測位航法学会 2021年度 次世代高精度衛星測位研究委員会

An Open Source GNSS SDR: Development and Applications

Tokyo Univ. of Marine Science and Technology (TUMSAT)

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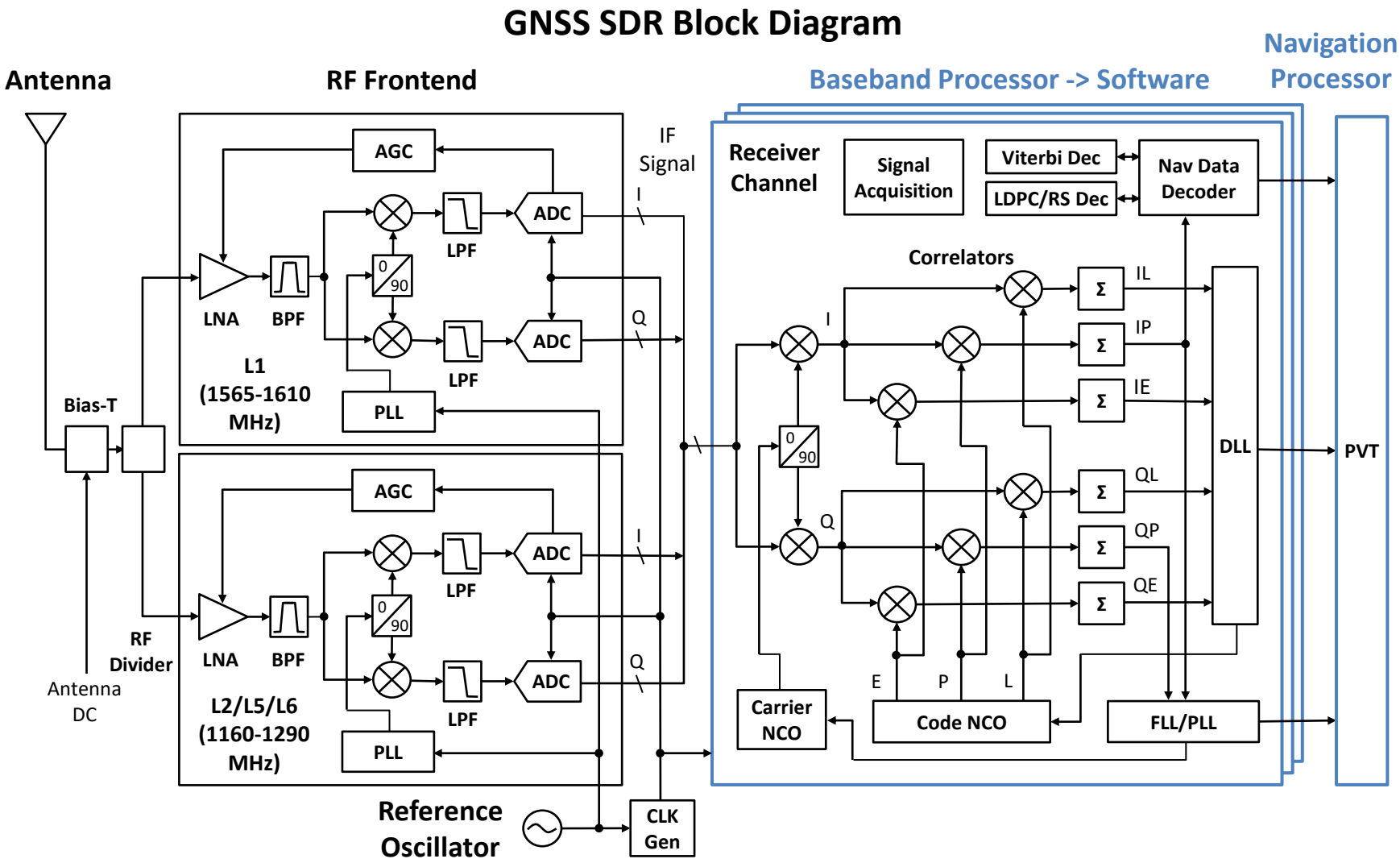
2022-02-21 @Online, Japan

Pocket SDR

GNSS Software Defined Receiver



GNSS SDR RF Frontends

RF Frontend	Vendor	# of CH	RF Band	ADC	RF LSI	FPGA	Host I/F
USRP N210 [1]	Ettus Research	2CH (RX) 2CH (TX)	DC ~ 6 GHz	14 bit ~ 100 Msps	Custom Daughterboard	Spartan 3A-DSP	Giga-Ethernet
SiGe GN3S Sampler v3 [2]	GNSS Lab Univ Colorado	1CH (RX)	L1	2 bit ~ 16 Msps	SiGe4120	-	USB 2.0
Stereo [3]	NSL	2CH (RX)	L1 + L2/L5/L6	2/3 bit 26 Msps	MAX2769B + MAX2112	Spartan-6	USB 2.0
Blade RF [4]	NuBand	2CH (RX) 2CH (TX)	300 MHz ~ 3.8 GHz	12 bit ~ 40 Msps	LMS6002D	Cyclone IV E	USB 3.0
Lime SDR [5]	Lime microsystems	2CH (RX) 2CH (TX)	100 kHz ~ 3.8 GHz	12 bit ~ 61 Msps	LMS7002M	Cyclone IV EP4CE40F23	USB 3.0
NUT4NT [6]	Amungo Navigation	4CH (RX)	L1/L2/ L5/L6	2 bit ~ 99 Msps	NT1065	Lattice ECP5	USB 3.0
Pocket SDR	-	2CH (RX)	L1 + L2/L5/L6	2 bit ~ 24 Msps	MAX2771 x 2	-	USB 2.0

