IPNTJ Summer School on GNSS 2014

GNSS-SDRLIB: Introduction and Practice of GNSS Software Receiver

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Introduction About My Research

1. UAV（Unmanned Aerial Vehicle）

- Generation Large Mosaic Image

- Monocular EKF-SLAM
- 3D Reconstruction from Images

- Path Planning
- 3D Map Construction
- Autonomous Navigation

- GNSS/INS Integration
- Detecting Invisible Satellites

2. UGV(Unmanned Ground Vehicle)

3. Positioning in Urban Area

Timetable

Class C-5 (8:30-9:50) Software Receiver and Multi-GNSS

1. Why GNSS software receiver?
2. Why Multi-GNSS?
3. Introduction of GLONASS, Galileo, BeiDou, and QZSS signals

Class C-6 (10:10-11:30) Front-end Practice

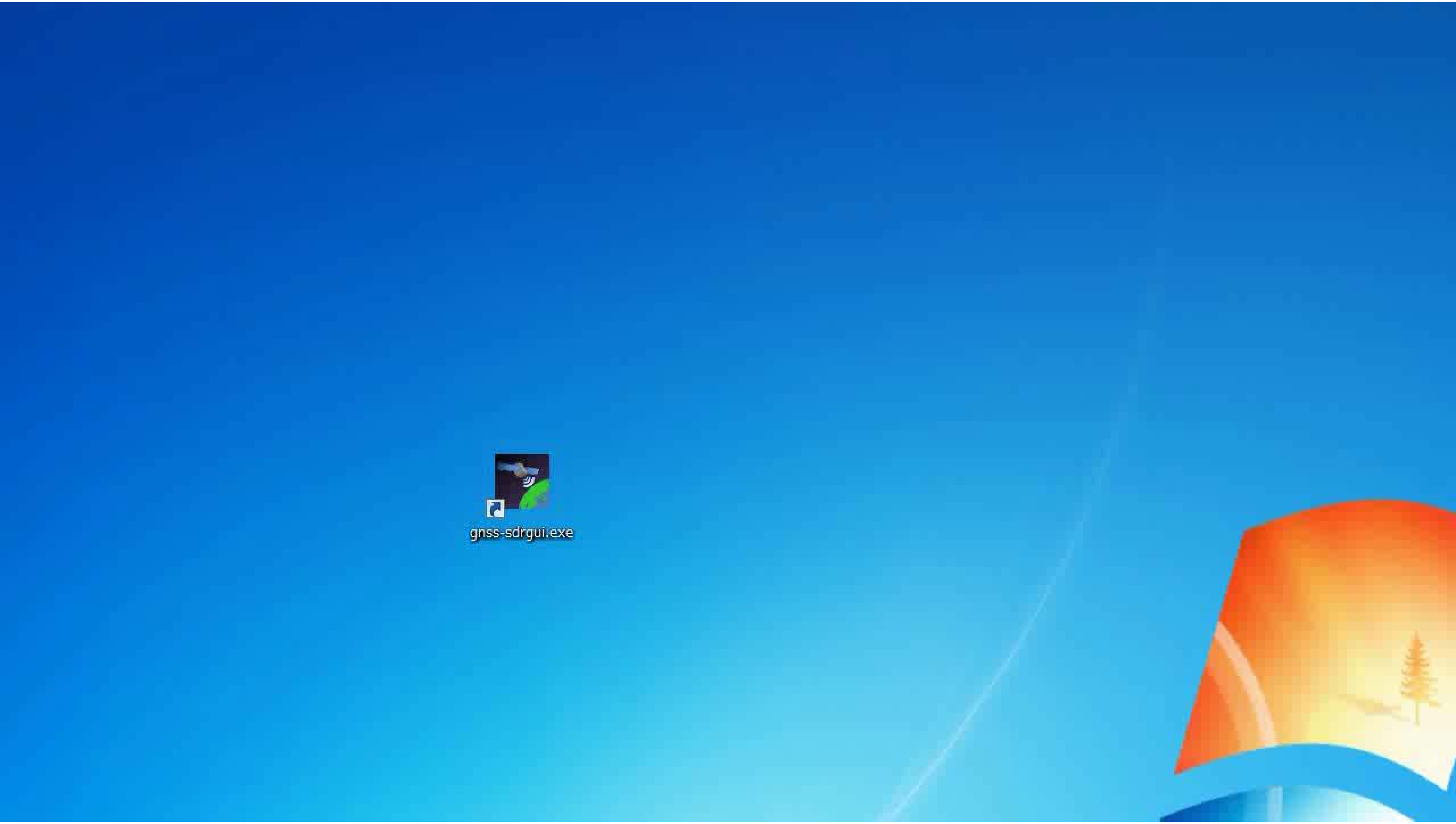
1. Front-end architecture
2. Handwork of recoding live GNSS signals using front-end device
3. Analysis of recorded GNSS IF data

SDR Practice (12:30-13:50) GNSS-SDRLIB Practice

1. Introduction of GNSS-SDRLIB
2. Practice of real-time positioning using GNSS-SDRLIB

Goal of This Seminar

Real-time positioning using GNSS-SDRLIB and front-end



Video URL： http://youtu.be/vVHOFs93vlU

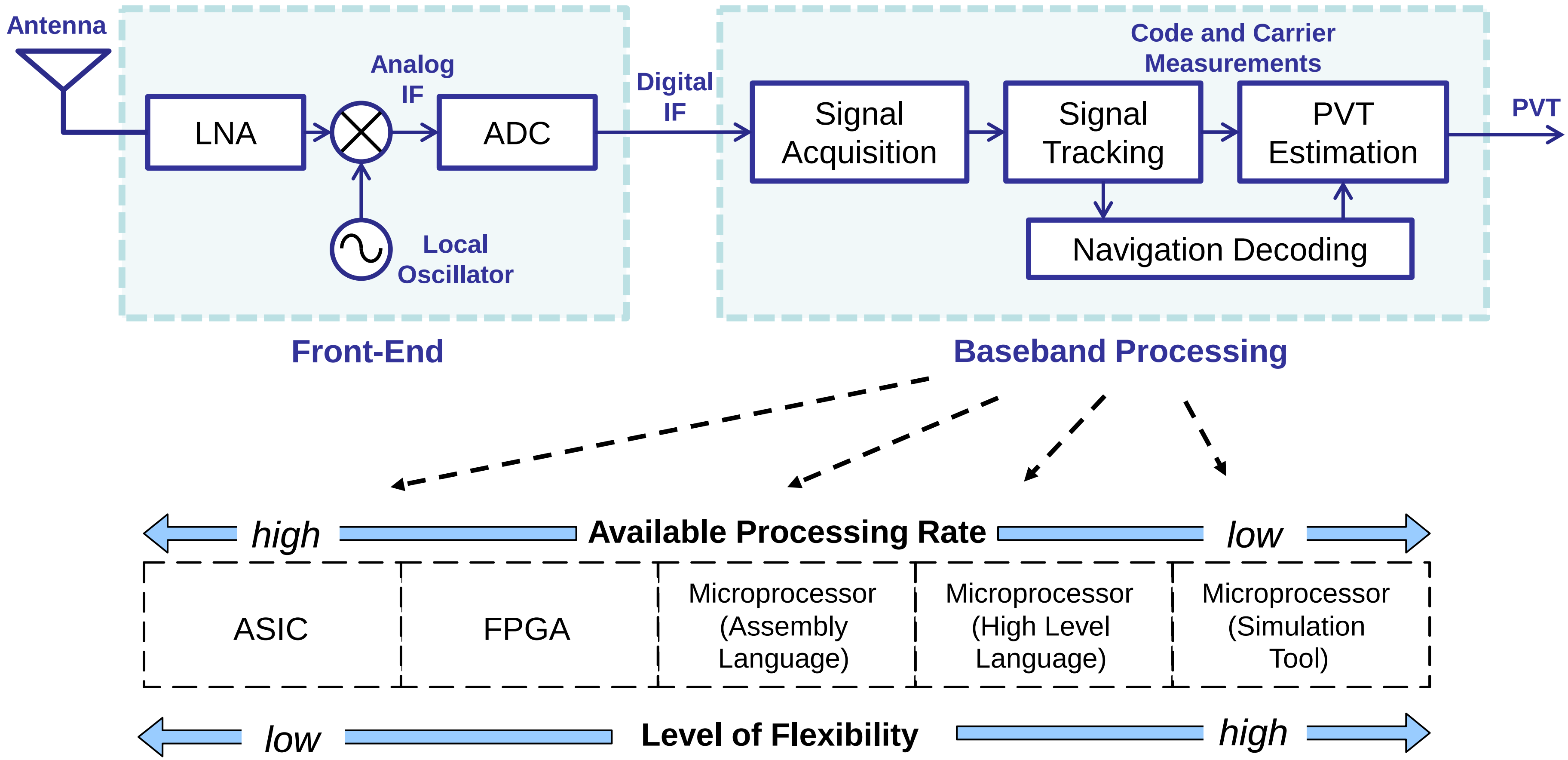
Class C5 (8:30-9:50)
Software Receiver and Multi-GNSS

Why Software Receiver? (1)

SDR（Software Defined Radio）

The software radio concept is built upon two basic principles

1. Move the analog-to-digital converter (ADC) as close to the antenna as possible
2. Process the resulting samples using a programmable processor



Why Software Receiver? (2)

Features	ASIC (Hardware)	SDR (Software)
Upgradability	◆ A fixed platform ◆ Dictate the potential capabilities of the receiver	◆ Re-programmable ◆ Re-configurable
Acquisition	◆ Serial search Acquisition ◆ Convolution in the time domain	◆ Parallel Search Acquisition ◆ FFT, Multiplication in the frequency domain
Tracking	◆ More efficient ◆ Cost effective	◆ Depends on the processor MIPS availability
Power Consumption	◆ Less power consumption	◆ More power consumption
Cost effectiveness	◆ More Hardware, More cost	◆ Less Hardware less cost

Open-Source GNSS Software Receivers

SoftGNSS
http://ccar.colorado.edu/gnss/
- MATLAB source codes, only for GPS L1 and post processing.

Fast GPS
http://sourceforge.net/projects/fastgps/
C++, only for GPS L1 and post processing

OpenSourceGPS
http://sourceforge.net/projects/osgps/
C++, only for GPS L1, real-time processing

GPS-SDR
https://github.com/gps-sdr
- C++, only for GPS L1, real-time processing

GNSS-SDR
https://code.google.com/p/gnsssdr/
- SCILAB, only for post processing, Multi-GNSS support (GPS, GLONASS, BeiDou L1)

GNSS-SDR
http://gnss-sdr.org/
- C++, Real-time Processing and Multi-GNSS support (GPS, Galileo, SBAS L1)

GNSS-SDRLIB

GNSS-SDRLIB http://www.taroz.net/gnsssdrlib_e.html
https://github.com/taroz/GNSS-SDRLIB

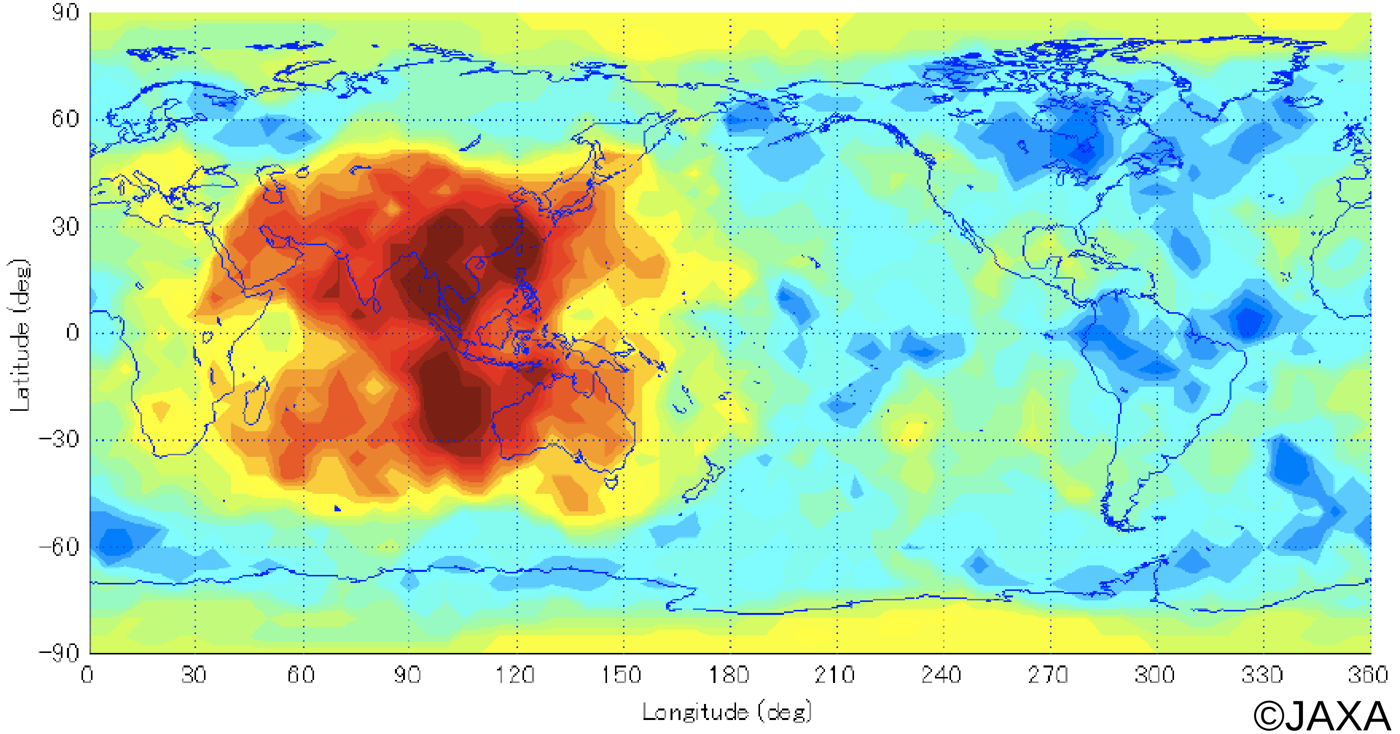
Version 1.0 Beta, 2013 March
Version 1.0 , 2013 June
Version 2.0 Beta, 2014 June

- **GNSS signal processing functions written in C**
  - Code generation of all existing satellites
  - Signal acquisition / tracking functions
  - Decoding navigation messages
  - Pseudo-range / carrier phase measurements
- **GUI application (AP) written in C++/CLI**
- **Visualization of GNSS signal processing in real-time**
- **Real-time positioning with RTKLIB**
- **Observation data can be outputted in RINEX or RTCM format**
- **Support following signals (tracking and decoding navigation message)**
  - GPS, GLONASS, Galileo, BeiDou, QZSS L1 signals
  - Decoding QZSS SAIF/LEX message and SBAS message
- **Support commercial front-ends for real-time positioning**
- **Support RF binary file for post processing**

Real-time Processing and Multi-GNSS support

Why Multi-GNSS?

Visible satellite number (mask angle 30 degrees)



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2020:

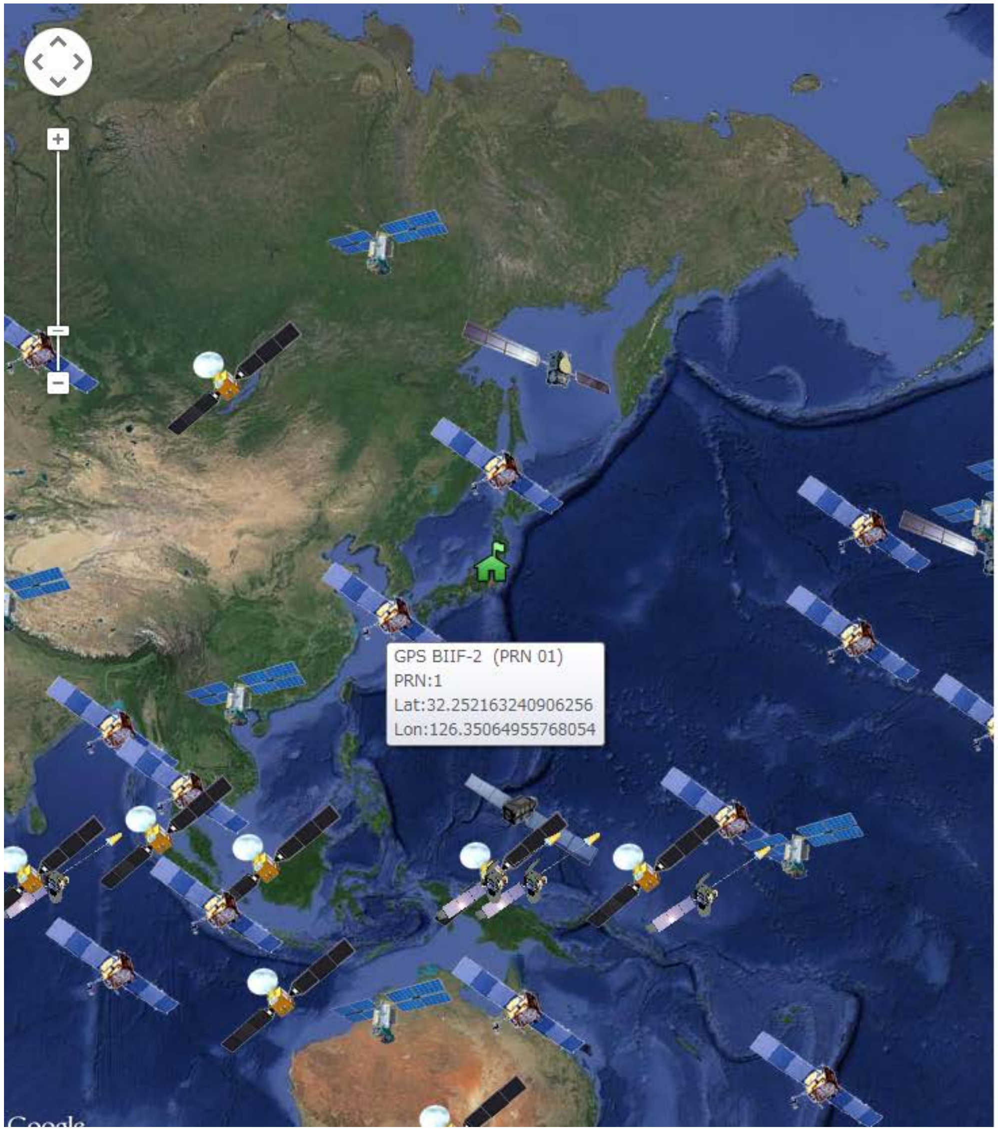
GPS(27)+Glonass(24)+Galileo(30)+COMPASS(35)+IRNSS(7)+QZSS(3)+SBAS(7)

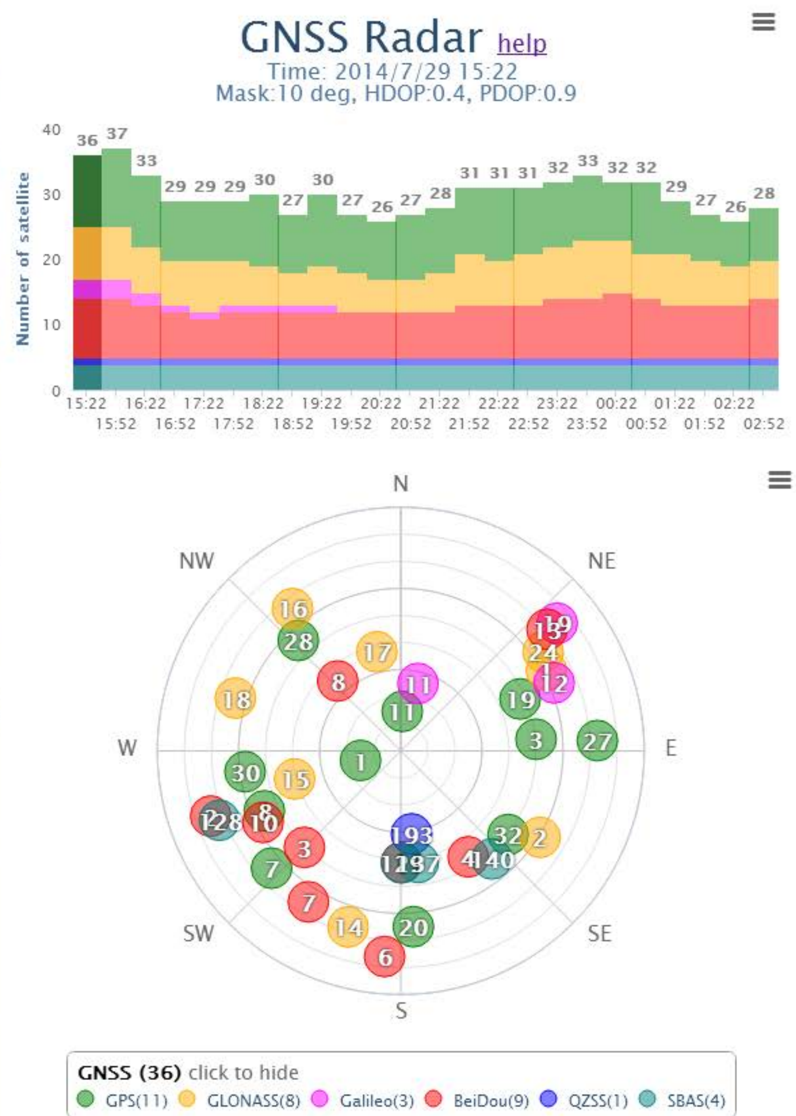
Increase of satellites

Improvement of Availability, Accuracy, Continuity, Efficiency, Reliability …

How to Check Multi-GNSS Constellation?

GNSS-Radar: http://www.taroz.net/GNSS-Radar.html





How to Use GNSS-Radar

Source Code: https://github.com/taroz/GNSS-Radar

Options:

Set the observer location by latitude and longitude (the unit is degree)

ULR+?lat=xxx&lon=xxx (default: lat=35.7&lon=139.8 (Tokyo))

e.g. http://www.taroz.net/GNSS-Radar.html?lat=-37.8&lon=145

Set the elevation mask angle when computing the sky plot (the unit is degree)

ULR+?elemask=xxx (default: elemask=10)

e.g. http://www.taroz.net/GNSS-Radar.html?elemask=45

Set the time offset when computing the sky plot (the unit is hour)

ULR+?offhr=xxx (default: offhr=0)

e.g. http://www.taroz.net/GNSS-Radar.html?offhr=12

Set the time interval when computing the sky plot (the unit is minutes)

ULR+?tint=xxx (default: tint=30)

e.g. http://www.taroz.net/GNSS-Radar.html?tint=5

Set the number of times when computing the sky plot

ULR+?ntimes=xxx (default: tint=24, 24*30min=12hour)

e.g. http://www.taroz.net/GNSS-Radar.html?ntimes=48

Android version

https://play.google.com/store/apps/details?id=taroz.net.GNSS_Radar

Search “GNSS” in google play!

iOS version

https://itunes.apple.com/us/app/gnss-radar/id901597709

Search “GNSS” in iTunes Store!

Multi-GNSS Signals (1)

Around **L1 frequency** (1575.42 MHz)

GNSS	GPS/QZSS	QZSS		GALILEO		GLONASS	BeiDou
Service Name	C/A	L1C		E1		C/A (G1)	B1I
Center Freq.	1575.42 MHz	1575.42 MHz		1575.42 MHz		1602+ 0.5625K MHz	1561.098 MHz
Signal Component	Data	L1CD Data	L1CP Pilot	E1B Data	E1C Pilot	Data	Data
I/Q	Q	I	Q	I	Q	I	I
Band Width	2.046 MHz	4.096 MHz		24.552 MHz		1.002 MHz	2.046 MHz
Modulation	BPSK(1)	BOC(1,1)		CBOC(6,1,1/11)		BPSK	QPSK
Code Freq.	1.023 MHz	1.023 MHz		1.023 MHz		0.511 MHz	2.046 MHz
Code Chips	1023	10230		4092		511	2046
Code Length	1ms	10 ms	10 ms	4 ms	4 ms	1 ms	1 ms
Nav. Data	NAV	CNAV-2	-	I/NAV	-	NAV	D1/D2 NAV
Min. Received Power	-158.5 dBW	-163.0 dBW	-158.25 dBW	-163.0 dBW	-158.25 dBW	-161.0 dBW	-163.0 dBW

Multi-GNSS Signals (2)

Around **L2 frequency** (1227.60 MHz)

GNSS	GPS/QZSS		GLONASS
Service Name	L2C		C/A (G2)
Center Freq.	1227.60 MHz		1246+ 0.4375K MHz
Signal Component	L2CM Data	L2CL Pilot	Data
I/Q	I		I
Band Width	2.046 MHz		1.022 MHz
Modulation	BPSK		BPSK
Code Freq.	0.5115 MHz		0.511 MHz
Code Chips	10230	767250	511
Code Length	20 ms	1.5 s	1 ms
Nav. Data	CNAV	-	NAV
Min. Received Power	-160.0 dBW		-167.0 dBW

Multi-GNSS Signals (3)

Around **L5 frequency** (1176.45 MHz)

GNSS	GPS/QZSS		GALILEO				BeiDou
Service Name	L5		E5a		E5b		B2I
Center Freq.	1176.45MHz		1176.45MHz		1207.14MHz		1207.14 MHz
Signal Component	L5I Data	L5Q Pilot	E5aI Data	E5aQ Pilot	E5bI Data	E5bQ Pilot	B2I Data
I/Q	I	Q	I	Q	I	Q	I
Band Width	20.46 MHz		20.46 MHz		20.46 MHz		24.0 MHz
Modulation	BPSK(10)		BPSK(10)		BPSK(10)		BPSK(10)
Code Freq.	10.23 MHz		10.23 MHz		10.23 MHz		10.23 MHz
Code Chips	10230		10230		10230		10230
Code Length	1 ms	1 ms	1 ms	1 ms	1 ms	1 ms	1 ms
Nav. Data	CNAV	-	F/NAV	-	I/NAV	-	D1/D2 NAV
Min. Received Power	-157.9 dBW	-157.9 dBW	-155.0 dBW	-155.0 dBW	-155.0 dBW	-155.0 dBW	-163 dBW

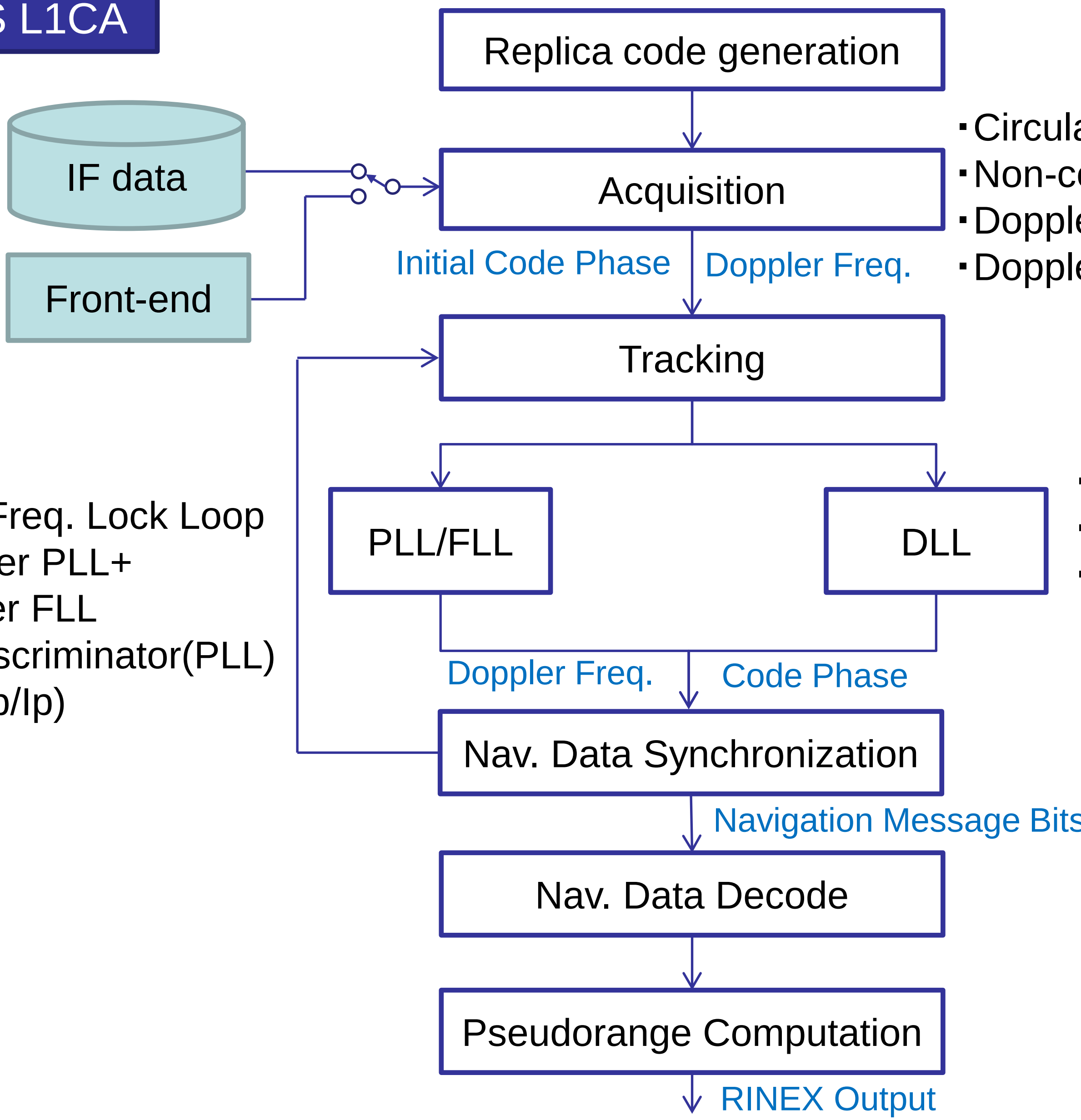
Multi-GNSS Signals (4)

Navigation Message

Band	System	Signal	Nav. Type	Rate	Error Detection / Correction	Preamble bits	Secondary Code
L1	GPS/ QZS	L1CA	NAV	50 bps, 300 bits, 6 sec.	Hamming Code	8bit	-
		L1C	CNAV-2	100 bps, 1800 bits, 18 sec.	BCH+LDPC+Interleving	None	1800 bits
	GALILEO	E1	I/NAV	125 bps, 250 bits, 2 sec.	½Convolusion+Interleaving+CRC	10bit	25 bits (E1C)
	GLONASS	G1	NAV	50 bps, 100 bits, 2 sec.	Hamming Code	30bit	-
	BeiDou (MEO)	B1I	D1 NAV	50 bps, 300 bits, 6 sec.	BCH+Interleaving	11bit	NH20
	BeiDou (GEO)	B1I	D2 NAV	500 bps, 300 bits, 0.6 sec.	BCH+Interleaving	11bit	-
	SBAS	L1	SBAS	250 bps, 250 bits, 1 sec.	½Convolusion	(8x3) bit Encoded	-
L2	GPS/QZS	L2C	CNAV	25 bps, 300 bits, 12 sec.	½Convolusion	8bit	-
	GLONASS	G2	NAV	50 bps, 100 bits, 2 sec.	Hamming Code	30bit	-
L5	GPS/ QZS	L5	CNAV	50 bps, 300 bits, 6 sec.	½Convolusion	8bit	NH10 (L5I), NH20 (L5Q)
	GALILEO	E5a	F/NAV	25 bps, 250 bits, 10 sec.	½Convolusion+Interleaving+CRC	10bit	20 bits (E5aI) 100 bits (E5aQ)
	GALILEO	E5b	I/NAV	125 bps, 250 bits, 2 sec.	½Convolusion+Interleaving+CRC	10bit	4 bits (E5bI) 100 bits (E5aQ)
	BeiDou (MEO)	B1I	D1 NAV	50 bps, 300 bits, 6 sec.	BCH+Interleaving	11bit	NH20
	BeiDou (GEO)	B1I	D2 NAV	500 bps, 300 bits, 0.6 sec.	BCH+Interleaving	11bit	-

How to Acquire and Track GNSS Signals

GPS L1CA



- Circular correlation by FFT
- Non-coherent integration
- Doppler search step: 200 Hz
- Doppler search range: -7~+7kHz

- Phase/Freq. Lock Loop
- 2nd order PLL+ 1st order FLL
- Error discriminator(PLL) atan(Qp/Ip)

- Delay Lock Loop
- Carrier aid 2nd order DLL
- Error discriminator (E-L)/(E+L)/2

Strategy for Using Multi-GNSS Signals (1)

L1 Frequency Signals（G1, E1, B1）

- Do acquisition and tracking as with the GPS L1CA
- Differences are …
  - Chip rate and chip length
    - ➡Difference is only replica code generation
  - Modulation type (E1:BOC)
    - ➡We need to change a part of tracking method
  - Navigation Message
    - ➡Read ICD and implement it!

