TriG GNSS Receiver Development

- The refraction and reflection of GNSS signals enable remote sensing of the ionosphere, atmosphere and Earth’s surface with robust and cost effective technology.
- NASA’s BlackJack and TurboRogue GPS receivers have demonstrated these capabilities on numerous missions (SRTM, CHAMP, SAC-C, GRACE, ICESat, JASON, OSTM, COSMIC, etc).
- NASA’s GNSS space-borne receivers need to be upgraded due to rapidly evolving GNSS signals and advancing science requirements.
2007 NASA Decadal Survey Recommends:

- NASA should implement a set of 15 missions phased over the next decade. All of the appropriate low Earth orbit (LEO) missions should include a Global Positioning System (GPS) receiver to augment operational measurements of temperature and water vapor.

- In view of the importance of the occultation measurement and the accurate positioning of the satellite for other sensor measurements, GPS receivers should be a standard part of both NASA and NPOESS low-Earth-orbit payloads.

- The receivers envisioned in the Survey are described as:
  - The payloads would be advanced RO receivers that could receive GPS, GLONASS, and Galileo radio signals.
TriG GNSS Receiver

- Next Generation GNSS Science Instrument
  - Precise Orbit Determination (POD)
  - GNSS Radio Occultation (RO)
    - Neutral Atmosphere, Ionosphere, and Scintillation
  - GNSS Reflections
- Developed in collaboration with Broad Reach Engineering (BRE)
- Upcoming missions:
  - COSMIC-2, ICESat-2, DSAC, and other NASA/NOAA missions
- Key missions needs:
  - Track more GNSS signals…
  - Higher SNR (particularly for RO and reflection)
  - Higher reliability to meet mission critical needs
  - Greater flexibility to accommodate requirements
TriG GNSS Receiver for COSMIC-2

COSMIC-2 Mission Objective:
- Providing operational global GNSSRO-based Earth observations (including refractivity, temperature, moisture, and electron content and density profiles of the troposphere, stratosphere, and ionosphere)

Partnership: NOAA/USAF (SSAEM)/NSPO (Taiwan)

Orbit: 500km equatorial (24°); 800km polar

Number of S/C: 12

Launch: 6 S/C on 2015; 6 S/C on 2017

Mission Life: 5 years

Key GNSS Receiver Requirements:
- GPS/Glonass FDMA (Threshold) / Galileo (Objective)
- Neutral Atmospheric Soundings / day / payload:
  - 1125 (Threshold) / 1600 (Objective)
- Ionospheric Soundings & Arc / day / payload:
  - 1125 (Threshold) / 2250 (Objective)
- Ionosphere Scintillation
TriG GNSS Receiver Heritage

JPL/NASA BlackJack GPS Receivers: > 115 Flight Years of Successful Space Operation
The most precise GPS receivers flown in space – enabling new science and navigation capabilities

45-cm accuracy
SRTM
Feb 2000

4-cm accuracy
CHAMP
Jul 2000

4-cm accuracy
Sub-meter real-time demo
SAC-C
Nov 2000

1-cm accuracy
JASON-1
Dec 2001

1-cm accuracy
GRACE
Mar 2002

Dec 2002
FedSat

Dec 2002
ICEsat

Apr 2006
COSMIC

Apr 2008
C/NOFS

Jun 2008
OSTM

5-cm accuracy

Yoaz Bar-Sever
Key Features

- Scalable 3U Architecture
- Receives GNSS signals (GPS, Galileo, GLONASS, Compass, ...) + DORIS
- Multiple digitally steered high-gain beams.
- Linux based Science processor allow easy modification of onboard processing by non-receiver experts
- Large reconfigurable signal processing resources
- Advanced signal processing including open-loop tracking, Blue Shift processing, etc.
- Allow either internal or external frequency reference.
- Highly reliable design with TID > 40 krad
- Autonomous Operations
TriG Hardware Architecture

TriG receiver electronics are based on the 3U architecture comprised of 4 main components:

- RF Downconverter (RFDC)
  - Four RF channels per antenna input
- GNSS Navigation Processor
- Science Processor
- Reconfigurable Digital Processor
3U Scalable Architecture

8 antenna inputs, dual processor configuration for COSMIC-2 GNSS RO Mission

3 antenna inputs, single processor candidate configuration for the DESDynl Mission

Scalable 3U architecture enabling optimization to meet specific mission requirements
Receive All GNSS Signals

- Wide bandwidth RF Downconverter capable of receiving all GNSS signals:
  - GPS, Galileo, GLONASS, Compass
  - Other navigation signals (QZSS, DORIS, etc)
- TriG will track both legacy and new GPS signals
  - Provide uninterrupted multi-frequency GPS tracking service through 2020 retirement of semi-codeless
- Tracking more GNSS signals will improve both POD and the quality and quantity of the measurements from RO and surface reflection observations.
Multiple Digital Beam Steering

- TriG accommodates up to 16 antenna inputs with four frequency channels each.

- Digitally combined to produce multiple beams with high-gain for all receive frequencies.

- Improves both low and high altitude occultation performance as well as the ability to acquire synoptic surface reflections data over a wide swath of ocean or solid earth.

