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Basic GNSS Introduction, Applications and Low-Cost Receiver Systems

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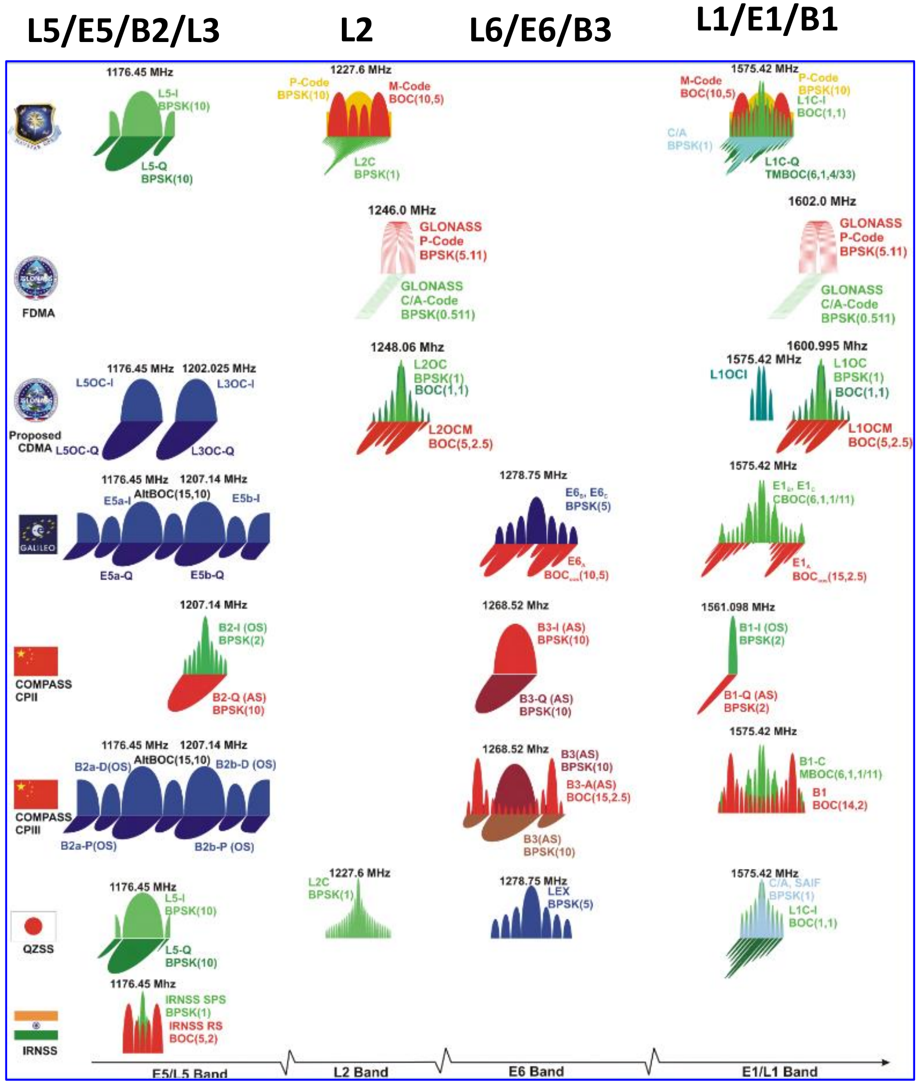
What is GNSS?

- GNSS or Global Navigation Satellite System is an acronym used to represent all navigation satellite systems such as

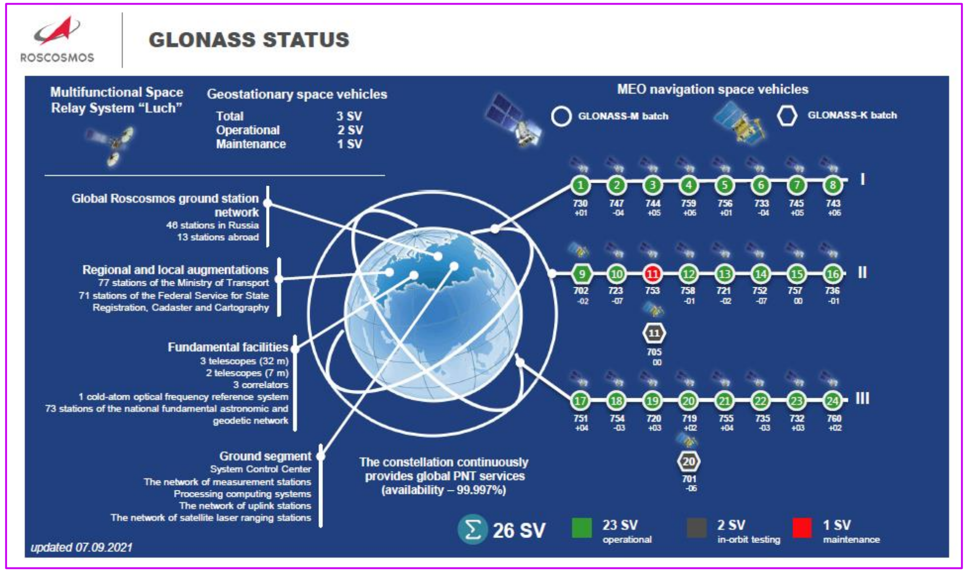
Satellite	Country	Coverage
GPS	USA	Global
GLONASS	Russia	Global
Galileo	Europe	Global
BeiDou (BDS)	China	Global
QZSS (Michibiki)	Japan	Regional
NavIC	India	Regional

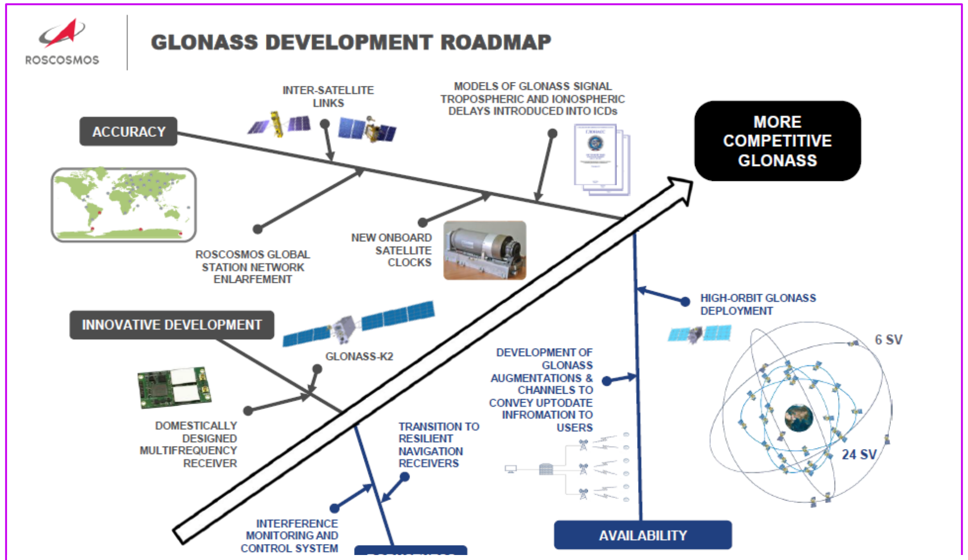
- ✓ GPS and GLONASS have signals for civilian and military usage
  - ❖ Military signals are encrypted and not available for civilian use
- ✓ Galileo and BeiDou also have Open and Restricted Signals
- ✓ All civilian signals are freely available
- ✓ Technical information for civilian signals are made public
  - ❖ Necessary to develop a receiver
  - ❖ Its called ICD (Interface Control Document) or IS (Interface Specification)

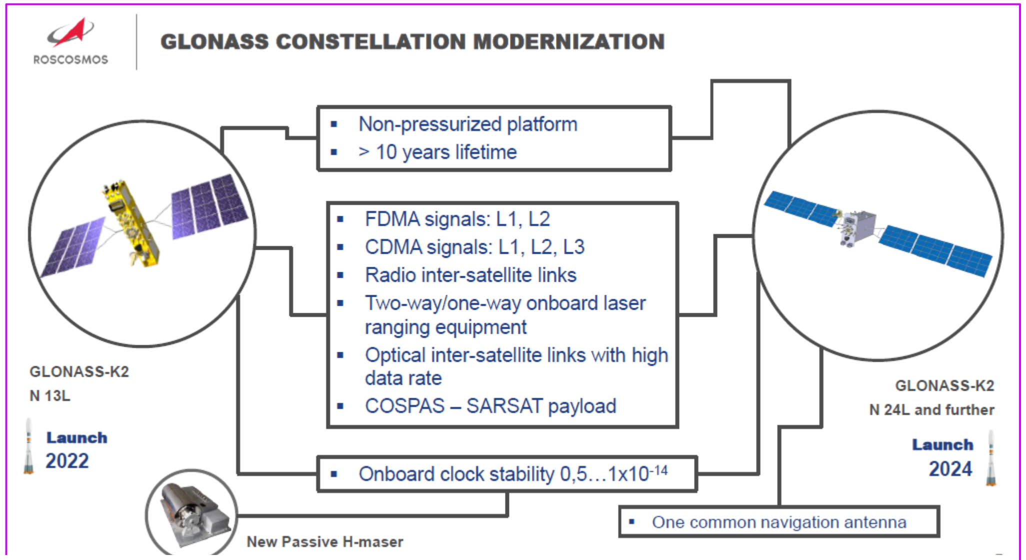


https://gssc.esa.int/navipedia/images/c/cf/GNSS_All_Signals.png

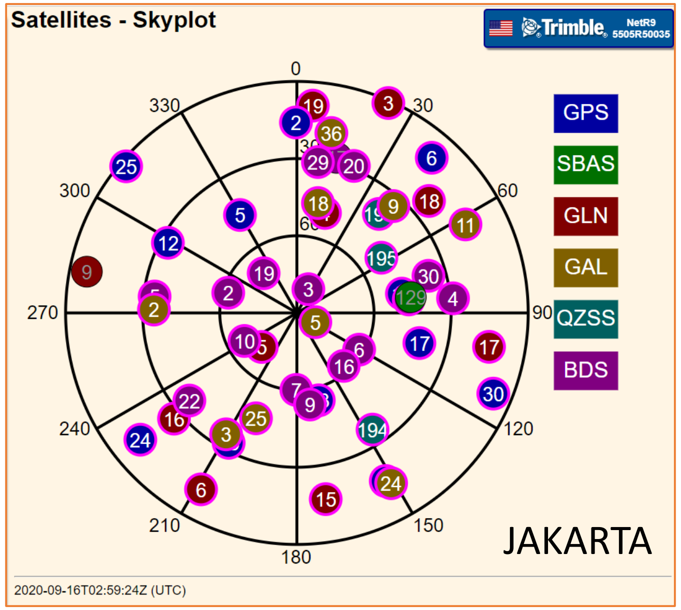
GLONASS

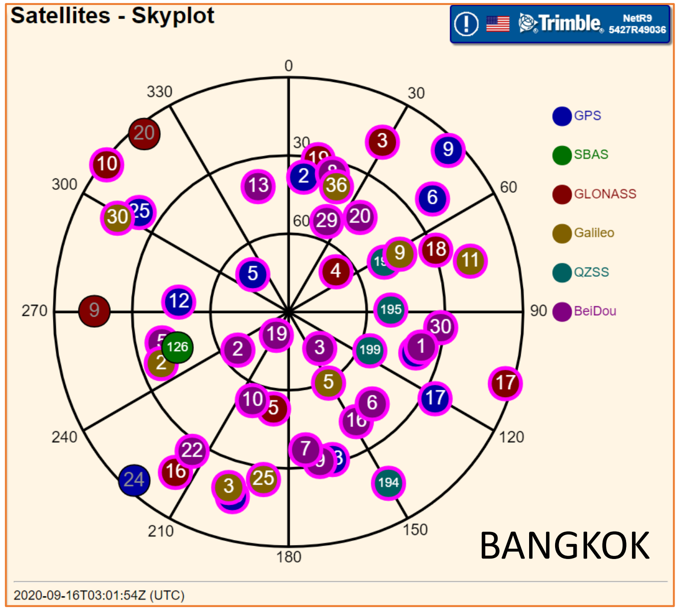


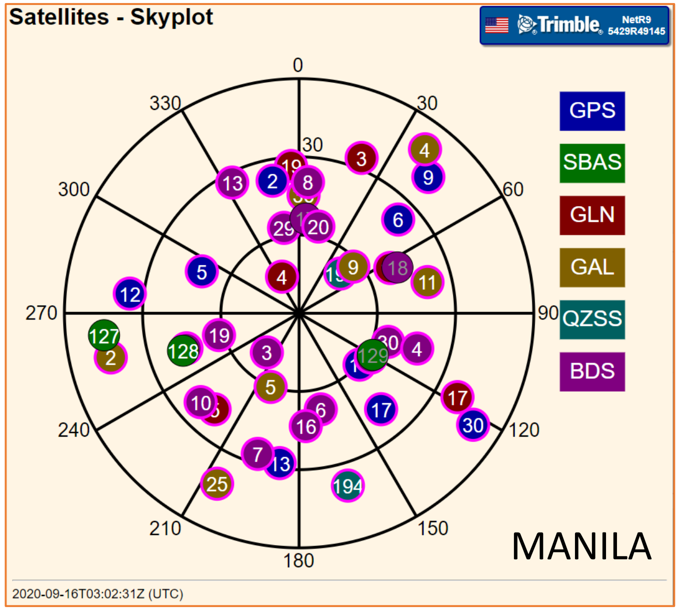


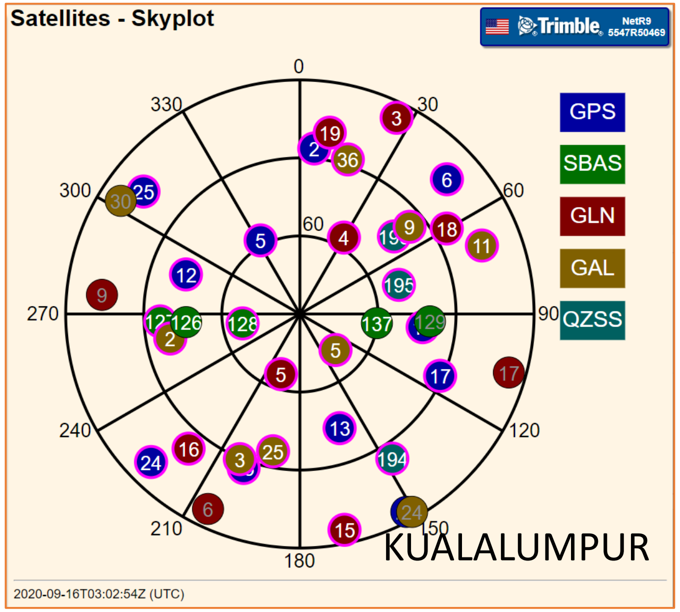


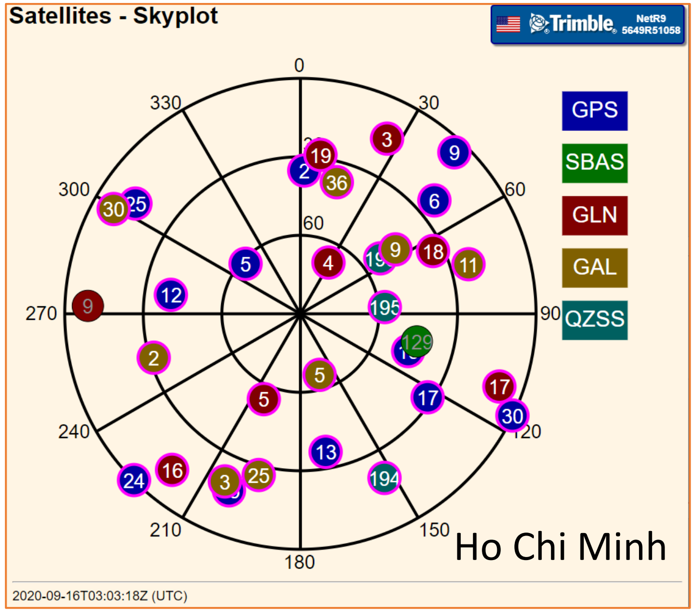
These slides were taken from ICG Website. Please refer the original presentation material at https://www.unoosa.org/documents/pdf/icg/2021/ICG15/01.pdf

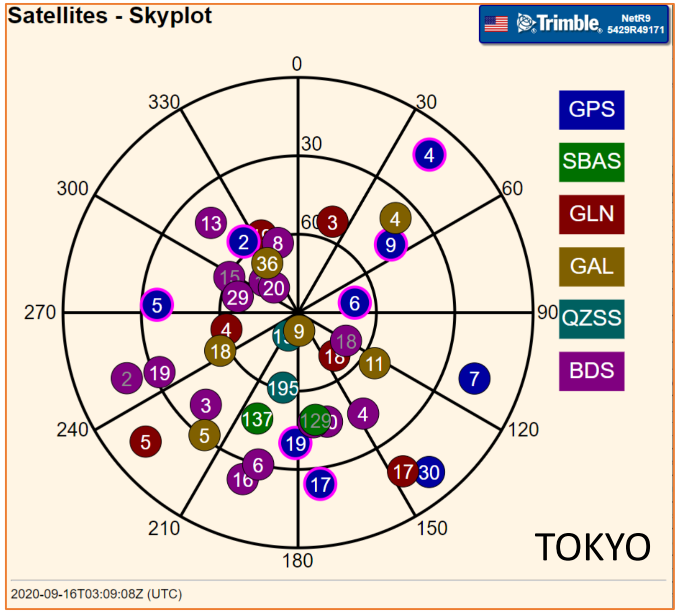












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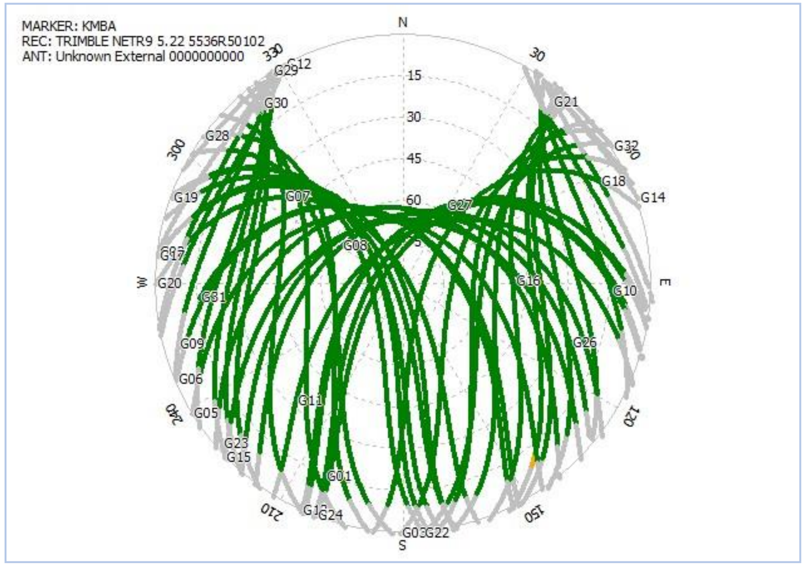
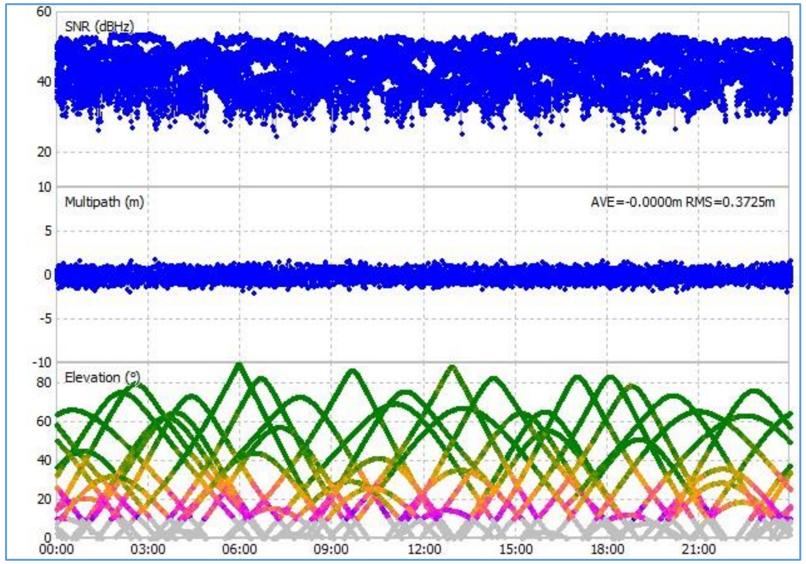
We do not have BeiDou data in Kualalumpur and Ho Chi Minh stations because of license limitation in the receiver