USRP N210

GN3S Sampler

Stereo

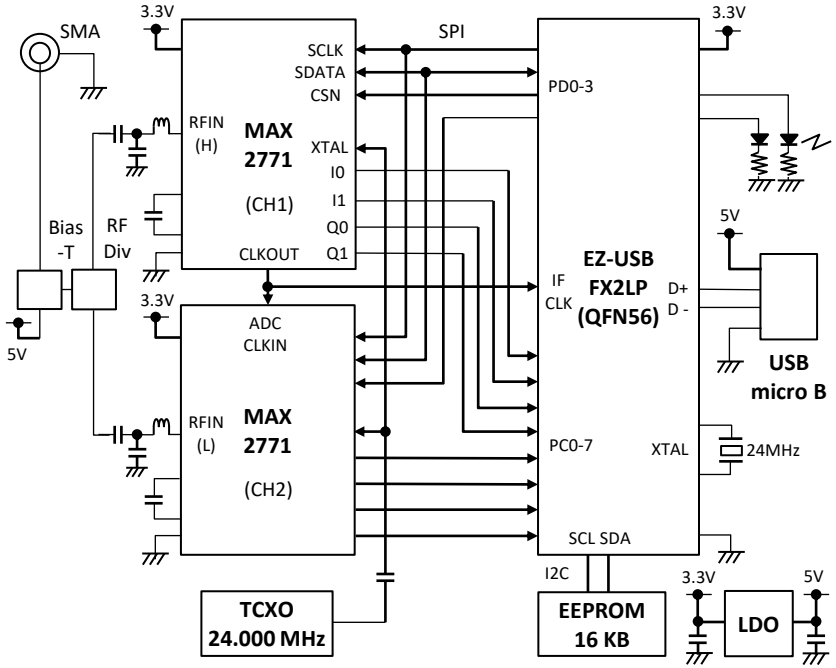
Blade RF

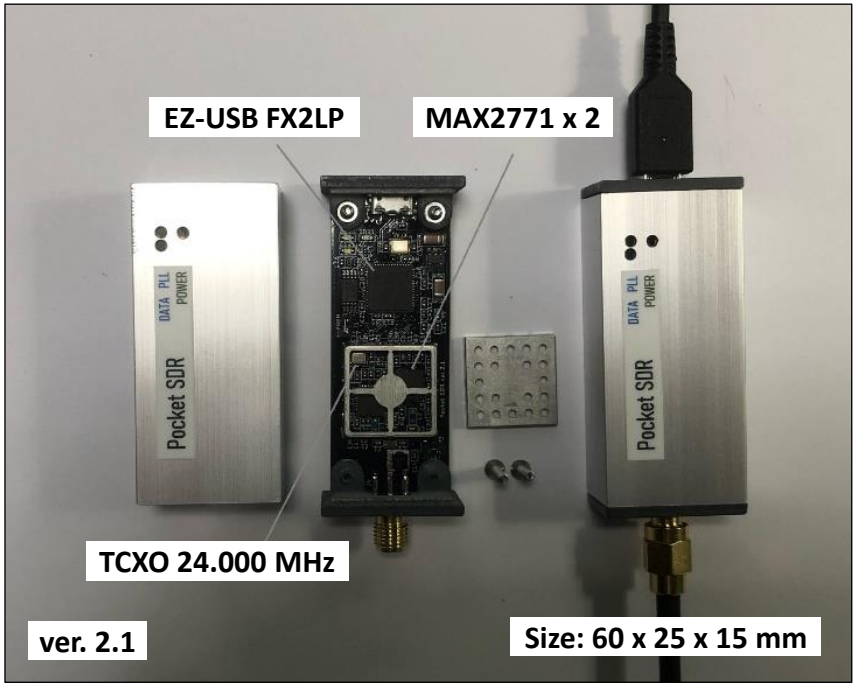
Lime SDR

NUT4NT

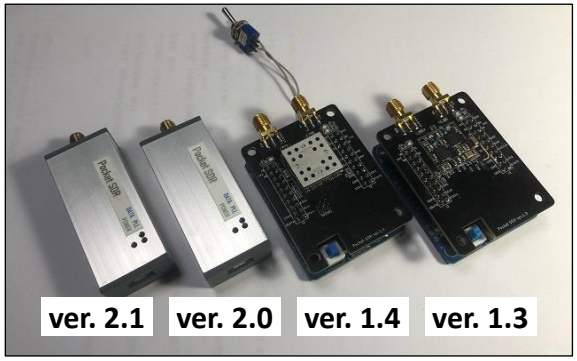
[1] https://www.ettus.com/all-products/un210-kit/, [2] https://ccar.colorado.edu/gnss/, [3] https://gmvnsl.com/advanced-gnns-hw-sw/,
[4] https://www.nuand.com/bladerf-1/, [5] https://limemicro.com/products/boards/limesdr/, [6] https://www.amungo-navigation.com/

Pocket SDR RF Frontend





LO Frequency	:	**CH1 1525 ~ 1610 MHz (L1 band)**
	:	**CH2 1160 ~ 1290 MHz (L2/L5/L6 band)**
IF Bandwidth	:	**2 ~ 20 MHz**
Sampling Rate	:	**4, 6, 8, 12, 16 or 24 Msps**
Sampling Type	:	**I or I/Q, 2 bits**
Host I/F	:	**USB 2.0, micro B**
Power	:	**5V 140 mA, USB bus power**
Parts Cost	:	**~ $50**



GNSS SDR Software

Software		GNSS-SDR	GNSS-SDRLIB	Pocket SDR
URL		https://gnss-sdr.org	https://github.com/taroz/GNSS-SDRLIB	https://github.com/tomojitakasu/PocketSDR
Current Release		v0.0.15 (Aug 2021)	v2.0 Beta (Dec 2014)	ver. 0.7 (Feb 2022)
GitHub Stars		☆ 966	☆ 299	☆ 48
Processing Mode		Post Processing, Real-time	Post Processing, Real-time	Post Processing
GNSS Signals	GPS	L1C/A, L2C, L5	L1C/A	L1C/A, L1C, L2C, L5
	GLONASS	L1C/A, L2C/A	L1C/A	L1C/A, L2C/A, L3OC
	Galileo	E1B/C, E5a	E1B	E1B/C, E5a, E5b, E6B/C
	QZSS	-	L1C/A, L1SAIF, LEX	L1C/A, L1C/B, L1C, L1S, L2C, L5, L5S, L6D/E
	BDS	B1I, B3I	B1I	B1I, B1C, B2I, B2a, B2b, B3I
	NavIC	-	-	L5-SPS
	SBAS	-	L1C/A	L1C/A, L5
Supported RF Frontends		USRP, UmTRX, HackRF One, Blade RF, RTL-SDR	SiGe GN3S sampler v2/v3, Stereo, Blade RF, RTL-SDR	Pocket SDR RF Frontend
OS		Windows, Linux, macOS, others	Windows, Linux	Windows, Linux
Language		C++, C	C, C++/CLI	Python 3, C
External Library		GNU Radio, Boost, FFTW3, VOLK, Armadillo, LAPACK/BLAS, glog, gflags, matio, pugiXML, Protocol Buffers, OpenSSL, RTKLIB	FFTW3, LIBFEC, RTKLIB, libusb	FFTW3, LIBFEC, LDPC-codes, RTKLIB, CyAPI or libusb-1.0

Pocket SDR Software

RF Frontend Utilities

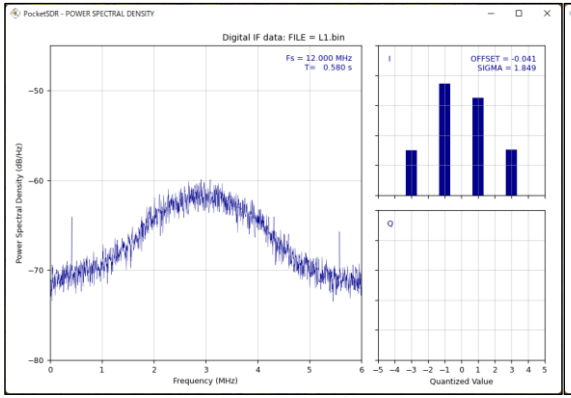
- pocket_conf : Device Configurator for RF Frontend
- pocket_dump : IF Data Sampler for RF Frontend

