Introduction to Global Navigation Satellite System (GNSS) Software GPS Receiver

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GNSS Receiver Introduction
Block Diagram of GPS Receiver

Antenna → Pre-Amp → Down Converter → A/D Converter → Baseband Signal Processing

Oscillator → Frequency Generator → AGC

Acquisition → Tracking → Navigation Data → Position Output User Interface
Information Required to Process GNSS Signal

- Signal Frequency
- Modulation Type
- PRN Code Generation
- PRN Code Chip Rate
- Navigation Message Data Rate
- Navigation Message Structure
  - Frame Structure

All these necessary data are given in the ICD (Interface Control Document) of each satellite system. ICD is also called IS (Interface Specification) document.

http://www.gps.gov/technical/icwg/
http://qz-vision.jaxa.jp/USE/is-qzss/index_e.html
http://qzss.go.jp/en/
## GPS Signals

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency, MHz</th>
<th>Signal Type</th>
<th>Code Length, msec</th>
<th>Chip Rate, MHz</th>
<th>Modulation Type</th>
<th>Data / Symbol Rate, bps/sps</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>1575.42</td>
<td>C/A</td>
<td>1</td>
<td>1.023</td>
<td>BPSK</td>
<td>50</td>
<td>Legacy Signal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C_{Data}</td>
<td>10</td>
<td>1.023</td>
<td>BOC(1,1)</td>
<td>50 / 100</td>
<td>From 2014</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C_{Pilot}</td>
<td>10</td>
<td>1.023</td>
<td>TMBOC</td>
<td>No Data</td>
<td>BOC(1,1) &amp; BOC(6,1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P(Y)</td>
<td>7 days</td>
<td>10.23</td>
<td>BPSK</td>
<td></td>
<td>Restricted</td>
</tr>
<tr>
<td>L2</td>
<td>1227.60</td>
<td>CM</td>
<td>20</td>
<td>0.5115</td>
<td>BPSK</td>
<td>25 / 50</td>
<td>Modulated by TDM of (L2CM xor Data) and L2CL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CL</td>
<td>1500</td>
<td>0.5115</td>
<td>BPSK</td>
<td>No Data</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>P(Y)</td>
<td>7 days</td>
<td>10.23</td>
<td>BPSK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L5</td>
<td>1176.45</td>
<td>I</td>
<td>1</td>
<td>10.23</td>
<td>BPSK</td>
<td>50 / 100</td>
<td>Provides Higher Accuracy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Q</td>
<td>1</td>
<td></td>
<td></td>
<td>No Data</td>
<td></td>
</tr>
</tbody>
</table>
GPS Signal Processing Method

• Make a Replica Signal in the GPS Receiver
  • Make a Replica of Carrier Signal
  • Make a Replica of PRN Code
  • The GPS signal can be acquired only when
    • the frequency of the replica carrier replica matches the frequency of the carrier in the received signal
    • The replica of PRN code aligns with the PRN code of the incoming signal

• Signal Acquisition
  • Identify visible satellites with coarse Doppler and Code Phase

• Signal Tracking
  • Continuously track the signal for visible satellites with fine Doppler and Code Phase

• Navigation Message Decoding
  • Decodes navigation message data bits to extract necessary parameters for position computation
  • Get necessary time related parameters

• Position Computation
  • Compute pseudorange, carrier phase etc and compute 3-D position, velocity and SNR
Signal Acquisition

• Generate a replica signal
  • Generate a carrier with Doppler
    • Doppler could be from -10kHz to +10kHz at 500Hz (Max) interval
    • Sample it at desired sampling frequency
  • Generate PRN Code
    • For all satellites to be acquired or visible ones
    • Sample it at desired sampling frequency
  • Represent “1” by “-1” and “0” by “1”
    • Simplifies XOR operation by multiplication
Make a Replica of Carrier Signal with Doppler Frequency

The frequency of L1 Band of GPS L1C/A signal, $f_0$: 1575.45MHz
But, due to Doppler this frequency changes when it arrives to the receiver.
Thus the frequency is $f_0 + f_{dop}$. But, we don’t know the Doppler frequency.
So, we have to search for all possible Doppler Frequency Range.
This is done by estimating Maximum Doppler that will be seen at the receiver.
It depends on Satellite Speed, User Speed and Clock errors in the receiver.
The maximum Doppler possible due to satellite and receiver velocities is about 5kHz.
So if we include Clock Errors, the maximum Doppler will be within 10kHz.
Hence, GPS receivers search Doppler within a range of +10kHz to -10Khz.
Thus, the replica carrier frequency would be from $f = 1575.42MHz \pm 10kHz$

Matlab Code Example:
```matlab
fif = 4e6;
fs = 16e6;
fdo = 5e3;
f = fif+fdo;
t = 1e-3;
tt = 0:1/fs:t-1/fs;
A = sqrt(2);
S = A*cos(2*pi*f*tt); % This is replica of Carrier Signal
figure;
plot(tt,S);
figure;
psd(S,2048,fs);
```