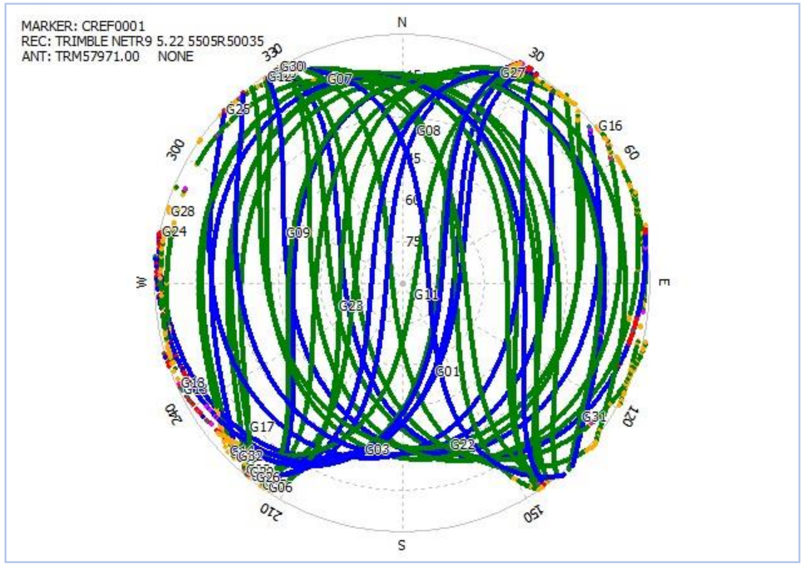
GPS Skyplots: Tokyo, Jakarta and Maputo

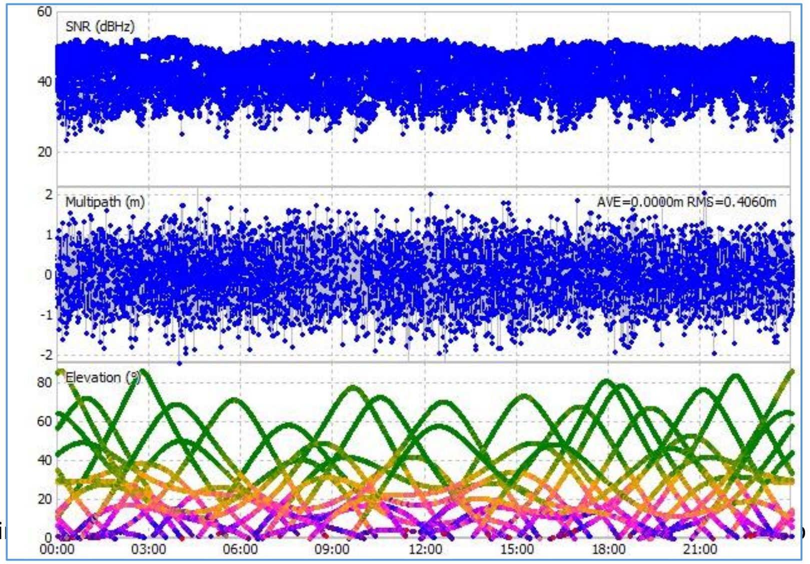
Tokyo Base-Station



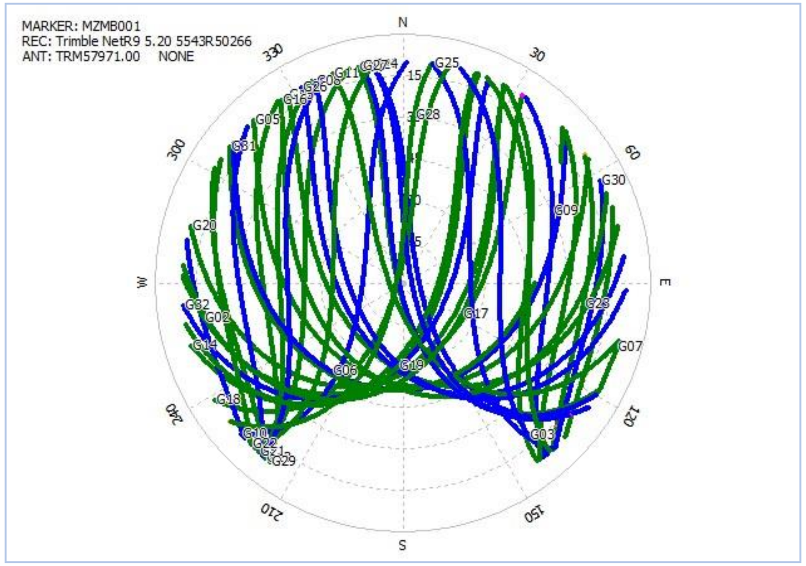


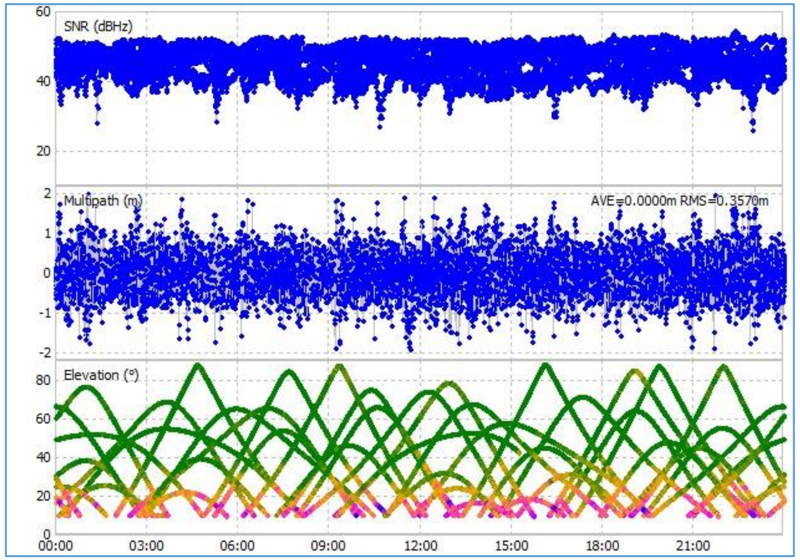
Jakarta Base-Station





Maputo Base-Station

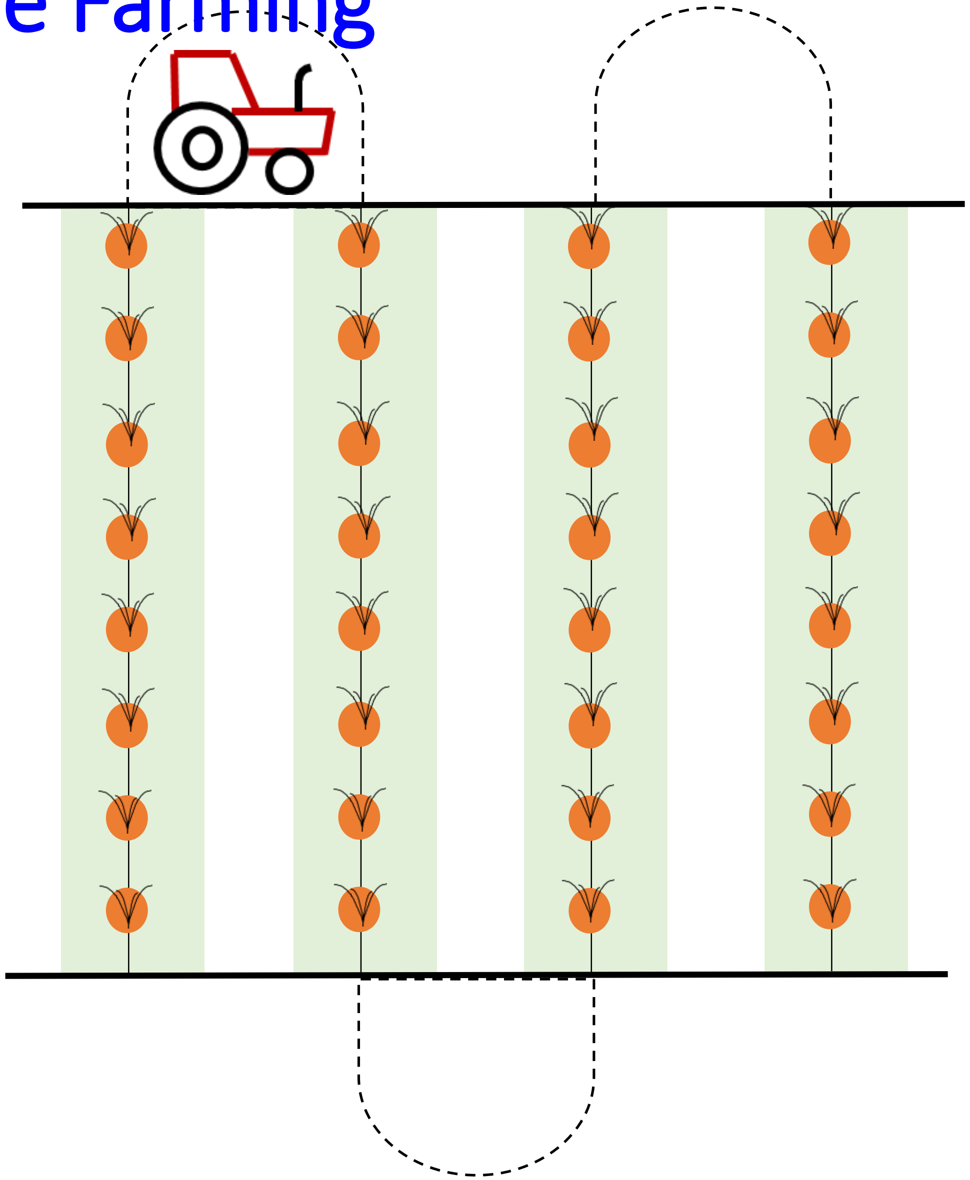




Lots of Opportunities for these GNSS Applications…..

- Legal & Law Enforcement
  - Geo-Fencing
  - Geo-Security
  - Illegal Fishing
- Pay-As-You-Drive
  - Toll Fee
  - ERP
- ITS / ADAS
  - Auto-Driving
  - V2V / V2X
- **Surveying**
  - **Mapping**
  - **GIS**
  - **UAV / UMV**
- Tax Collection
  - Insurance
  - Alternate for Fuel Tax Collection
- Secured Transport of Dangerous Goods
  - Supply-Chain Management
- IoT
  - M2M
  - Robotics
- Emergency & Safety Services
  - SoL, e-Call
  - ERA-GLONASS
  - Early Warning
- Agriculture
  - Precision Farming
- AI
  - Medical Health Services
  - People Flow
- **Transport**
  - **Vehicles**
  - **Rail**
  - **Aviation**
  - **Space**
- Timing Applications
  - Telecom
  - Finance
  - Power Grid
- Scientific Applications
  - Space Weather
  - VLBI
- LBS
  - Game
  - Entertainment
  - Advertisement
  - Marketing

GNSS for Precise Farming



Before and after seedling, the tractor has to irrigate, put fertilizer and spray pesticides where there are plants.
If they are put far from the plant, it will affect the yield.

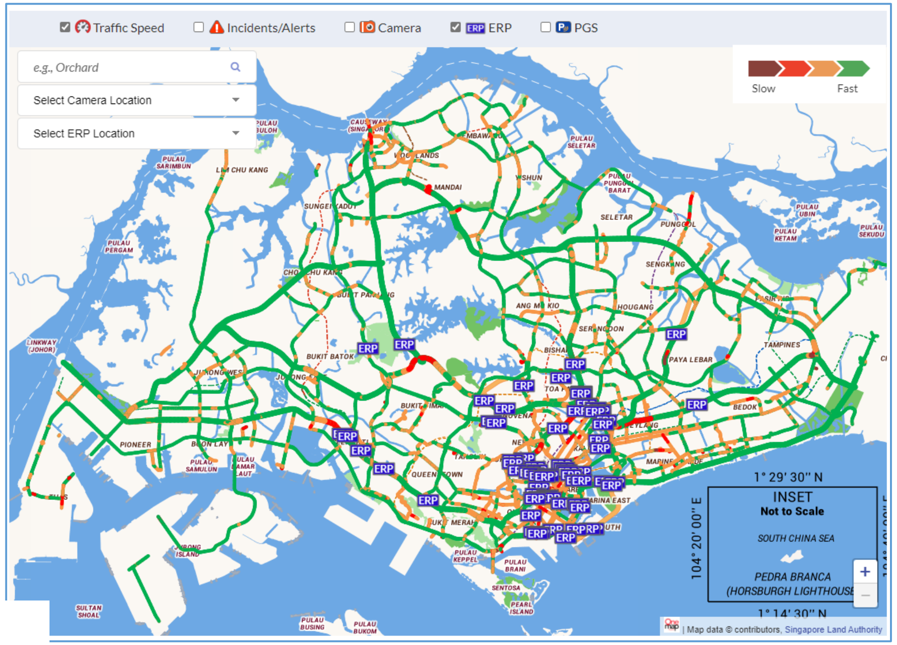
This requires few centimeter level of accuracy so that the tractor can automatically perform the job at different stages of plant growth and harvesting.

GNSS is a core system to provide this level of accuracy.

Road Pricing : ERP to ERP 2.0 (Singapore)

ERP → ERP2.0

ERP is based on Gantry System
Requires construction of huge structures

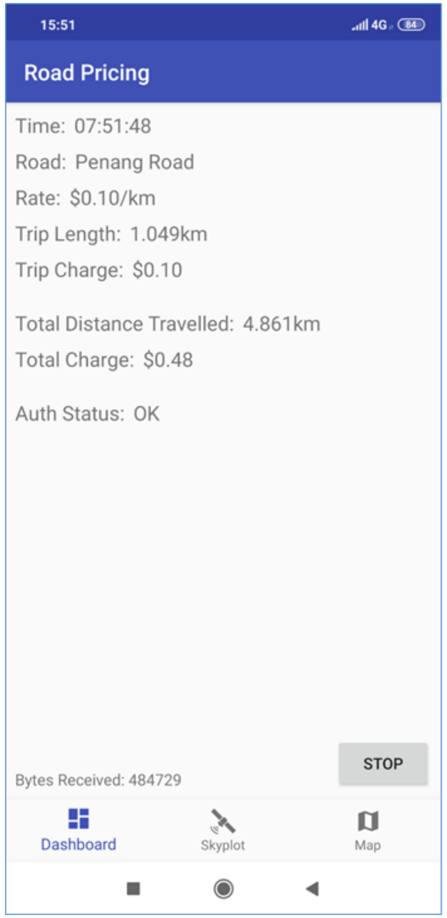


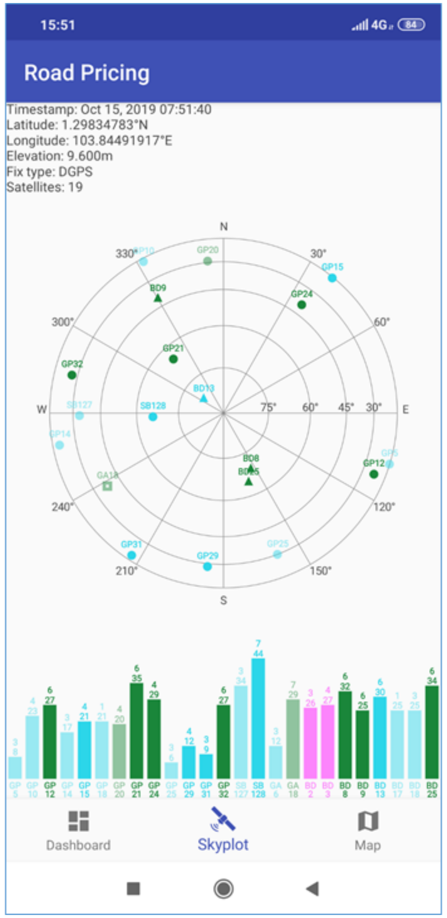
ERP 2.0 is based on Satellite System (GNSS)

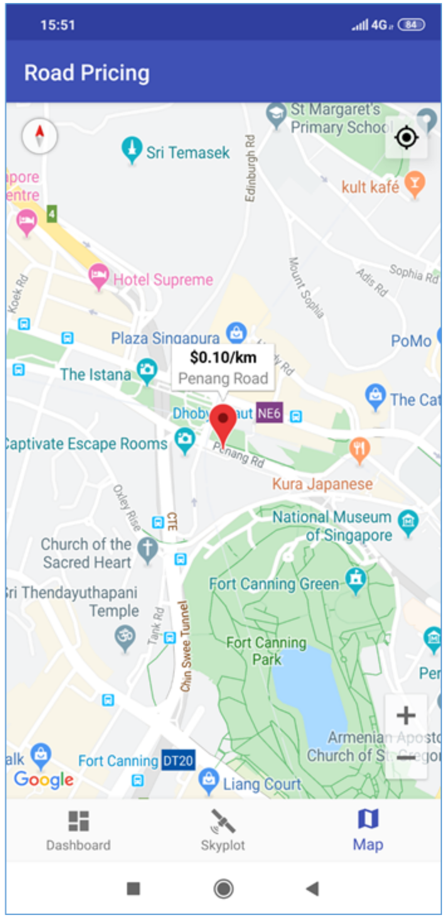
Source: https://onemotoring.lta.gov.sg/content/onemotoring/home/driving/traffic_information/traffic-smart.html

Dynamic Road Pricing (DRP) based on GNSS

- Dynamically charge for road usage
  - Pricing is variable and based on
    - Distance, time, location,
    - Vehicle type, lane and occupancy
    - Traffic congestion condition
- Reward road users for using alternate routes to avoid congested route
  - Payback the drivers who help to minimize traffic congestion
- No Physical Toll Gates
  - GPS-based system is used for Location, Distance and Lane occupation
  - Can be implemented on any road section
    - Not limited to only highways, express ways or toll roads
- Global Seamless Implementation
  - The same system can be implemented globally
  - The same In-vehicle device can be used globally
    - Single system for smooth cross-border operation
    - Once a border is crossed, charging or rewarding rates can be updated automatically







Fishing Boat Monitoring

Fishing boats in Bali, Indonesia

Fisheries Industry of Pakistan: Business Report – Ravi Magazine
https://www.ravimagazine.com/fisheries-industry-pakistan-business-report/

- Monitoring of Fishing Boats is necessary to fishing industry.
- This will help the fishermen to generate more income in long-term.
- Over-fishing, Illegal fishing shall be stopped to protect marine ecology and bio-diversity.