⬇

Not so difficult except for decoding navigation message!

Strategy for Using Multi-GNSS Signals (2)

Other Frequency Signals (G2, E5ab, B2I, L5, LEX…)

- If L1 code is tracked, the Doppler and code phase computation is aided by L1 information
  - Doppler2 = Freq2/Freq1*Doppler1
  - Cphase2 = Cphase1 + (DCB)

➡ Acquisition is not necessary

- No need to decode navigation data
  - But time information is useful
  - Additional information in another navigation message

⬇

Only tracking loop is needed to generate pseudorange and carrier phase

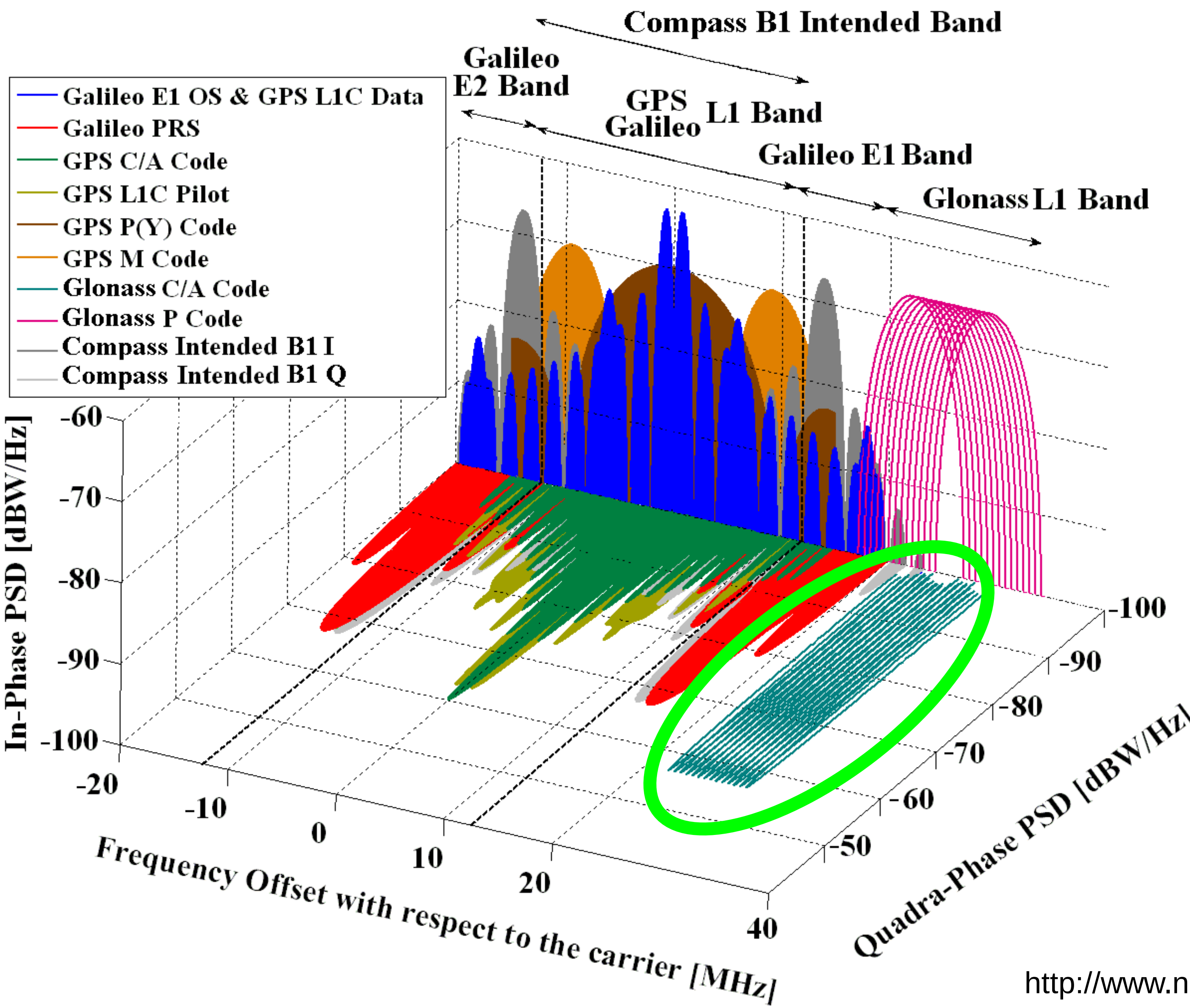
GLONASS

GLONASS Signal Specification

GNSS	GLONASS	
Service Name	C/A (G1)	C/A (G2)
Center Freq.	1602+ 0.5625K MHz	1246+ 0.4375K MHz
Signal Component	Data	Data
I/Q	I	I
Band Width	1.022 MHz	1.022 MHz
Modulation	BPSK	BPSK
Code Freq.	0.511 MHz	0.511 MHz
Code Chips	511	511
Code Length	1ms	1ms
Min. Received Power	-161.0 dBW	-167.0 dBW

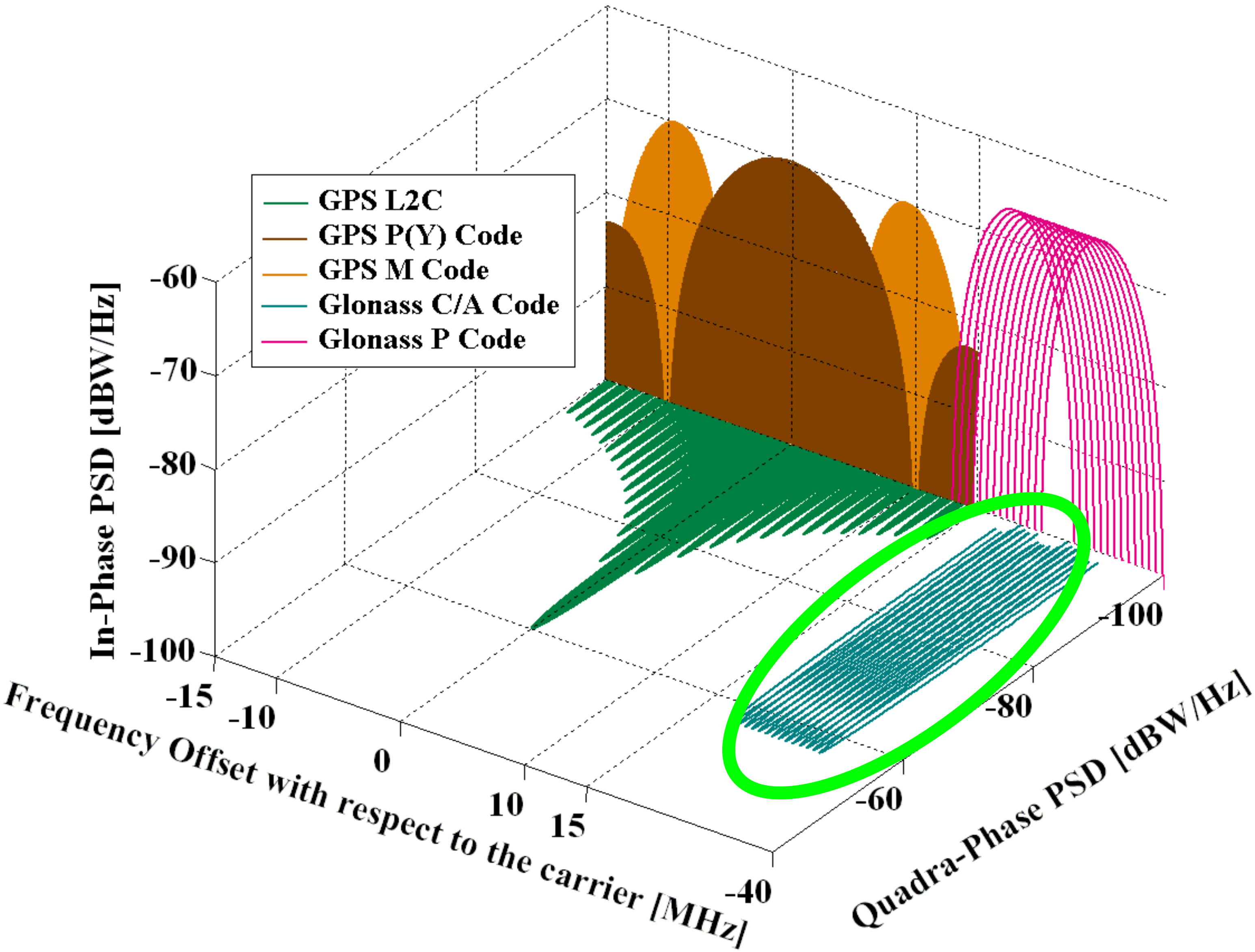
- FDMA (Frequency-division multiple access)
  - Transmitting the same code
  - Transmitting on a different frequency (15-channels)
- Half code chipping rate, Half number of code chips compared with GPS L1CA

GLONASS G1 Signal



http://www.navipedia.net/

GLONASS G2 Signal



http://www.navipedia.net/

Strategy of Acquisition and Tracking G1 Signal

- **FDMA**
  - Add frequency offset when we search the Doppler frequency in acquisition step
- **Acquisition and Tracking**
  - Nothing to change…
  - Half computational cost!
- **Decoding navigation message**
  - No special encoding technique
  - Message structure and length are different from GPS
- **Code Generation**
  - Generating only one code
- **Difference of G1 and G2 signals**
  - Only transmitting frequency
  - The rest is completely the same!

Generating GLONASS G1/G2 Code

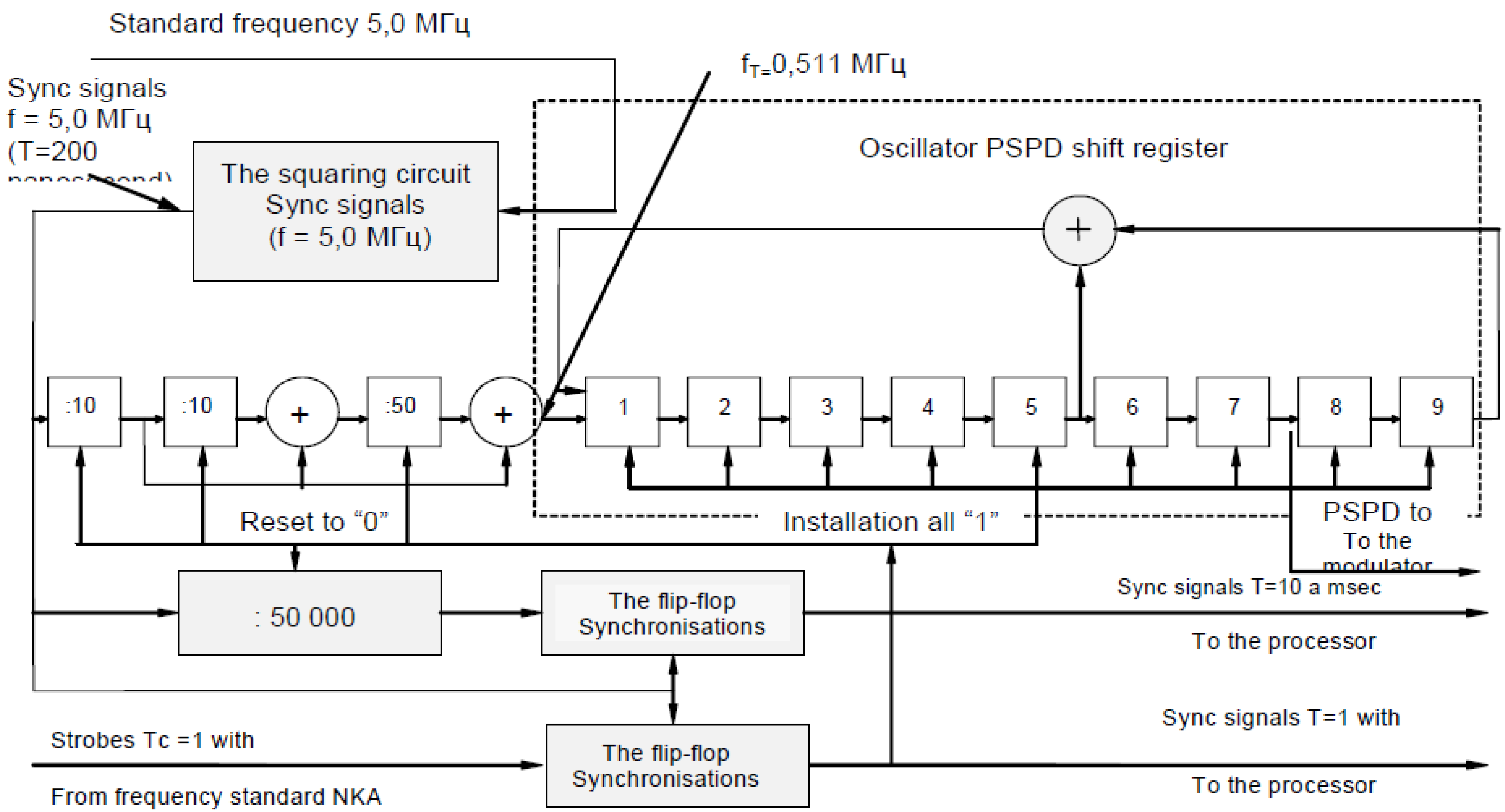
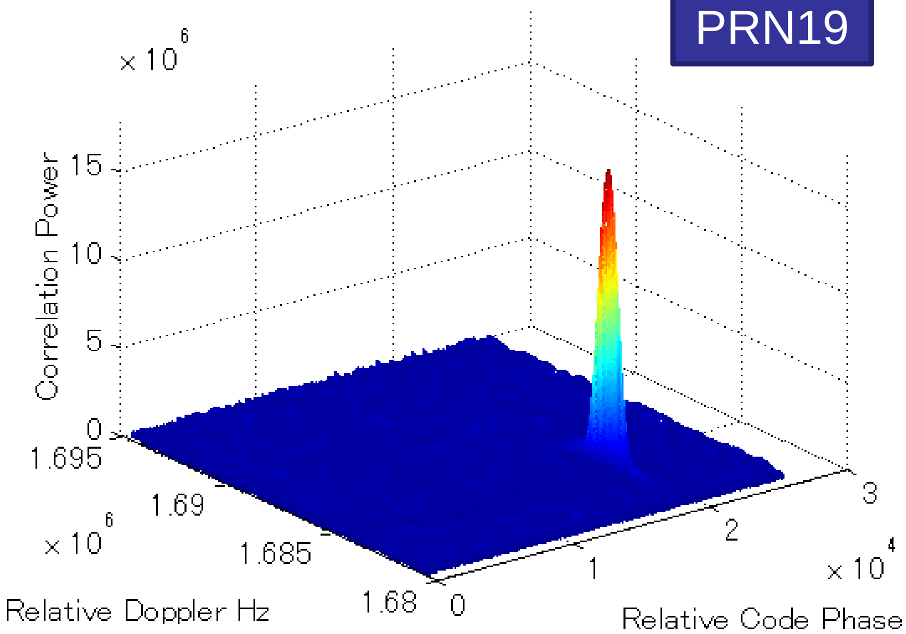


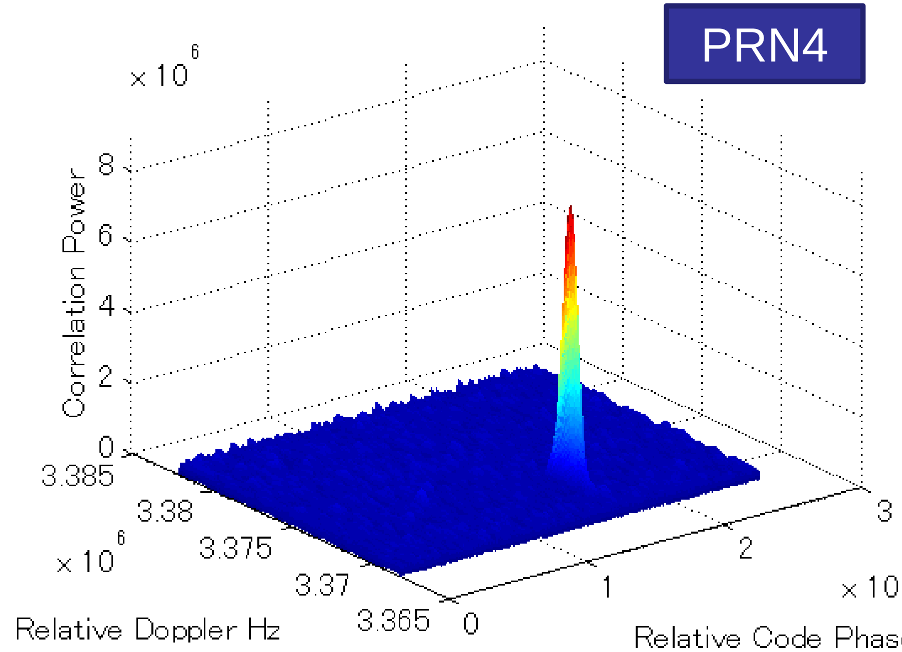
Figure 3.3 GLONASS INTERFACE CONTROL DOCUMENT

