測位航法学会全国大会2022 研究発表会

Develeopment of QZSS L6 Receiver without Pilot Signal by using SDR

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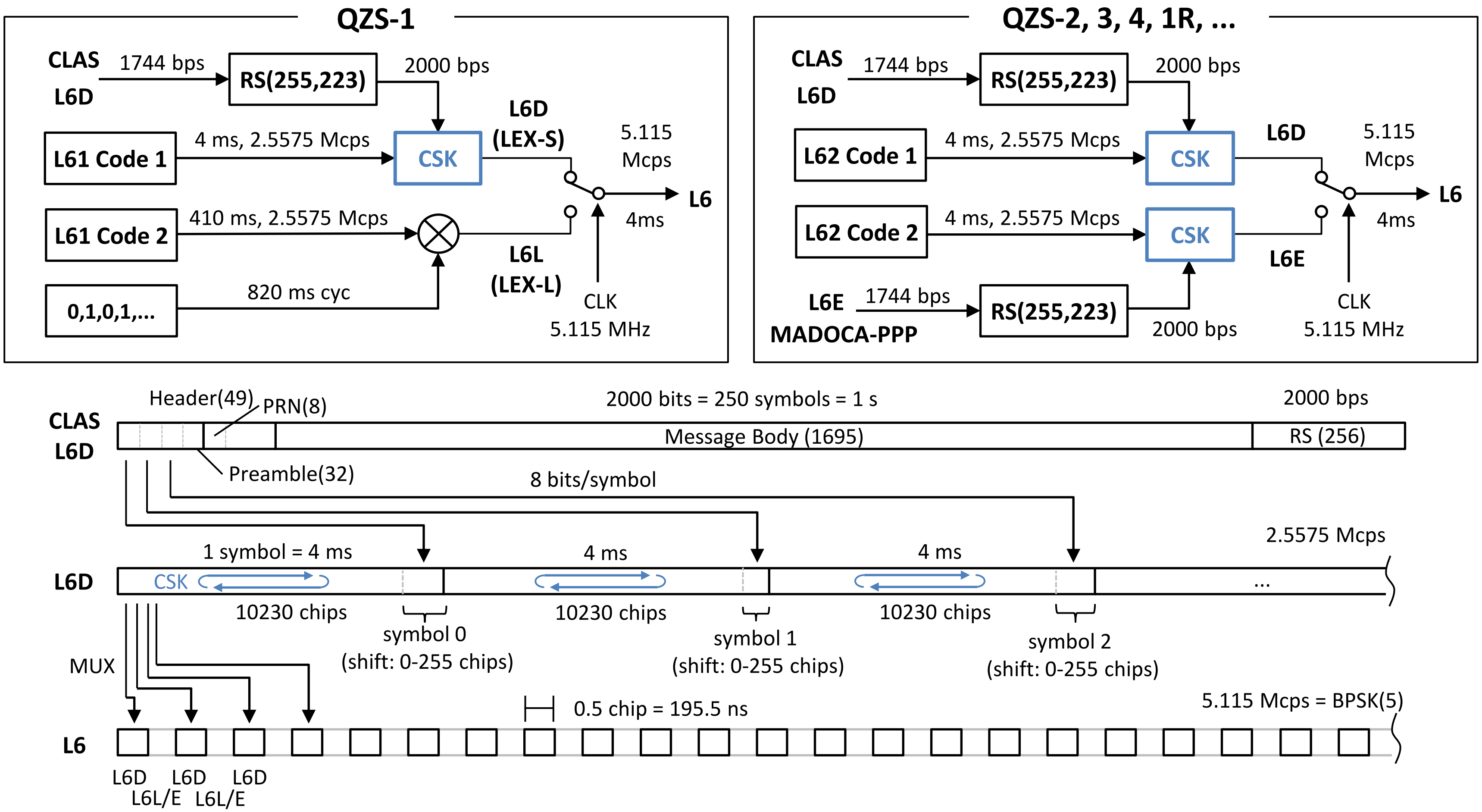
2022-06-10 @Online, Japan

Background

QZSS L6 Signal Structure

Carrier Frequency: 1278.75 MHz, Modulation: CSK + BPSK(5)



[1] IS-QZSS-L6-003, Quasi-Zenith Satellite System Interface Specification Centimeter Level Augmentation Service, August 20, 2020

Existing L6 Receivers

Commercial Receivers Supporting L6

- Trimble : NetR9, Alloy (only track QZS-1 L6, no L6 NAV data)
- NovAtel : OEM7 (only track QZS-1 L6, no L6 NAV data)
- JAVAD : TR-2S/3S, TRE-3S/L (only track QZS-1 L6 ?)
- Septentrio : AsteRx4, AsteRx-m3 CLAS, mosaic-CLAS (no L6 range info ?)
- u-blox : NEO-D9C (no L6 range info, only 2CH)
- Allystar : HD9310 (no L6 range info, L6D or L6E)
- MSJ, Mitsubishi, Core, LHTC ...

Limitations

- Tracking L6L (LEX-L) and decoding CSK assisted by L6L as pilot CH [1]
  -> only QZS-1, long acquisition time for L6L
- Decoding CSK assisted by L1C/A or L2C as pilot CH -> needs dual freq. or wide BW RF frontend, needs IFB calibration, long acquisition time for L2C
- No L6 range info of QZS-2 ~ for PVT
- Complicated H/W with many (> 256) correlators to decode CSK

[1] 王 他, QZS-LEX受信機, GPS/GNSSシンポジウム2010, 2010年11月4 ~ 6日, 東京海洋大学越中島

New L6 Receiver Design

Design Goal

Simple and Low-Cost Architecture

- No pilot signal CH
- Narrow BW (10 MHz) single RF frontend
- Simplified FFT-based parallel correlator to decode CSK
- Full L6 signals (2CH x 7 sats) trackable by minimum H/W

