White Paper

Toward the future with much accurate positioning, navigation and timing technology

Presented by SDR-SAT technology team

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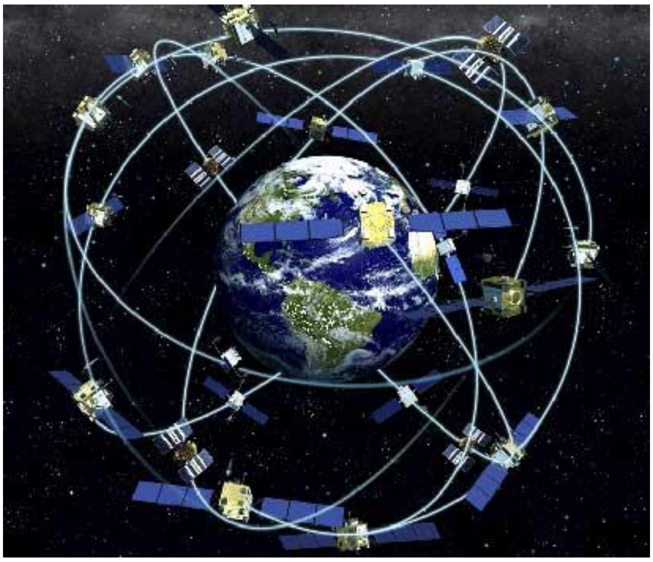
http://www.kke.co.jp/en/solution/theme/sdr-sat.html

2018



GNSS Constellation in 2018

The human society evolves with technology and the importance of positioning, navigation and timing (PNT) systems has been increased significantly in the recent decades. PNT is now, one of the most important infrastructure as well as the legacy ones, such as road, railroad, power grid. Since the launch of the first generation of GPS in early 80s, US (Global Positioning System:GPS), Russia (GLObal NAvigation Satellite System:GLONASS) and China (北斗:BeiDou) are competing launch of their own satellite system and now, they seem to have already constructed their own independent global PNT systems, followed by EU (Galilleo). They are called ‘Global Navigation Satellite System:GNSS’. Other than that, India has their own satellite system (Indian Regional Navigational Satellite System:IRNSS). It covers a limited region and called a regional navigation satellite system (RNSS). Japan’s Quasi-Zenith Satellite System (QZSS) is intended to complement GPS and Galileo to enhance the accuracy of positioning in the region.

Until 2020, it is said that GNSS constellation over the globe will be up to 150 satellites and most of the populated area in the middle latitude may be covered with more than 20~25 satellites in 24 hours, 365 days a year. With GNSS receiver which is capable of multi-GNSS reception, it is expected to have very precise positioning and timing, except for polar region where relatively less constellation

Required Accuracy and the Reality

Once the infrastructure is deployed, dozens of applications will be invented and become depending on the system. Additionally, most of the newly developed applications require much accurate PNT solution to serve. Automatic driving system is the typical one. To support such *demanding* applications and GNSS generally has some problems, the most serious one is caused by *‘multipath’* radio propagation.

Multipath Radio Propagation

In the urban area, especially in newly developed countries in Asia region, most of the deployment of PNT applications are located in urban area, where many tall buildings with concrete and iron cover the dense populated area. In that situation, even if they have more than 20 satellites at the same time on the sky, it would be many chances to have only a few satellites with direct-path. To locate a receiver as 3D position, it requires at least four satellite at the same time. In this urban situation, no precise positioning can be expected. Actually, the receiver also utilize no direct-path satellite for positioning in some case, even though it contains multipath delay, caused by reflection on the building’s wall or diffraction on the edge. The delay on the path causes significant error on the calculation of pseudo-range, which is given by dividing arrival time duration with the speed of light (c).

SDR-SAT

Improve GNSS Receivers

All the GNSS receivers are based on the same theory and mechanisms. They calculate the range from each visible satellite through detecting 'code phase'. Radio signal from a satellite is coded with a sequence of peculiar pseudo random number, which is called 'code'. Using correlators to detect the 'code phase' of each satellite, and then, solve the pseudo range to fix the location using the pseudo range values of more than four satellites with trigonometry. This method is called, *'code positioning'* or *'standalone positioning'*. The maximum accuracy could be less than 1 meter unless there is no accuracy decreasing factor, such as multipath radio propagation.

