Introduction to QZSS, GNSS Positioning Methods and Low-Cost Receiver Systems

Faculty Development Program (FDP) on GNSS/ NavIC and Applications
21 – 25 September 2021

Dinesh Manandhar, Associate Professor (Project)
Center for Spatial Information Science (CSIS), The University of Tokyo

22nd September 2021

dinesh@csis.u-tokyo.ac.jp

QZSS (Quasi-Zenith Satellite System) “MICHIBIKI” Introduction

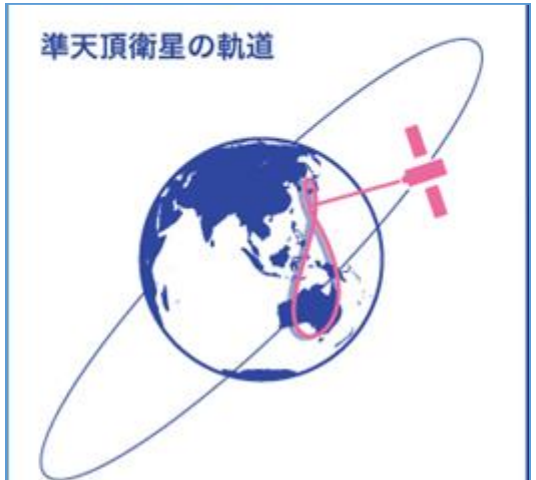


Image: MGA 2019, Mitsubishi

QZSS Introduction

- The first QZSS satellite was launched in September 2010.
- Today, there are four satellites in the space.
- QZSS orbit is designed so that it can provide good position data even in highly dense urban area like Tokyo.
- It is designed interoperable with GPS satellites.
- QZSS provides unique new services such as MADOCA, CLAS and DCR.
- QZSS was declared operational in November 2018.
- The future constellation of QZSS will have 7 satellites.
- QZSS Information Links:
  - https://qzss.go.jp/en/overview/downloads/movie_qzss.html
  - https://qzss.go.jp/en/

QZSS was Declared Operational on 1st NOV 2018

Declaration Ceremony of QZSS Operation

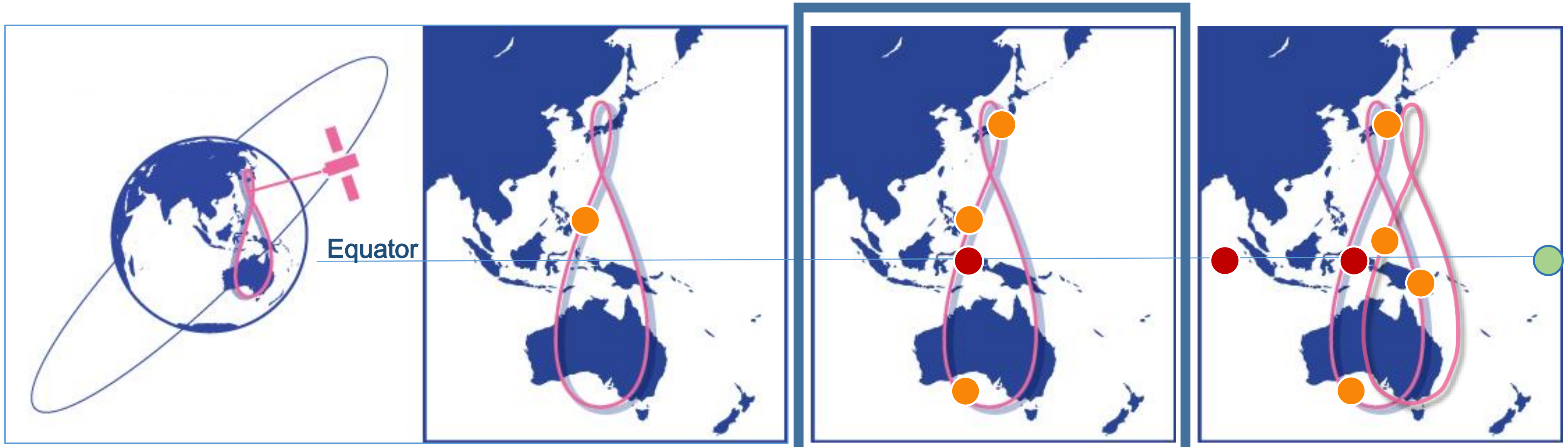
http://qzss.go.jp/events/ceremony_181105.html

QZSS Signals and PRN ID

PRN	SVN	Satellite	Launch Date (UTC)	Orbit	Positioning Signals
193	J001	QZS-1	2010/9/11	QZO	L1C/A, L1C, L2C, L5
183					L1S
193					L6
194	J002	QZS-2	2017/6/1	QZO	L1C/A, L1C, L2C, L5
184					L1S
196					L5S
194					L6
199	J003	QZS-3	2017/8/19	GEO	L1C/A, L1C, L2C, L5
189					L1S
197					L5S
137					L1Sb
199					L6
-					Sr/Sf
195	J004	QZS-4	2017/10/9	QZO	L1C/A, L1C, L2C, L5
185					L1S
200					L5S
195					L6

Source: https://qzss.go.jp/technical/satellites/index.html

QZSS Constellation Plan



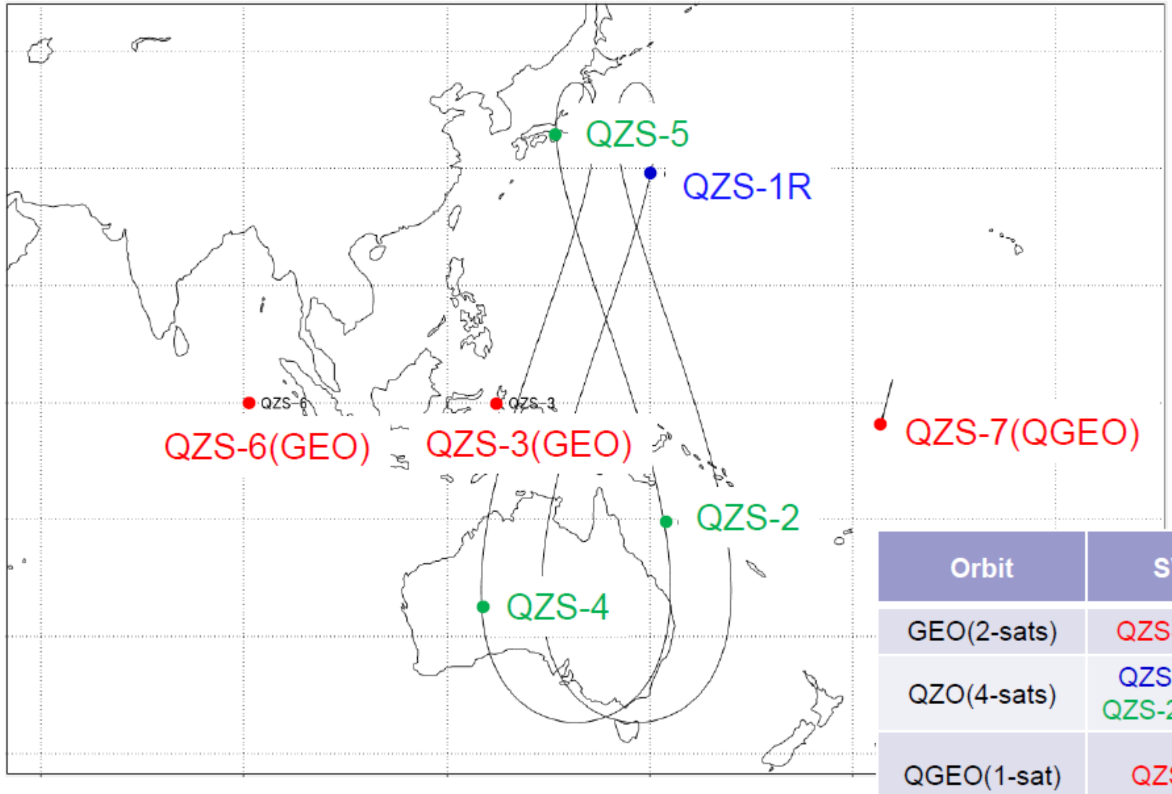
	1 sat constellation	4 sat. constellation	7 sat. constellation
Number of Satellites	QZO ●: 1	QZO ●: 3, GEO ●: 1	QZO●:4, GEO●:2, QGO●:1
Purpose	Research & Development	Operational Complements GPS for positioning	Operational, Autonomous Positioning Capability with QZSS only
Government Authority	JAXA	Cabinet Office	Cabinet Office
Operation	2010～ (10 years)	2018～ (15 years)	2023～ (15 years)
Service Time / day (Japan)	8 hours / day	24 hours / day	24 hours / day

QZO: Quasi-zenith Orbit / GEO: Geosynchronous Orbit / QGO: Quasi-geostationary Orbit

Source: MGA 2019, Mitsubishi

2. QZSS 7SV Constellation Design

QZSS Constellation Plan



7-QZSS Ground Track

Orbit	SV	Center Longi. (deg.)
GEO(2-sats)	QZS-3, 6	127E, 90.5E
QZO(4-sats)	QZS-1R, QZS-2, 4, 5	148E(nom) 139E(nom)
QGEO(1-sat)	QZS-7	185E(nom)

*QGEO: Quasi Geostationary Earth Orbit (i>1deg, e=0.008)

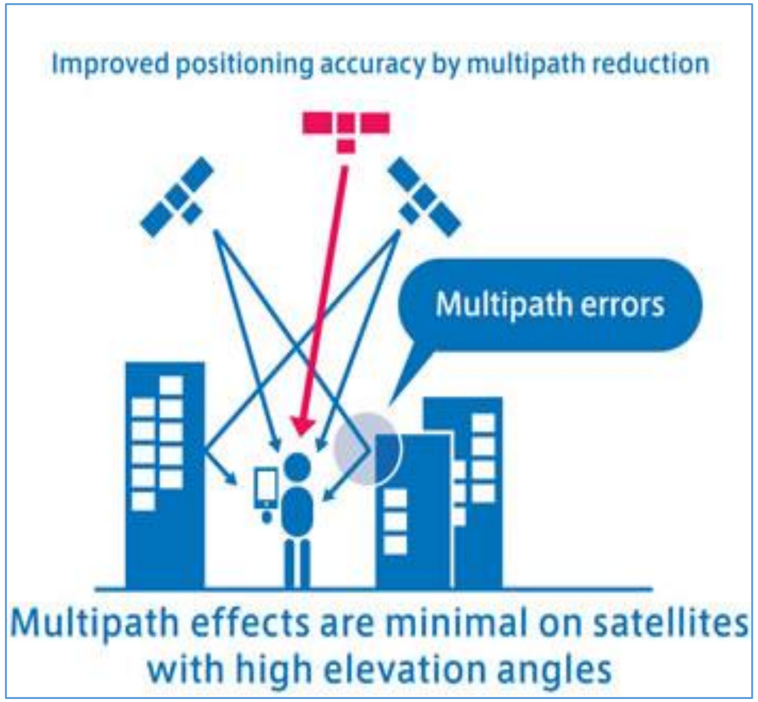
Cabinet Office
National Space Policy Secretariat

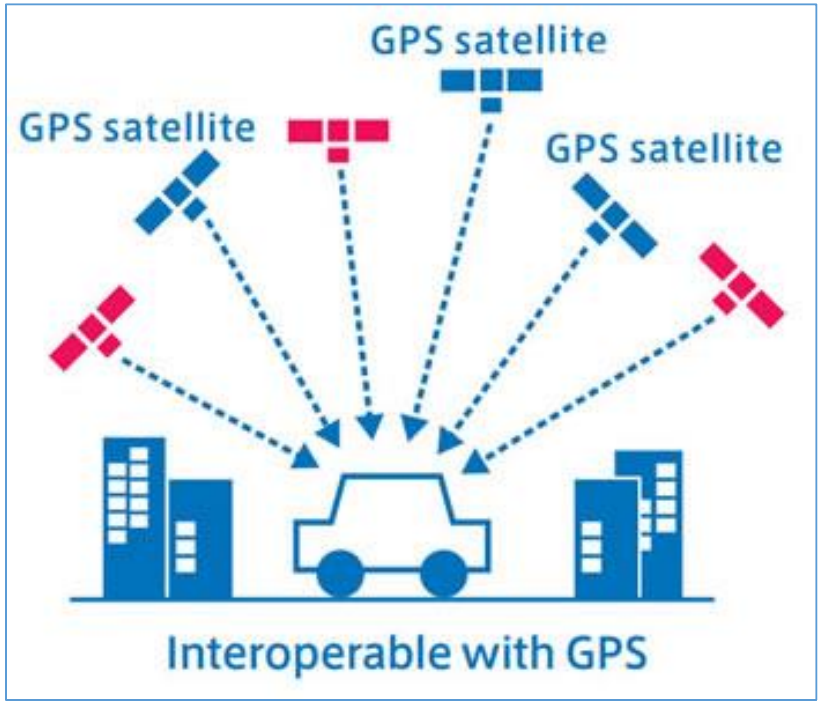
8

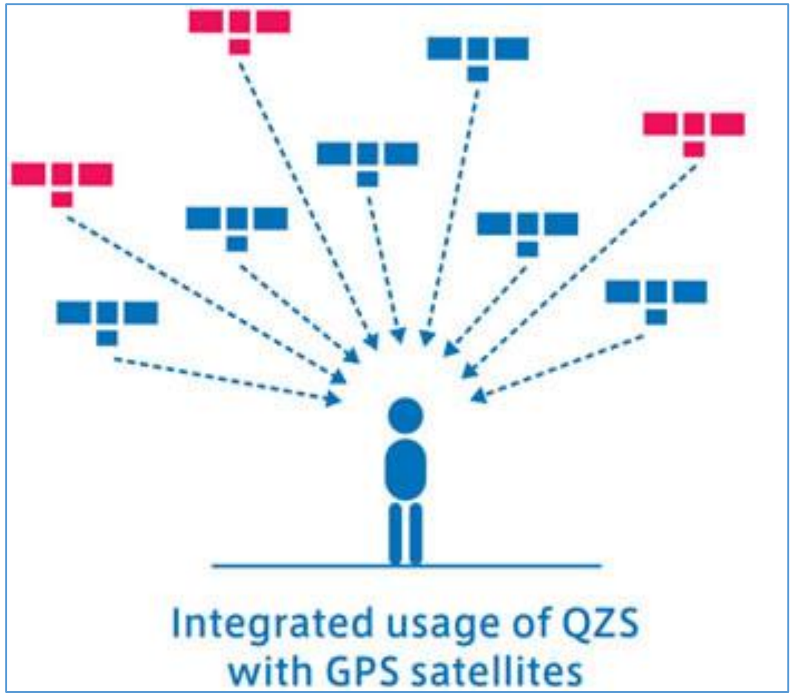
This slide is taken from presentation slides of S. Kogure, Introduction to Michibiki and EWS, presented on 13th July 2021

Characteristics of QZSS

- QZSS signal is designed in such a way that it is **interoperable with GPS**
- QZSS is visible near zenith; improves visibility & DOP in dense urban area
- Provides Orbit Data of other GNSS signals
- Provides **Augmentation Data for Sub-meter and Centimeter level position accuracy**
- Provides Messaging System during Disasters





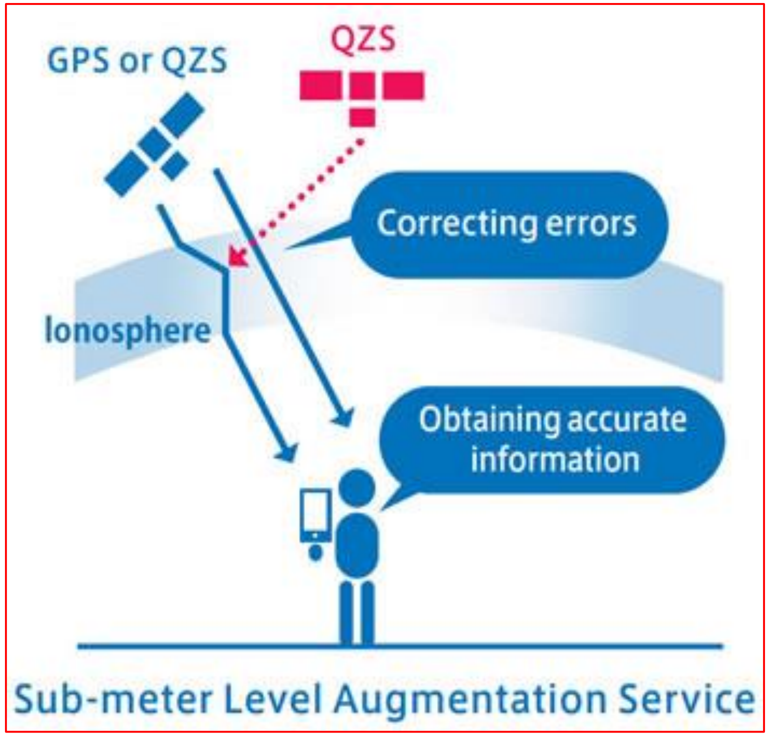


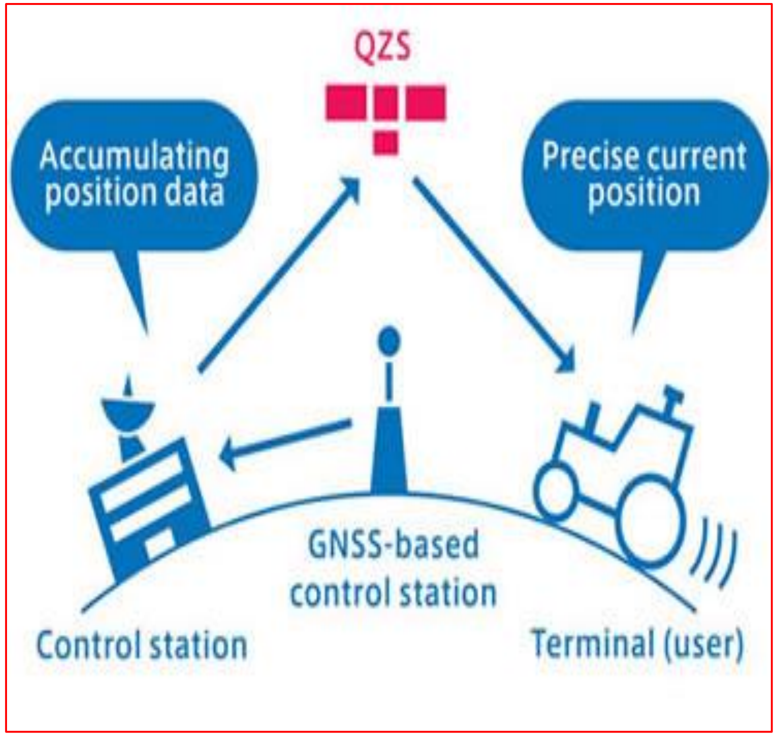
Merits of QZSS

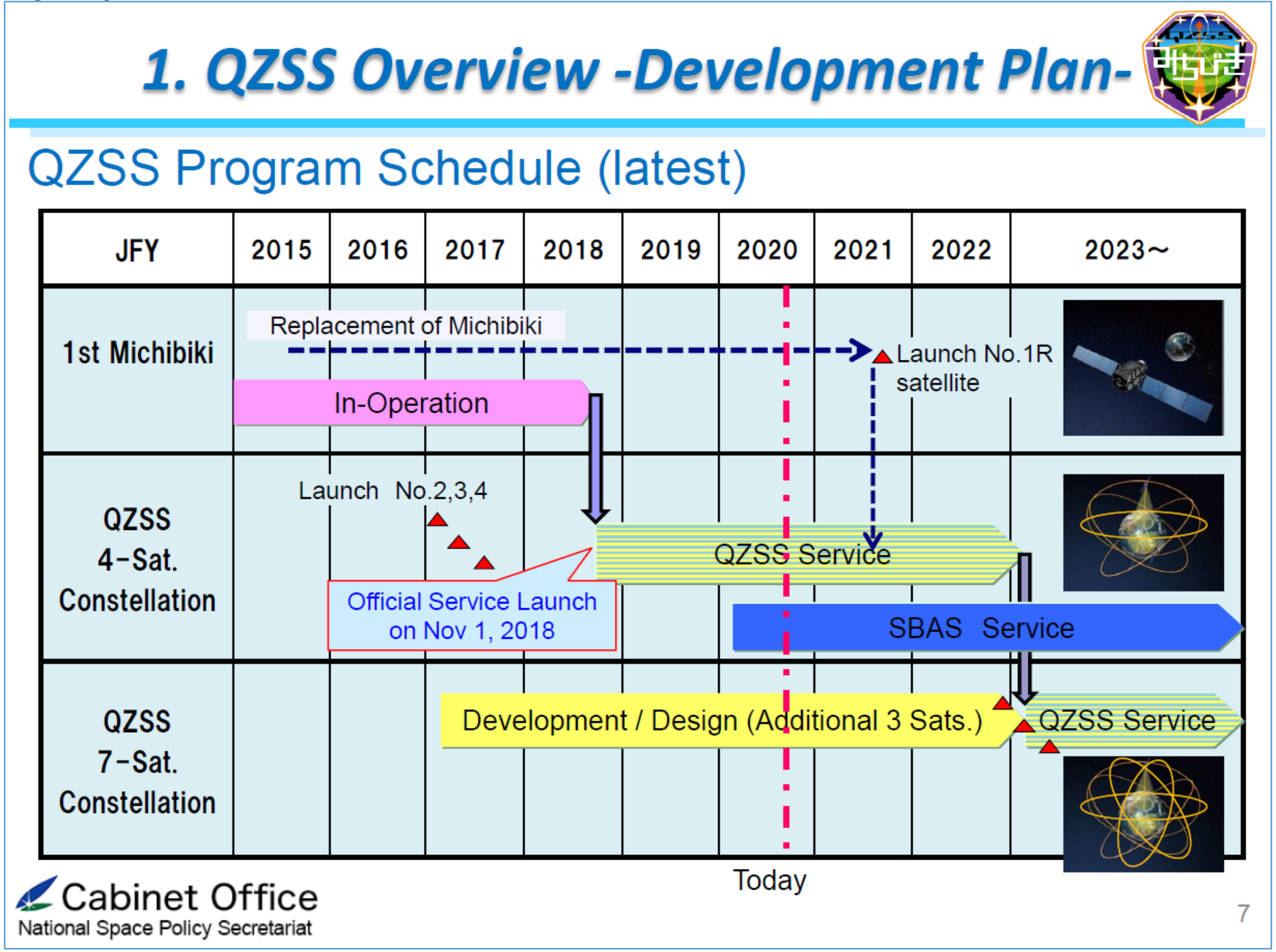
- Disaster and Crisis Management
- Short Message broadcast during Disaster

- Sub-Meter Level Augmentation Service (SLAS)

- High-Accuracy Positioning Services
- CLAS and MADOCA







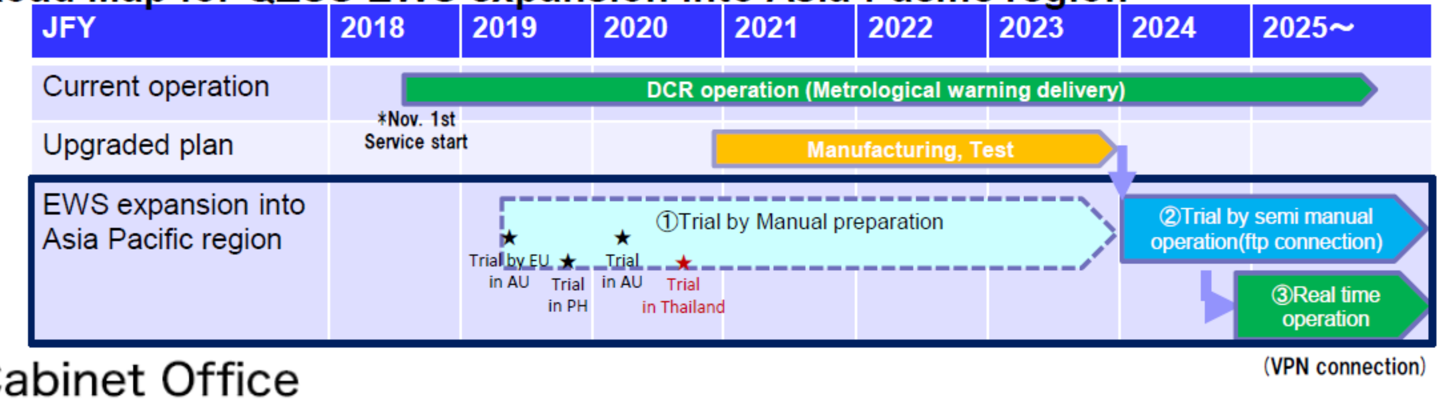
This slide is taken from presentation slides of S. Kogure, Introduction to Michibiki and EWS, presented on 13th July 2021

2. QZSS 7SV Constellation Design
Latest Updates -Early Warning Service (EWS)-

- QZSS L1S signal is sharing 250 bps data stream with SLAS and Disaster and Crisis Report service.
- DCR service is currently providing weather information generated by JMA for Japanese domestic users.
- Common EWS format is being investigated in collaboration with EC.
- QZSS ground segment will be upgraded to support EWS in 2024-2025 and distribute EWS once every 4 seconds through QZS-1 to 4 satellites.