Fast Signal Acquisition

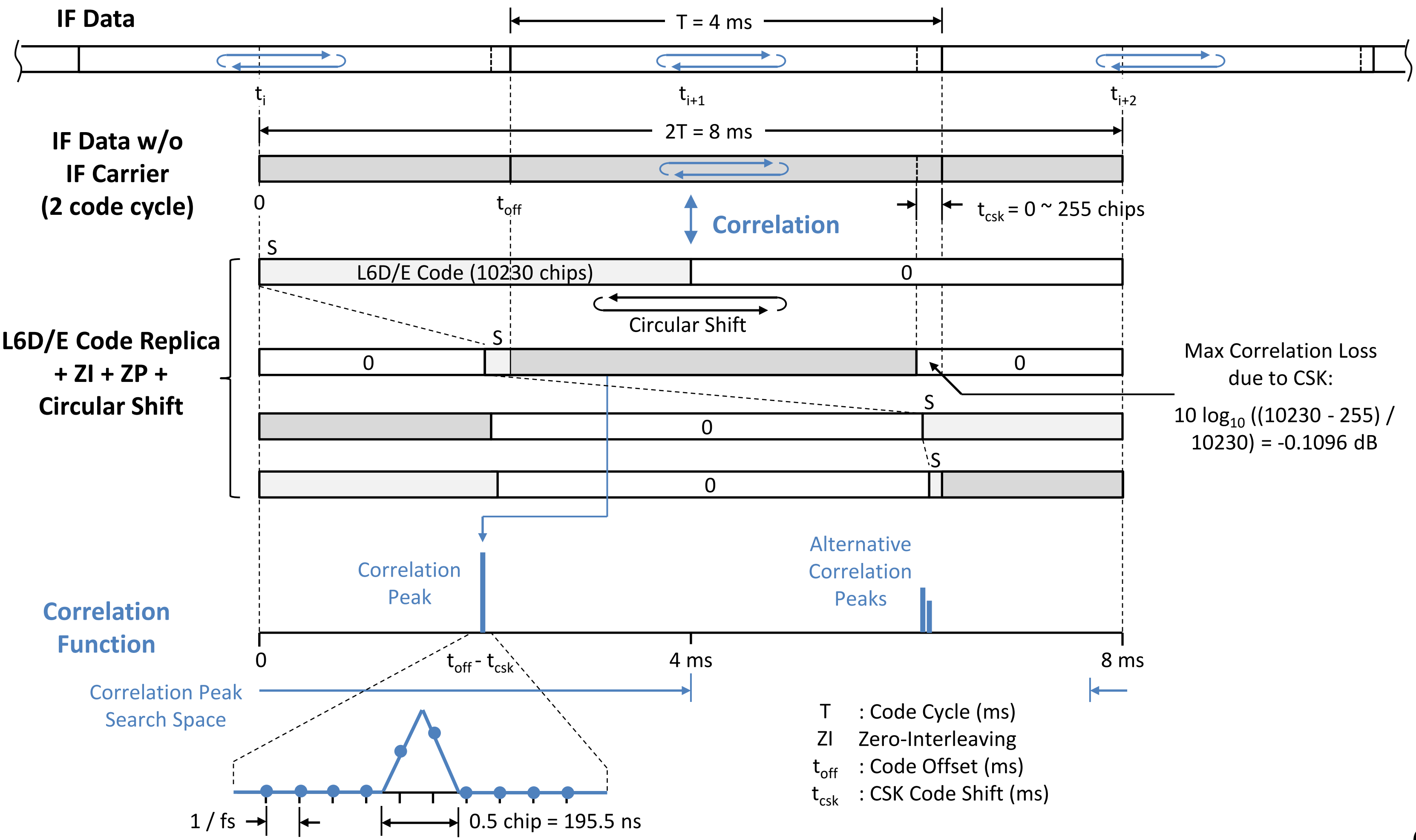
- Direct search of L6 code
- No need of multi-stage acquisition
- High availability of L6 NAV data in severe environment

Range Info Available for PVT

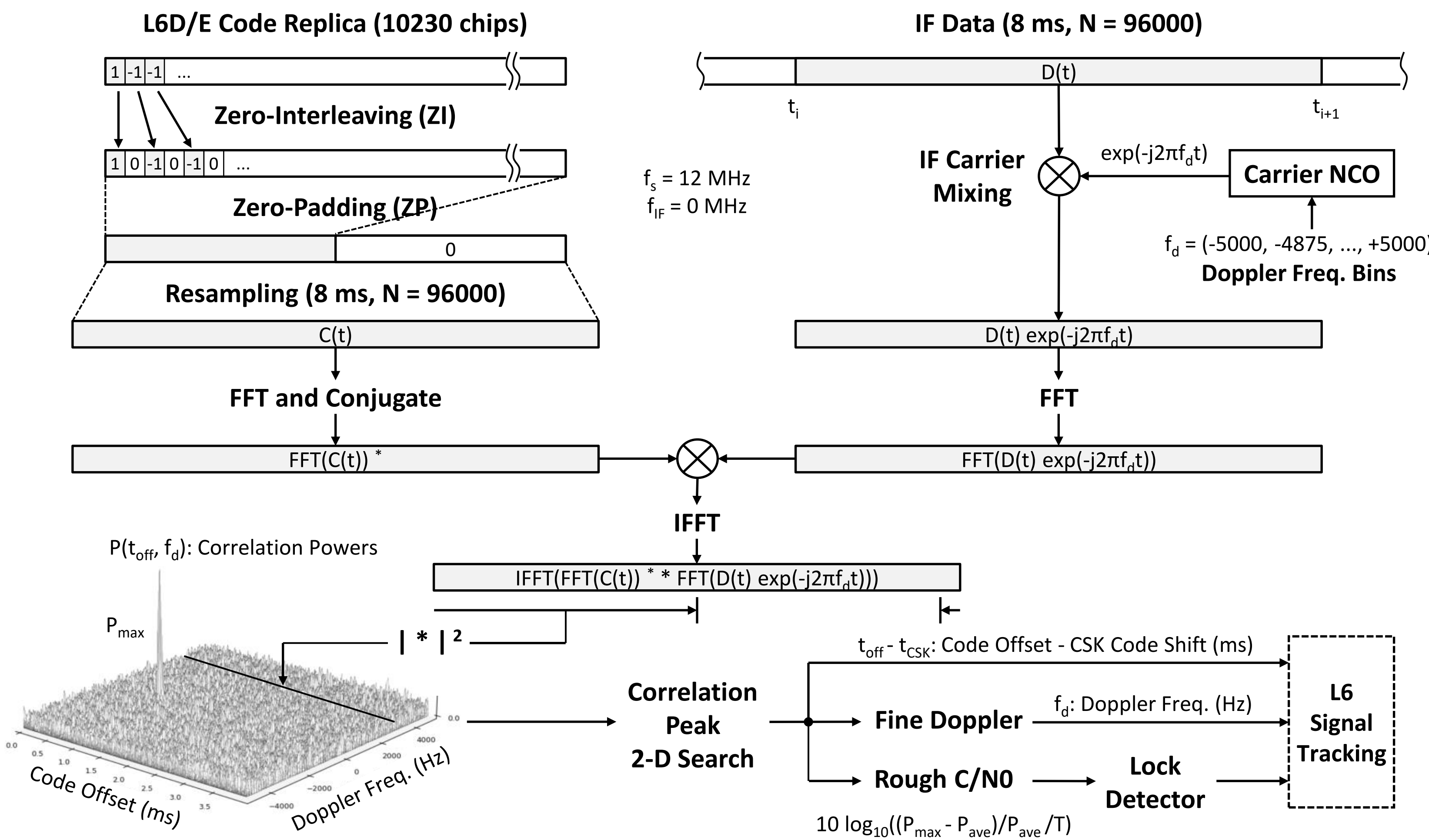
- For L6-only standard positioning with A-GNSS
- For quad-freq. (L1/L2/L5/L6) RTK or PPP-AR

L6 Signal Acquisition (1/2)

