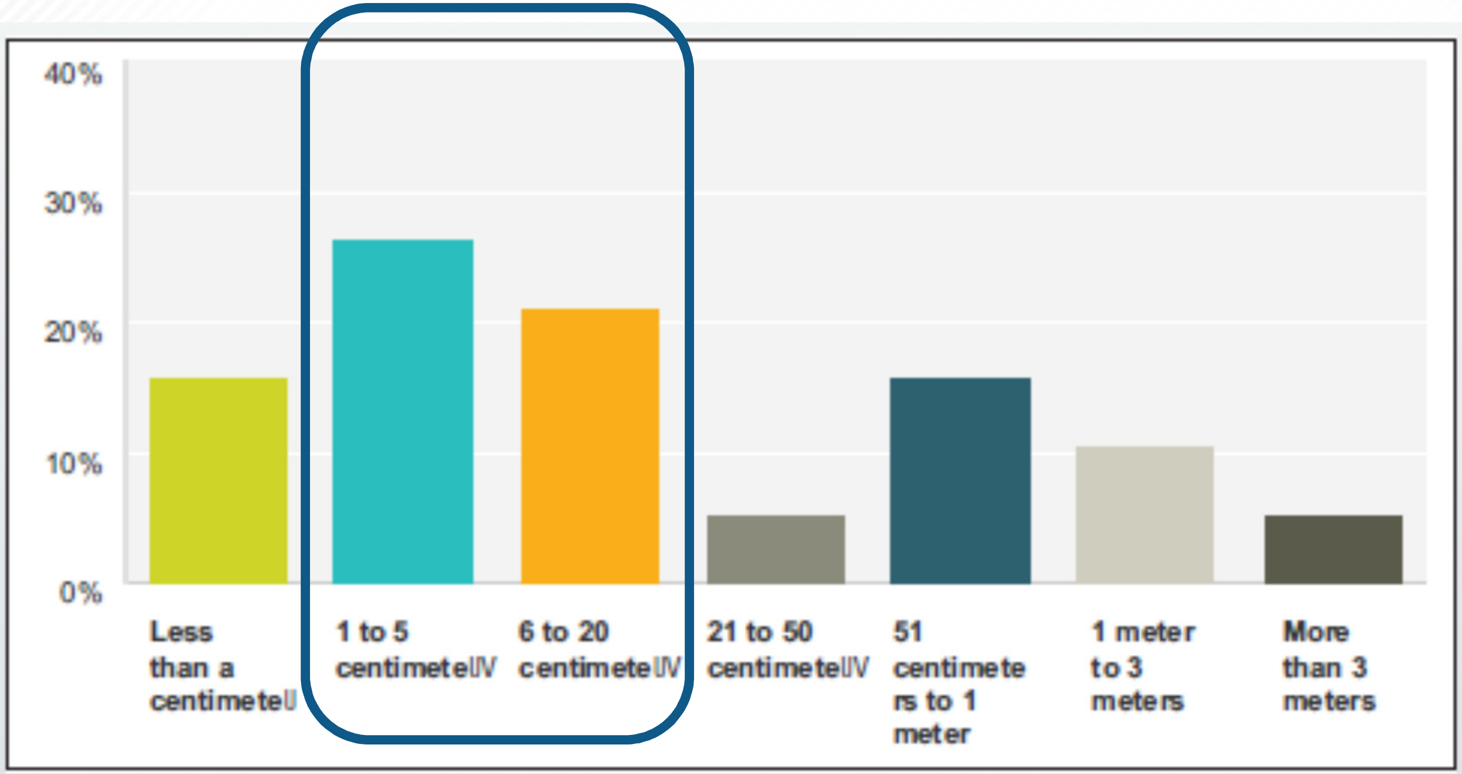
	Application Category	Range of Benefits ($billions)	Mid-range Benefits ($billions)
A	Precision Agriculture — grain*	10.0–17.7	13.7
A	Construction — earthmoving with machine guidance*	2.2–7.7	5.0
A	Surveying	9.8–13.4	11.6
A	Air Transportation	.119–.168	0.1
C	Rail Transportation — positive train control	.010–.100	0.1
C	Maritime Transportation — private-sector use of nautical charts and related marine information*	.106–.263	0.2
A	Fleet vehicle connected telematics*	7.6–16.3	11.9
A	Timing —average of eLoran and GEOs estimates	.025–.050	0.1
A, B	Consumer and Other Non-Fleet Vehicle — average of estimates based on willingness-to-pay and value of time*	7.3–18.9	13.1
	TOTAL	**37.1–74.5**	**55.8**