New Market and Business Opportunities

Asia-Pacific will continue to account for more than half of the global GNSS installed base

European Union (EU28)

	2019 Value	2019 %	2029 Value	2029 %
Installed Base	0.7 bln	11.0	1.0 bln	11.0
Revenue (€)	38.4 bln	25.5	65.3 bln	20.1
Devices per capita	1.4		2.1	

Russia and Non-EU 28 (Non-EU28 Europe)

	2019 Value	2019 %	2029 Value	2029 %
Installed Base	0.3 bln	4.0	0.3 bln	3.5
Revenue (€)	9.7 bln	6.4	16.3 bln	5.0
Devices per capita	1.1		1.5	

North America

	2019 Value	2019 %	2029 Value	2029 %
Installed Base	1.0 bln	15.9	1.5 bln	15.2
Revenue (€)	40.3 bln	26.7	92.2 bln	28.4
Devices per capita	2.0		2.7	

Asia-Pacific

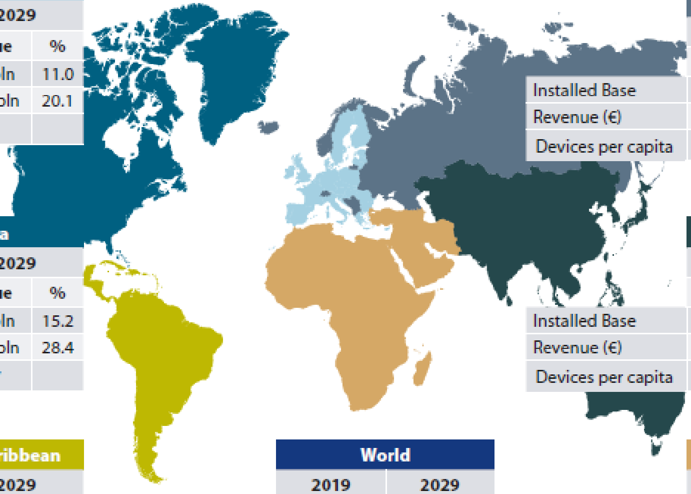
	2019 Value	2019 %	2029 Value	2029 %
Installed Base	3.4 bln	53.2	5.1 bln	53.5
Revenue (€)	46.0 bln	30.5	106.0 bln	32.7
Devices per capita	0.8		1.1	

South America + Caribbean

	2019 Value	2019 %	2029 Value	2029 %
Installed Base	0.6 bln	9.7	0.9 bln	9.3
Revenue (€)	8.1 bln	5.4	13.2 bln	4.1
Devices per capita	1.2		1.6	

World

	2019 Value	2029 Value
Installed Base	6.4 bln	9.5 bln
Revenue (€)	150.7 bln	324.4 bln
Devices per capita	0.8	1.1



Middle East + Africa

	2019 Value	2019 %	2029 Value	2029 %
Installed Base	0.4 bln	6.3	0.7 bln	7.5
Revenue (€)	8.2 bln	5.4	31.4 bln	9.7
Devices per capita	0.2		0.4	

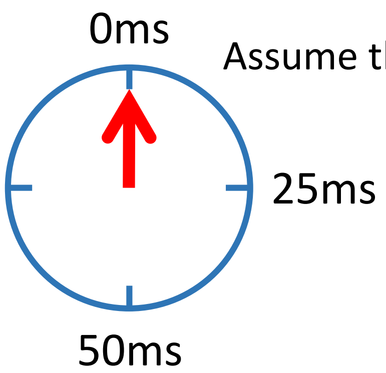
Consumer Solutions	The wearables market is on the rise, while dual-frequency and high accuracy are gaining traction in smartphones. Leveraging the hardware as a platform, software and apps provide endless opportunities to tailor the use of position to the needs of mass market users.
Road	As vehicles become more intelligent and automated, and the Mobility-as-a-Service business expands, the industry faces the challenge of introducing high-end GNSS solutions on a mass-market scale.
Manned Aviation	ICAO's Global Air Navigation Plan (GANP) provides a roadmap for the deployment of new operational concepts and technologies to improve the global efficiency of ATM.
Drones	GNSS is a key enabler for drones ensuring safe navigation and reliability for both consumer and commercial applications. As the industry matures, the supply chain is becoming increasingly specialised and in some cases the operator role is absorbed into end-user organisations.
Maritime	The use of satellite-based augmentation systems is becoming the primary source of accurate positioning across the maritime and inland waterway domains.

Emergency Response	Multi-constellation is the recognized paradigm by all major beacon manufacturers. Innovative features such as Return Link and Remote Activation are on the rise.
Rail	Railways are in the process of digitalization and GNSS is part of the game. GNSS based solutions for signalling applications will help reduce cost and enhance performance.
Agriculture	GNSS has become an integral part of smart, connected and integrated farm management solutions and a key driver for precision farming across the whole crop cycle.
Geomatics	The role of traditional GNSS surveying is transforming owing to the integration of emerging digital data collection techniques, high-precision GNSS services, cloud computing and sensor fusion.
Critical Infrastructures	Emerging paradigms such as Time-as-a-service (TaaS) and innovative applications are expected to drive growth in the GNSS Critical infrastructures segment. The market is stimulated by an increased need for resilience and improved accuracy, as well as by regulation.

Source: Page 6 of GSA GNSS Market Report, Issue 6, 2019, European GNSS Agency (GSA)

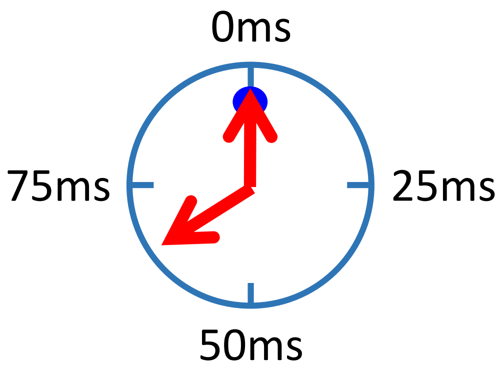
How does a GPS/GNSS Receiver Work?

GNSS: How does it work?
Determine the Distance using Radio Wave

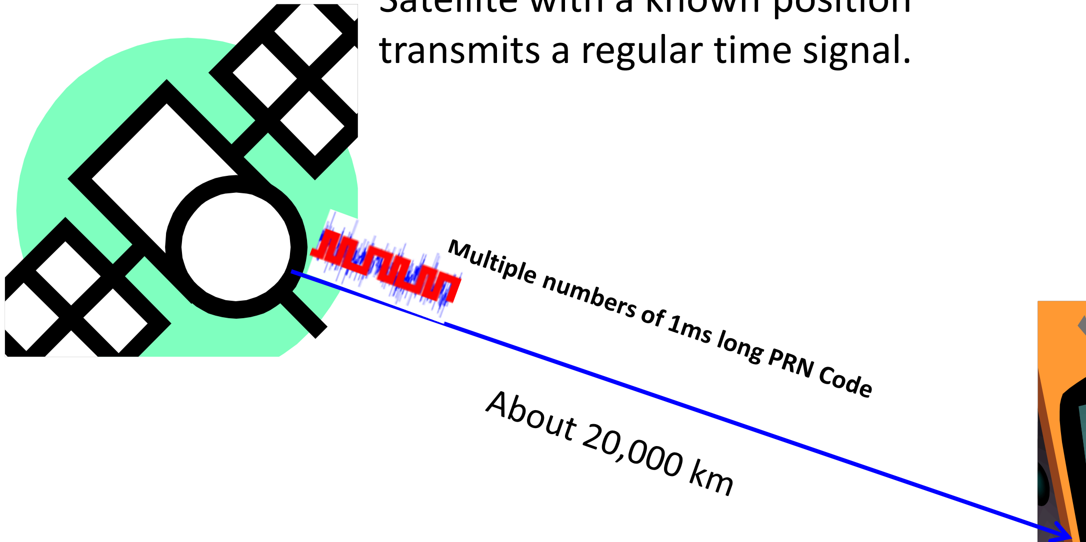


Assume that the Satellite Transmits Signal at 0ms.

If Receiver receives the same Signal after 67ms,
Distance = 67x300,000 = 20,100Km



Satellite with a known position
transmits a regular time signal.



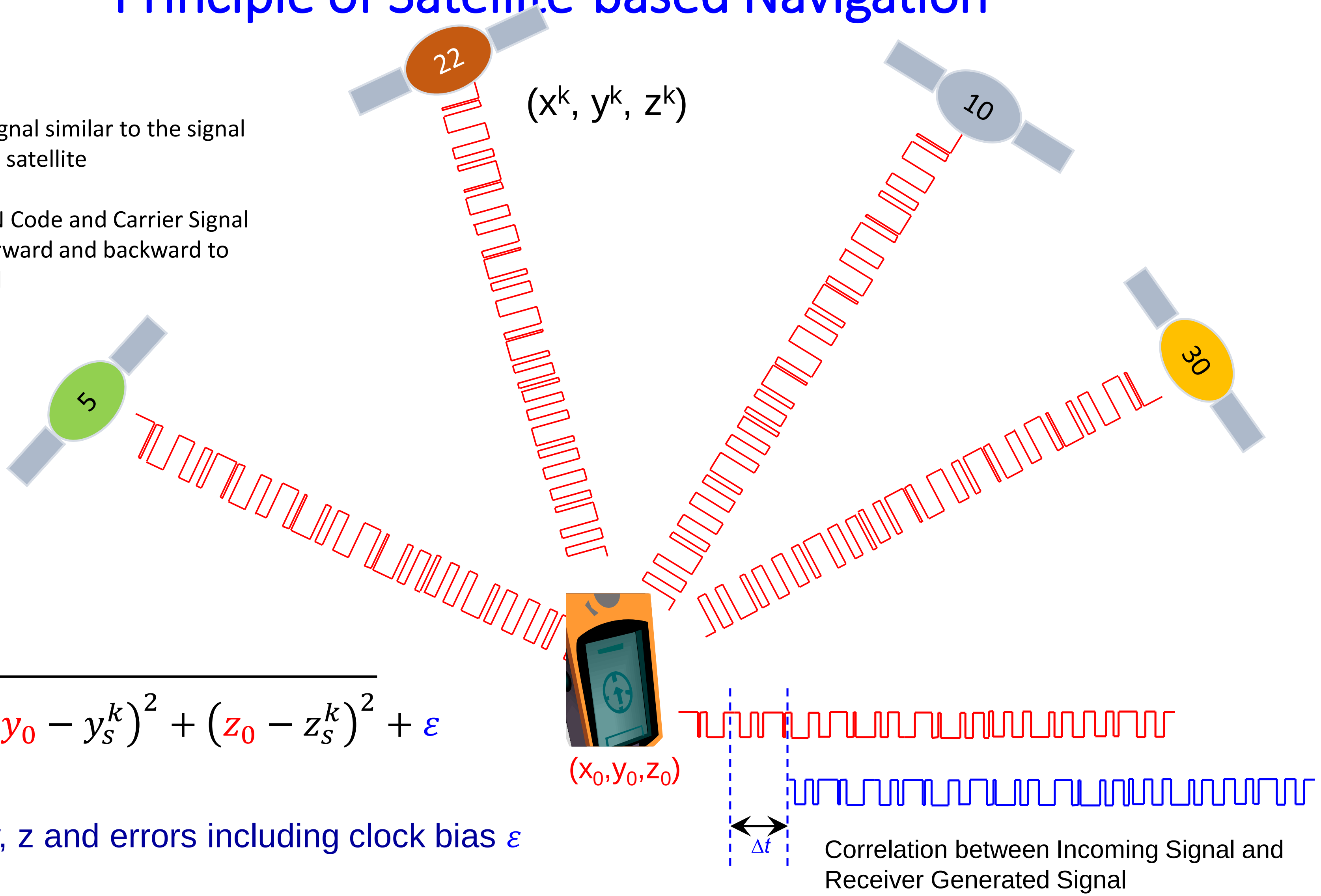
Distance = (Reception Time - Transmission time) × Speed of light

Speed of Light: 300,000 km/s

GNSS: How does it work?
Principle of Satellite-based Navigation

Receiver generates its own GPS signal similar to the signal coming from the satellite for each satellite

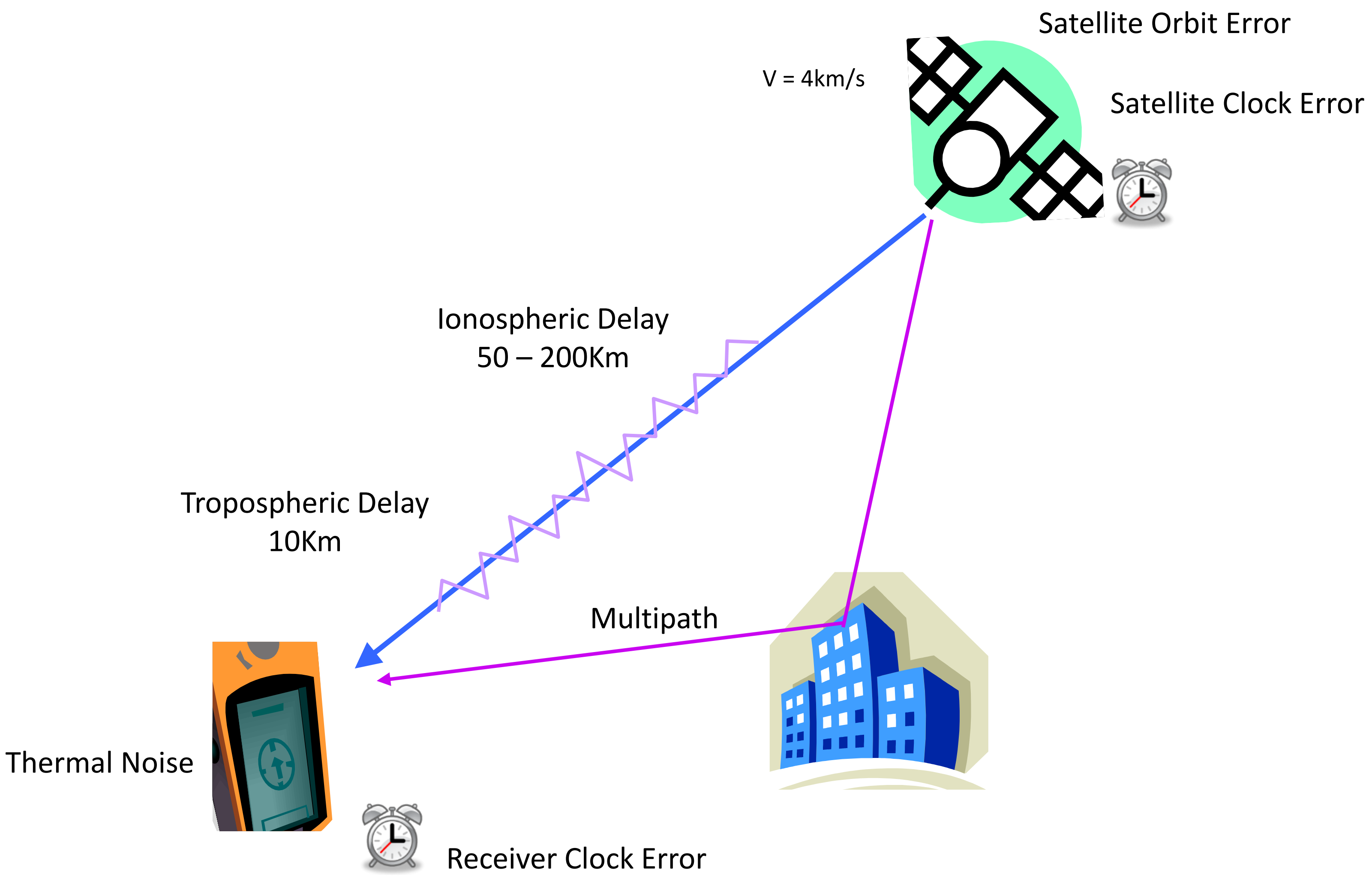
- ➔ Its called Replica Signal
- ➔ The Replica Signal includes PRN Code and Carrier Signal
- ➔ This Replica Signal is moved forward and backward to match with the incoming signal



$$\rho^k = \sqrt{(x_0 - x_s^k)^2 + (y_0 - y_s^k)^2 + (z_0 - z_s^k)^2} + \varepsilon$$

If k ≥ 4, solve for x, y, z and errors including clock bias ε

Error sources



Pseudorange equation

Ideal Case: $\rho_0 = c(t_r - t_s)$

Real Case: $\rho = \rho_0 + c(\delta t_r - \delta t_s) + Iono + Tropo + Multipath + \xi$

Receiver Clock Error

Satellite Clock Error

Ionospheric Delay

Tropospheric Delay

Multipath Error

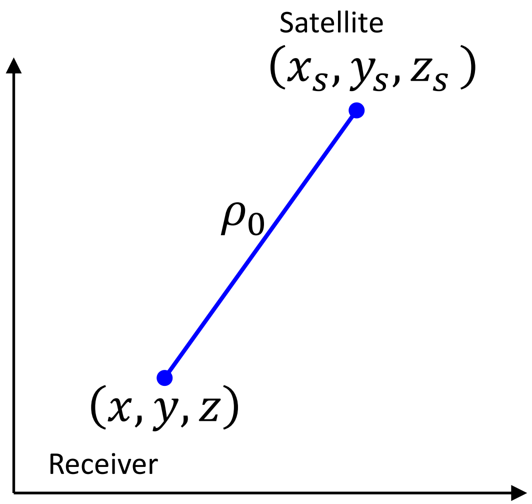
Thermal Noise

Simplified Equation: $\rho = \rho_0 + c(\delta t_r - \delta t_s) + \varepsilon$

Pseudorange model

$$\rho = \underbrace{\sqrt{(x - x_s)^2 + (y - y_s)^2 + (z - z_s)^2}}_{\rho_0} + c(\delta t_r - \delta t_s) + \varepsilon$$

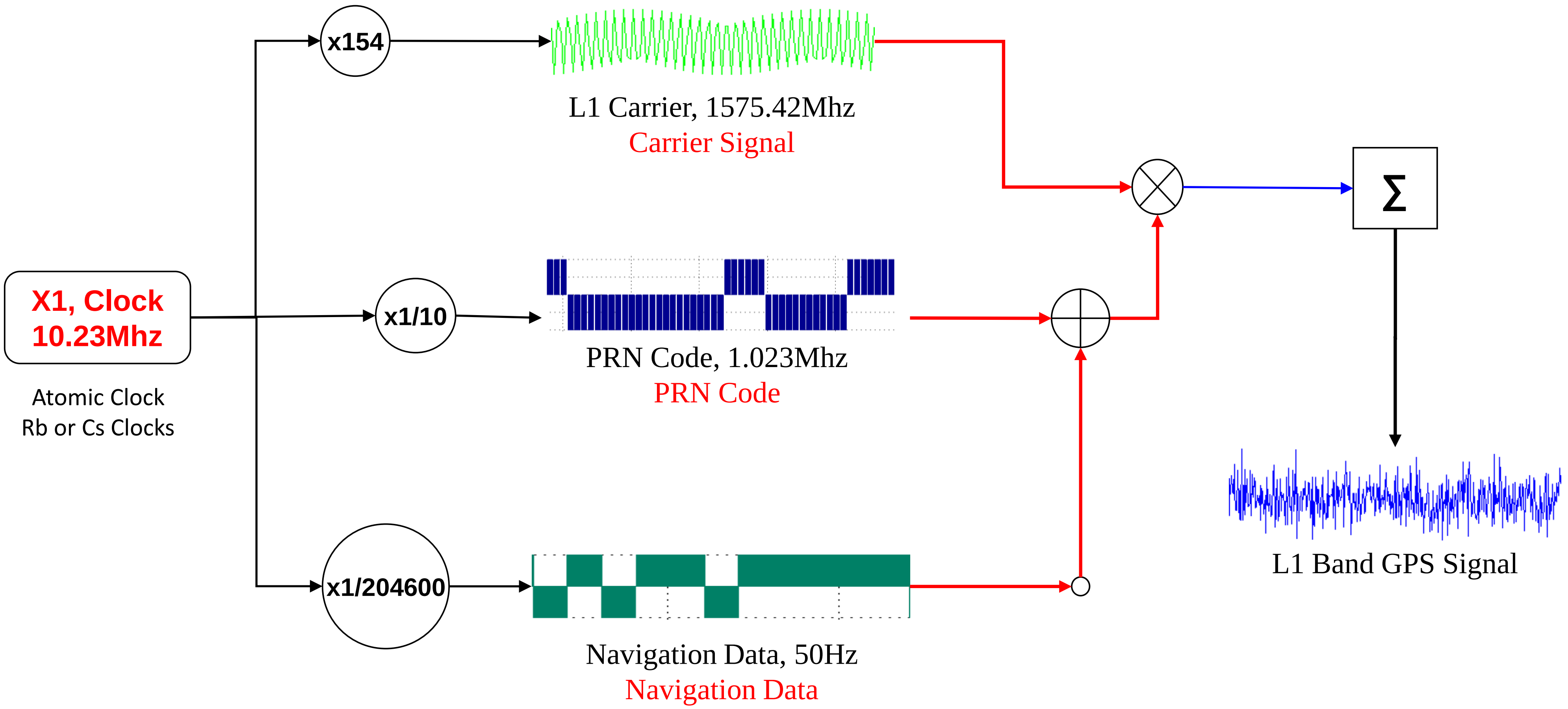
Where:
x, y, z : Unknown receiver position
delta tr: Unknown receiver clock error
epsilon : minimize this error by finding an optimal solution



Range between satellite and receiver

- In order to solve the above equations, we need “n” simultaneous nonlinear equations from “n” pseudorange observations.
- We need at least 4 independent observations in order to determine 4 unknown parameters, x, y, z and receiver clock error.