Circular Correlation with ZP (Zero-Padding) for 2 code cycle IF Data



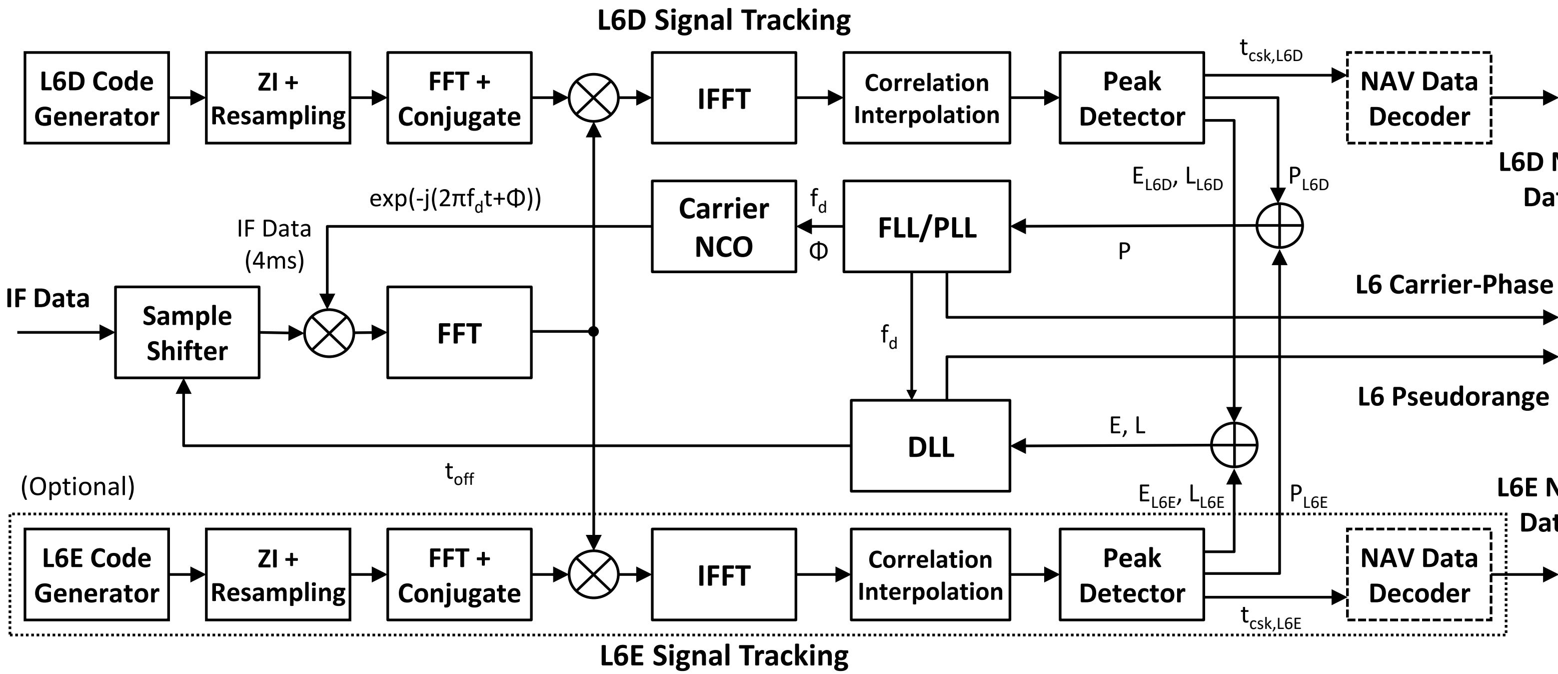
L6 Signal Acquisition (2/2)



L6 Signal Tracking (1/2)

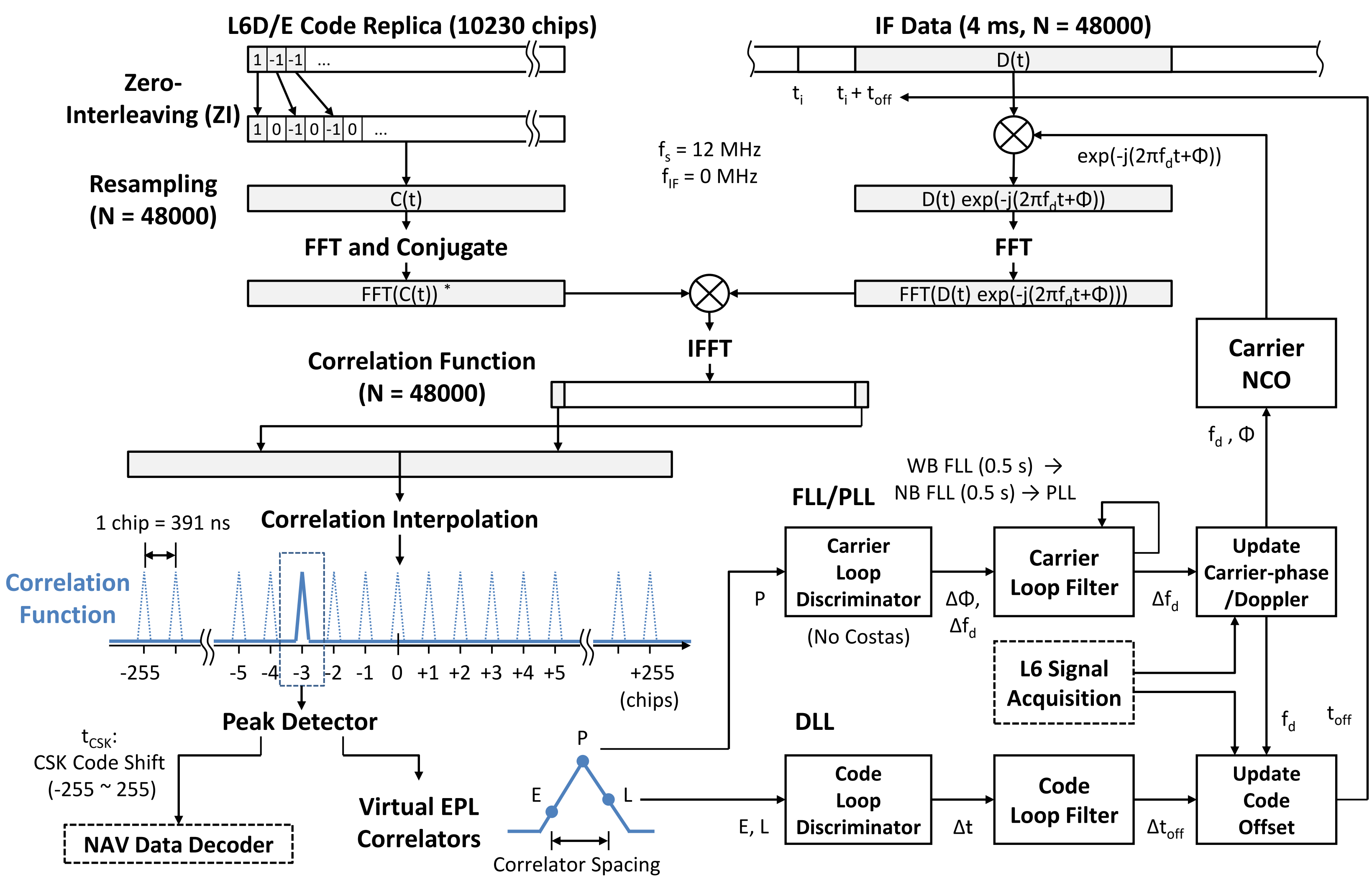
Signal Tracking

- FFT-based parallel correlator to decode CSK
- Detect correlator peak in CSK code shift space (± 255 chips)
- Virtual EPL correlators by correlator interpolation
- Standard FLL/PLL and DLL by virtual EPL correlators