A = confident, B = indicative, C = notional.
*Includes benefits from purchase input cost savings.
Note: Numbers may not add to totals due to rounding.

▲ TABLE 1 Preliminary 2013 U.S. GPS economic benefit estimates.

Source: Irv Levenson, "The Economic Benefits of GPS", GPS World, September 2015, p. 36

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



▲ **HOW ACCURATE** is good enough for the majority of your sector?

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

**MC – Machine Control*
*** Ag - Agriculture*

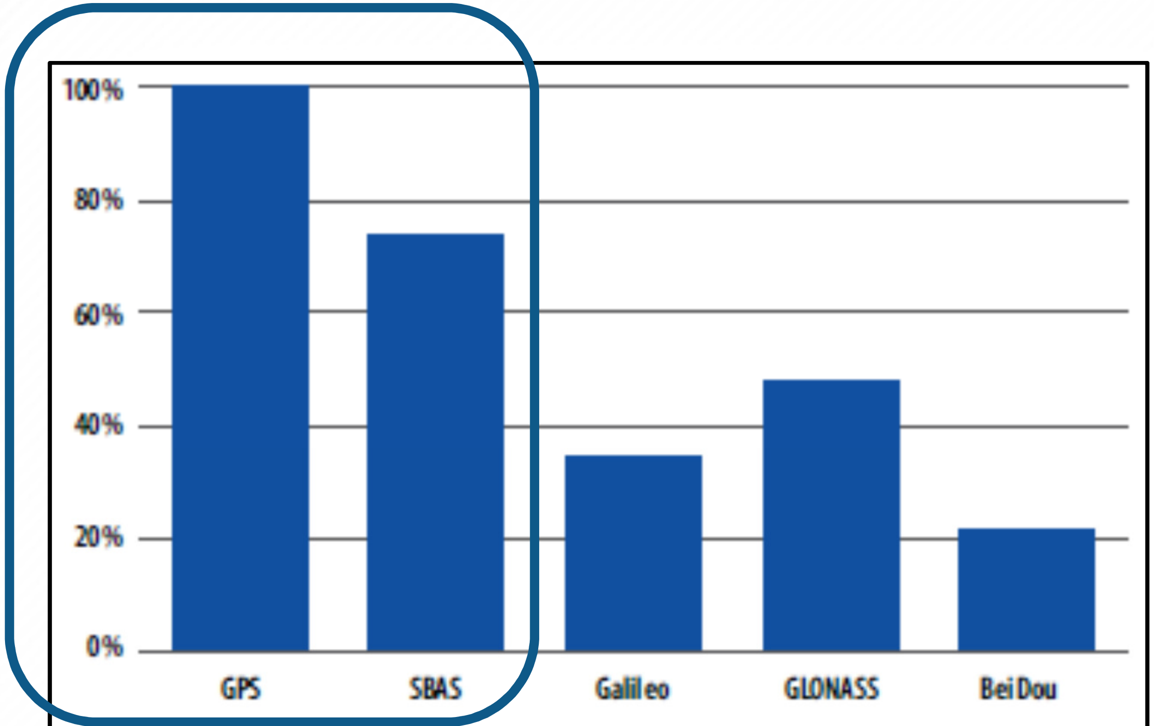
Today customers, who want better accuracy and reliability may benefit from using range measurements of:

- **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



▲ **FIGURE 3** Multi-constellation trends: GNSS capability in receivers. Source: GSA GNSS Market Report.

Source: Greg Turetzky, "Receiver Design for the Future: How the Internet of Things Now Drives Location Technology ", GPS World, September 2015, p. 16

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?

