Introduction to Global Navigation Satellite System (GNSS)

Software GPS Receiver

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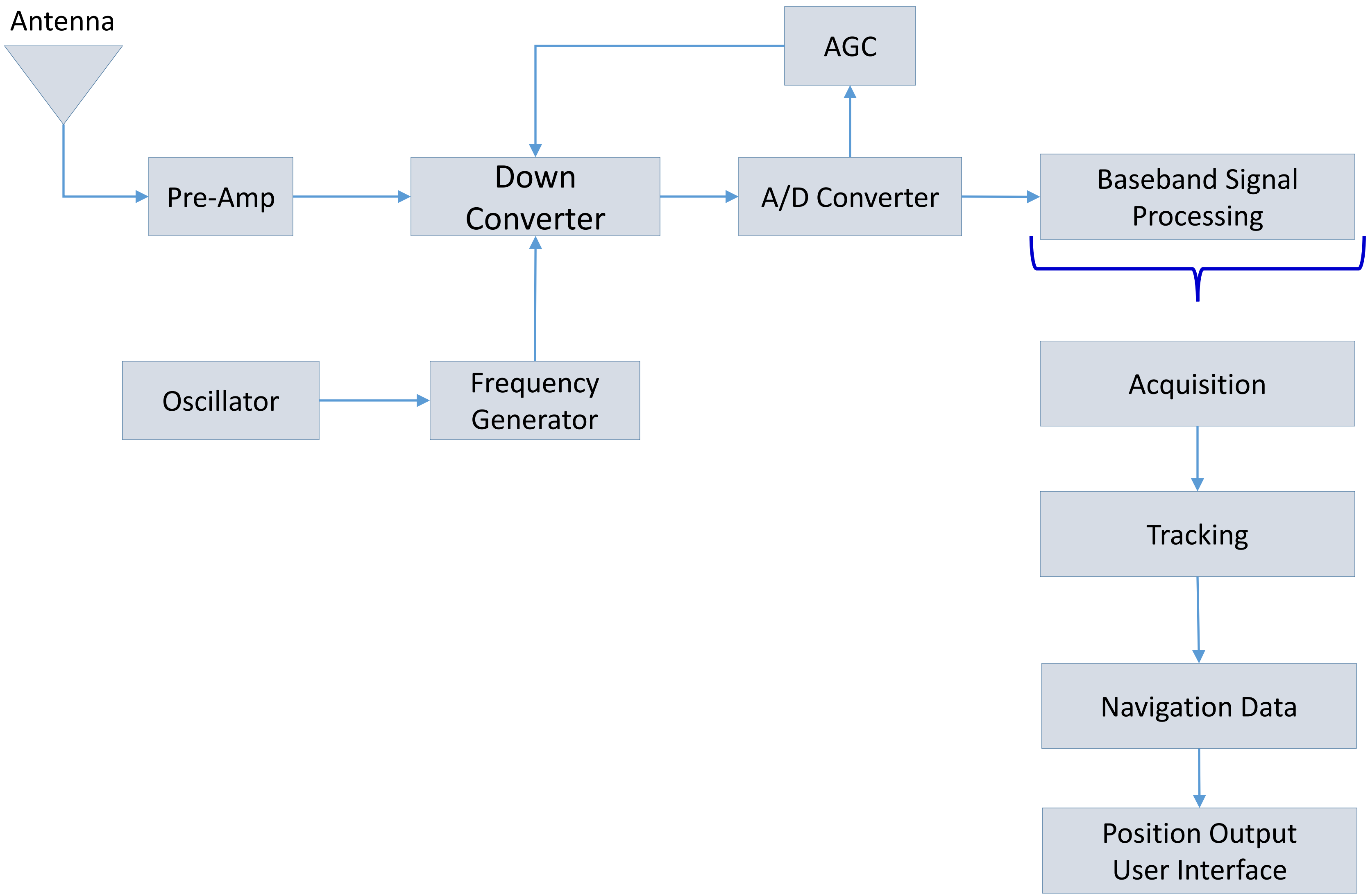
GNSS Receiver Introduction

Block Diagram of GPS Receiver



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

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

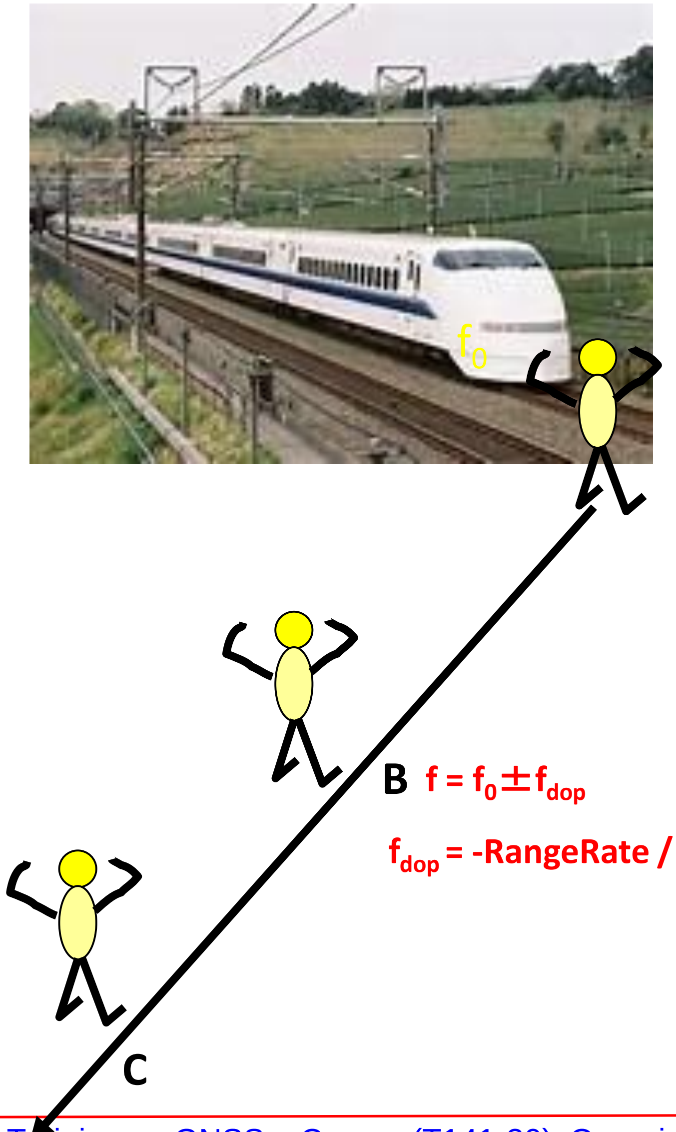
GPS Signal Processing Method