GNSS SDR Software

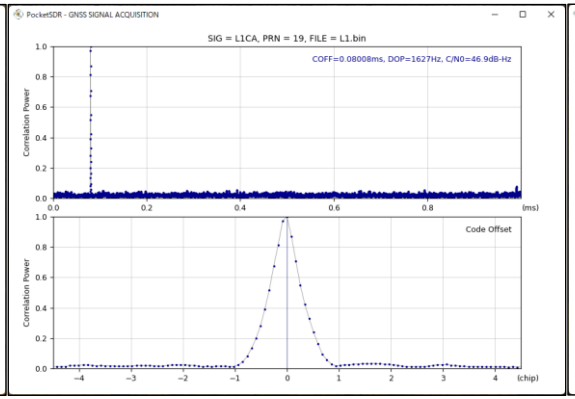
- pocket_psd.py : PSD Analysis of Sampling Data
- pocket_acq.py : GNSS Signal Search and Acquisition
- pocket_trk.py : GNSS Signal Tracking and Navigation Data Decoding
- pocket_snap.py : Snapshot Positioning with Sampling Data

Environment

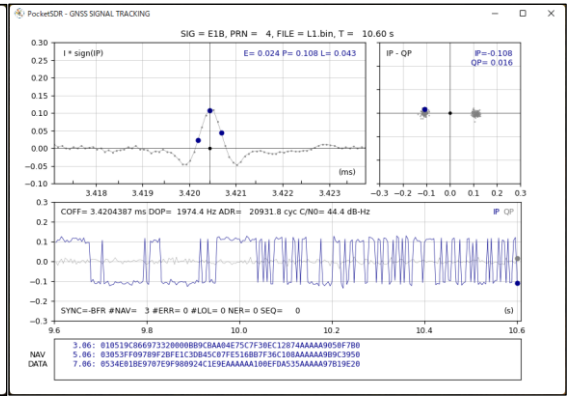
- Windows or Linux, Python 3 (Numpy, Scipy and matplotlib)