Signal	Service Name	Center freq.	Modulation	Bit Rate
L1S	Sub-meter Level Augmentation Service (SLAS)	1575.42MHz	BPSK	250bps
	DC Report Service			

Road Map for QZSS EWS expansion into Asia Pacific region



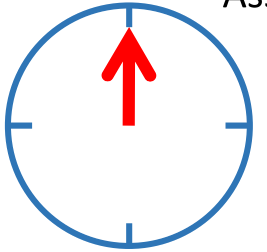
Cabinet Office
National Space Policy Secretariat

16

This slide is taken from presentation slides of S. Kogure, Introduction to Michibiki and EWS, presented on 13th July 2021

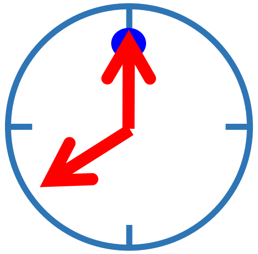
How does a GPS/GNSS Receiver Work?

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

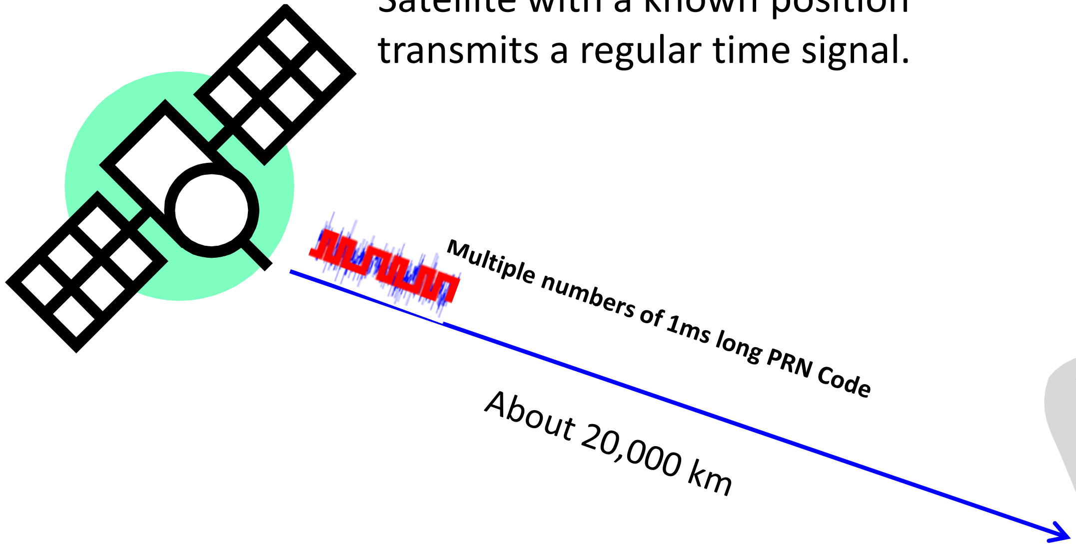


Assume that the Satellite Transmits Signal at 0ms.

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

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

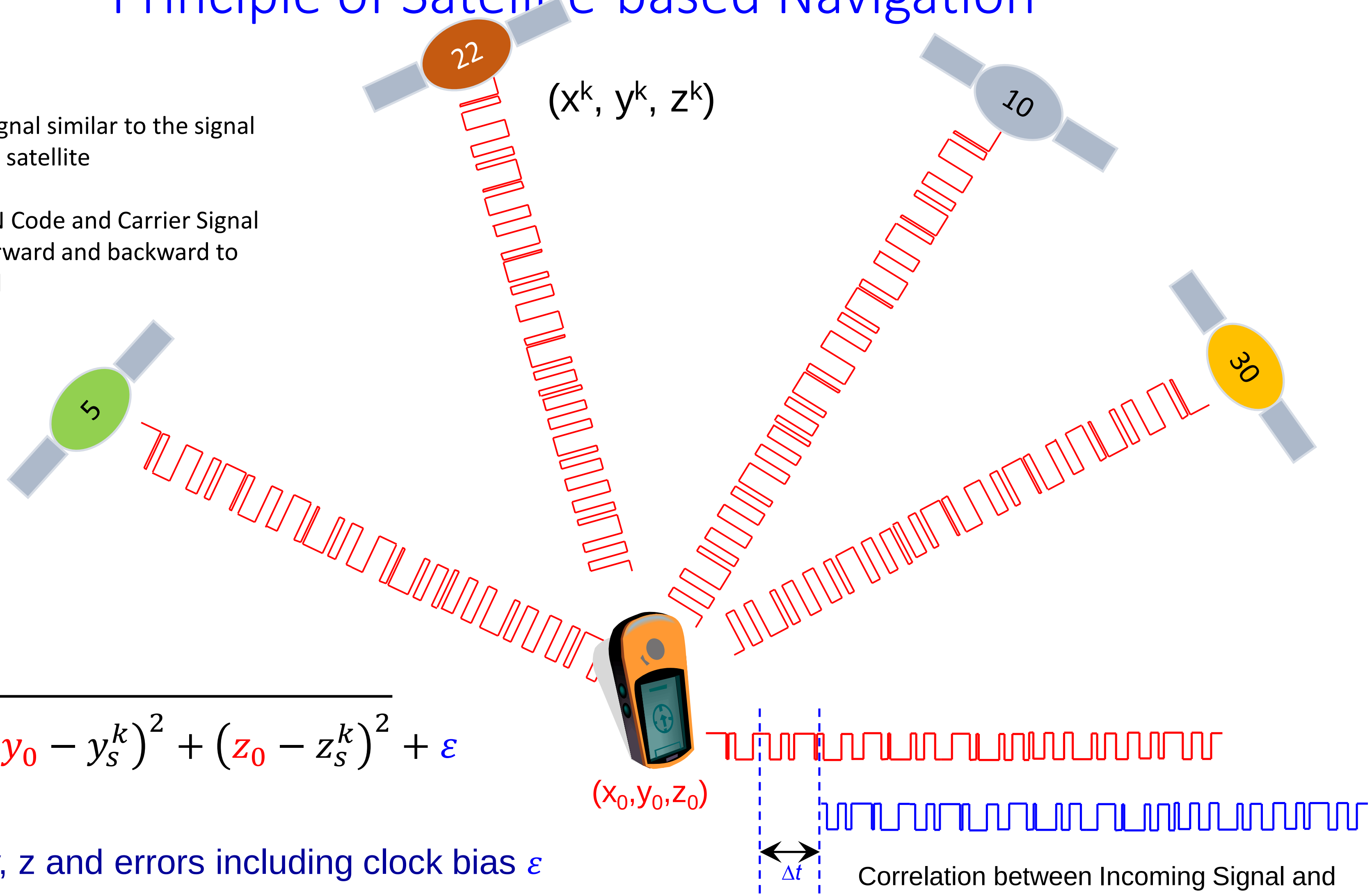
GNSS: How does it work?
Principle of Satellite-based Navigation

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

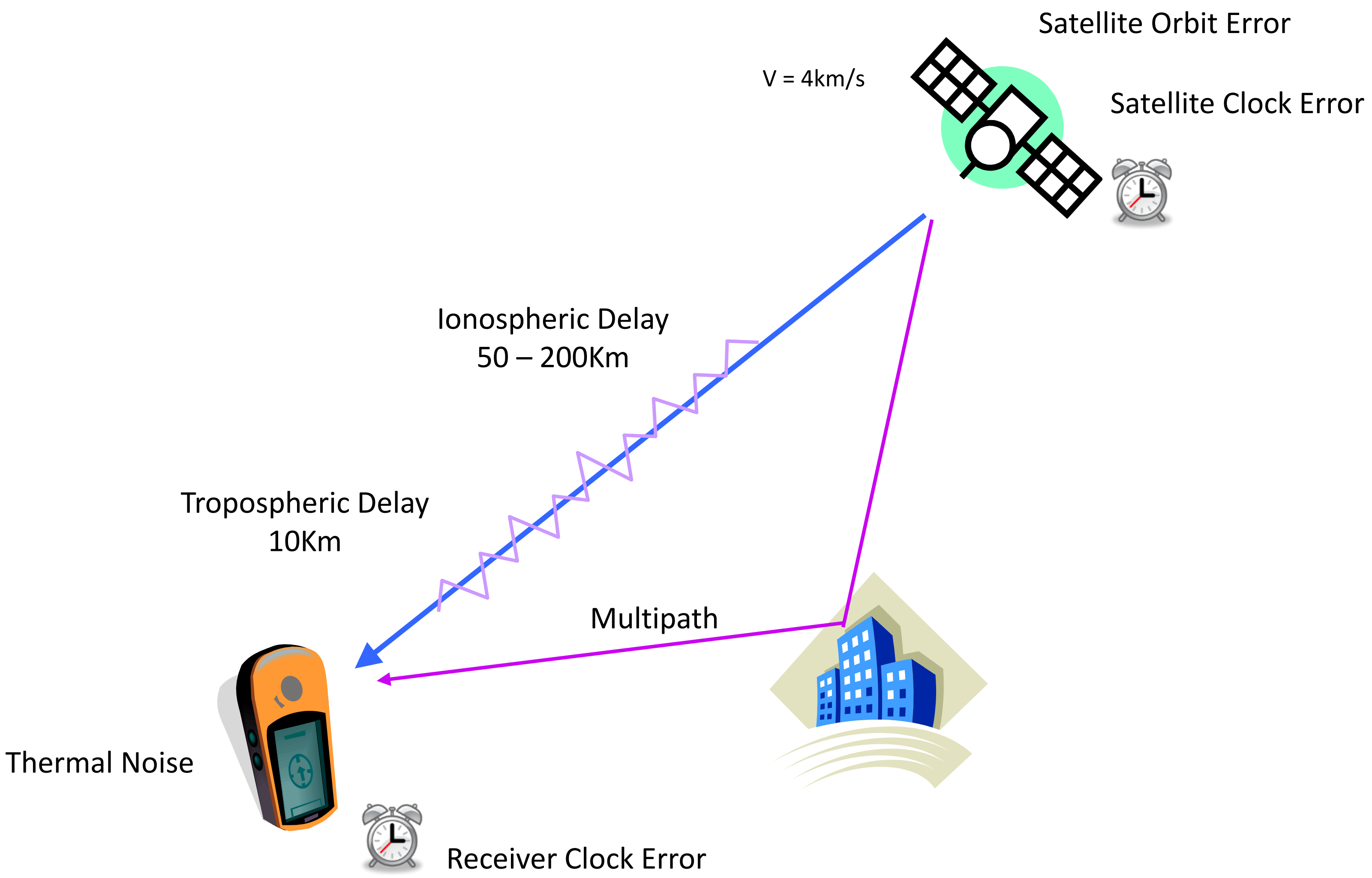


$$\rho^k = \sqrt{\left(x_0 - x_s^k\right)^2 + \left(y_0 - y_s^k\right)^2 + \left(z_0 - z_s^k\right)^2} + \varepsilon$$

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

Correlation between Incoming Signal and Receiver Generated Signal

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

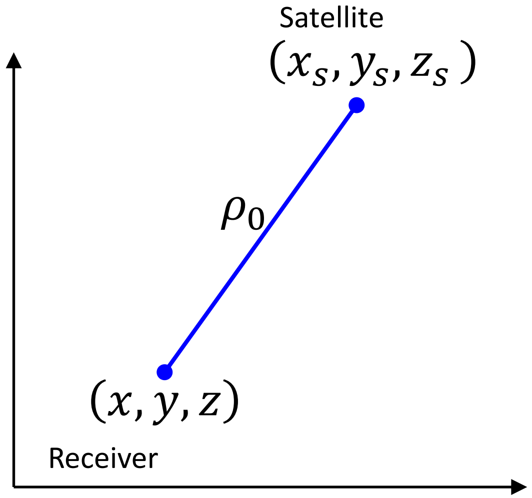
Multipath Error

Thermal Noise

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

Pseudorange model

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

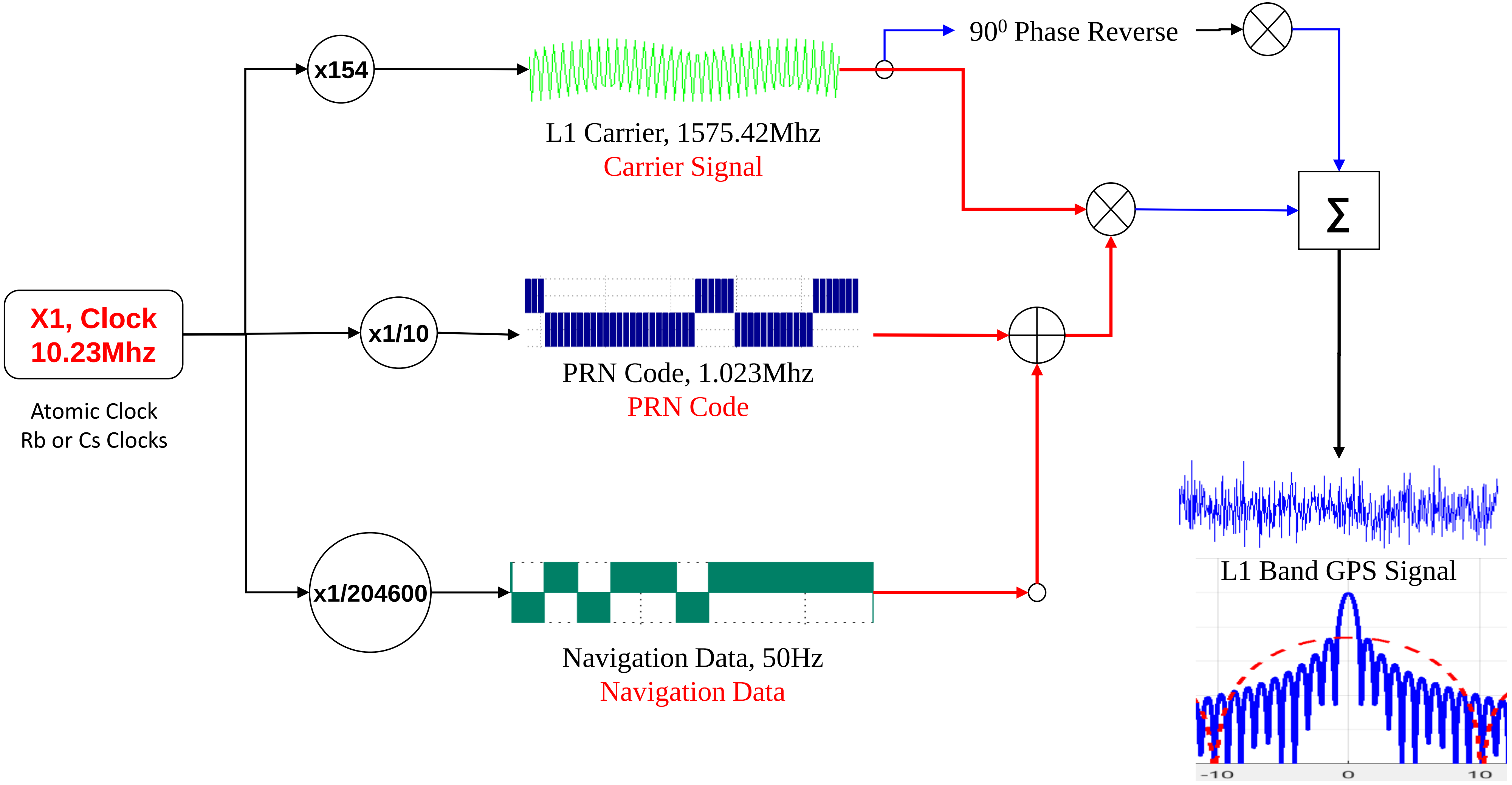


Range between satellite and receiver

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

- 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.

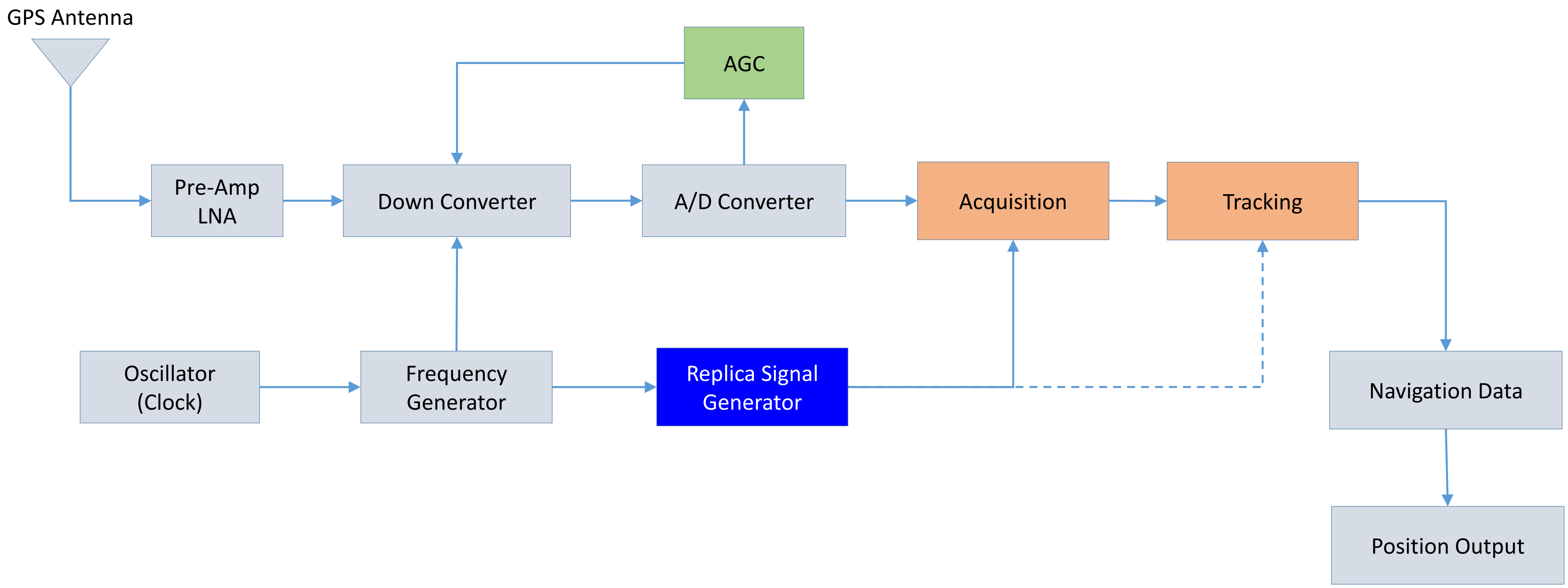
GPS L1C/A Signal Structure (Satellite Side)



GPS L1C/A Signal Structure

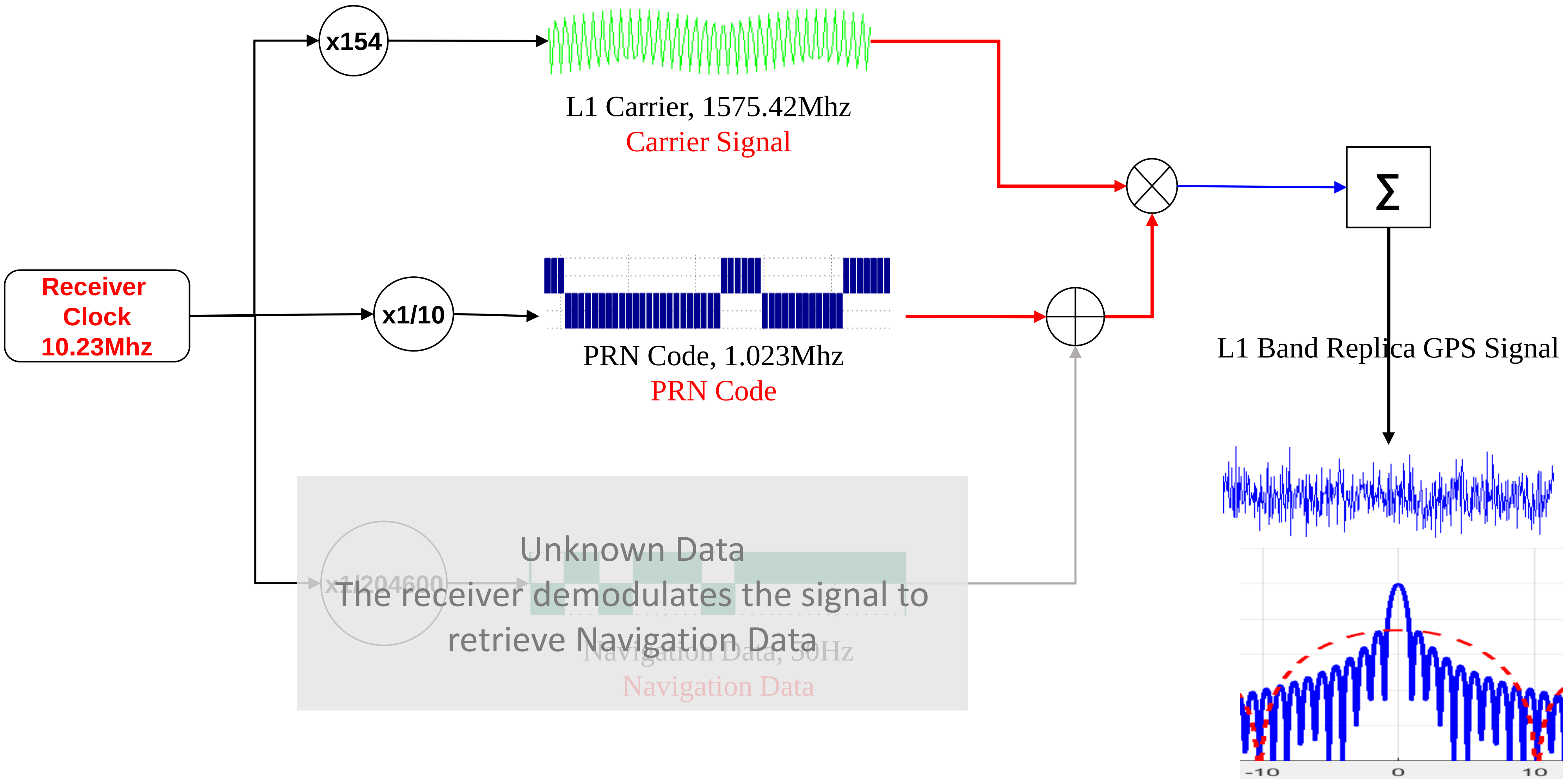
- Carrier Signal
  - It defines the frequency of the signal
  - For example:
    - GPS L1 is 1575.42MHz, L2 is 1227.60MHz and L5 is 1176.45MHz
- PRN Code
  - Necessary to modulate carrier signal
  - Used to identify satellite ID in the signal
  - Should have good auto-correlation and cross-correlation 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



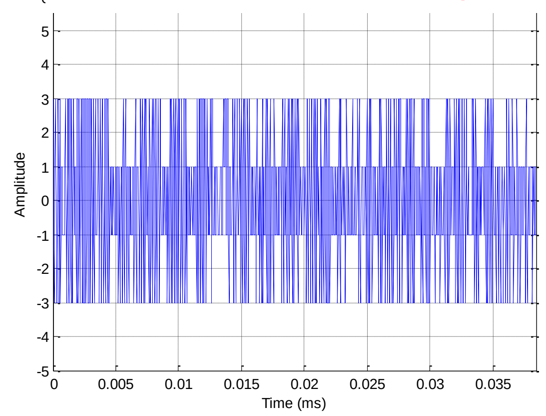
Dinesh Manandhar, CSIS, The University of Tokyo, dinesh@csis.u-tokyo.ac.jp

GPS L1C/A Replica Signal at Receiver Side

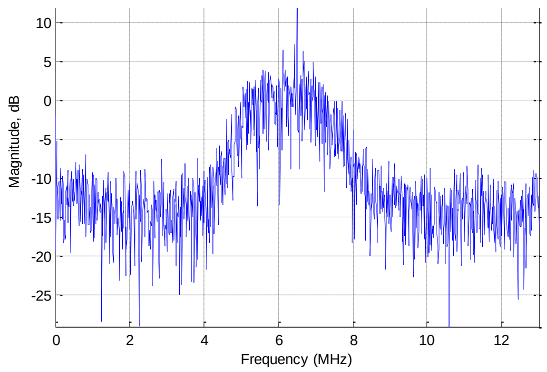


How does GPS Signal Look Like?