- 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 freqency
  - Generate PRN Code
    - For all satellites to be acquired or visible ones
    - Sample it at desired sampling freqency
  - Represent “1” by “-1” and “0” by “1”
    - Simplifies XOR operation by multiplication

Make a Replica of Carrier Signal with Doppler Frequency



B $f = f_0 \pm f_{dop}$

f_{dop} = -RangeRate / WaveLength

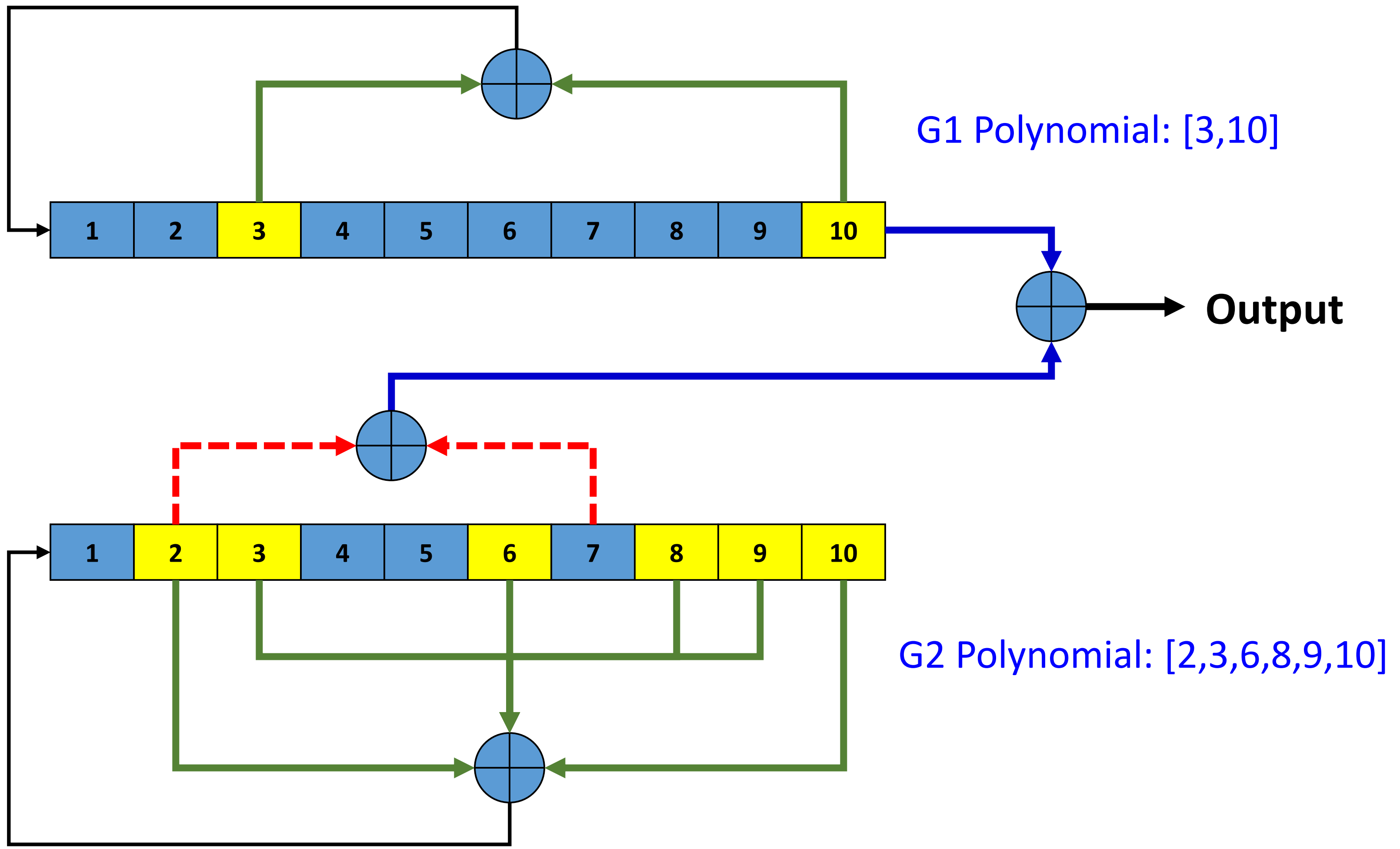