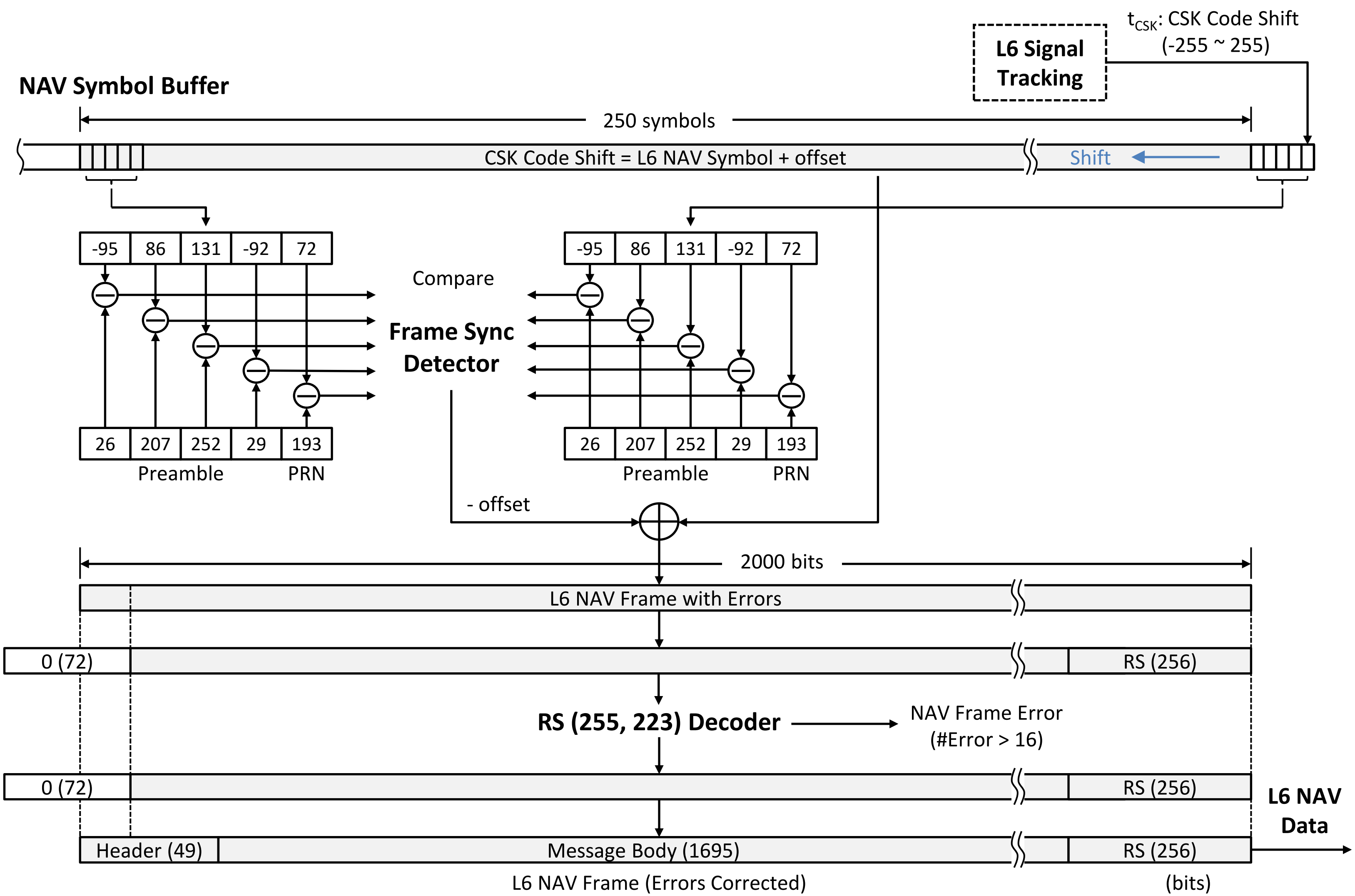


t_{off}: Code Offset, t_{CSK}: CSK Code Shift, f_d: Doppler Freq, Φ: Carrier Phase, P, E, L: Prompt, Early, Late Correlator

L6 Signal Tracking (2/2)



L6 NAV Data Decoder



Implementation by SDR

Pocket SDR

Pocket SDR [1]

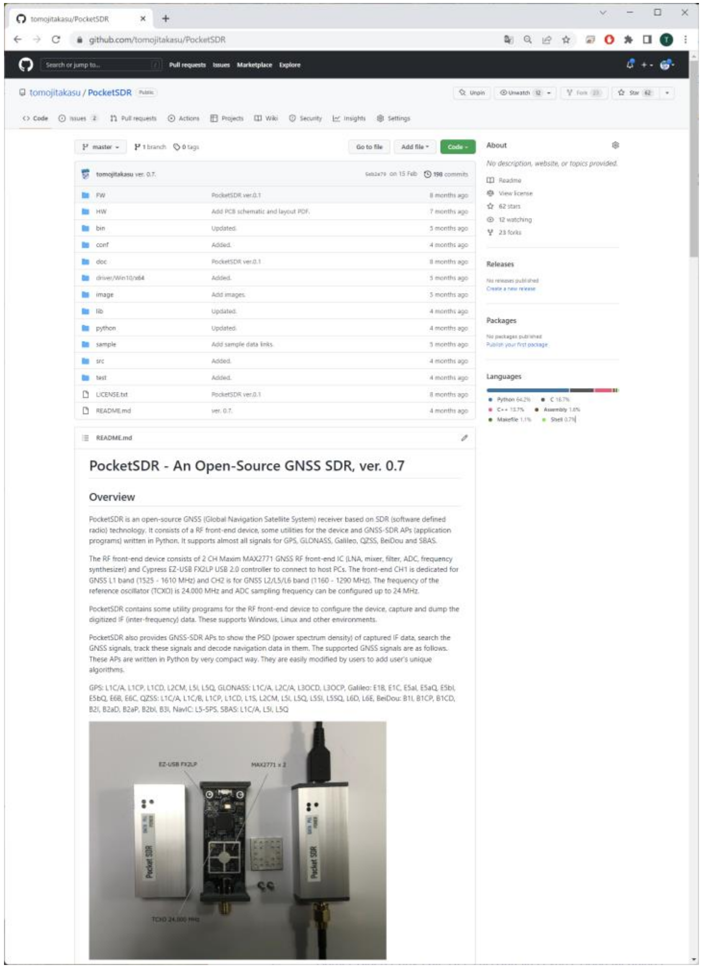
- An open-source GNSS-SDR project
- Current release: ver. 0.7 (2022-02-15)
- RF frontend H/W, F/W and driver
- GNSS-SDR APs and utilities

GNSS-SDR APs

- Written by Python 3 and C
- Support most of GNSS signals incl. L6
- Signal acquisition (pocket_acq.py)
- Signal tracking and NAV data decoding (pocket_trk.py)

External Libraries

- FFTW3 (FFT/IFFT)
- LIBFEC (FEC decoding incl. RS(255,223))
- RTKLIB



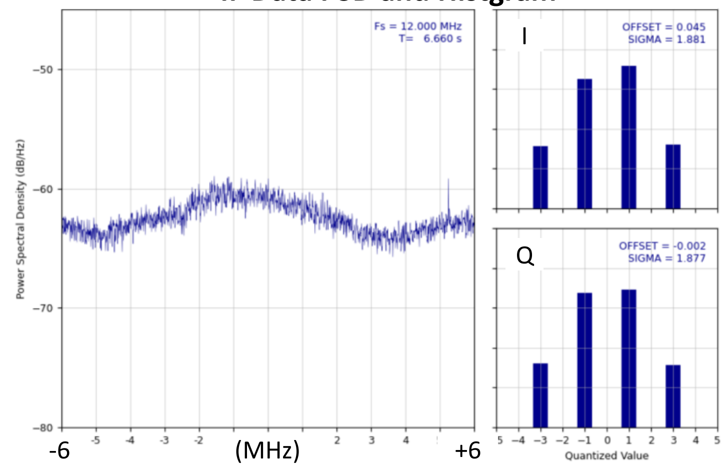
[1] PocketSDR: An Open-Source GNSS SDR (https://www.github.com/tomojitakasu/PocketSDR)