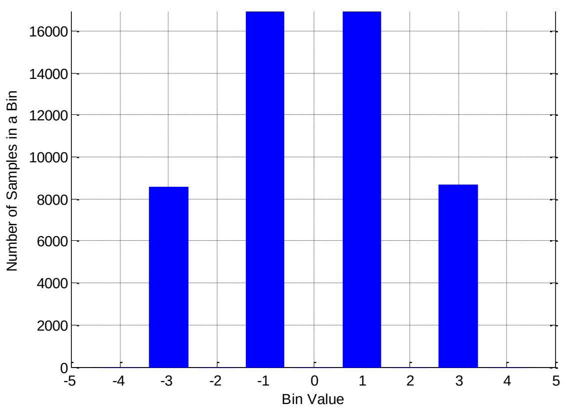
Time-domain Plot of GPS IF Signal



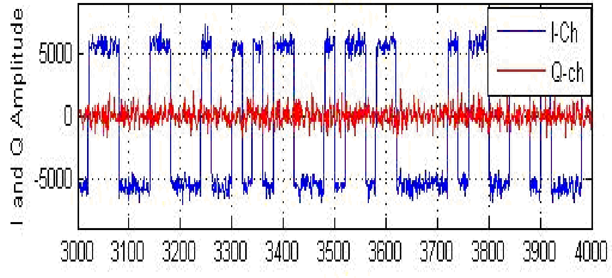
Frequency-domain Plot of GPS IF Signal (Fourier Transform)

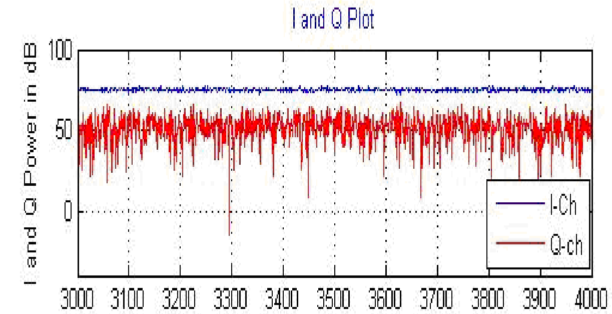


Histogram of GPS IF Signal

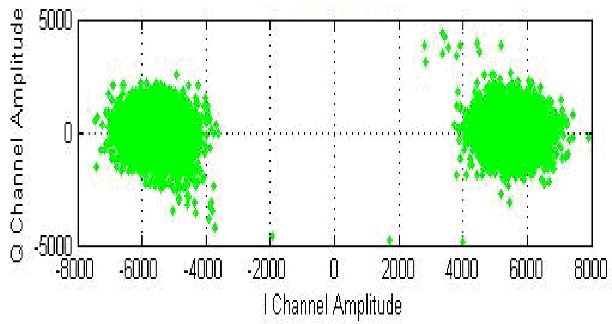


Tracking Output (I and Q Channels)

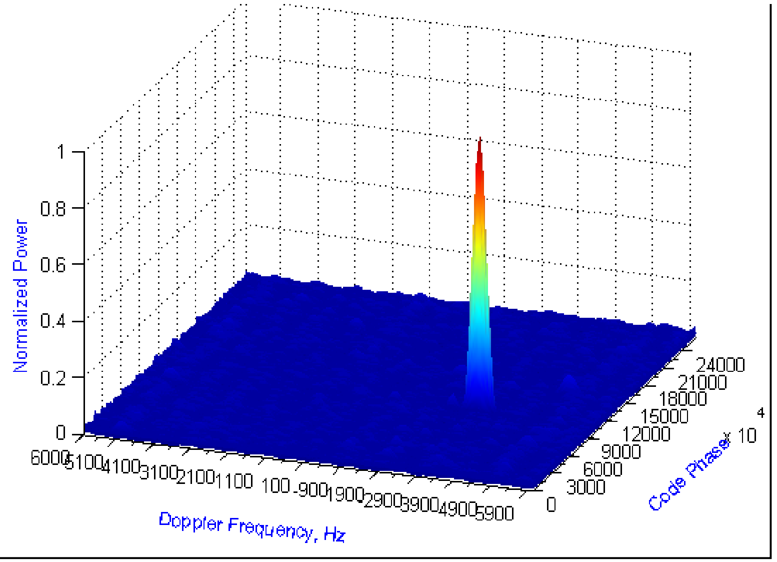




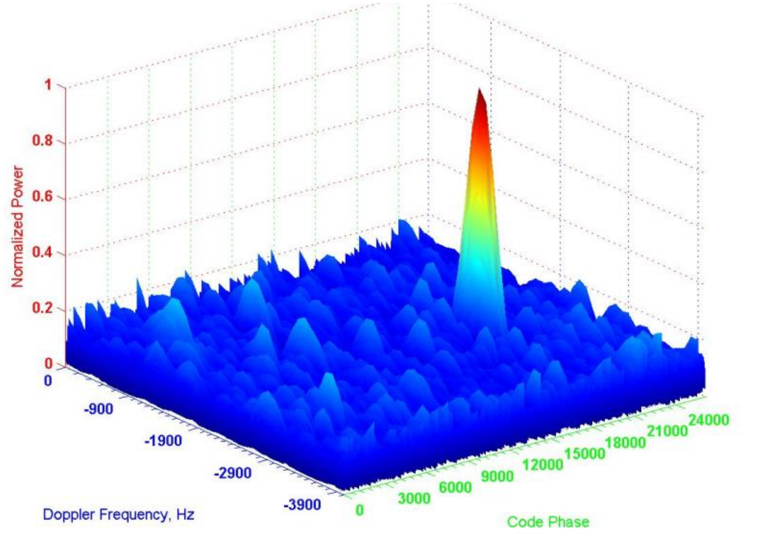
Scatter Plot of I and Q Channels, shows BPSK Modulation



Acquisition of GPS L1C/A Signal with Low Noise

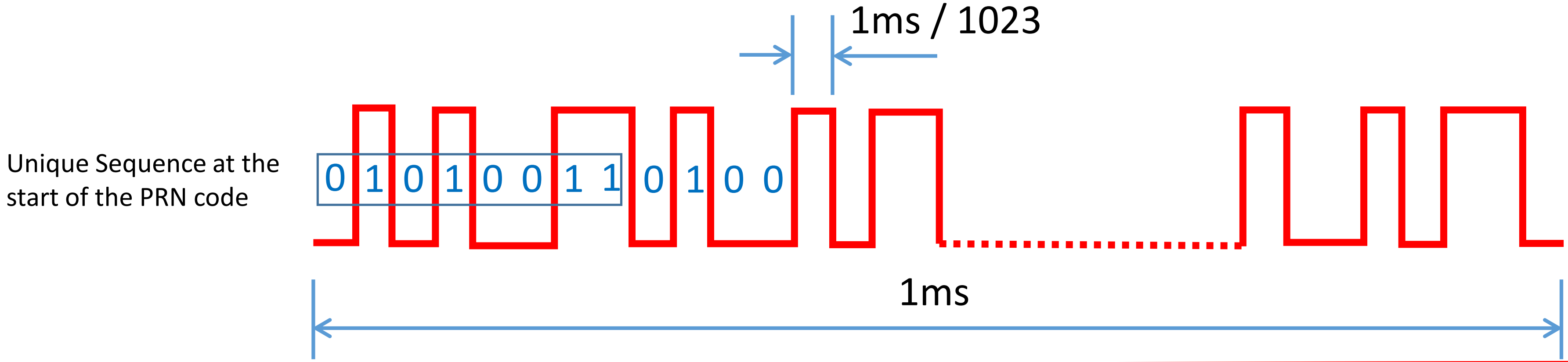


Acquisition of GPS L1C/A Signal with Higher Noise



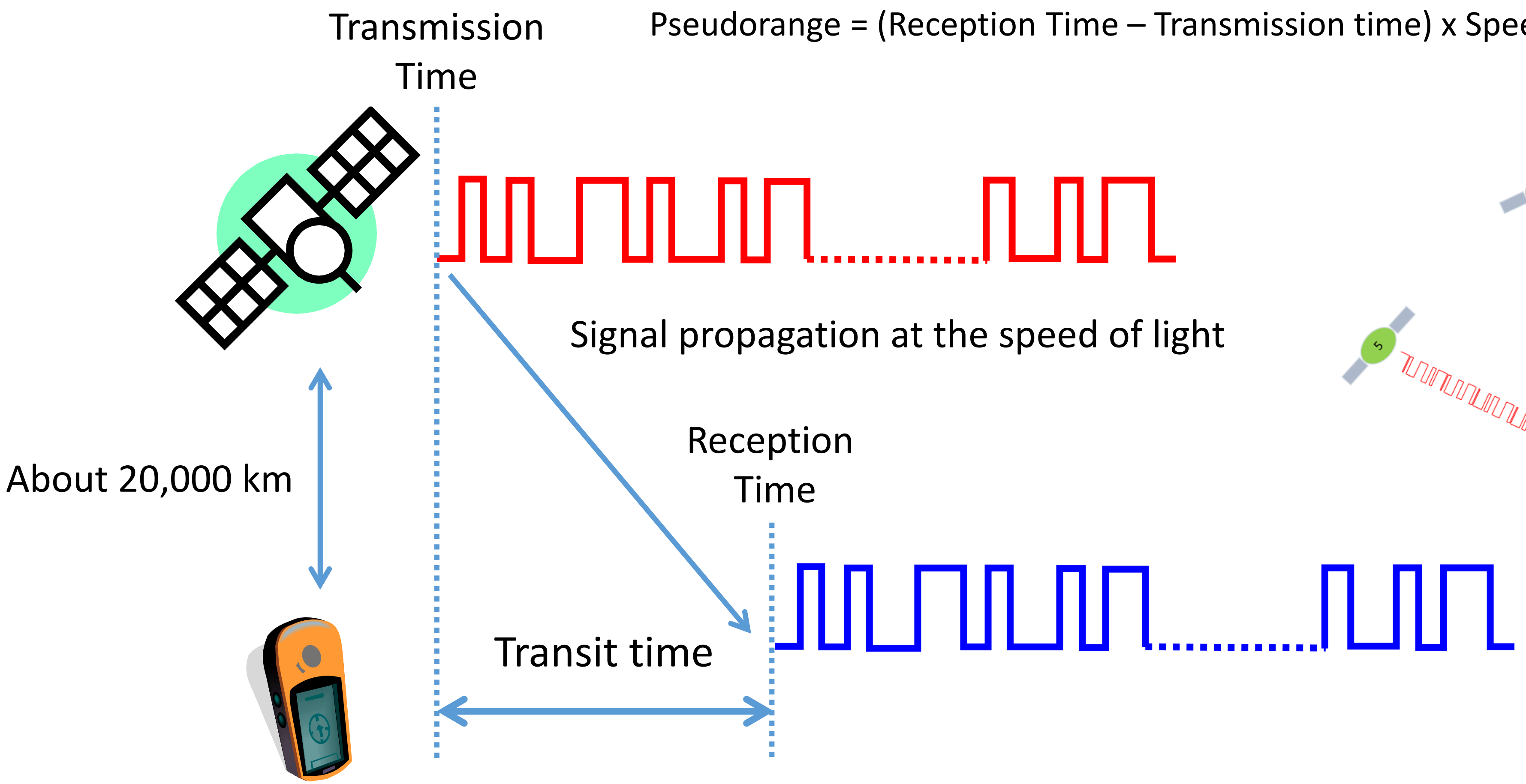
PRN (Pseudo Random Noise) Code

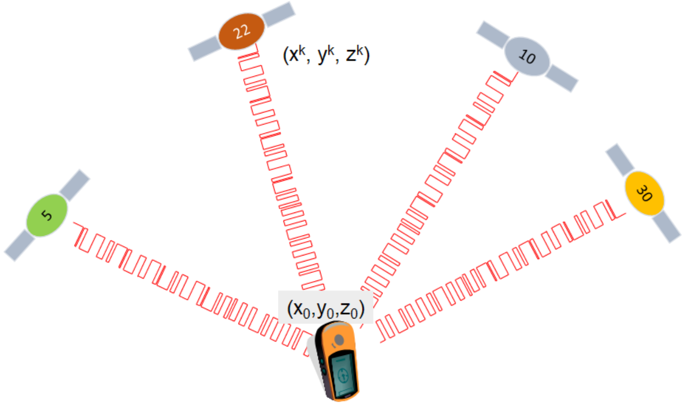
- PRN Code is a sequence of randomly distributed zeros and ones that is one millisecond long.
  - This random distribution follows a specific code generation pattern called Gold Code.
  - There are 1023 zeros and ones in one millisecond.
- Each GPS satellite transmits a unique PRN Code.
  - GPS receiver 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



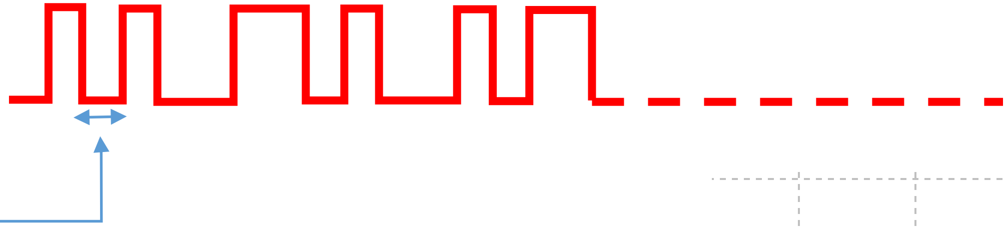


A GPS receiver measures the signal transmission time from the code phase at signal reception time.

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

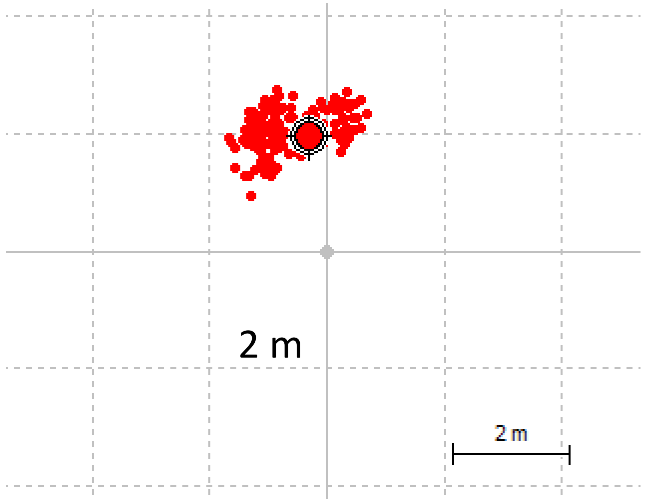
Pseudorange (Code-Phase Measurement) - 2

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



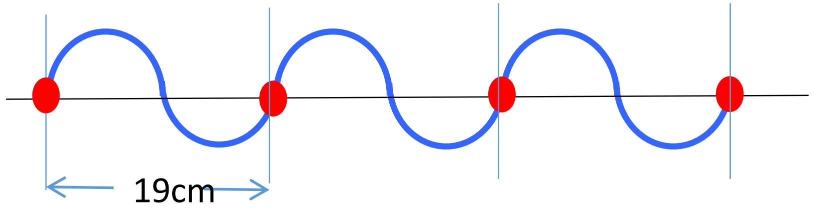
1-bit or chip corresponds to 1/1023 ms.
This is about 293m (say 300m) in distance.

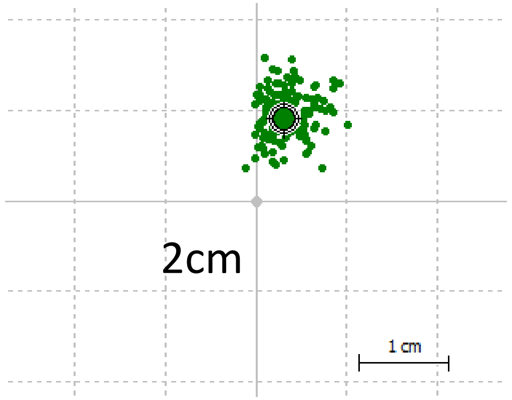
In the receiver, signals are resampled at certain frequency, say 10MHz.
This means every chip will be further divided into 10 smaller chips.
If it is possible to detect code phase at 1/10 of this sampled chip, then range measurement accuracy would be about 300/10/10 = 3m.
However, there are various types 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.



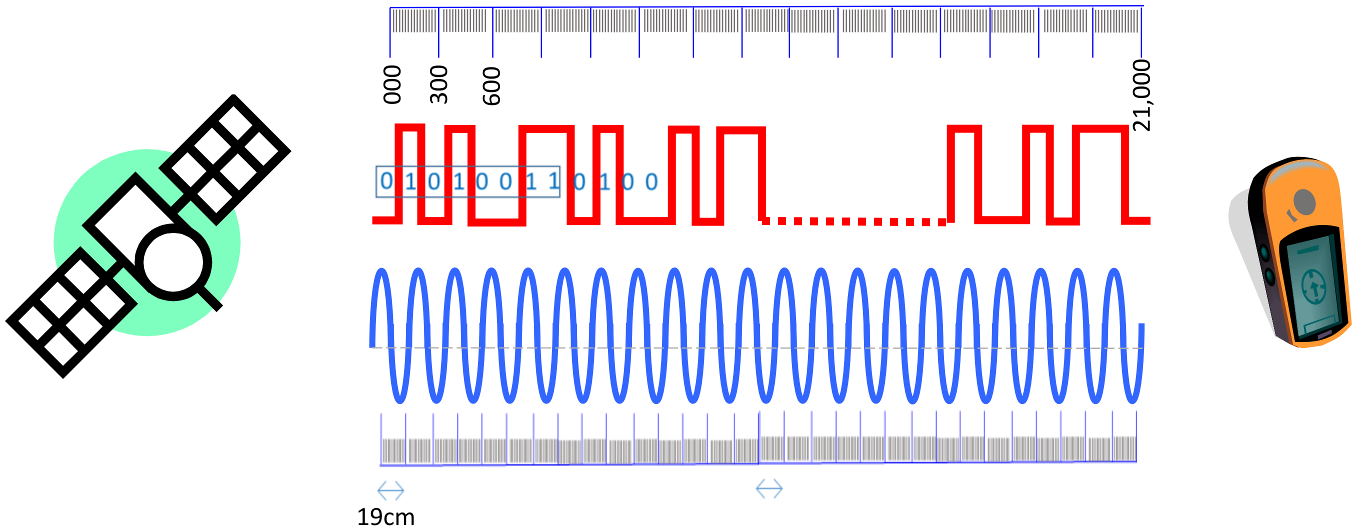
Carrier-Phase Measurement – 1

- 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 $1/10^{th}$ 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



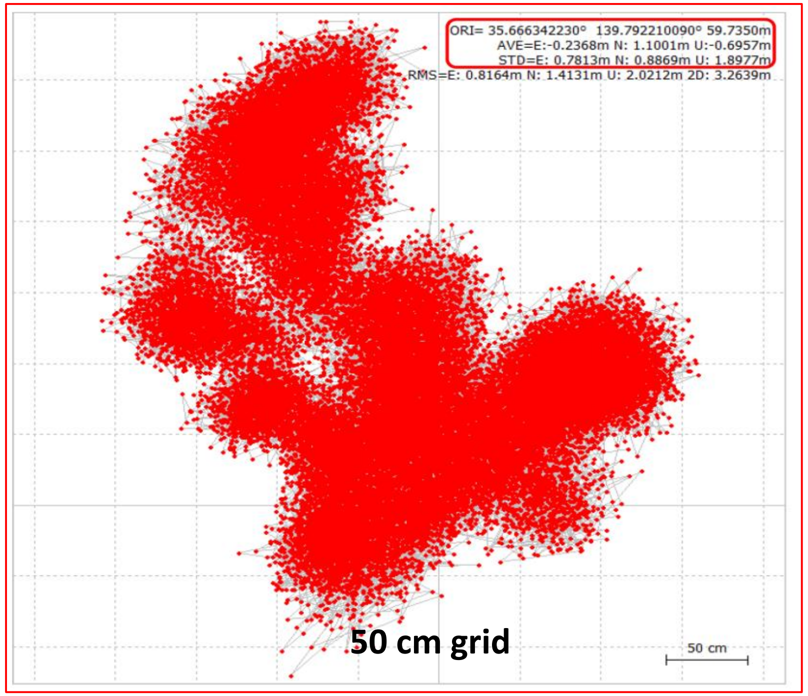
Code-Phase Measurement	Carrier-Phase Measurement
Measuring distance between the satellite and the receiver with a tape that has distance markings as well as distance values written. So that we can measure correct distance.	Measuring distance between the satellite and the receiver with a tape that has 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?