pocket_psd.py



pocket_acq.py



pocket_trk.py

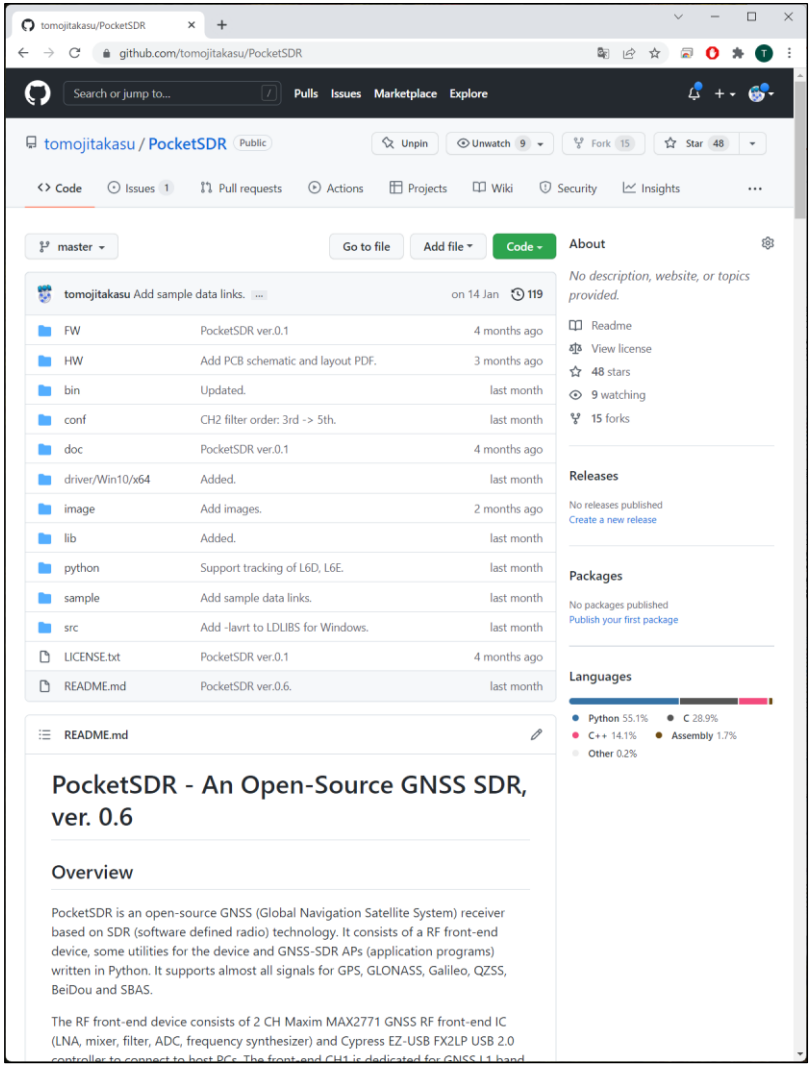
Supported GNSS Signals

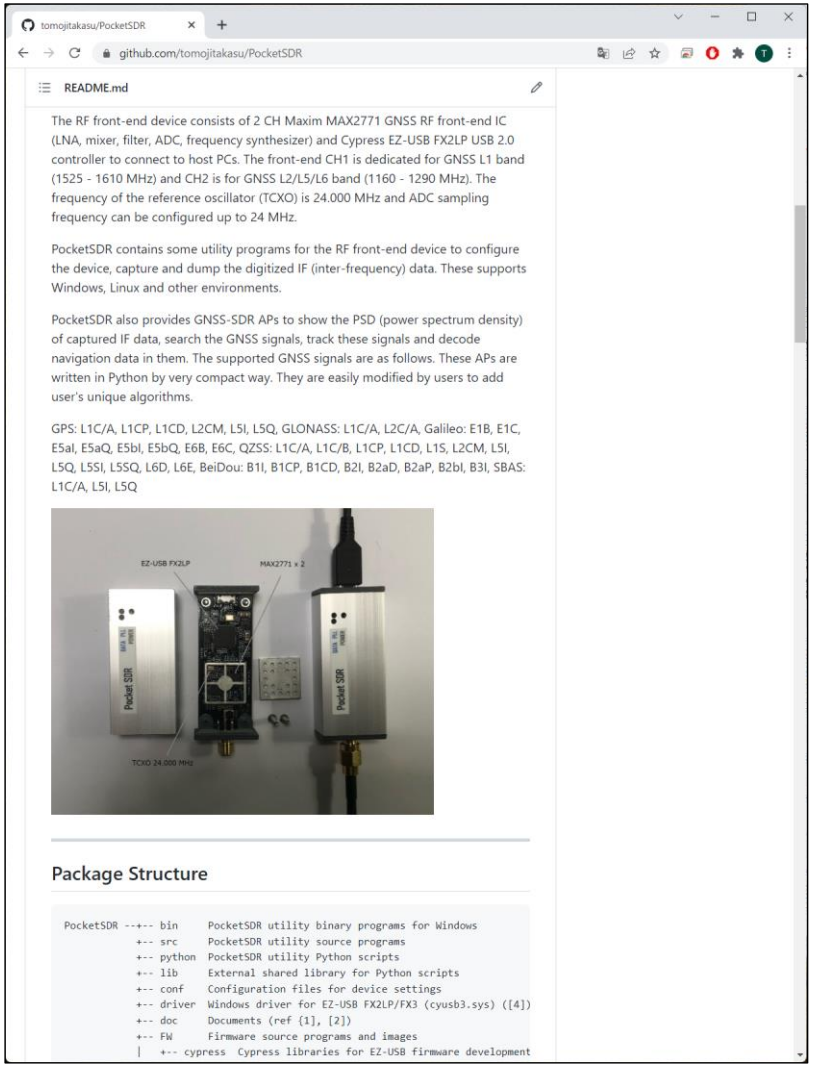
System	Freq. (MHz)	Signal	Modulation	Spreading Code		Nav Data
				Primary (chips)	Overlay (chips)	
GPS	1575.42	L1C/A	BPSK(1)	1023	-	LNAV
		L1C-D	BOC(1,1)	10230	-	CNAV-2
		L1C-P	TMBOC(6,1,4/33)	10230	1800	-
	1227.6	L2C-M	BPSK(1), TDM	10230	-	CNAV
		L2C-L		767250	-	-
	1176.45	L5-I	BPSK(10)	10230	10 (NH)	CNAV
		L5-Q	BPSK(10)	10230	20 (NH)	-
GLONASS	1602.0 + 0.5625K	L1C/A	BPSK(0.5)	511	10	GLO-STR
	1246.0 + 0.4375K	L2C/A	BPSK(0.5)	511	10	GLO-STR
	1202.025	L3OCd	BPSK(10)	10230	10 (NH)	GLO-STR
		L3OCp	BPSK(10)	10230	5 (BC)	-
Galileo	1575.42	E1-B	CBOC(6,1,1/11)	4092	-	I/NAV
		E1-C	CBOC(6,1,1/11)	4092	25	-
	1176.45	E5a-I	BPSK(10)	10230	20	F/NAV
		E5a-Q	BPSK(10)	10230	100	-
	1207.14	E5b-I	BPSK(10)	10230	4	I/NAV
		E5b-Q	BPSK(10)	10230	100	-
	1278.75	E6-B	BPSK(5)	5115	-	C/NAV
		E6-C	BPSK(5)	5115	100	-
QZSS	1575.42	L1C/A	BPSK(1)	1023	-	LNAV
		L1C/B	BOC(1,1)	1023	-	LNAV
		L1C-D	BOC(1,1)	10230	-	CNAV-2
		L1C-P	TMBOC(6,1,4/33)	10230	1800	-
		L1S	BPSK(1)	1023	-	L1S

System	Freq. (MHz)	Signal	Modulation	Spreading Code		Nav Data
				Primary (chips)	Overlay (chips)	
QZSS (cont.)	1227.6	L2C-M	BPSK(1), TDM	10230	-	CNAV
		L2C-L		767250	-	-
	1176.45	L5-I	BPSK(10)	10230	10 (NH)	CNAV
		L5-Q	BPSK(10)	10230	20 (NH)	-
		L5S-I	BPSK(10)	10230	10 (NH)	L5S
		L5S-Q	BPSK(10)	10230	20 (NH)	-
	1278.75	L6L	BPSK(5), TDM	1048575	-	-
		L6D		10230	-	CLAS
		L6E		10230	-	MADOCA
BDS	1561.098	B1I	BPSK(2)	2046	20 (NH)	D1
					-	D2
	1575.42	B1C-D	BOC(1,1)	10230	-	B-CNAV1
		B1C-P	QMBOC(6,1,1/11)	10230	1800	-
	1207.14	B2I	BPSK(2)	2046	20 (NH)	D1
					-	D2
	1176.45	B2a-D	BPSK(10)	10230	5	B-CNAV2
		B2a-P	BPSK(10)	10230	100	-
	1207.14	B2b-I	BPSK(10)	10230	-	B-CNAV3
					-	B2b-PPP
	1268.52	B3I	BPSK(10)	10230	20 (NH)	D1
					-	D2
NavIC	1176.45	L5-SPS	BPSK(10)	10230	-	IRN-NAV
	2492.028	S-SPS	BPSK(10)	10230	-	IRN-NAV
SBAS	1575.42	L1C/A	BPSK(1)	1023	-	SBAS
	1176.45	L5-I	BPSK(10)	10230	10 (NH)	L5 SBAS
		L5-Q	BPSK(10)	10230	20 (NH)	-