The frequency of L1 Band of GPS L1C/A signal, f0: 1575.45MHz
But, due to Doppler this frequency changes when it arrives to the receiver.
Thus the frequency is f0+fdop. But, we don't know the Doppler frequency.
So, we have to search for all possible Doppler Frequency Range.
This is done by estimating 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 ±10kHz

Matlab Code Example:

```
fif = 4e6;
fs = 16e6;
fdop = 5e3;
f = fif+fdop;
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 fdop = 0;
See the peak of the Power Spectrum when Doppler is on and off.

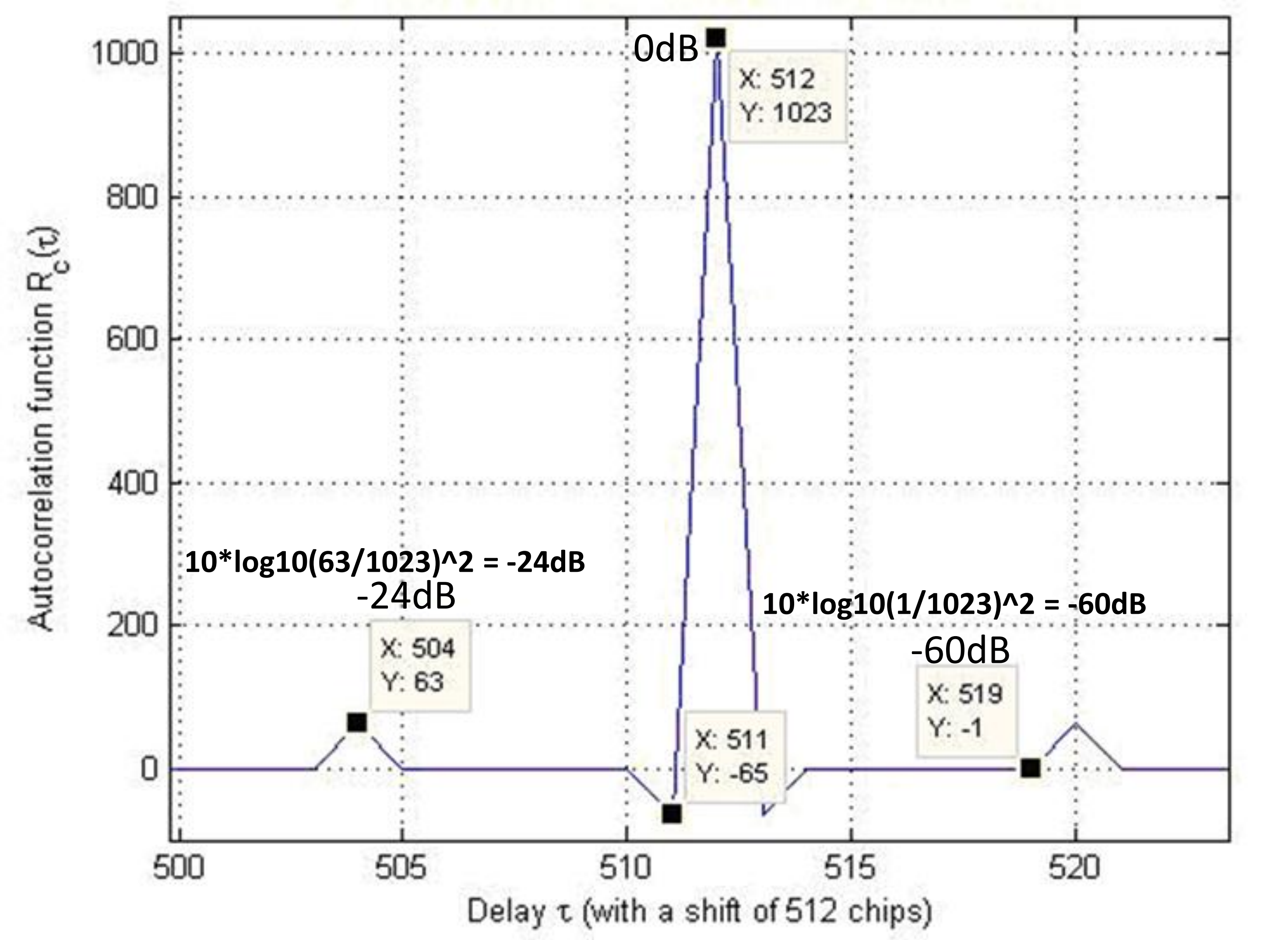
Make a Replica of PRN Code



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 o f 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



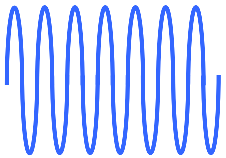
Exclusive OR (XOR)

Smart way of Implementing XOR

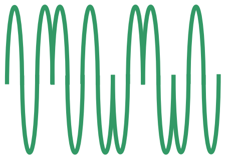