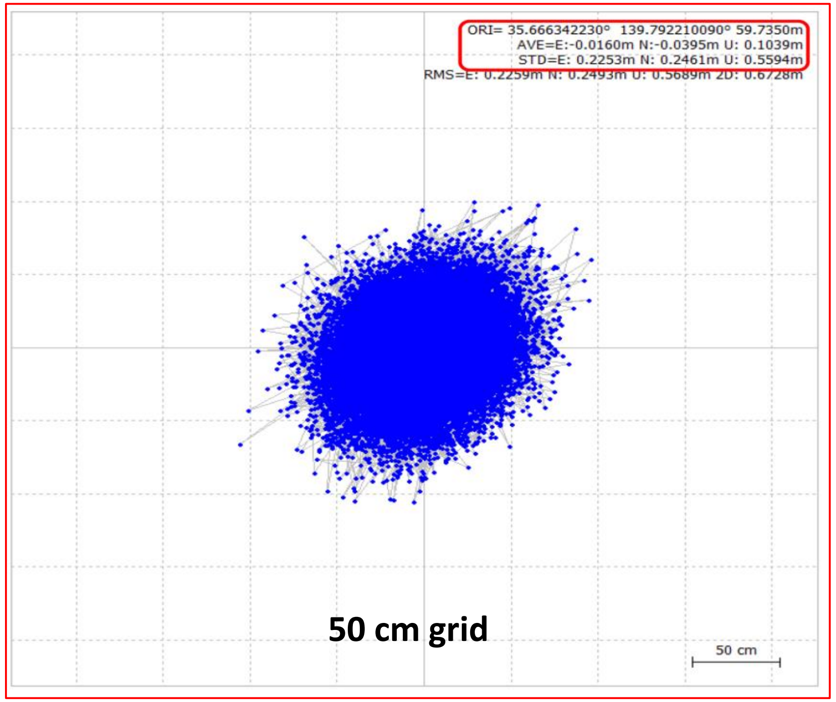
GPS Position Accuracy

How to achieve accuracy from few meters to few centimeters?

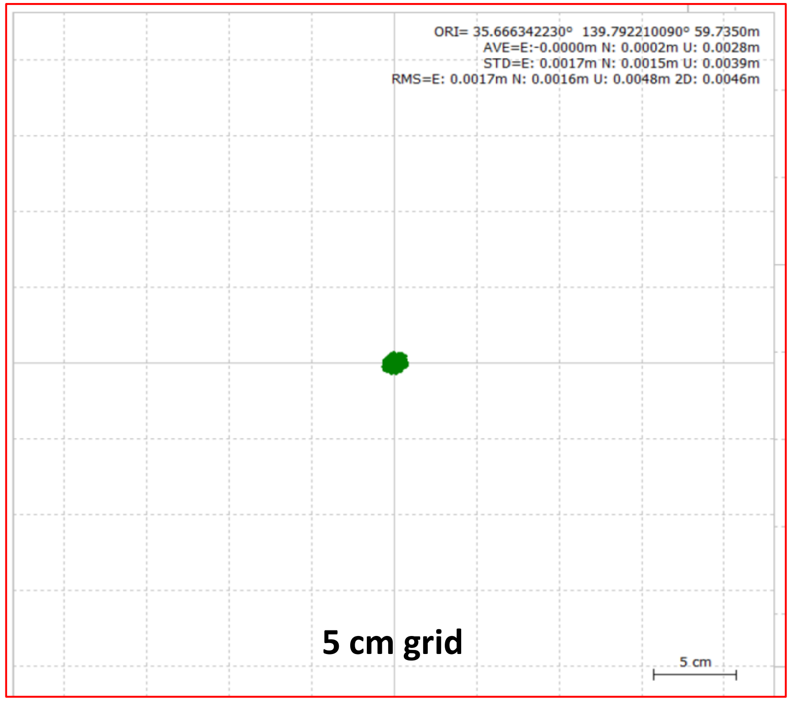
meter → centimeter



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

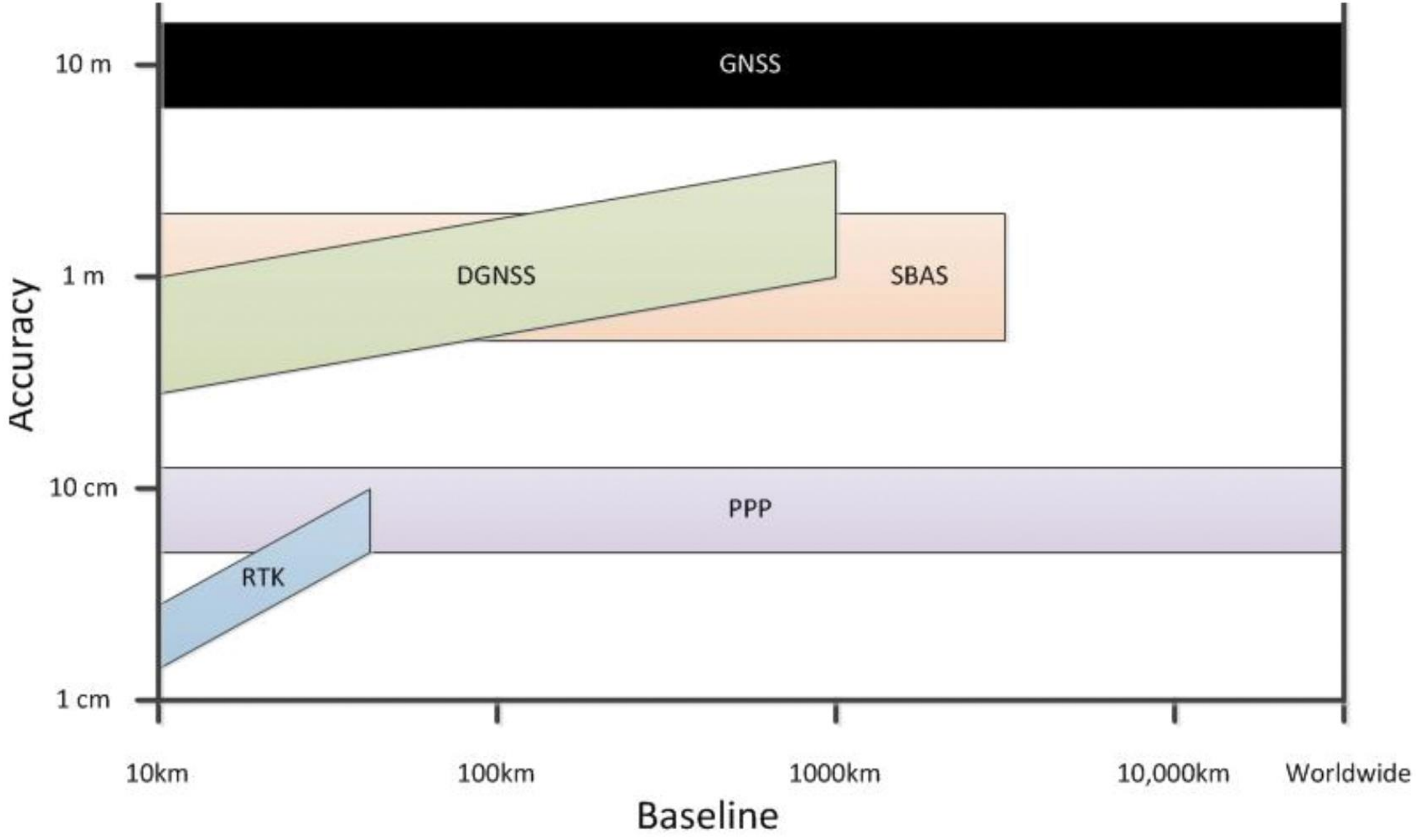
How to Improve Accuracy?

- 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

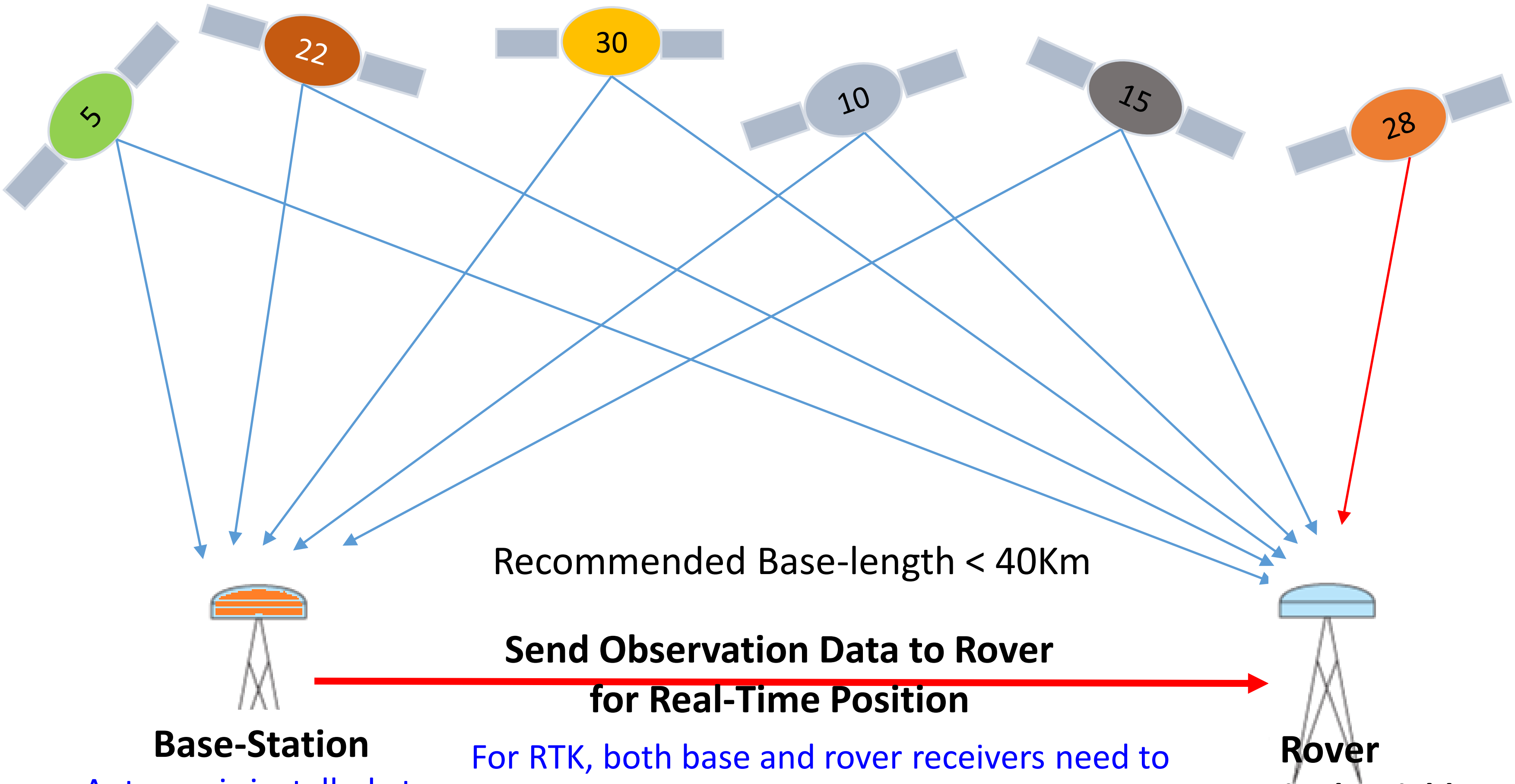
Which Method: DGPS, SBAS, RTK, PPP?



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

How to Remove or Minimize Common Errors?

Use Differential Correction



Recommended Base-length < 40Km

Send Observation Data to Rover for Real-Time Position

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

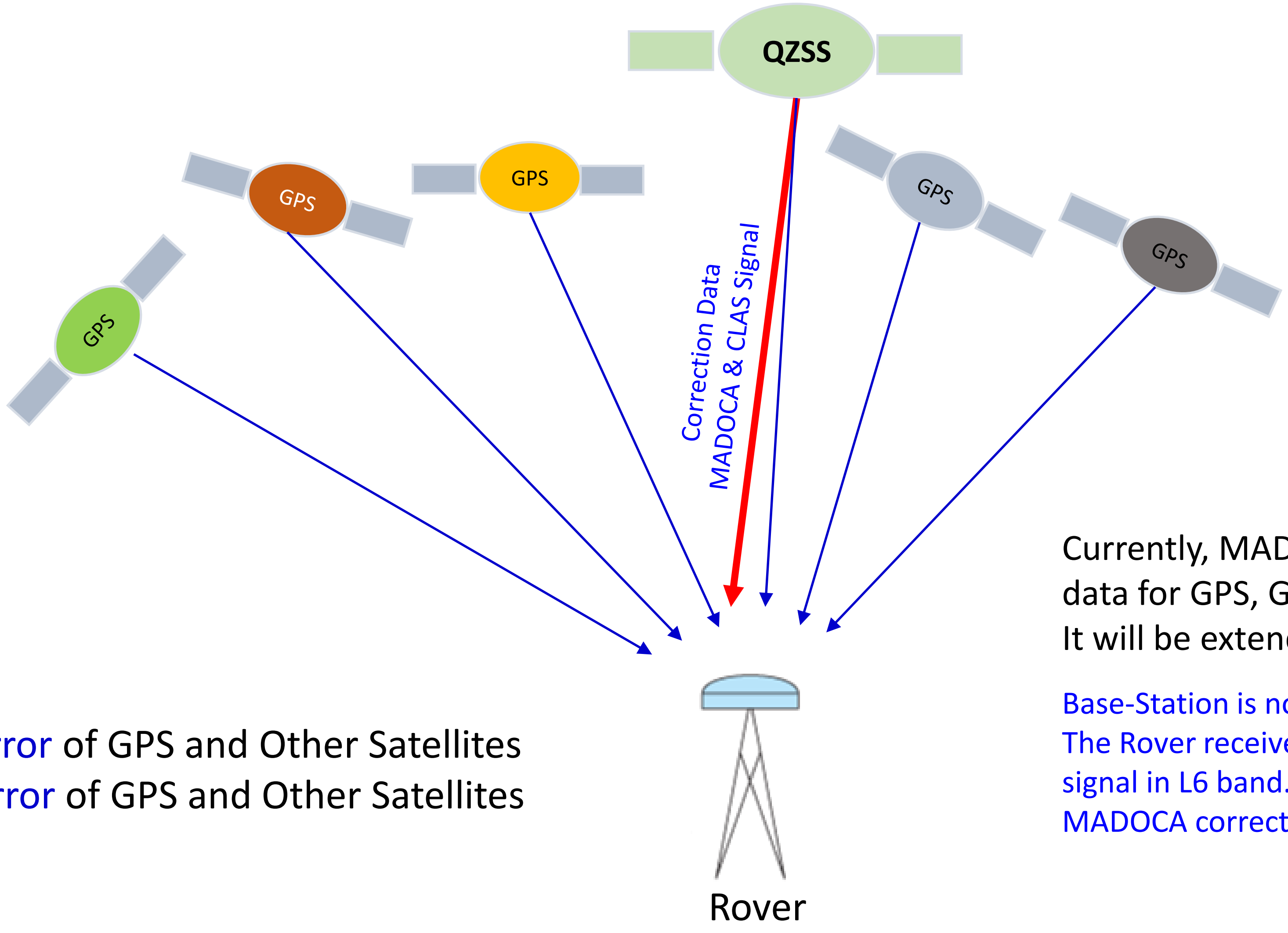
(Either fixed or moving)

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

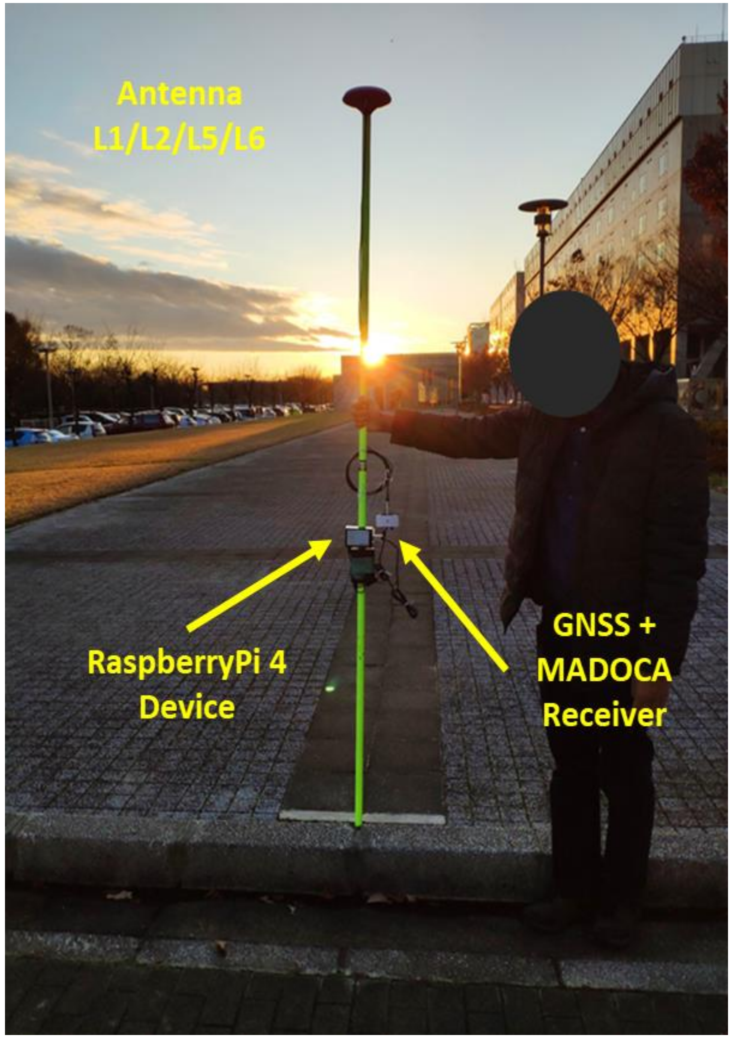


Correction Data:
Satellite Orbit Error of GPS and Other Satellites
Satellite Clock Error of GPS and Other Satellites

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.

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

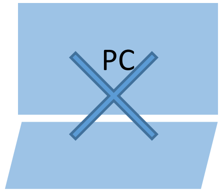
MAD-π

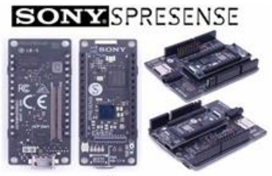
RTKDROID

RTKLIB

MADROID

MAD-WIN

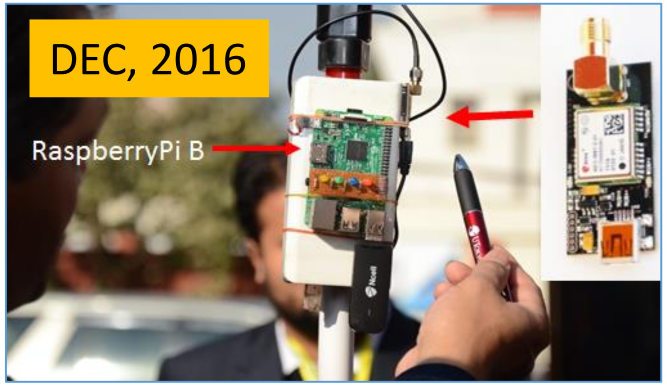




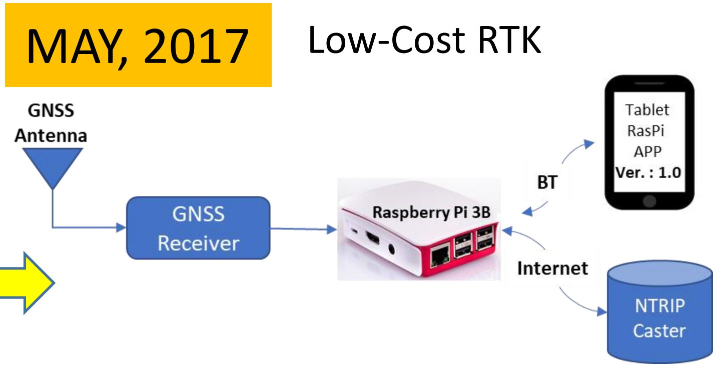
GNSS Equipment for Education and Training

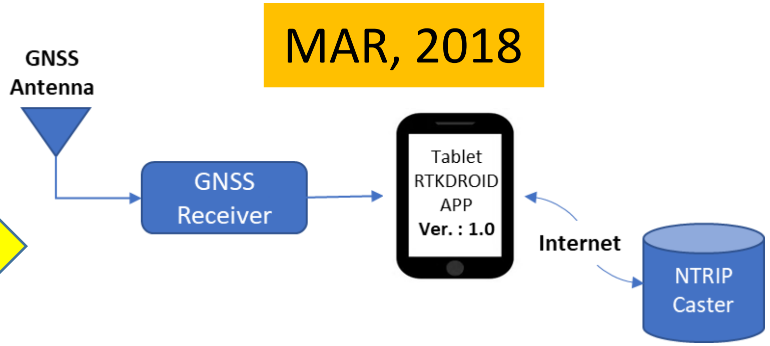
Low-Cost GNSS Receivers are necessary for promotion of GNSS technology to conduct lectures, trainings and pilot projects.
We need low-cost high-accuracy receivers in large quantities.

Low-Cost High-Accuracy Receiver system Development Cycle

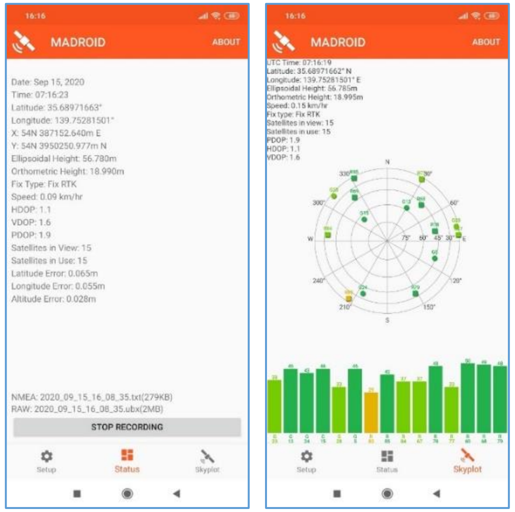


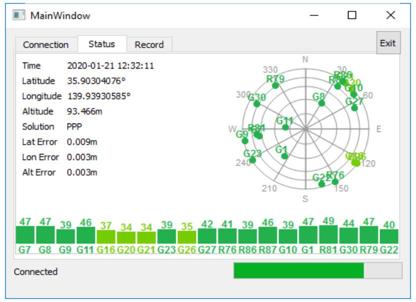
Low-Cost RTK

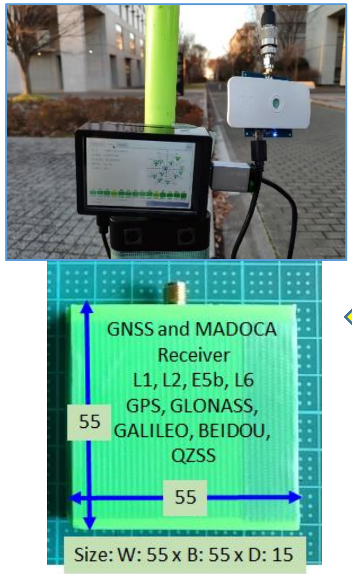




Low-Cost MADOCA







DEC, 2019

Enhancement of MADOCA System 2021

Android Device
RTK / MADOCA / EWS / SAR System
2022

What type of smart-phone will emerge by 2025 ?