Red: supported by pocket_acq.py and pocket_trk.py

GitHub

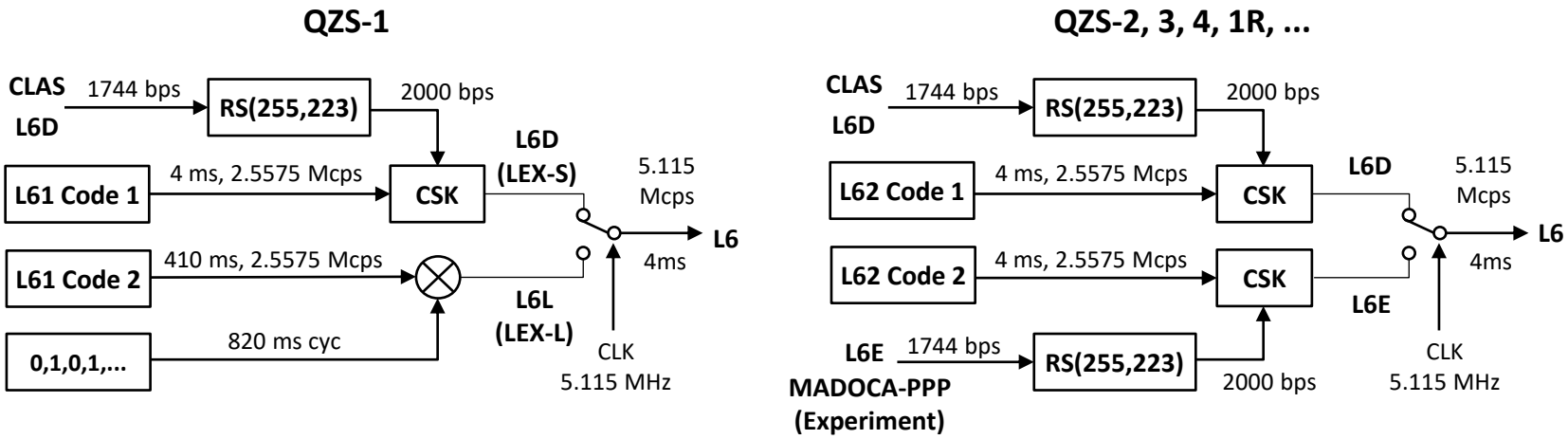


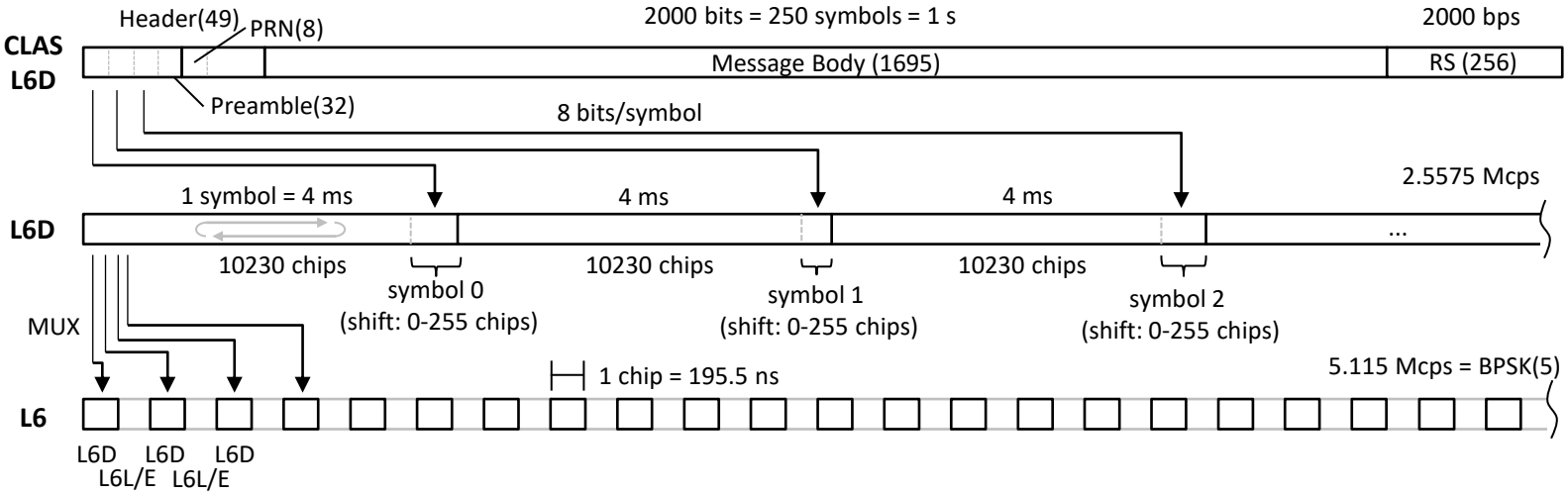


https://github.com/tomojitakasu/PocketSDR

Applications of Pocket SDR

QZSS L6 Signal





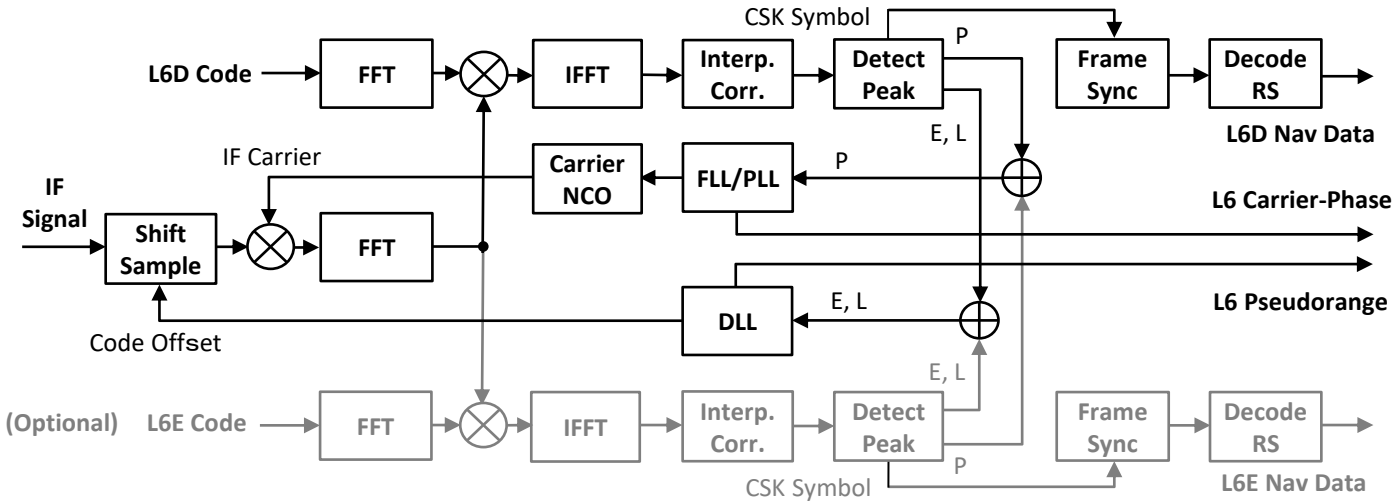
L6 CSK Receiver (1/2)

Existing Technique to Decode L6 CSK

- Decoding CSK referenced to L6L pilot (only for QZS-1)
- Decoding CSK referenced to L1 or L2C pilot (need dual freq. or wide BW)
- No Tracking L6D/E directly (no pseudorange or carrier-phase w/o DLL or PLL)
- NovAtel (only track QZS-1), u-blox D9C (L2C pilot), Allystar HD9310 (L1 pilot ?)

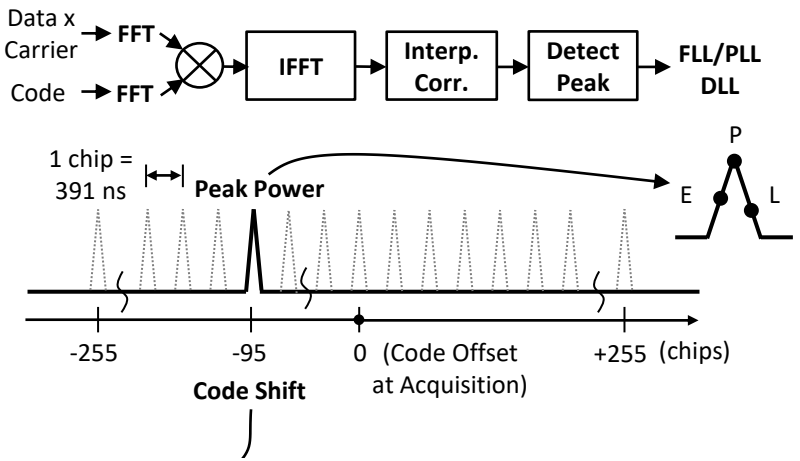
L6 CSK Receiver w/o pilot signal by Pocket SDR

- pocket_trk.py (ver. 0.6 ~)
- Narrow BW (10 MHz) IF to track BPSK(5)
- L6 Pseudorange and carrier-phase available for PVT