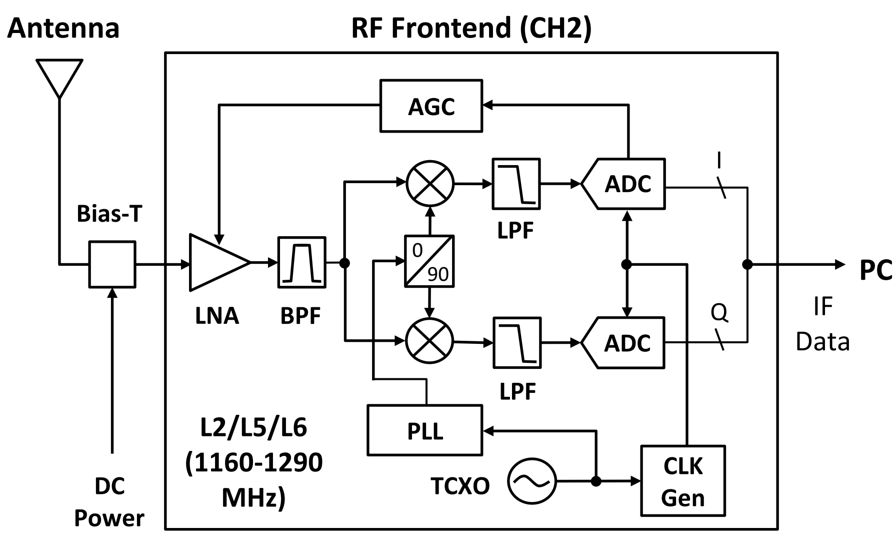
RF Frontend

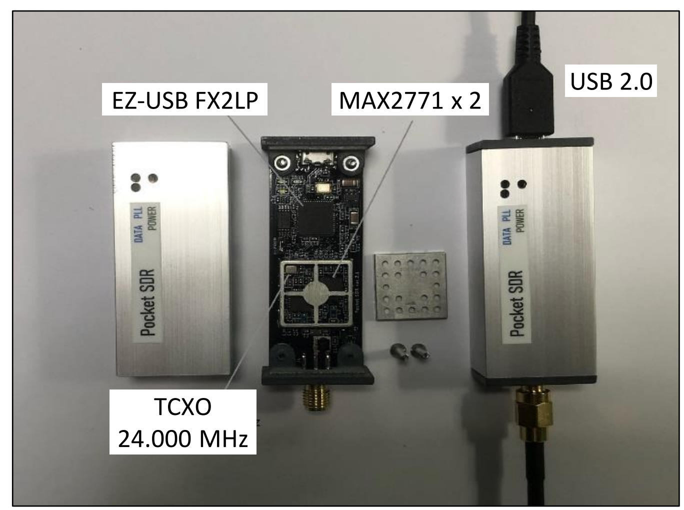
Settings for L6 Receiver

Channel	: CH2 (L2/L5/L6-band)
LO Frequency	: 1278.75 MHz
IF Frequency	: 0 MHz
IF Filter BW	: 8.7 MHz (3rd Order)
Sampling Frequency	: 12 MHz
Sampling Type	: I/Q, 2 bits

