Multisystem GNSS receivers for High precision applications with using global high-precision service

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Topcon Positioning Systems

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Full Spectrum GNSS Technology Provider

- In-house development of all core GNSS technology
- Multi-constellation ASIC development
  4\textsuperscript{th} generation multi-core designs are currently in production
- Precision mobile and infrastructure antennas
- Full range of OEM and application-specific receivers that cover all GNSS frequencies
- Leading-edge tracking, navigation, fusion, and network algorithm development
Horizontal accuracy shall be better than 10 cm
Multi GNSS. Excavator

- Excavator control w/ RTK
- High precision application
- Horizontal accuracy better than 10 cm
- Challenge: maintain FIX while rotating with boom up
- GPS+GLO provides best results

<table>
<thead>
<tr>
<th></th>
<th>% FIX</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS-only</td>
<td>73 %</td>
</tr>
<tr>
<td>GLO-only</td>
<td>68 %</td>
</tr>
<tr>
<td>GPS+GLO</td>
<td>99 %</td>
</tr>
</tbody>
</table>
Area of High Precision GNSS Application – Land Levelling

Example of Land Levelling Operation

Vertical accuracy shall be better 3 cm
Multi GNSS. Land Levelling

- Land levelling
- High precision application
- Vertical accuracy better than 3 cm
- RTK (GPS + GLO)
- Operation near trees – challenging area
- GPS+GLO provides best results
- When close to trees, only GPS+GLONASS provide reliable high accuracy positioning required for land levelling

<table>
<thead>
<tr>
<th></th>
<th>% FIX</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS-only</td>
<td>92 %</td>
</tr>
<tr>
<td>GLO-only</td>
<td>87 %</td>
</tr>
<tr>
<td>GPS+GLO</td>
<td>98 %</td>
</tr>
</tbody>
</table>

- Red: GPS+GLONASS
- Gray: GPS Only
- Blue: GLONASS Only
All GNSS receivers as a minimum support GPS and GLONASS systems.

Two systems (GPS and GLONASS), two frequencies, GNSS boards with digital processing in ASIC.

Multi-system (GPS/GLONASS/GALILEO/COMPASS/QZSS), multi-frequency GNSS boards with system-in-package in ASIC.
Multi GNSS in obstructed areas

- Shaded environment (Urban canyons, Moscow)
- RTK (GPS, GLO, BDS)
- As many GNSS available as higher FIX positions availability in shaded environment

<table>
<thead>
<tr>
<th></th>
<th>% FIX</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS-only</td>
<td>53.3%</td>
</tr>
<tr>
<td>GLO-only</td>
<td>39.6%</td>
</tr>
<tr>
<td>GPS+GLO</td>
<td>92.4%</td>
</tr>
<tr>
<td>GPS+GLO+BDS</td>
<td>93.2%</td>
</tr>
</tbody>
</table>

- NO_SOLUTION
- Standalone
- Code_DIFF
- RTK Float
- RTK Fix
Example of Satellites for GPS/GLONASS/GALILEO/COMPASS/SBAS

Number of satellites

Epoch

Number of satellites

GPS
GLONASS
GALILEO
BEIDOU
SBAS
Tracked ALL
• 452-Channel Vanguard Technology with Universal Tracking Channels
• Tracking multi-frequency signals from all GNSS constellations including GPS, GLONASS, QZSS, Galileo and BeiDou
• Successful tracking and demodulation of advanced QZSS signal structures such as the LEX signal in E6
• High precision code and carrier phase measurements up to 100 Hz
• Built-in Bluetooth® and WiFi® connectivity
• Integrated web interface with advanced receiver management features
• 32GB SDHC storage support
• Extended operation (>15 hours) using integrated batteries
• Support for charging and Power over Ethernet
What does multi-GNSS capable receiver really mean?

- All satellites are equal to each other (GPS, GLONASS, GALILEO, BEIDOU)
- Data processing w/o any constellation preference
- RTK solution with a limited number of mixed satellites
- RTK / PPP solution where only one system is used: GPS or GLONASS or GALILEO or BEIDOU
Multi constellation RTK solution

- RTK positioning
- ASIA region
- Static, short base line
- FIXED Solutions

Accuracies (RMS), mm:

<table>
<thead>
<tr>
<th>System</th>
<th>98% Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS-only</td>
<td>3.8</td>
</tr>
<tr>
<td>GLO-only</td>
<td>4.0</td>
</tr>
<tr>
<td>BDS-Only</td>
<td>7.3</td>
</tr>
</tbody>
</table>

Cumulative: 8.6 9.6 17.0
### GALILEO for RTK solution

RTK solution with 4 GPS satellites and 2 GALILEO satellites

<table>
<thead>
<tr>
<th>Trial</th>
<th>GPS Used</th>
<th>GAL Used</th>
<th>Successful Fixed Solutions (%)</th>
<th>Time to fix (sec)</th>
<th>RMS Horizontal (cm)</th>
<th>RMS Vertical (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>4</td>
<td>99,3</td>
<td>2,6</td>
<td>1,34</td>
<td>1,44</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>4</td>
<td>99,3</td>
<td>2,2</td>
<td>1,28</td>
<td>1,56</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3</td>
<td>99,3</td>
<td>2</td>
<td>1,12</td>
<td>1,54</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>2</td>
<td>99,3</td>
<td>2</td>
<td>1,02</td>
<td>2,72</td>
</tr>
</tbody>
</table>