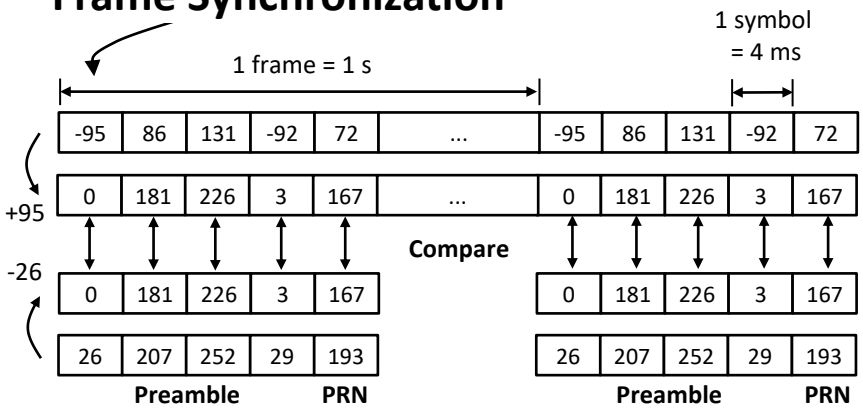


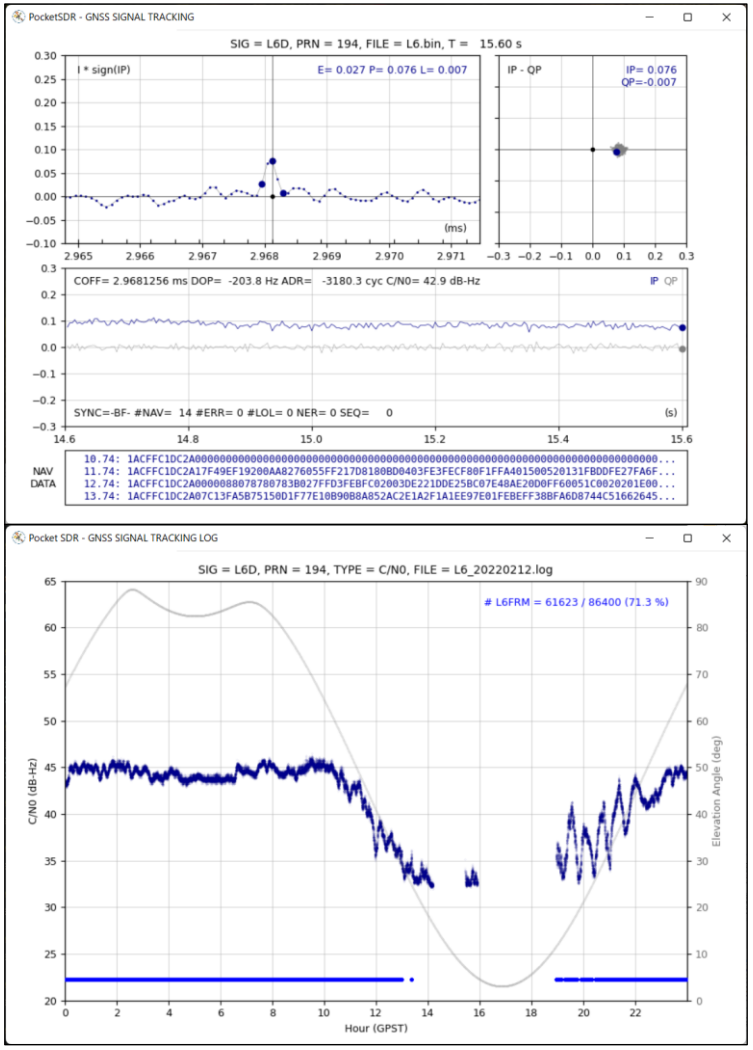
L6 CSK Receiver (2/2)

Generate Correlator Outputs EPL



Frame Synchronization





24H Real-time Tracking Status by pocket_trk.py

Snapshot Positioning (1/2)

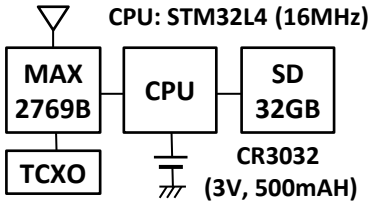
Snapshot Positioning

- Recode only DIF data in < 100 ms
- PVT by post-processing
- NAV data provided by external sources
- Very low power consumption by duty-cycling

Snapshot Positioning by Pocket SDR

- pocket_snap.py (ver. 0.7 ~)
- L1 band (1575.42 MHz)
- GPS L1C/A, Galileo E1C, QZSS L1CP, BDS B1CP
- 4 or 6 Msps x I/Q x 2bits x 8 ~ 20 ms DIF
- Input RINEX NAV for Ephemerides

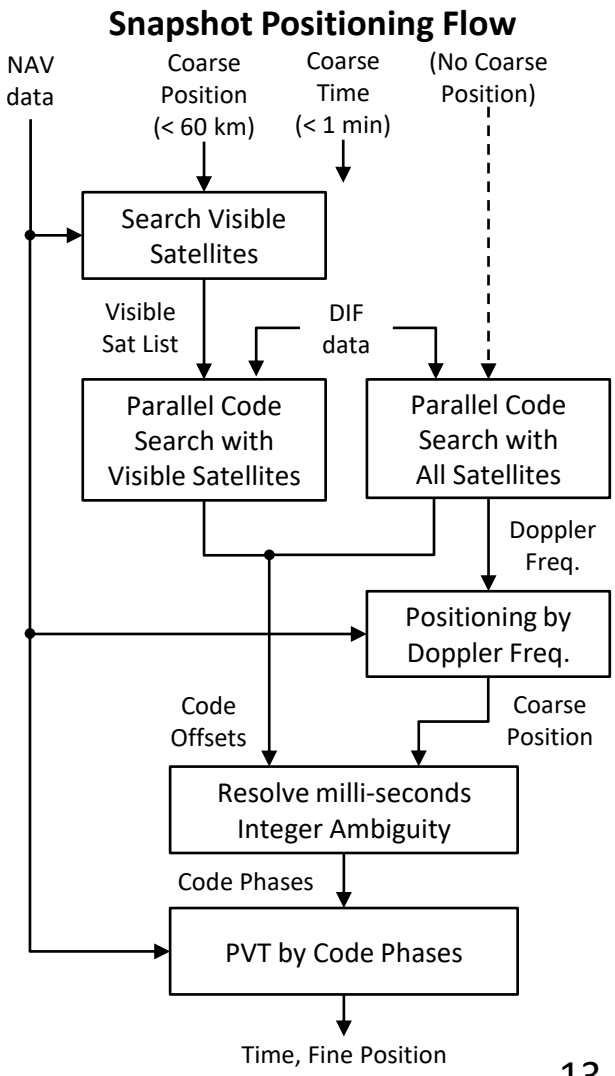
Snapshot Receiver Example



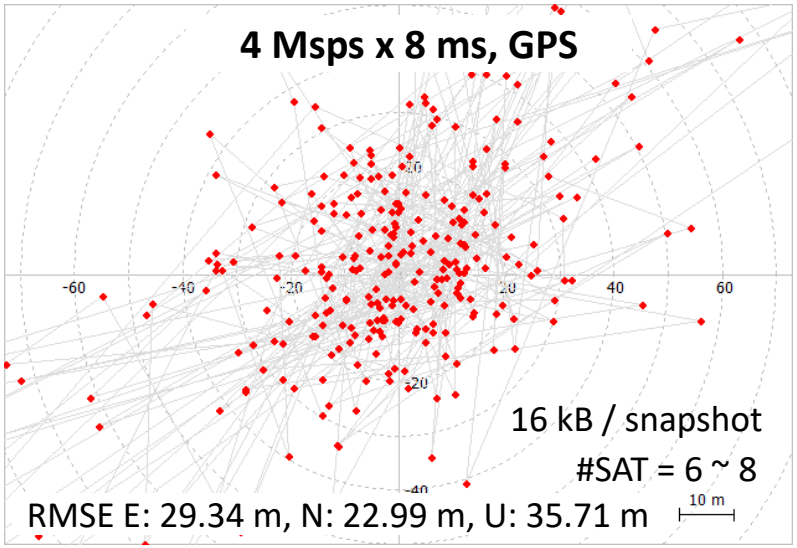
6 Msps x I/Q x 2 bits x 20 ms = 60 kB / snapshot
60 kB x every 1 min x 370 days = 32 GB