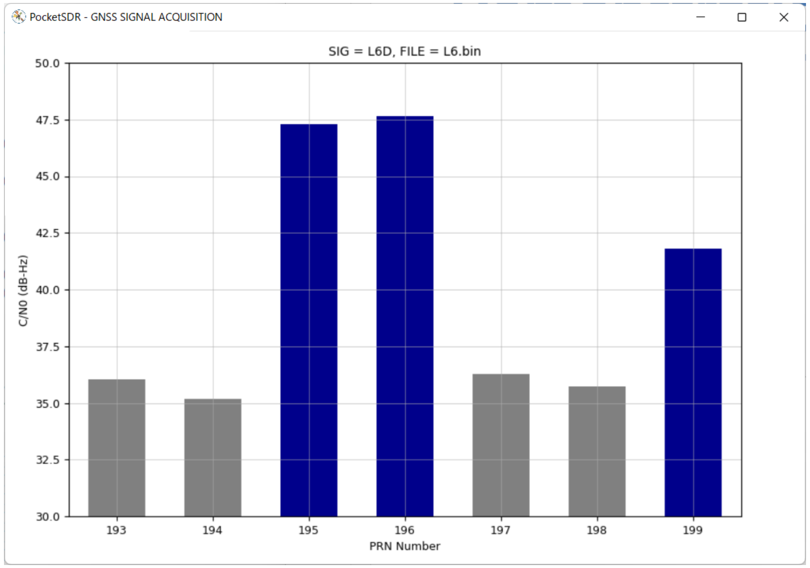
IF Data PSD and Histgram



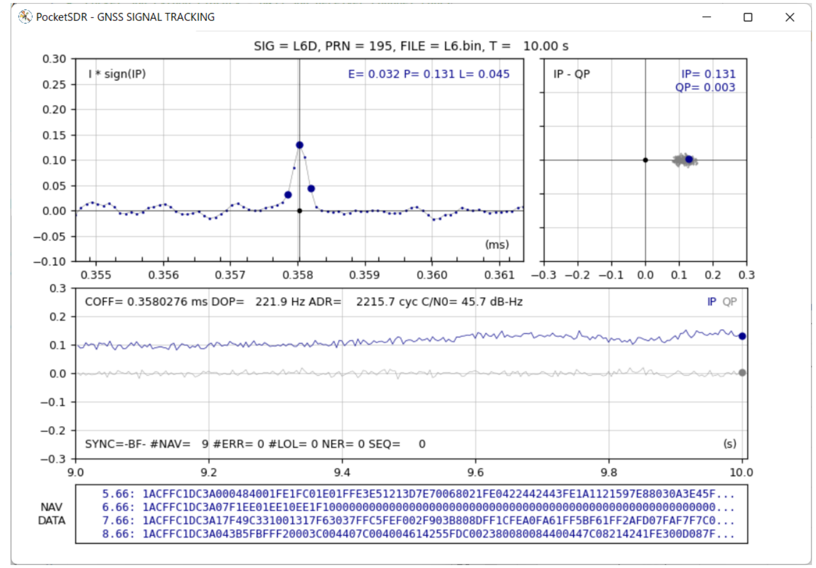




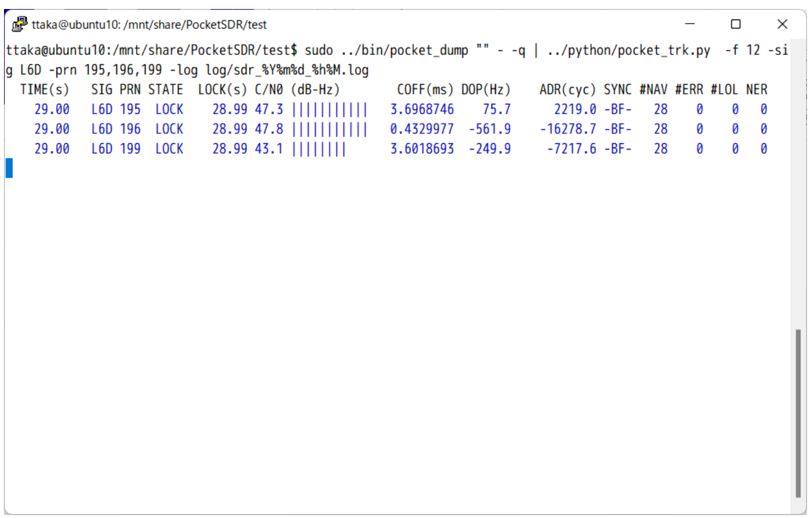
Snapshots



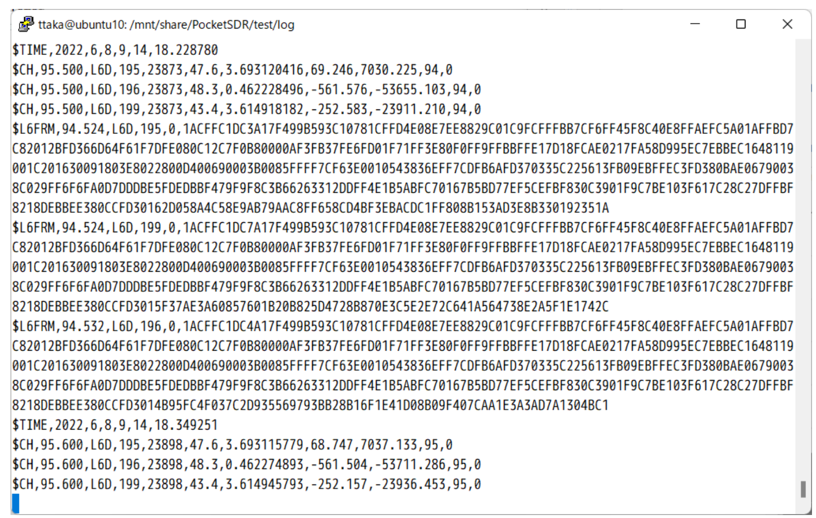
PocketSDR - GNSS SIGNAL ACQUISITION
SIG = L6D, FILE = L6.bin
C/N0 (dB-Hz)
PRN Number
193
194
195
196
197
198
199



PocketSDR - GNSS SIGNAL TRACKING
SIG = L6D, PRN = 195, FILE = L6.bin, T = 10.00 s
I * sign(IP)
E= 0.032 P= 0.131 L= 0.045
(ms)
IP - QP
IP= 0.131
QP= 0.003
COFF= 0.3580276 ms DOP= 221.9 Hz ADR= 2215.7 cyc C/N0= 45.7 dB-Hz
IP QP
SYNC=-BF- #NAV= 9 #ERR= 0 #LOL= 0 NER= 0 SEQ= 0
(s)
NAV DATA
8.66: 1ACFFC1DC3A043B5FBFFF20003C004407C004004614255FDC0023800800844004 47C08214241FE300D087F...



ttaka@ubuntu10: /mnt/share/PocketSDR/test
ttaka@ubuntu10:/mnt/share/PocketSDR/test$ sudo ../bin/pocket_dump "" - -q | ../python/pocket_trk.py -f 12 -si
g L6D -prn 195,196,199 -log log/sdr_%Y%m%d_%h%M.log
TIME(s) SIG PRN STATE LOCK(s) C/N0 (dB-Hz) COFF(ms) DOP(Hz) ADR(cyc) SYNC #NAV #ERR #LOL NER
29.00 L6D 195 LOCK 28.99 47.3 ||||||||||| 3.6968746 75.7 2219.0 -BF- 28 0 0 0
29.00 L6D 196 LOCK 28.99 47.8 ||||||||||| 0.4329977 -561.9 -16278.7 -BF- 28 0 0 0
29.00 L6D 199 LOCK 28.99 43.1 |||||||| 3.6018693 -249.9 -7217.6 -BF- 28 0 0 0