XOR			Multiplication		
0	1	1	1	-1	-1
1	0	1	-1	1	-1
0	0	0	1	1	1
1	1	0	-1	-1	1

Represent “1” by “-1” and “0” by “1”

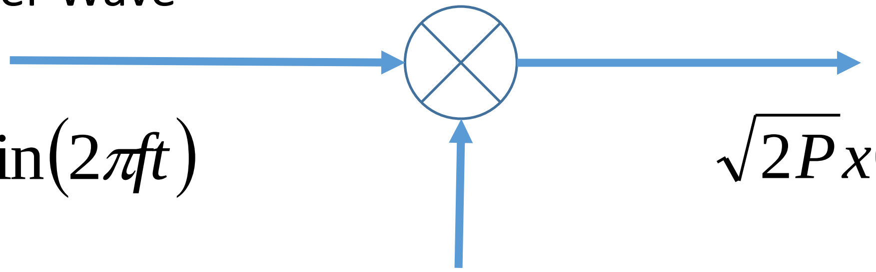
Replica Signal in the Receiver



Carrier Wave



Replica Signal in the Receiver



$$\sqrt{2P}\sin(2\pi ft)$$

$$\sqrt{2P}\,x(t)\sin(2\pi ft)$$

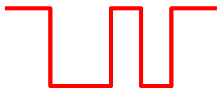
$f = f_0 + f_{doppler}$

PRN

For Satellite
$f = f_0$ = 1575.42MHz for L1C/A Signal

$$x(t)$$