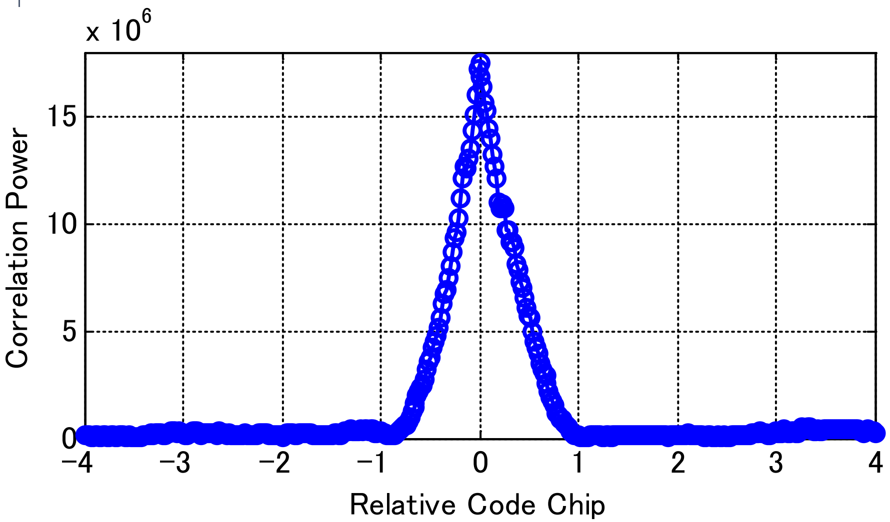
- 511bit M-sequence codes
- Very simple

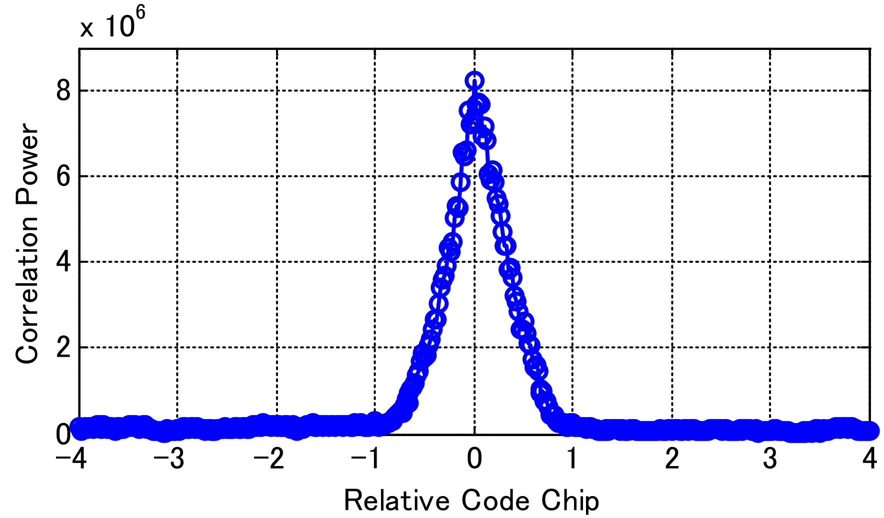
Example of Acquisition of G1 Signal

26Msps, Bandwidth=4.2MHz





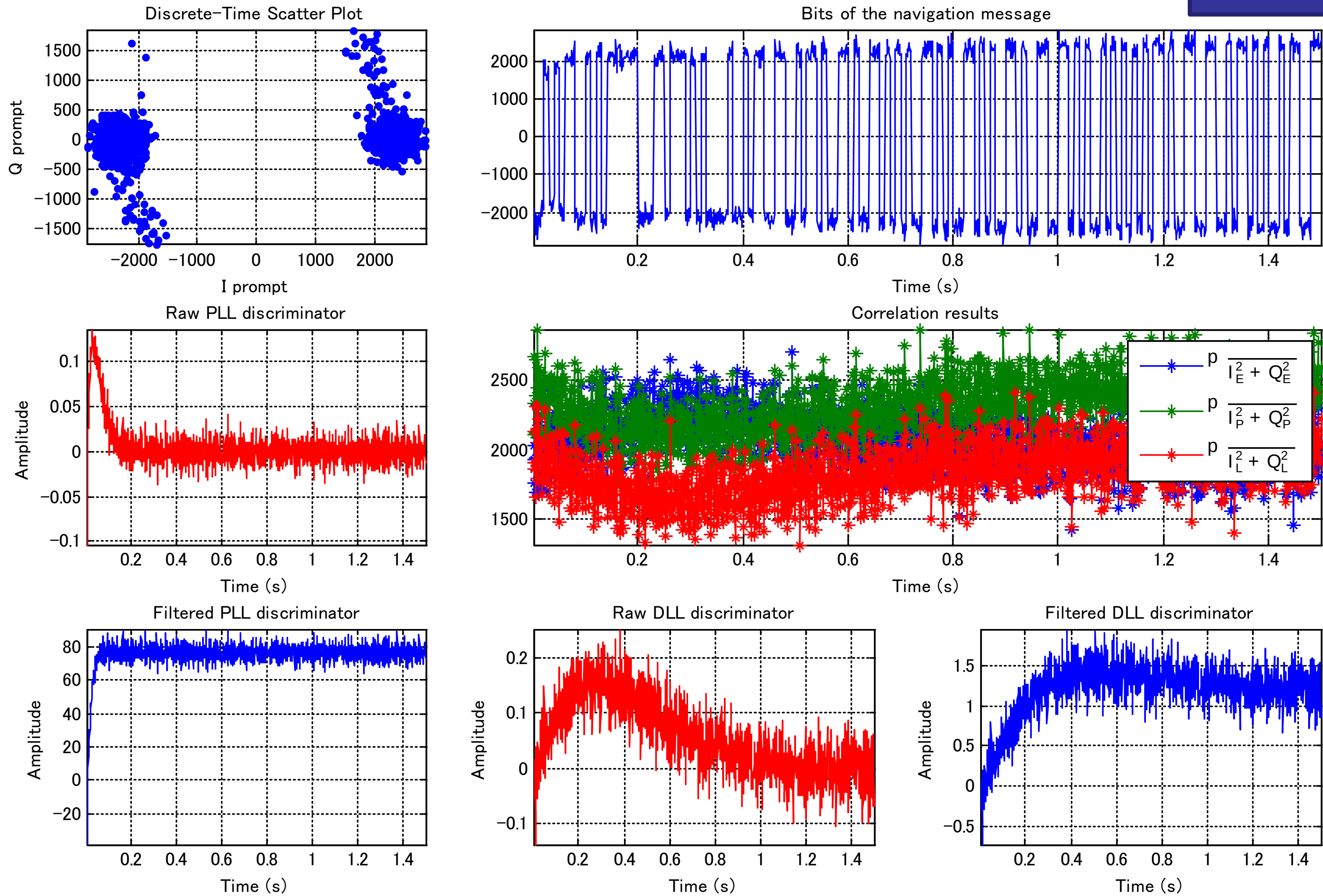




Example of Tracking of G1 Signal

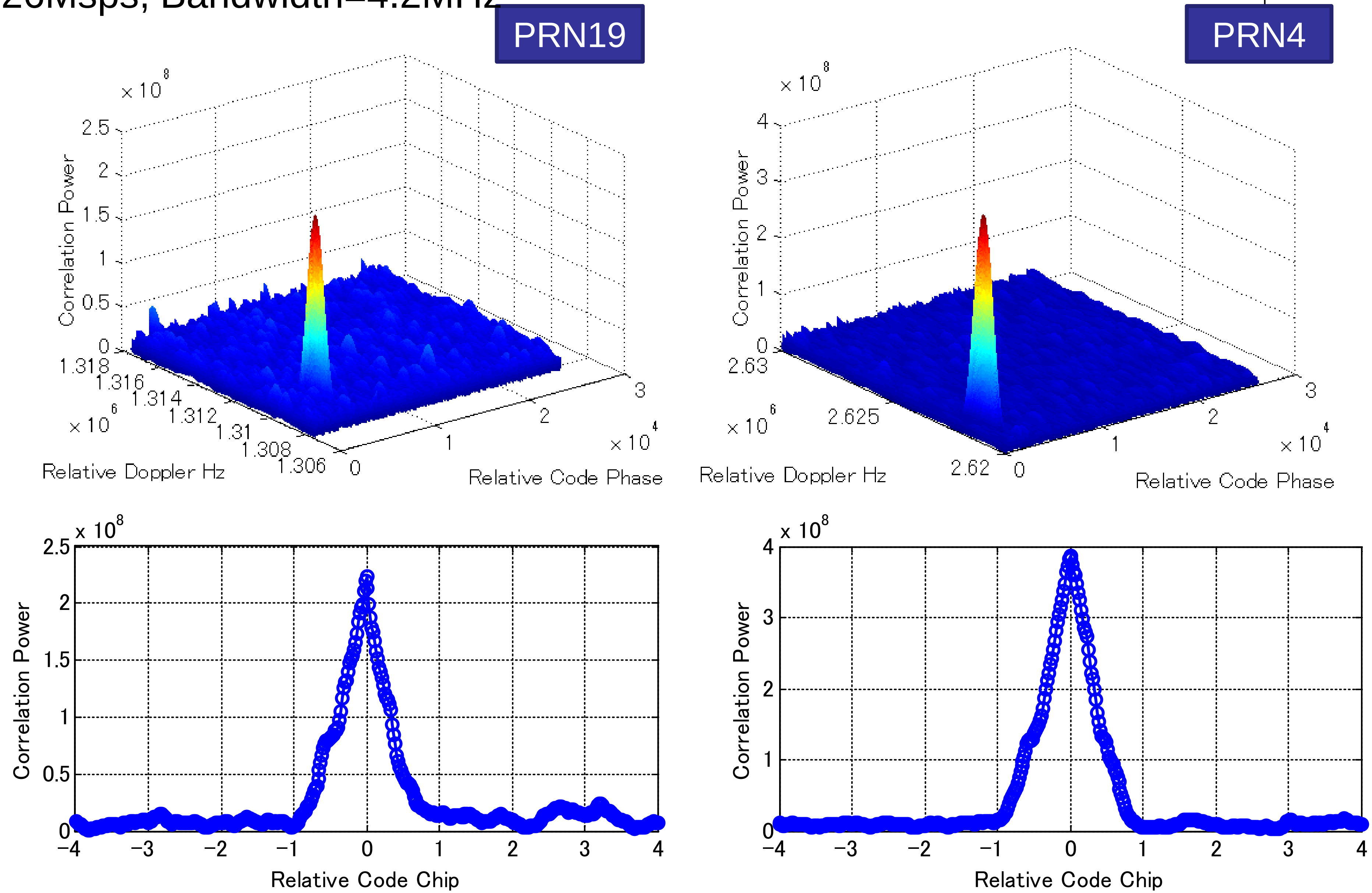
26Msps, Bandwidth=4.2MHz

PRN19



Example of Acquisition of G2 Signal

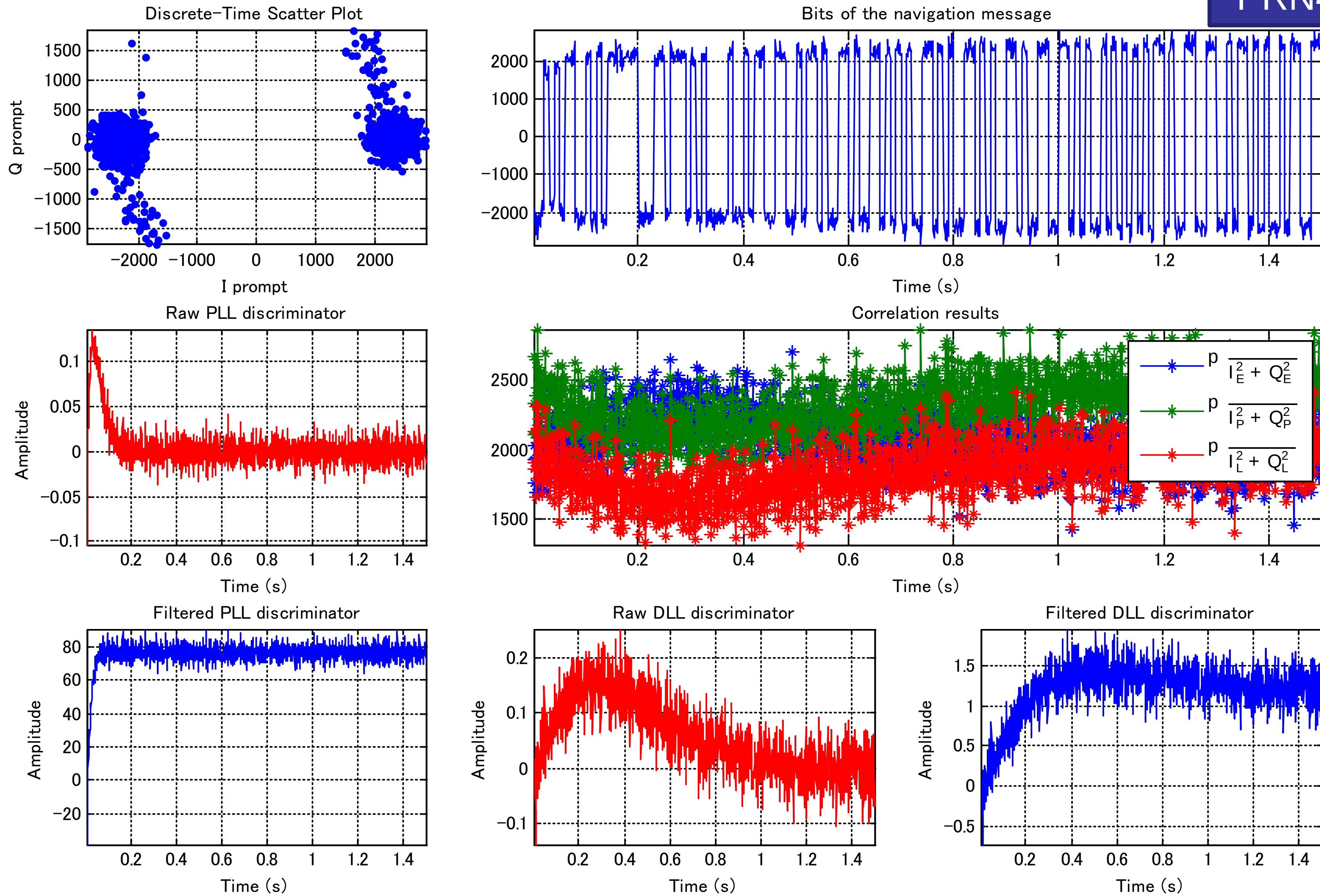
26Msps, Bandwidth=4.2MHz



Example of Tracking of G2 Signal

26Msps, Bandwidth=4.2MHz

PRN4



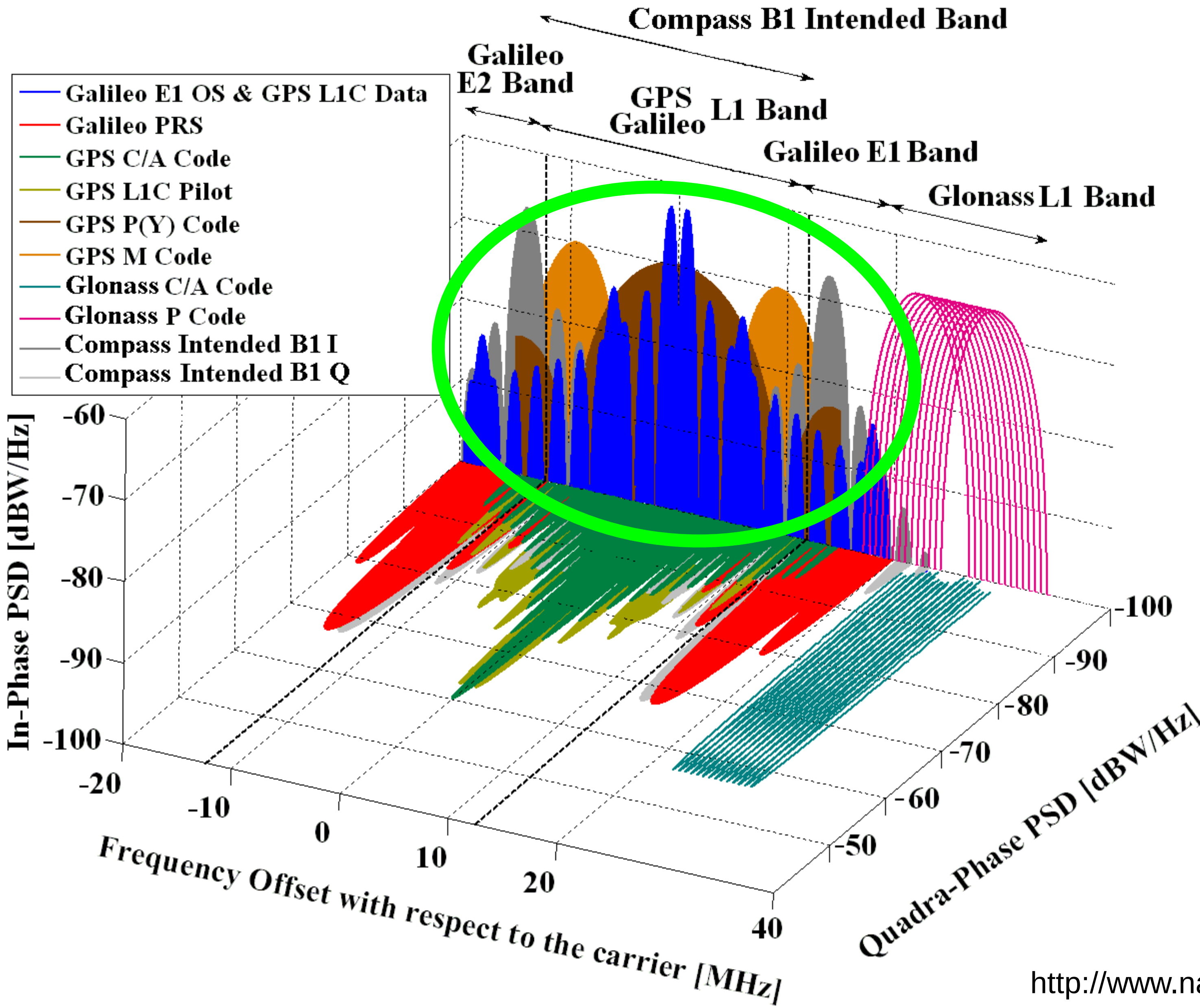
Galileo

Galileo Signal Specification

	GALILEO					
Service Name	E1		E5a		E5b	
Center Freq.	1575.42MHz		1176.45MHz		1207.14MHz	
Signal Component	E1B Data	E1C Pilot	E5aI Data	E5aQ Pilot	E5bI Data	E5bQ Pilot
I/Q	I	Q	I	Q	I	Q
Band Width	24.552 MHz		20.46 MHz		20.46 MHz	
Modulation	CBOC(6,1,1/11)		BPSK(10)		BPSK(10)	
Code Freq.	1.023 MHz		10.23 MHz		10.23 MHz	
Code Chips	4092		10230		10230	
Code Length	4 ms	4 ms	1 ms	1 ms	1 ms	1 ms
Nav. Data	I/NAV	-	F/NAV	-	I/NAV	-
Min. Received Power	-163.0 dBW	-158.25 dBW	-155.0 dBW	-155.0 dBW	-155.0 dBW	-155.0 dBW

- Long code (4ms) compared with GPS L1CA
- BOC(Binary Offset Carrier) modulation
  - Generating code and BOC modulation
  - We have to modify the tracking method
- Decoding of I/NAV and F/NAV is little complicated…

Galileo E1 Signal



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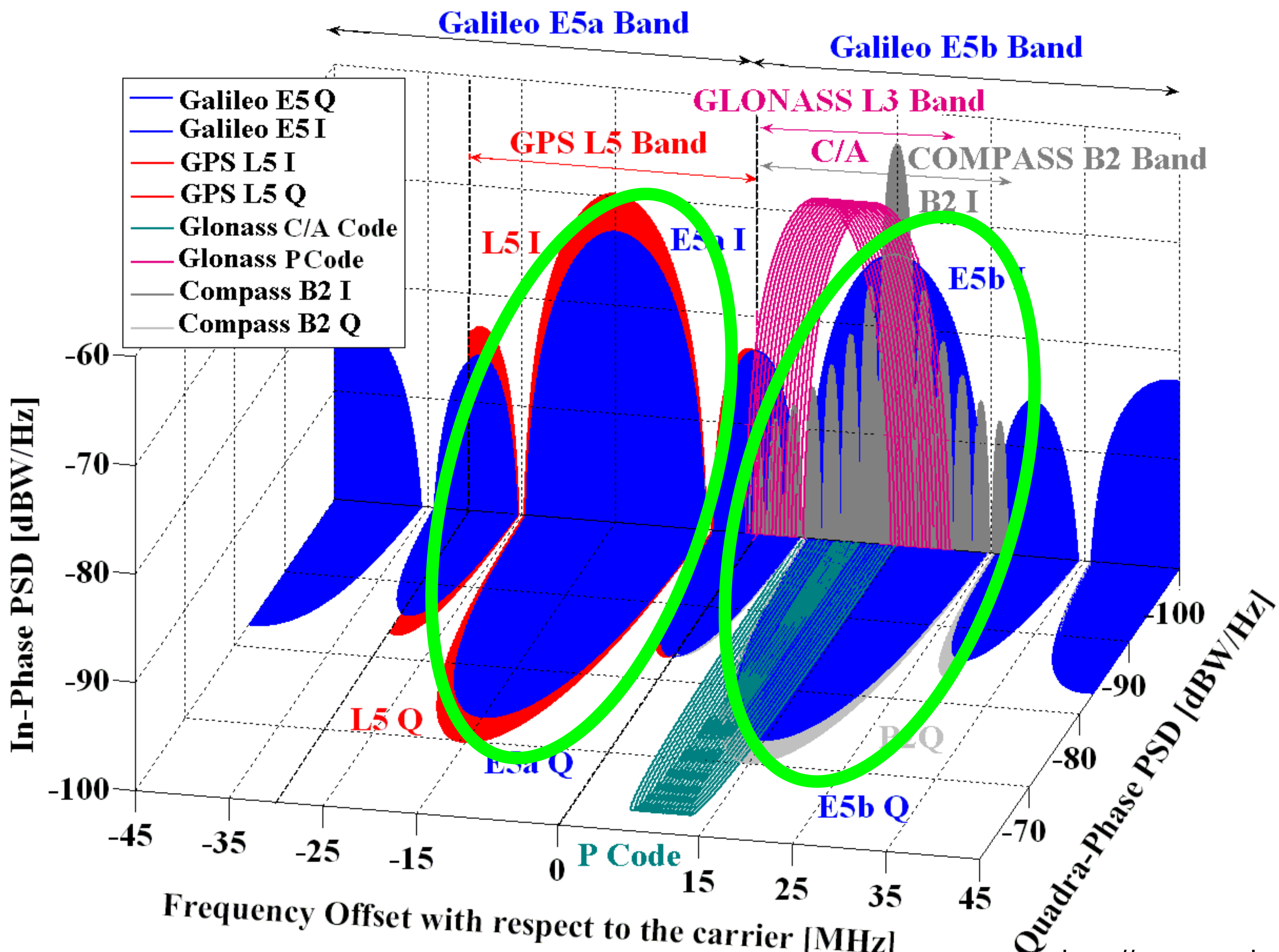
Galileo E5a and E5b Signals

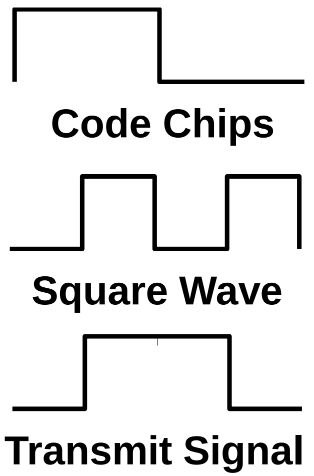


http://www.navipedia.net/

Strategy of Acquisition and Tracking E1 Signal

- Currently only 4 satellites

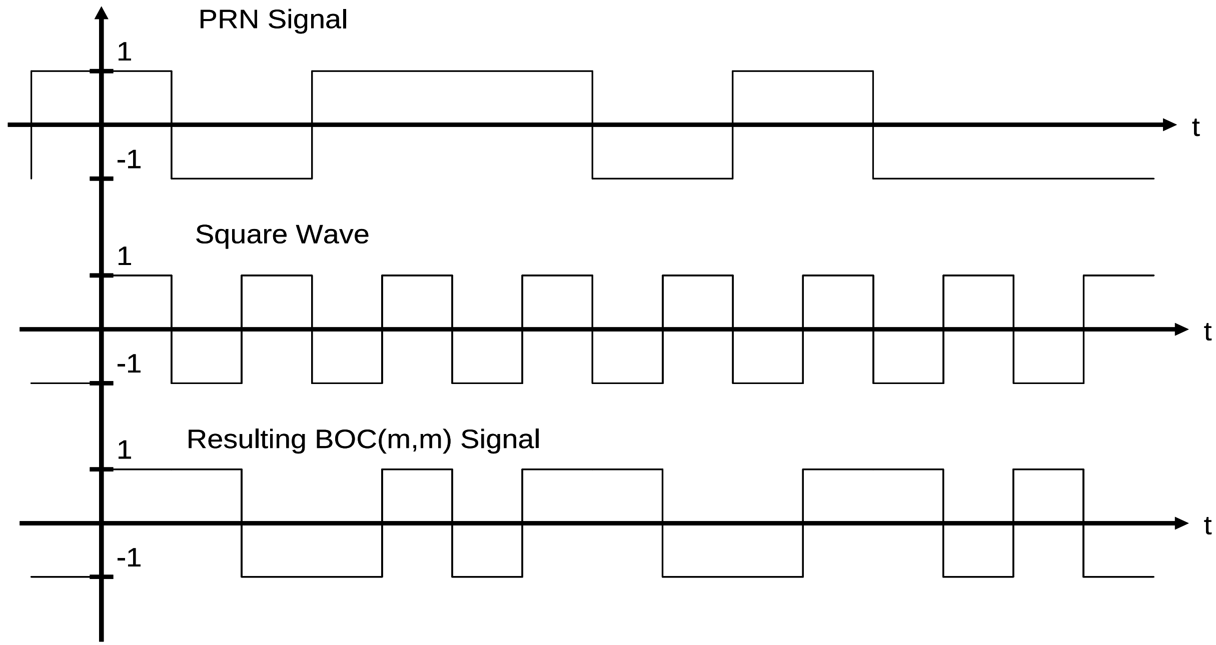
- Generating BOC modulated code
  - Use BOC(1,1) instead of CBOC (6,1,1/11)
  - Code frequency and rate will be doubled (4092→8184,1.023→2.046MHz)

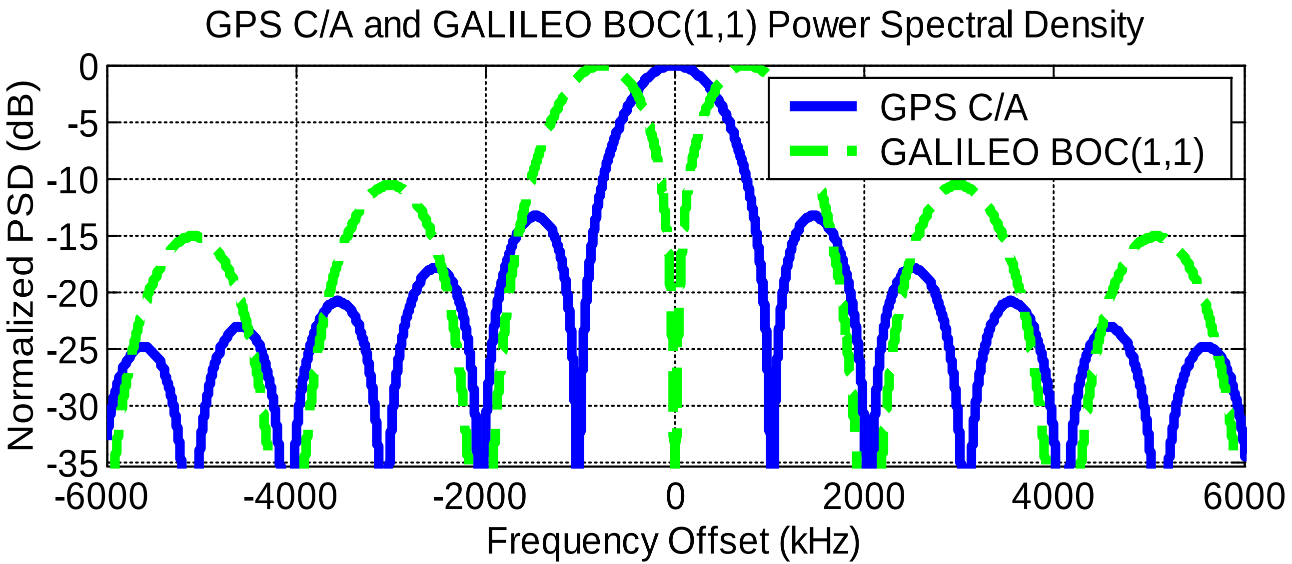


- Decoding I/NAV and F/NAV
  - 1/2 convolutional code + interleaving
    - Viterbi decoder + de-interleaving

- Generating E1 Code
  - Memory codes (Random codes)
  - E1B(data code), E1C(dataless code)
  - Four times as long as GPS L1C code (4ms)

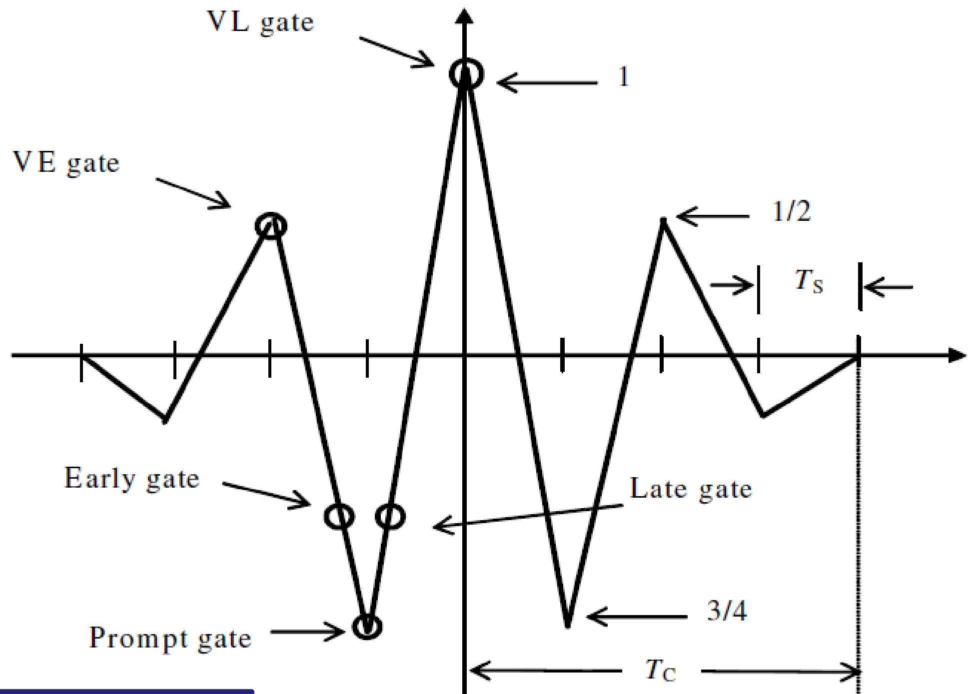
Binary Offset Carrier (BOC) Signal (1)





Binary Offset Carrier (BOC) Signal (2)

Bump-Jumping (BJ)



1. Adding VE(very early) and VL(very late) correlation points
2. Monitoring VE and VL status, and jump to the main lobe if the threshold exceeded

Other Algorithms

Single Sideband (SSB)	The Offset Carrier Modulation for GPS Modernisation, 1999
Bump-Jumping (BJ)	Tracking algorithm for GPS offset carrier signal, 1999
Multiple-Gate Discriminators (MGD)	Unambiguous Tracker for GPS Binary-Offset Carrier Signals , 2003
Autocorrelation Side-Peak Cancellation Technique (ASPeCT)	ASPeCT: unambiguous sine-boc(n,n) acquisition/tracking technique for navigation applications, 2007
Double Estimator (DE)	Double estimator–a new receiver principle for tracking BOC signals, 2008

Generating E1B/C codes

- From Galileo ICD…

> The E1-B and E1-C primary codes are pseudo-random memory code sequences according to the hexadecimal representation provided in Annex C.

- All E1B/E1C codes are in ICD in HEX format

```
E1B Code No 1
F5D710130573541B9DBD4FD9E9B20A0D59D144C54BC7935539D2E75810FB51E494093A0A19DD7
9C70C5A98E5657AA578097777E86BCC4651CC72F2F974DC766E07AEA3D0B557EF42FF57E6A58E
805358CE9257669133B18F80FDBDFB38C5524C7FB1DE079842482990DF58F72321D9201F8979E
AB159B2679C9E95AA6D53456C0DF75C2B4316D1E2309216882854253A1FA60CA2C94ECE013E2A
8C943341E7D9E5A8464B3AD407E0AE465C3E3DD1BE60A8C3D50F831536401E776BE02A6042FC4
A27AF653F0CFC4D4D013F115310788D68CAEAD3ECCCC5330587EB3C22A1459FC8E6FCCE9CDE84
9A5205E70C6D66D125814D698DD0EEBFEAE52CC65C5C84EEDF207379000E169D318426516AC5D
1C31F2E18A65E07AE6E33FDD724B13098B3A444688389EFBBB5EEAB588742BB083B679D42FB26
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2F14A8F4903A12329732A9768F82F295BEE391879293E3A97D51435A7F03ED7FBE275F102A832
02DC3DE94AF4C712E9D006D182693E9632933E6EB773880CF147B922E74539E4582F79E39723B
4C80E42EDCE4C08A8D02221BAE6D17734817D5B531C0D3C1AE723911F3FFF6AAC02E97FEA69E3
76AF4761E6451CA61FDB2F9187642EFCD63A09AAB680770C1593EEDD4FF4293BFFD6DD2C3367E
85B14A654C834B6699421A
```

No.1
~
No.50

Allocate memory and copy data!

Decoding I/NAV and F/NAV Message

- ½ convolutional code + interleaving
- Use of secondary (overlay) code for synchronization

½ convolutional code

Constrain length = 7
G1 1111001 171(OCTAL)
G2 1011011 133(OCTAL)