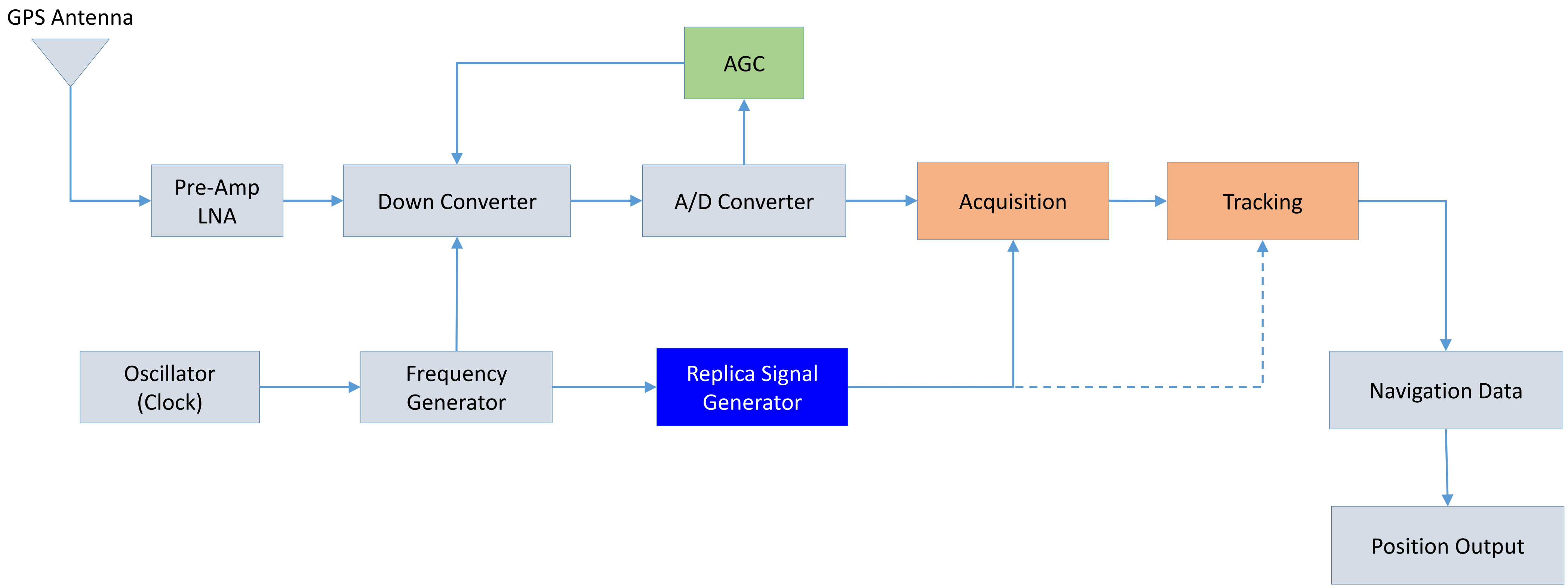
GPS L1C/A Signal Structure (Satellite Side)



GPS L1C/A Signal Structure

- Carrier Signal
  - It defines the frequency of the signal
  - For example:
    - GPS L1 is 1575.42MHz, L2 is 1227.60MHz and L5 is 1176.45MHz
- PRN Code
  - Necessary to modulate carrier signal
  - Used to identify satellite ID in the signal
  - Should have good auto-correlation and cross-correlation properties
- Navigation Data
  - Includes satellite orbit related data (ephemeris and almanac data)
  - Includes satellite clock related information (clock errors etc.)
  - Includes satellite health information

Block Diagram of GPS Receiver



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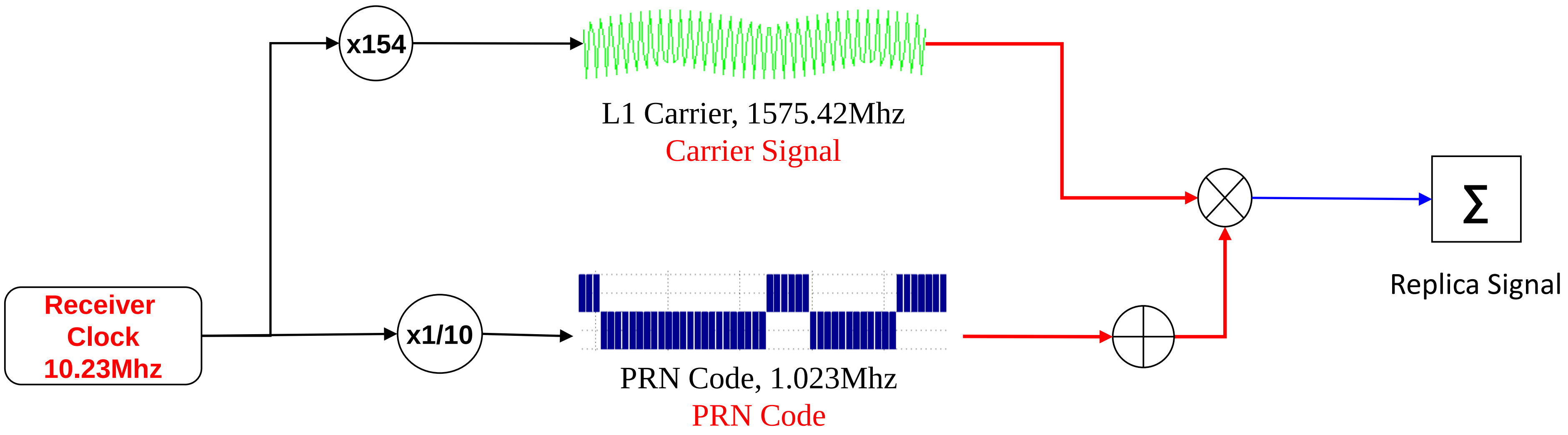
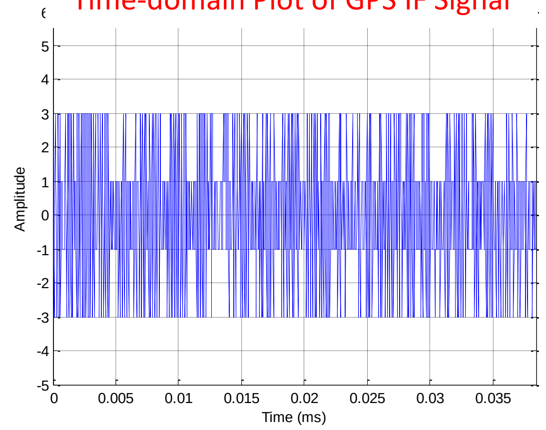
GPS L1C/A Replica Signal at Receiver Side

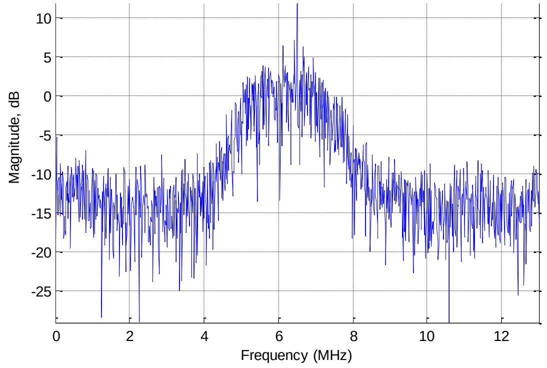


How does GPS Signal Look Like?

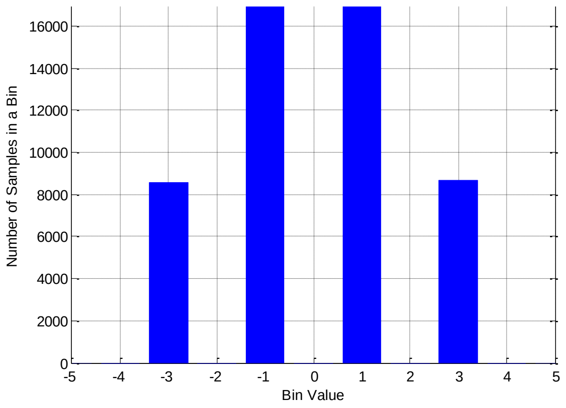
Time-domain Plot of GPS IF Signal



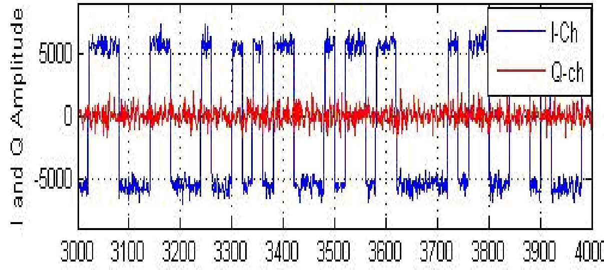
Frequency-domain Plot of GPS IF Signal (Fourier Transform)



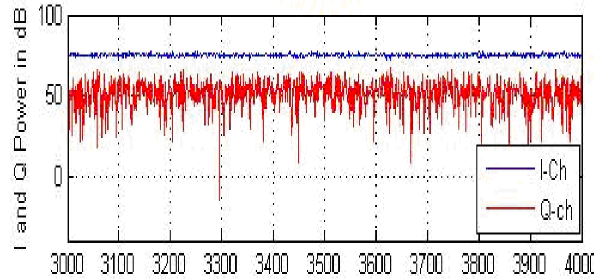
Histogram of GPS IF Signal



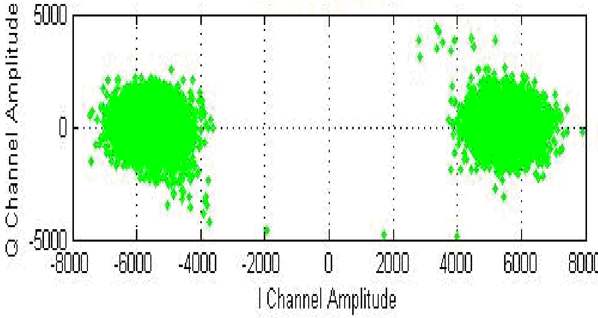
Tracking Output (I and Q Channels)



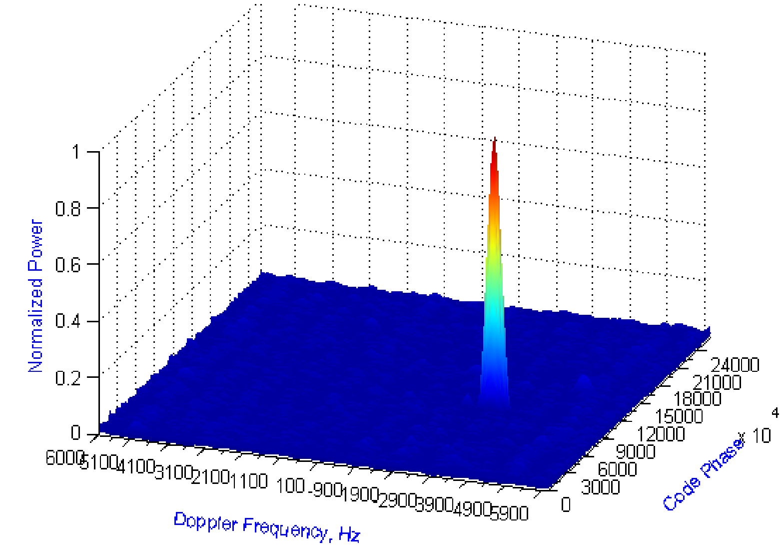
I and Q Plot



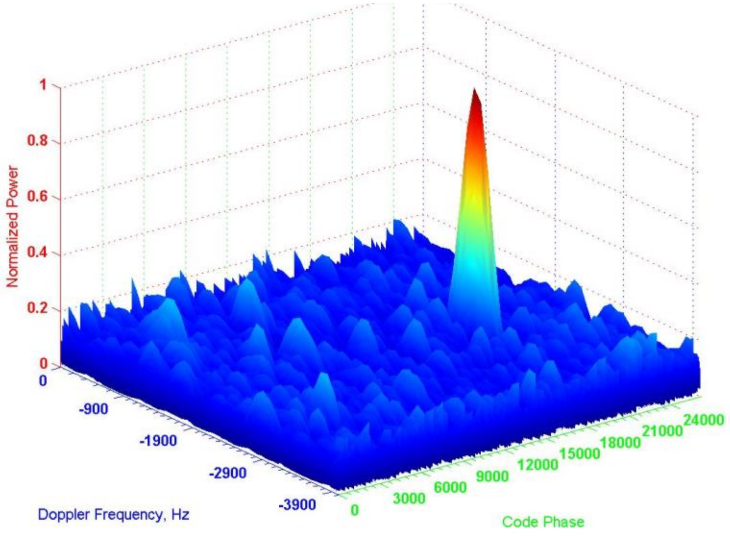
Scatter Plot of I and Q Channels, shows BPSK Modulation



Acquisition of GPS L1C/A Signal with Low Noise

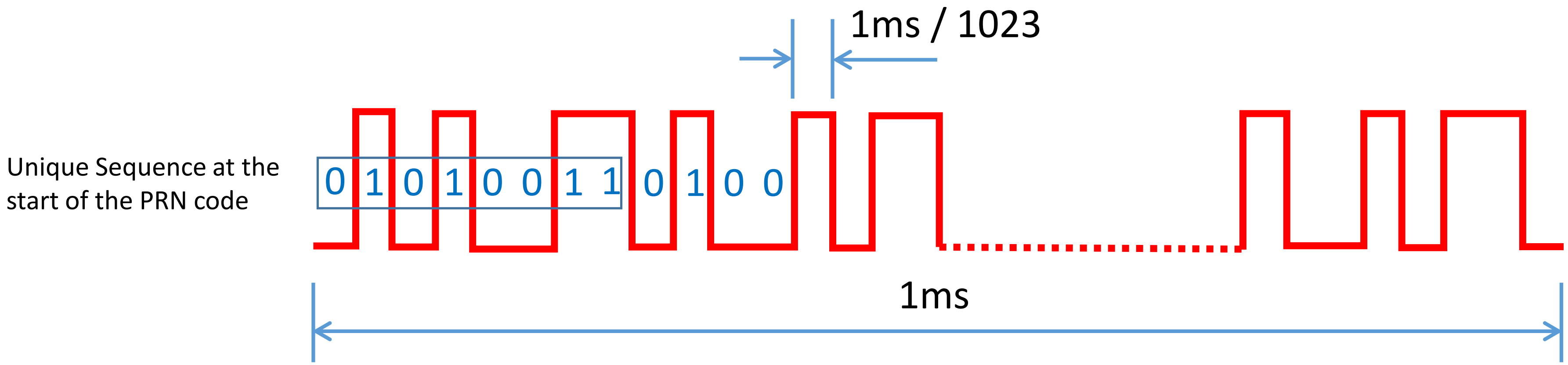


Acquisition of GPS L1C/A Signal with Higher Noise



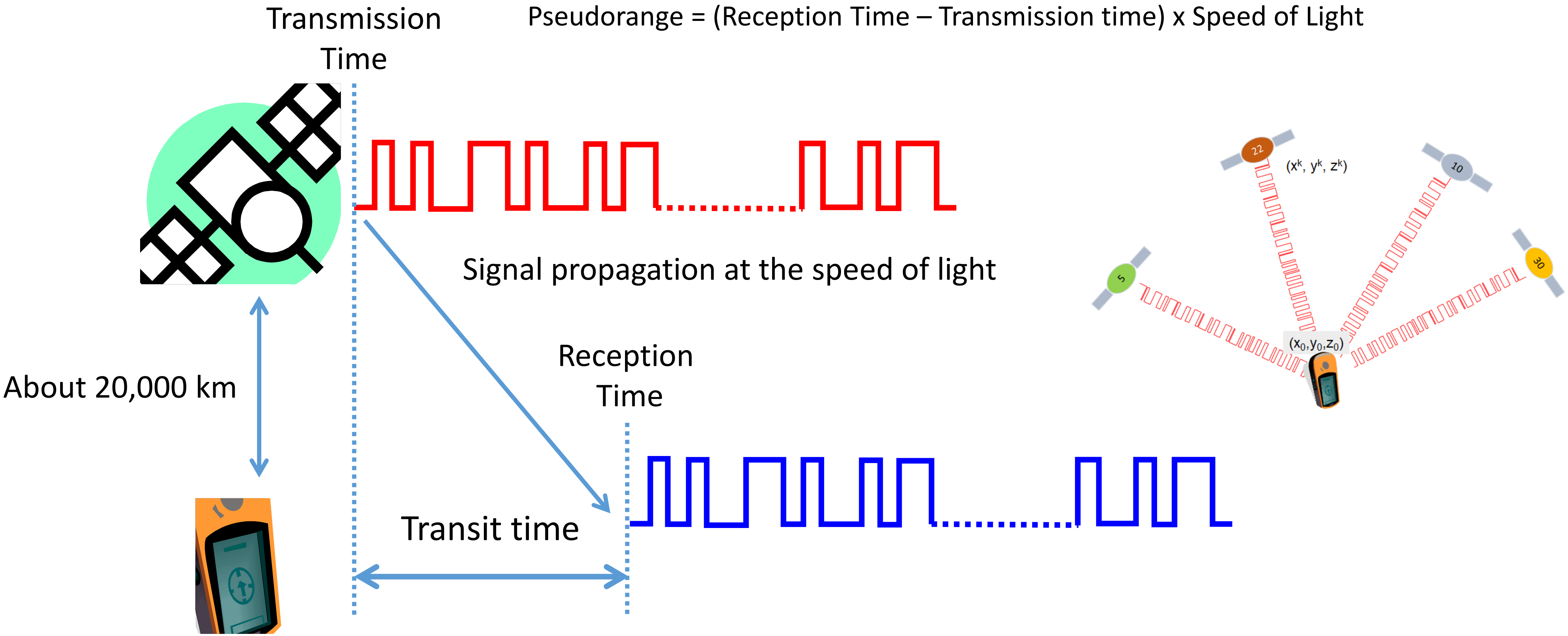
PRN (Pseudo Random Noise) Code

- PRN Code is a sequence of randomly distributed zeros and ones that is one millisecond long.
  - This random distribution follows a specific code generation pattern called Gold Code.
  - There are 1023 zeros and ones in one millisecond.
- Each GPS satellite transmits a unique PRN Code.
  - GPS receiver identifies satellites by its unique PRN code or ID.
- It continually repeats every millisecond
  - The receiver can detect where the PRN code terminated or repeated.
  - A unique sequence of bits indicates start of a PRN code.
- It helps to measure signal transit time and compute pseudorange between the receiver and the satellite
- Its also called C/A (Coarse Acquisition) code in GPS



Pseudorange (Code-Phase Measurement) - 1

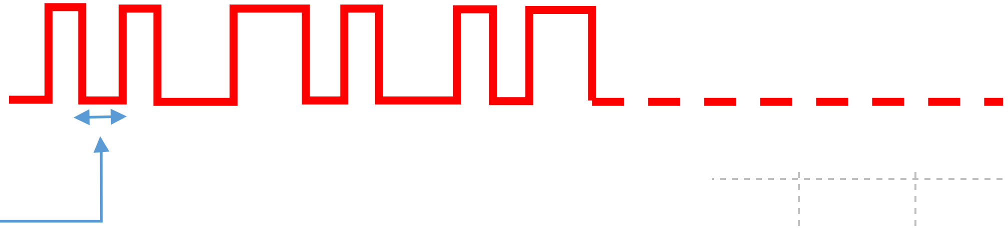
Pseudorange = (Reception Time – Transmission time) x Speed of Light



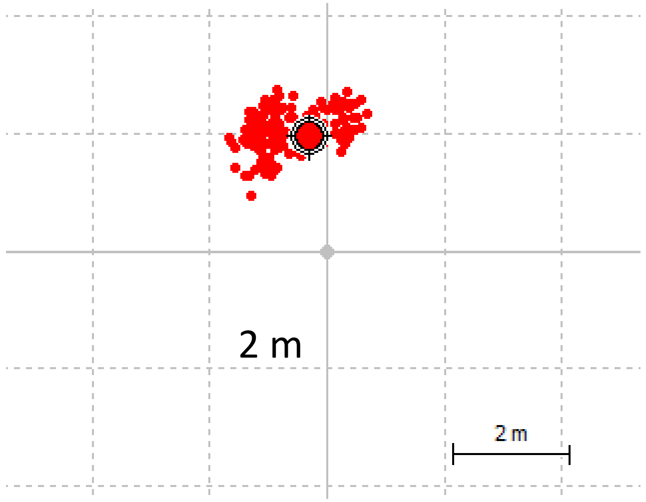
A GPS receiver measures the signal transmission time from the code phase at signal reception time.