More Accurate, More Precise, …

As described above, the multipath causes a great problem in terms of accuracy of PNT system. It may sometime results tens of meters of positioning error within an urban canyon district, such as New York, Shanghai, Singapore, Seoul and Tokyo metropolitan area. This may have serious impact on PNT applications not just transportations, but also telecommunication infrastructure, which relies on precise timing.

The Role of GNSS Signal Generator and GNSS Software Receiver

To achieve much accurate positioning and much precise timing, universities, national institutes and corporate research institutes all over the world are

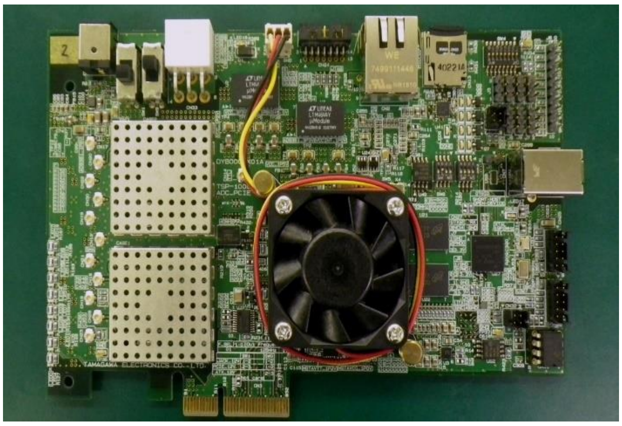


Figure 1 TME's 2-channel SDR board

tackling with multipath, interference and others.

Depending on the case, sometimes it's not easy to reproduce the same situation every time it requires. For example, a specific mix of multipath signals are merely reproduced again. In this case, record and replay is the popular tool to help spiral improvement approach.

On the other hand, in the case when trying to produce some specific situation on its own, record and replay is no use. Assume you are in the laboratory in Beijing, thinking of reproducing some situation at some place of southern hemisphere. In this case, GNSS signal generator is the tool for you.

SDR GNSS Signal Generator

Software defined radio (SDR) is a great technology, which brings us various benefits. SDR enables to develop inherently very complex radio system with very low cost. Most of the recent complex radio systems, including GNSS, are complex enough and almost impossible to implement without the help of any software approach. SDR-SAT accommodates a general purpose SDR board(s) with two radio channels. The hardware does nothing with GNSS. It's just a generic radio transceiver. Current version of SDR-SAT does not use receiver portion of the SDR board. The SDR board is from TME (Tamagawa Electronics Co. Ltd.) and it is composed of two SDR transceiver chips, AD9364, from Analog Devices, Inc. SDR-SAT also accommodates GPGPU, which accelerates the baseband signal processing significantly and it enables multipath signal generation with more than 100 paths for each satellite.

SDR-SAT

Comprehensive User Interface

SDR-SAT has an ‘easy-to-use’ intuitive GUI. The simple, online map-based scenario editor enables to create any receiver’s motion with mouse clicks. With internet connection, the online ‘Open Street Map (OSM)’ displays any place on the globe when playing GNSS signal. It also capable of importing external comma separated (CSV) format of time, latitude, longitude and height list. User may use Google Maps to create any route with KML format and import it as a SDR-SAT scenario.

GUI provides various kind of graphs and charts including satellites’ *Sky-Map*, antenna patterns and so on. When generating GNSS signal, a dialog allows to configure various parameters. They includes multipath signal environments, noise and or CW jamming synthesis, type of antenna, logging on/off, and so on.