- RTK positioning
- Europe region (Sweden)
- Short trials
- Just few GPS and GALILEO are used
- GALILEO only solution possible
Topcon TopNet Global-D PPP service
Worldwide coverage
http://www.topnetlive.com/
Multi constellation PPP technology

- PPP positioning
- Asia / Europe region

<table>
<thead>
<tr>
<th>Constellation</th>
<th>Accuracy (RMS), cm</th>
<th>98%, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS+GLO+BDS</td>
<td>1.3</td>
<td>2.9</td>
</tr>
<tr>
<td>GPS-only</td>
<td>2.2</td>
<td>3.8</td>
</tr>
<tr>
<td>GLO-only</td>
<td>3.2</td>
<td>6.1</td>
</tr>
<tr>
<td>BDS-only</td>
<td>7.2</td>
<td>15.8</td>
</tr>
</tbody>
</table>
Accuracy and first convergence period for the clear sky conditions and GPS and GLONASS GNSS. Static.

Accuracy after convergence

Convergence period

Precision statistic (STD) after convergence for TopNET Global D. Static.

<table>
<thead>
<tr>
<th>Value</th>
<th>Standard Deviation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>Latitude</td>
</tr>
<tr>
<td>TopNET Global D</td>
<td>0.002</td>
</tr>
</tbody>
</table>
Service provides:

- a few centimeter accuracy (5-6 cm);
- convergence time less than 30 minutes;
- supporting GPS and GLONASS GNSS;
- more stable solution than Float PPP solution;
- improvements in first convergence period and Fast Reconvergence features.

### Accuracy after convergence

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<th>Mode</th>
<th>Standard Deviation (m)</th>
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<tr>
<td></td>
<td>Latitude</td>
</tr>
<tr>
<td>TopNET Global C</td>
<td>0.002</td>
</tr>
</tbody>
</table>
**Fast Reconvergence** feature provides user with a possibility to get fast high accuracy using PPP algorithms after shading or obstacles.

**Test scenario** - Every 30 minutes GNSS antenna has been disconnected from navigation receiver for 20 seconds. After that only few seconds are needed to get converged solution back.
What is SkyBridge?

- **SkyBridge feature** allows RTK user to get high accuracy navigation solution in the case of absence RTK corrections or RTK fix solution;
- SkyBridge provides TopNET Global-C solution without **first convergence** and with **improved accuracy** using RTK FIX position for seeding;
- SkyBridge uses mix of **RTK** and **PPP** technologies;
- RTK is a **differential positioning technology** and it provides **high accuracy** navigation solution **relative to base station** coordinates;
- PPP is an **absolute navigation technology** that provides sub decimeter accuracy in the ECEF **absolute coordinate system** (ITRF 2014).
- Test setup:
- After 10 minutes of operation RTK corrections have been terminated for 20 minutes.
- Several iterations have been made.
- RTK Base has precise coordinates in ITRF 2014.
SkyBridge results

Zoomed instantaneous seeding from RTK Fix to TopNET Global-C solution when Data-Link has been lost

Base corrections Delay

Data-Link Delay
QZSS CLAS service

- QZSS covers East Asia and Oceania region;
- CLAS – free open PPP service;
- Service provides precise corrections in RTCM3 Compact SSR format – CSSR;
- CSSR transmits precise orbits, clocks, code and phase biases, troposphere and ionosphere corrections.
- CSSR format much more effective than SSR
GNSS receivers with QZSS CLAS support

- Net-G5 base and Hiper HR rover support the QZSS CLAS;
- Tracking the QZSS satellites;
- Output of RAW bitstream;
- Output of PPP solutions.

<table>
<thead>
<tr>
<th>Feature</th>
<th>First FW</th>
<th>Future Firmware</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVs support</td>
<td>QZS-1</td>
<td>QZS-1,QZS-2,QZS-3,QZS-4</td>
</tr>
<tr>
<td>PRNs support</td>
<td>193</td>
<td>any two (192,194,195,196,197)</td>
</tr>
<tr>
<td>Raw measurement</td>
<td>QZS-1 L6-pilot</td>
<td>QZS-1 L6-pilot</td>
</tr>
<tr>
<td>CLAS raw stream</td>
<td>QZS-1</td>
<td>QZS-1,QZS-2,QZS-3,QZS-4</td>
</tr>
<tr>
<td>RCTM3</td>
<td>no</td>
<td>Yes</td>
</tr>
<tr>
<td>PPP solution</td>
<td>no</td>
<td>Yes</td>
</tr>
</tbody>
</table>
PPP technology with QZSS CLAS service

- PPP positioning
- CLAS service
- Precise corrections to GPS, GALILEO and QZSS
- Japan region

PPP horizontal accuracy after convergence, cm

<table>
<thead>
<tr>
<th></th>
<th>RMS</th>
<th>95%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.99</td>
<td>7.86</td>
</tr>
</tbody>
</table>

CLAS service

longitude error

CLAS service

altitude error