(12) **United States Patent**
Whitehead et al.

(10) **Patent No.:** **US 6,469,663 B1**
(45) **Date of Patent:** **Oct. 22, 2002**

(54) **METHOD AND SYSTEM FOR GPS AND WAAS CARRIER PHASE MEASUREMENTS FOR RELATIVE POSITIONING**

(75) Inventors: **Michael L. Whitehead**, Scottsdale, AZ (US); **Walter Feller**, Airdrie (CA)

(73) Assignee: **CSI Wireless Inc.** (CA)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/695,530**

(22) Filed: **Oct. 24, 2000**

Related U.S. Application Data

(60) Provisional application No. 60/191,026, filed on Mar. 21, 2000.

(51) **Int. Cl.**[7] **G01S 5/02**; H04B 7/185
(52) **U.S. Cl.** **342/357.03**; 342/357.09; 342/357.1; 701/215
(58) **Field of Search** 342/357.03, 357.09, 342/357.1; 701/215

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,170,776	A	10/1979	MacDoran	343/112 D
4,667,203	A	5/1987	Counselman, III	342/357
4,812,991	A	3/1989	Hatch	364/458
4,963,889	A	10/1990	Hatch	342/357
5,148,179	A	9/1992	Allison	342/357
5,177,489	A	1/1993	Hatch	342/357
5,293,170	A	3/1994	Lornez et al.	342/352
5,296,861	A	3/1994	Knight	342/357
5,359,332	A	10/1994	Allison et al.	342/357
5,442,363	A	8/1995	Remondi	342/357
5,451,964	A	9/1995	Babu	342/357
5,519,620	A	5/1996	Talbot et al.	364/449
5,828,336	A	10/1998	Yunck et al.	342/357
5,877,725	A	3/1999	Kalafus	342/357
5,890,091	A	3/1999	Talbot et al.	701/215
5,914,685	A	6/1999	Kozlov et al.	342/357
5,936,573	A	8/1999	Smith	342/357
5,944,770	A	8/1999	Enge et al.	701/207
5,949,371	A	9/1999	Nichols	342/352
6,230,097	B1 *	5/2001	Dance et al.	701/207
6,307,505	B1 *	10/2001	Green	342/357.09

OTHER PUBLICATIONS

Global Positioning System Standard Positioning Service Signal Specification; 2nd Edition, Jun. 2, 1995.
GPS Interface Control Document ICD–GPS–200C; Navstar GPS Space Segment and Navigation User Interfaces; IRN–200C–002; Sep. 25, 1997—reprinted Feb. 1998.
Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment; RTCA (Requirements and Technical Concepts for Aviation); Document No. RTCA/DO–229A; Jun. 8, 1998; Prepared by: SC–159.

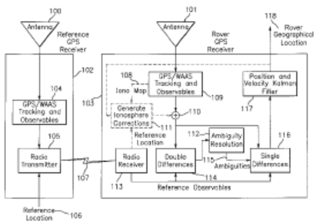
* cited by examiner

Primary Examiner—Theodore M. Blum
(74) *Attorney, Agent, or Firm*—Cantor Colburn LLP