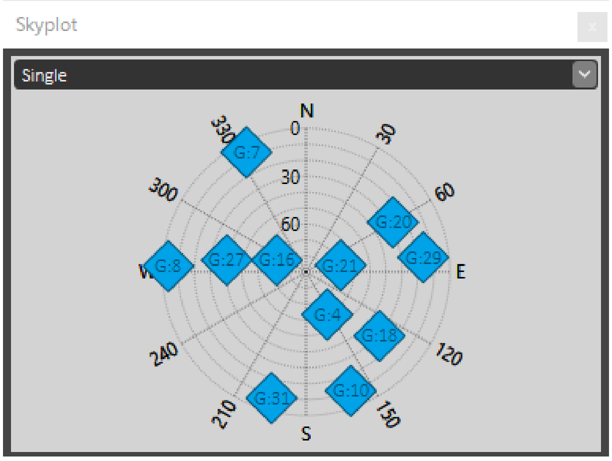


Figure 4 'Sky Plot' for GNSS Constellation

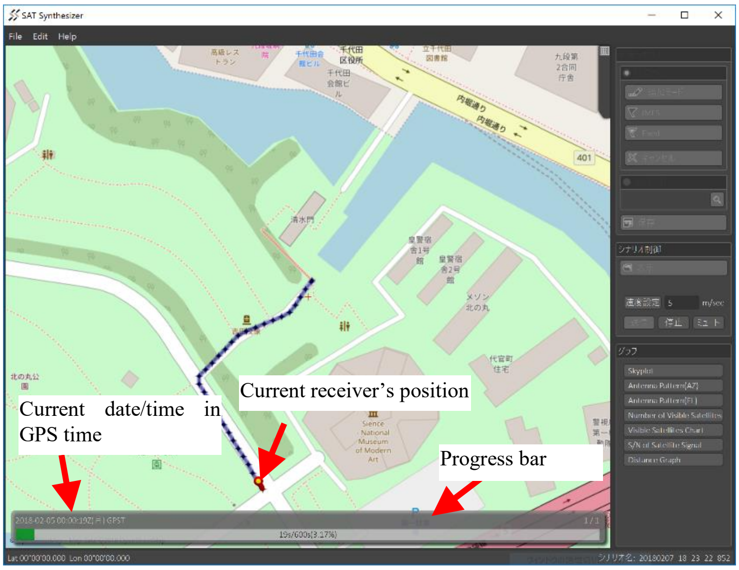


Figure 3 Signal Generation with 2D MAP Display

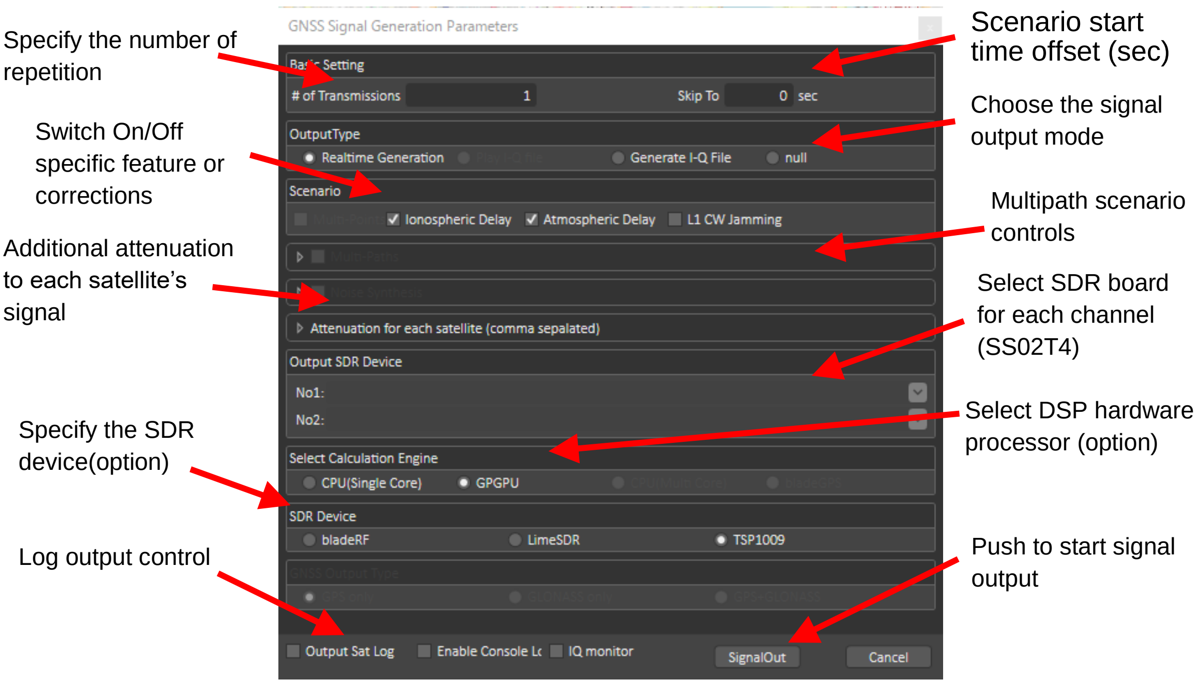


Figure 2 Various Parameters for Signal Generation

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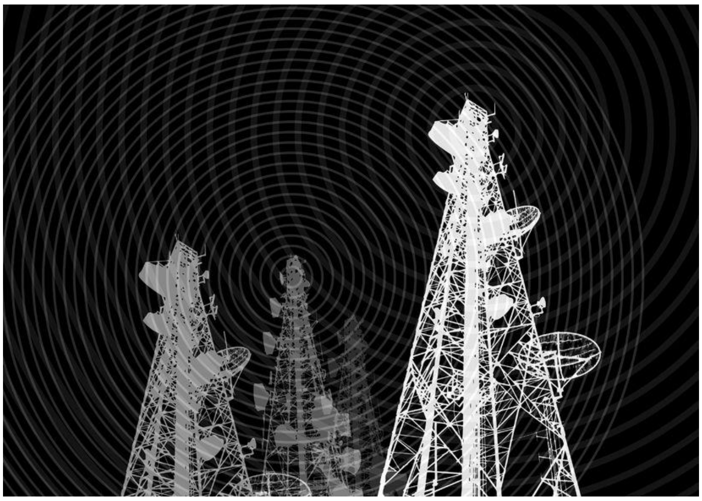
Solving Problems in the Real-World

Hardware-in-the-Loop (HIL)

In the automotive world, not just the top companies in the automotive industry, but also new comers such as IT giants, are competing to supremacy of so-called automated driving car. In these years, many of the mid-range or high-class cars tend to be equipped with certain level of ADAS (Advanced driver-assistance systems). Companies have been spending a large amount of budget on developing those systems every year.

For the development of those systems, simulation environment is the key component.



Positioning under Jamming / Interference

The infrastructure is becoming more important and the threat of terrorist attack to PNT infrastructure is becoming more serious. Once it happens, many urban functions will be paralyzed instantly.

Protecting the infrastructure from the attacks, one of the effective way is to detect the attacks and alert them. Generally, there is no easy way to distinguish interfered GNSS signal from the non-interfered one. Nonetheless, researchers are making effort to find the way of detecting them and preventing or mitigating the damage. GNSS signal generator is one of the essential tools. It is capable of generating any fake navigation message with any waveform, at any timing, just like terrorists or some crimes committed for fun. In many cases they should also use the same kind of technology, based on SDR.

Precise Time Synchronization

Recent LTE or 5G base stations are migrating from using FDD to TDD for duplexing downlink and uplink channels, because of the shortage of bandwidth. With TDD, it's easier to acquire a frequency which has certain amount of continuous bandwidth than FDD. However, it requires precise synchronization of timing among adjacent base stations to avoid unnecessary interference among them and user equipment. The amount of precision is 1 microsecond or less than 1 microsecond and they are now, relying on GNSS. It is known that in some cases in urban environment, multipath GNSS signal degrade the precision down to 100 nsec.

To mitigate the influence of multipath in urban canyon environment, researchers are investigating the method to exclude satellite signals which contain more than certain level of multipath signal. SDR-SAT is used for generating GNSS signals at any multipath condition.