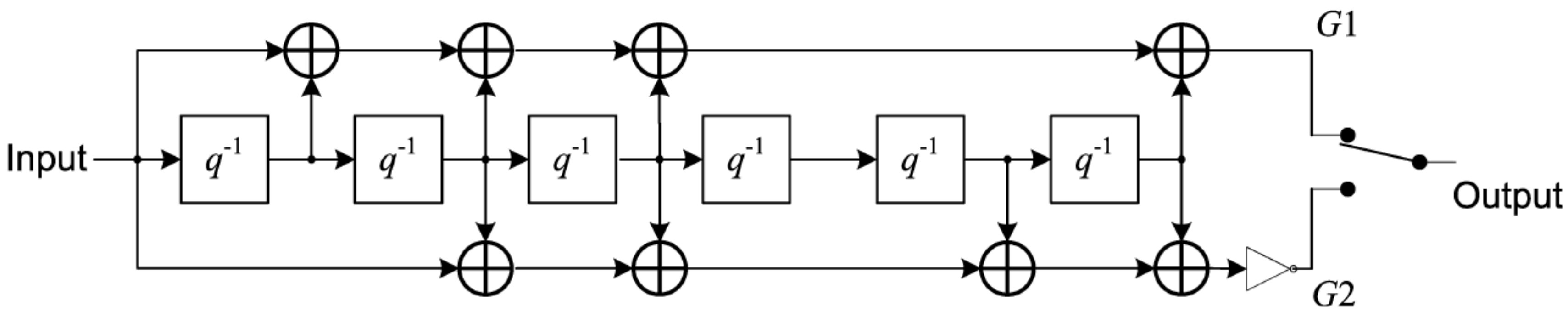


Figure 13. Convolutional Coding Scheme

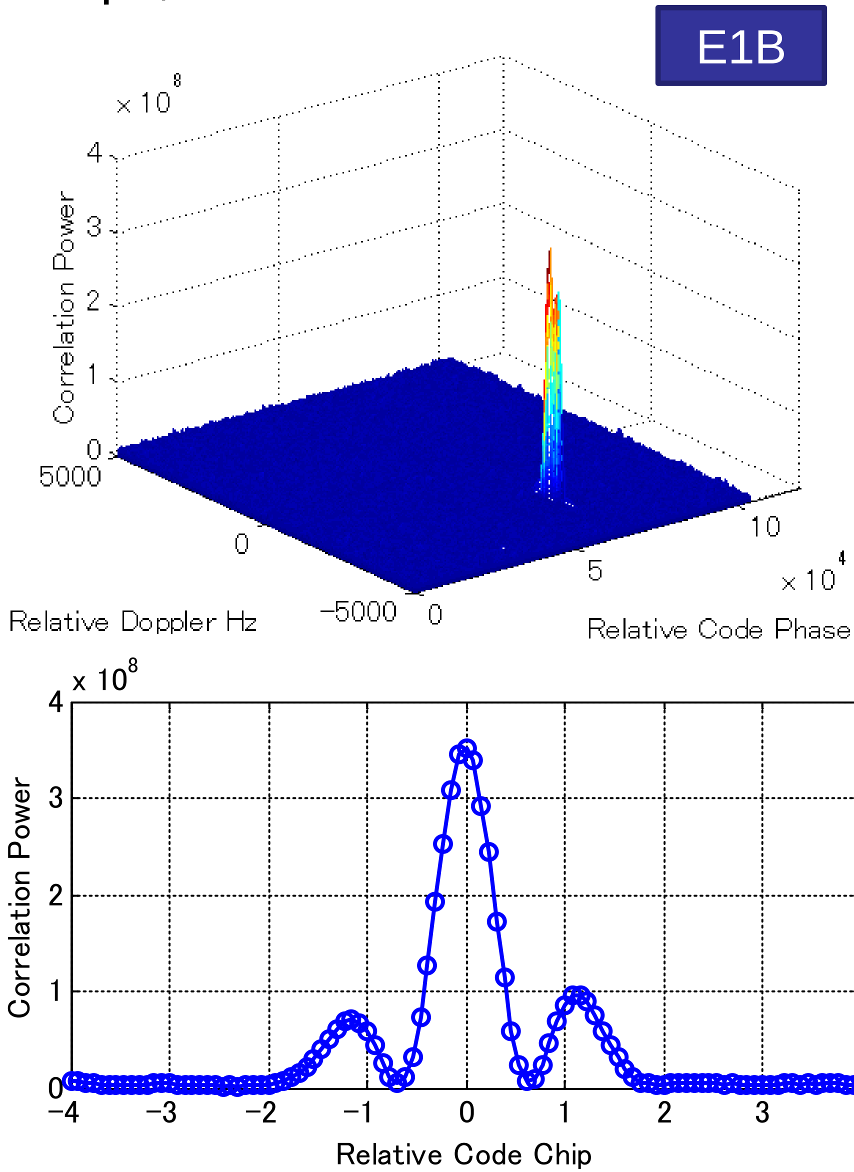
Decoding convolutional code

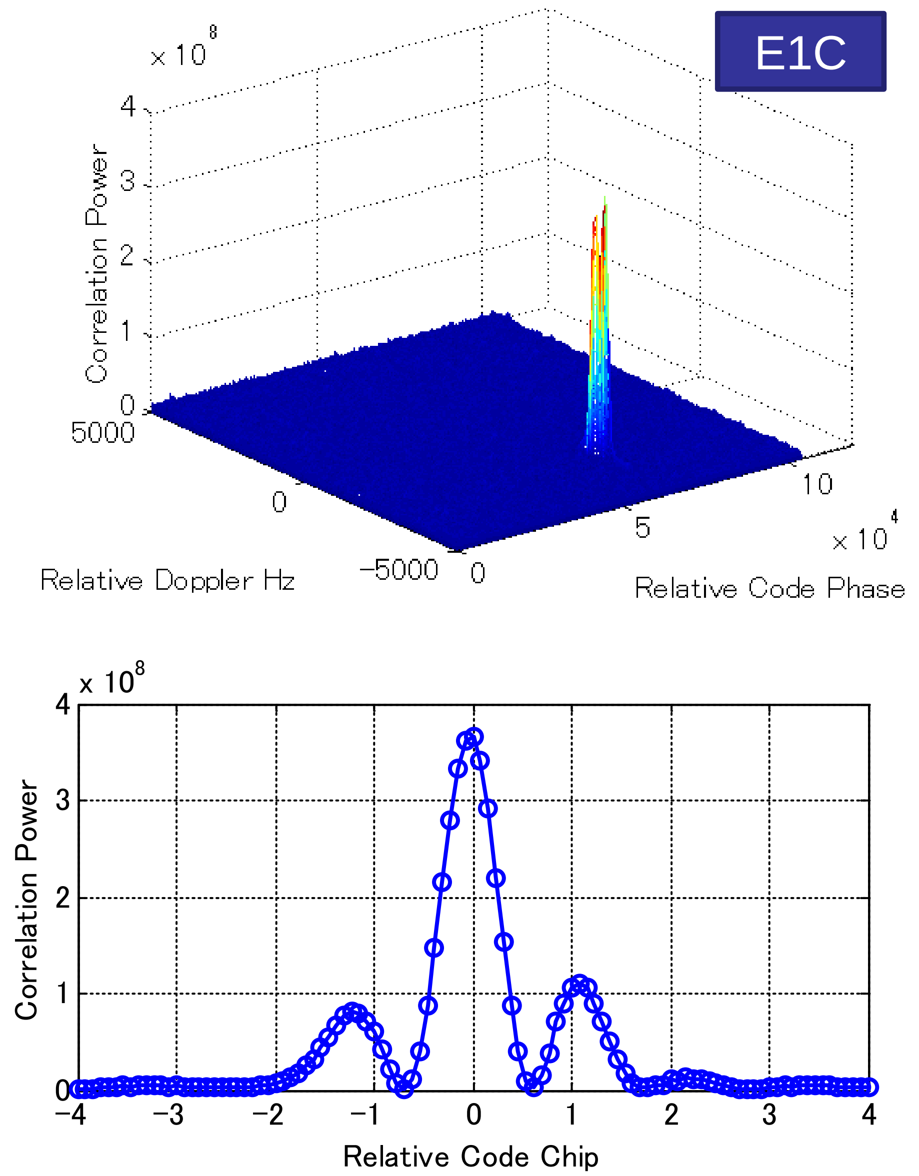
Fano decoder, Viterbi decoder

- GPS L2C and L5 also use the1/2 convolutional code

Example of Acquisition of E1 Signal

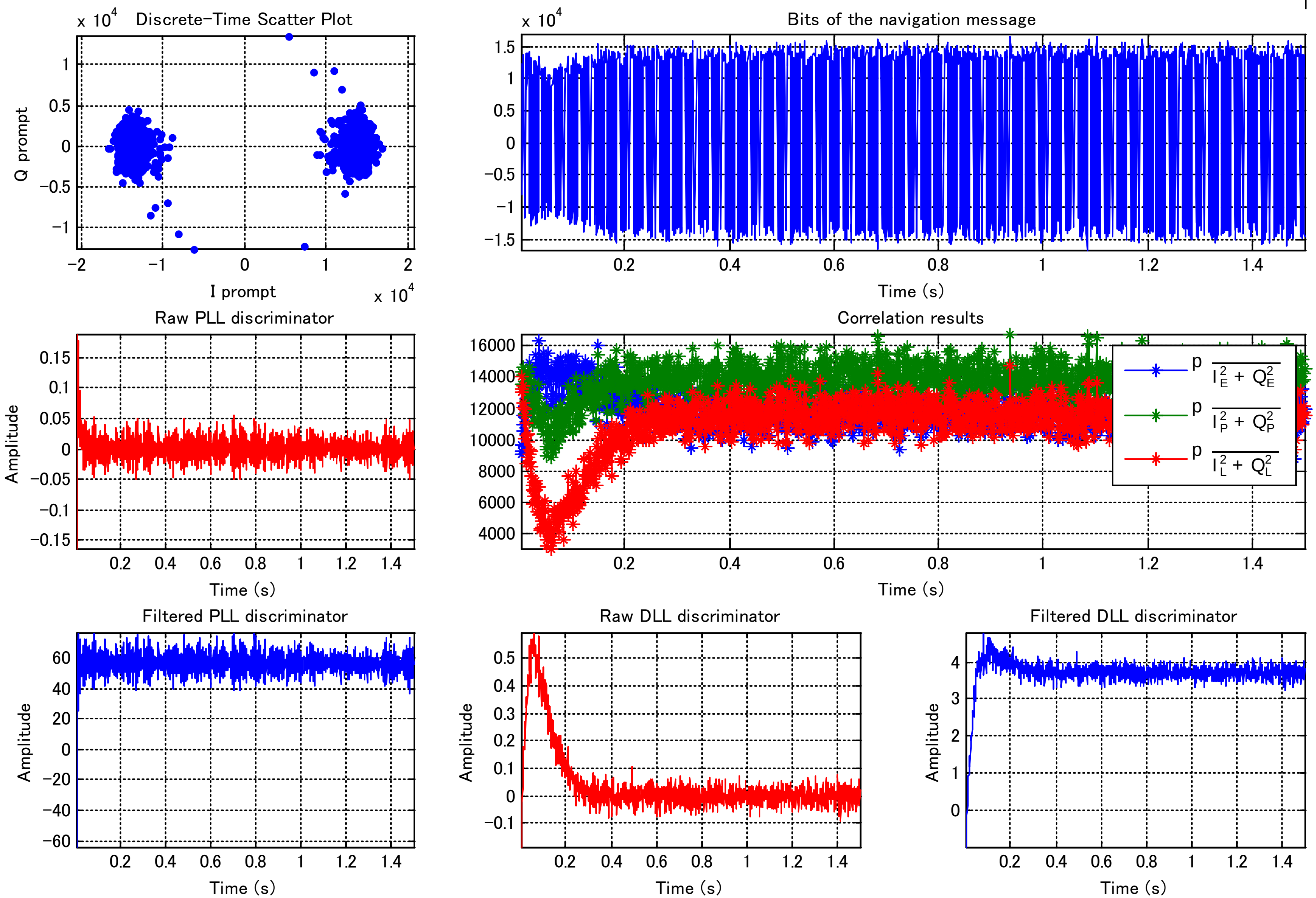
26Msps, Bandwidth=4.2MHz





Example of Tracking of E1 Signal

26Msps, Bandwidth=4.2MHz



Strategy of Acquisition and Tracking E5 Signal

- BPSK modulation
  - Same as GPS signal!
- Decoding I/NAV or F/NAV
  - No need to decode if I/NAV(E1B) has been decoded
- E5a/b code
  - 10230chip and 1ms, same as GPS L5
- If E5 code is generated, totally same as GPS L5 signal

E5a/b I/Q Code Generation

- Using linear feedback shift register
- HEX codes are also in ICD
  - It is hard to copy and paste…

C.3. Primary Codes for the E5a-I Component

E5aI Code No 1

3CEA9DA7B07B13A6CC0AE53DAD1EE2A0FCC70009338C08AC0EE457F76A1690815C3C940AB7224
87CC8F3D1F4C428828E7FD2A21230E42A3BBDF1E792165F644D0E0335F95EBDC93D6005CC0C68
0DB7B0E1B8C4946B7974319F9816141DB9E01011E4F20DA8F1B8E15A6F618CF599C3F5C1A1B27
6D51318ED4119BCE0ACD0332F3DD8F88EC5215AB311C51FF4987DA93B09A43BA84CF08032F6CB
28F43043C5458681 1D870AD6FA27AA63785345C8BCDD3DA26A0134738BC7E08461D5409FF0B79
1D8574CE797FC5EF7821055028CB4AF92AE1088F8806CD55F0E5FDFCD8D74ED801B2B44AD5D79
D1924D41DDC6AB2070B5360CB64CCF487FE517420348CC39BF50BDF78BE7DA91542FEAB689457
B3EE69E43C75FADC303F31032FD96B7DC70A88C3B7BAC7322B285D9CFB3A93AC8B890165F2384
8FAD8477DBDD3D0AA4CB3CD73A48000B6D134DA2DA70B56E590A101AEE78864DA0C64A7BCC6B3
7CD6F31E9AFF10CA4D47630752D253944632DF6EC60AECDCD223F29399CDA3B74D1DFA5471277
EE6C814464A8C55D3C0B83B36B6AC9FA90CE876ACDF65E3EA3FD61D309EB71ED29A3D510B2F4C
0B6D6C5B57EC9060CFBE48389DCB17CBB2284E7F578565B91503B06F49CF3E8534870AEB6AD97
07265A9A1E6E2E5E6DF6DAA367239A96EF5B02C19A4543D537EB4D9D73966C09E9B52B4706F57
B3E0987885EB84DEA26F7823D895F62015188ED38C04CC6714F797FDB0BC713E3D0208462F9A6
8E3872A167BF1BF9791AEE8BB73CF527C50975B55C4E5C2F2E95B677F833ECC878D1764839608
CC1108A75EE9E58FFCFE4CB52884E7AF15EE0632E0729DA1CF5B7A227028CFE1E08F8B881E1A7
43D52DD27BED33DE0EE75DC031B4864CF192DFEAF64F726D73321363A233F81C57232432D2B0A
5A4C44F4320847A9C143F378F204185D2B571482FE45D6BCA152E6EA7223BFC6DCE06CEF90CE9
14623EAB9B1EC789B2051B4AB711DABF5B16FCD970F437B8860313B4F1F14D384EE3976B7E55
2FDCB7E1BD9BE18B722E37C853ADC7E1CC2870A02881F95B78487780E1D1C29641510 9CF07AB
3D0782A9F451CBEB3E8B919917AEDBCA8A8E563AD3784639793E0F25CC9CC62240FA04B2F141
71BF5C84EAC5643115955 6B8BCE077A51469A87737D3D6F06D97DD479FCC35129F4499C19EF9
BDCEA9D4941B3756CDE1997C3AFCAE62B6D9E23341E11CD05A7FFF52F5814011A84D737E1264
09006BEF5F19E3C6A9C7521B44741A8282755A8F0DC2FA0E1F6CA4FB34D8CD5FAA27E1880886
725B9634376137C1BBC46934F83958112D03082DDD6148F353BD1DD24B9F8FD7AD89C40DA0A9
A8DBE3608038CD56FFC4ACA35241D76FAC4CAE1211AAD9D73D51C81C59BCE05F71C345730D3A
C670F8F533A950EF24B00EFE6A3F1354694ABCC6FD9EC4E74DDE1F287AD4F847A297ECCCC39A
029EFCDDDB19932D906B9CEDFCBE0D422CEE305DD05E407340F28EEEA866664D60AF293A45D5
6D5C0000B05F79463DB513ED488DE7BD4EC9EACFEF973B23CE4E9539EFCB797456CF5FD1EC54
DCEE80B39063C48B91A5C2D2BEBC81B9B46D0AD6503BE5AACED2BA5EBE81F630B4E07510356E
229F7FC5EA532B8729CDB819E066A15379AC6942CD4BC5E97C6791E098105C323A3A3DA3880D
EE5562ABBA2BDC9906F4486B51ACF8AA4405E9D7A63DB9E3058782DD9AF3995FFB3D34AEF982
4A0B3DC62C339325B60706C068F0198BD8FA658396D06931B069155217690C7F88FD230CDB38
3E48530BD47722FC

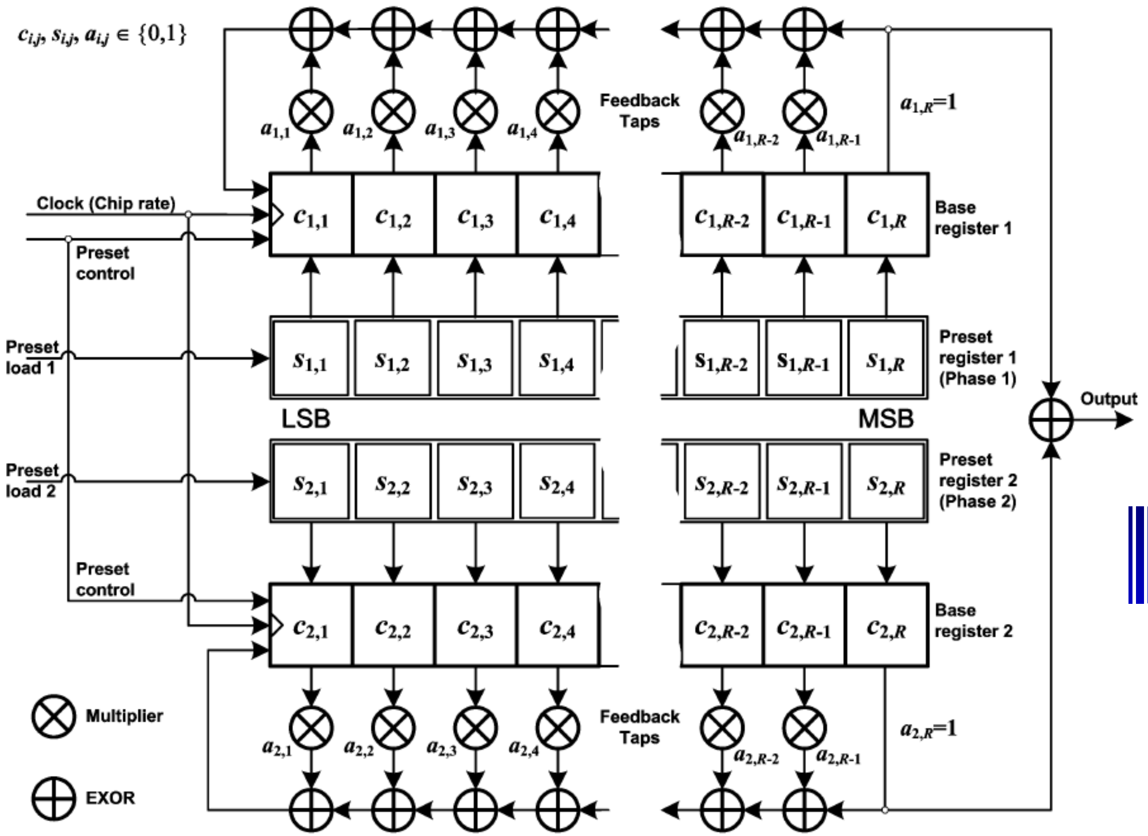
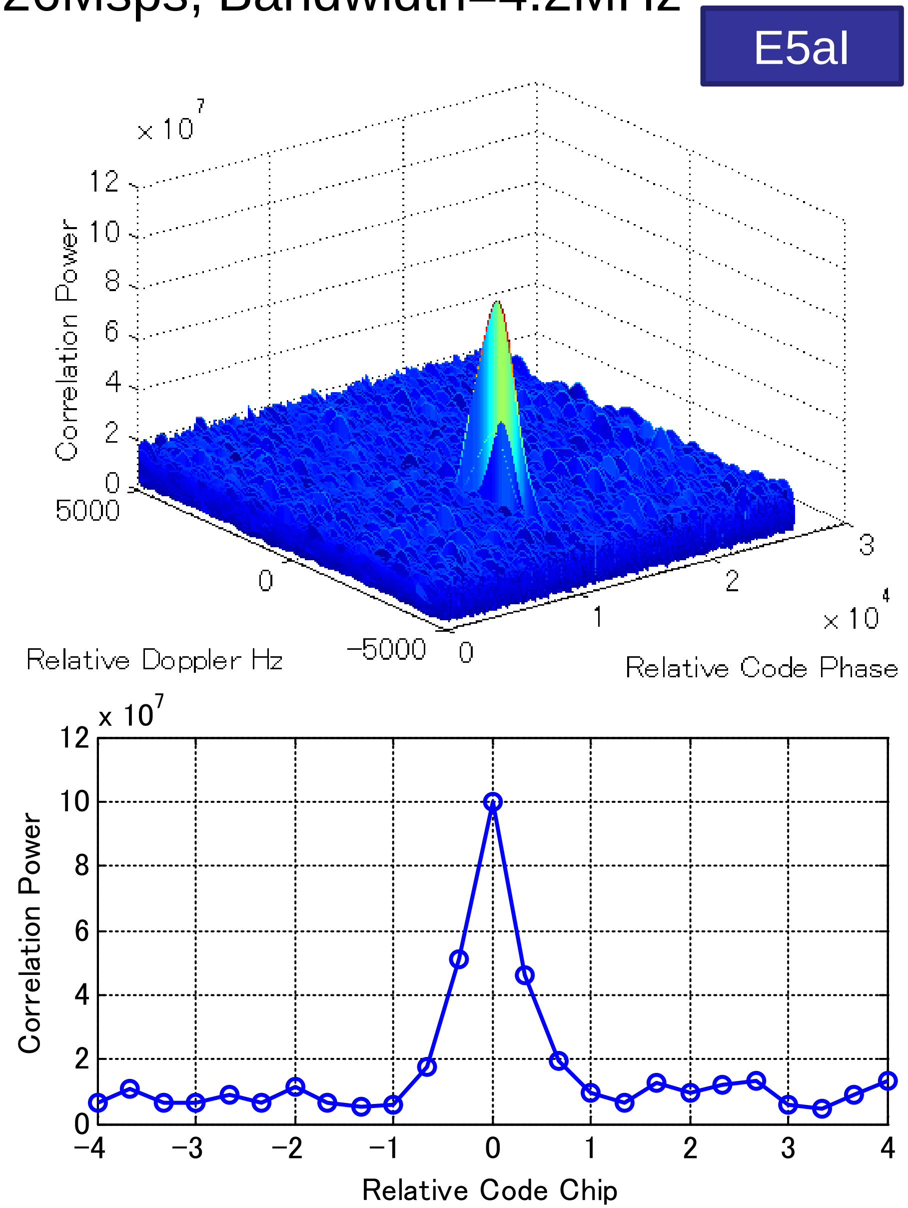


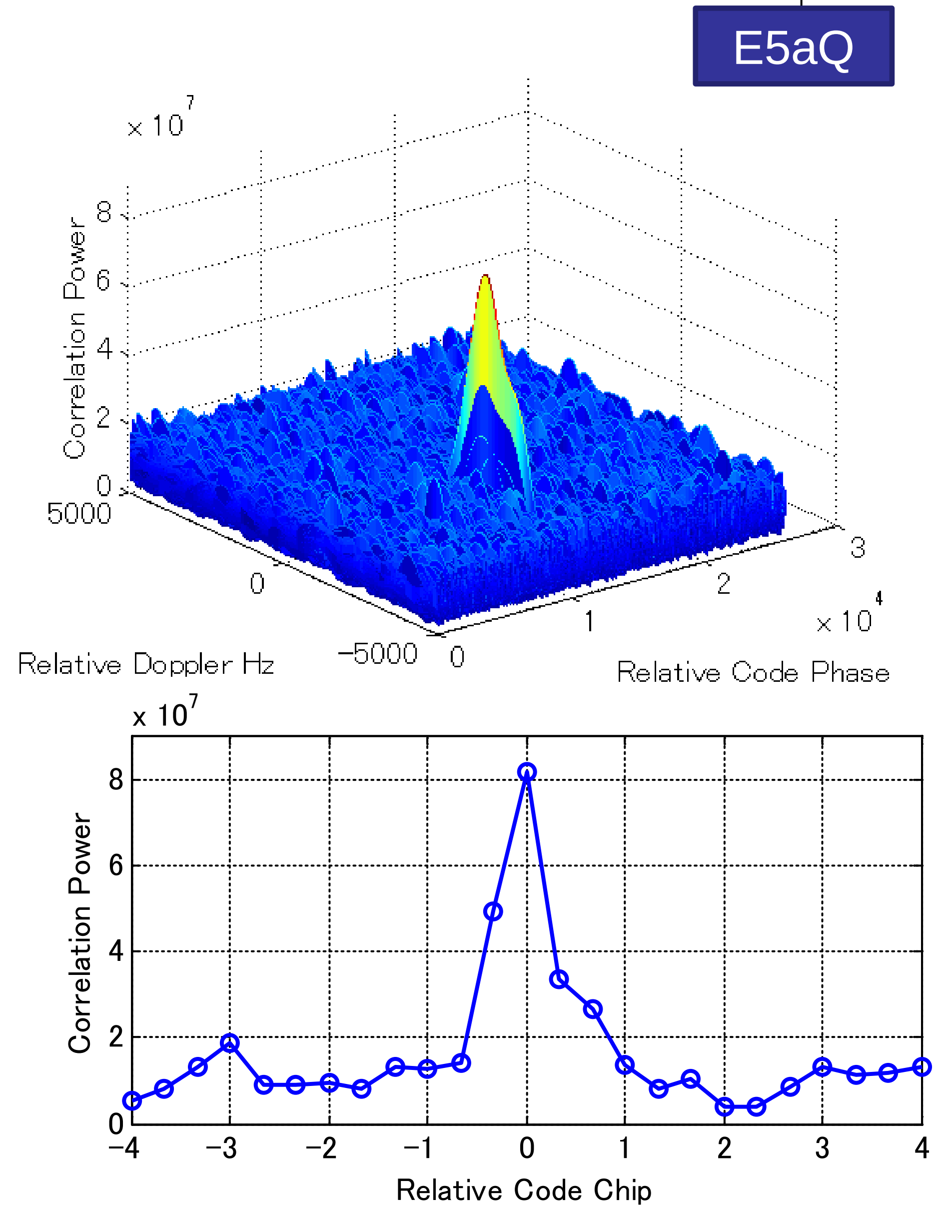
Figure 10. LFSR Based Code Generator for Truncated and Combined M-sequences

Generating E5aI, E5aQ, E5bI, and E5bQ codes

Example of Acquisition of E5a I/Q Signals

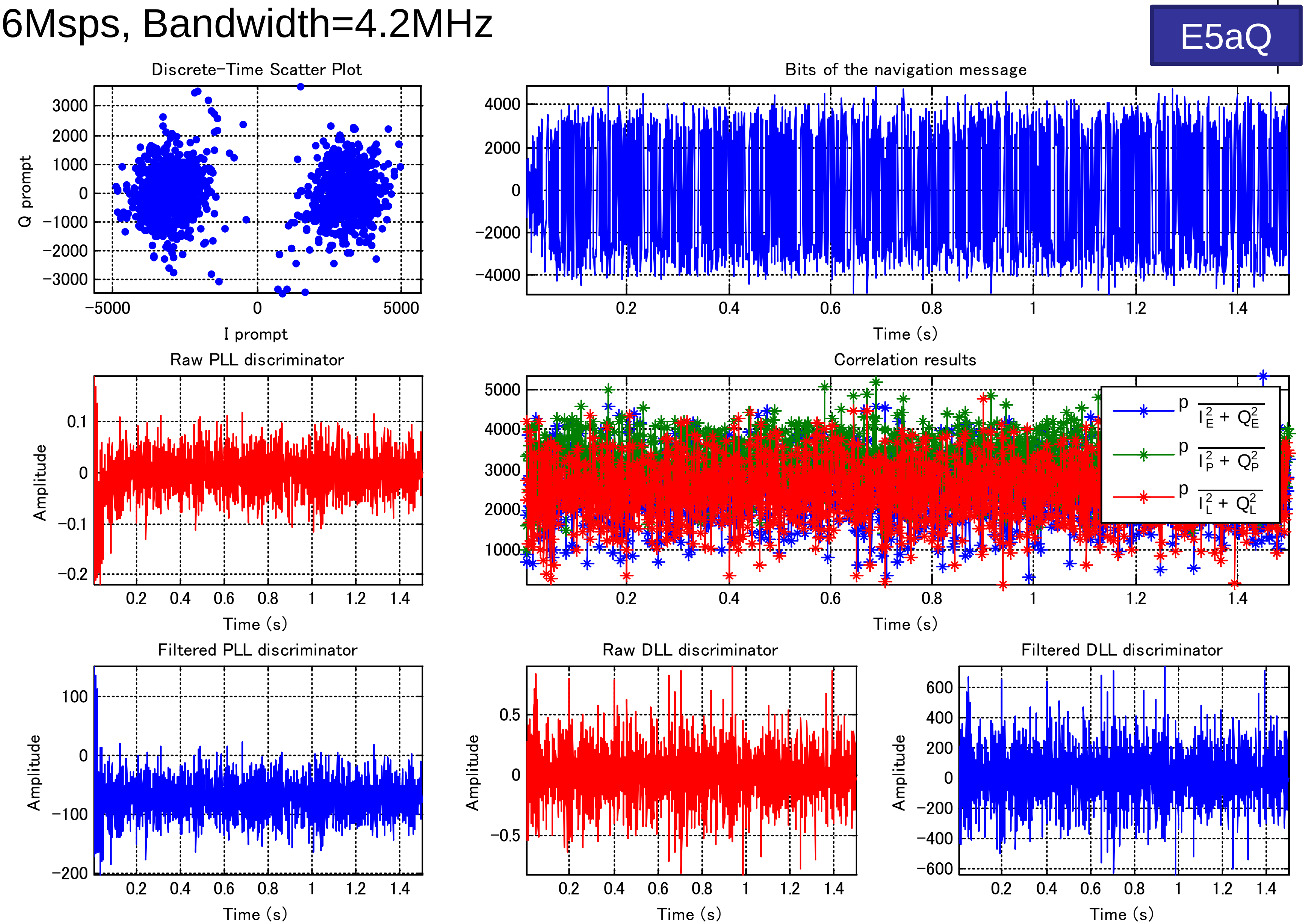
26Msps, Bandwidth=4.2MHz





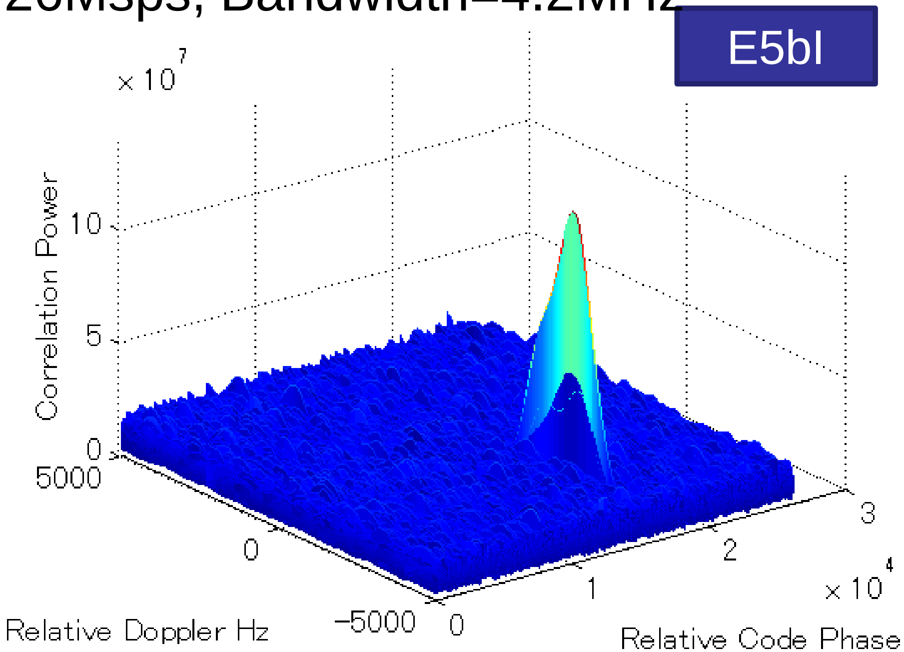
Example of Tracking of E5a I/Q Signals

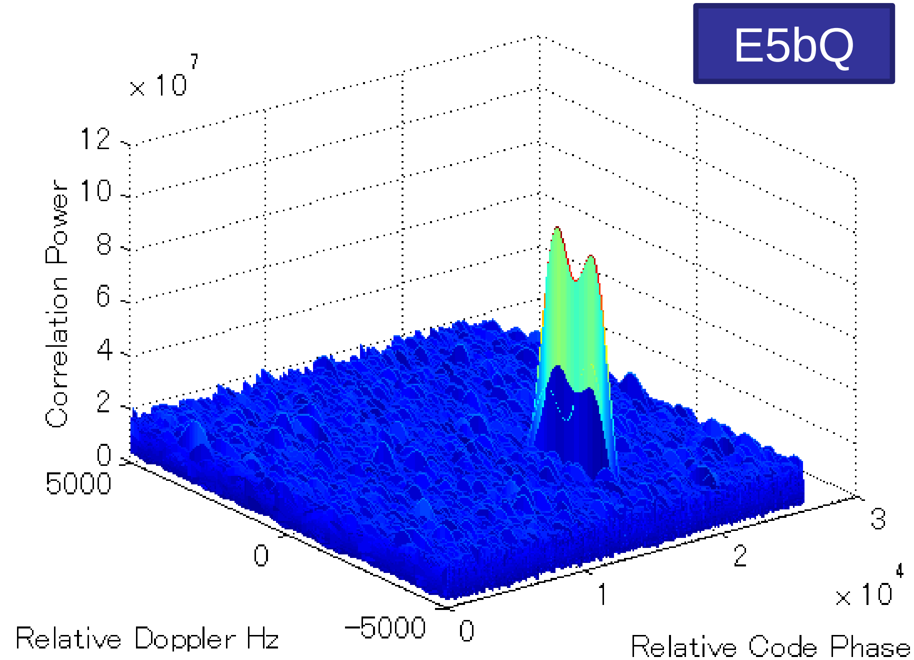
26Msps, Bandwidth=4.2MHz

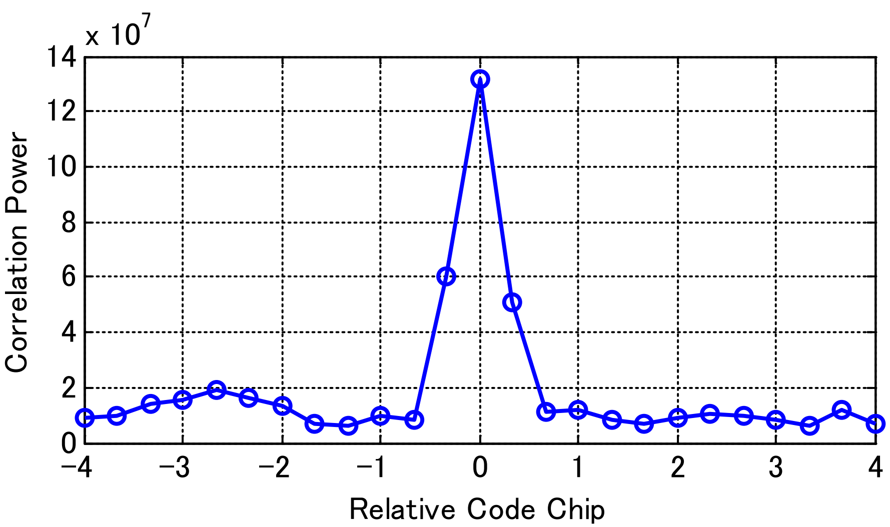


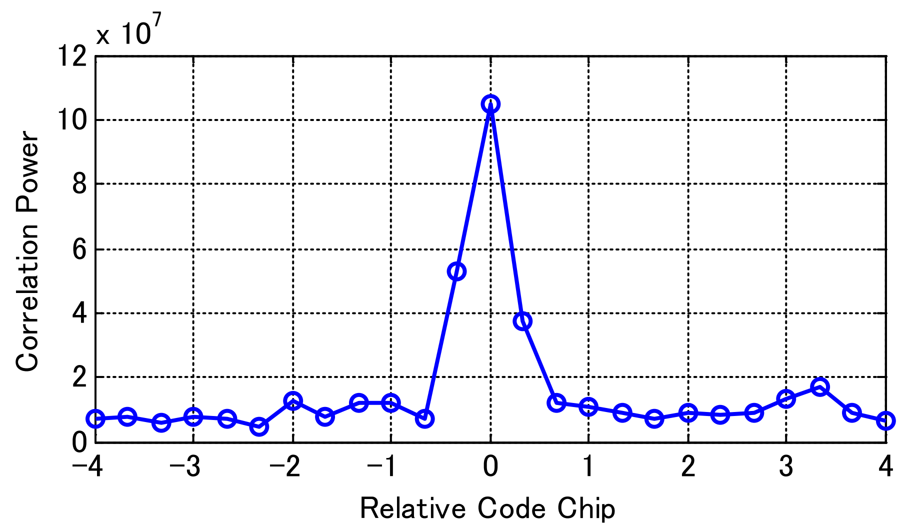
Example of Acquisition of E5b I/Q Signals