Pseudorange (Code-Phase Measurement) - 2

1-sequence of PRN Code is 1023 bits, 1ms long.
This corresponds to 300Km



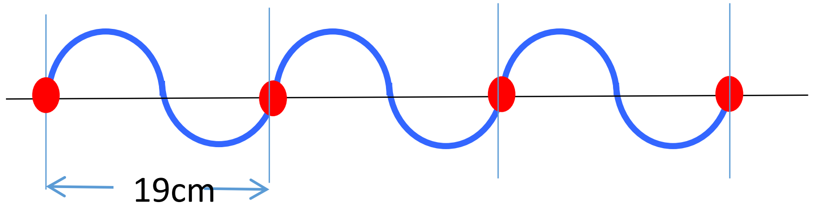
1-bit or chip corresponds to 1/1023 ms.
This is about 293m (say 300m) in distance.

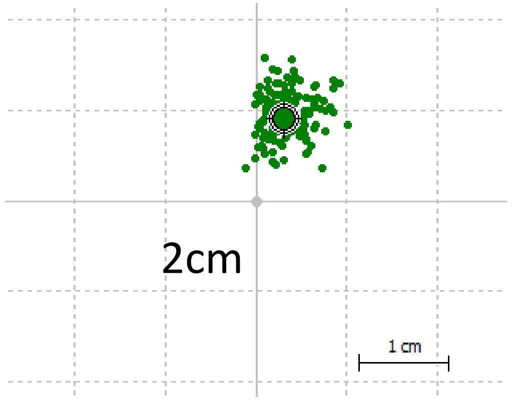


In the receiver, signals are resampled at certain frequency, say 10MHz.
This means every chip will be further divided into 10 smaller chips.
If it is possible to detect code phase at 1/10 of this sampled chip, then range measurement accuracy would be about 300/10/10 = 3m.
However, there are various types of noises and this accuracy may not be possible.
Normally, GPS L1C/A guarantees an accuracy within 10m.
Thus, using Code-Phase (PRN code) measurement, the accuracy will be limited to few meters level.

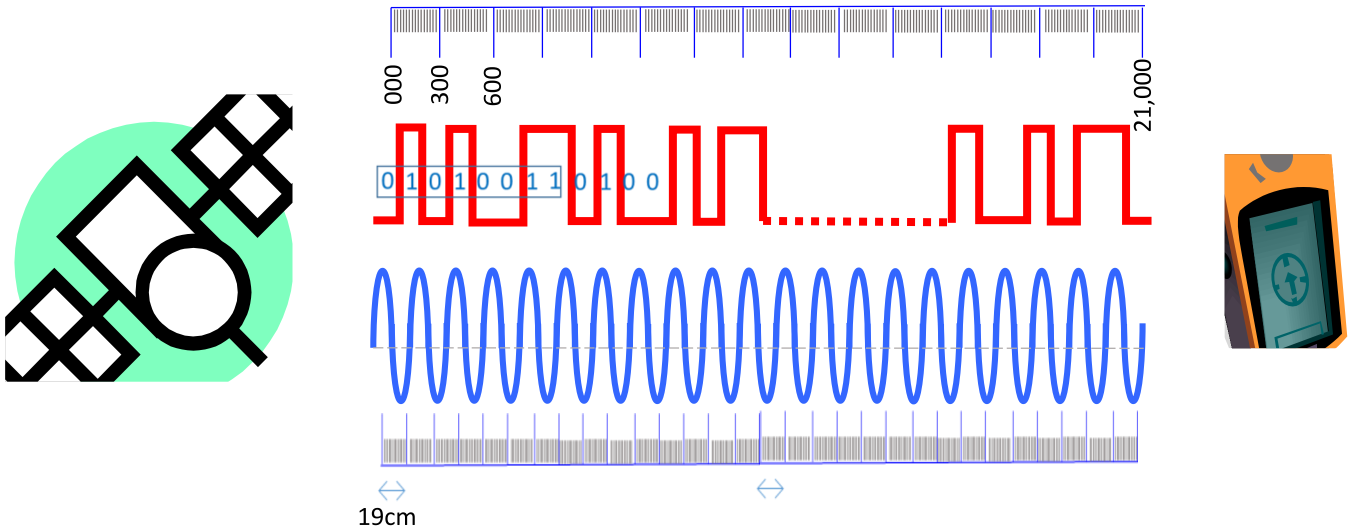
Carrier-Phase Measurement – 1

- Carrier-Phase measurement is done by counting the number of cycles coming from the satellite to the receiver.
- However, there are many complexities in measuring total number of cycles (N) from the satellite to the receiver.
  - This is called integer ambiguity
  - This is due to the fact that all cycles are the same and there are no headers to tell the receiver when a new cycle has arrived after number of cycles as in PRN code.
    - A PRN code has a header to tell the receiver that this is the beginning of the PRN code that is 1023 chips long.
    - There are algorithms to solve this problem of ambiguity resolution.
- One complete cycle for GPS L1 band is 19cm long.
  - Thus, if we can measure one wavelength, we can get 19cm accuracy
  - If we can measure 1/10th of a cycle, we get about 2cm accuracy.
  - Thus, Carrier-Phase measurement can provide centimeter level accuracy.





Code-Phase (PRN Code) vs. Carrier-Phase Measurement



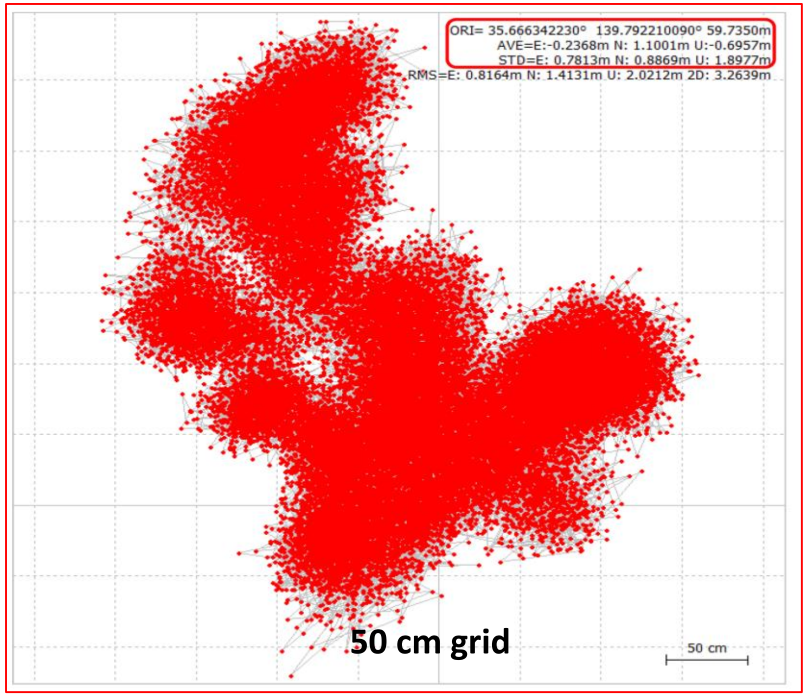
Code-Phase Measurement	Carrier-Phase Measurement
Measuring distance between the satellite and the receiver with a tape that has distance markings as well as distance values written. So that we can measure correct distance.	Measuring distance between the satellite and the receiver with a tape that has distance markings but distance values are not written. We only know that each distance marker is 19cm apart. So, we need to count at certain point the number of cycles separately that's coming to the receiver. This is called integer ambiguity solving.
Only provide meter level accuracy	Provides centimeter level accuracy
Simple and required measurement. It's part of signal demodulation process. So this can't be avoided.	Counting of number of cycles (solving integer ambiguity) is not required if carrier-phase based measurement such as RTK or PPP is not required.

How to Improve GPS Accuracy?

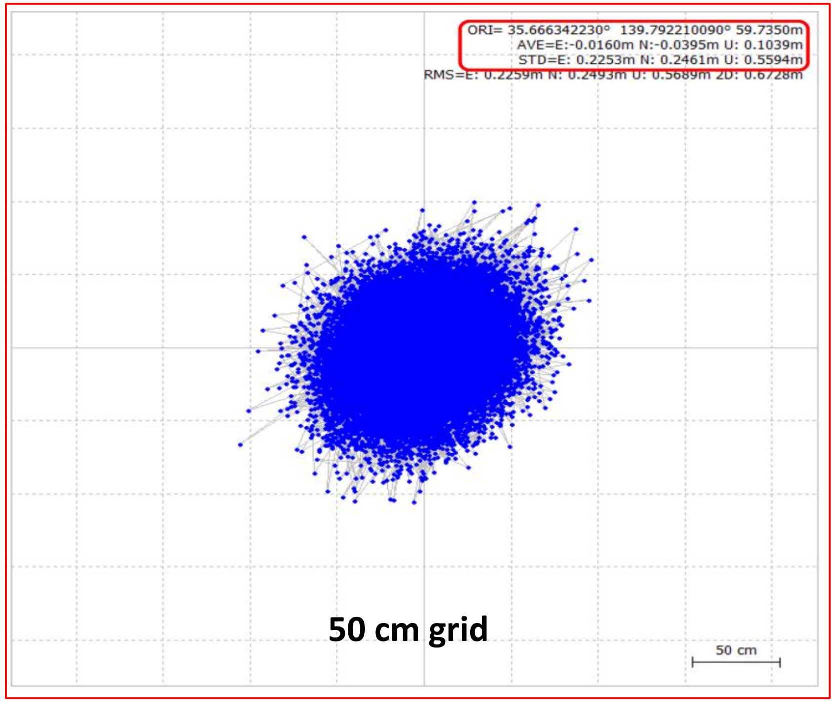
GPS Position Accuracy

How to achieve accuracy from few meters to few centimeters?

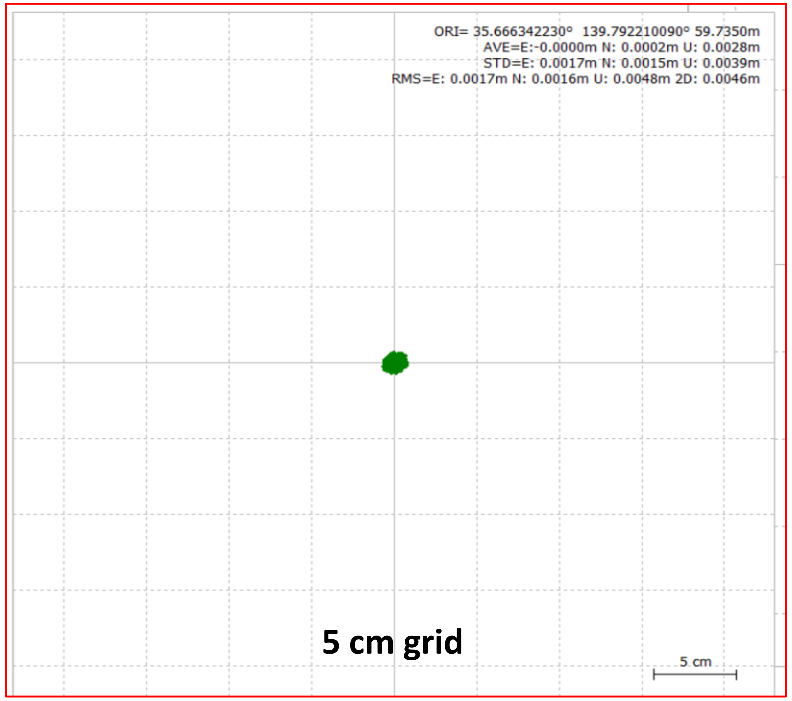
meter → centimeter



SPP (Single Point Position)



DGPS (Differential GPS)
Code-phase observation



RTK (Real Time Kinematic)
Carrier-phase observation

Errors in GPS Observation (L1C/A Signal)

Error Sources	One-Sigma Error , m		Comments
	Total	DGPS	
Satellite Orbit	2.0	0.0	Common errors are removed
Satellite Clock	2.0	0.0	
Ionosphere Error	4.0	0.4	Common errors are reduced
Troposphere Error	0.7	0.2	
Multipath	1.4	1.4	
Receiver Circuits	0.5	0.5	

If we can remove common errors, position accuracy can be increased.

Common errors are: Satellite Orbit Errors, Satellite Clock Errors and Atmospheric Errors (within few km)

Values in the Table are just for illustrative purpose, not the exact measured values.
Table Source : http://www.edu-observatory.org/gps/gps_accuracy.html#Multipath

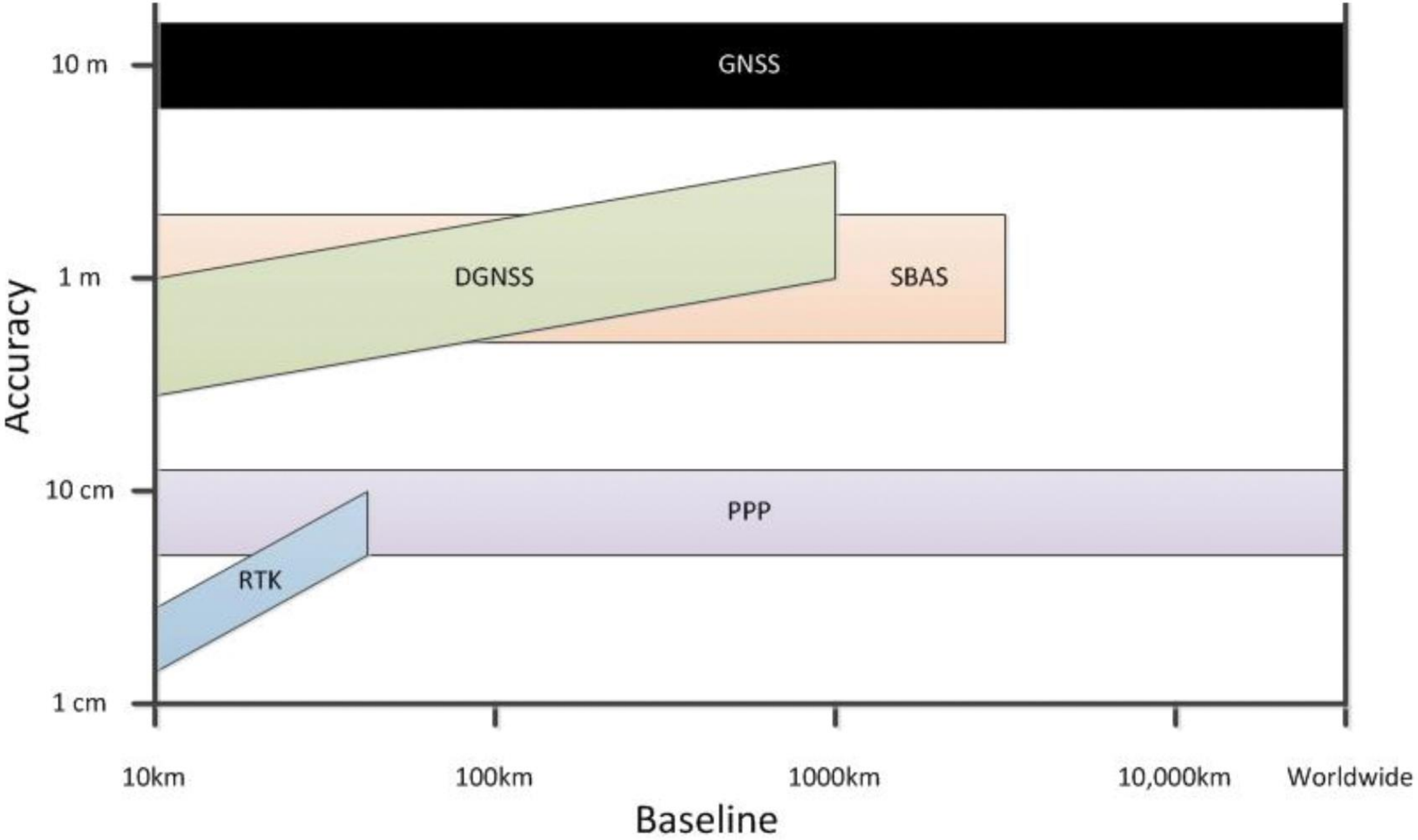
How to Improve Accuracy?