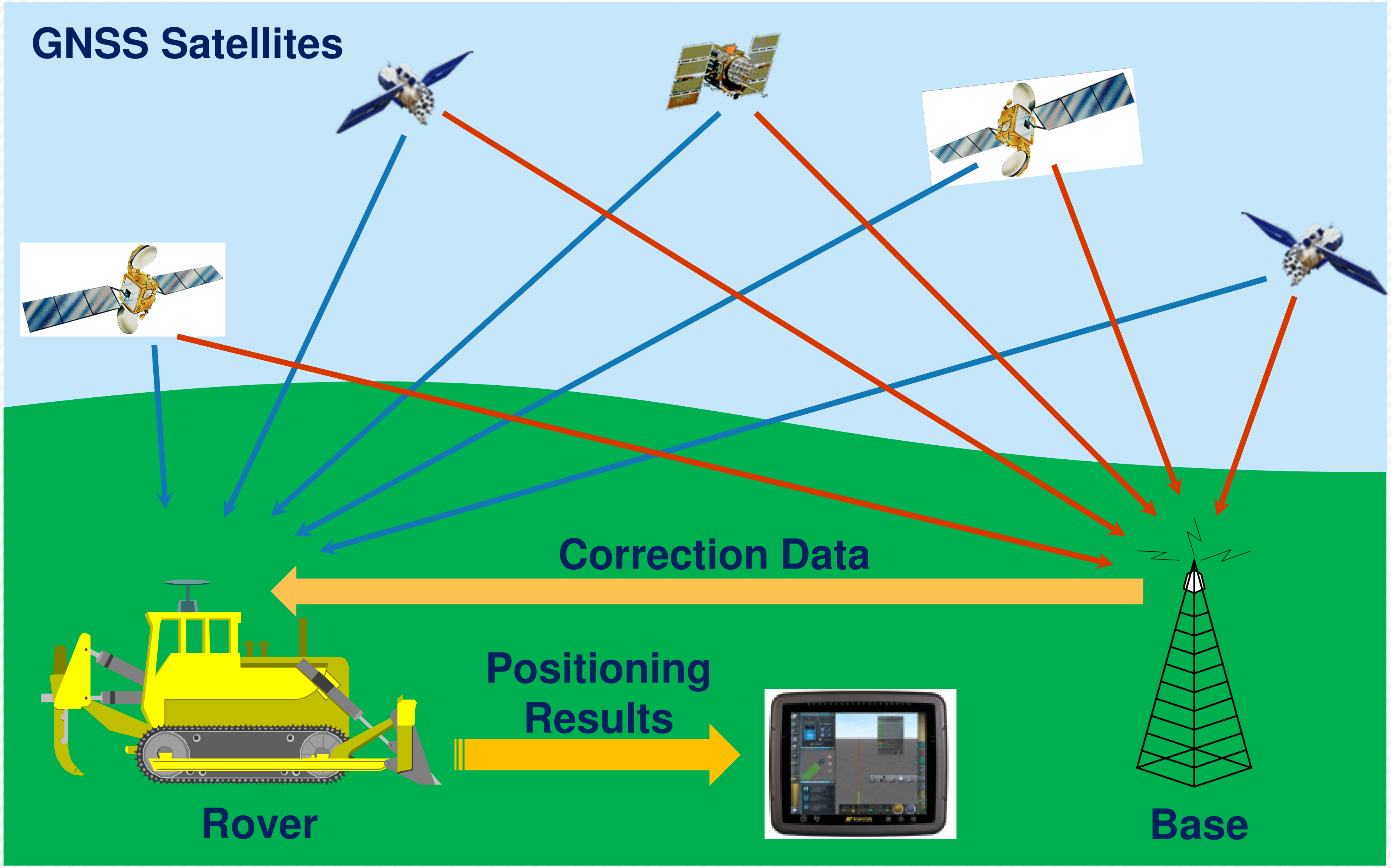
(57) **ABSTRACT**

A technique of accurately determining the relative position between two points using carrier phase information from receivers capable of making code and carrier phase measurements on signals transmitted from GPS satellites as well as signals transmitted from WAAS, EGNOS, MSAS or other Wide Area Augmentation System satellites (hereafter referred to simply as WAAS satellites). These signals are processed by a receiving system to determine relative position, for the purpose of surveying or otherwise, with the accuracy of carrier phase measurements being obtained. Signal processing similar to that used in existing GPS carrier phase based relative positioning receivers is used with WAAS signals as well. Benefits include faster and more reliable integer ambiguity resolution, protection from cycle slips and loss of sufficient satellites, and possibility of extending the operating range by allowing increased separation of reference and base receivers by incorporating ionospheric models provided by WAAS.

70 Claims, 5 Drawing Sheets



How RTK Is Organized



What Is RTK?