26Msps, Bandwidth=4.2MHz





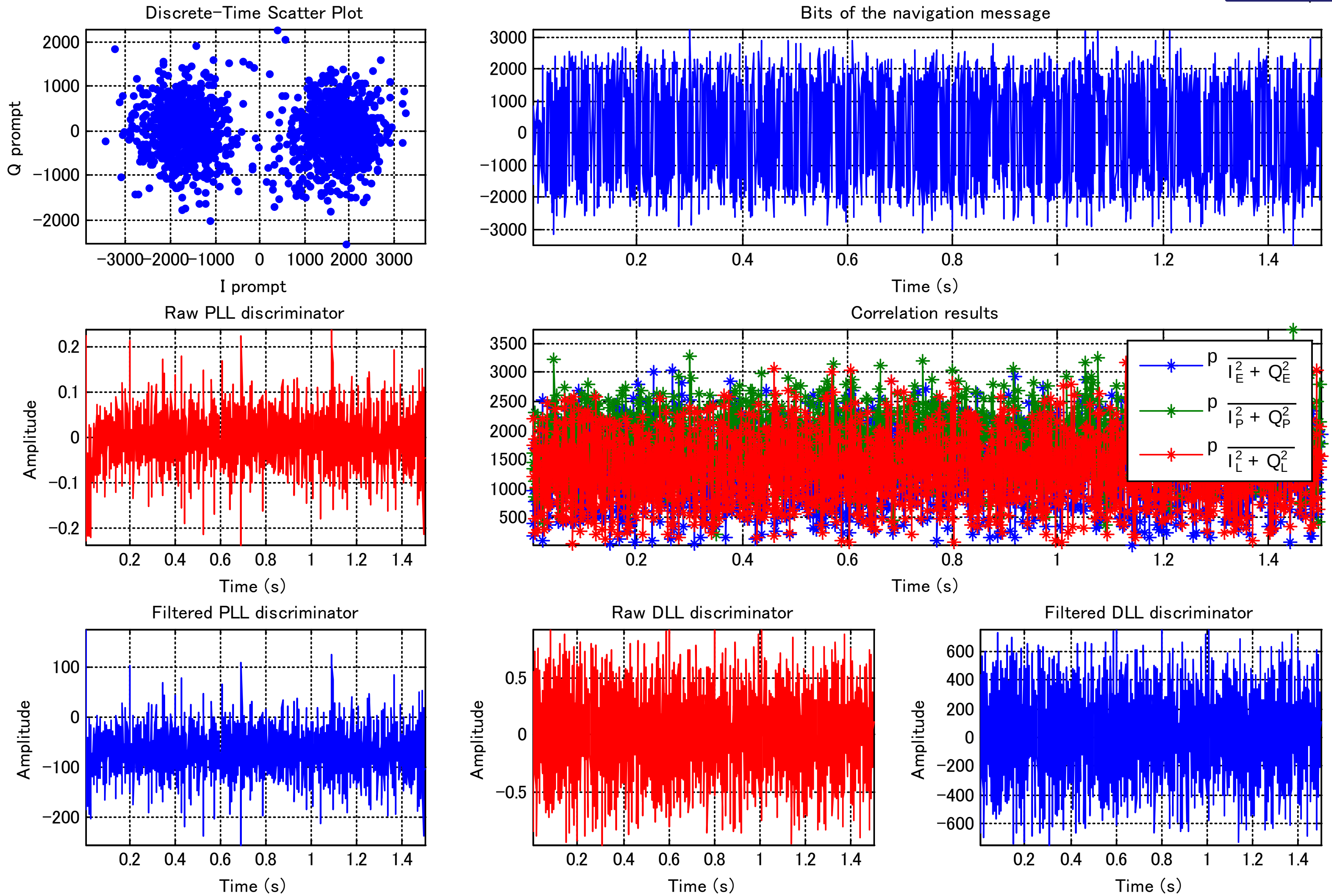




Example of Tracking of E5b I/Q Signals

26Msps, Bandwidth=4.2MHz

E5bQ



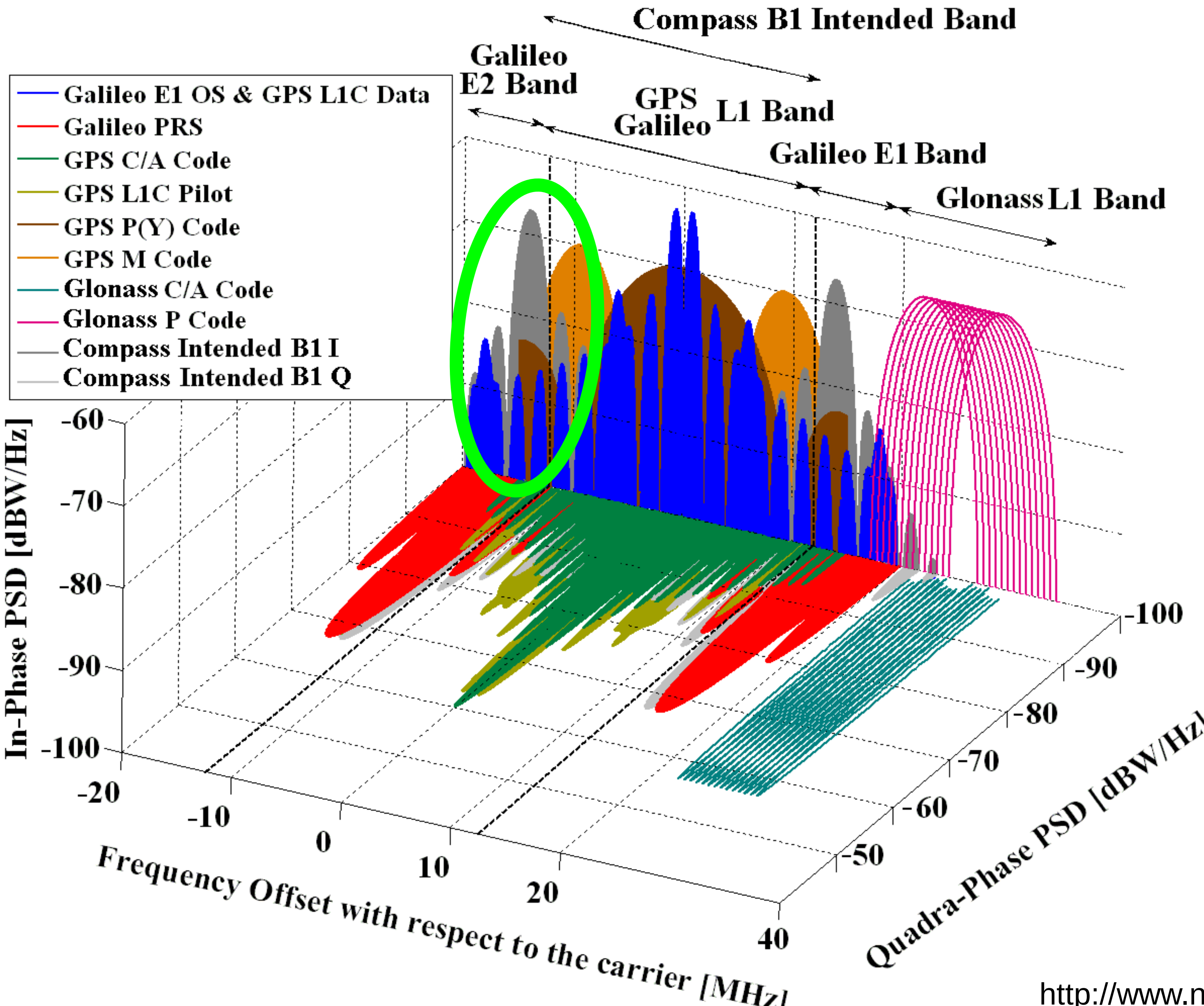
BeiDou

BeiDou Signal Specification

	BeiDou		
Service Name	B1I	B2I	B3I
Center Freq.	1561.098 MHz	1207.14 MHz	1268.52 MHz
Signal Component	Data	Data	Data
I/Q	I	I	I
Band Width	2.046 MHz	2.046 MHz	?
Modulation	QPSK	QPSK	QPSK
Code Freq.	2.046 MHz	2.046 MHz	10.23 MHz
Code Chips	2046	2046	10230
Code Length	1 ms	1 ms	1 ms
Nav. Data	D1/D2 NAV	D1/D2 NAV	?
Min. Received Power	-163.0 dBW	-163.0 dBW	-163.0 dBW

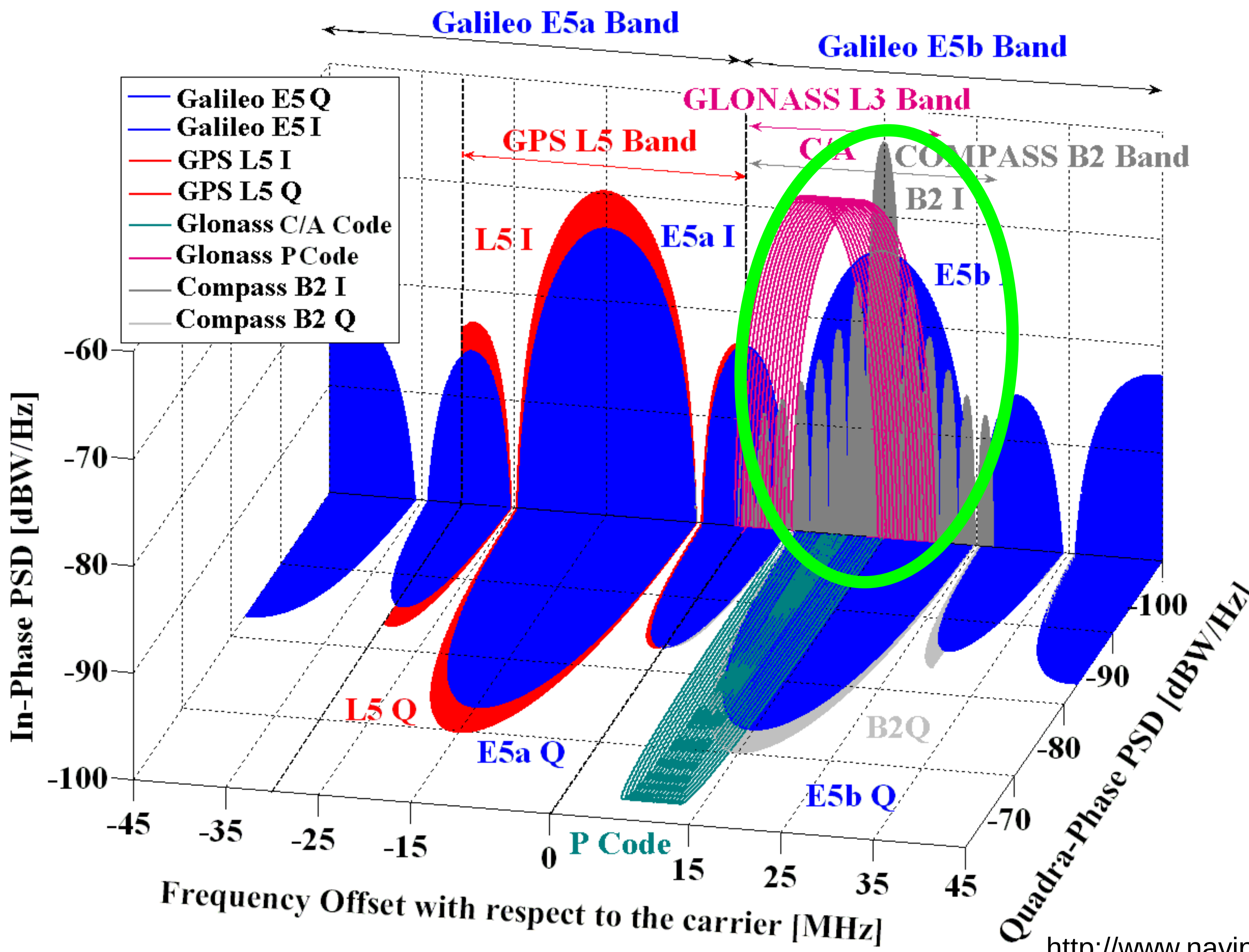
- B1I ICD was published in the end of 2012
- Center frequency of B1I signal has a little offset from GPS L1CA
  - Antenna problem…
- MEO/IGSO and GEO broadcast different navigation message

BeiDou B1I Signal



http://www.navipedia.net/

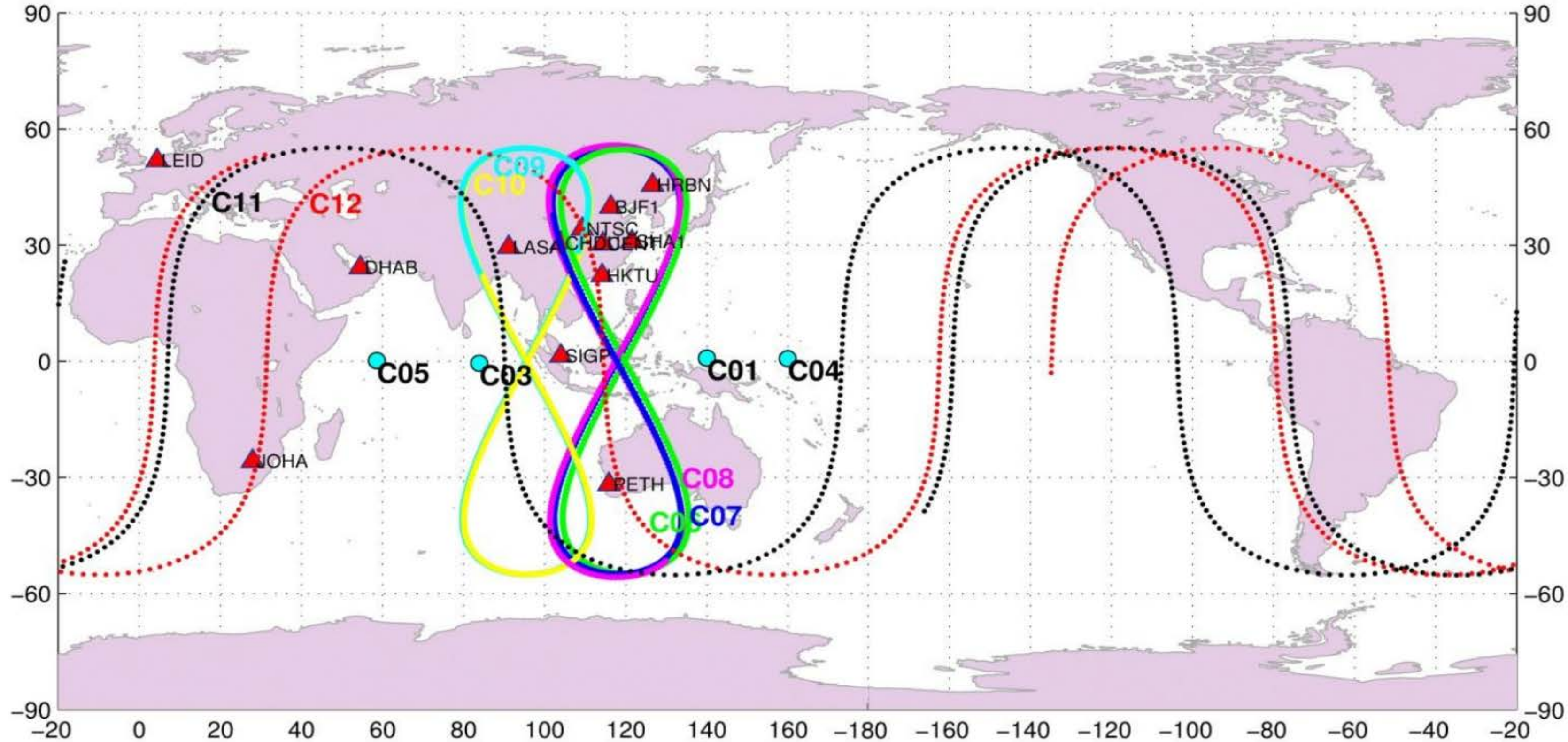
BeiDou B2I Signal



http://www.navipedia.net/

BeiDou Satellite Orbits

Orbit	Number of Satellite	Navigation Message	Altitude
Medium Earth Orbit (MEO)	5	D1 NAV	21,528km
Inclined Geosynchronous Satellite Orbit (IGSO)	5	D1 NAV	35,786km
Geostationary Earth Orbit (GEO)	5	D2 NAV	35,786km



Sensors **2013**, *13*(3), 2911-2928

Strategy of Acquisition and Tracking B1 Signal

- Many satellites can be used in Asia region
- Chip length and chip rate are twice as much as GPS
  - Code length is 1 ms!
- Normal noncoherent integration does not work well
  - Navigation bit may be changed every 1 ms because of NH20 (secondary code)
- Separate process by PRN (GEO or Not)

B1 Code Generation

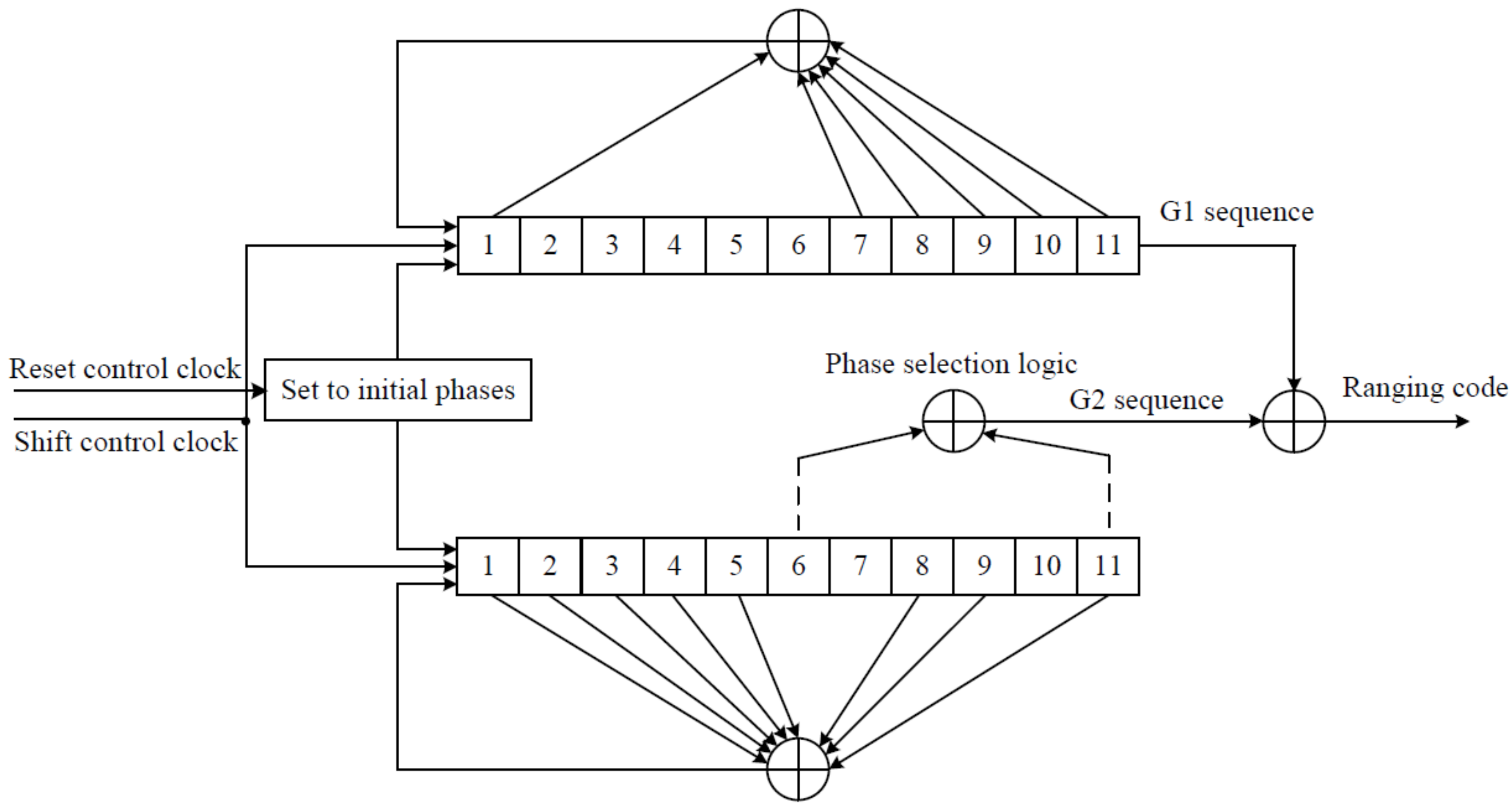


Figure 4-1 The generator of C_{B1I}

- ◆Gold code
- ◆Generating structure is almost same as GPS L1CA
- ◆PRN is assigned 1 to 37

Decoding D1/D2 Navigation Messages

- BCH encoding＋interleaving
- MEO/IGSO ⇒ D1 Nav. GEO ⇒ D2 Nav.
  - D1 NAV 50bps
  - D2 NAV 500bps

Message Structure of D1/D2 Navigation Message

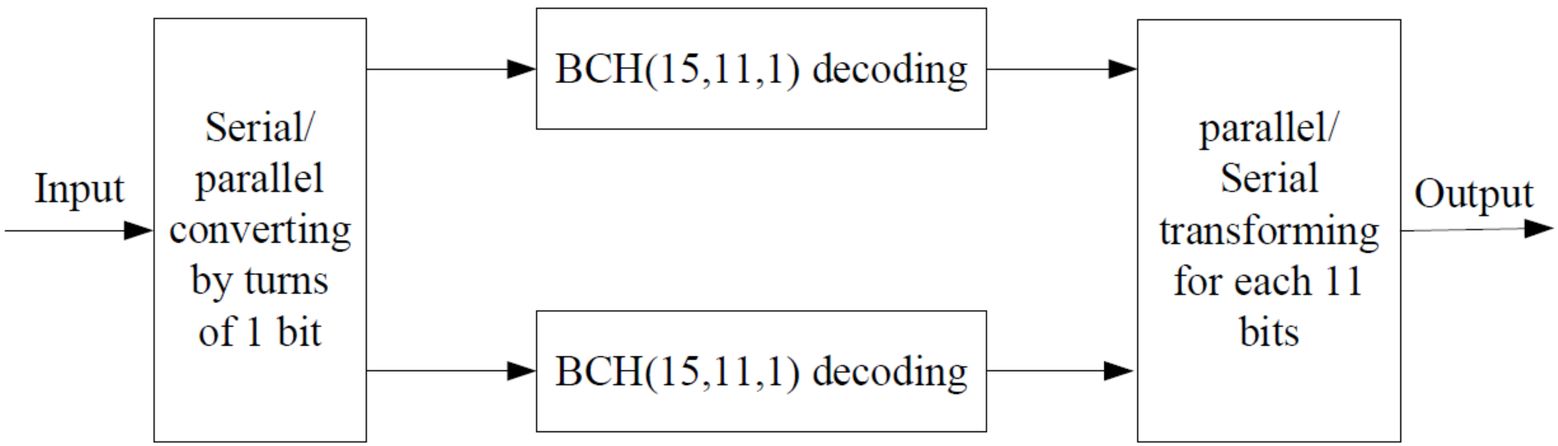
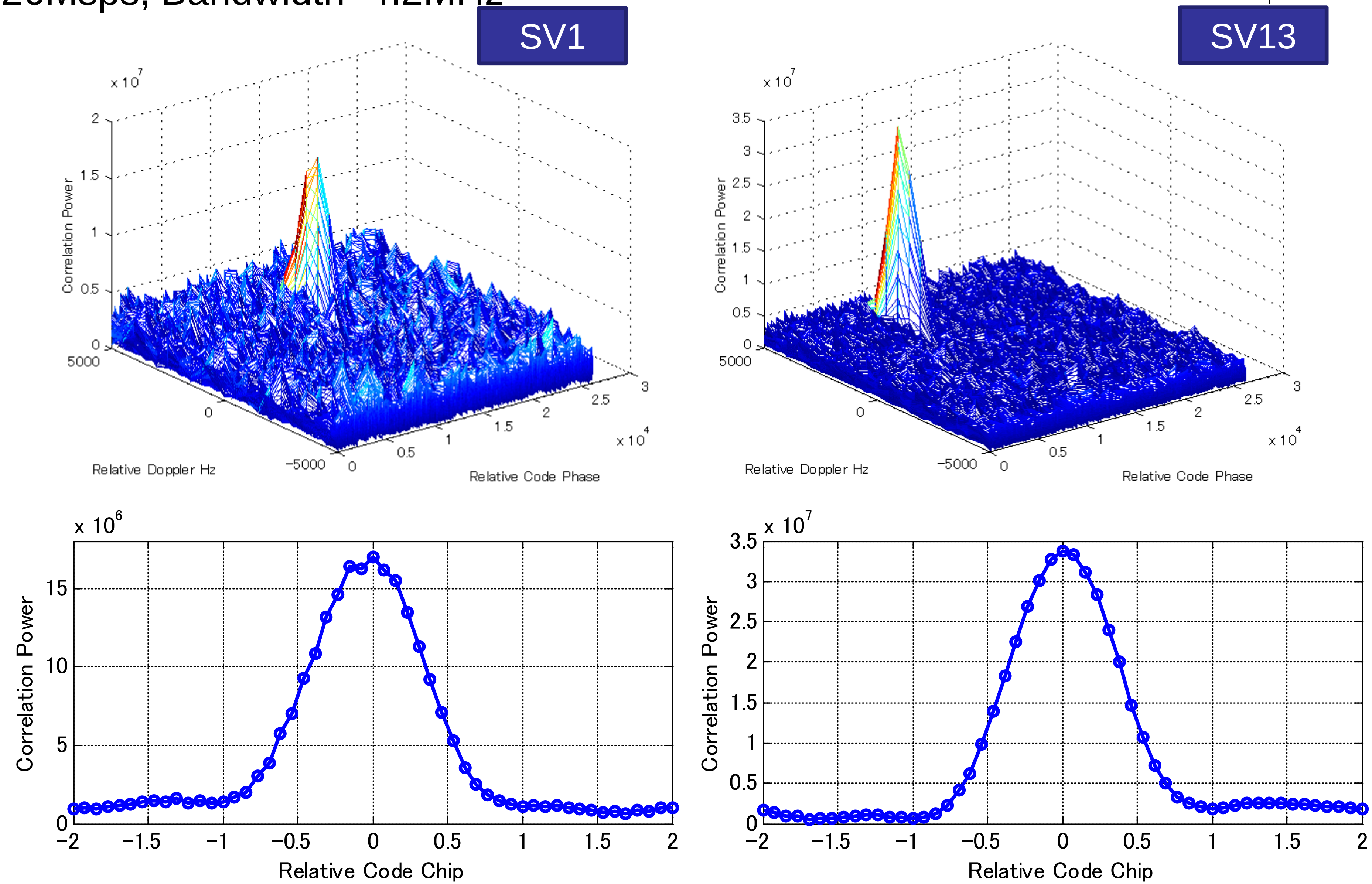


Fig 5-3 Processing of received down-link NAV message

- BCH decoding algorithm is written in ICD

Example of Acquisition of B1I Signal

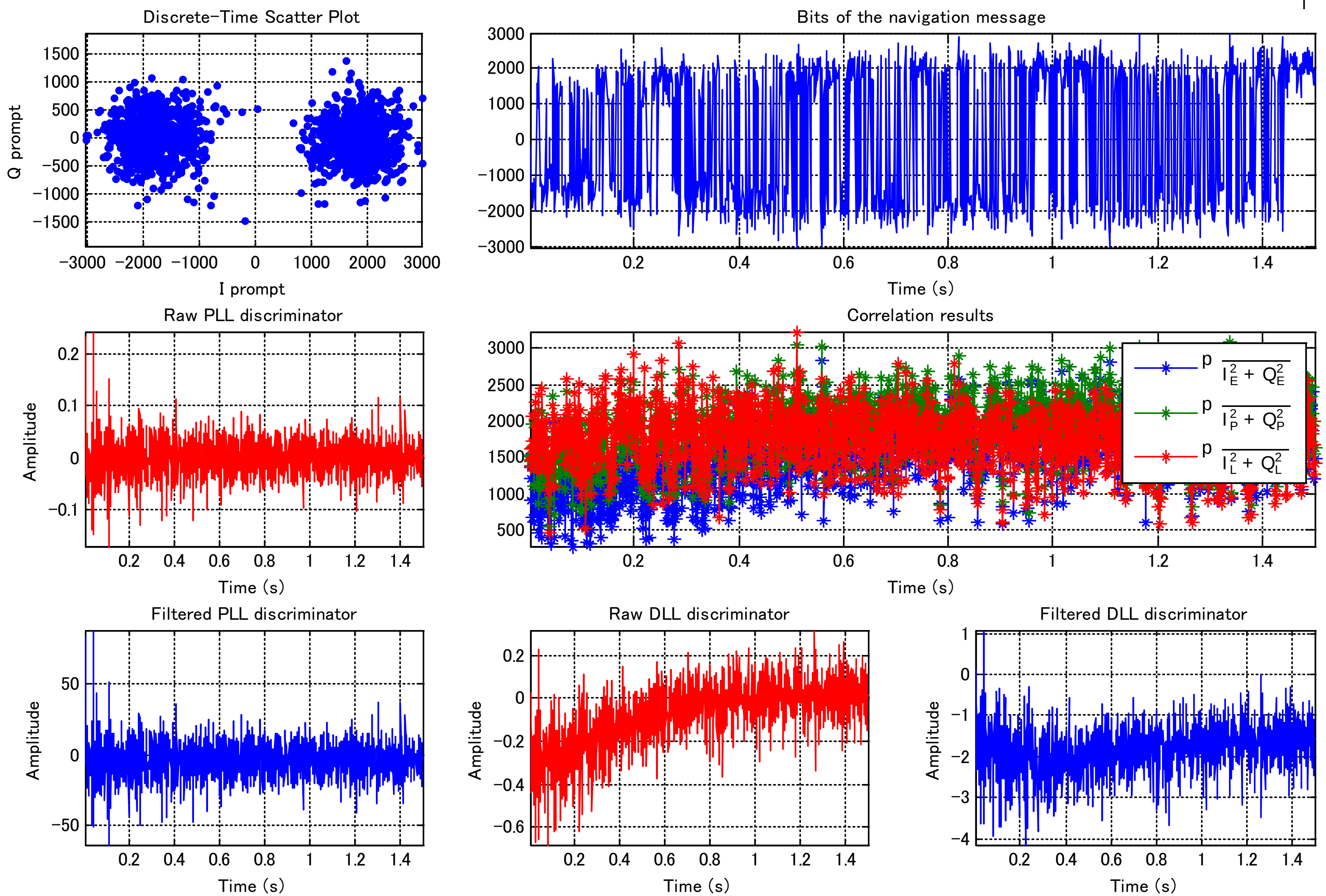
26Msps, Bandwidth=4.2MHz



Example of Tracking of B1I Signal

26Msps, Bandwidth=4.2MHz

SV1



QZSS

QZSS Signal Specification

	QZSS							
Service Name	L1C		L2C		L5		LEX	
Center Freq.	1575.42MHz		1227.60MHz		1176.45MHz		1278.75MHz	
Signal Component	L1CD Data	L1CP Pilot	L2CM Data	L2CL Pilot	L5I Data	L5Q Pilot	Short (Data)	Long (Pilot)
I/Q	I	Q	I		I	Q	I	
Band Width	4.096 MHz		2.046 MHz		20.46 MHz		42.0 MHz	
Modulation	BOC(1,1)		BPSK(1)		BPSK(10)		BPSK(5)	
Code Freq.	1.023 MHz		0.5115 MHz		10.23 MHz		0.5115 MHz	
Code Chips	10230		10230	767250	10230		10230	1048575
Code Length	10 ms	10 ms	20 ms	1.5 s	1 ms	1 ms	4 ms	410 ms
Nav. Data	CNAV-2	-	CNAV	-	CNAV	-	LEX	-
Min. Received Power	-163.0 dBW	-158.25 dBW	-160.0 dBW		-157.9 dBW	-157.9 dBW	-155.7 dBW	