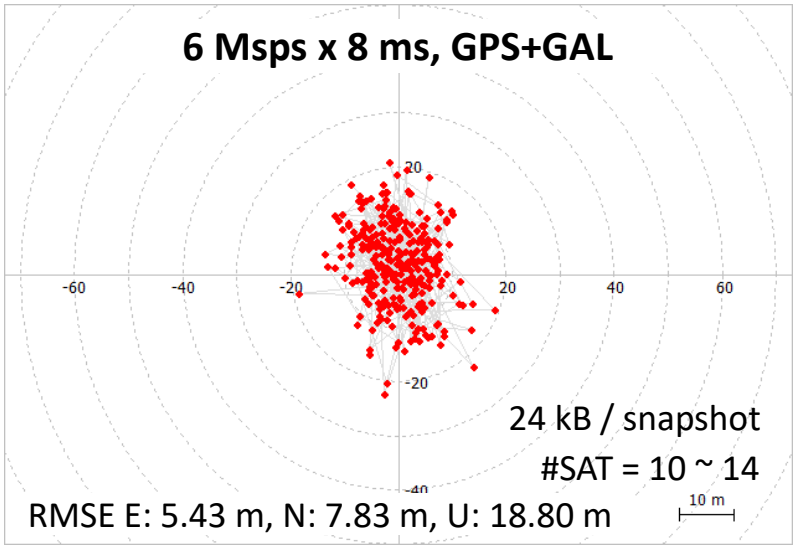
Power Budget

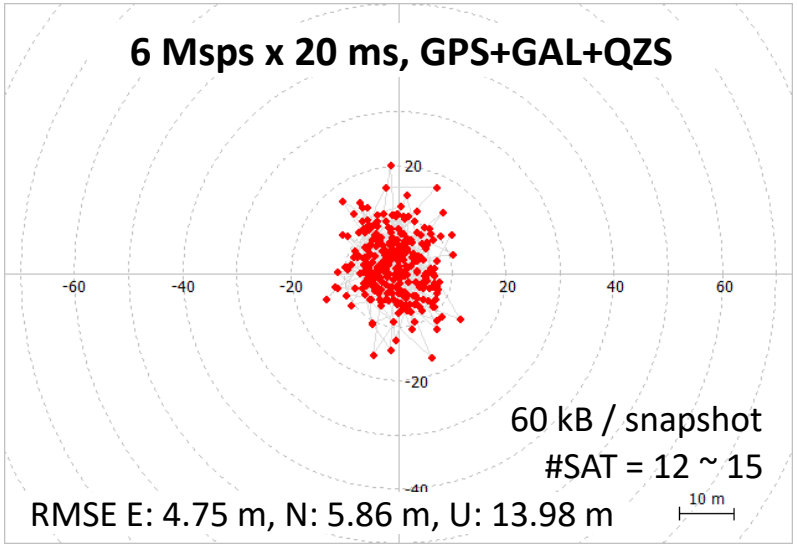
MAX2769B	: 20 mA x 25 ms
STM32L4	: 0.5 mA x 105 ms
TCXO	: 1.5 mA x 25 ms
SD-Card	: 30 mA x 80 ms
Subtotal	: 0.0083 mAH / snapshot
Standby	: 0.0002 mAH / H
Total	: 444 mAH / (1440 x 370)

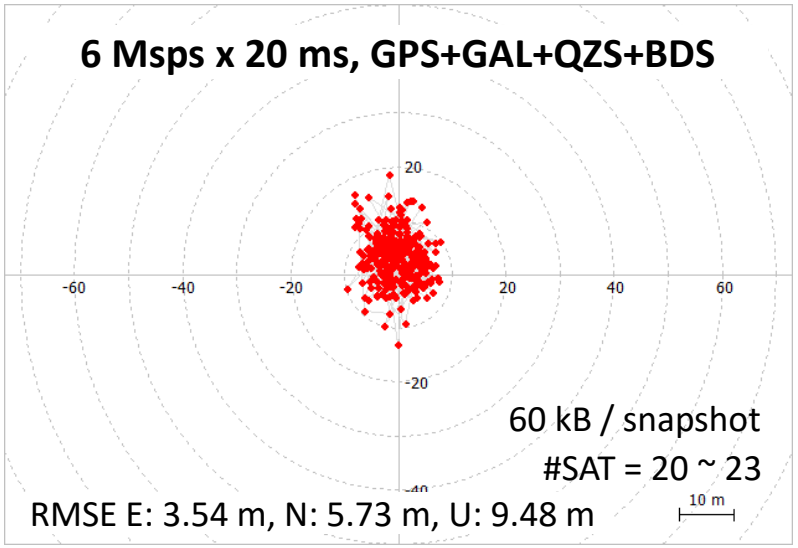


Snapshot Positioning (2/2)









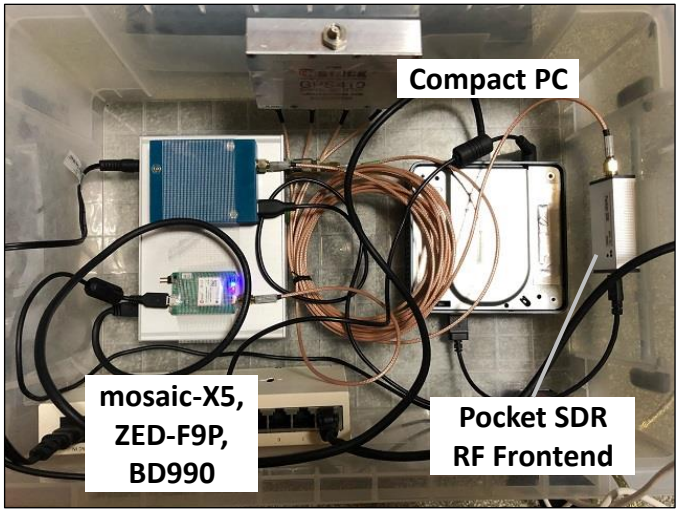
Horizontal Scatter Plots of 300 Snapshots, Post-processed by pocket_snap.py