- Both Code-Phase and Carrier-Phase observations are necessary
  - Carrier-phase provides centimeter level resolution
- Need to remove or minimize the following errors:
  - Satellite Related Error
    - Satellite orbit errors
    - Satellite clock errors
  - Space Related Errors
    - Ionospheric errors
    - Tropospheric erros
  - Receiver Related Errors
    - Receiver clock error
    - Receiver circuit related

High-Accuracy Observation Methods

- Basically three types of Observation
  - DGPS (Differential GPS)
    - Code-phase observation
    - Requires Base-station (Reference Station)
  - RTK (Real Time Kinematic)
    - Code-phase and Carrier-Phase Observation
    - Requires Base-station (Reference Station)
  - PPP (Precise Point Positioning)
    - Code-phase and Carrier-phase observation
    - Does not require base-station

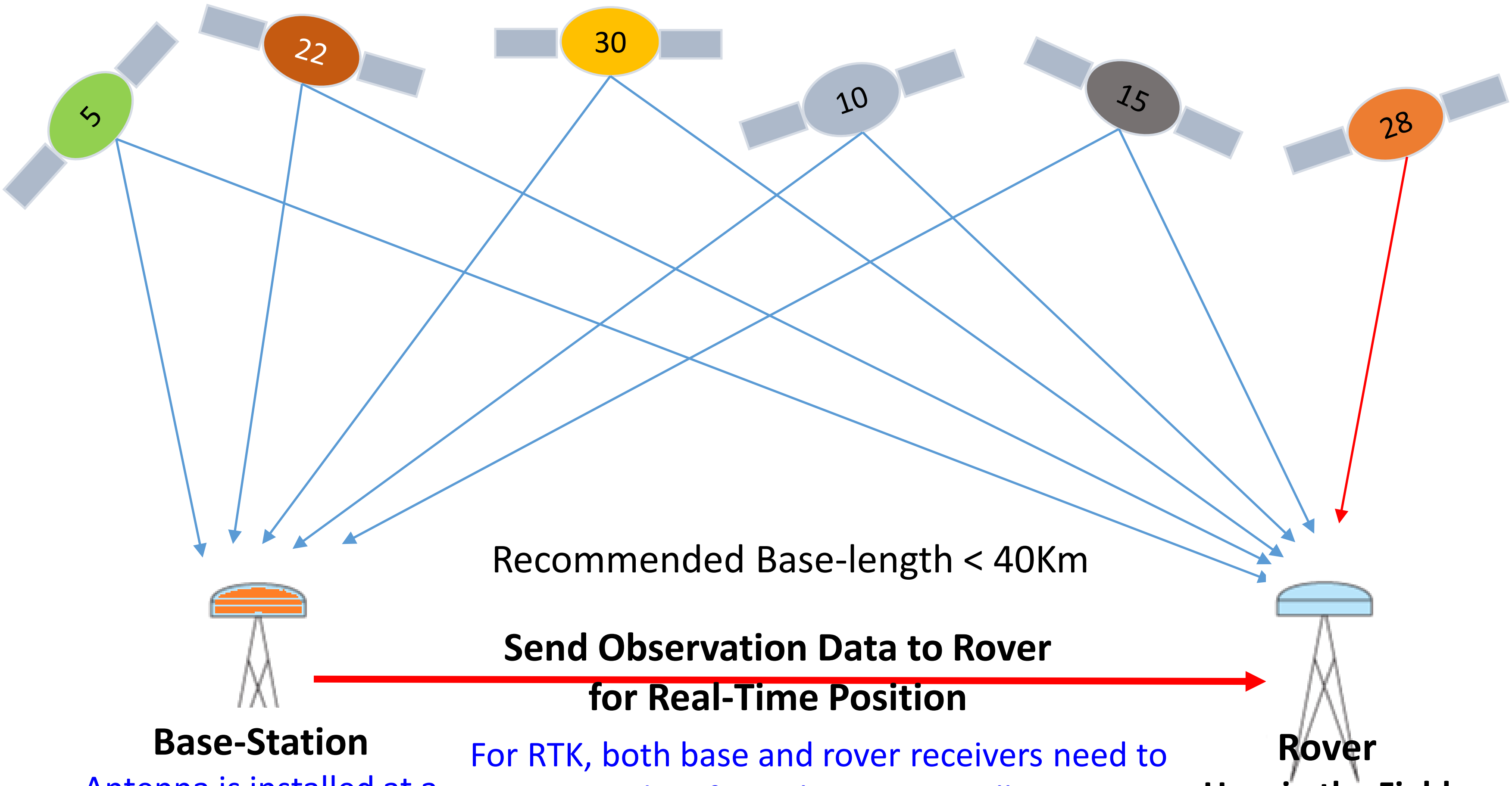
Which Method: DGPS, SBAS, RTK, PPP?



http://www.novatel.com/an-introduction-to-gnss/chapter-5-resolving-errors/

How to Remove or Minimize Common Errors?

Use Differential Correction



Base-Station

Antenna is installed at a known-position

For RTK, both base and rover receivers need to use data from the same satellites

Rover

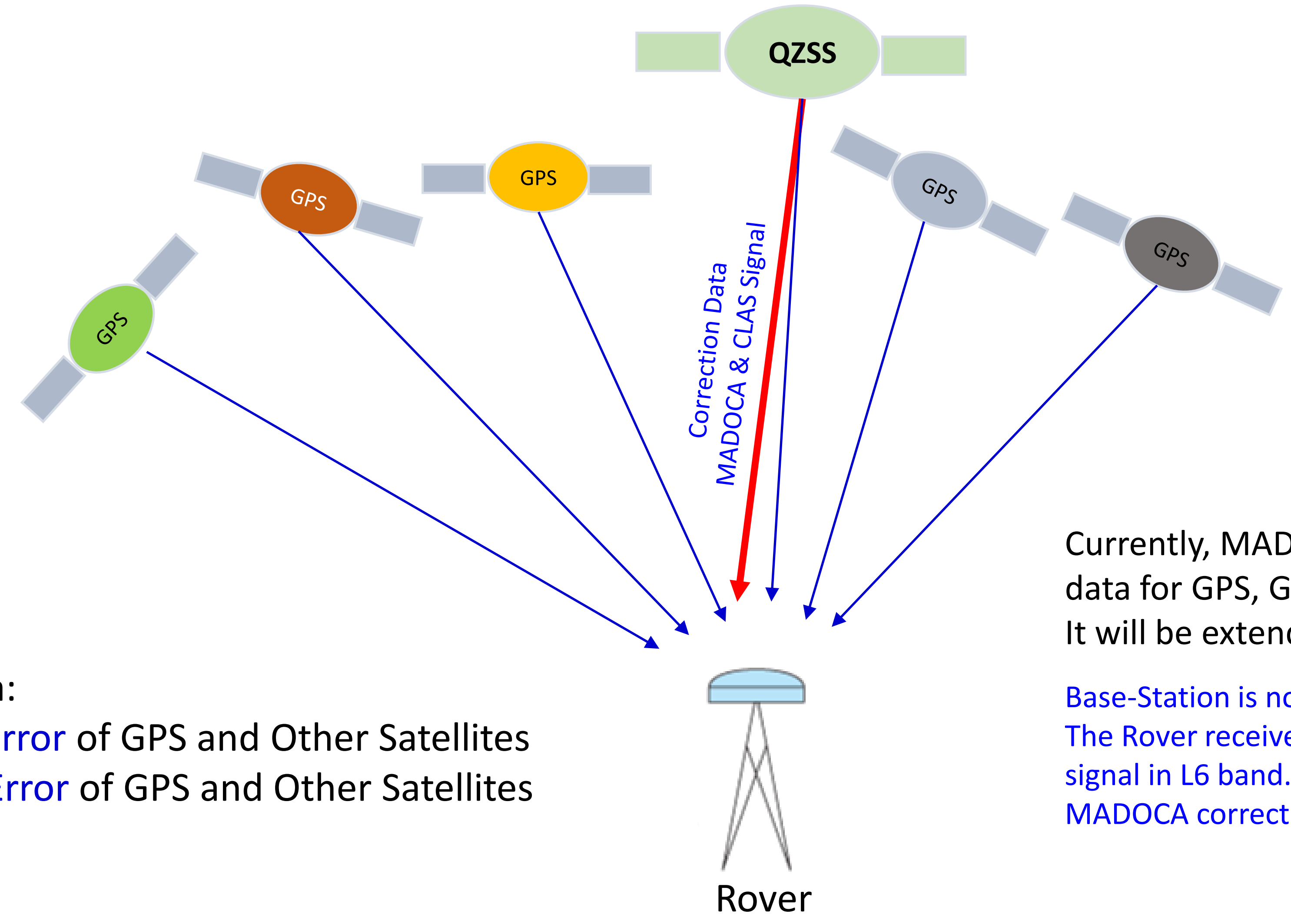
User in the Field

(Either fixed or moving)

Use RINEX data for post-processing

Base-station Antenna position shall be known in advance

How to Remove or Minimize Common Errors?
Principle of QZSS MADOCA and CLAS Services

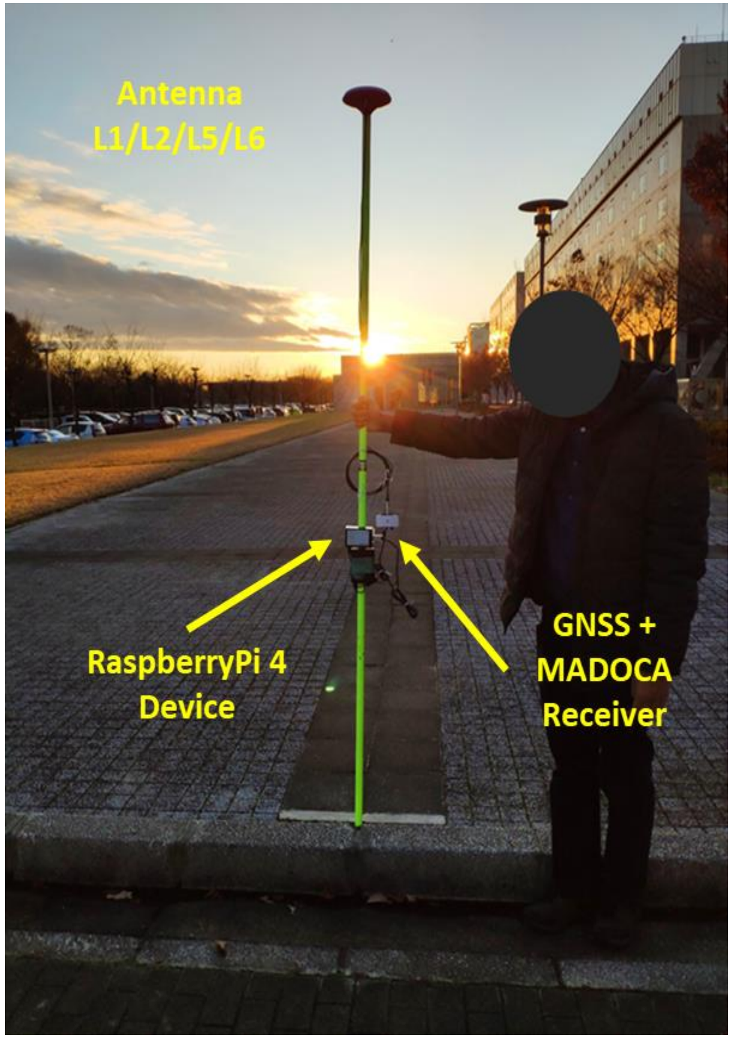


Currently, MADOCA provides correction data for GPS, GLONASS and QZSS.
It will be extended for Galileo in future.

Base-Station is not required.
The Rover receiver should be able to receiver MADOCA signal in L6 band.
MADOCA correction data is also available online.

Correction Data:
Satellite Orbit Error of GPS and Other Satellites
Satellite Clock Error of GPS and Other Satellites

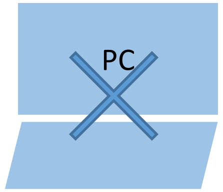
Low-Cost High-Accuracy Receiver Systems
RTKDROID, MADROID, MAD-WIN, MAD-π

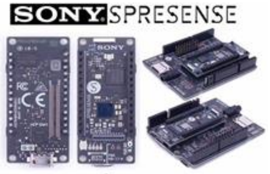


Objectives

- Develop Low-Cost High-Accuracy Positioning Systems (L-CHAPS)
  - System Integration of commercially available receiver or module
    - For RTK and MADOCA
  - Avoid use of computer to minimize the cost
    - Use Single Board Computer (SBC)
      - RaspberryPi, Arduino, Spresense
    - Use Tablet or Smart-Phone
      - Android devices are quite flexible and easier to use
- Develop Easy to Use System in Field
  - A user without GNSS knowledge shall be able to use
  - Self-understanding interface
  - Suitable for remote operation and data logging
  - Operate with mobile power-banks
- Promote GNSS and MADOCA Technologies Abroad through
  - Lectures, Trainings, Seminars, Workshops and Events
  - Joint Research and Joint Projects

RTKDROID MAD-π RTKLIB MADROID MAD-WIN

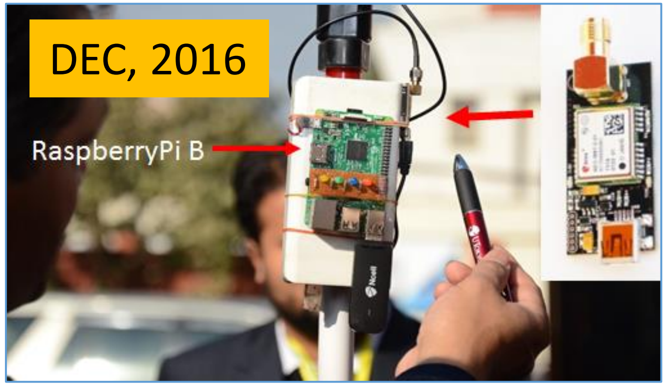




GNSS Equipment for Education and Training

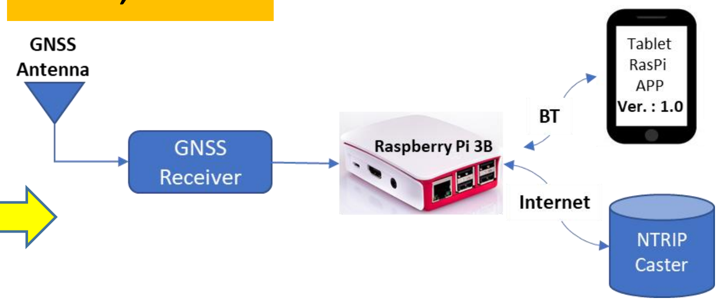
Low-Cost GNSS Receivers are necessary for promotion of GNSS technology to conduct lectures, trainings and pilot projects. We need low-cost high-accuracy receivers in large quantities.

Low-Cost High-Accuracy Receiver system Development Cycle

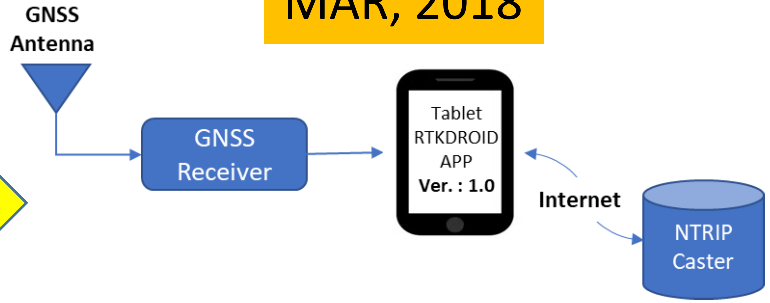


MAY, 2017

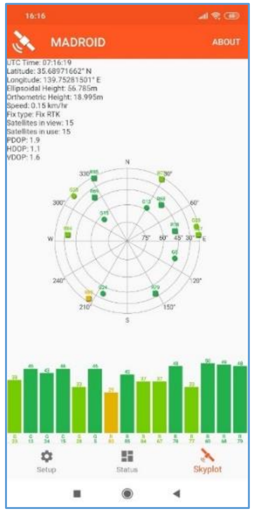
Low-Cost RTK

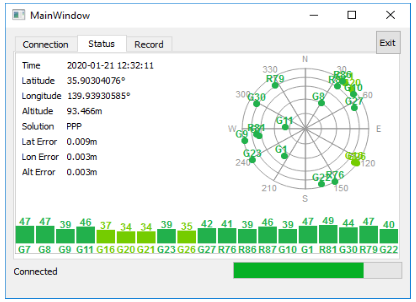


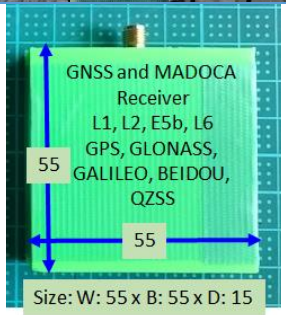
MAR, 2018



Low-Cost MADOCA







DEC, 2019

Enhancement of MADOCA System 2021

Android Device RTK / MADOCA / EWS / SAR System 2022

What type of smart-phone will emerge by 2025 ?

Dinesh Manandhar, CSIS, The University of Tokyo, dinesh@csis.u-tokyo.ac.jp

Our Definition of Low-Cost High-Accuracy

	Type	Target Cost	Current Cost	Description	Difficulties
Cost	RTK	$100	$300 - $600	Single or Dual Frequency Receiver Dual Frequency Antenna RaspberryPi Device	
	MADOCA	$300	$500 - $1,000	Dual Frequency GNSS Receiver Triple Frequency GNSS Antenna RaspberryPi Device	Low-cost MADOCA module is not yet available off-the-shelf Cost factor of Antenna

- Cost of accessories, cables, connectors and power supply unit are not included

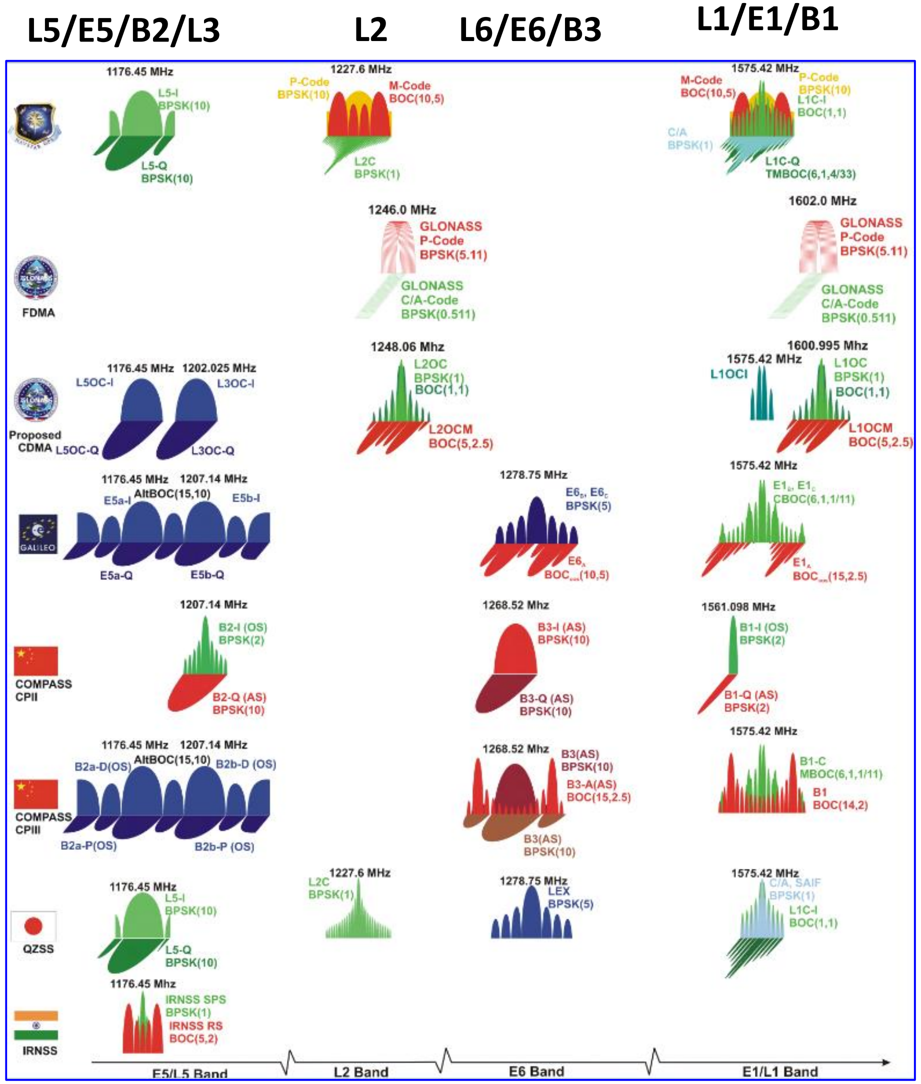
Many Applications require Low-Cost, Small-Size & Low-Power Receiver System

But, is it possible to get
High-Accuracy with Low-Cost Receivers?

Although the Normal Accuracy of GPS is about 10m,
why can we get Centimeter Level Accuracy?