- Compatible with GPS satellite
- Only satellite which broadcasts L1C signal
- Special correction message for PPP via LEX signal

Decoding L2C/L5 CNAV Message

CNAV Message 1/2 fixed convolutional code

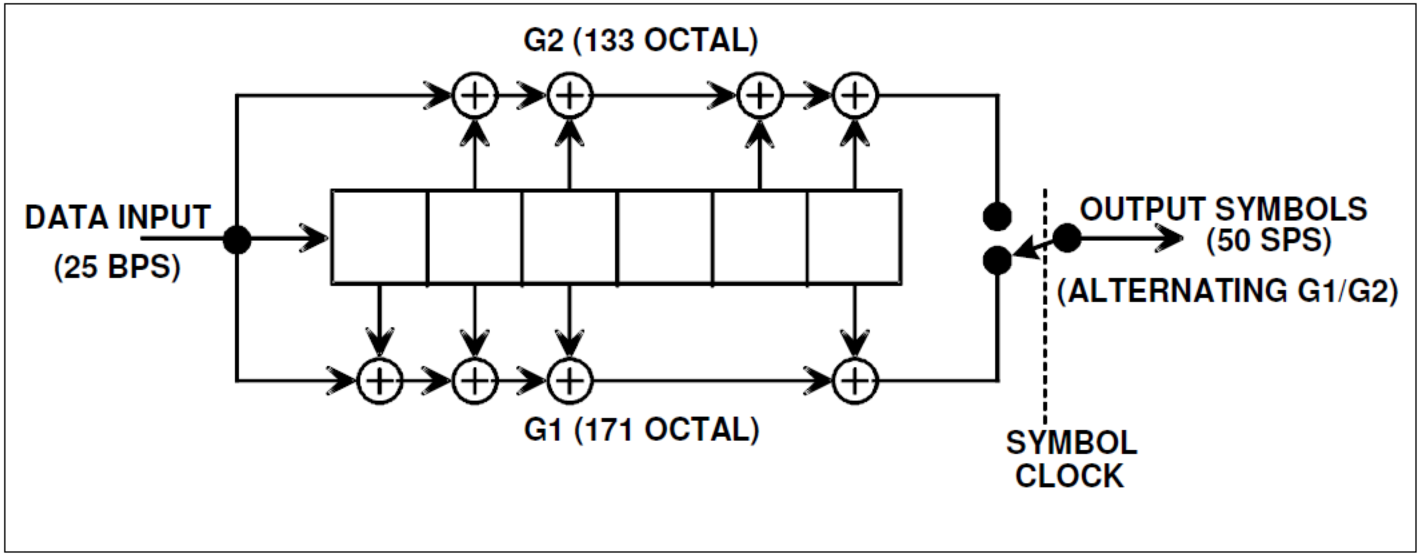


Fig. 3-14 IS-GPS-200F

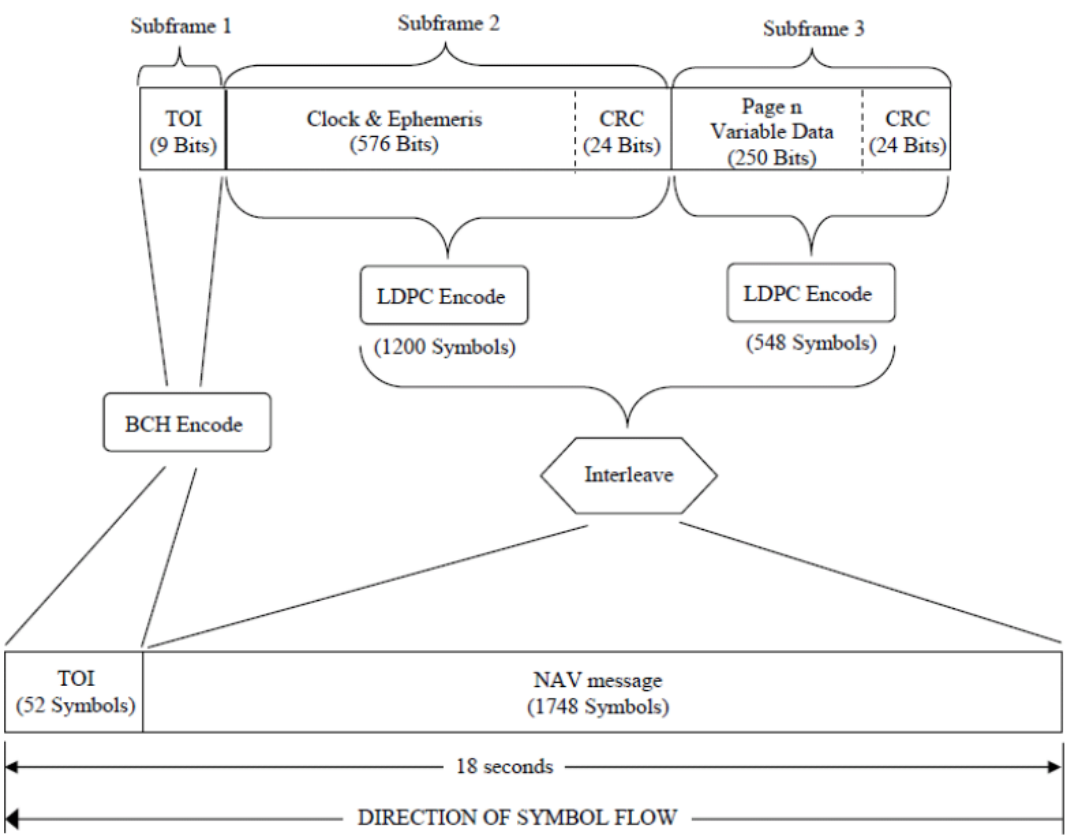
Decoding Method

- Viterbi Decoder / Fano Decoder…
- Same as Galileo I/NAV and SBAS Message

Decoding L1C CNAV-2 (1)

Message Structure of CNAV-2

BCH encoding＋LDPC encoding＋interleaving＋no preamble



CNAV2：18 seconds Long code Using overlay code for synchronization

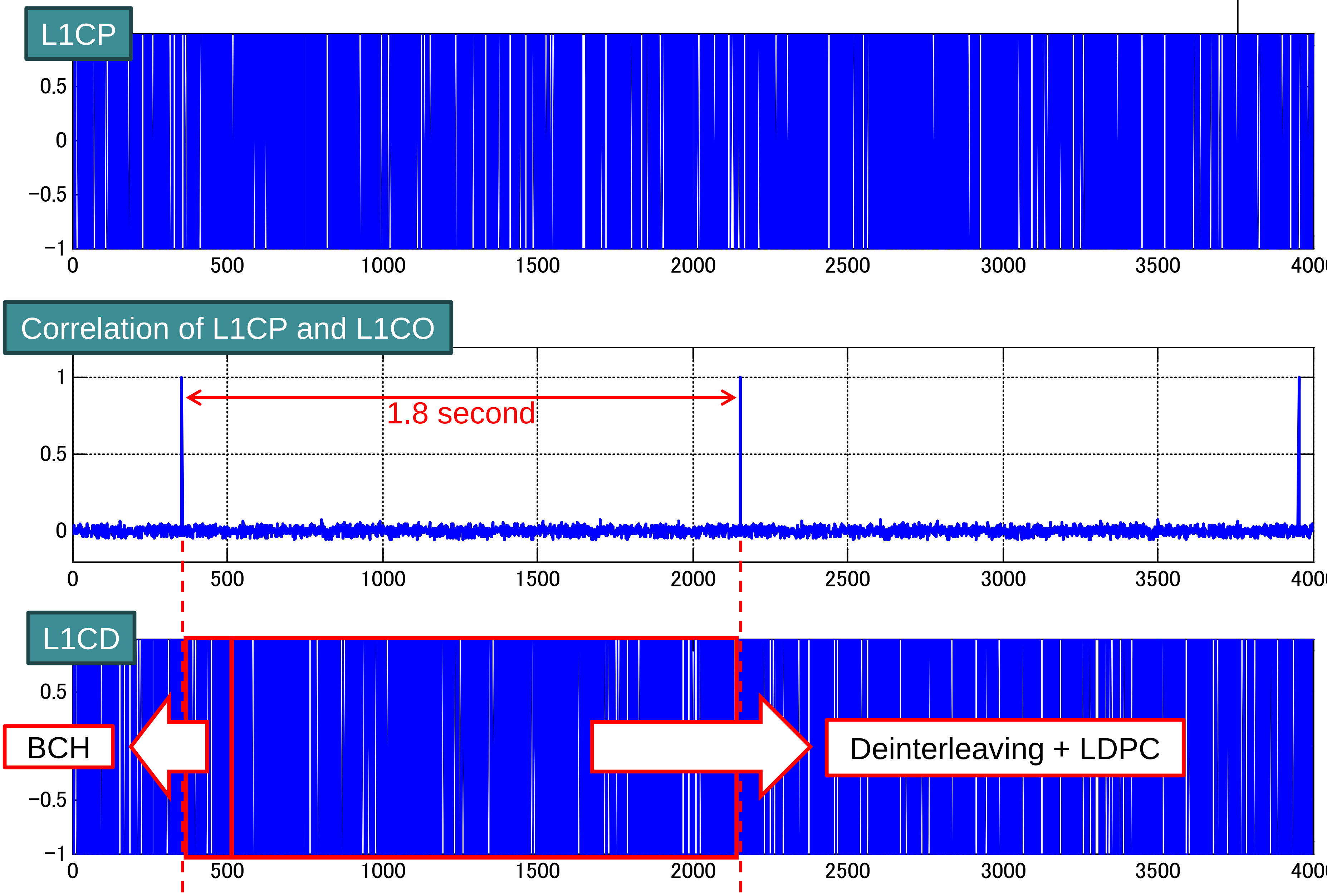
① Tracking L1CP and L1CD

② Correlation of L1CO code and L1CP bits

③ Extract L1CP code phase. Select TOO bits in L1CD bits using L1CP code phase, then BCH decoding

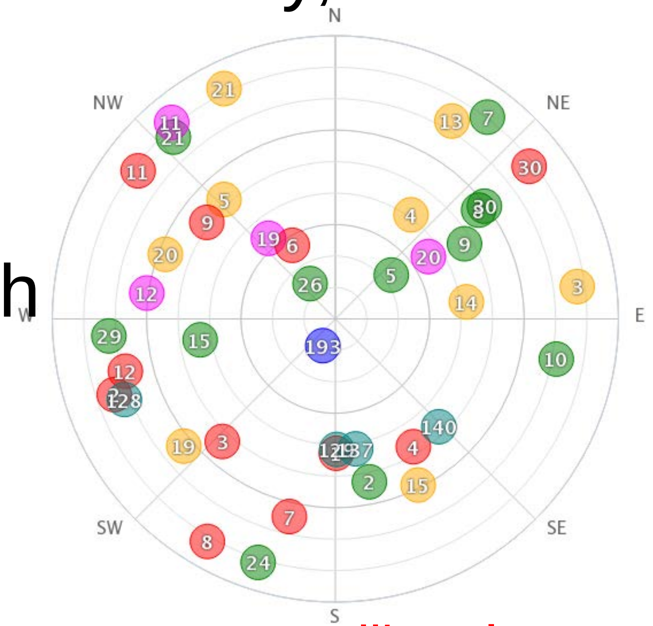
④ Deinterleaving NAV message and LDPC decoding

Decoding L1C CNAV-2 (2)



Summary

- Multi-GNSS improves positioning availability, accuracy, continuity, reliability…
- Currently, software GNSS receiver is essential for cutting-edge research
- How to implement multi-GNSS signal into software GNSS receiver
  - Acquisition and tracking each L1 code
  - L1 aided acquisition and tracking of secondary frequency code



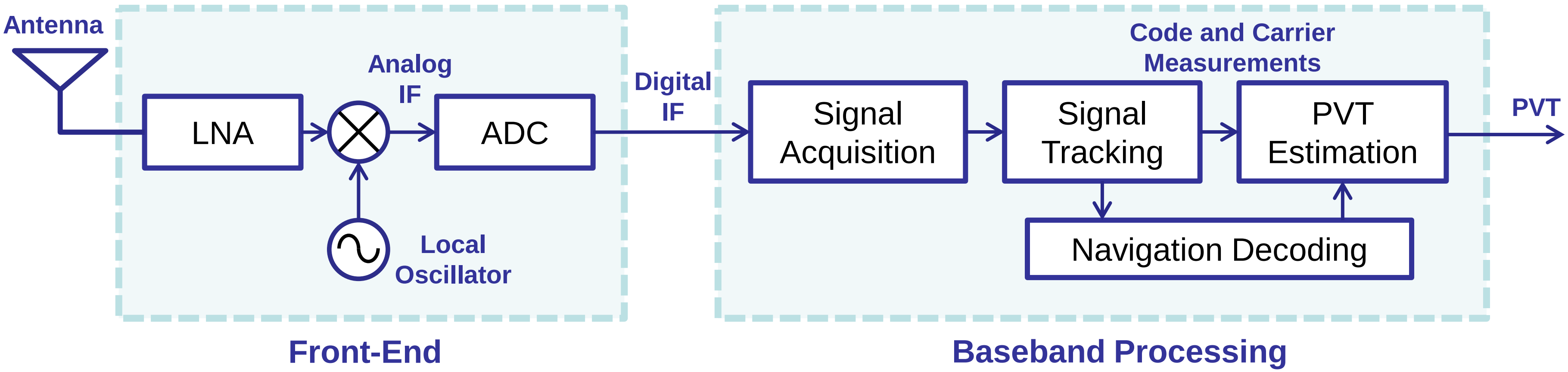
41 satellites！

Let's try to use multi-GNSS software receiver!

Class C6 (10:10-11:30)
Front-End Practice

GNSS Software Receivers

SDR（Software Defined Radio）



What is important to choose front-end?

- Price
- How many bands? (How many front-ends?)
- Sample rate
- Signal bandwidth
- Frequency range (Only L1 or not?)
- Connecter interface (USB2.0 / USB3.0 / Ethernet…)
- Sampling bits
- Oscillator accuracy

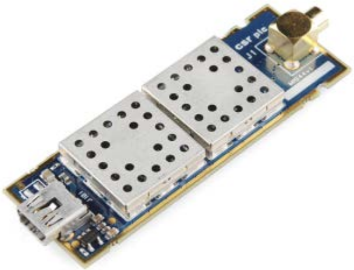
GNSS Front-end (1)

DVB-T dongle (RTL-2832U)

・$10, Frequency: 24M-1.7GHz, Sampling: 2.56MHz
・Poor clock accuracy

Nuand BladeRF (LMS6002D)

・$420, Frequency: 300Hz~3.8GHz, Sampling: ~40Msps
・Tx function (transmitter)



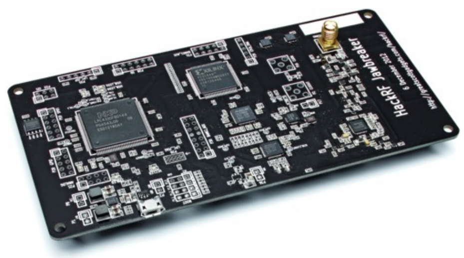
SiGe GN3S sampler V2/V3 (SiGe4120)

・$450, Frequency: 1575.42MHz, Sampling: 4MHz
・For only GPS L1 signal

NSL STEREO (MAX2769b+MAX2112)

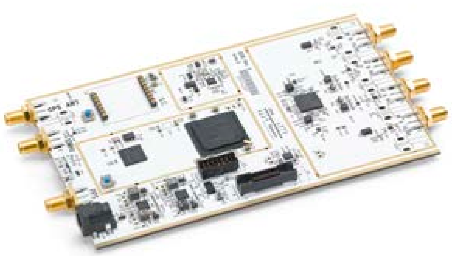
・$850, Frequency: 300Hz~3.8GHz, Sampling: ~40MHz
・Two front-ends

GNSS Front-end (2)



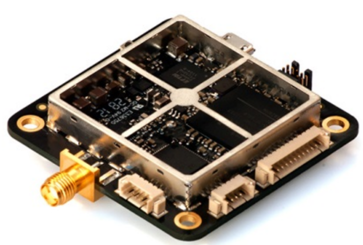
HackRF (LMS6002D)

- $300, Frequency: 30M-6GHz, Sampling: 20MHz
- Kick Starter project



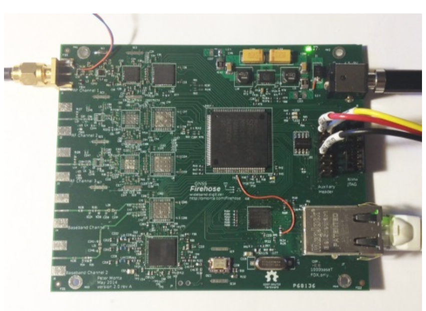
Ettus USRP (AD9361)

- $1100, Frequency: 300~3.8GHz, Sampling: 40Msps
- Two front-ends
- Tx function (transmitter)



SwiftNav Piksi (MAX2769)

- $525, Frequency: 1575.42MHz, Sampling: 16Msps
- For only GPS L1 signal
- RTK GPS enable? (FPGA based)



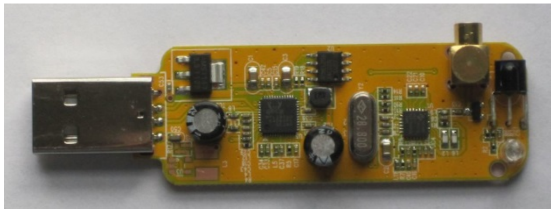
GNSS Firehose (MAX2112)

- $?, Frequency: 300Hz~3.8GHz, Sampling: ~40MHz
- Three front-ends
- Open Source Project

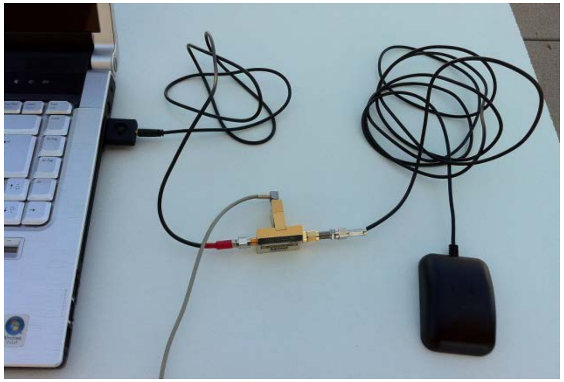
Which is Best?

RTL-SDR

- RTL-SDR
  - Most famous SDR front-end device
  - Using Elonics E4000 turnerchip
  - Using Realtek RTL2832U ADC
- Cheap (about $10~$20)
- Large community
  - http://sdr.osmocom.org/trac/wiki/rtl-sdr
- Active antenna cannot be used in default



Using GPS signal splitter and another GPS receiver (http://blog.goo.ne.jp/osqzss)

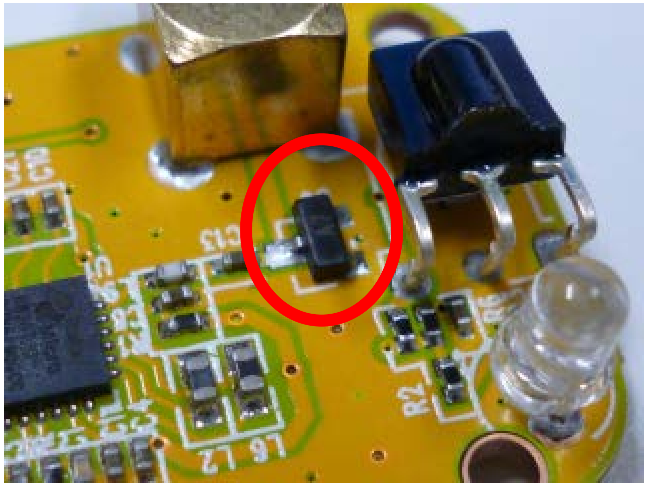


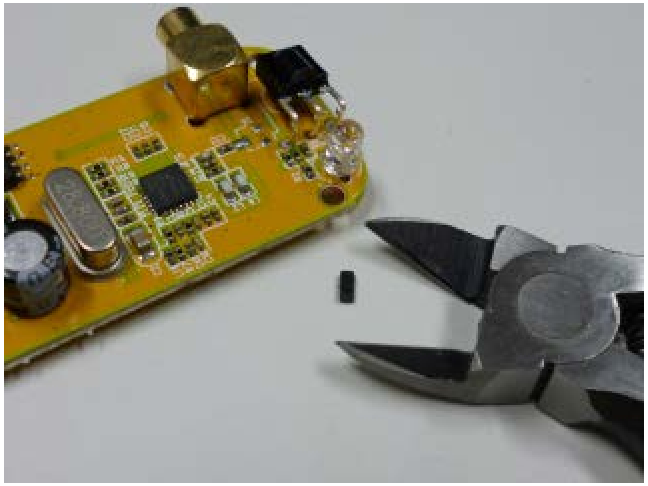
Using a bias-T network (http://gnss-sdr.org)

We have to modify RTL-SDR Dongle to supply voltage into the antenna connecter

Modified RTL-SDR for GNSS Receiver (1)

- Remove diode (red circle in the picture)





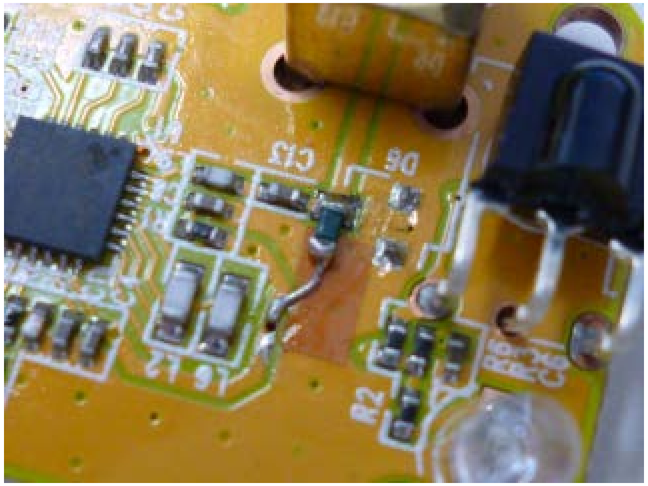
- Remove resist to expose the copper line using knife

OSQZSS: http://blog.goo.ne.jp/osqzss/e/cf966583c4b01596edb66f0608b1d29d

Modified RTL-SDR for GNSS Receiver (2)

- I used Inductor (47nH 270mA) EPCOS B82496C3470J

- Solder inductor and connect to exposed copper line

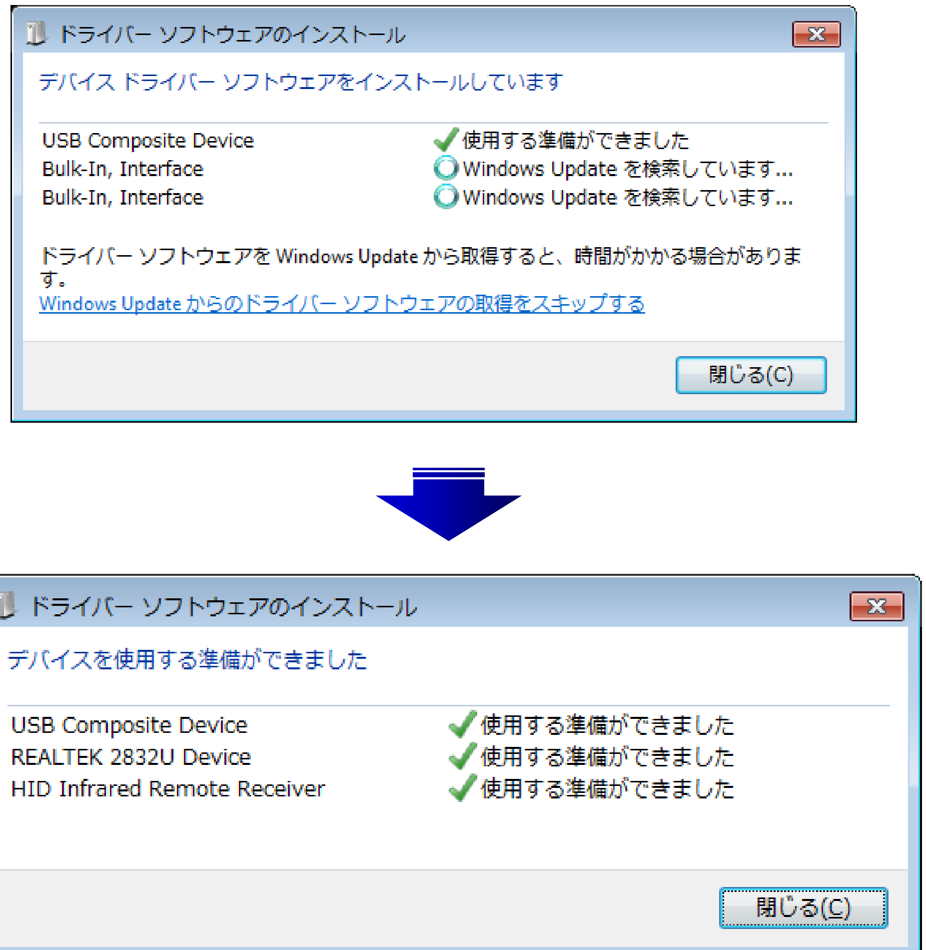


It is not so difficult!