Table 1 SDR-SAT Hardware Specification

	SS02T2	SS02T4	SS02T2OX	SS02T4OX
Peak Power Range	-99dBm～-10dBm (at L1=1575.42MHz)			
Frequency Range	GPS L1(1575.42MHz)*1 GLONASS L1(1602.0MHz)*1 *1 SDR H/W covers all the L band frequency and it's fully controlled by software.			
Number of RF Output	1	2	1	2
External Clock Input	-		10MHz, 1pps, GNSS*2 *2 Turn on/off DC power supply w/software	
External Sync Output	-		10MHz, 1pps	
Sampling Frequency	16MHz			
Signal Bandwidth	8MHz			
Quantization bit	12bit			
Reference oscillator	TCXO (<0.5ppm)		OCXO (< ±10ppb)	
Long Time Stability	> 72hours			
Power Supply	100V~220V AC(50Hz, 60Hz)			
Size (WHD)	W430mm x D522mm x H176			
Weight	32kg			
Processor / FPGA	Intel Core i7-6700 (8M Cache 3.40GHz) / Xillinx ZYNQ SoC			
DAC	AD9364 x2 with common reference oscillator			
Memory	8GB			
Storage	SSD 450GB			
Graphic (GPGPU)	ELSA GeForce GTX 1080 8GB GLADIAC			
OS	Windows 10 Enterprise LTSB 2016 High End 64bit Edition			