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

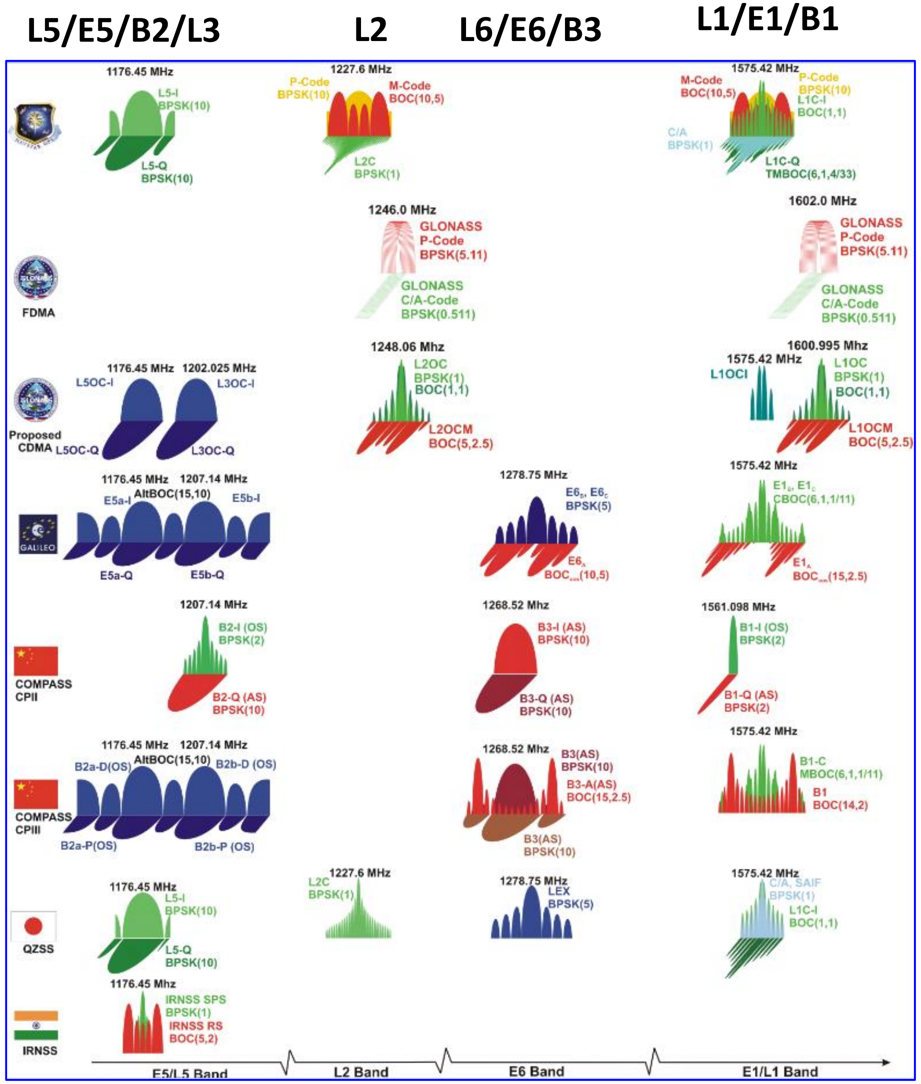
Many Applications require
Low-Cost, Small-Size & Low-Power
Receiver System

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

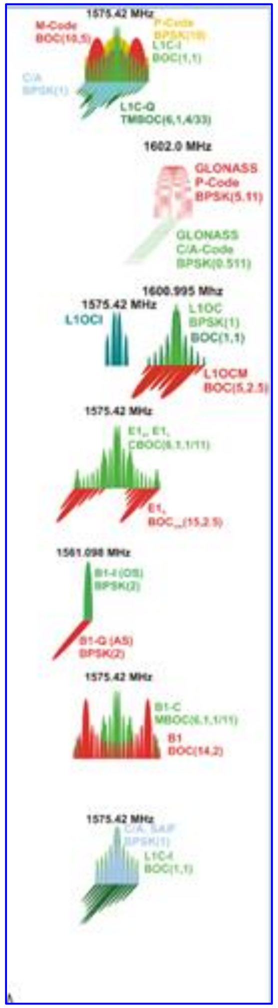
- Multi-frequency
  - GPS : L1/L2/L5
  - GLONASS : L1/L2/L3
  - GALILEO : E1/E5/E6
  - BDS : B1/B2/B3
  - QZSS : L1/L2/L5/L6
  - NAVIC : L5/S
- Multi-system
  - GPS, GLONASS, GALILEO, BeiDou, QZSS, NAVIC, SBAS etc
- Price varies from $1, 000 to $30,000 or more



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-Frequency GNSS Chips for Mass Market
- Low Cost:
  - Less than $300 (Multi-GNSS, L1 Only) including Antenna and all necessary Hardware, Software
    - Our target is within $100 including everything.

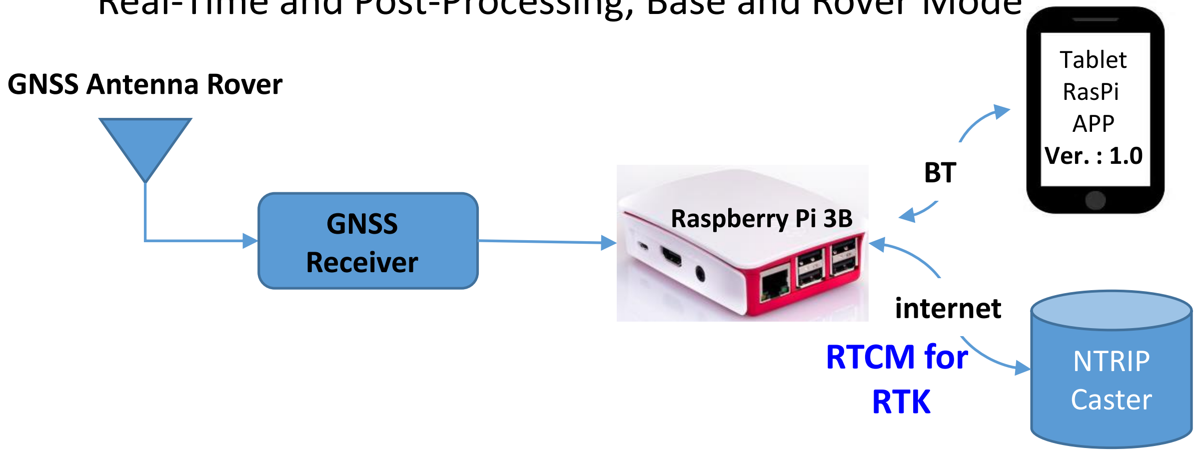
L1/E1/B1*



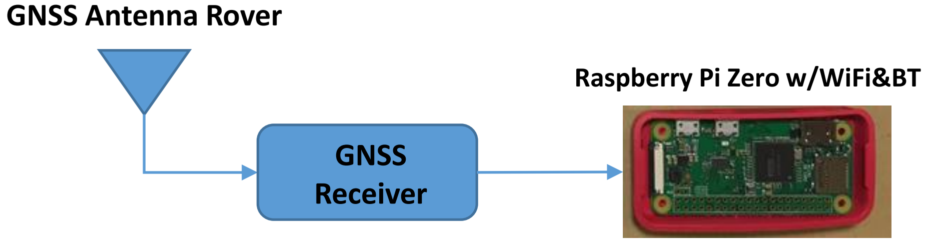
*Note: Only one signal type from each system is processed
e.g. GPS has L1C/A and L1C in L1, ,but only L1C/A is used in Low-Cost Receiver

Low-Cost RTK Receiver System

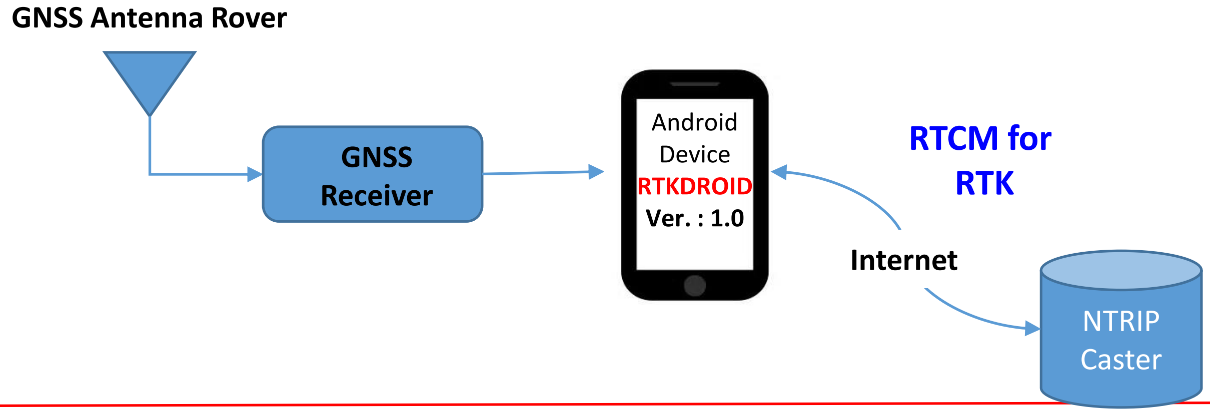
TYPE R1 Type A: Low-Cost, High-Accuracy Receiver System
Real-Time and Post-Processing, Base and Rover Mode



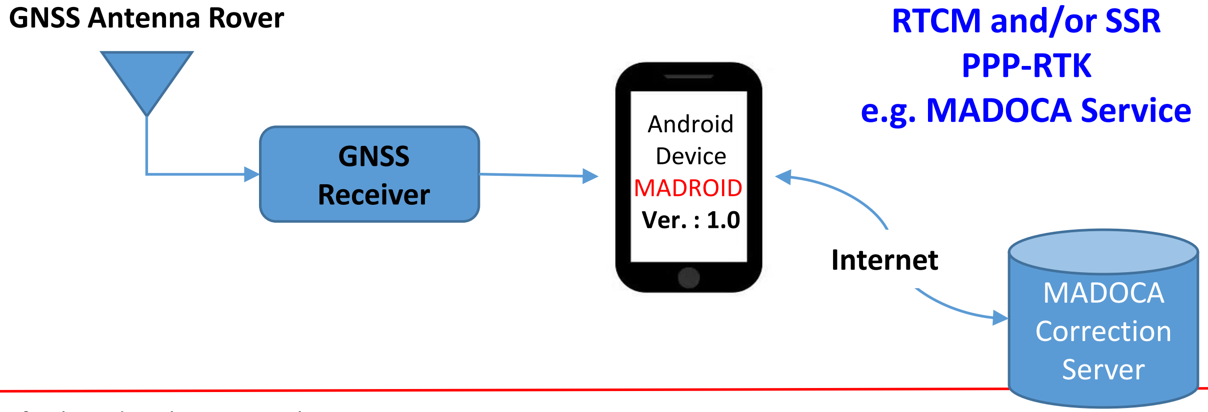
TYPE R2 Type B: Low-Cost, High-Accuracy Receiver System
For Post-Processing & Rover Mode Only



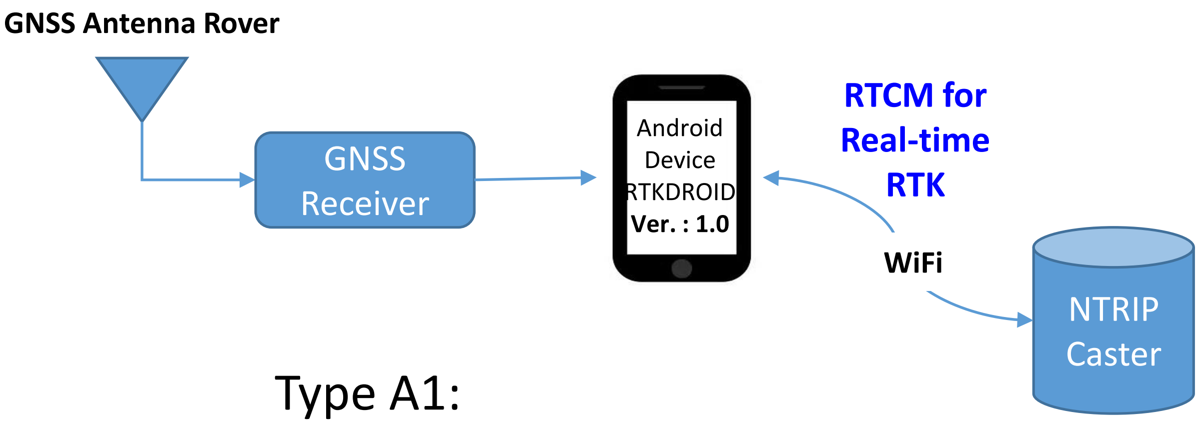
TYPE A1 Type C: Low-Cost, High-Accuracy Receiver System
Real-Time and Post-Processing, Rover Mode Only



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

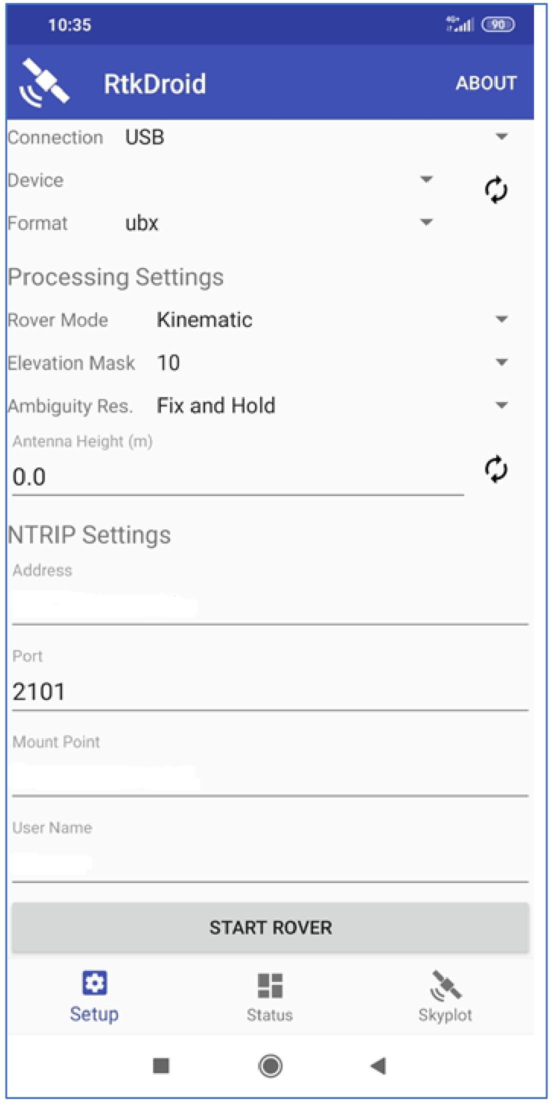
GNSS Receiver Module

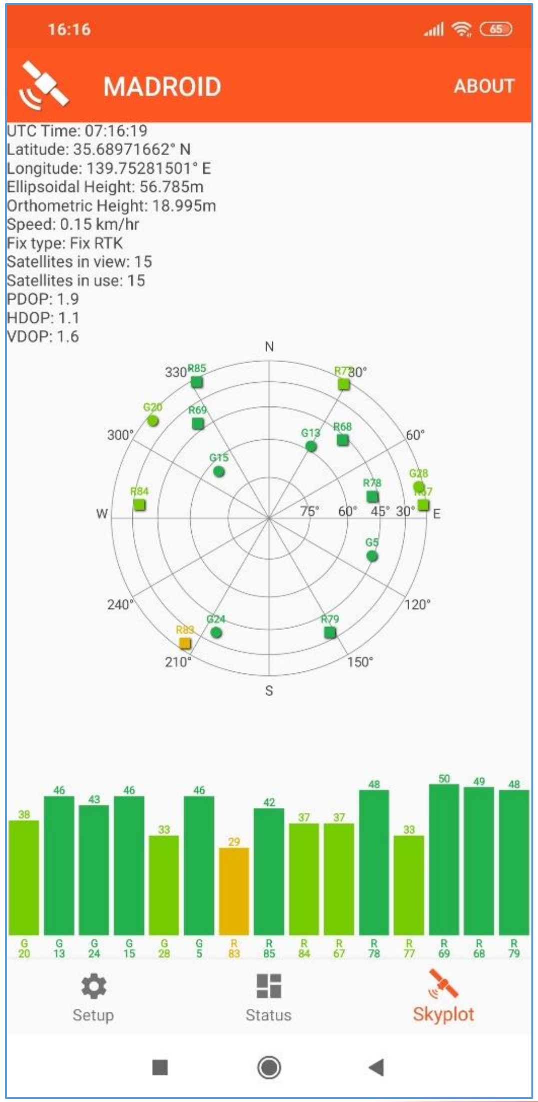
Screen Shots of RTKDROID and MADROID

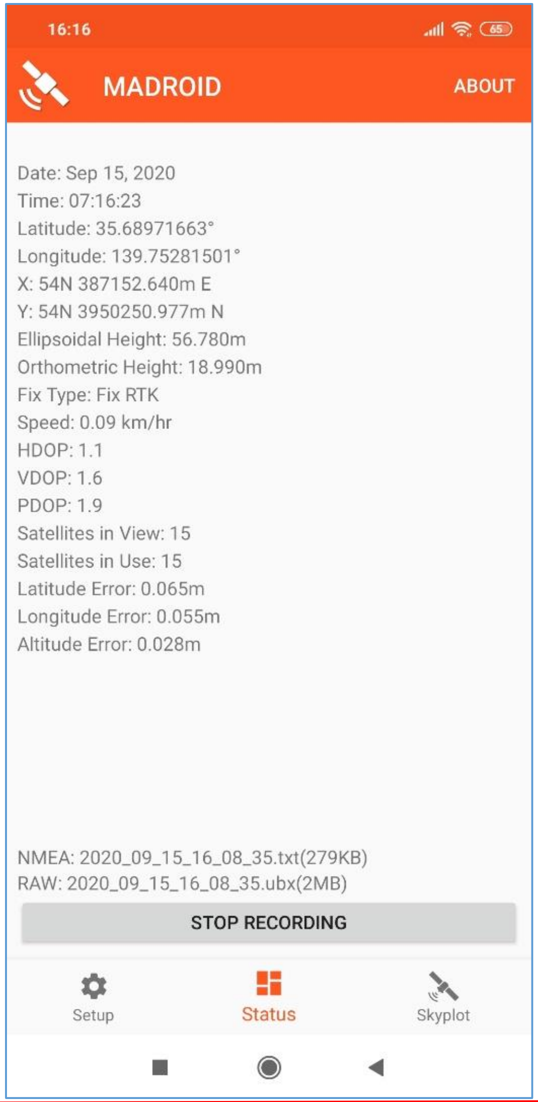
Connect GNSS receiver to Android device

(1) RTKDROID :
For RTK or PPK

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

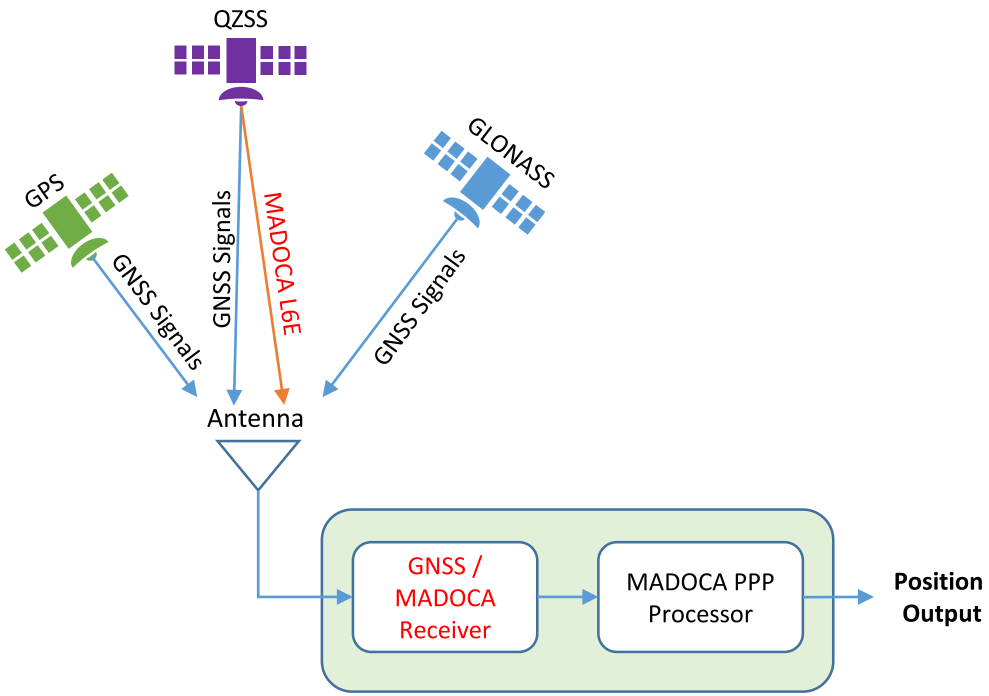




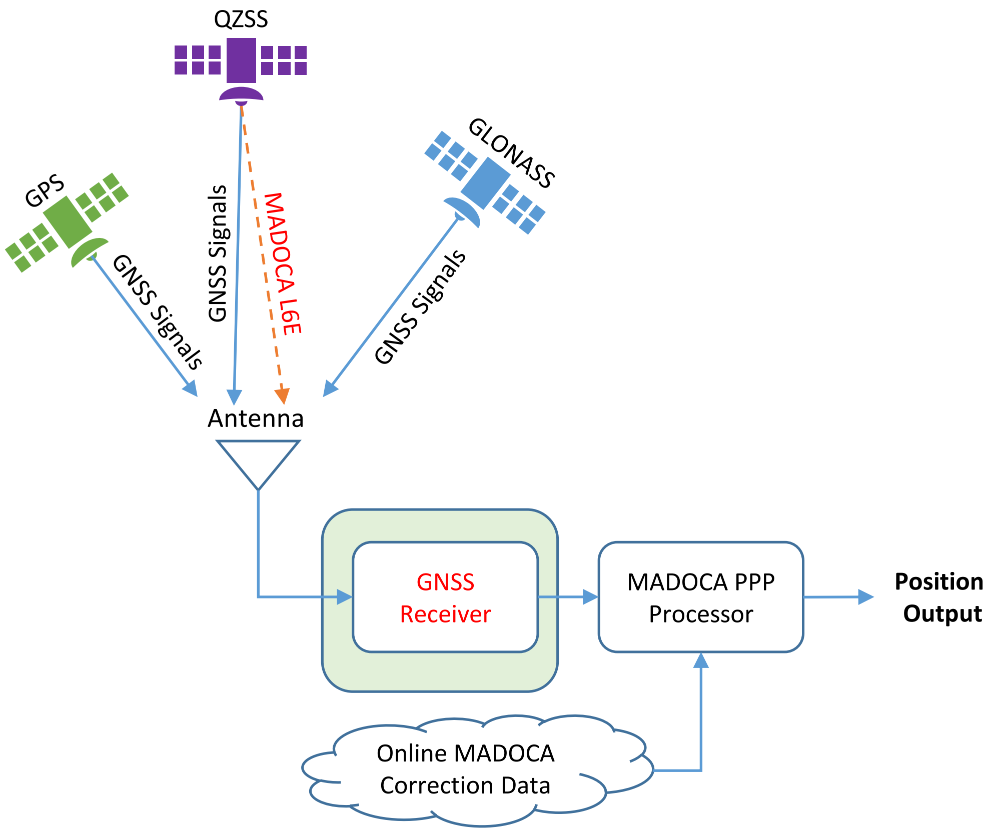


MADOCA System: Direct from QZSS or Online Correction Data

GNSS Receiver + MADOCA Decoder



GNSS Receiver Only



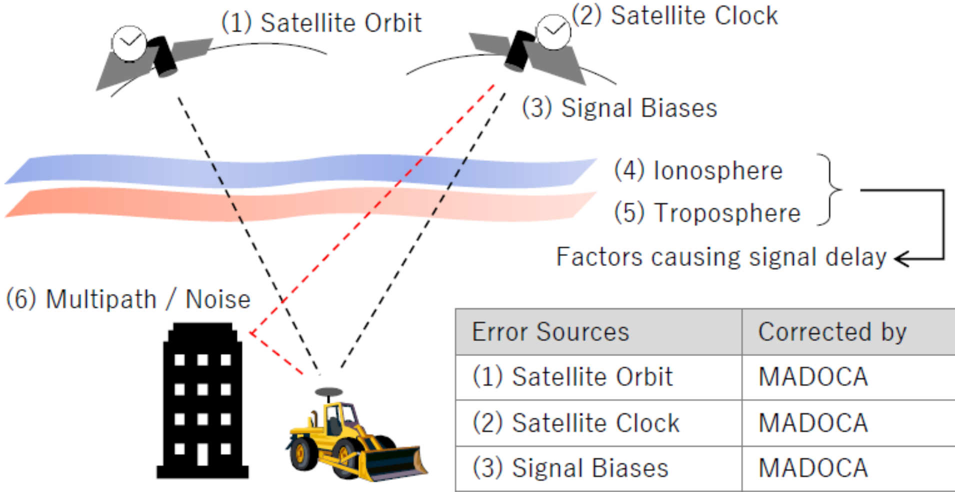
Dinesh Manandhar, CSIS, The University of Tokyo, dinesh@csis.u-tokyo.ac.jp

How does MADOCA Work?