OSQZSS: http://blog.goo.ne.jp/osqzss/e/cf966583c4b01596edb66f0608b1d29d

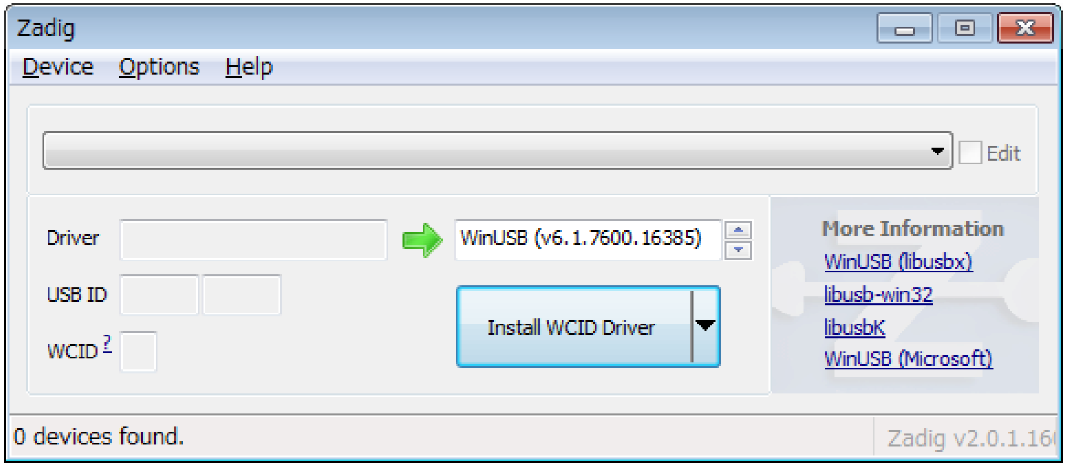
Install RTL-SDR Driver (1)

- Insert the USB tuner on a free USB port and
- Let windows install drivers as they find out all the latest drivers

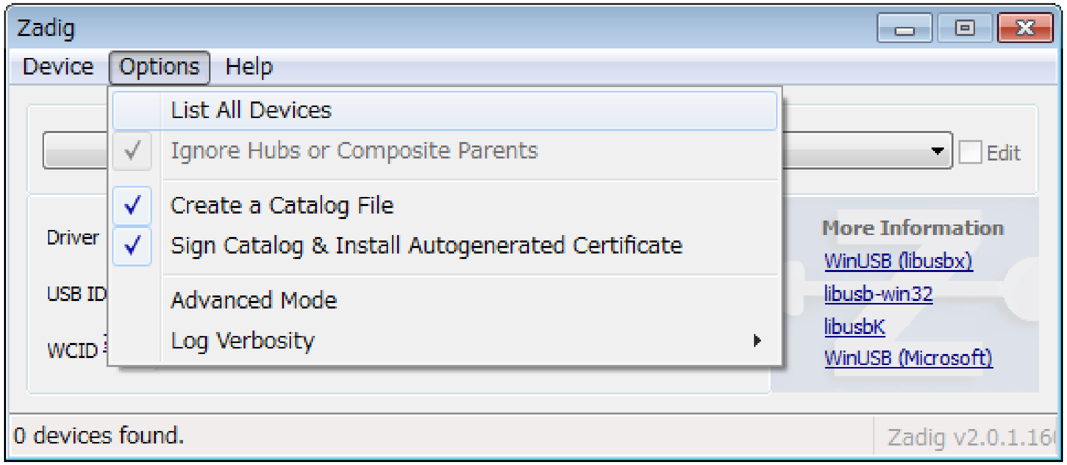


Install RTL-SDR Driver (2)

- Run the Zadig.exe file

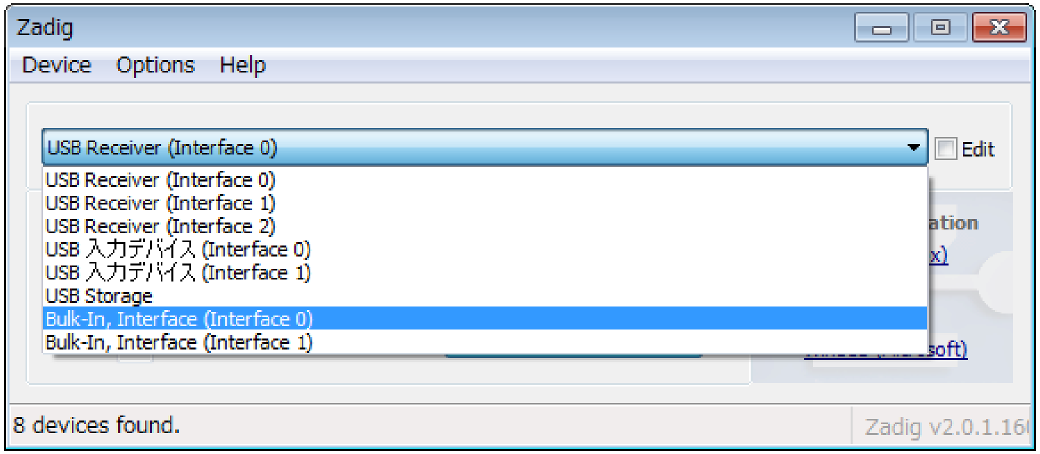


- Click on Option and select “List All Devices”

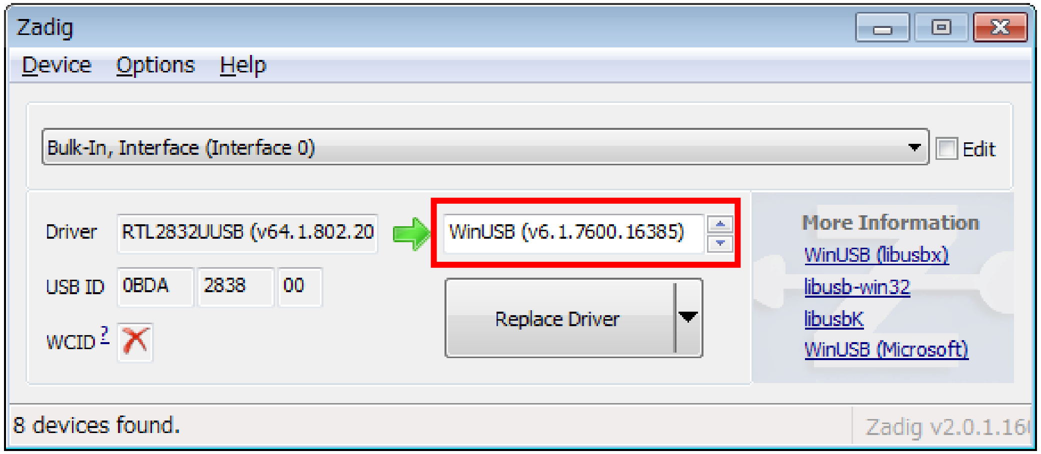


Install RTL-SDR Driver (3)

- Choose the one that says "Bulk-In, Interface (Interface 0)" or "RTL2832UUSB"

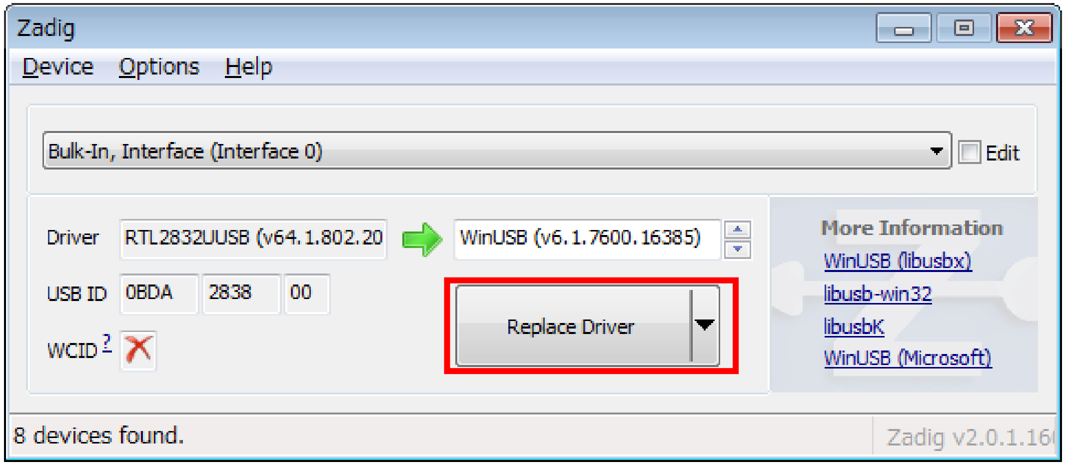


- In the box to the right of the green arrow make sure "WinUSB" is chosen



Install RTL-SDR Driver (4)

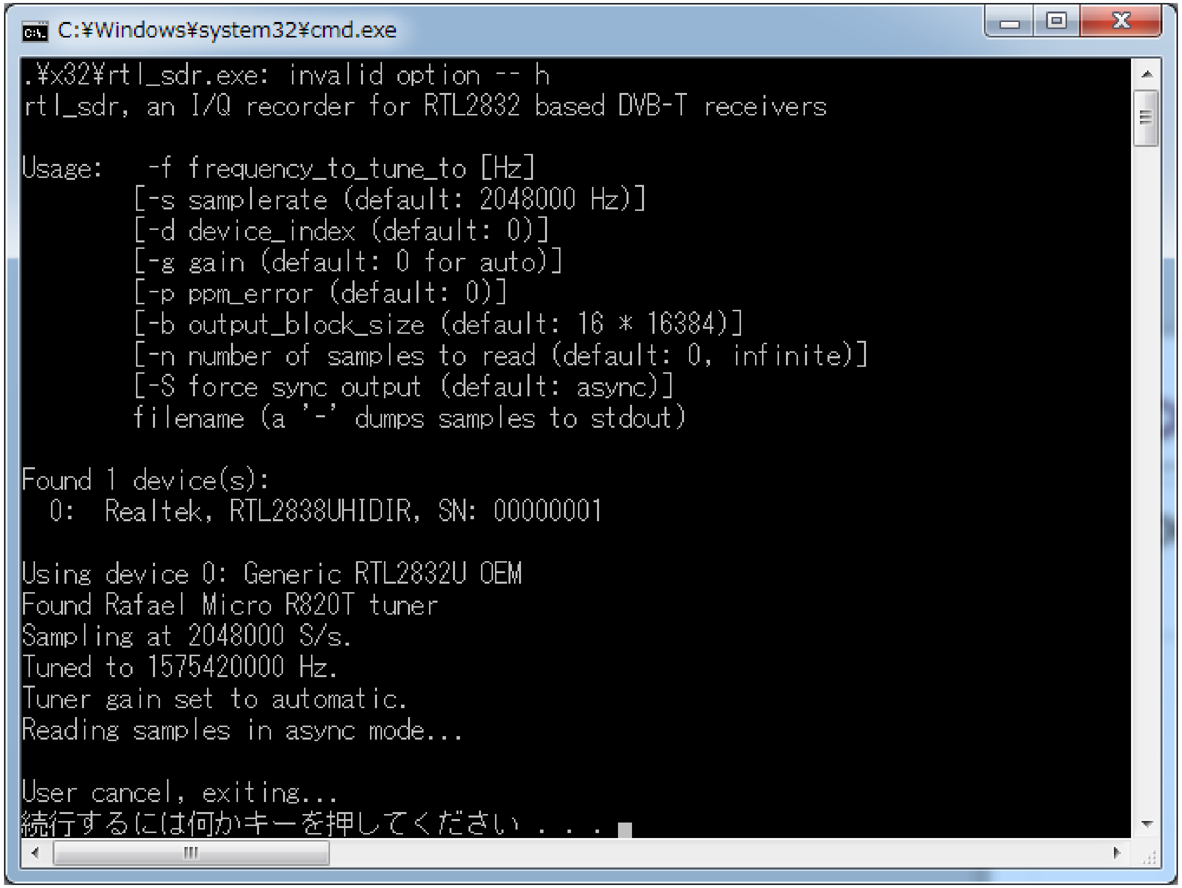
◆ Press "Replace Driver" button



◆ You can find the "Bulk-In, Interface (Interface 0)" or "RTL2838UHIDR" in the "device manager"

Recording RF data using RTL-SDR

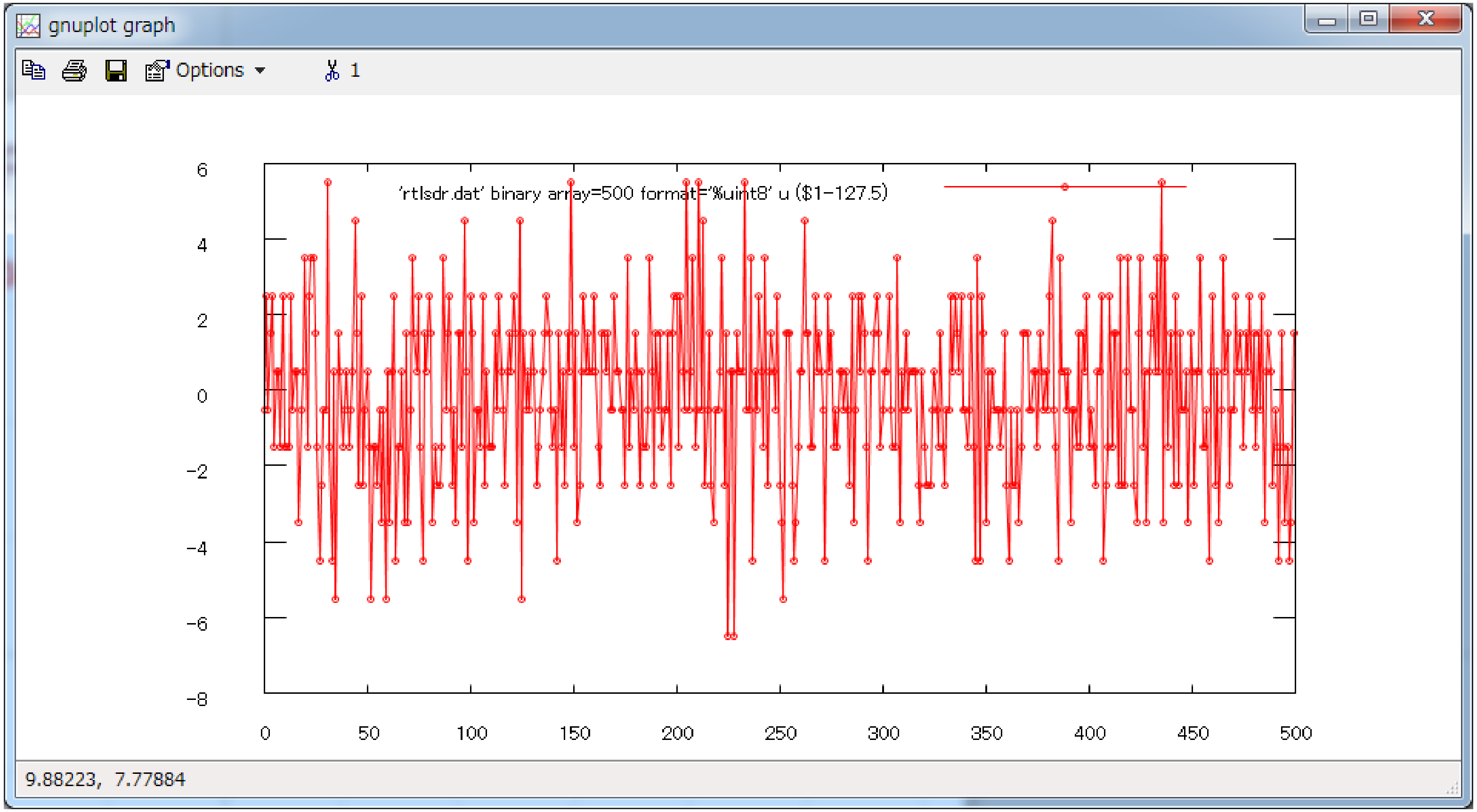
- Open “rtl-sdr” folder and run “1_rtlsdr_logger.bat”



- “rtlsdr.dat” file will be generated
  - Current setting is 2048000 samples = 1 second (2.048Msps)
  - <u>Please try to change options</u> in “1_rtlsdr_logger.bat”

Plot Recorded RF Data

- Click “2_plot_data.bat”



- RTL-SDR format of samples is 8bit (1byte)
  - I1 Q1 I2 Q2….
  - Almost noise…

SDR Practice (12:30-13:50)
GNSS-SDRLIB Practice

GNSS-SDRLIB Features

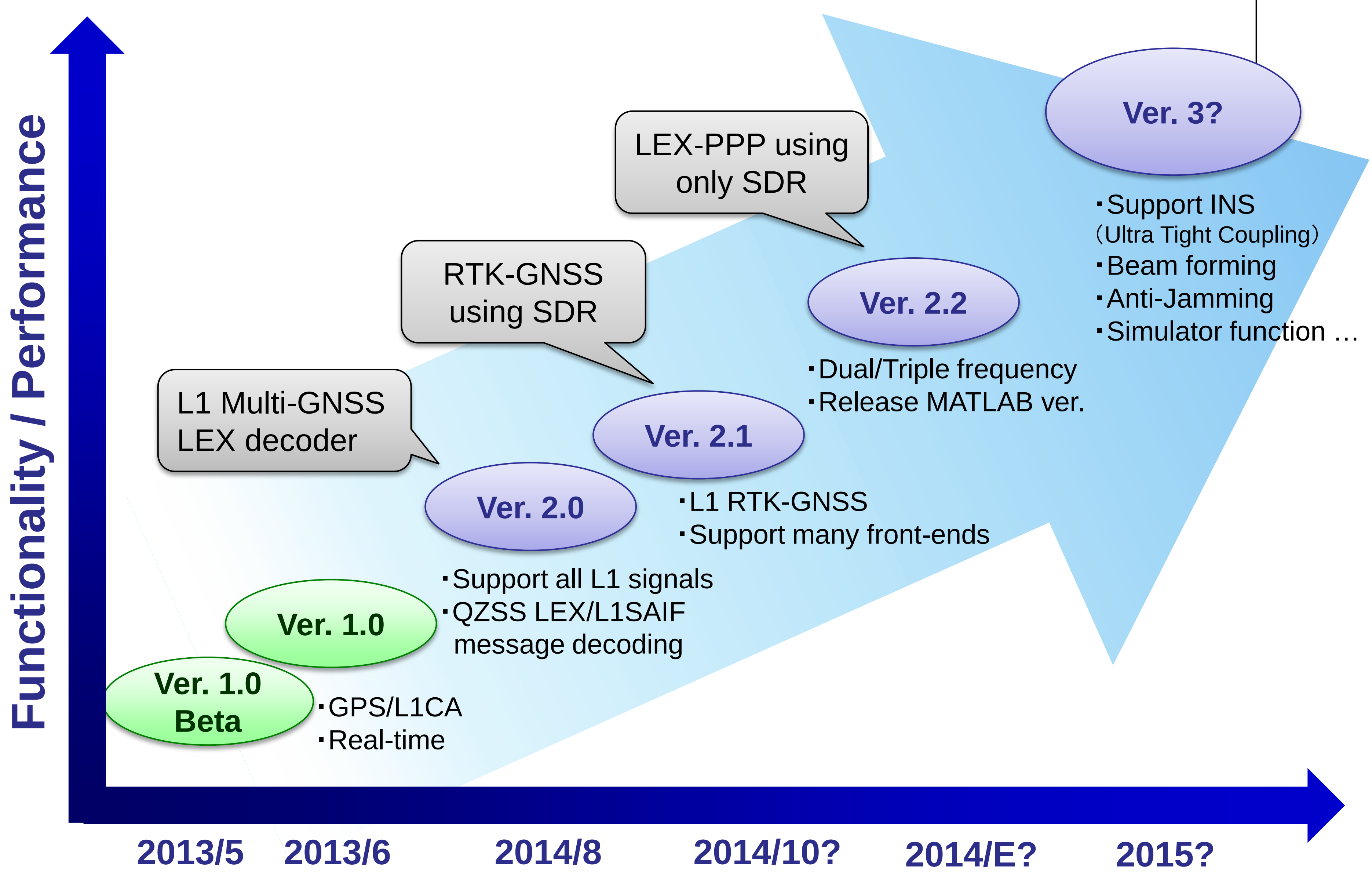
GNSS-SDRLIB http://www.taroz.net/gnsssdrlib_e.html https://github.com/taroz/GNSS-SDRLIB

Version 1.0 Beta, 2013 March
Version 1.0 , 2013 June
Version 2.0 Beta, 2014 June

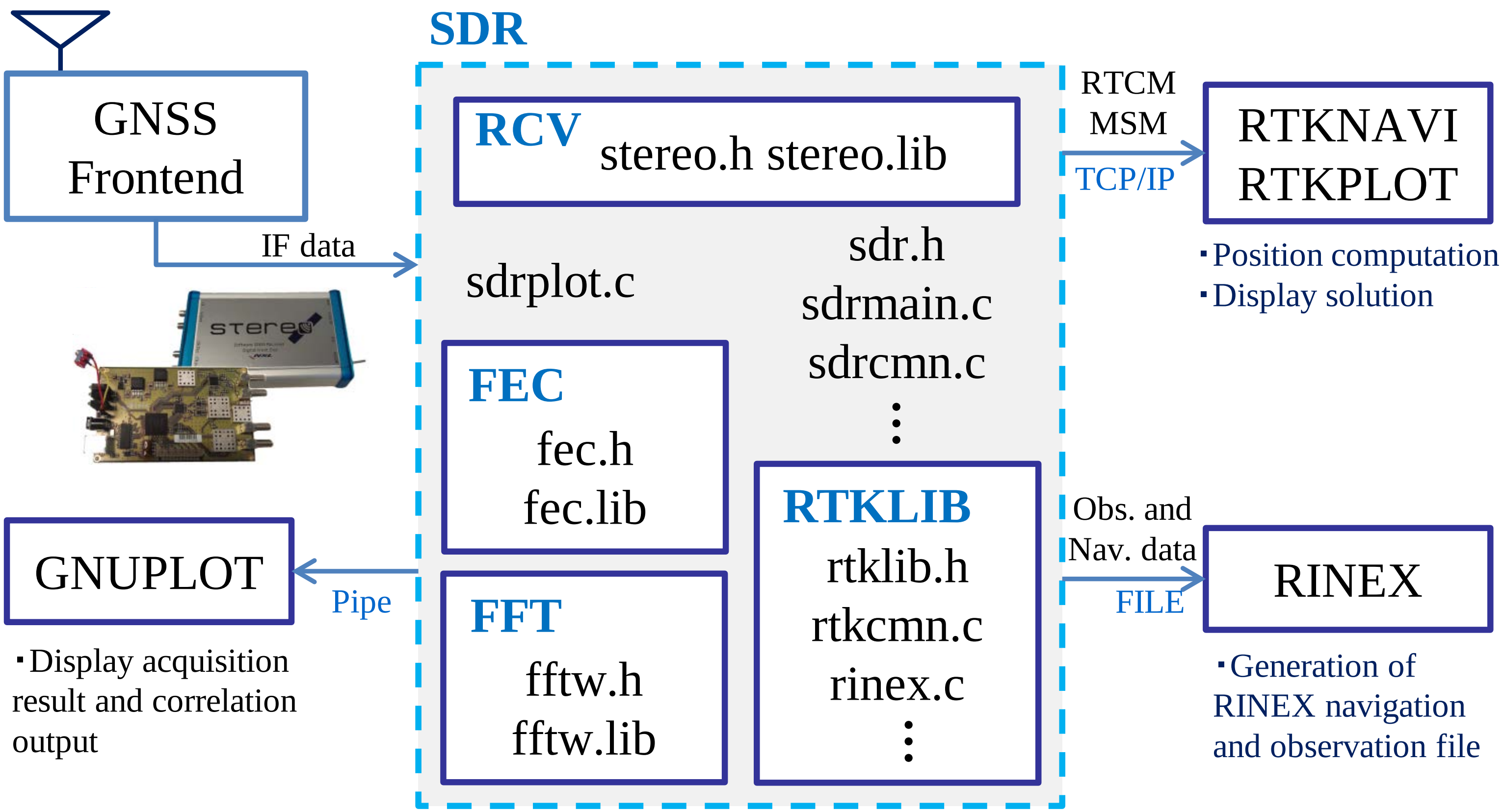
- **GNSS signal processing functions written in C**
  - Code generation of all existing satellites
  - Signal acquisition / tracking functions
  - Decoding navigation messages
  - Pseudo-range / carrier phase measurements
- **GUI application (AP) written in C++/CLI**
- **Visualization of GNSS signal processing in real-time**
- **Real-time positioning with RTKLIB**
- **Observation data can be outputted in RINEX or RTCM format**
- **Support following signals (tracking and decoding navigation message)**
  - GPS, GLONASS, Galileo, BeiDou, QZSS L1 signals
  - Decoding QZSS SAIF/LEX message and SBAS message
- **Support commercial front-ends for real-time positioning**
- **Support RF binary file for post processing**

Real-time Processing and Multi-GNSS support

GNSS-SDRLIB Roadmap



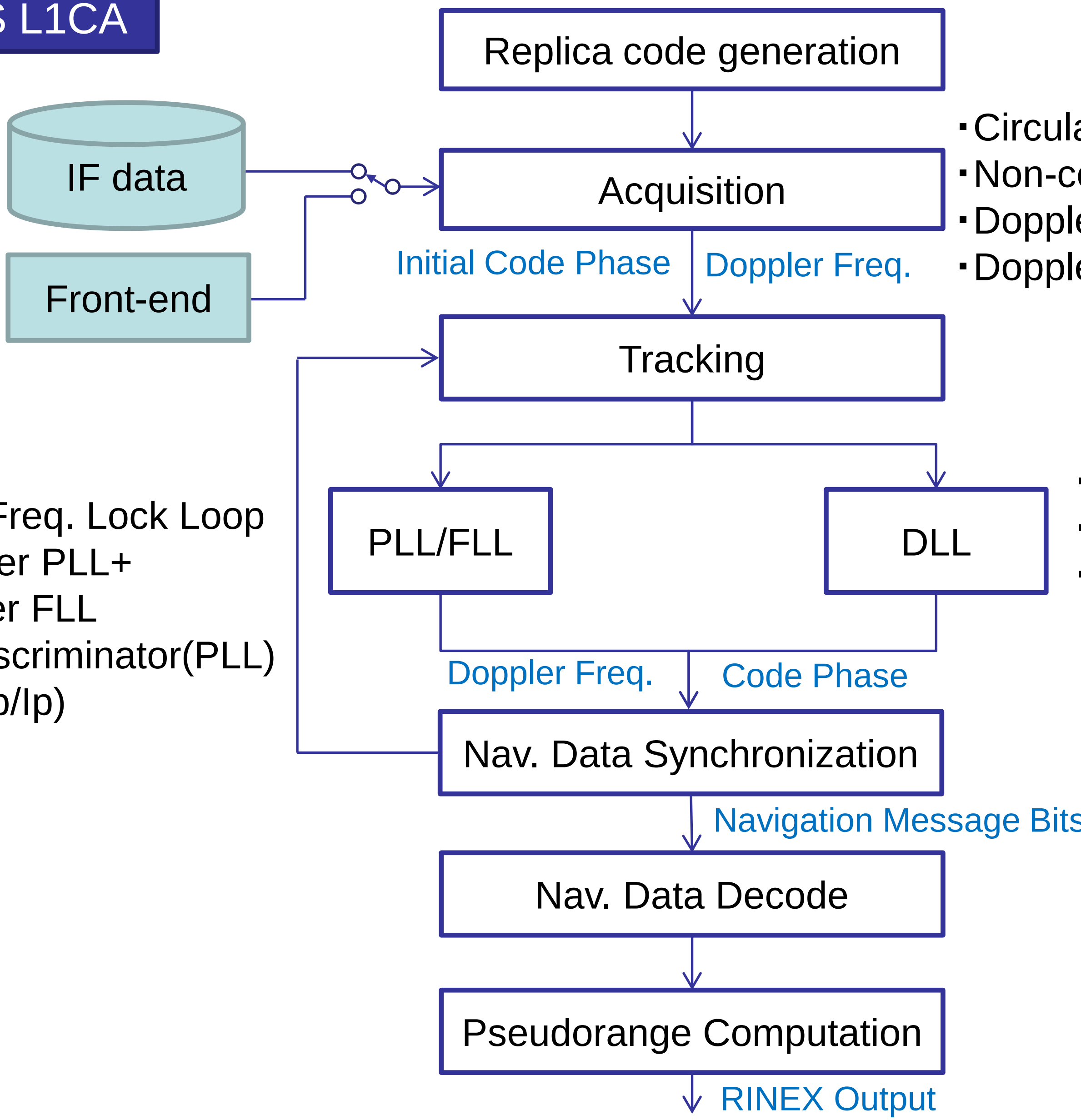
GNSS-SDRLIB Configuration



- Using FFT (Fast Fourier Transform) library
  - FFTW: http://www.fftw.org/)
- Using FEC (Forward Error Correction) library
  - http://www.ka9q.net/code/fec/
- Using RTKLIB
  - http://www.rtklib.com/

Acquisition and Tracking GNSS Signals

GPS L1CA



- Circular correlation by FFT
- Non-coherent integration
- Doppler search step: 200 Hz
- Doppler search range: -7~+7kHz

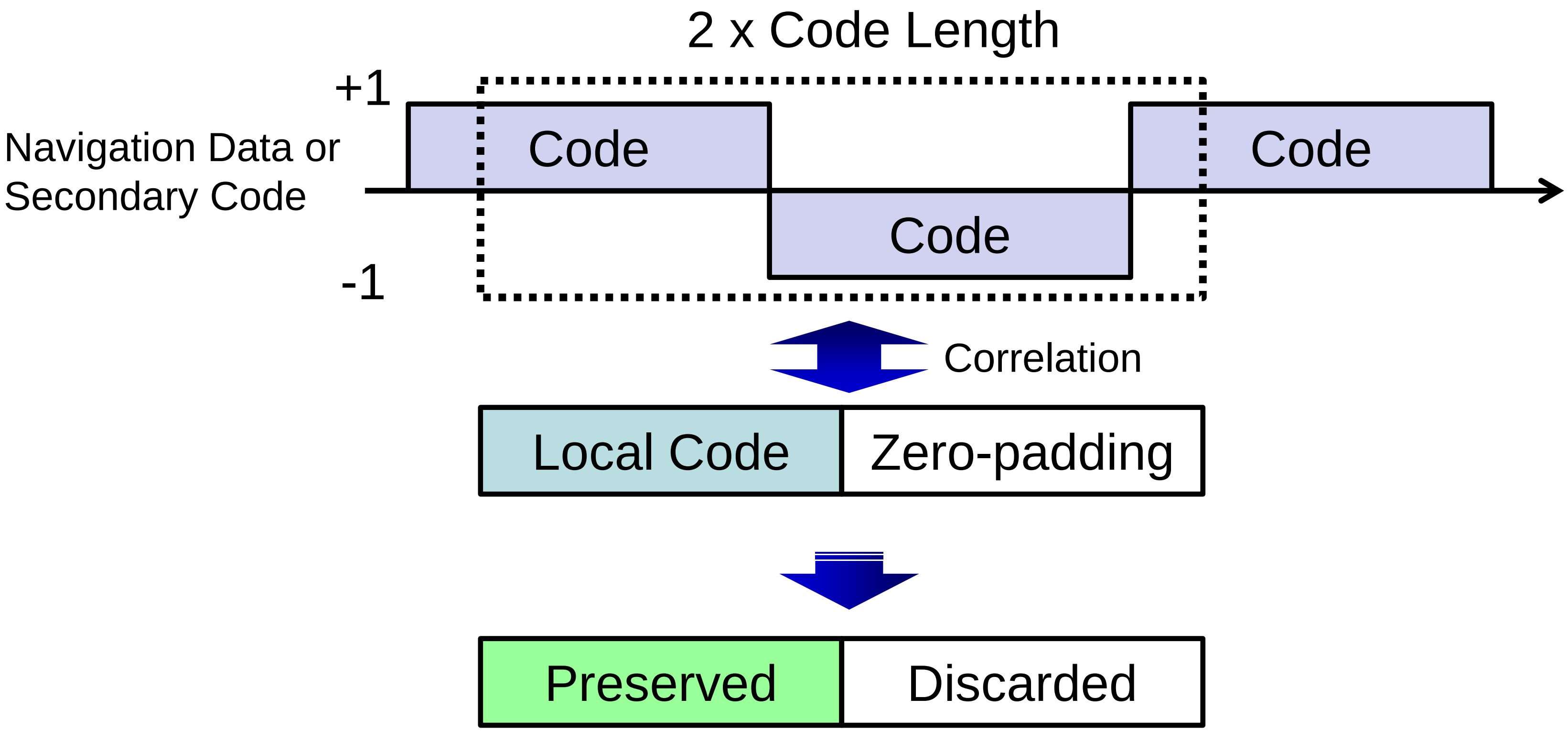
- Phase/Freq. Lock Loop
- 2nd order PLL+ 1st order FLL
- Error discriminator(PLL) atan(Qp/Ip)

- Delay Lock Loop
- Carrier aid 2nd order DLL
- Error discriminator (E-L)/(E+L)/2

Acquisition Method

Circular correlation by Zero-padding FFT

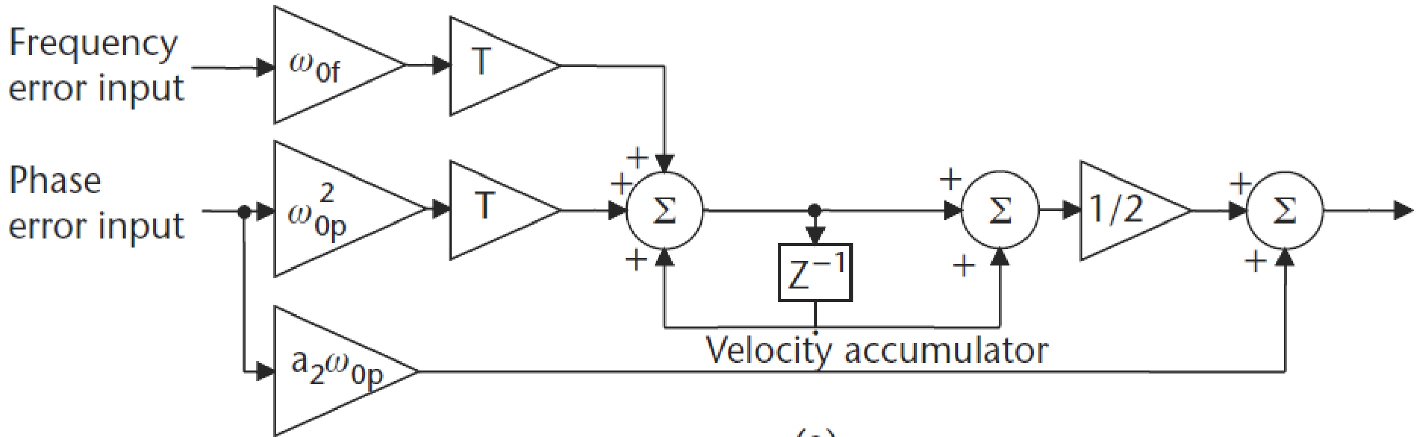
Ziedan, N. I., and Garrison, J. L. "Unaided acquisition of weak GPS signals using circular correlation or double-block zero padding"



- Perfect correlation can be obtained when navigation bit is changed
- Computational cost is doubled

Tracking Method

- 2^{nd} order PLL with 1^{st} order FLL



(a)

Elliott D. Kaplan, Christopher Hegarty , Understanding GPS: Principles And Applications

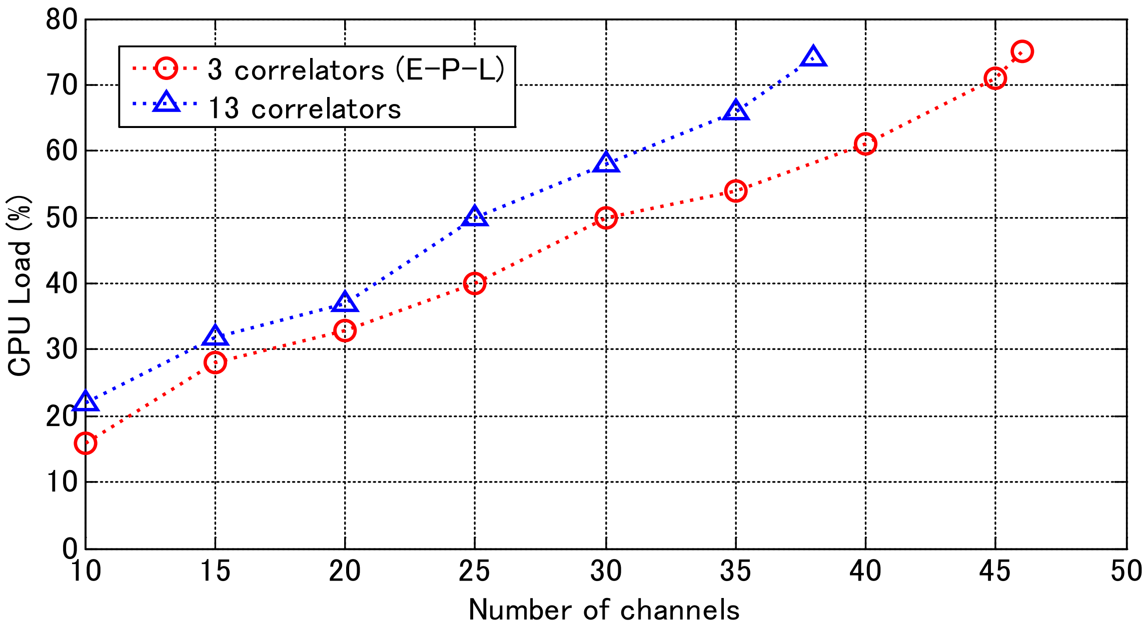
- Carrier aided 2^{nd} order DLL
- E-P-L correlator / Multi correlator
- Integration correlation result (4ms~20ms)
- Display correlation output in real-time

Real-time Processing Performance

How to speed up?

