GPS III Arrived – An Initial Analysis of Signal Payload and Achieved User Performance

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Motivation

• GPS III-1 (SVN 74) is the first satellite of a new GPS generation

• New signal on board → L1C

• Signal quality comparing to previous GPS generations

• From the perspective of the user
  • Transmit & received power over elevation (satellite antenna pattern)
  • Signal deformation analysis (L1C, L5)
  • First multipath & noise and clock estimates
**Expectations / ICD**

- Signals onboard of GPS III in L1 band

<table>
<thead>
<tr>
<th>Component</th>
<th>Modulation</th>
<th>Chipping rate [MHz]</th>
<th>Minimum received power [dBW]</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>C/A</td>
<td>BPSK(1)</td>
<td>1.023</td>
<td>–158.5</td>
<td>IS-GPS-200J (2018)</td>
</tr>
<tr>
<td>L1C data</td>
<td>BOC(1,1)</td>
<td>1.023</td>
<td>–163.0</td>
<td>IS-GPS-800E (2018)</td>
</tr>
<tr>
<td>L1C pilot</td>
<td>TMBOC(6,1,4/33)</td>
<td>1.023</td>
<td>–158.25</td>
<td>IS-GPS-800E (2018)</td>
</tr>
<tr>
<td>P(Y)</td>
<td>BPSK(10)</td>
<td>10.23</td>
<td>–161.5</td>
<td>IS-GPS-200J (2018)</td>
</tr>
<tr>
<td>M</td>
<td>BOC(10,5)</td>
<td>10.23</td>
<td>–158.0</td>
<td>Marquis and Reigh (2015)</td>
</tr>
</tbody>
</table>

- How GPS manages the implementation of an additional signal on L1 band:
  - **Interplexing**: Majority voting of L1C (data+pilot) and P(Y)-code* in In-phase channel and C/A-code on Quadrature channel
  - **What about M-code?**

- L2 and L5 signals as known from GPS IIF

Spectral view

• First signal transmission captured by GNSS receivers on January 9, 2019

• First spectral overview captured at ground station Weilheim, Germany on January 9, 2019 using a 30 m dish

• Measured L1 spectrum in comparison with the theory and GPS IIF
Transmit Power - GPS IIF versus GPS III

- Equivalent isotropic radiated power (EIRP) measured at Weilheim, Germany
- Considered satellites: GPS III-1 and GPS IIF-2
- Data captured every 5 minutes at Weilheim ground station over a full satellite pass

Different pattern shapes can be observed for all frequency bands. What could be the origin?
- Constellation plots show good signal quality in terms of possible signal distortions based on their clear constellation points and almost straight chip transitions for GPS III-1.
Inphase (I) & Quadrature (Q) Data Constellation View

- GPS III-1 L1 IQ constellation over measurement time
- M-Code phase relation according to other L1 signals changes over elevation (measurement time)

Measurement time

- Conclusion: M-code transmission not via same antenna network as for the other L1 signals (C/A, P(Y)+L1C)
L1 Gain Patterns of individual Components

- IQ constellation provides amplitude relation between C/A-code, L1C+P(Y)-code and M-code
- Spectra over time provide power relation over time. For separation purposes, one can use a part only with M-code and another one only with P(Y)+L1C respectively C/A-code (illustrated by the red boxes).
- Combining IQ constellation and transmit power information over time, one can separate gain patterns for L1 C/A-, M- and L1C+P(Y) components

M-code is transmitted via a separate antenna or at least using only a part of the antenna network used for the rest of the L1 signals
Transmit Power - GPS IIF versus GPS III

• Conclusions of IQ constellation and power spectra analysis regarding transmit pattern of GPS III:
  • L1: Superposition of C/A+P(Y)+L1C antenna network and M-code antenna network with different gain patterns
  • L2: Superposition of P(Y)+L2C antenna network and M-code antenna network with different gain patterns
  • L5: Seems to be a new antenna

• What does the transmitted power mean for users and their signal strength reception?
Signal strength from the perspective of the user

- Carrier-to-noise density ratio of GPS signals tracked by a Septentrio PolaRx5 receiver with a Leica AR1203+GNSS antenna in Oberpfaffenhofen, Germany.

- Measured minimum received power for L1 C/A-code of -157.9 dBW at 5° elevation (ICD -158.5 dBW)
Signal Deformation & Differential Code Bias Estimation: L1 band

- Performance of the new GPS L1C signal in differential GNSS applications, like Ground Based Augmentation Systems (GBAS)
- Differential code bias estimation GPS III-1 L1C versus Galileo E1C based on S-curve bias method

GPS III-1

GSAT 0209

Reference Receiver settings based on the current draft MOPS for aviation applications:

- Spacing = 0.1 chip
- Bandwidth = 24 MHz
Signal Deformation & Differential Code Bias Estimation: L5 band

- Differential code bias estimates for GPS III-1 versus GPS IIF-1 for L5 pilot

<table>
<thead>
<tr>
<th>Reference Receiver settings based on the current draft MOPS for aviation applications:</th>
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<tr>
<td>Spacing = 1 chip</td>
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<tr>
<td>Bandwidth = 24 MHz</td>
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</table>

- Very low differential biases up to 25 MHz input bandwidth and a wide range of correlator spacing for both GPS satellites

### Table

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<thead>
<tr>
<th>Signal</th>
<th>Digital distortions [ns]</th>
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<tbody>
<tr>
<td>GPS IIF-1</td>
<td></td>
</tr>
<tr>
<td>GPS III-1</td>
<td></td>
</tr>
<tr>
<td>L5 data</td>
<td>5.1</td>
</tr>
<tr>
<td>L5 pilot</td>
<td>3.6</td>
</tr>
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</table>
Receiver Tracking: Multipath & Noise

- Multipath & noise estimation based on Javad TR_3 receiver data from IGS station (POTS00DEU) at Potsdam, Germany

GPS III-1 (G04)  

- Multipath combination

\[
MP(p_i, \varphi_i, \varphi_j) = p_i - \varphi_i - 2 \frac{f_j^2}{f_i^2 - f_j^2} (\varphi_i - \varphi_j)
\]

- RMS in 5 deg elevation bins
Interfrequency Clock Bias (IFCB)

• Interfrequency clock bias estimation based on triple carrier phase observations using measurements of 7 stations

• For lower elevations the triple carrier phase combination is dominated by noise and multipath

• Results:
  • Block IIF: small orbit-periodic variations can be seen for the Block IIF satellite (within cm-range, peak-to-peak approx. 4 cm)
  • Block III: no orbit periodic variations
GPS III-1 current signal status (August 2019)

- Reduced transmit power on all 3 bands

- Instead of nominal C/A-code the non-standard code is transmitted on L1

- L1C PRN moved from 4 to 117, L5 PRN has also moved
Conclusion and Outlook

• The new GPS III generation has started signal transmission

• The new signal L1C is present and shows good quality in terms of signal distortions and noise & multipath characteristics

• M-code transmission is partially separated from other signals on L1 and L2

• Minimum received power for L1 C/A-code is in line with ICD, but with low margin to its proposed minimum

• L5 signal has comparable signal distortions to GPS IIF block satellites

• Good consistency of L1/L2/L5 carriers, no signs of orbit dependent interfrequency bias variations

• Currently the GPS III-1 uses non-operational signal transmission
Thank you for your attention – Any questions?