- MADOCA
  - Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis
- Provides an accuracy of 10cm
- MADOCA signal broadcasts the following correction data:
  - Satellite Orbit, Satellite Clock, Signal Biases
- Currently, correction data are broadcasted for GPS, GLOANSS and QZSS satellites

product	Interval	RTCM Message			
	Estimate	Provide	GPS	GLONASS	QZSS
Orbit correction	30	1	1057	1063	1246
Clock correction	1	1	1058	1064	1247
HR-Clock correction	1	1	1062	1068	1251
URA	1	1	1061	1067	1250

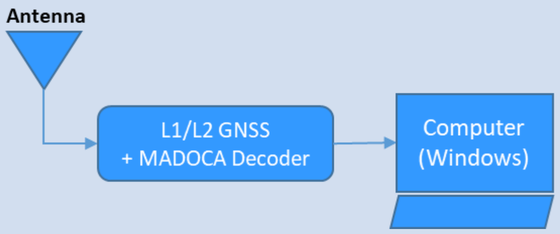
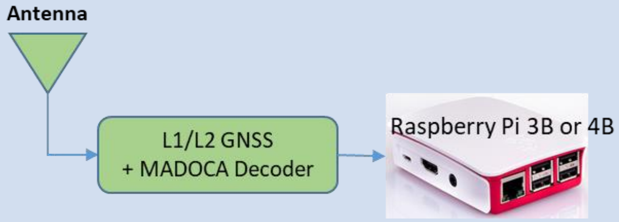
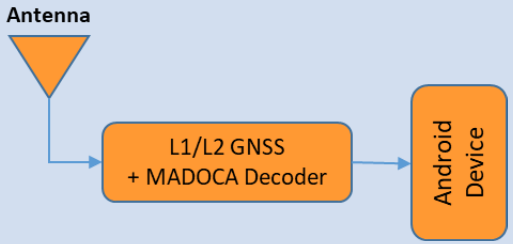
Table Source: https://www.gpas.co.jp/service_madoca.php



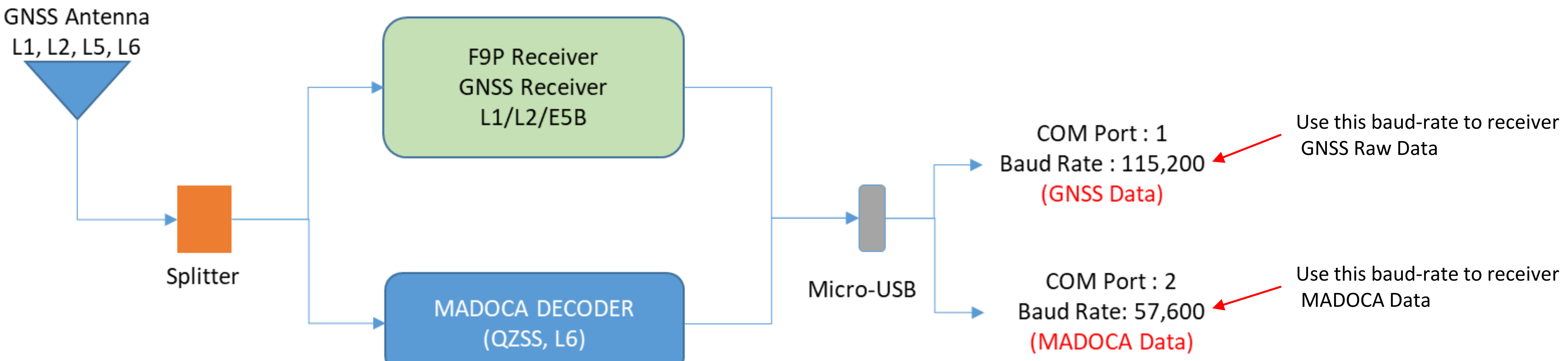
Error Sources	Corrected by
(1) Satellite Orbit	MADOCA
(2) Satellite Clock	MADOCA
(3) Signal Biases	MADOCA
(4) Ionosphere	Positioning Process
(5) Troposphere	Positioning Process
(6) Multipath / Noise	N/A

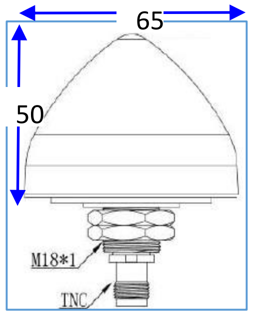
Image from presentation file: Introduction to MADOCA by H. Kakimoto, GPAS Company

Low-Cost MADOCA Receiver Systems: Product Types

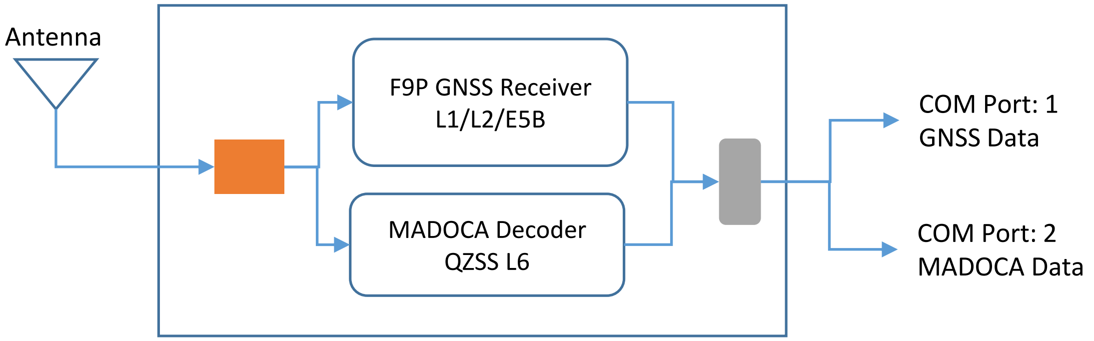
	MAD-WIN	MAD-π	MADROID
Platform / OS	Windows	RaspberryPi 3B or 4B	Android Device
GNSS Receiver	Default : u-blox F9P Other: Any dual-frequency Receiver	Default : u-blox F9P only	Default : u-blox F9P Other: Any dual-frequency Receiver
MADOCA Receiver	U-blox D9 only	U-blox D9 only	NA (MADOCA Online Correction 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			

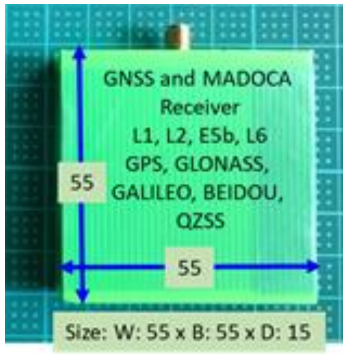
MADOCA PPP Receiver System



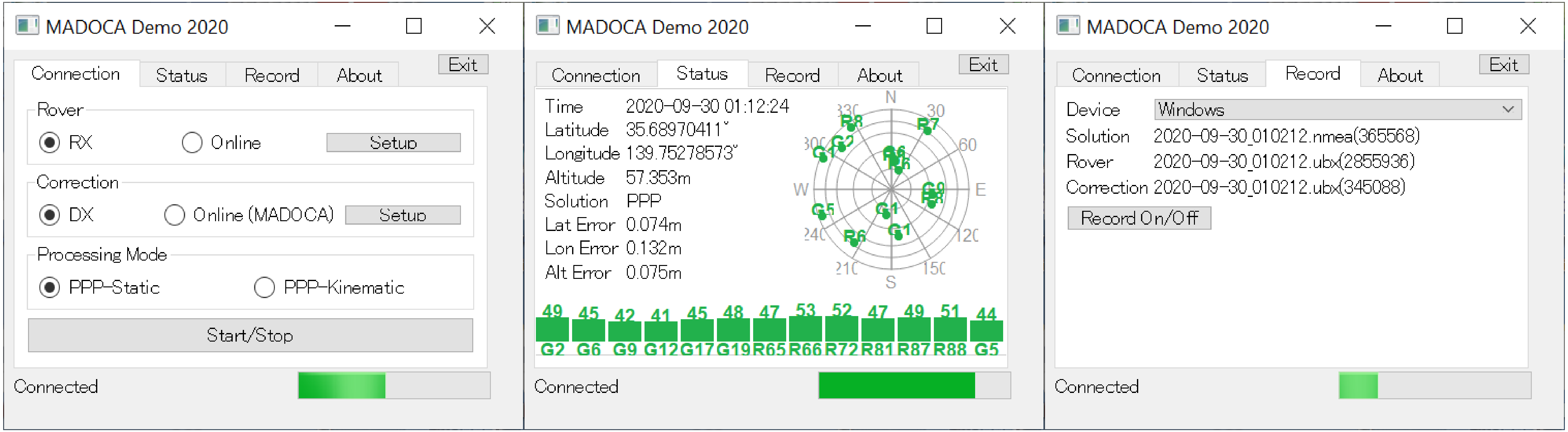


GNSS Antenna





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

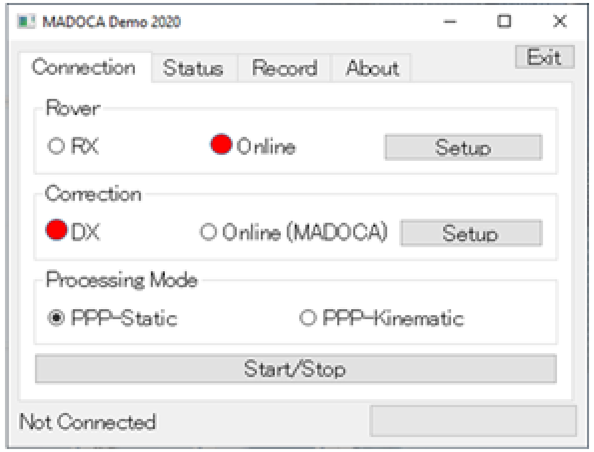
3. Correction: MADOCA PPP Correction Data in receiver's proprietary format

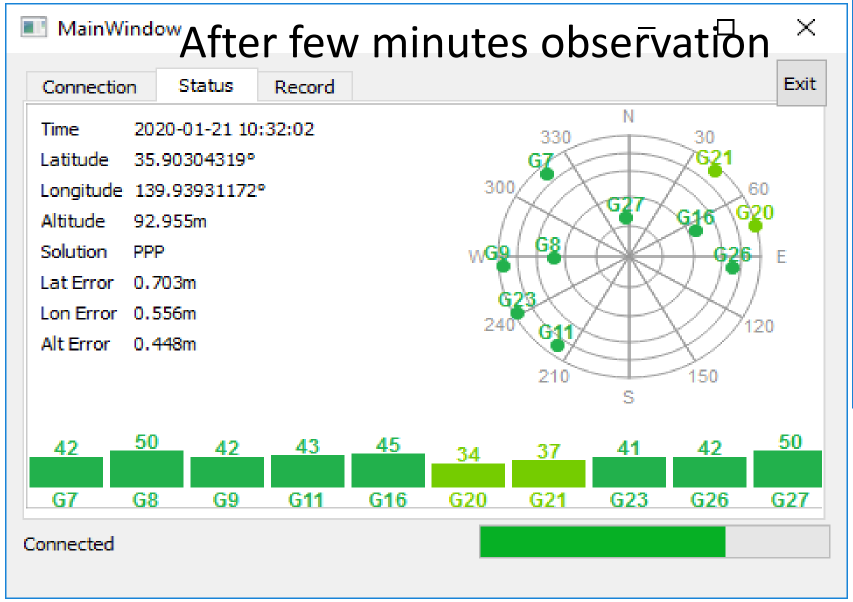
Can be used for Post-Processing MADOCA

Center for Spatial Information Science
The University of Tokyo
東京大学 THE UNIVERSITY OF TOKYO

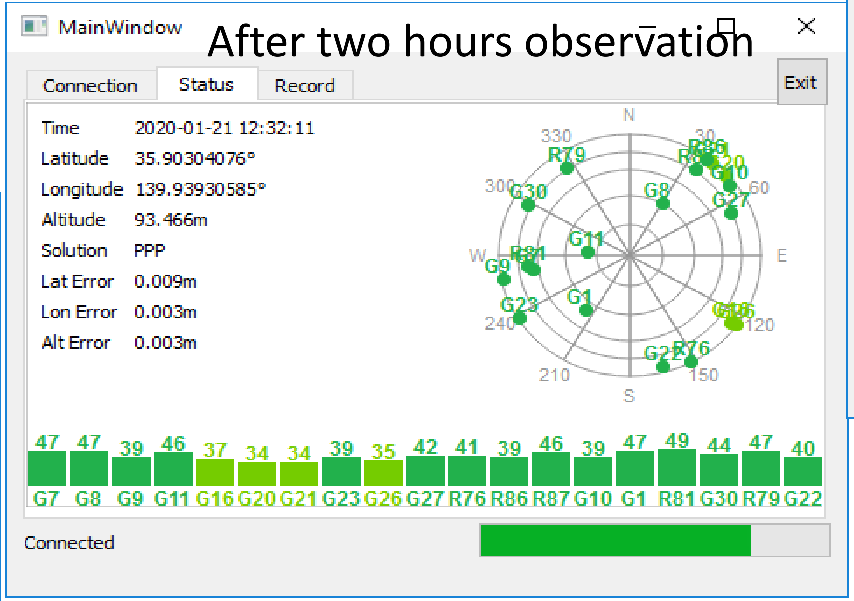
MAD-WIN Data Observation

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

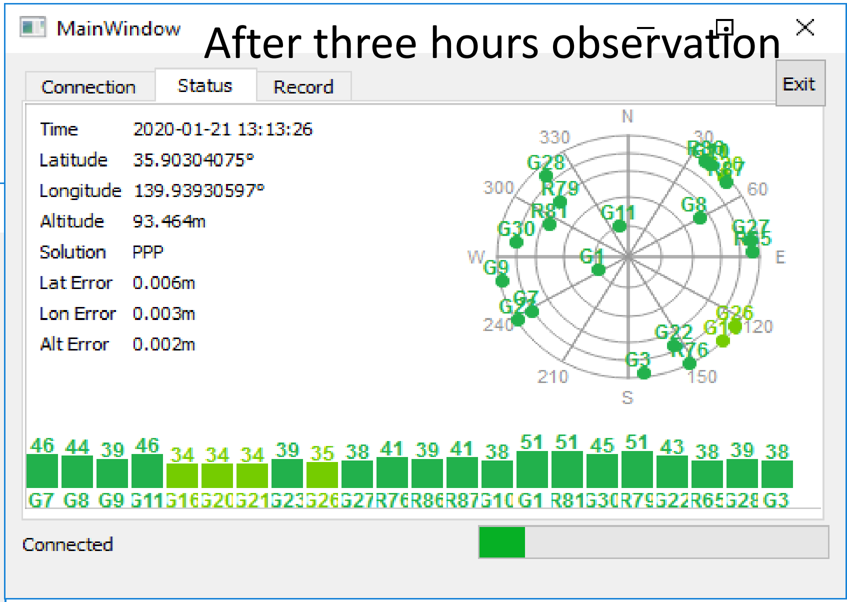




After few minutes observation



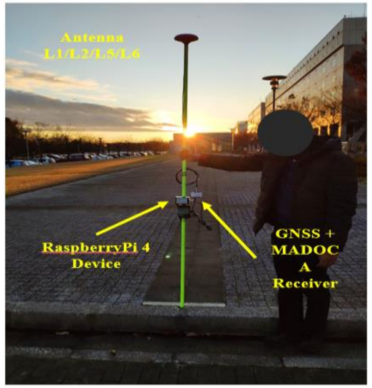
After two hours observation

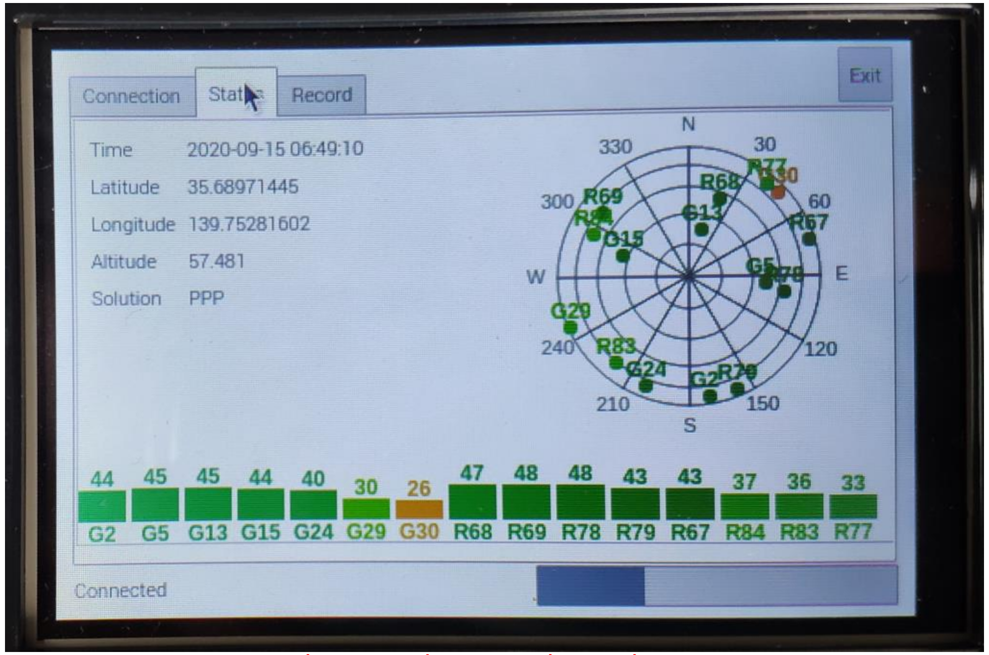


After three hours observation

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



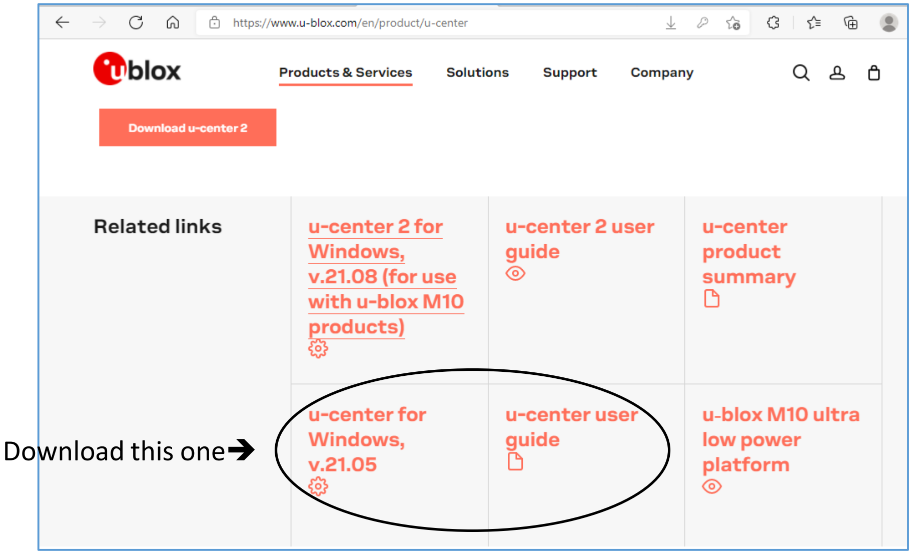


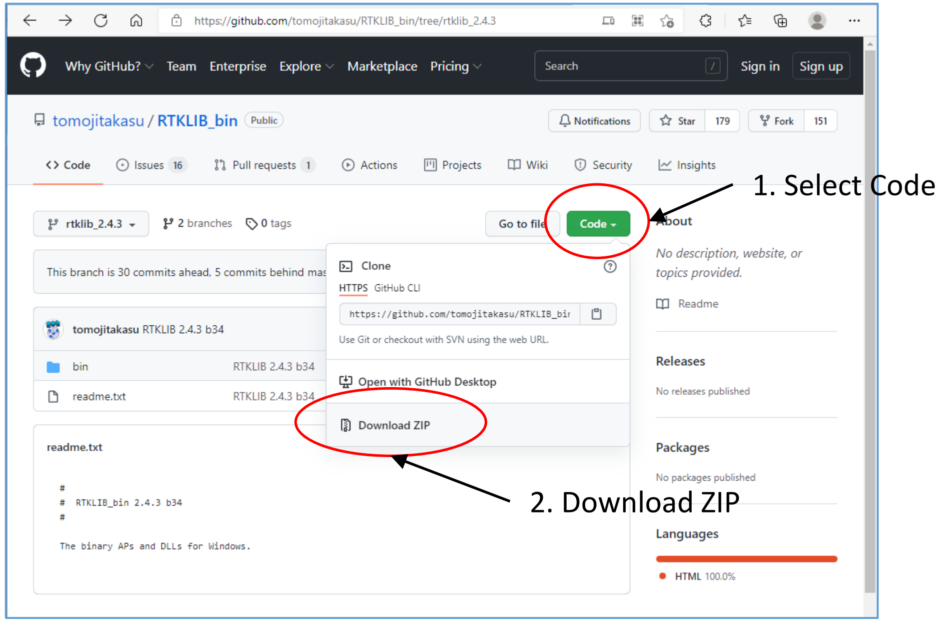
Raspberry-Pi device with Touch Screen

MADOCA Data Processing

GNSS Data Processing Software

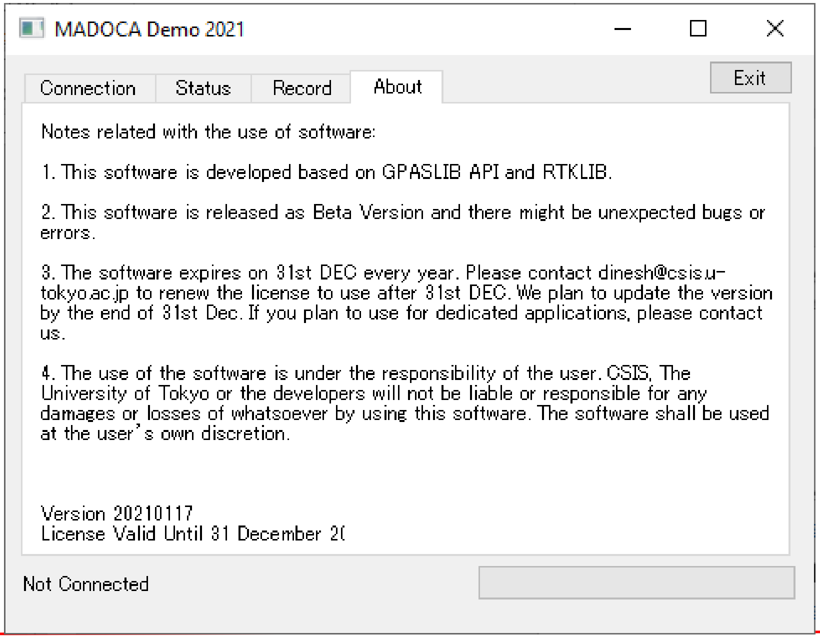
- Software
  - U-center v.21.05
    - Data logging and viewing software from u-blox. Necessary to log and set-up u-blox receivers
    - https://www.u-blox.com/en/product/u-center
    - Also, u-center 2 v.21.08 is available. You may try it, but we use u-center for exercise.
  - RTKLIB
    - RTKLIB is very powerful software for RTK and PPP. It has many functions for data conversion, data logging for RTK, DGPs etc.
    - RTKLIB V. 2.4.3 b34
      - http://www.rtklib.com/
      - https://github.com/tomojitakasu/RTKLIB_bin/tree/rtklib_2.4.3
  - RTKDROID
    - https://home.csis.u-tokyo.ac.jp/~dinesh/LCHAR.htm
    - RTK Software based on RTKLIB for android device.
    - Only for use with u-blox M8T, M8P or F9P receivers connected to an android device
  - MAD-WIN / MAD-PI / MADROID
    - MAD-WIN is for MADOCA-PPP processing for high-accuracy for Windows PC.
    - Google drive link will be provided to download software