- **<u>Signal Acquisition</u>**
  - Dependent on FFT library
  - Currently, FFTW3.3.3, 64bit Single precision is used
- **<u>Signal Tracking</u>**
  - Using SIMD (Single Instruction Multiple Data) for correlation

Real-time Processing Performance（20Msps, Core i7-3770, SSE2）

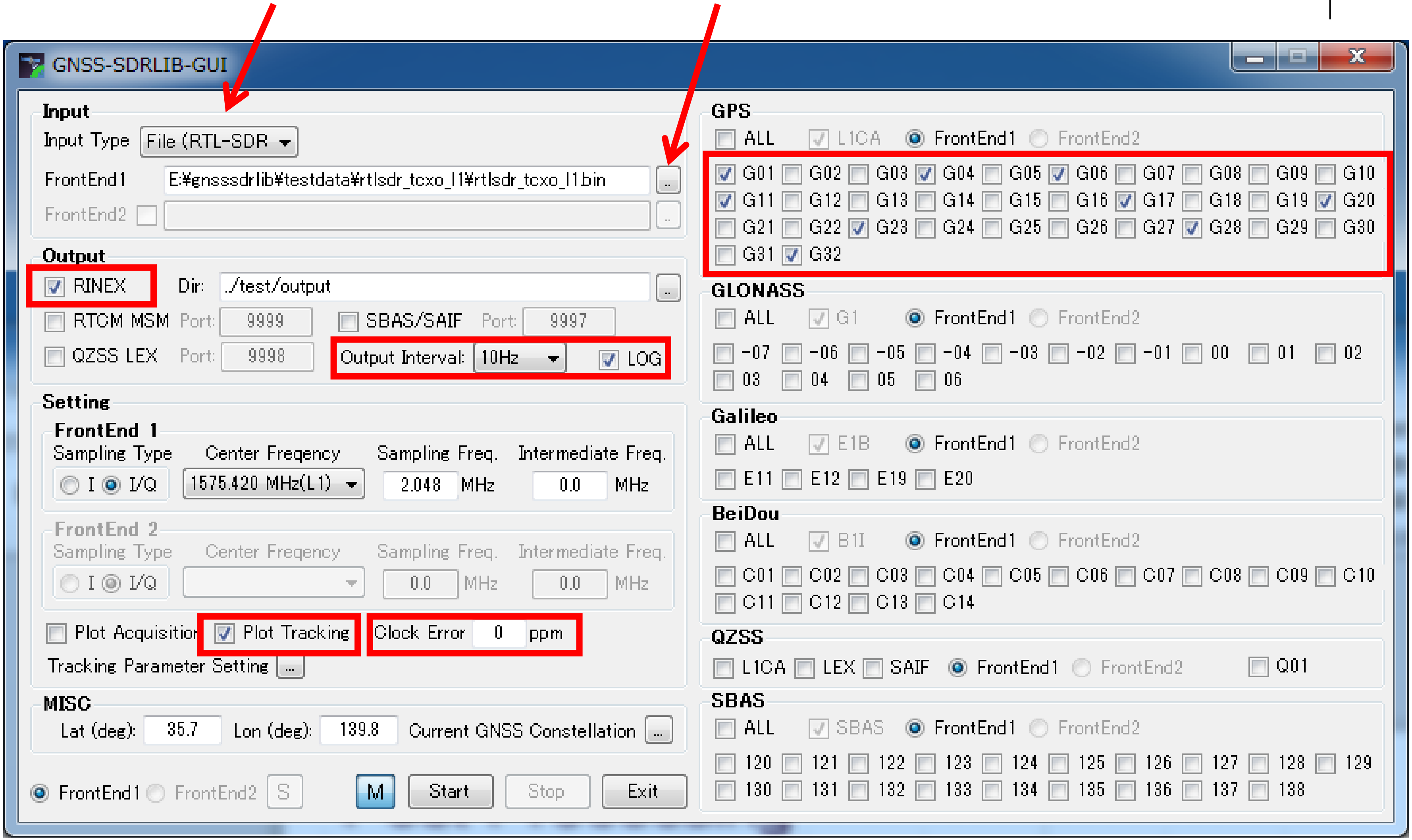


➡ <u>In the case of E-P-L correlator, it works with 45 channels!</u>

GNSS-SDRLIB Practice

Post Processing Setting

Select “File (RTL-SDR)” Select “../../testdata/rtlsdr_tcxo_l1.bin”

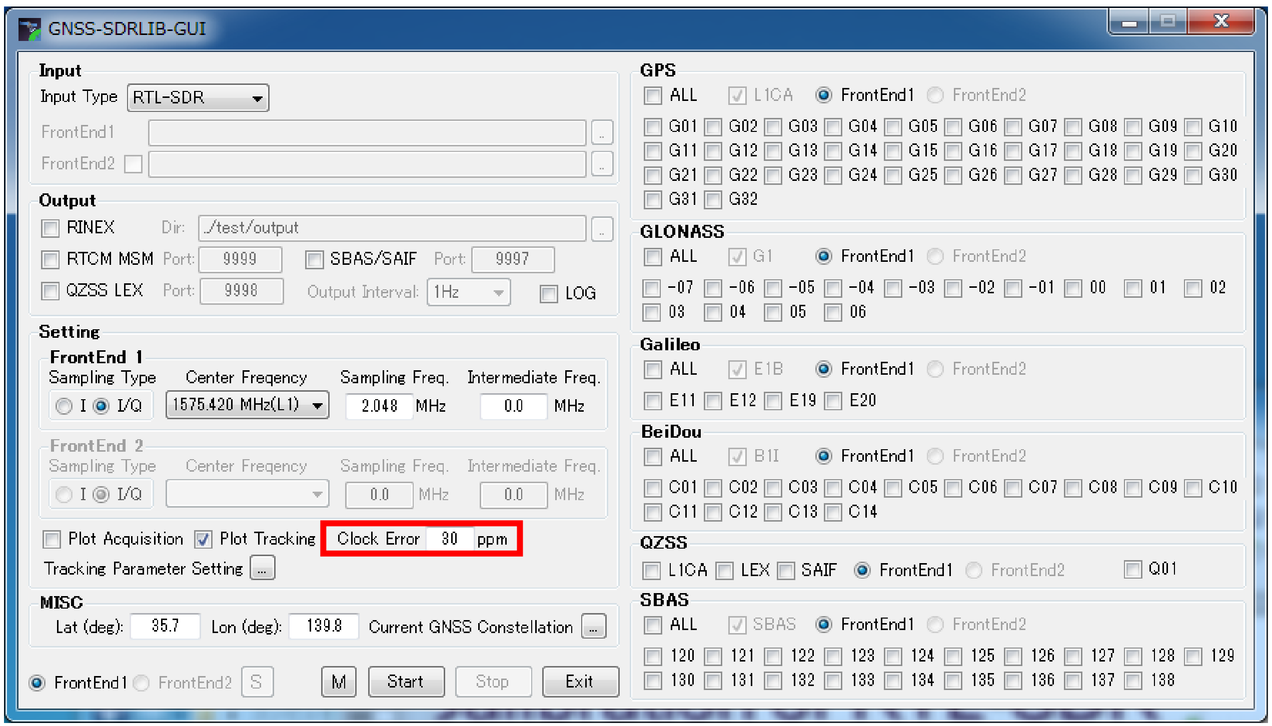


Real-time Processing – Environment –

- **Antenna is installed on rooftop of building**
  - Not open-sky environment
- **Signals are re-emitted by GPS repeater in the room**
  - Multipath and directivity problem

Calibration of RTL-SDR

- **<u>Accuracy of oscillator is very poor!!!!</u>**
  - Large bias error (10~90 ppm!)
  - Large drift error and not stable
- **<u>How to calibrate?</u>**
  - Check signal acquisition result with changing ppm offset!

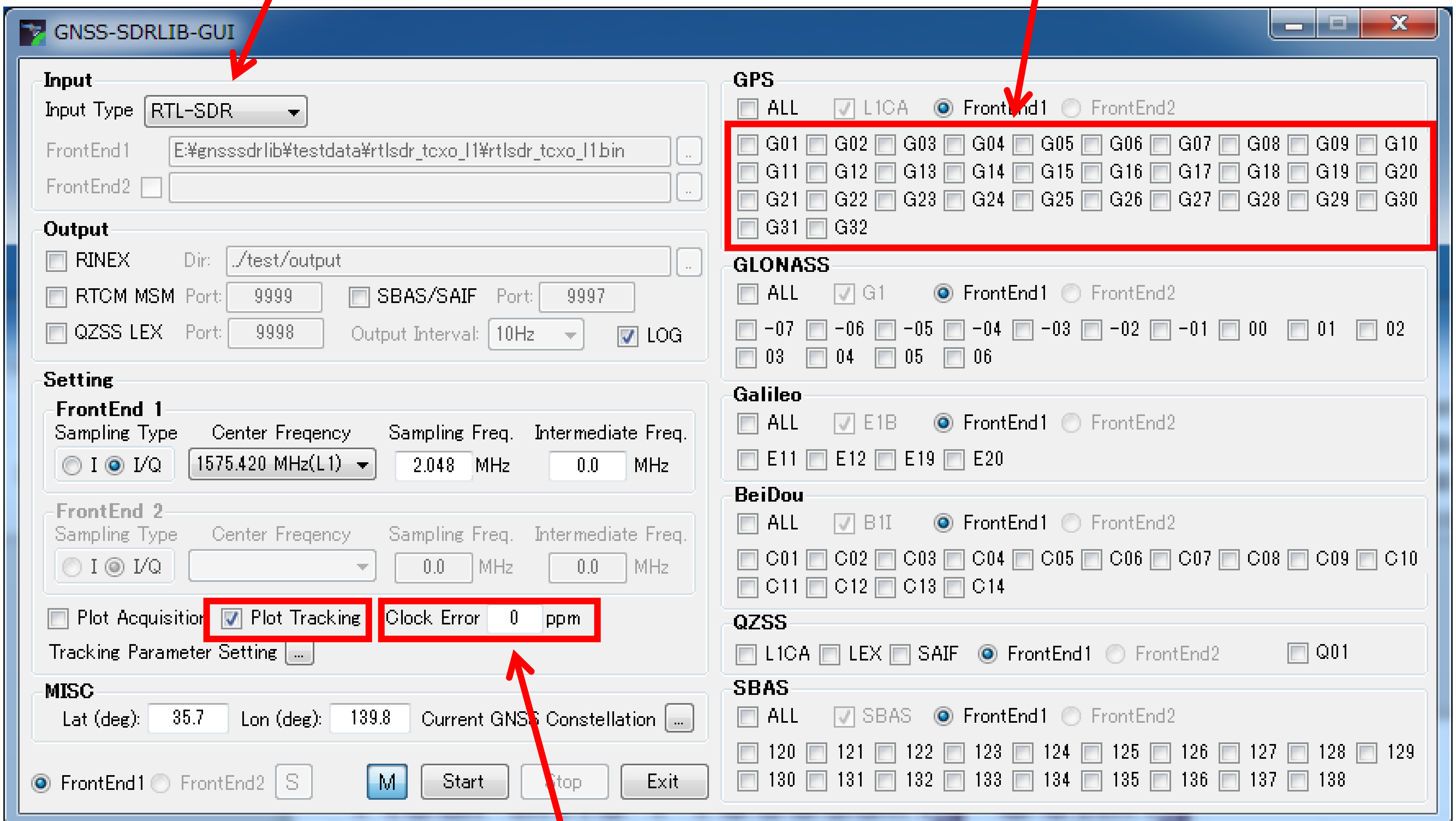


Try to change to 10,20,30,40,50,60,70,80 …

Real-time Processing – Setting –

Select “File (RTL-SDR)”

Select most high-elevation satellite

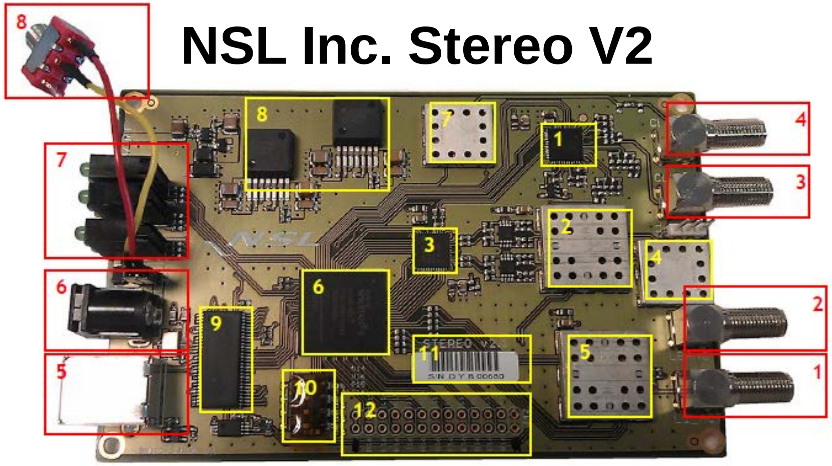


Try to change to 10,20,30,40,50,60,70,80 …

Demonstration 1
Positioning with Multi-GNSS

Front-end for Multi-GNSS Constellation

NSL Inc. Stereo V2



£650

1. LMK03033C clock distribution chip
2. Maxim/Dallas MAX2112 RF front-end
   ⇒ For L Band (925 - 2175MHz)
3. Maxim/Dallas MAX19506 dual 8-bits ADC
4. MMIC amplifiers
5. Maxim/Dallas MAX2769B RF front-end
   ⇒ For L1 GNSS(1550 - 1610MHz)
6. Xilinx Spartan-6 FPGA
7. TXC 26MHz TCXO oscillator

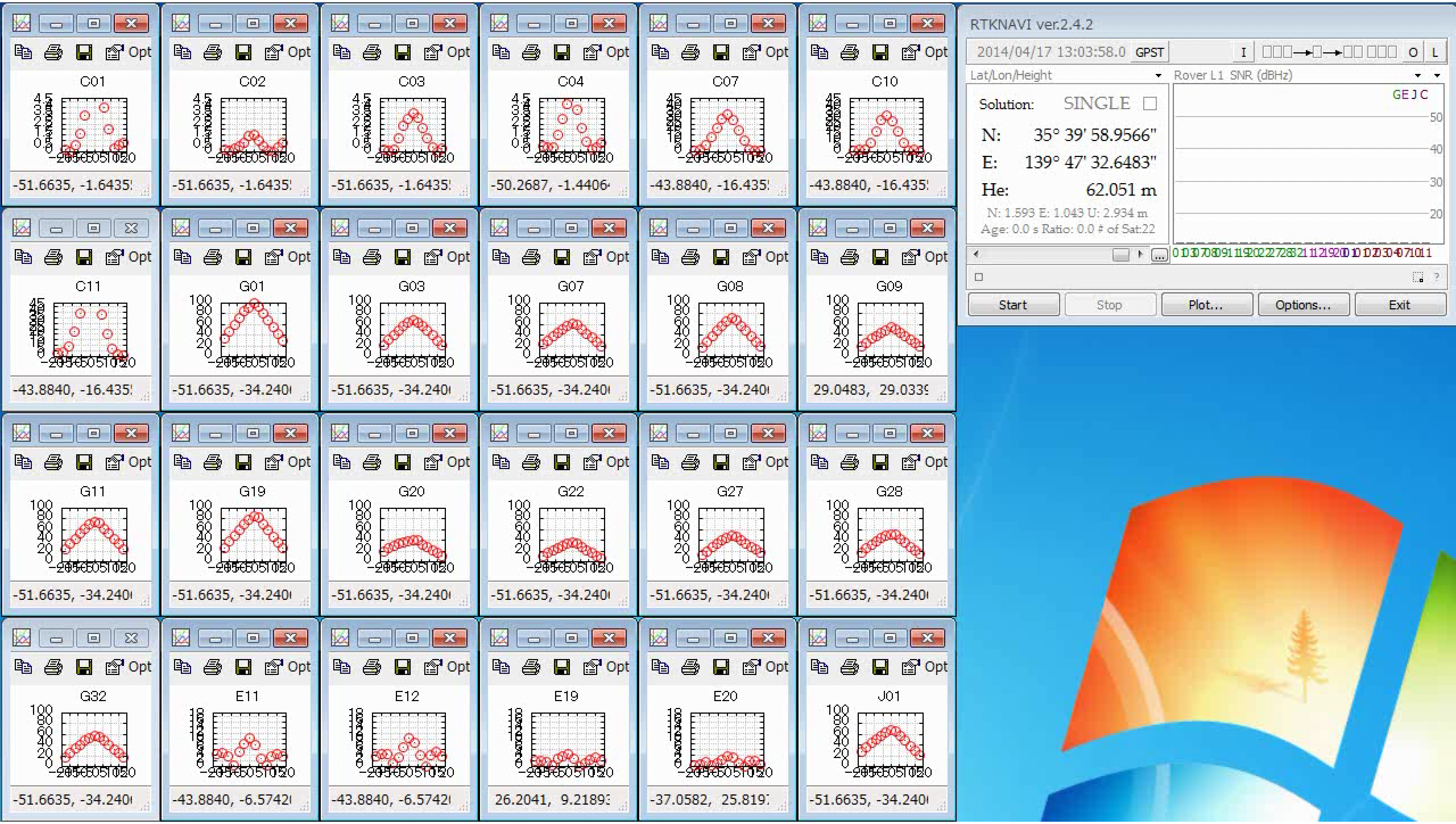
£800

http://www.nsl.eu.com/primo.html

- USB 2.0 interface
- Simultaneously recording two front-end data
- All front-end setting is configurable
  - Center frequency
  - Bandwidth
  - Sample rate (8MHz~40MHz)

Demonstration of Multi-GNSS

2014/4/17, TUMSAT, GPS/QZS/Galileo/BeiDou



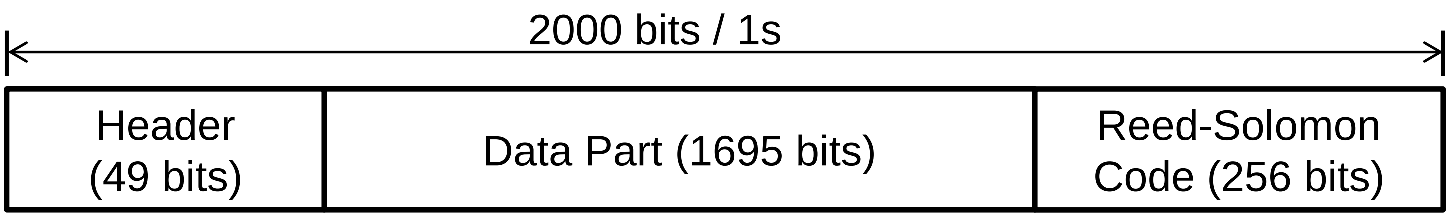
Video URL: http://youtu.be/N5tScnIQzkI

Demonstration 2
MADOCA-LEX PPP

LEX Message

LEX data structure

- 1 message = 2000 bits / 250 symbols, 2 kbps
- Length of overlaid code is 4 ms and it represents 1 symbol
- Using code shift keying (CSK) modulation
- Reed-Solomon error correction



MADOCA-LEX data structure

- Multi-GNSS real-time orbit/clock data (Currently, GPS/GLONASS/QZSS)
- Message format is based on RTCM SSR

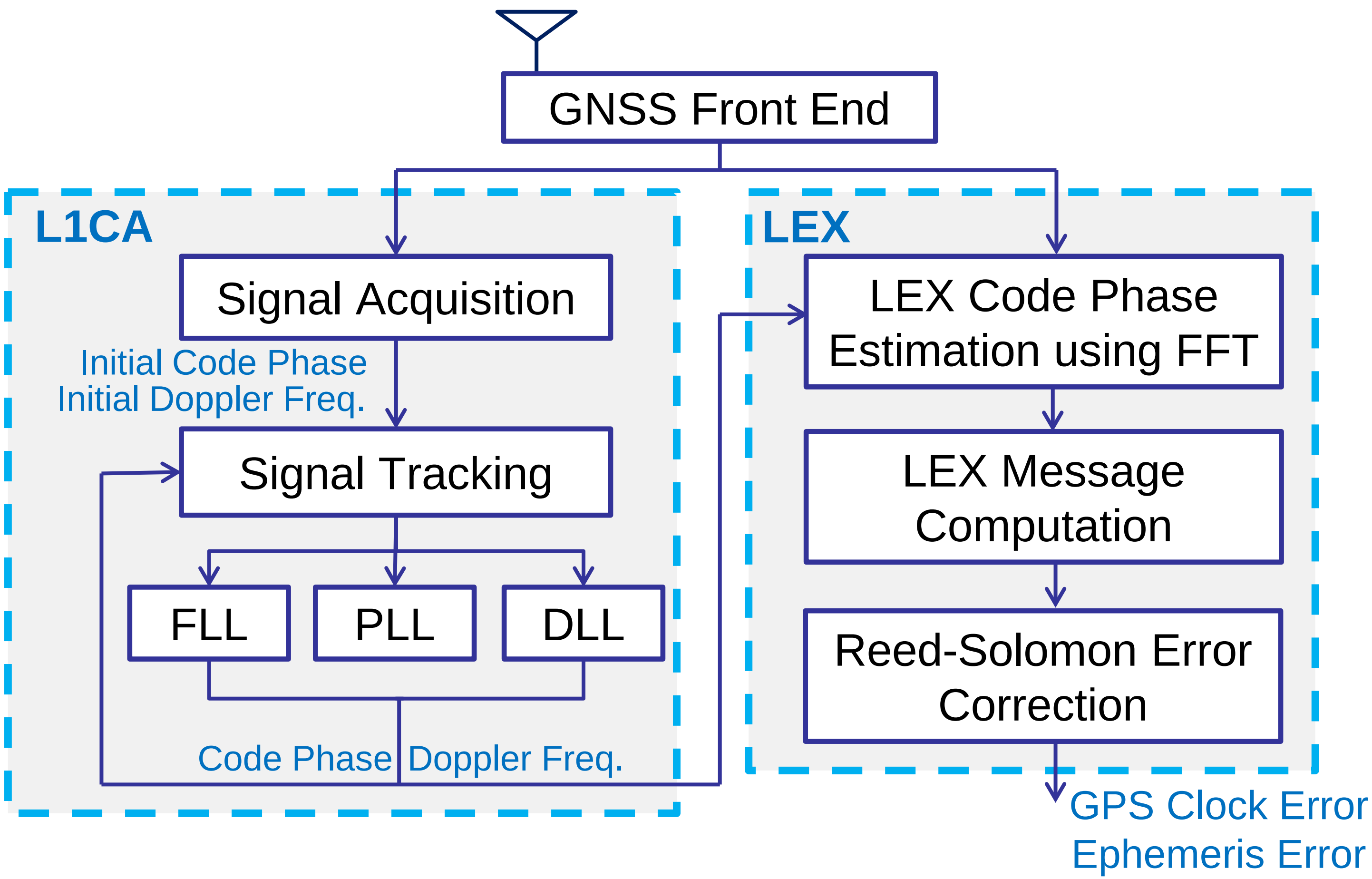
	SSR Message #				Update
	GPS	GLONASS	QZSS	Galileo	
Orbit	1057	1063	1246	1240	30 s
High rate clock	1062	1068	1251	1245	2 s

⇨ Decoding CSK modulated message using software GNSS receiver!

LEX Decoding Method

Approach

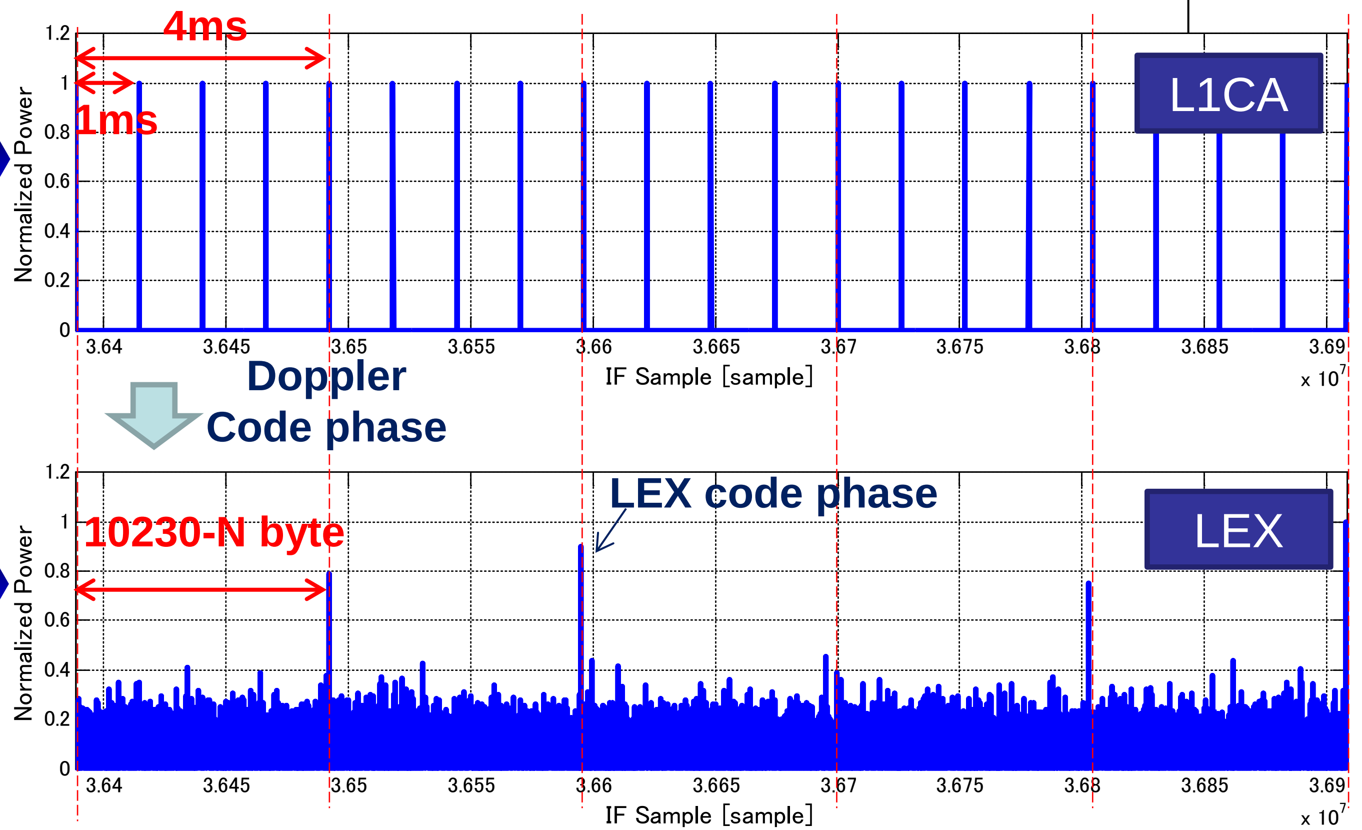
- LEX signal uses code shift keying (CSK) modulation
- L1CA Code phase and Doppler assistance for decoding LEX
- FFT based CSK modulation decoding



LEX Decoding Example

The estimated L1CA code phases

Computing the LEX message symbol by taking the difference between the L1CA code phase and LEX code phase



- ○ No need to track LEX ranging code (no DLL, PLL, etc.)
- ○ Easy implementation
- △ Computational cost