Miniature Space GPS Receiver
by means of Automobile-Navigation Technology

Institute of Space and Astronautical Science,
Japan Aerospace Exploration Agency
(ISAS/JAXA)

Yusuke HAMADA, Nobuyuki TOMITA
Hirobumi SAITO, Takahide MIZUNO, Kousuke KAWAHARA, Kenji SHINKAI
Hiroyuki SASAKI

koubun@isas.jaxa.jp
Outline

• Introduction
• Issues and Solutions
• Performance
• Radiation Tolerance
• All-Sky GPS Antenna
• Conclusions


## Introduction

- **GPS (Global Positioning System) receivers**

<table>
<thead>
<tr>
<th></th>
<th>Spaceborne GPS Receivers</th>
<th>Automobile-Navigation GPS Receivers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weight</strong></td>
<td>Several kg</td>
<td>&lt; 100 grams</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>&gt; 10 W</td>
<td>&lt; 1W</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>~ $ 1 million</td>
<td>~ $ 500</td>
</tr>
</tbody>
</table>
Acknowledgements

- Institute of Space and Astronautical Science
  Japan Aerospace Exploration Agency (ISAS / JAXA)

- Mitsubishi Electric Corporation
- Japan Radio Corporation
- Institute of Space Technology and Aeronautics
  Japan Aerospace Exploration Agency (ISTA / JAXA)
- NT Space
- AmTech Corporation
## Specification of the selected commercial GPS receiver for automobile-navigation

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiving Channels</td>
<td>8 Channels</td>
</tr>
<tr>
<td>RF input Frequency</td>
<td>L1 : 1.575 GHz C/A</td>
</tr>
<tr>
<td>RF input Sensitivity</td>
<td>-132 dBm</td>
</tr>
<tr>
<td>Power supply DC</td>
<td>+5.0 V 180 mA</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>0.9 W</td>
</tr>
<tr>
<td>Weight</td>
<td>35 g</td>
</tr>
<tr>
<td>Size</td>
<td>58.7×36.3×11.0 mm³</td>
</tr>
</tbody>
</table>
Issues and Solutions

These are general issues.

- Large Doppler Shift in Orbit
  - Expansion of Frequency Scanning Range

- Time Tag Error
  - Output of Accurate Time Tag
Large Doppler Shift in Orbit

- On the ground (Automobile)
  - Doppler shift: $\Delta f_d = \pm 7$ kHz
  - Frequency scanning range: $\Delta f_s = \pm 17$ kHz

- In the low earth orbit (Satellite)
  - Doppler shift: $\Delta f_d = \pm 45$ kHz

Altitude 690 km  Polar orbit

ROM Modification: Expansion of frequency scanning range

$\Delta f_s = \Delta f_d + \Delta f_o = (\pm 45) + (\pm 12) = \pm 57$ kHz

koubun@isas.jaxa.jp
Time Tag Error

- Automobile-navigation GPS receivers
  - Output data
    - Position data with coarse time tag

- If time tag error is 0.2 sec \((V \times \Delta T)\)
  - Automobile (40 m/sec) \(\rightarrow\) Position error 8 m
  - Satellite (7500 m/sec) \(\rightarrow\) Position error 1500 m

- Spaceborne GPS receivers require accurate time tag
Solution to Time Tag Issue

• Modification of Software in ROM
  – First Version  ( INDEX )
    • Pseudorange output with accurate time
      Positioning calculation by external computer
  – Second Version  ( on going by ISTA / JAXA )
    • Position with accurate time tag
    • Pseudorange output
    • Ephemeris output
Performance tests with GPS Simulator

- GPS Simulator
  - STR2760 (SPIRENT Inc.)
  - Output Channels: 10 ch
  - Signal: L1 (1.575 GHz)
Performance of Acquisition

Acquisition Time

TTFF (Time to First Fix) : < 60 min (Cold Start)
Position Error of Receiver Measurement in Orbit

( without error of ionosphere, ephemeris data and satellite clock, etc )

- Position Error of Receiver Measurement : 2 m ( RMS )
- PDOP : 2.7 ( RMS )
- Receiver Measurement Error : 0.8 m ( RMS )

\[
\text{Position error} = \sigma_{\text{range}} \times \text{PDOP}
\]

Altitude: 690 km
Sun Sync. Orbit
## Estimated Error in Orbit

<table>
<thead>
<tr>
<th>Error source</th>
<th>Estimated error in orbit ( RMS [m] )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ephemeris data</td>
<td>2.1*</td>
</tr>
<tr>
<td>GPS satellite clock</td>
<td>2.1*</td>
</tr>
<tr>
<td>Ionosphere</td>
<td>5.4**</td>
</tr>
<tr>
<td>Receiver measurement</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Total range error</strong></td>
<td>6.2</td>
</tr>
</tbody>
</table>

| Position error ( PDOP = 2.7 ) | 16.7                                |

* Reference : P.W. Parkinson, “Global Positioning System”

** NATO Standard Agreement STANAG 4294 Issue 1

\[
\text{Ionospheric delay} = \frac{82.1 \times \text{TEC}}{F_c^2 \times \left( \sqrt{\sin^2 E + 0.076 + \sin E} \right)} \\
\text{TEC} = 1.0 \times 10^{17} [\text{m}^{-2}]
\]
Radiation Tolerance

• Total Dose Radiation test with Co60
  20 krad

• Radiation test with proton of 30 and 200 MeV
  SEL-free
  SEU-Once per several days (200 MeV)
All-Sky GPS Antenna for INDEX
Conclusions:

(1) We developed a spaceborne GPS receiver based on a automobile-navigation GPS reciever.

(2) Modifications of software in ROM
   • Expansion of frequency scanning range
   • Output of pseudorange with accurate time tag

(3) This GPS receiver is able to be used in LEO.
   • Cold start acquisition : less than 60 min.
   • Position accuracy       : less than 20 m.
   • SEL-free for 200 MeV proton.
   • SEU once per several days.

will be onboarded on INDEX satellite in the next year.
Thank you
Backup Slides
Miniature Space GPS Receiver
by means of Automobile-Navigation Technology

ISAS/JAXA
Miniature Space GPS Receiver
by means of Automobile-Navigation Technology

Positioning Error
LAT[deg]

Positioning Error [m]
LAT [deg]

Time [hour]