Request for HW/SW

- MADOCA Receiver Systems are distributed to overseas universities for joint research and pilot projects
  - Includes HW and SW
  - Signing of MTA (Material Transfer Agreement) Document is necessary for HW
  - If only SW is required, please send request through
    - https://home.csis.u-tokyo.ac.jp/~dinesh/LCHAR.htm
  - SW is provided under the understanding that the recipients provide feedbacks and some sample data
  - Feedbacks are necessary to improve and debug the products



Go To MAIN PAGE

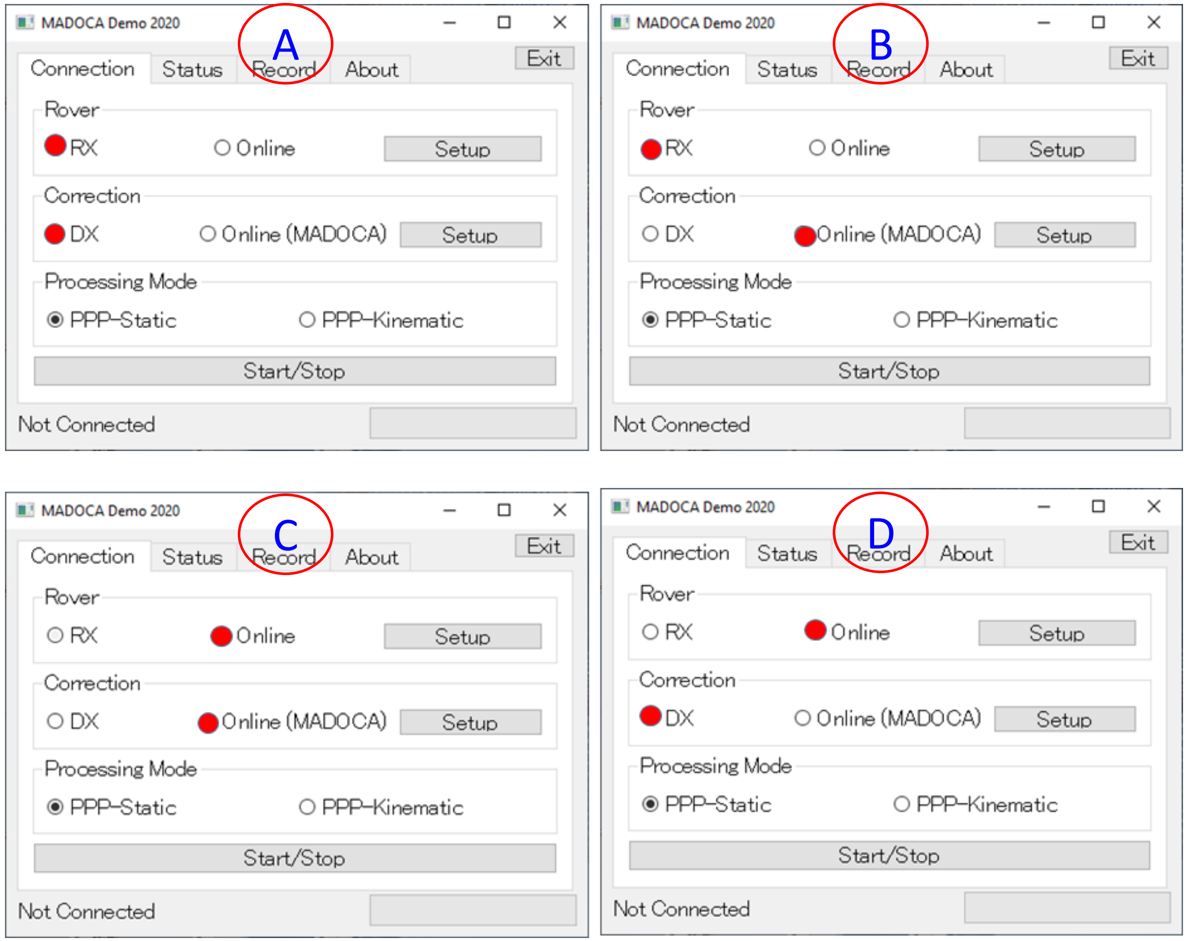
Low-Cost High-Accuracy Receiver Systems

Receiver Systems: Type A, Type B, Type C, Type D

Note: APKs can be downloaded from the following links:
Please send e-mail to dinesh{@}csis.u-tokyo.ac.jp for password.
Following information are necessary:
1. Name
2. Affiliation (Organization Name)
3. Purpose (Optional)

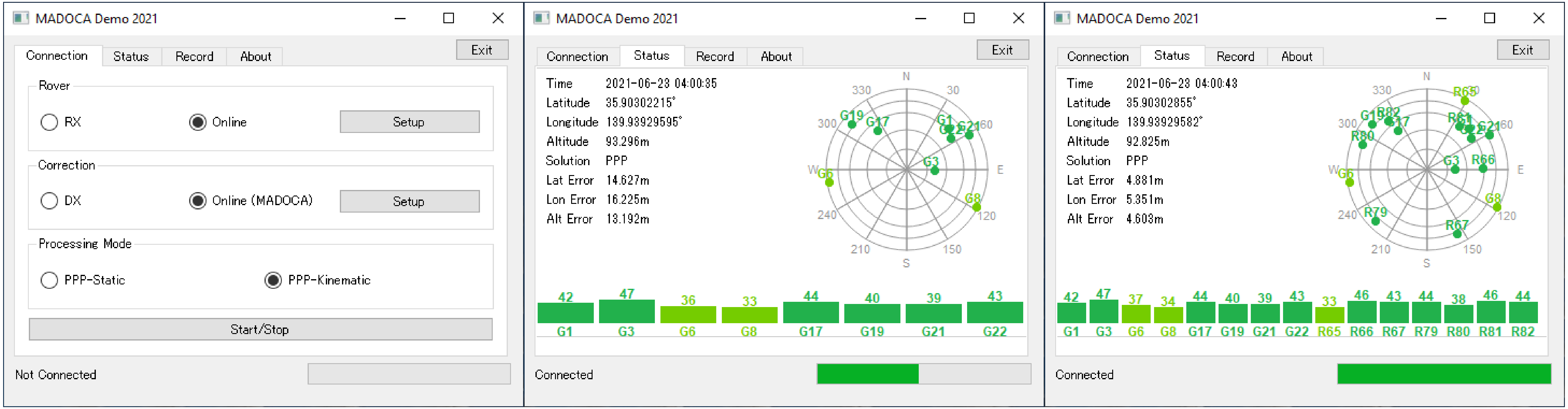
	APK Name	Description
1	RTKDROID (click to download) Register for Password and Updates	**RTK based on RTKLIB 2.4.3** Receiver Type: Single or Dual Frequency Receiver Receiver and Data Compatibility: u-blox: M8T, M8P, F9P in UBX Format Septentrio in SBF Format Other Receivers in RTCM3 Format Connection: (1) USB using OTG cable with Android Device (2) Bluetooth
2	MADROID We will provide software for joint research and pilot projects based on MADOCA. Please contact me if your institute or organization is interested. Register here for MADOCA PPP Software	**PPP with MADOCA Correction Data** Receiver Type: Dual Frequency Receiver Receiver and Data Compatibility: u-blox: F9P in UBX Format Septentrio in SBF Format Other Receivers in RTCM3 Format Connection: USB using OTG cable with Android Device Download Presentation File

MAD-WIN / MAD-PI User Interface

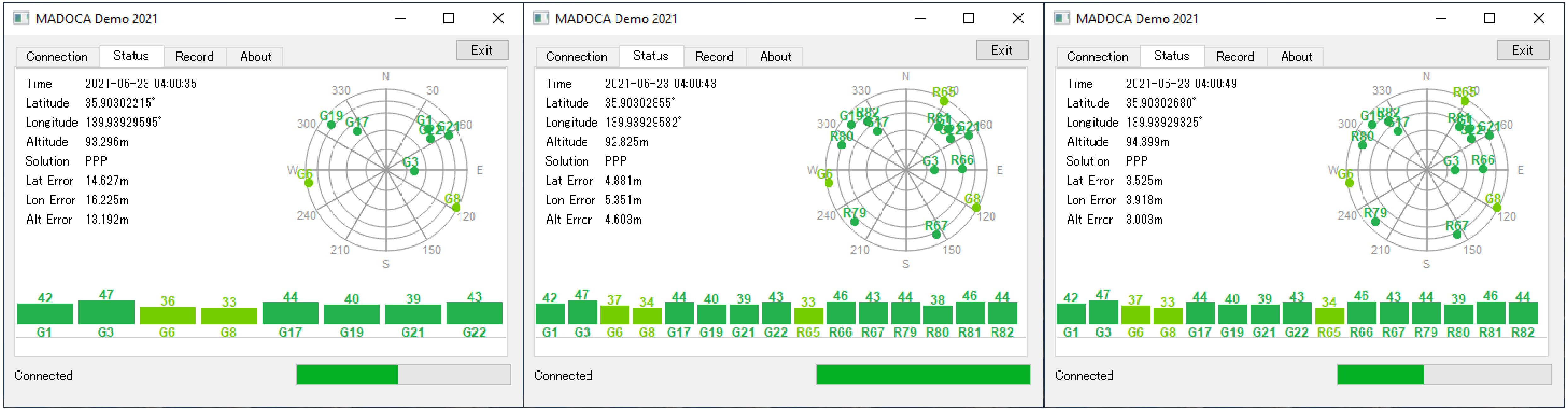


Cases	GNSS Receiver	MADOCA Correction Data	Selection Setting in the Program
Case A	Connect Receiver Directly	Connect MADOCA Receiver Directly	RX and DX
Case B	Connect Receiver Directly	Get MADOCA correction data through NTRIP	RX and Online (MADOCA)
Case C	Connect Receiver though NTRIP	Get MADOCA correction data through NTRIP	Online and Online (MADOCA)
Case D	Connect Receiver though NTRIP	Connect MADOCA Receiver Directly	Online and DX

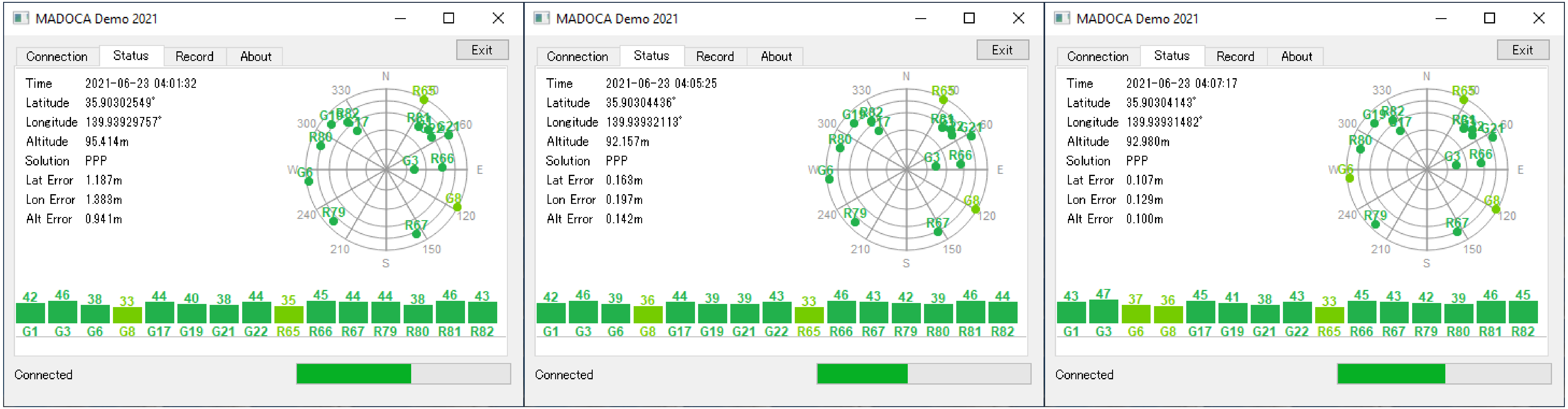
MADOCA PPP Test Results



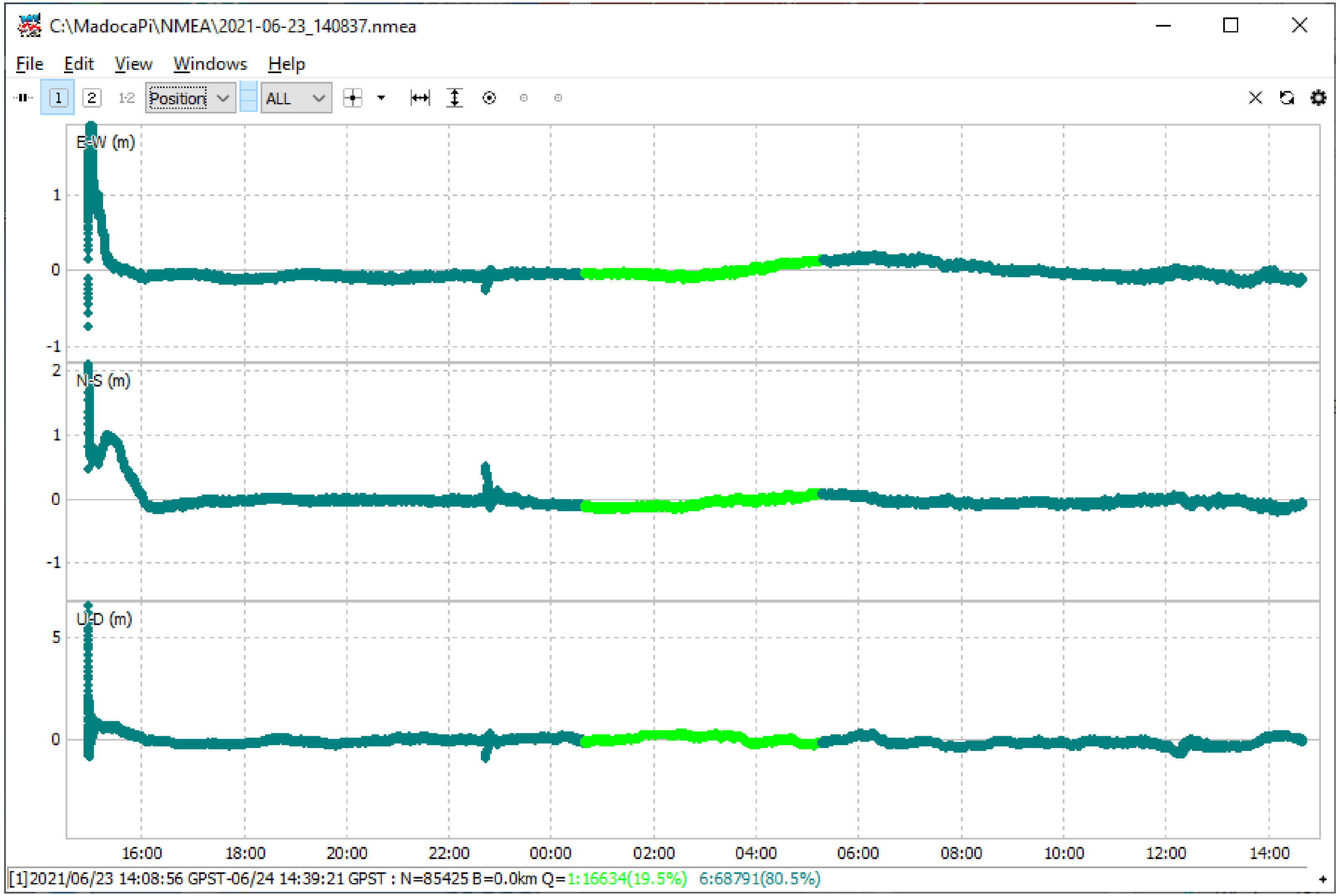
MADOCA PPP Test Results



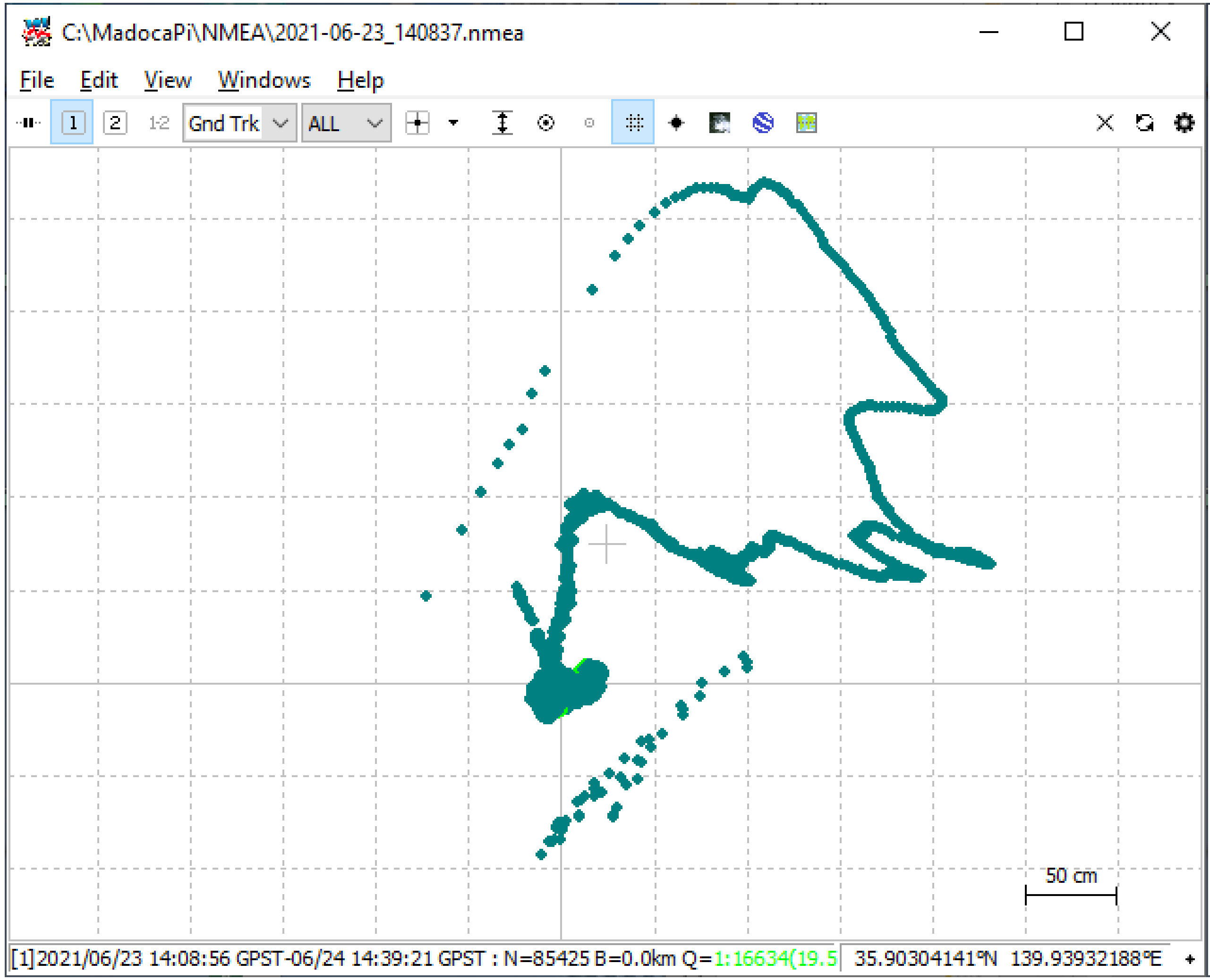
MADOCA PPP Test Results

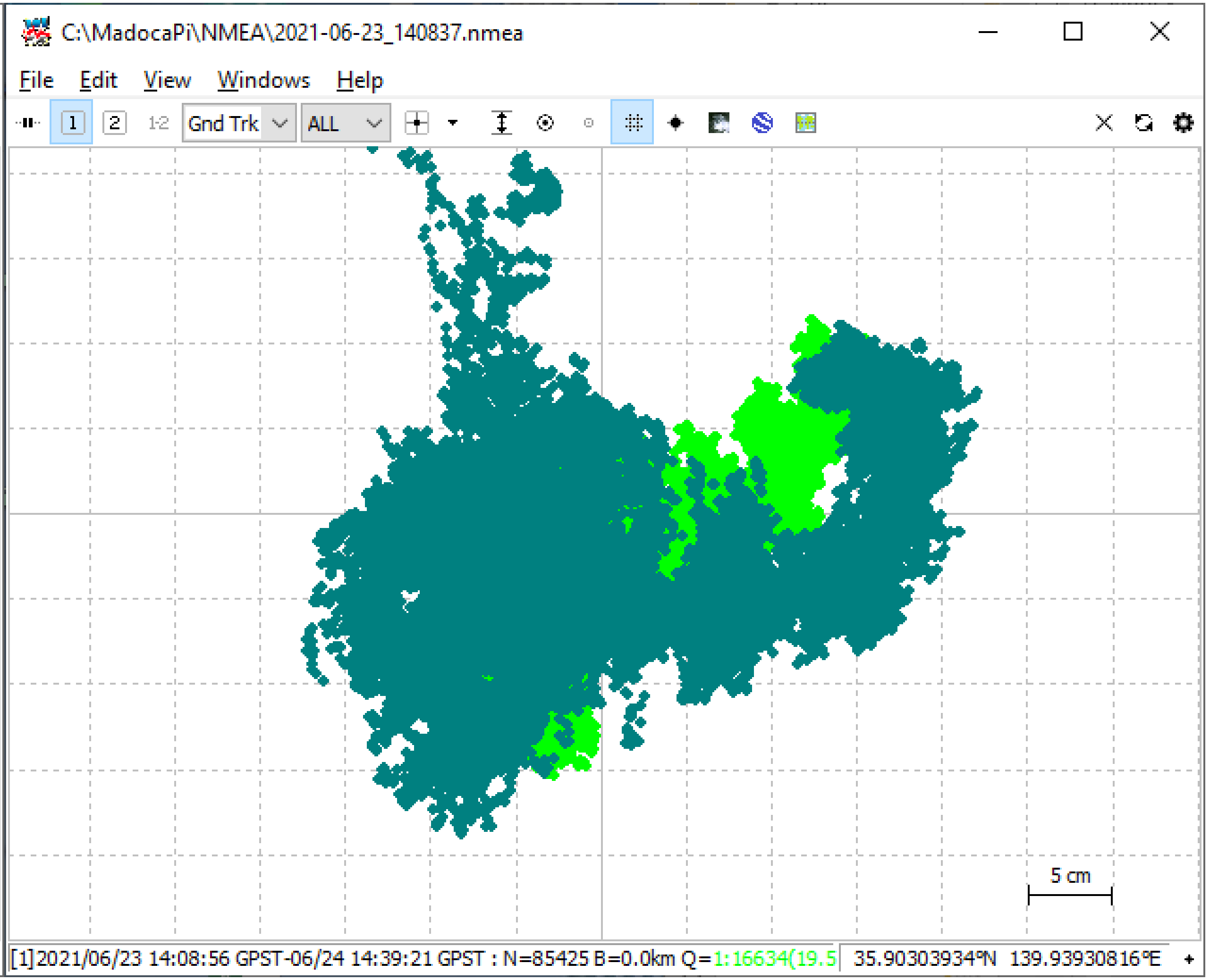


MADOCA PPP Test Results (24 hours)