ttaka@ubuntu10: /mnt/share/PocketSDR/test/log
$TIME,2022,6,8,9,14,18.228780
$CH,95.500,L6D,195,23873,47.6,3.693120416,69.246,7030.225,94,0
$CH,95.500,L6D,196,23873,48.3,0.462228496,-561.576,-53655.103,94,0
$CH,95.500,L6D,199,23873,43.4,3.614918182,-252.583,-23911.210,94,0
$L6FRM,94.524,L6D,195,0,1ACFFC1DC3A17F499B593C10781CFFD4E08E7EE8829C01C9FCFFFBB7CF6FF45F8C40E8FFAEFC5A01AFFBD7
C82012BFD366D64F61F7DFE080C12C7F0B80000AF3FB37FE6FD01F71FF3E80F0FF9FFBBFFE17D18FCAE0217FA58D995EC7EBBEC1648119
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8218DEBBEE380CCFD30162D058A4C58E9AB79AAC8FF658CD4BF3EBACDC1FF808B153AD3E8B330192351A
$L6FRM,94.524,L6D,199,0,1ACFFC1DC7A17F499B593C10781CFFD4E08E7EE8829C01C9FCFFFBB7CF6FF45F8C40E8FFAEFC5A01AFFBD7
C82012BFD366D64F61F7DFE080C12C7F0B80000AF3FB37FE6FD01F71FF3E80F0FF9FFBBFFE17D18FCAE0217FA58D995EC7EBBEC1648119
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8C029FF6F6FA0D7DDDBE5FDEDBBF479F9F8C3B66263312DDFF4E1B5ABFC70167B5BD77EF5CEFBF830C3901F9C7BE103F617C28C27DFFBF
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$L6FRM,94.532,L6D,196,0,1ACFFC1DC4A17F499B593C10781CFFD4E08E7EE8829C01C9FCFFFBB7CF6FF45F8C40E8FFAEFC5A01AFFBD7
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8218DEBBEE380CCFD3014B95FC4F037C2D935569793BB28B16F1E41D08B09F407CAA1E3A3AD7A1304BC1
$TIME,2022,6,8,9,14,18.349251
$CH,95.600,L6D,195,23898,47.6,3.693115779,68.747,7037.133,95,0
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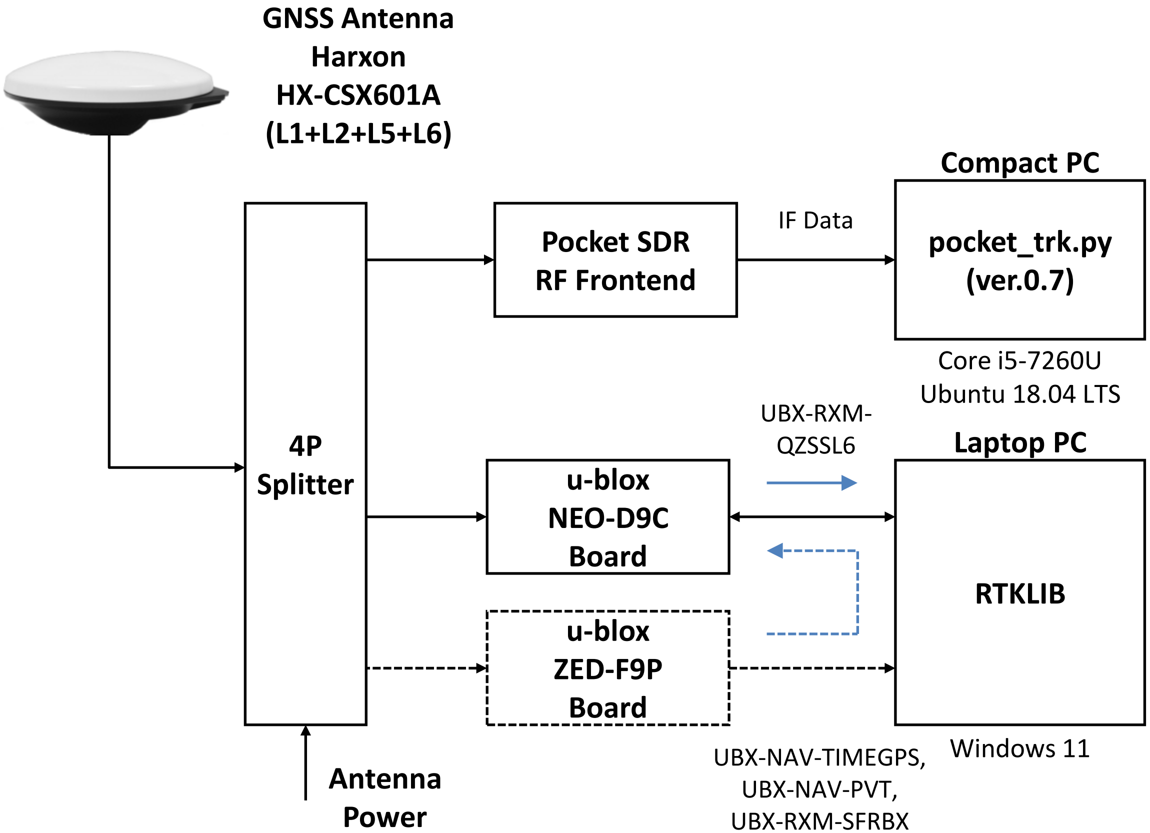
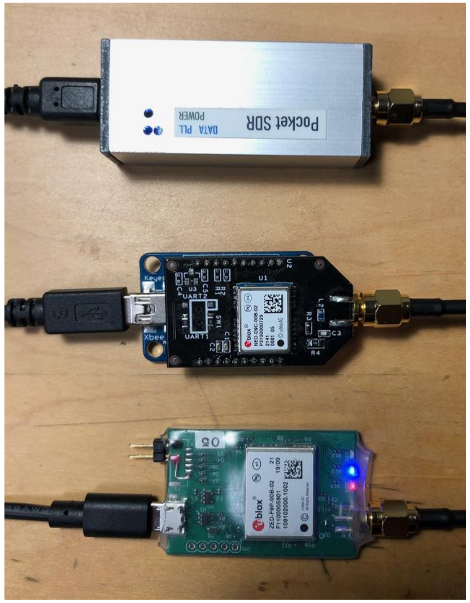
Performance Evaluation