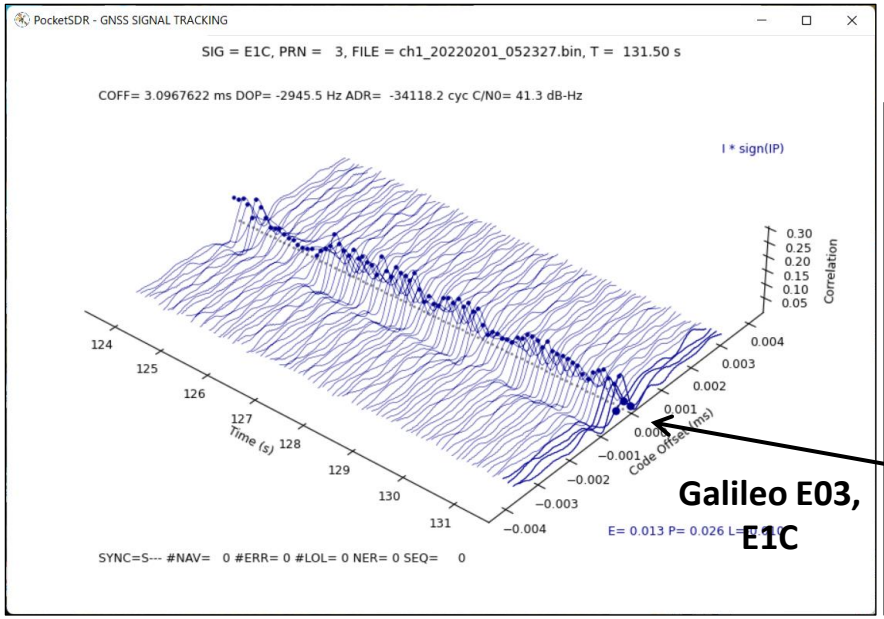
GNSS Signal Recorder

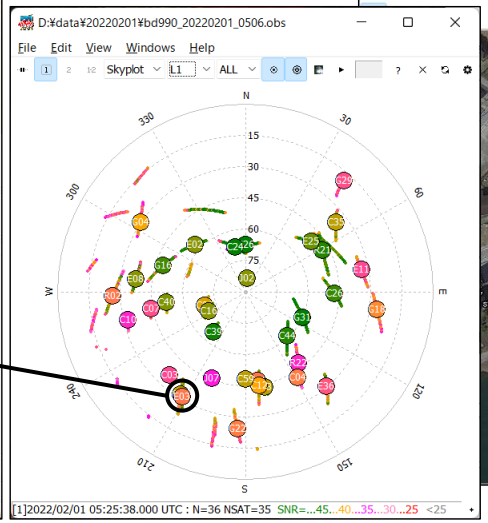
GNSS Signal Recorder by Pocket SDR

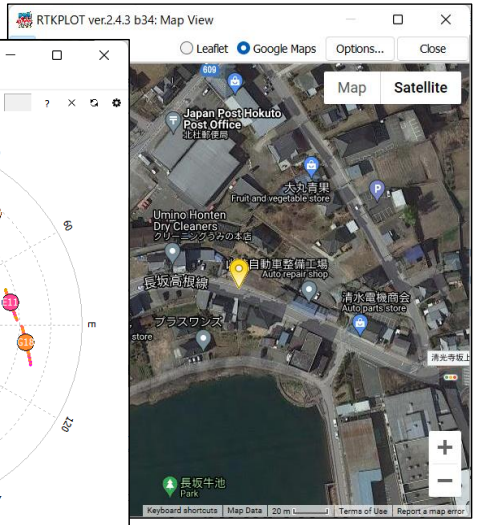
- 2 CH x 24 Msps x I/Q x 2 bits (L1 + L5)
- Compact PC (Core i5 7260U, 2C/4T, RAM 8GB)
  + Ubuntu 18.04 LTS (Linux kernel 4.15)
- Max Capture Time: ~ 4.5 H / M.2 SSD 512 GB

Signal Analysis by pocket_trk.py









Galileo E03, E1C

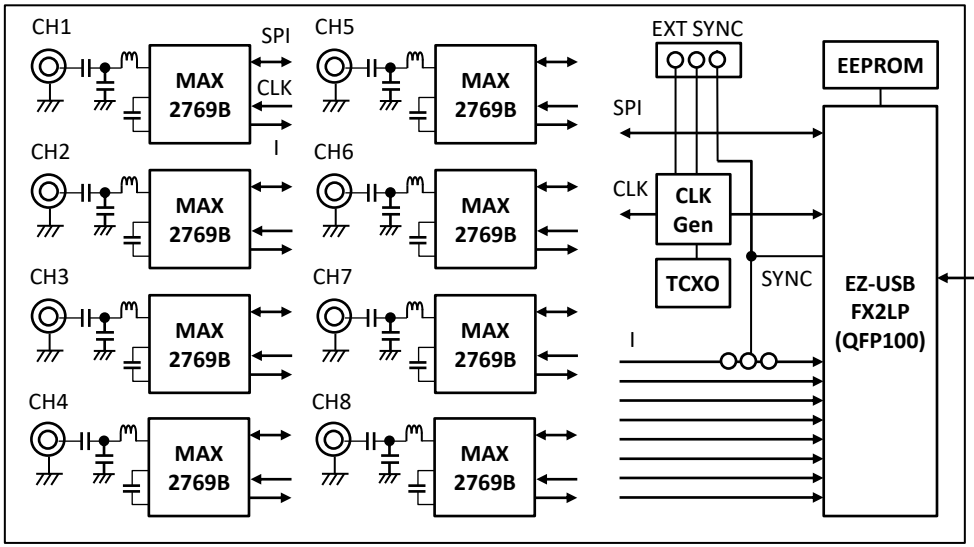
Post-processed by pocket_trk.py

Future Work

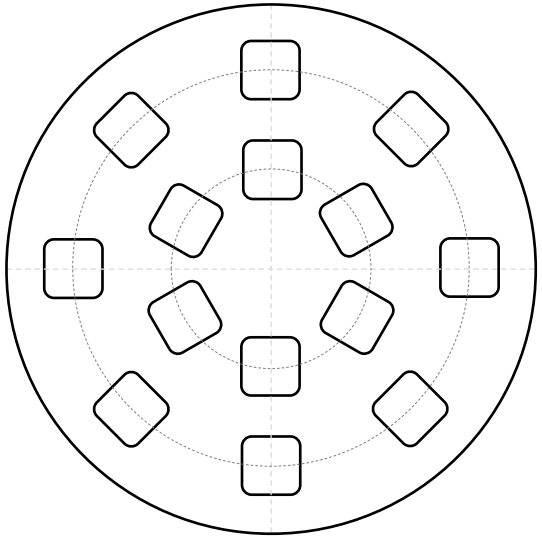
14 CH GNSS SDR RF Frontend

- GPS L1C/A, Galileo E1B/C, QZSS L1C/A and BDS B1C
- MAX2769B x 8 + EZ-USB FX2LP (QFP100, 16 bit Slave FIFO) / board
- 8 CH x 6 Msps x I/Q x 2 bits / board
- 14 CH x 6 Msps x I/Q x 2 bits / 2 boards (each 1 CH for board-synchronization)
- Total Parts Cost ~ $150 / 2 boards

For Multipath-rejection, Anti-jamming, Anti-spoofing, ...



8 CH GNSS SDR RF Frontend Board



14 Elements GNSS Antenna