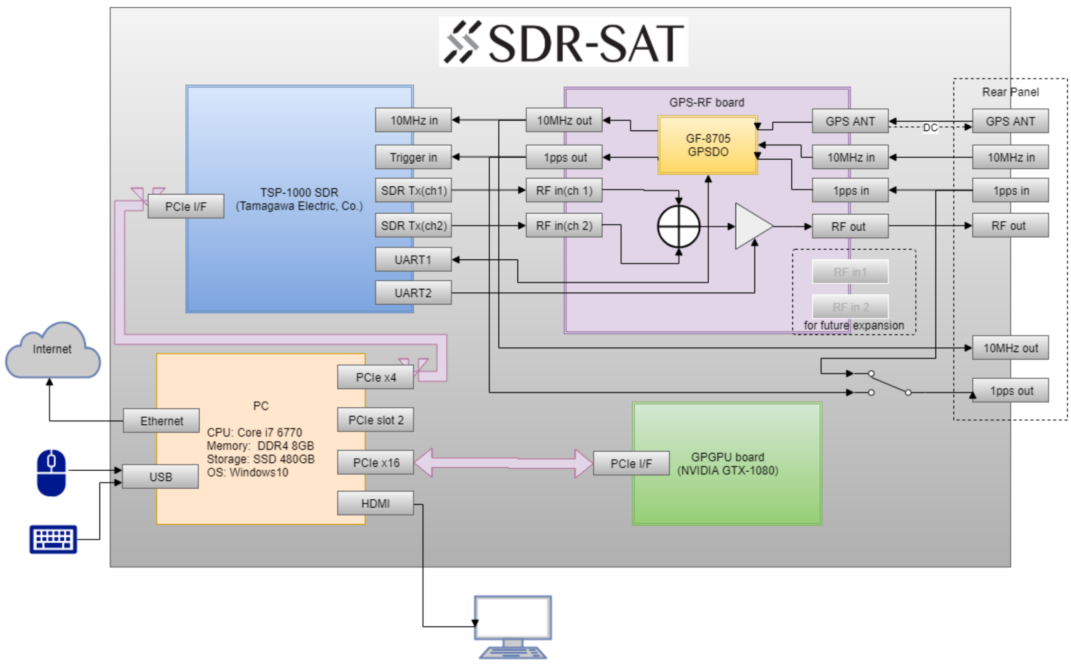


Table 2 SDR-SAT Interface to External Devices/Equipment

Connector	SS02T2	SS02T4	SS02T2OX	SS02T4OX
RF-OUT1(SMA-J)	SDR RF output 1	SDR RF output 1	SDR RF output 1	SDR RF output 1
RF-OUT2(SMA-J)	-	SDR RF output 2	-	SDR RF output 2
ANT IN(SMA-J)	-	-	GNSS Signal Input for GPSDO (w/ DC 5V for active antenna)	
10M OUT(SMA-J)	-	-	Reference Clock 10MHz Output	
1PPS OUT(SMA-J)	-	-	Reference Clock 1pps Output	
10MHz IN(SMA-J)	-	-	Reference Clock 10MHz Input	
1PPS IN(SMA-J)	-	-	Reference Clock 1pps Input	
PWR	100V~220V AC(50Hz, 60Hz)			
USB	Hi-Speed(2.0) x2 Super-Speed(3.0) x2			
LAN	GbE x2 * SDR-SAT has to be connected to the Internet			
DISPLAY	DVI-D,VGA, HDMI, DisplayPort			

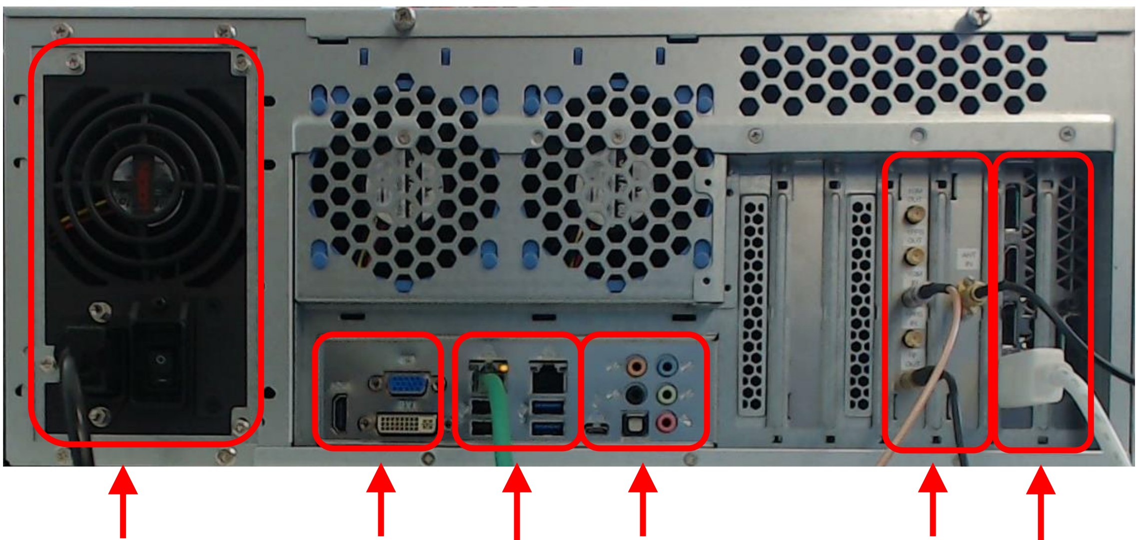


Figure 5 SDR-SAT Rear Panel Layout (SDR-SAT SS02T2OX)