- Reduces multipath and RFI susceptibility by providing reduced gain toward the sources of multipath and RFI.
Dual Processor Architecture

- Dual processors with more than 6 times the throughput of the BlackJack GPS receiver
- Navigation Processor based on the BlackJack design that has successfully flown on more than 16 flight missions
- New Science Processor based on Linux operating system
  - Allows signal processing algorithms to be developed on standard Desktop Linux systems
  - Eliminates the need for receiver experts to implement advanced experiments
- Navigation processor with one RFDC constitutes a low power and mass TriG configuration for precise positioning
Flexible Architecture with Large Reconfigurable Resources

- Software and signal processing firmware are fully reconfigurable post-launch.
- Large reconfigurable signal processing logic resources with up to 300 reconfigurable satellite signal processing channels.
- Programmable LO in the RFDC allows each RF channel to down-convert signals from any GNSS frequency within the front-end bandwidth.
- Individual RF channels are enabled as needed to control power consumption.
Advanced Signal Processing

- **Multi-Lag Processing:**
  - Allows use of a spread of range and Doppler models so that rising signals can be reliably captured for atmospheric occultation.

- **Time Delayed Processing:**
  - Large buffer memory for sample data storage allows occultation data to be processed after receiving more accurate models of SC geometry and oscillator behavior from the Navigation processor.

- **Open Loop Tracking**
  - Generate data from signals below the threshold for closing tracking loops
Frequency Reference

- Internal Ovenized Crystal Oscillator (OCXO)
  - < 3E-12 (1 sec) for 1 sec clock differencing
  - < 6E-11 (0.01 sec) for 100 Hz clock differencing

- Allow external USO inputs for
  - Zero difference allows for better precision at highest altitudes and traceability to International Standard of Unit (SI) for Climate Benchmark.
  - High precision inter-satellite ranging missions (e.g. GRACE-FO)
High-Rel Features

- TriG offers higher reliability design to meet mission critical needs
  - Use high-rel parts with TID of > 40 krad
  - Single Event Latchup (SEL) threshold of > 60MeV
  - Implemented Single Event Upset (SEU) mitigation
    - Memory Error Detection and Correction (EDAC)
    - FPGA configuration memory scrubbing
    - Triple Module Redundancy (TMR) voting scheme on EEPROM
    - Selective TMR could be implemented in the signal processing FPGA if necessary pending on mission requirements
Fully Autonomous Operation

- **GNSS Realtime Nav Processor**
  - Acquires and tracks GNSS signals
  - Sets Real Time Clock
  - Generates Position, Velocity, and Time (Option for 10-cm-level realtime solution)
  - Outputs time-tagged phase/range/snr
  - Tightly coupled with science processor

- **Science Processor**
  - Schedules Iono/Atmo Occ Profiles and reflection measurements
  - Extracts 1 ms phase/range/amp
  - Formats observables
Recent Development Status

- TriG Engineering Model (EM) has been built and testing is currently underway at Broad Reach Engineering and at JPL.
- Porting of BlackJack GPS software to run on the Navigation Processor is nearly complete.
- Preliminary performance of the wide-band RFDC has been verified against a BlackJack GPS receiver:
  - The SNR across all RF channels is comparable to the performance of the high-performance BlackJack/IGOR receiver front-ends.

**SNR difference of < 0.5dB between 4 RF channels**
TriG RFDC L1-L2 Group Delay Variation
(key parameters for absolute TEC and TEC variation)

- Less than 2 ns over temperature range from 0 to +40C.
TriG RFDC Double Differenced L1-L2 Phase
(key parameters for absolute TEC and TEC variation)

Double differenced phase (MAX L1-L2)-(Miranda L1-L2)

- Double differenced phase 1sigma=6.28ps
- 10 point smoothed

RFDC temperature

- < than 10 ps over temperature range from 0 to +40C.
Key Milestones

- Verify GPS Tracking Performance    April 2012
- Integrate GLONASS Tracking Capability  Sept 2012
- Verify RO Tracking Performance      Nov 2012
<table>
<thead>
<tr>
<th>Configuration</th>
<th>Power (W)</th>
<th>Mass (kg)</th>
<th>Dimension LxWxH (cm)</th>
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<tbody>
<tr>
<td>Single Antenna/Single Processor</td>
<td>16 to 20</td>
<td>4</td>
<td>20 x 16 x 12</td>
</tr>
<tr>
<td>Four Antenna/Single Processor</td>
<td>18 to 25</td>
<td>4</td>
<td>20 x 16 x 12</td>
</tr>
<tr>
<td>Four Antenna/Dual Processor</td>
<td>30 to 50</td>
<td>5</td>
<td>20 x 20 x 12</td>
</tr>
<tr>
<td>Eight Antenna/Dual Processor</td>
<td>40 to 60</td>
<td>6</td>
<td>20 x 23 x 12</td>
</tr>
</tbody>
</table>

- TriG GNSS receiver is scalable and the mass, power, and dimensions varies with configuration.
- Antenna assembly is not included in the mass and dimensions estimates.
Summary

- TriG is the next generation of NASA scalable space GNSS Science Receiver

- Will track all GNSS and additional radiometric signals (GPS, GLONASS, Galileo, Compass, and DORIS)

- Scalable 3U architecture and fully software and firmware reconfigurable, enabling optimization to meet specific mission requirements.

- TriG GNSS EM is currently undergoing testing and expected to complete full performance testing later this year.
Acknowledgements

- This task was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (Earth Systematic Mission Program Office – ESMPO).

- The authors would like to thank Ted Stecheson, Jacob Gorelik, and Tim Rogstad for their work on porting software to the TriG Navigation and Science processors; and Jehhal Liu for his work on the signal processing FPGA.

- Special thanks to Broad Reach Engineering for improvements they made to the BlackJack design with their IGOR occultation instrument.