High-End Survey Grade Receivers

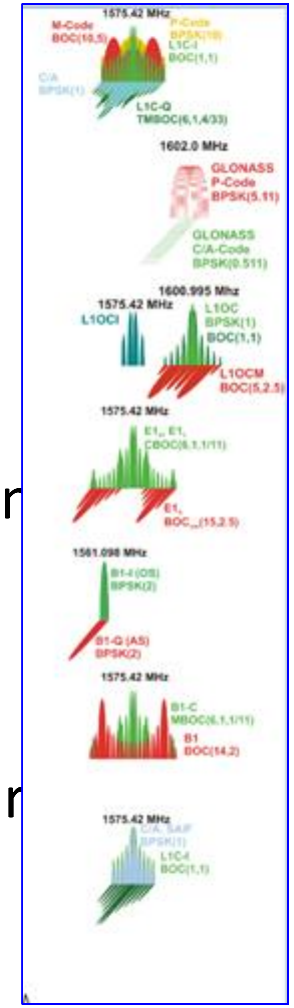
- Multi-frequency
  - GPS : L1/L2/L5
  - GLONASS : L1/L2/L3
  - GALILEO : E1/E5/E6
  - BDS : B1/B2/B3
  - QZSS : L1/L2/L5/L6
  - NAVIC : L5/S
- Multi-system
  - GPS, GLONASS, GALILEO, BeiDou, QZSS, NAVIC, SBAS etc
- Price varies from $1, 000 to $30,000 or more



Low-Cost Receivers

- Multi-System
  - GPS, GLONASS, GALILEO, BeiDou, QZSS, SBAS etc
- Basically Single Frequency
  - L1/E1/B1-Band
  - Very soon: Multi-System, Multi Frequency, L1/L2 or L1/L5
    - Future trend for Mass Market System will be L1/L5
  - Some chip makers have already announced Multi-System, Multi-Frequen GNSS Chips for Mass Market
- Low Cost:
  - Less than $300 (Multi-GNSS, L1 Only) including Antenna and all necessar Hardware, Software
    - Our target is within $100 including everything.

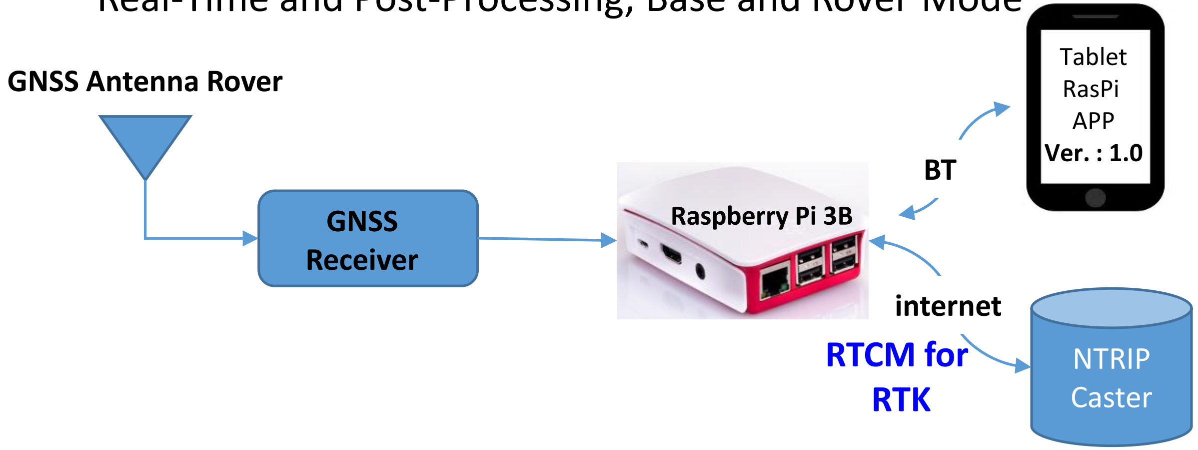
L1/E1/B1*



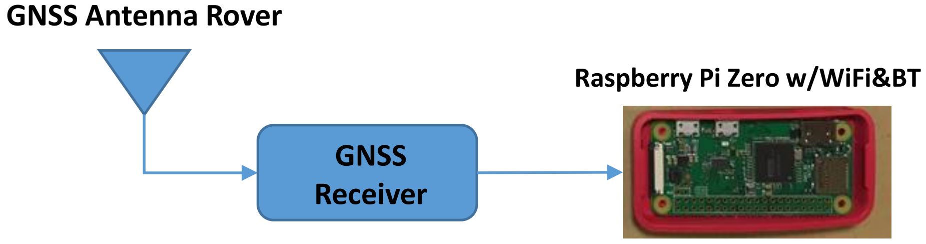
*Note: Only one signal type from each system is processed
e.g. GPS has L1C/A and L1C in L1, ,but only L1C/A is used in Low-Cost Receiver

Low-Cost RTK Receiver System

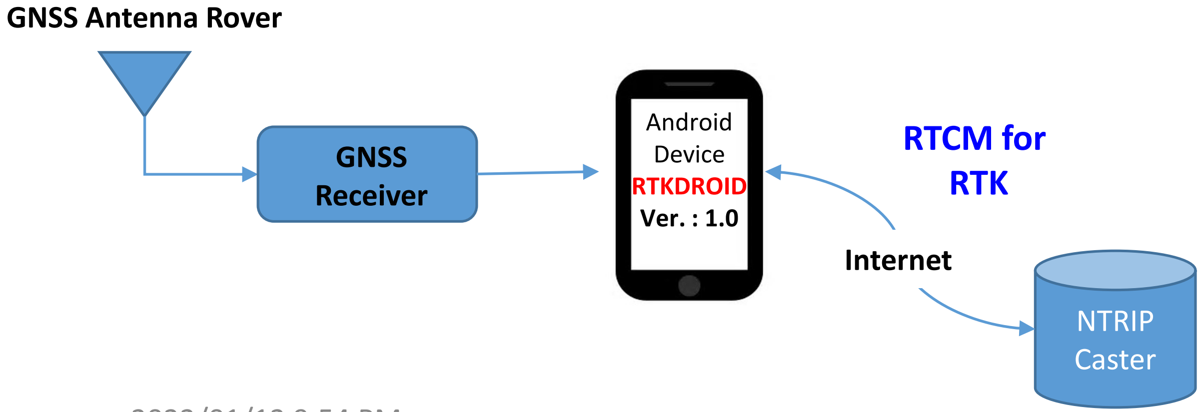
TYPE R1 Type A: Low-Cost, High-Accuracy Receiver System
Real-Time and Post-Processing, Base and Rover Mode



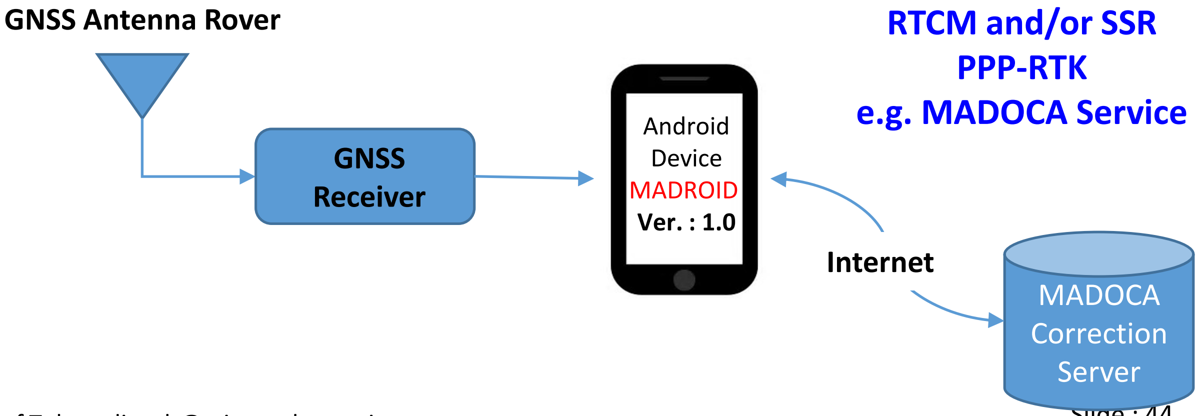
TYPE R2 Type B: Low-Cost, High-Accuracy Receiver System
For Post-Processing & Rover Mode Only



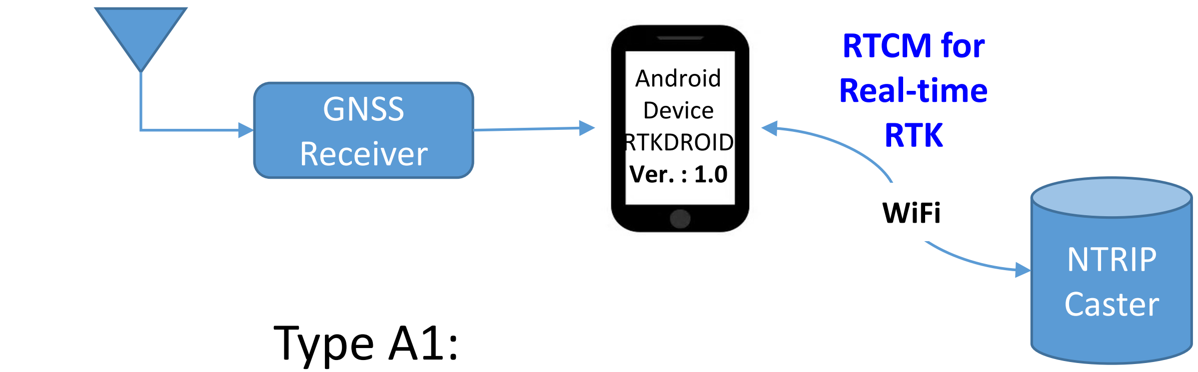
TYPE A1 Type C: Low-Cost, High-Accuracy Receiver System
Real-Time and Post-Processing, Rover Mode Only



TYPE MA Type D: Low-Cost, High-Accuracy Receiver System
Real-Time and Post-Processing, Rover Mode Only



Type – A1: GNSS Receiver with Android Device



Type A1:
Rover Mode
Real-Time and Post-Processing RTK
Based on RTKLIB Engine
Real-time processing in Android Device
APP: RTKDroid

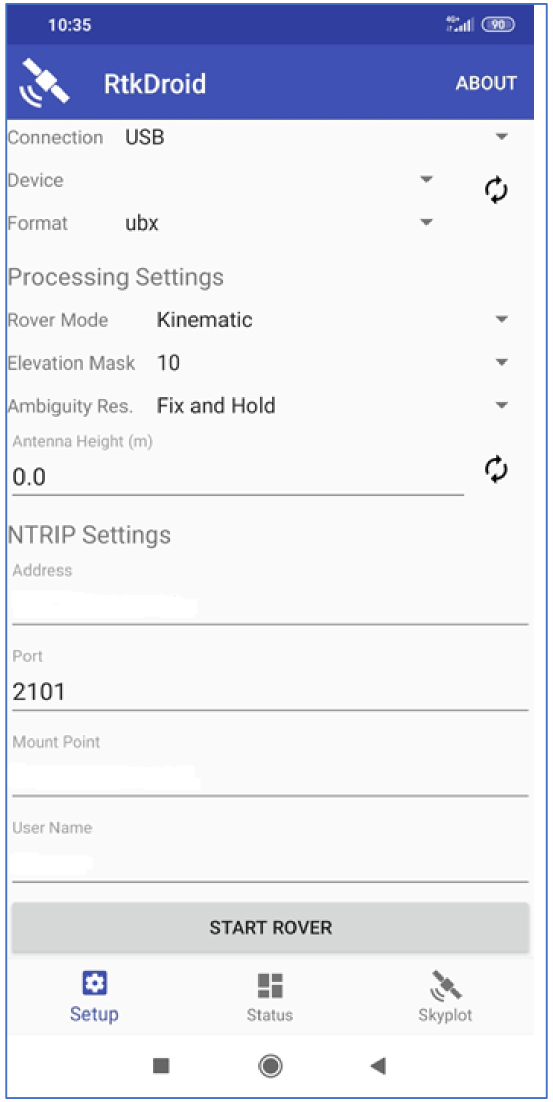
GNSS Receiver Module

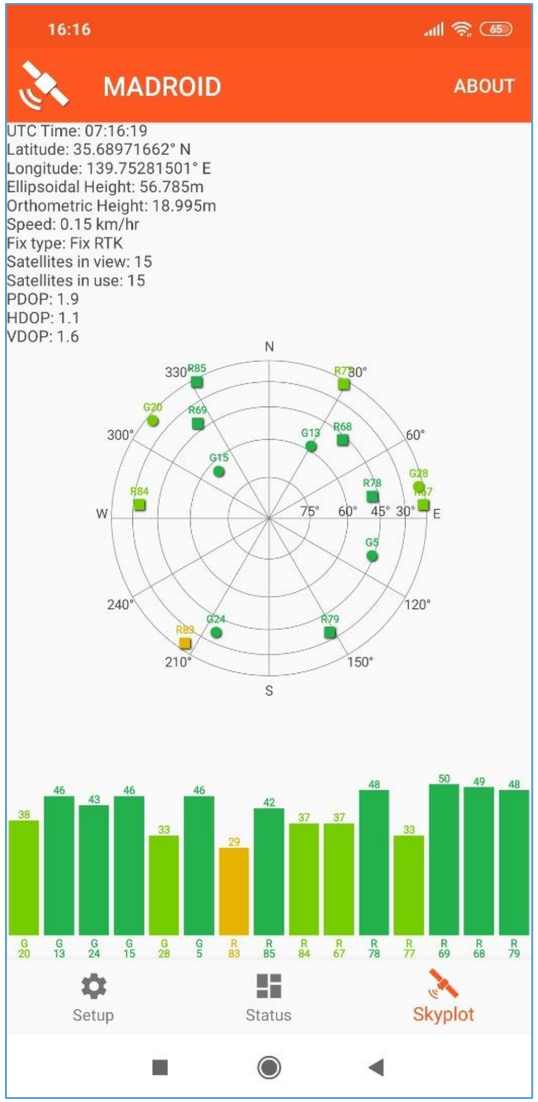
Screen Shots of RTKDROID and MADROID

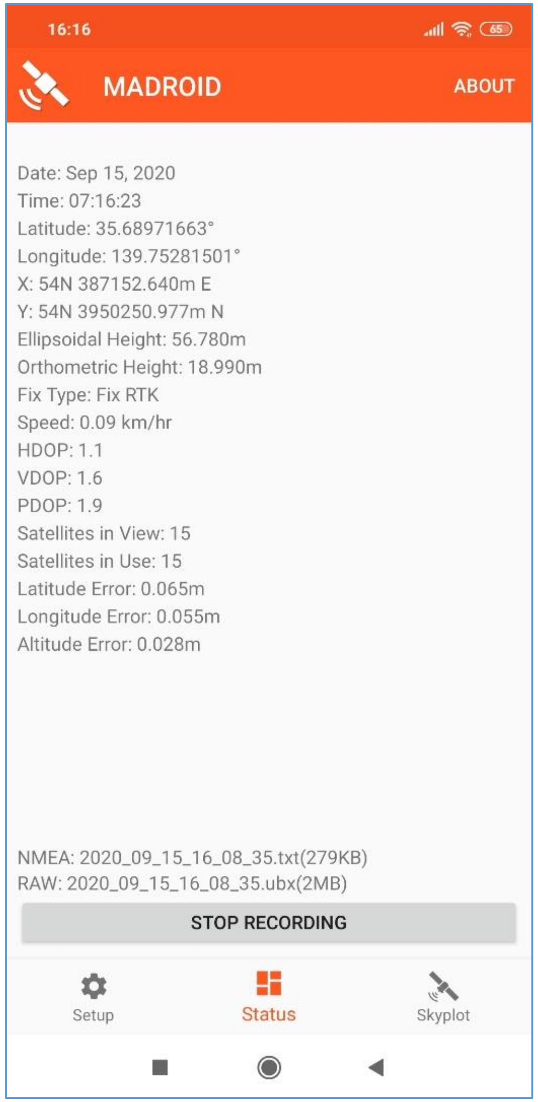
Connect GNSS receiver to Android device

(1) RTKDROID :
For RTK or PPK

(2) MADROID:
for MADOCA-PPP,
MADOCA-PPP/AR (future)

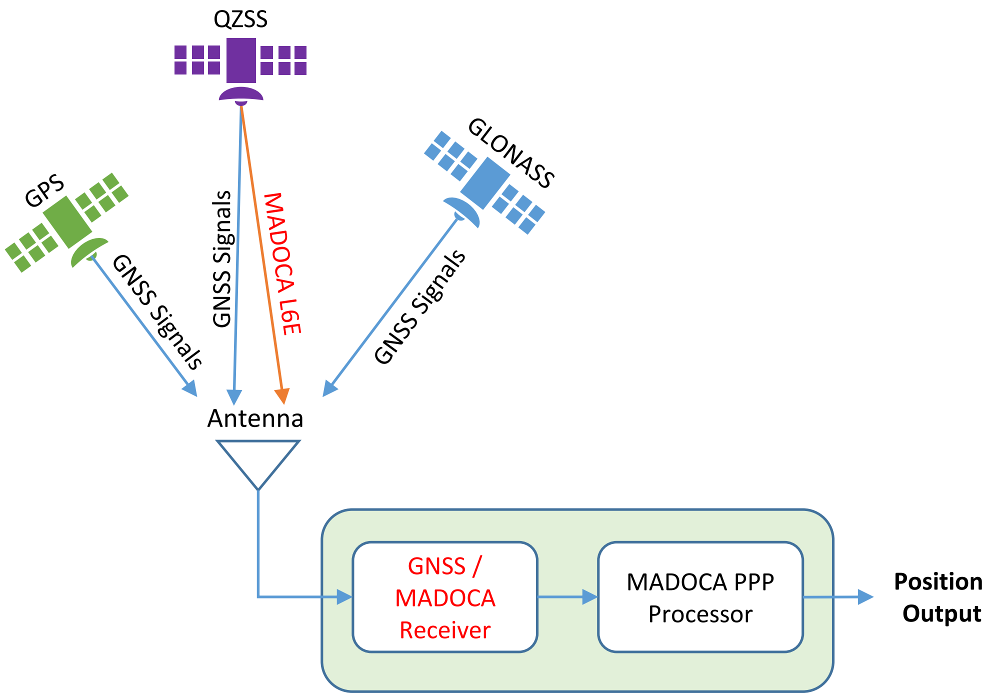




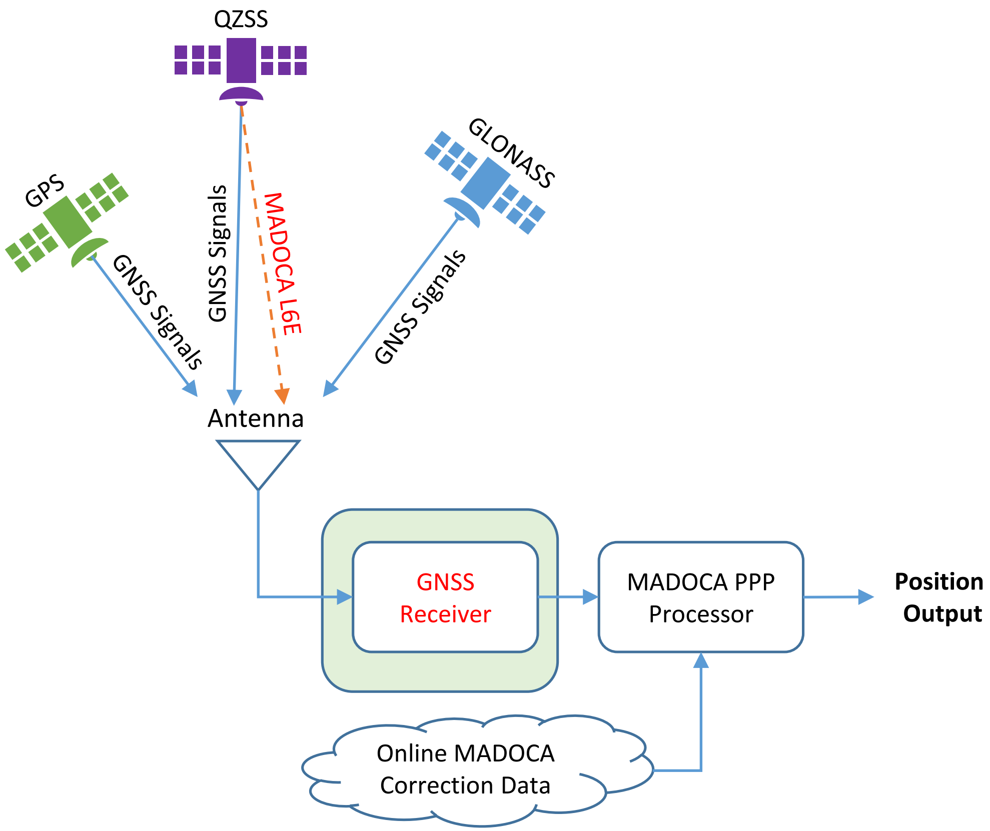


MADOCA System: Direct from QZSS or Online Correction Data

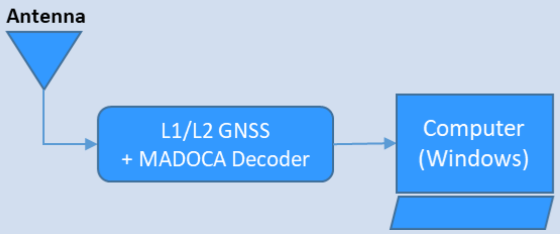
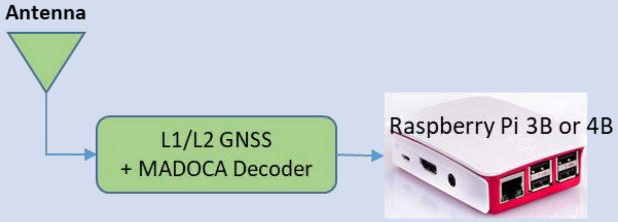
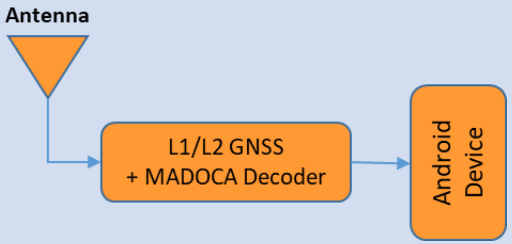
GNSS Receiver + MADOCA Decoder