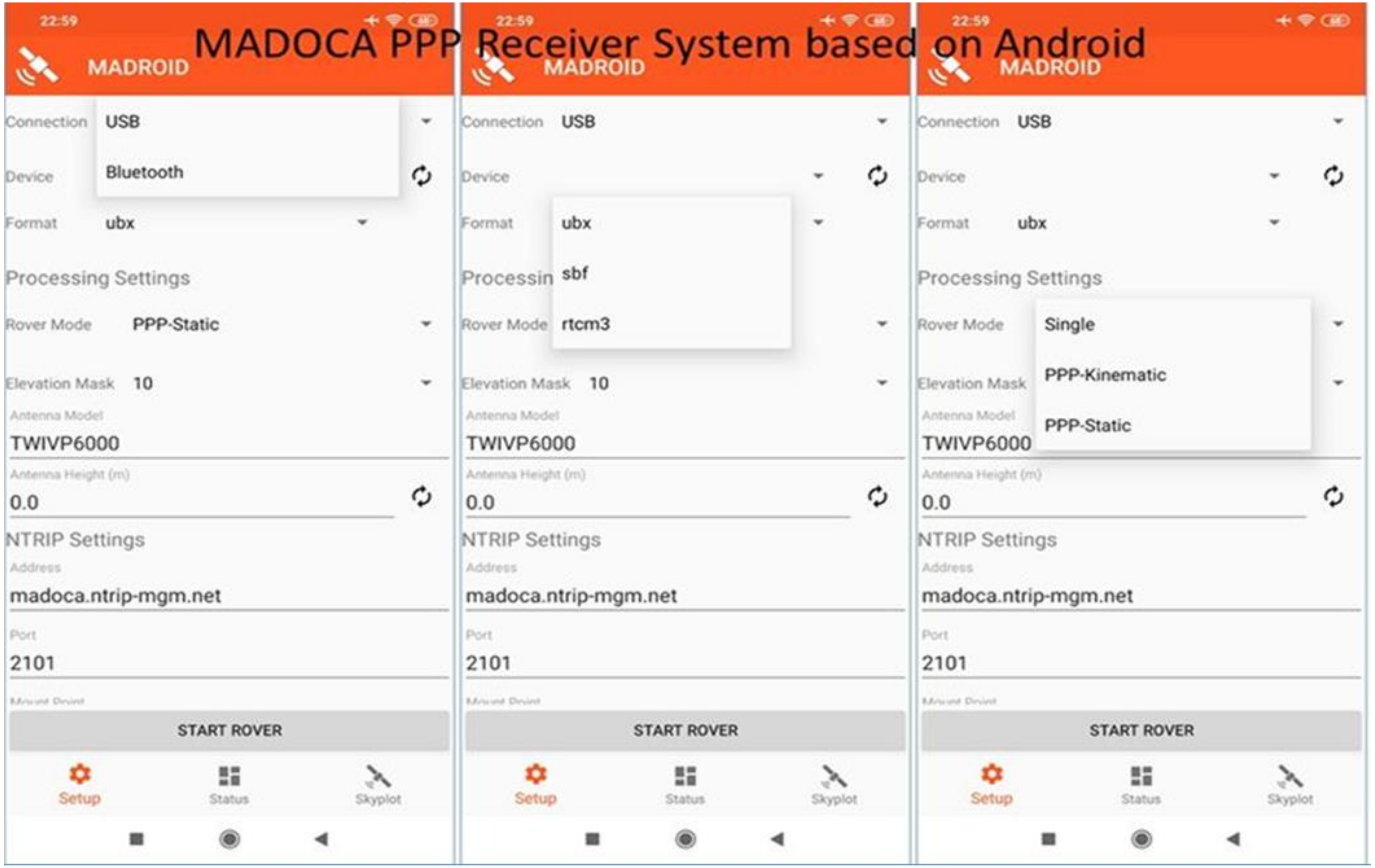
MADOCA PPP Test Results (24 hours)



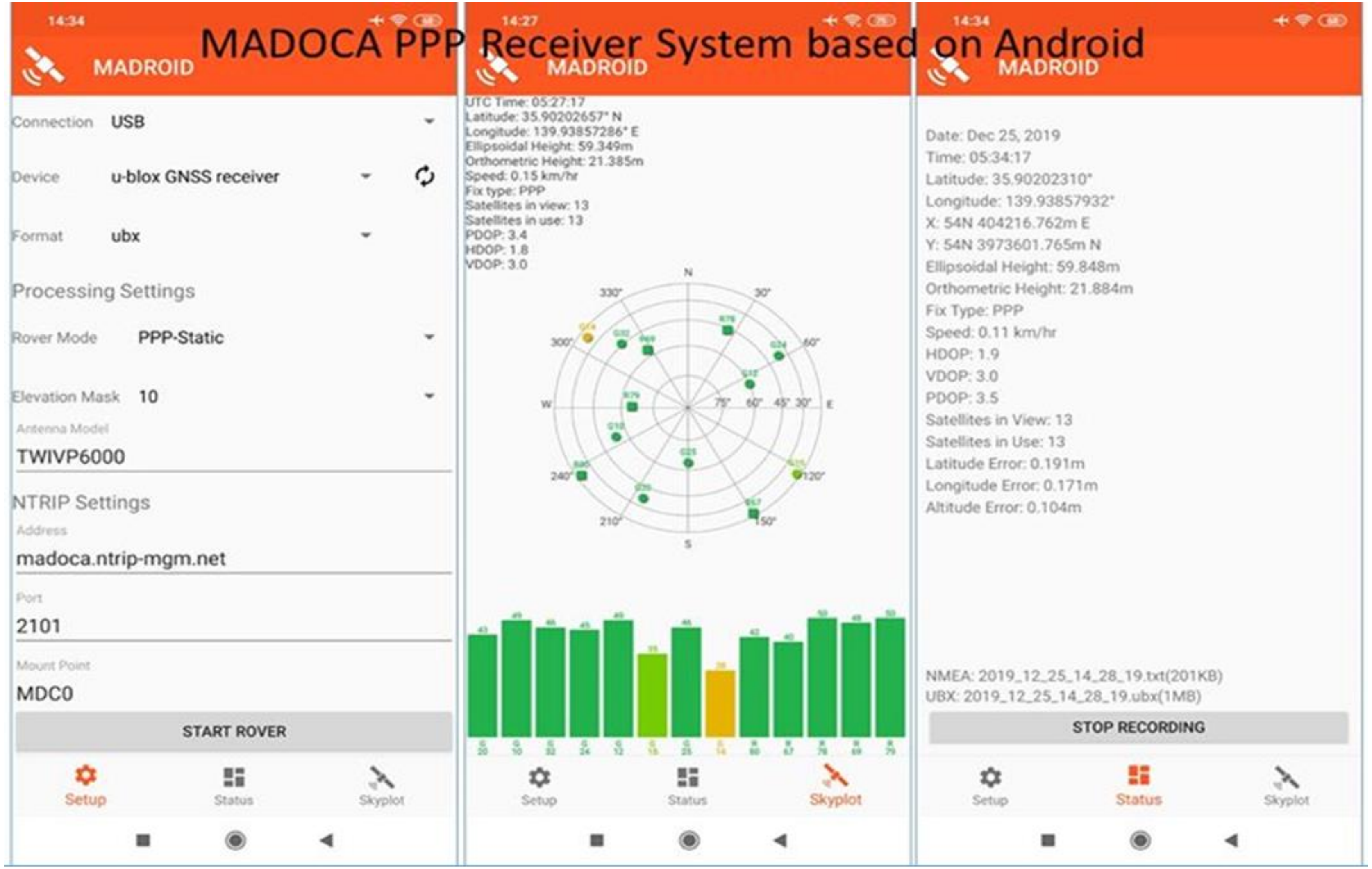


Dinesh Manandhar, CSIS, The University of Tokyo, dinesh@csis.u-tokyo.ac.jp

MADROID: MADOCA with Android Device

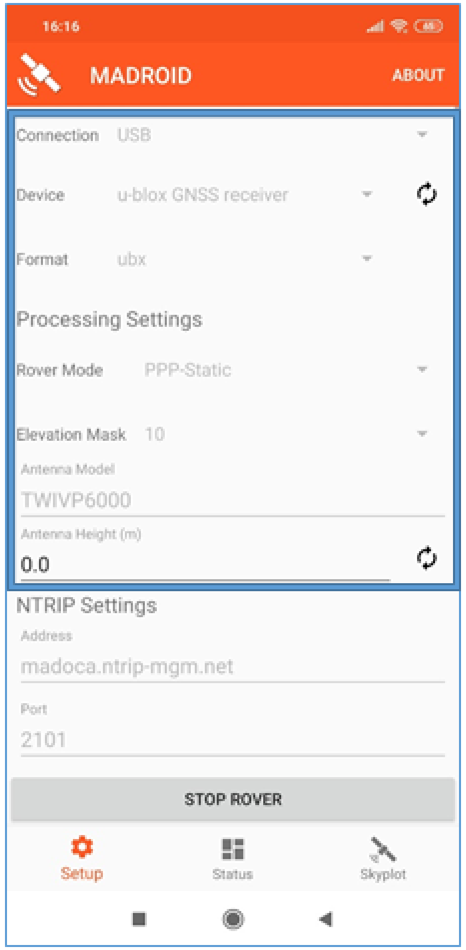


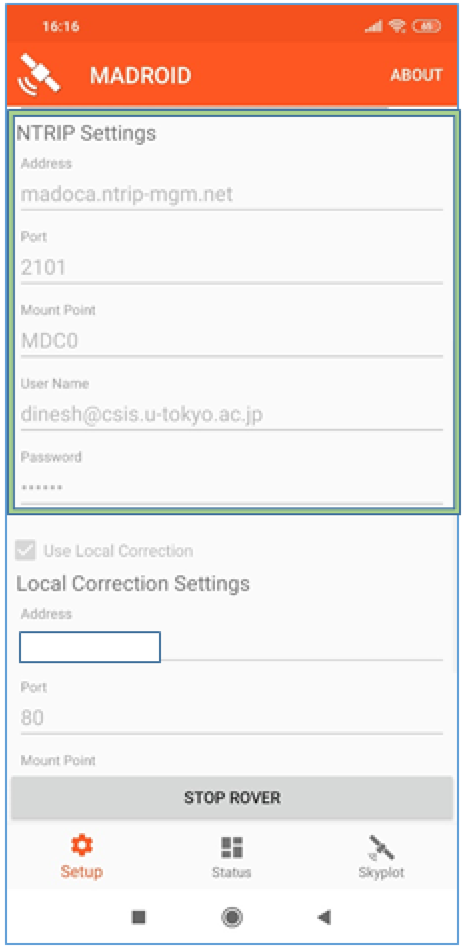
MADROID: MADOCA with Android Device

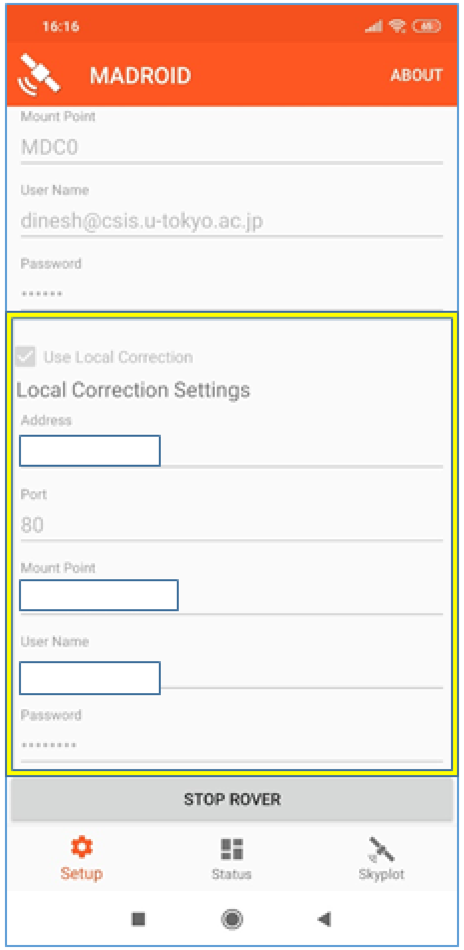


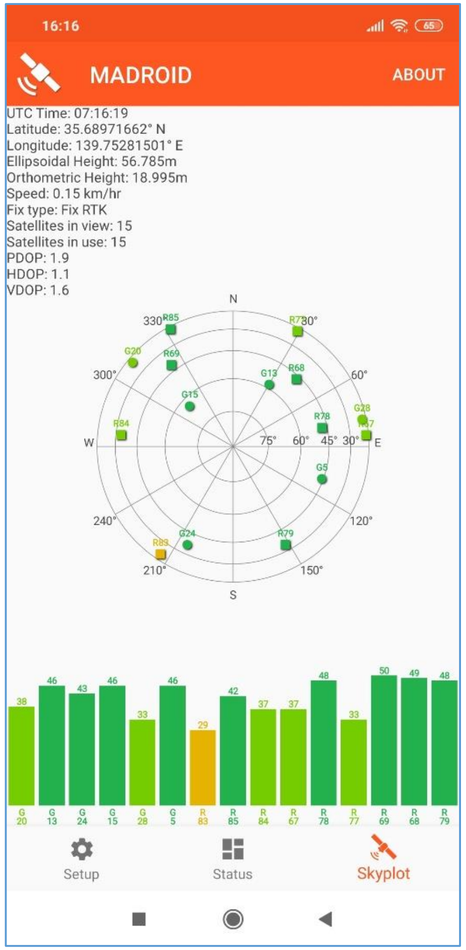
Dinesh Manandhar, CSIS, The University of Tokyo, dinesh@csis.u-tokyo.ac.jp

MADROID: PPP-RTK Test







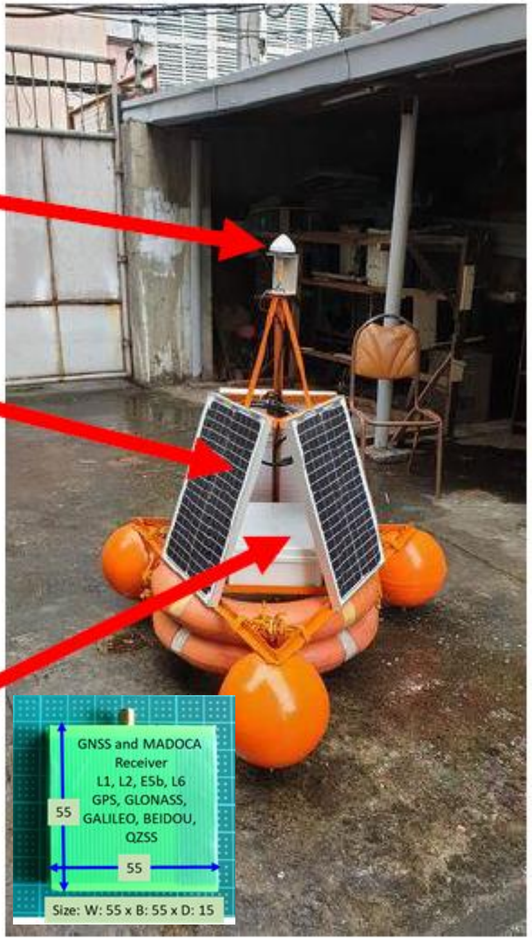


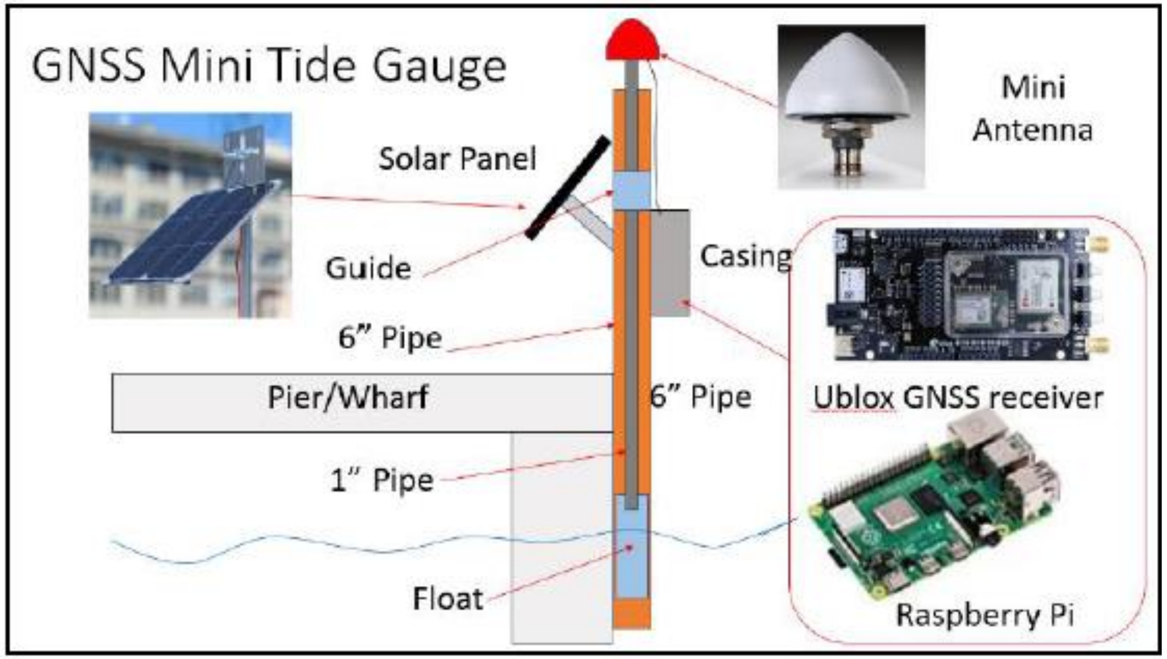
Low-Cost MADOCA Receiver for Sea-Level Rise Measurement

GNSS antenna

Solar power

TiBox enclosure containing the battery, raspberry pi and Ublox and MADOCA decoder





Source: Technical Report, GNSS/QZSS MADOCA PPP Data Acquisition for Sea Level Rise Measurement, DR. ROSALIE B. REYES, UP DGE and Project Leader, CLSR-Phil Project

GNSS Technology Promotion Activities

GNSS Trainings, Workshops and Seminars

- Conduct GNSS Trainings, Workshops and Seminars
  - Basically in Asian countries
    - Indonesia, Laos, Malaysia, Myanmar, Nepal, Thailand, The Philippines, Vietnam
    - Bangladesh, India, Singapore, Sri Lanka, Azerbaijan, Mongolia (planned in 2020 but postponed due to COVID)
  - Also, Some African Countries
    - Mozambique, Rwanda, Egypt
- Regular Training is conducted in January every year with support from ICG/UNOOSA
  - Training in 2018, 2019, 2020, 2021 (Online Only due to COVID)
    - https://home.csis.u-tokyo.ac.jp/~dinesh/GNSS_Train.htm
  - Training in 2022 (Hybrid Format)
    - On-Site training will be held in Pokhara City, Nepal
    - Limited travel funding is available for international participants (Depends on COVID situation)

RPD (Rapid Prototype Development) Challenge

- RPD Challenge is held every year for the past few years in collaboration with MGA, Japan.
- RPD Challenge is a platform to bring your ideas into prototypes.
- Experts in various fields assist you to shape-up your ideas into a working prototype system

PROGRAMME SCHEDULE

	STEP	DATE & TIME (THAI LOCAL TIME)		COURSE OVERVIEW
Online Streaming	LET'S GET STARTED Introduction	Aug-Sept		GNSS101 *GNSS101 lectures on Youtube
WEB BASED Online Workshop	STEP 1 Define scenario	10/2	10:00-18:00	Demo by RPD 2020 Teams Define Scenario / Idea Creation
	STEP 2 System design &project Planning	11/6	14:00-15:40	System Design
		11/20	14:00-15:35	Project Planning
	<ONLINE TECH DAYS>	12/4 12/5 12/18 12/XX	14:00-15:40	Special Lectures by Sony Group, AIS, The University of Tokyo, Advanced Institute of Industrial Technology
	STEP 3&4 Develop Prototype, Demonstration & Awards in Thailand	1/13	14:00-15:40	QZSS Testing
		1/14	14:00-15:30	Trouble shooting
PHYSICAL MEETING		FEB/MAR 1	10:00-17:00	Final Consultation by Experts
		FEB/MAR 2	08:00-16:00	Final Presentation & Demo

MGA RPD CHALLENGE 2021

Summary and Future Plans

- QZSS provides unique services for Early Warning System and High-Accuracy Positioning.
- We have developed Low-Cost MADOCA receiver systems
  - MAD-WIN, MAD-PI and MADROID
  - MAD-PI will be improved for remote data logging.
- We will integration of current system with other systems
  - Traffic monitoring, EWS Application, GIS data collection tool, ……..
- Trainings, Seminars, Workshops and Joint Projects with foreign universities will be conducted
  - Please join our programs for further promotion of the technology in the region
- We share GNSS data from different types of receivers
  - Data from high-end survey grade receivers to low-cost receivers are available upon request

Refer https://home.csis.u-tokyo.ac.jp/~dinesh/ for more information.