RTK – Real Time Kinematics:

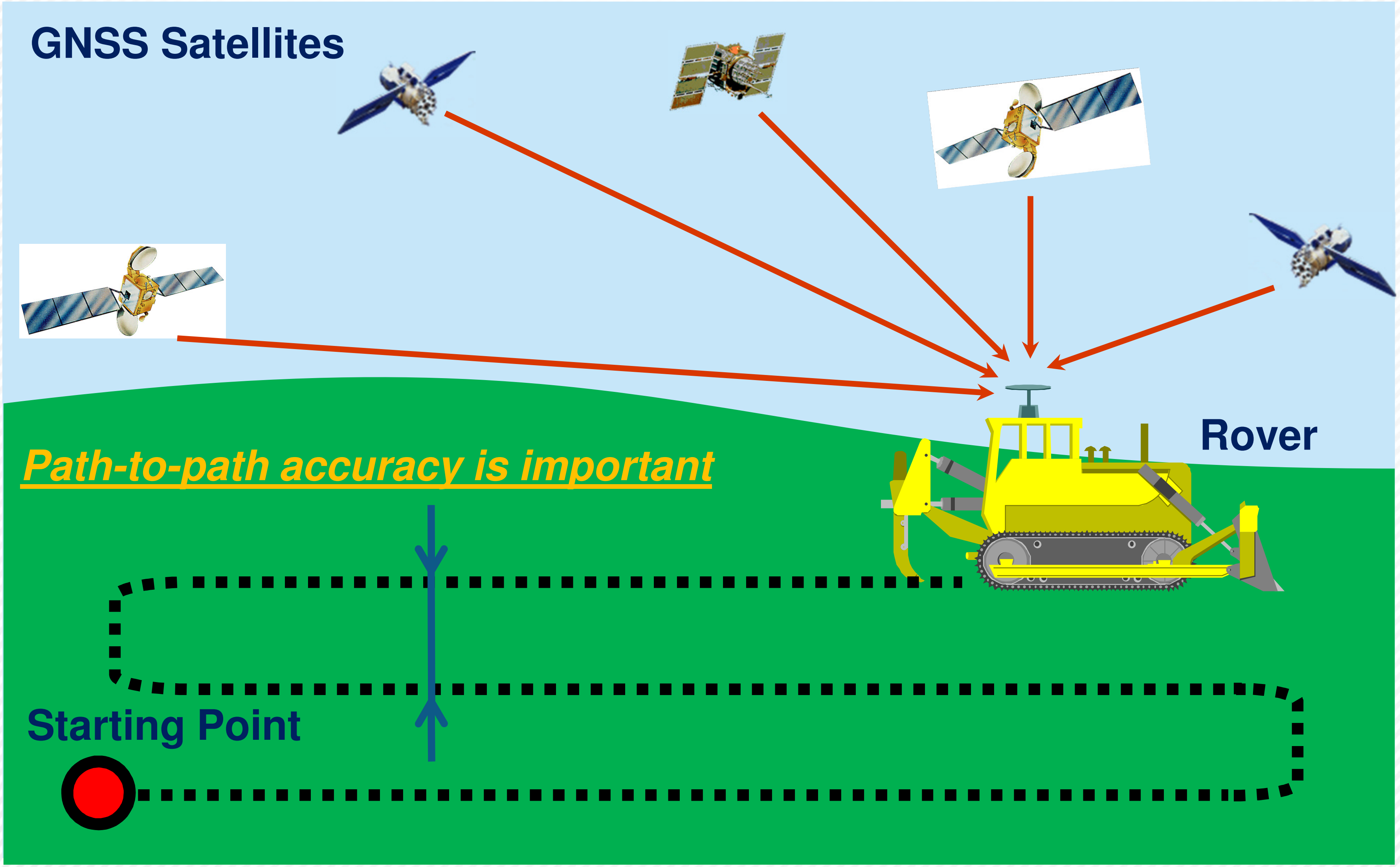
A methodology to provide real time positioning with an accuracy at centimeter level with respect to a base station.

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



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 that declared**
- **EGNOS – <u>unacceptable!</u> 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!

<u>As result, EGNOS ranging data cannot be used in DR with carrier phases due to poor GEO velocity accuracy!</u>

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 <u>not</u> 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.