+1

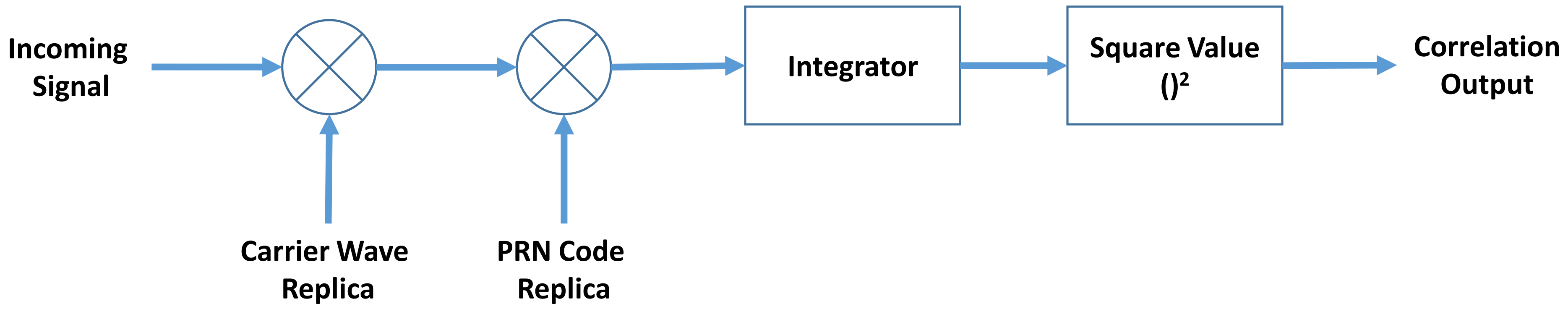


-1

1.023Mbps

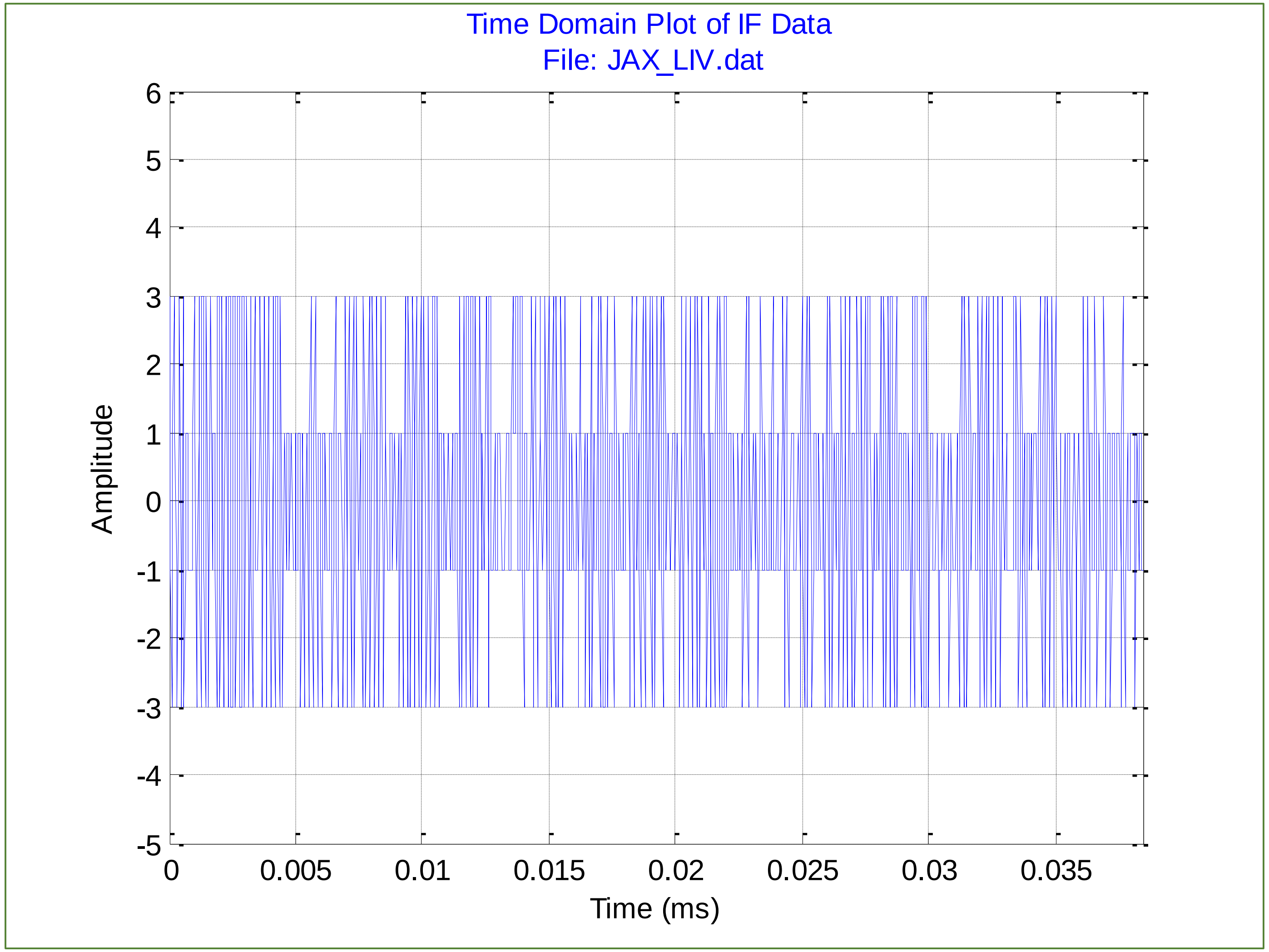
<u>But for Receiver Replica Signal</u>
$f = f_0 + f_{doppler}$ because of Doppler
$f_{doppler}$ varies from +10kHz to -10kHz

Acquisition

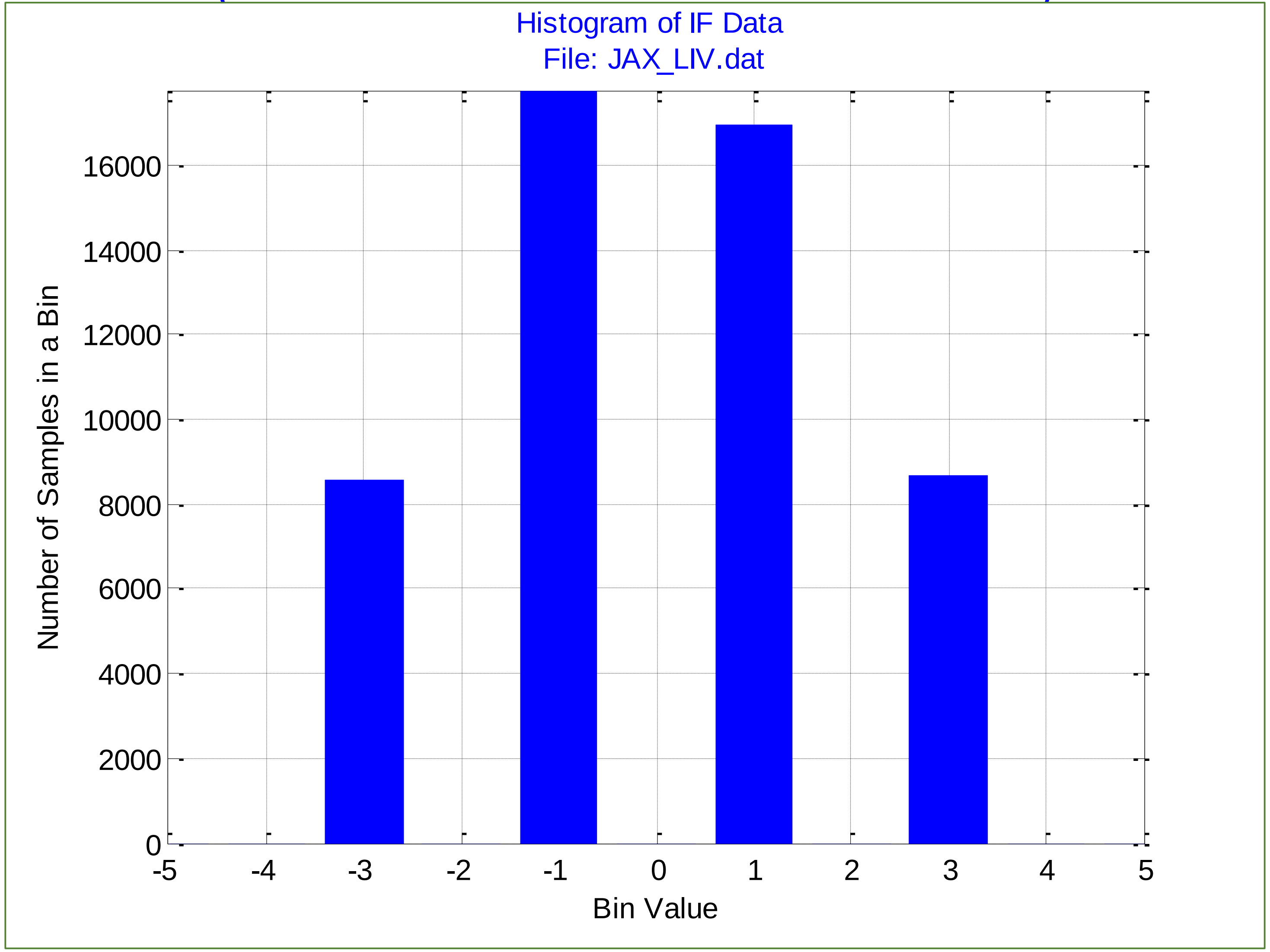


Identify visible satellites with coarse Doppler and Code Phase

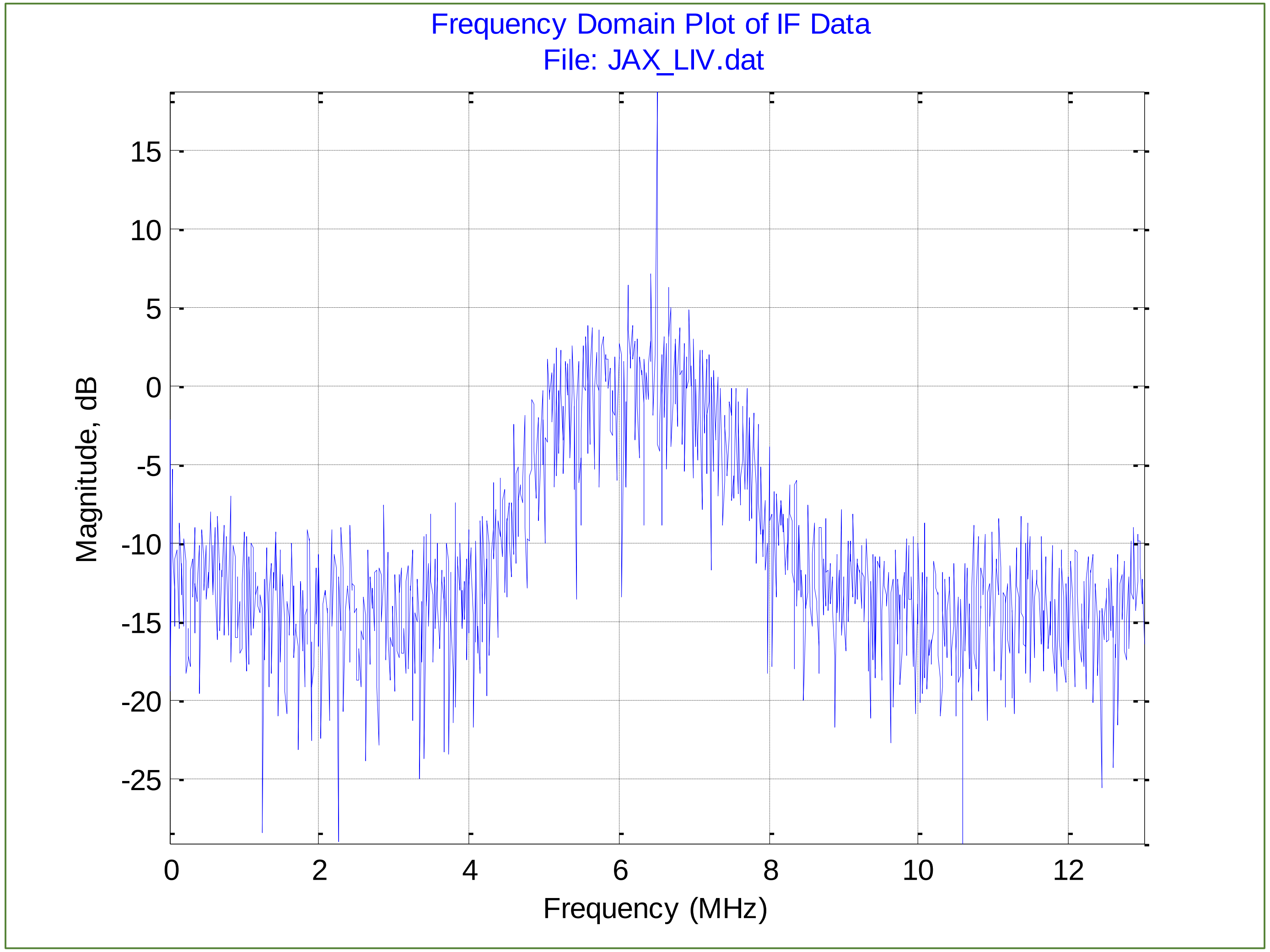
Plot of Replica Signal, GPS L1C/A