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Receiver

-GNSS Software Receiver for L5/L5S Signal-

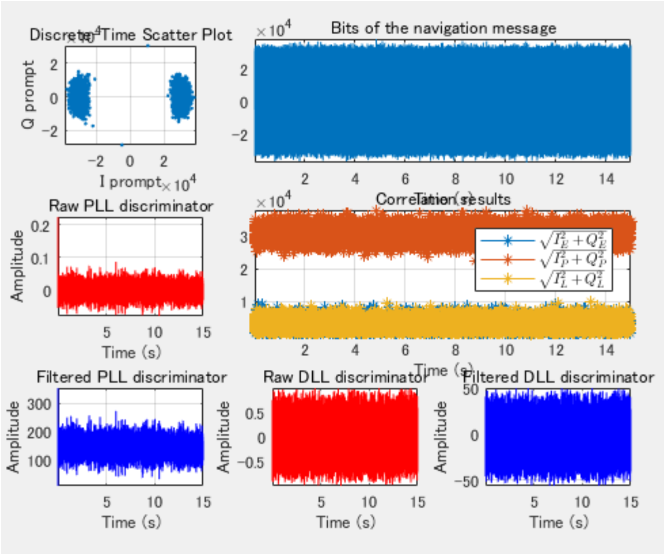

Figure 8 Tracking Result of GNSS Software Receiver for L5/L5S signal

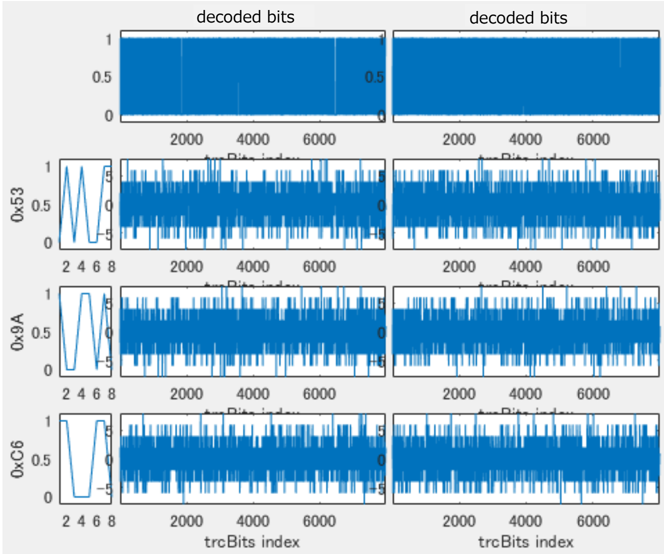

Figure 7 Decoded signal of L5/L5S Signal with GNSS Software Receiver

GNSS Software Receiver

Accompanying with GNSS Signal Generator and GNSS multipath radio propagation Simulators, GNSS Software Receiver is one of the most useful tools for research and development purpose at PNT community. In addition to the major L1CA signal, there are some minor radio signals, such as L5, L5S and L6 signals are broadcasted from some of the GNSS satellites.

However, it's not easy to find a receiver which is capable of receiving those minor signals. In this case, the combination of SDR front-end and Software Receiver is the useful tool for researchers. KKE provides GNSS Software Receiver for L5/L5S signals written in MATLAB™, which is based on a free L1CA receiver program[1] provided with a famous book by Kai Borre et.al. and the portion of the MATLAB source code is available under GPL[4]. Current version is a 'post-processing' receiver and supports various SDR front-end, including Nuand's bladeRF[2] and Amungo Navigation's NUT4NT[3]. We're planning to support NSL's STEREO, as well.

Related URLs:

[1] https://github.com/gnss-sdr/gnss-sdr

[2] https://www.nuand.com/

[3] https://www.amungo-navigation.com/nut4nt

[4] Under preparation in March 2018. Email to sdrsat@kke.co.jp

Figure 6 Four Channel GNSS Receiver Front End 'NUT4NT' from Amungo

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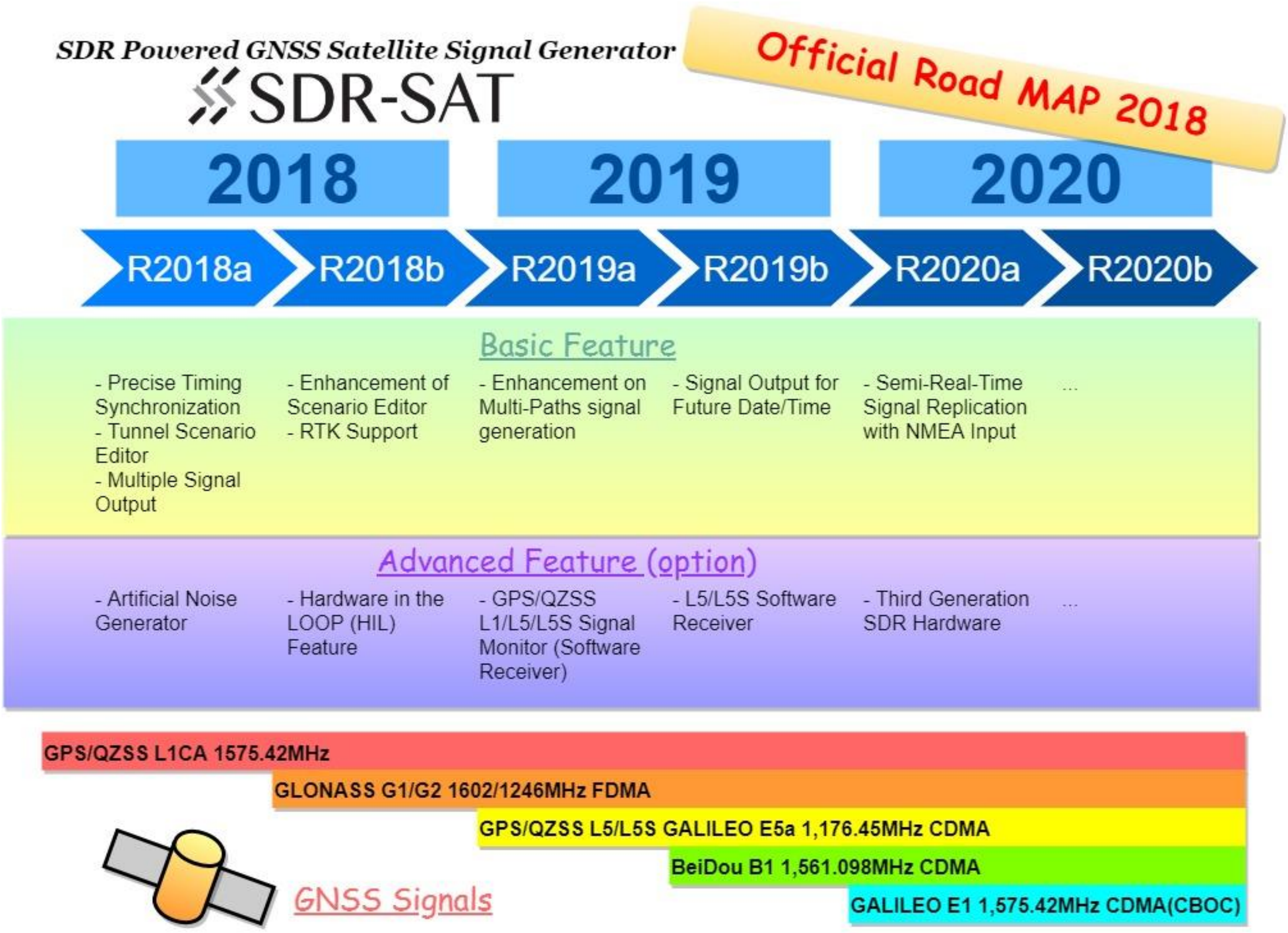
SDR Powered GNSS Satellite Signal Generator
SDR-SAT
Official Road MAP 2018
2018
2019
2020
R2018a
R2018b
R2019a
R2019b
R2020a
R2020b
Basic Feature
- Precise Timing Synchronization
- Tunnel Scenario Editor
- Multiple Signal Output
- Enhancement of Scenario Editor
- RTK Support
- Enhancement on Multi-Paths signal generation
- Signal Output for Future Date/Time
- Semi-Real-Time Signal Replication with NMEA Input
...
Advanced Feature (option)
- Artificial Noise Generator
- Hardware in the LOOP (HIL) Feature
- GPS/QZSS L1/L5/L5S Signal Monitor (Software Receiver)
- L5/L5S Software Receiver
- Third Generation SDR Hardware
...
GPS/QZSS L1CA 1575.42MHz
GLONASS G1/G2 1602/1246MHz FDMA
GPS/QZSS L5/L5S GALILEO E5a 1,176.45MHz CDMA
BeiDou B1 1,561.098MHz CDMA
GALILEO E1 1,575.42MHz CDMA(CBOC)
GNSS Signals

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