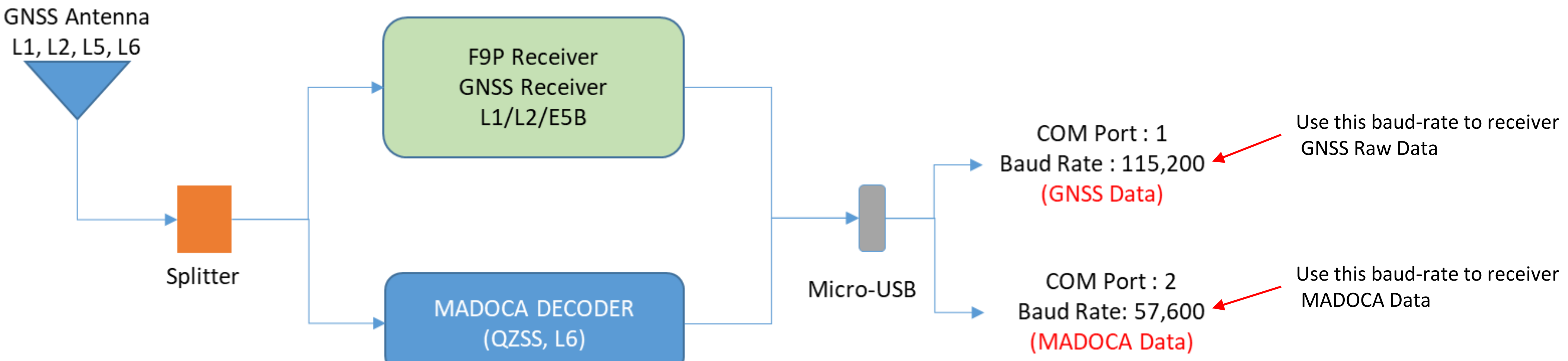
GNSS Receiver Only

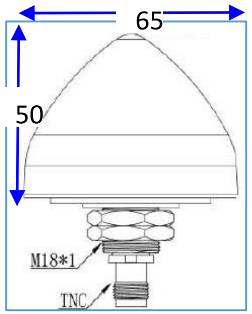


Low-Cost MADOCA Receiver Systems: Product Types

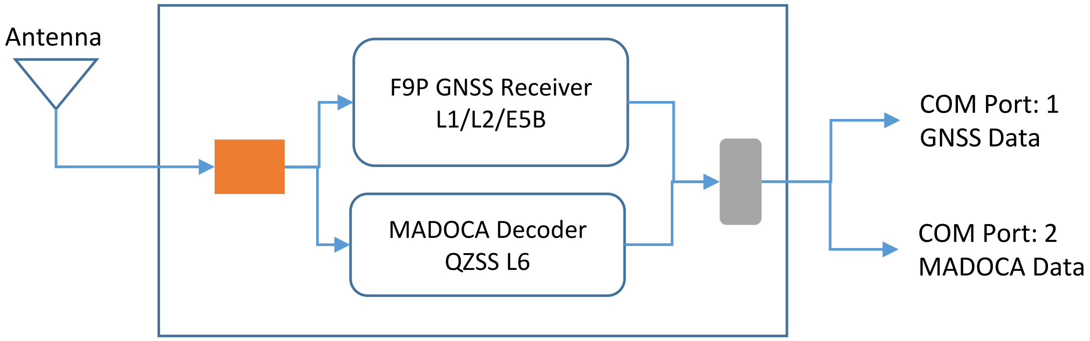
	MAD-WIN	MAD-π	MADROID
Platform / OS	Windows	RaspberryPi 3B or 4B	Android Device
GNSS Receiver	Default : u-blox F9P Other: Any dual-frequency Receiver	Default : u-blox F9P only	Default : u-blox F9P Other: Any dual-frequency Receiver
MADOCA Receiver	U-blox D9 only	U-blox D9 only	NA (MADOCA Online Correction Data only)
GNSS Receiver Data Format	UBX, SBF, RTCM3	UBX SBF, RTCM3 (For online GNSS data)	UBX
MADOCA Correction Data Format (Satellite)	UBX only	UBX only	NA
MADOCA Correction Data Format (Online)	Online Services from GPAS, UTokyo (Test Level) UBX or RTCM3	Online Services from GPAS, UTokyo (Test Level) Online Services UBX or RTCM3	GPAS Services, RTCM3 UTokyo Online Service in the next release
System Architecture			

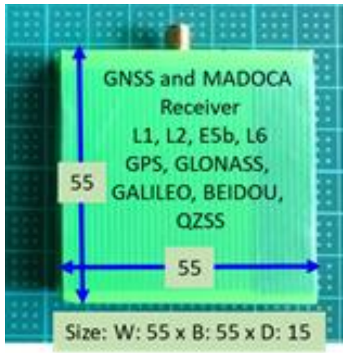
MADOCA PPP Receiver System



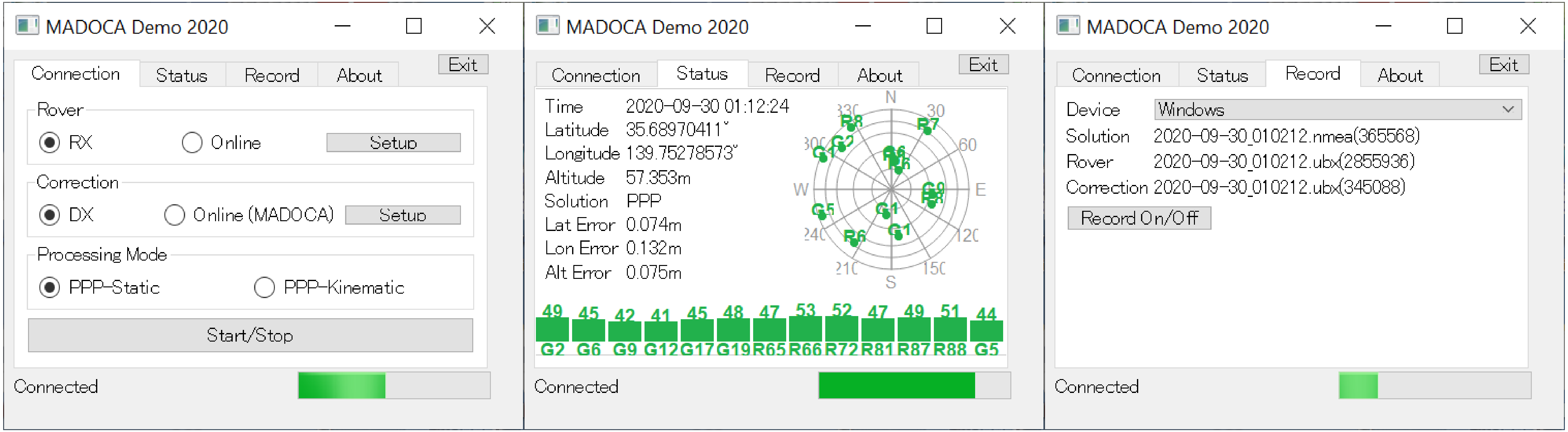


GNSS Antenna





MAD-WIN / MAD-PI User Interface



Log Files:

1. Solution: MADOCA PPP Solution in NEMA format
2. Rover: Rover RAW Data in receiver's proprietary format

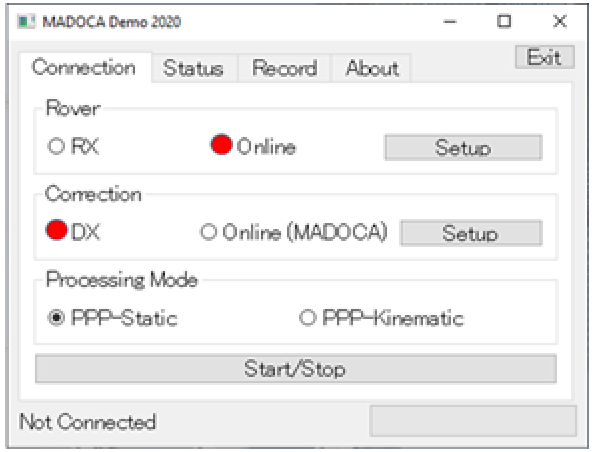
Can be used for PPK (Post-Processing Kinematic) Solution or Post-Processing PPP

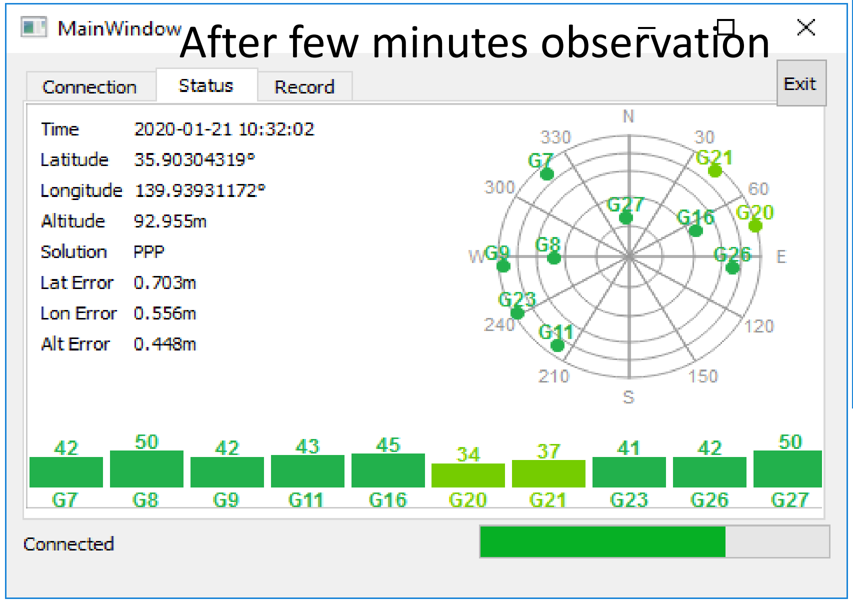
3. Correction: MADOCA PPP Correction Data in receiver's proprietary format

Can be used for Post-Processing MADOCA

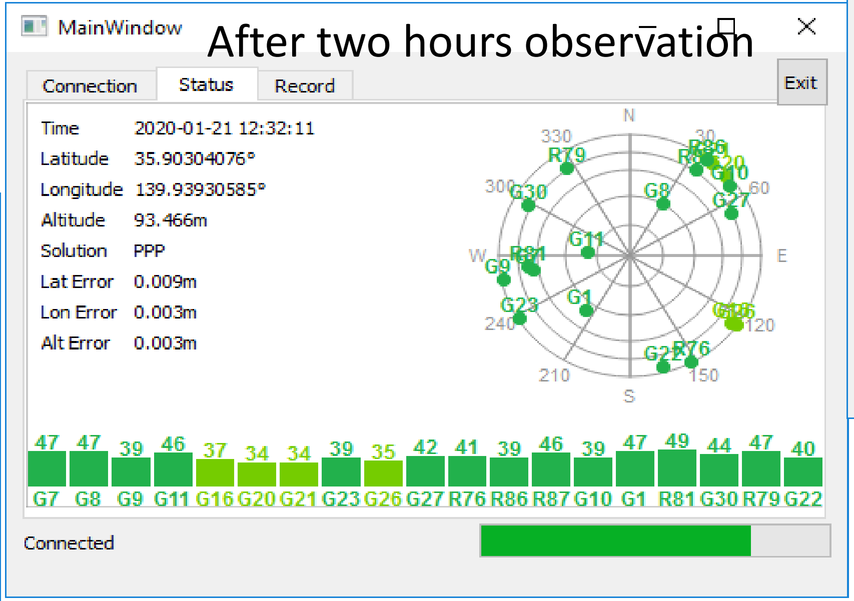
MAD-WIN Data Observation

Receiver: Online receiver access in Kashiwa / Correction Data: MADOCA Receiver in Bali

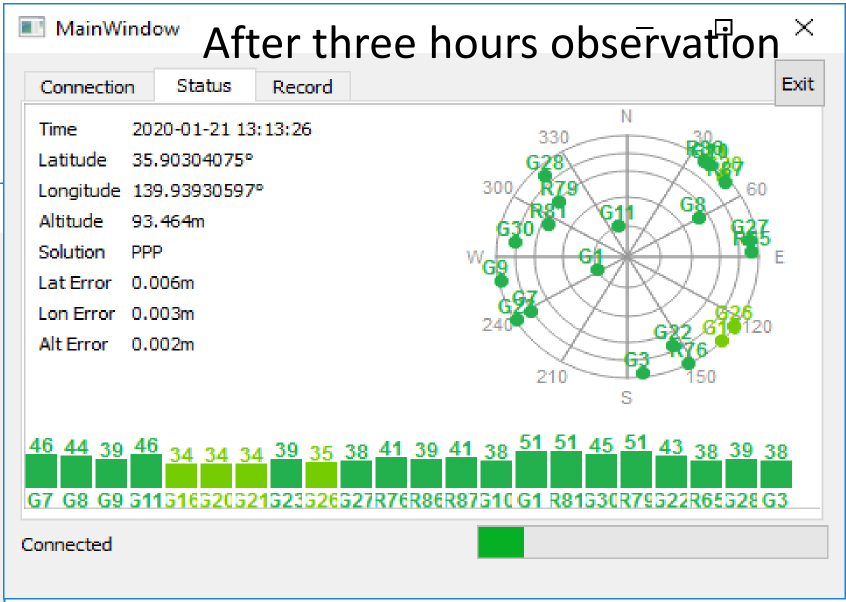




After few minutes observation



After two hours observation

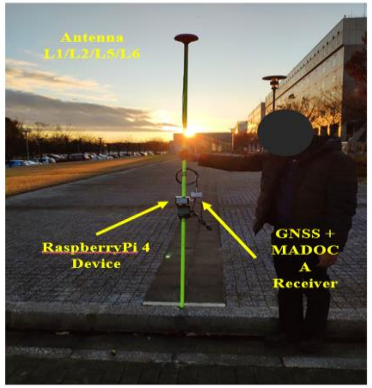


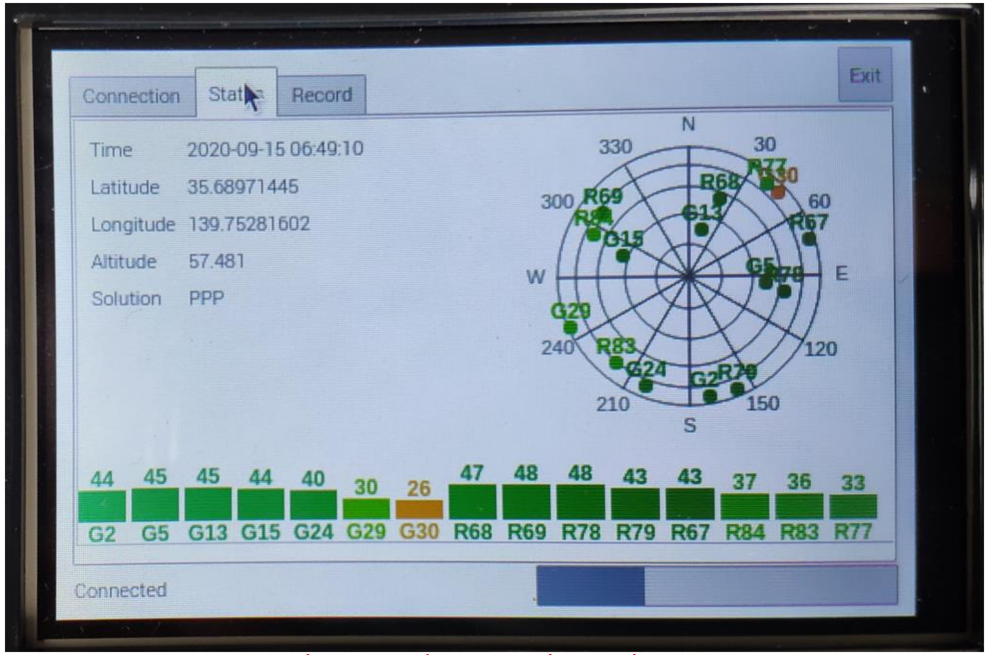
After three hours observation

Dinesh Manandhar, CSIS, The University of Tokyo, dinesh@csis.u-tokyo.ac.jp

MAD-PI:MADOCA with RaspberryPi Device

- MAD-Pi has been tested with RaspberryPi-3B device
  - It also works with RaspberryPi-4B
  - If the device does not work, please try with a different USB port
- Do not remove and insert SD Card several times. It may get damaged.
- Observation data can be logged to an external USB memory disk. Memory drive of upto 64GB is supported.
  - Files are created at 6-hour interval with Date/Time based filename.
- Ras-Pi 4 device consumes more power than Ras-Pi 3 device. Continuous operation of the device will generate heat. Keep the device in well ventilated area
  - Do not keep the device in a closed box
- We have set both Ras-Pi 3 and Ras-Pi 4 devices with touch screens for easy operation.
  - Mouse and External keyboard can be connected either via BT or USB ports
- Ras-Pi device can be connected by an Android device using BT





Raspberry-Pi device with Touch Screen