(Carrier & PRN Code Modulated)



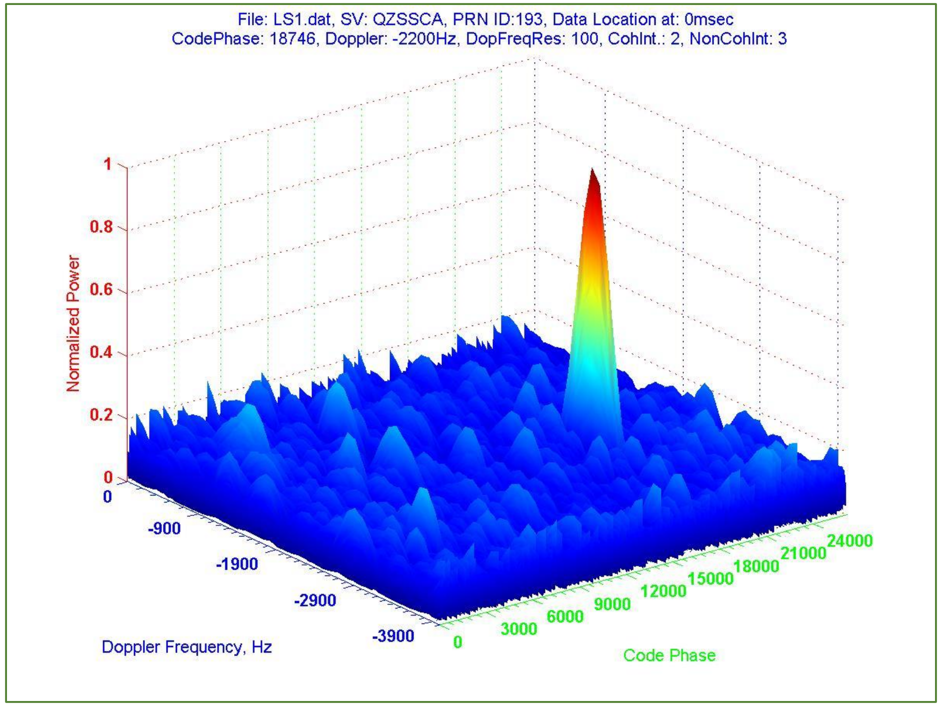
Histogram of Replica Signal, GPS L1C/A
(Carrier & PRN Code Modulated)

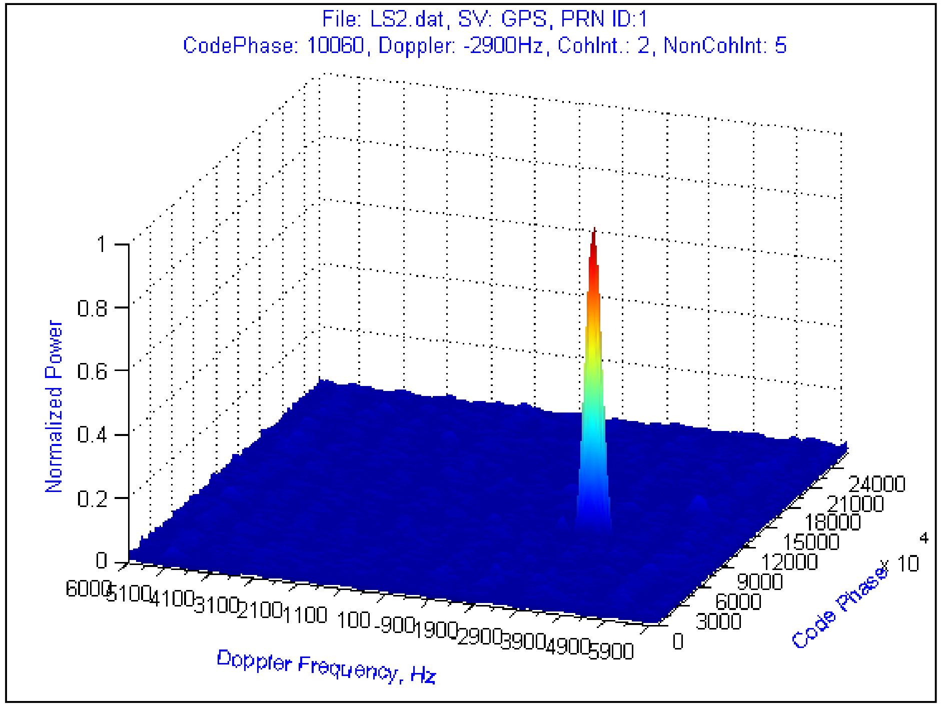


PSD (Fourier Transform) of Replica Signal, GPS L1C/A (Carrier & PRN Code Modulated)

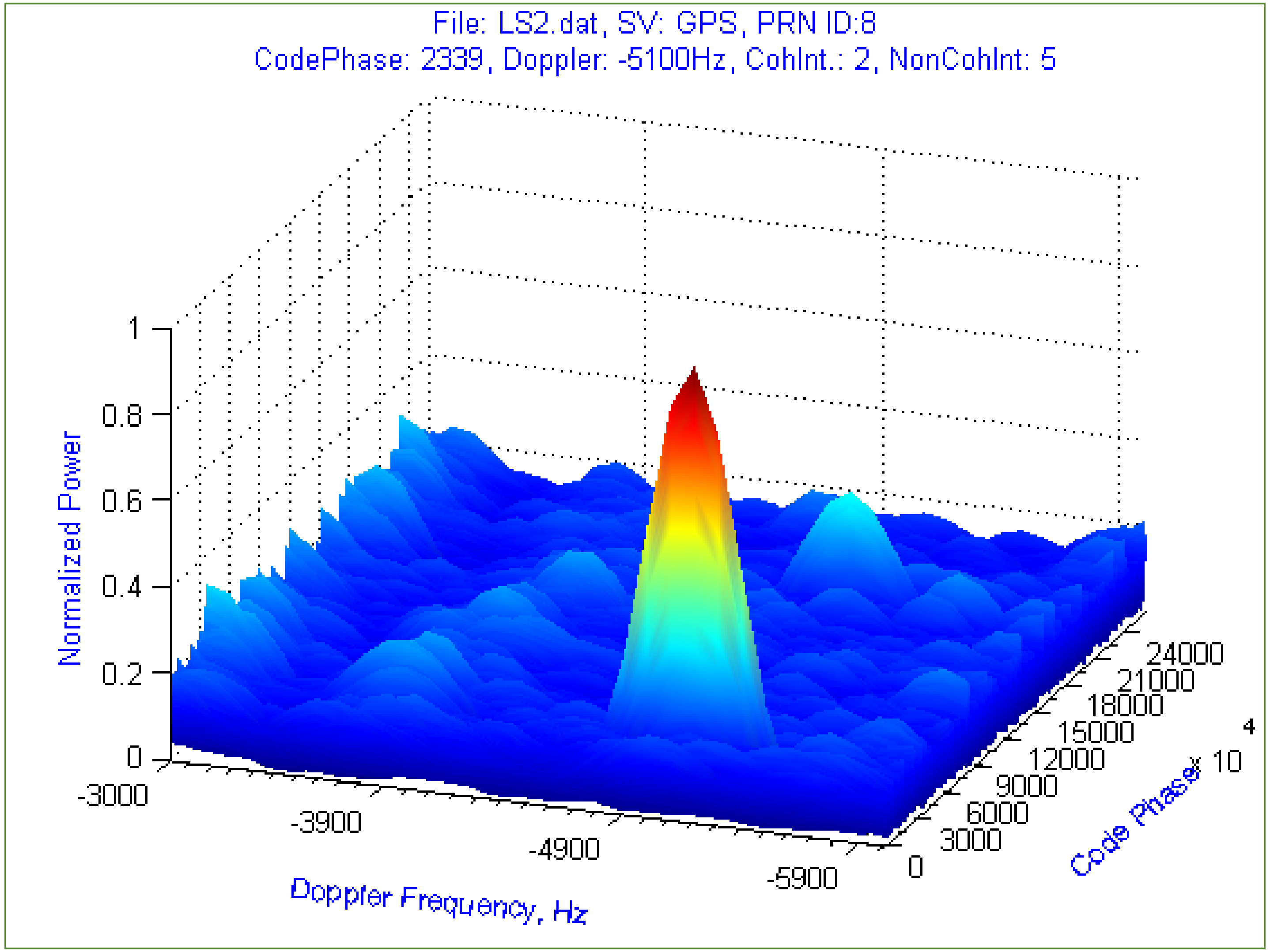


Acquisition of GPS L1C/A Signal

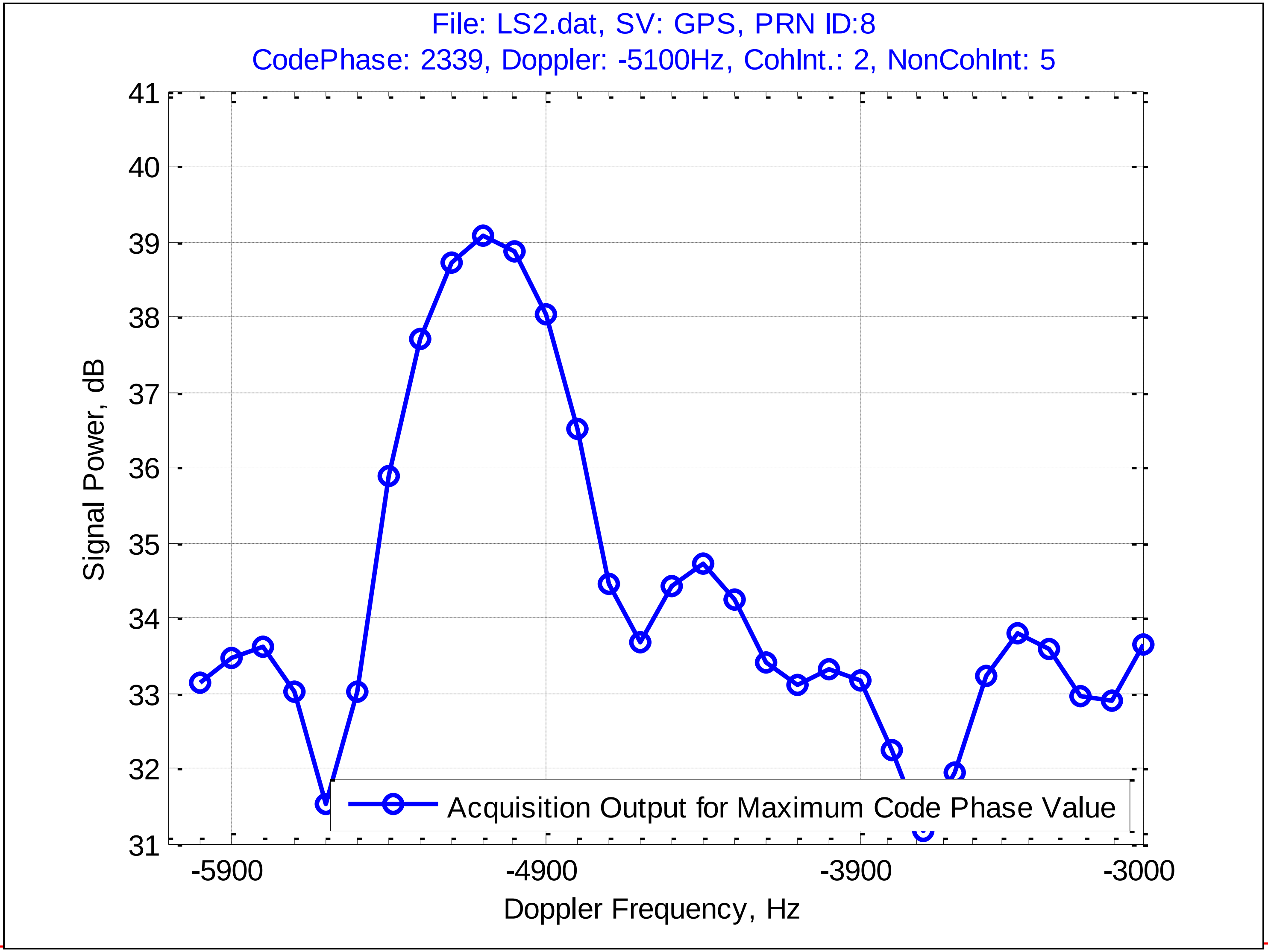




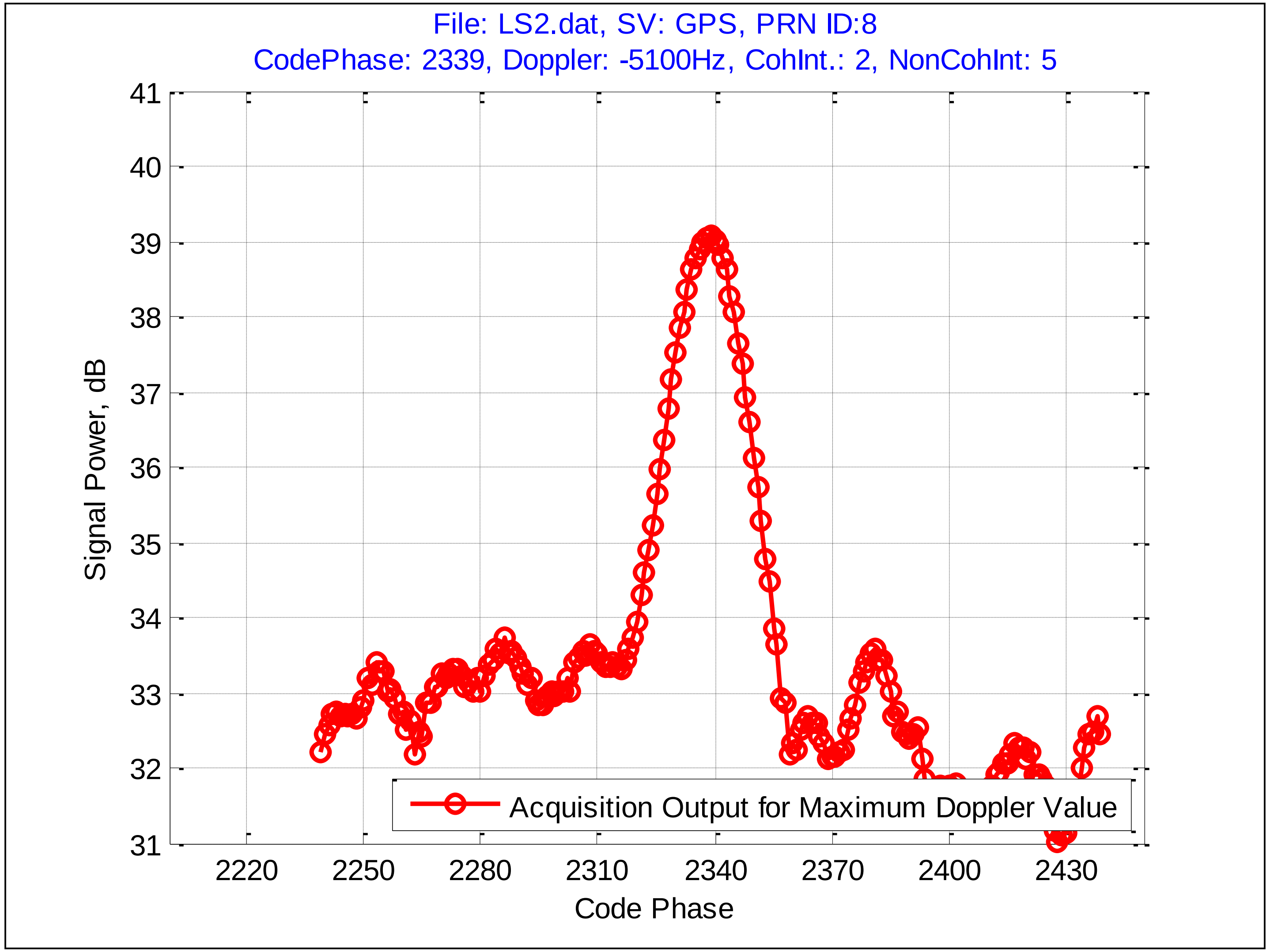