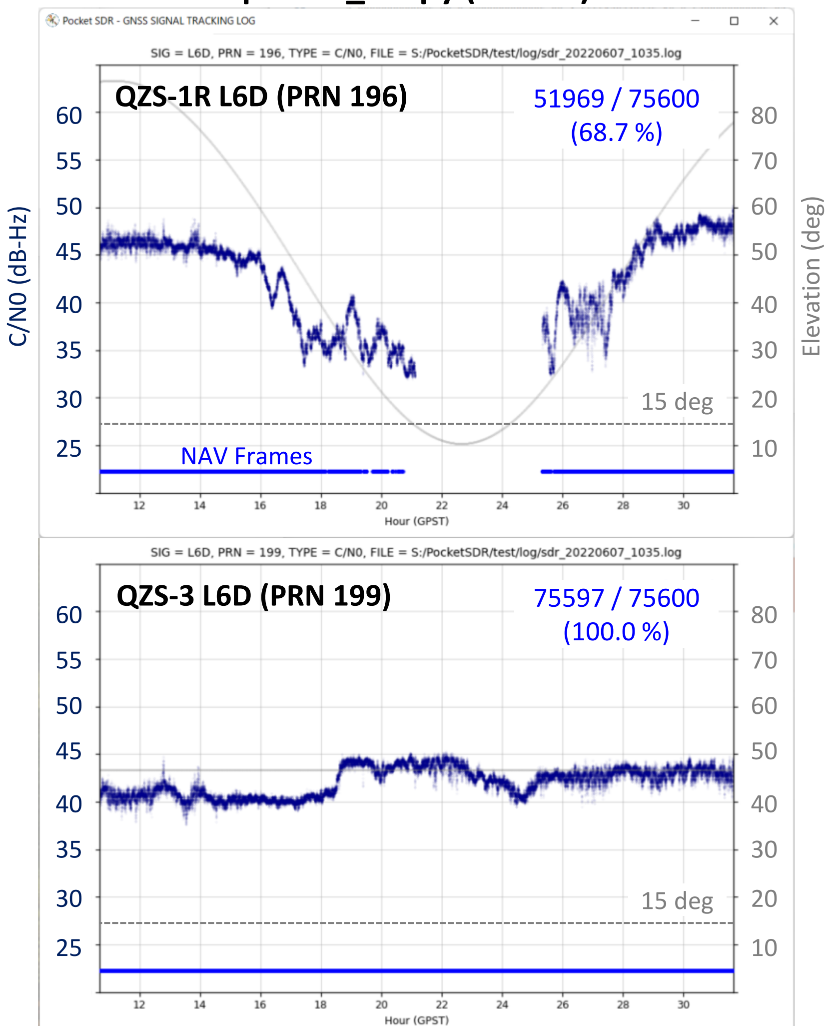
Test Configuration



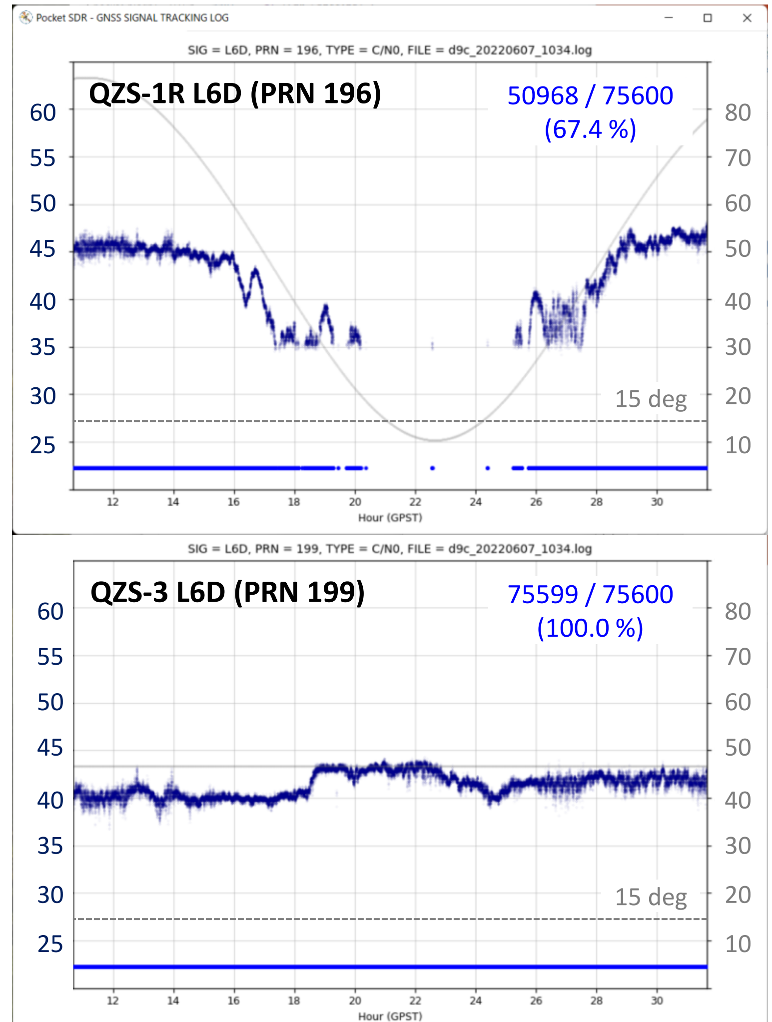


L6 C/N0 and NAV Data Rate

pocket_trk.py (ver.0.7)



u-blox NEO-D9C



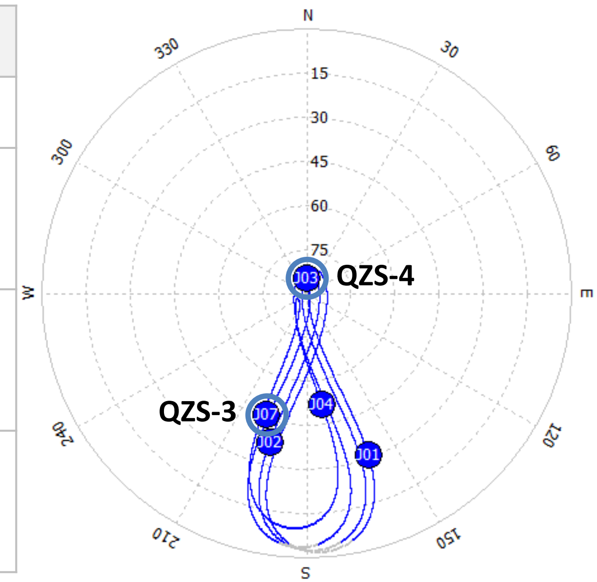
2022-06-07 10:40:00 ~ 2022-06-08 07:39:59 UTC (21 hours)

L6 Signal Acquisition Time

L6 Signal Acquisition Time *1

Satellite	QZS-4 (J03)	QZS-3 (J07)
Signal	L6D PRN 195	L6D PRN 199
pocket_trk.py (ver.0.7) *2	3.0 s (2 s ~ 4 s)	2.3 s (1 s ~ 3 s)
u-blox NEO-D9C	33.0 s (16 s ~ 77 s)	52.2 s (28 s ~ 89 s)
u-blox NEO-D9C aided by ZED-F9P	2.8 s (2 s ~ 4 s)	2.4 s (2 s ~ 3 s)

*1 Time to obtain 1st L6 NAV frame since RF signal on (average of 5 tries)
*2 Signal search cycle (CYC_SRCH) in pocket_trk.py modified to 1 s



2022-06-09 04:30:00 UTC

CPU Usage for SDR Codes

```
ttaka@ubuntu10: /mnt/share/PocketSDR/test
ttaka@ubuntu10:/mnt/share/PocketSDR/test$ sudo ../bin/pocket_dump "" - -q | ../python/pocket_trk.py  -f 12 -sig
L6D -prn 194,195,199 -log log/sdr_%Y%m%d_%h%M.log -ti 1
  TIME(s)   SIG PRN STATE  LOCK(s) C/N0 (dB-Hz)        COFF(ms) DOP(Hz)    ADR(cyc) SYNC #NAV #ERR #LOL NER
   351.00   L6D 194  LOCK   350.99 46.4 |||||||||     1.8773756    84.7    34177.2 -BF-  350    0    0   0
   351.00   L6D 195  LOCK   350.99 48.3 |||||||||||   3.4774932  -576.5  -205117.7 -BF-  350    0    0   0
   351.00   L6D 199  LOCK   350.99 44.2 ||||||||      2.4766337  -251.6   -87768.7 -BF-  350    0    0   0
```

pocket_trk.py
(ver. 0.7)
Signal: L6D
PRN: 194,195,196
(3CH)

```
ttaka@ubuntu10: ~
top - 11:41:04 up 127 days, 20:39,  4 users,  load average: 0.71, 0.73, 0.65
Tasks: 291 total,   2 running, 242 sleeping,   0 stopped,   0 zombie
%Cpu(s): 15.7 us,  0.5 sy,  0.0 ni, 83.7 id,  0.0 wa,  0.0 hi,  0.2 si,  0.0 st
KiB Mem :  8037644 total,  1055320 free,  2413876 used,  4568448 buff/cache
KiB Swap:  2097148 total,  2073084 free,    24064 used.  4970648 avail Mem

  PID USER      PR  NI    VIRT    RES    SHR S  %CPU %MEM     TIME+ COMMAND
 3741 ttaka     20   0  355888 191600  22116 R  59.8  2.4   8:13.08 python3
 3742 root      20   0  315640  58012   2512 S   3.3  0.7   0:39.19 pocket_dump
 1026 gdm       20   0 1148892  68940  24112 S   0.7  0.9 1203:20 gsd-color
 1531 ttaka     20   0  695980  60656  18580 S   0.7  0.8 1203:10 gsd-color
 3957 ttaka     20   0   45236   4492   3708 R   0.3  0.1   0:00.10 top
    1 root      20   0  225752   9040   6500 S   0.0  0.1   3:58.04 systemd
    2 root      20   0       0      0      0 S   0.0  0.0   0:01.46 kthreadd
    3 root       0 -20       0      0      0 I   0.0  0.0   0:00.00 rcu_gp
    4 root       0 -20       0      0      0 I   0.0  0.0   0:00.00 rcu_par_gp
    6 root       0 -20       0      0      0 I   0.0  0.0   0:00.00 kworker/0:0H-kb
    9 root       0 -20       0      0      0 I   0.0  0.0   0:00.00 mm_percpu_wq
   10 root      20   0       0      0      0 S   0.0  0.0   0:03.09 ksoftirqd/0
```

CPU Usage:
15.0 ~ 18.4 %
(user total)
58.9 ~ 67.1 %
(per 1 thread)

CPU:
Core i5-7260U
(2.2~3.4GHz, 2C/4T)
OS:
Ubuntu 18.04 LTS

Summary

Summary

Conclusion

- New L6 receiver design presented
- The L6 receiver implemented by SDR
- FLL/PLL and DLL work well to track L6 signal
- L6 NAV data properly decoded w/o pilot CH
- Performance comparable to commercial L6 receivers

Future Work

- Evaluation of L6 range info quality
- Porting Python 3 codes to C
  (for improvement of multi-threads performance)
- Comparison of QZSS L6 to Galileo E6