Try the above dcode with $f_{dop} = 0$;
See the peak of the Power Spectrum when Doppler is on and off.
Make a Replica of PRN Code

G1 Polynomial: [3,10]

G2 Polynomial: [2,3,6,8,9,10]
Properties of PRN Codes

• PRN Codes are designed in such a way they have only the following correlation values
  • All 1023 chips matches (s = 1)
  • Only either 63 or 65 chips matches out of 1023 chips (s = 63/1023 or 65/1023)
  • Only one chip matches out of 1023 chips (s = 1/1023)
• The number of Zeros and Ones in the PRN code differs by only one
Auto-Correlation Properties of GPS L1C/A PRN Code

$$10 \times \log_{10} \left( \frac{63}{1023} \right)^2 = -24 \text{dB}$$

$$10 \times \log_{10} \left( \frac{1}{1023} \right)^2 = -60 \text{dB}$$
Exclusive OR (XOR)

Smart way of Implementing XOR

<table>
<thead>
<tr>
<th>XOR</th>
<th>Multiplication</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Represent “1” by “-1” and “0” by “1”
Replica Signal in the Receiver

\[ \sqrt{2P} \sin(2\pi ft) \]

\[ \sqrt{2P} x(t)\sin(2\pi ft) \]

\[ f = f_0 + f_{\text{doppler}} \]

For Satellite
\[ f = f_0 = 1575.42\text{MHz for L1C/A Signal} \]

**But for Receiver Replica Signal**
\[ f = f_0 + f_{\text{doppler}} \]
Because of Doppler
\[ f_{\text{doppler}} \text{ varies from } +10\text{kHz to } -10\text{kHz} \]

1.023Mbps

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Identification of visible satellites using coarse Doppler and Code Phase
Plot of Replica Signal, GPS L1C/A (Carrier & PRN Code Modulated)

Time Domain Plot of IF Data
File: JAX_LIV.dat
Histogram of Replica Signal, GPS L1C/A (Carrier & PRN Code Modulated)

Histogram of IF Data
File: JAX_LIV.dat

Number of Samples in a Bin

Bin Value

-5 -4 -3 -2 -1 0 1 2 3 4 5

0
2000
4000
6000
8000
10000
12000
14000
16000

Training on GNSS – Course (T141-30), Organized by: GIC/AIT, S4D/CSIS and ICG, held at: GIC/AIT, Thailand from 23 – 26 JAN 2018
Dinesh Manandhar, CSIS, The University of Tokyo, dinesh@iis.u-tokyo.ac.jp
PSD (Fourier Transform) of Replica Signal, GPS L1C/A (Carrier & PRN Code Modulated)

Frequency Domain Plot of IF Data
File: JAX_LIV.dat
Acquisition of GPS L1C/A Signal
Acquisition Output shown in 3-D

File: LS2.dat, SV: GPS, PRN ID:8
CodePhase: 2339, Doppler: -5100Hz, CohInt.: 2, NonCohInt: 5
Acquisition Output shown for Doppler Frequency

File: LS2.dat, SV: GPS, PRN ID:8
CodePhase: 2339, Doppler: -5100Hz, CohInt.: 2, NonCohInt: 5
Acquisition Output shown for Code Phase (PRN Code Chip Delay)

File: LS2.dat, SV: GPS, PRN ID: 8
CodePhase: 2339, Doppler: -5100 Hz, CohInt.: 2, NonCohInt: 5
GPS Signal Tracking

• Tracking Loops (PLL & DLL) are used to continuously lock the incoming signal and demodulate it by using the carrier frequency and code phase values detected in Acquisition.

• PLL
  • Phase Lock Loop
  • To Track the Carrier Frequency

• DLL
  • Delay Lock Loop
  • To Track the Code Phase (PRN Code Delays)
GPS Signal Tracking Output

I and Q Plot

I and Q Power in dB

I and Q Scatter Plot
SNR & C/No

- **SNR**
  - Signal to Noise Ratio, unit is dB
  - S: Signal Power in dBm or dBW
  - N: Noise power in a given bandwidth in dBm or dBW

- **C/No**
  - Carrier to Noise Density, unit is dB-Hz
  - C: Carrier power in dBm or dBW
  - No: Noise power density in dBm-Hz or dBW-Hz

- SNR = C/No-BW (BW = bandwidth of the Front End)
  - If BW = 4Mhz = 10*log10(4000000) = 66dB
  - If C/No = 48dB-Hz
  - SNR = C/No-BW = 45-66 = -21dB

- Noise Density (No) at Room Temperature (290K): -204dBW/Hz
- Received Power (GPS L1C/A Signal) at Antenna: -158.5dBW
  - C/No = -158.5-(-204) = 45.5dB-Hz