Acquisition Output shown in 3-D



Acquisition Output shown for Doppler Frequency



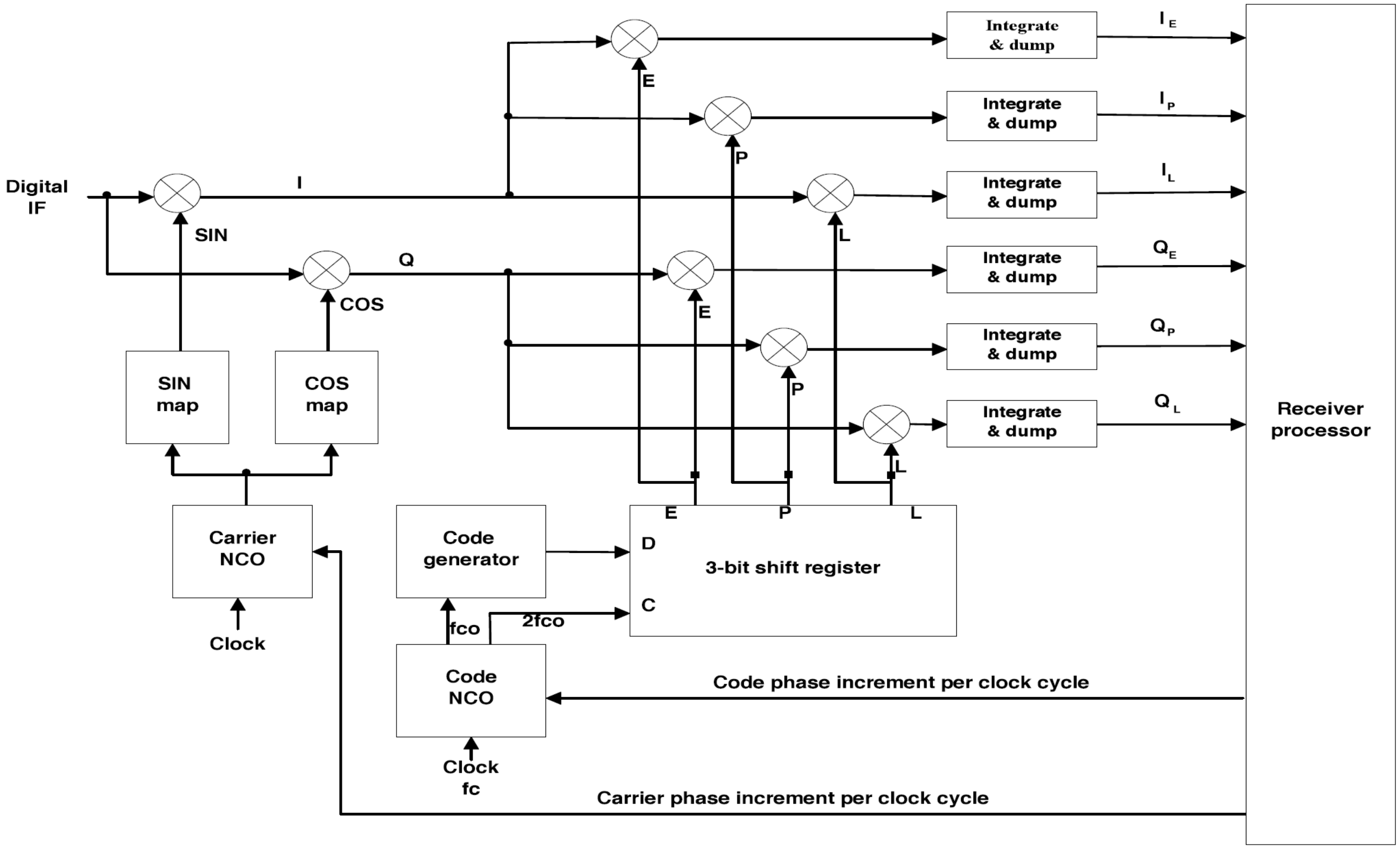
Acquisition Output shown for Code Phase (PRN Code Chip Delay)



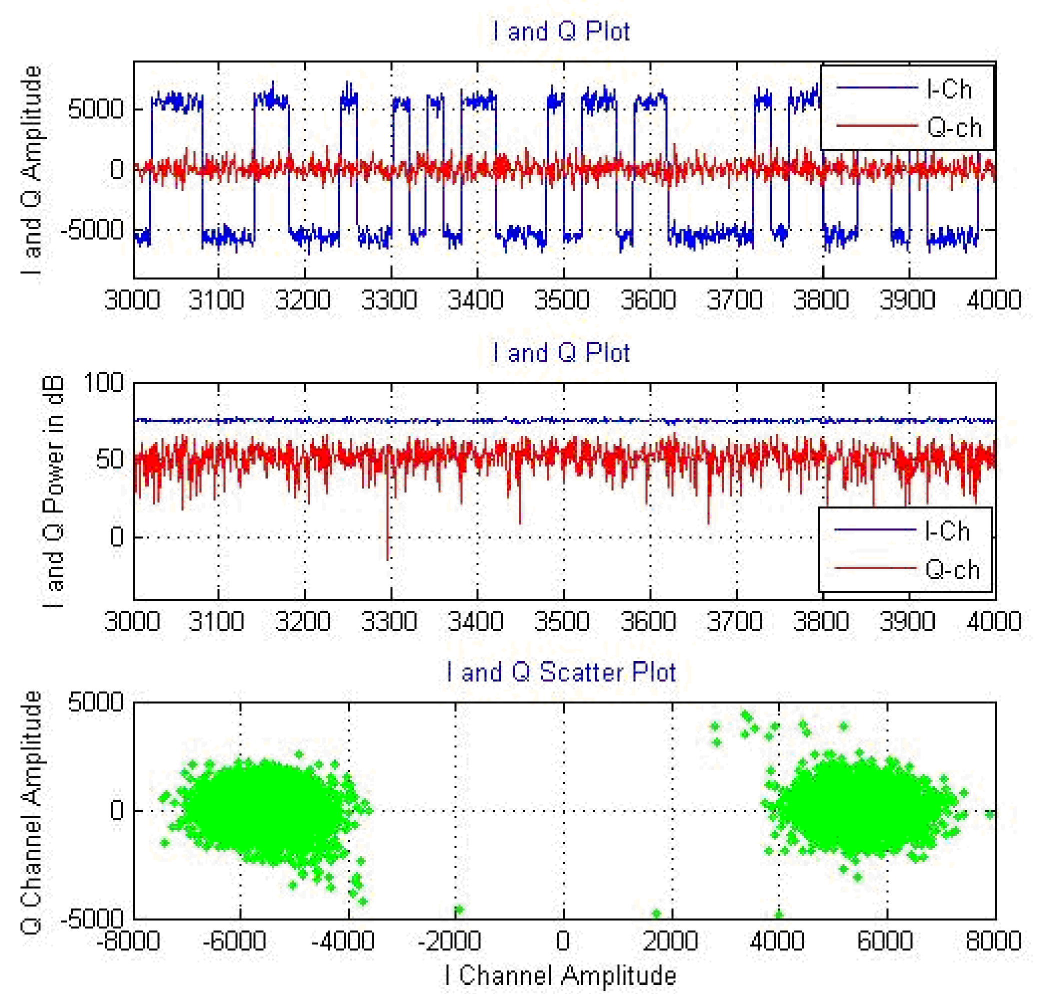
GPS Signal Tracking

- Tracking Loops (PLL & DLL) are used to continously 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



GPS Signal Tracking Output



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