Introduction to GNSS
(Global Navigation Satellite System)

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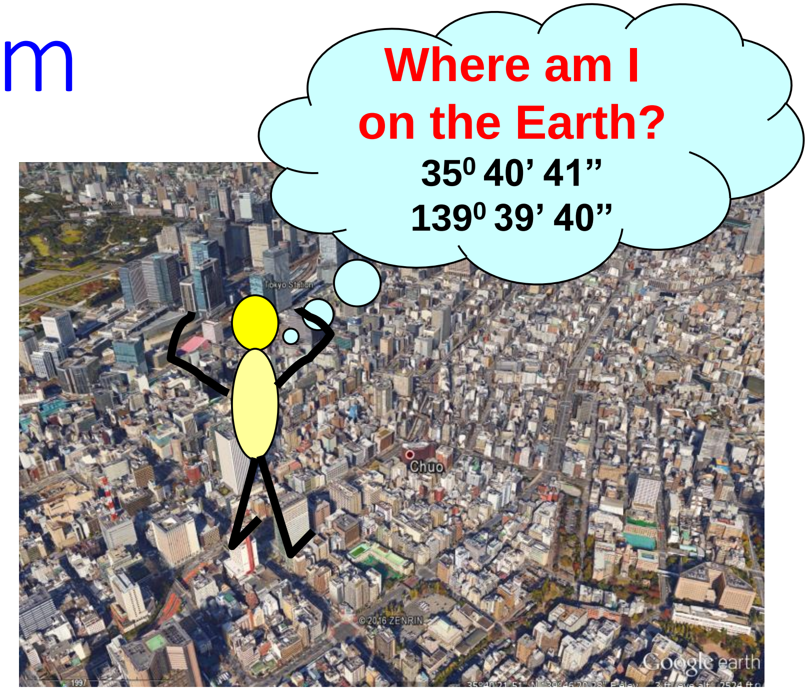
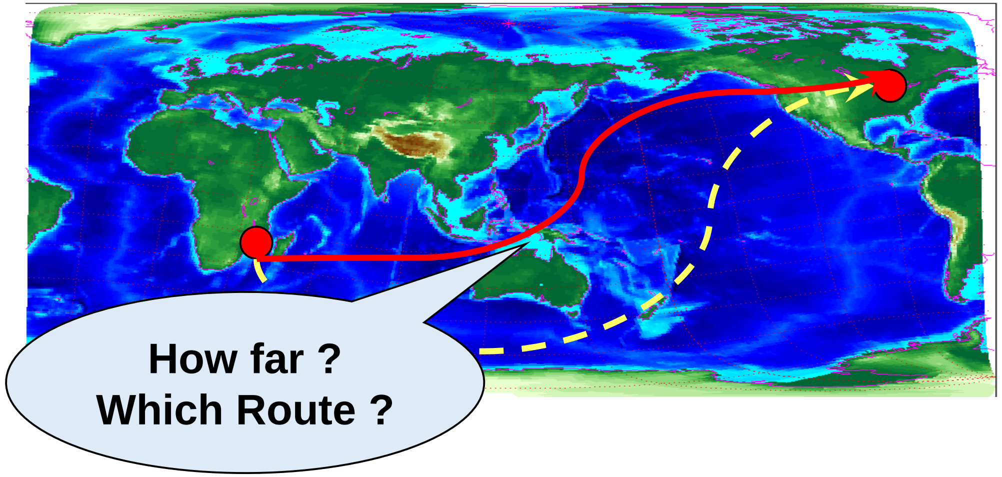
Part - A

Fundamental Problem

- How to know my location precisely ?
  - In any condition
  - At any time
  - Everywhere on earth (at least outdoors!)
- How to navigate to the destination?
  - Guidance or Navigation
- How to synchronize time globally?
  - Mobile phones
  - Financial Institutes





Navigation Types

- Landmark-based Navigation
  - Stones, Trees, Monuments
    - Limited Local use
- Celestial-based Navigation
  - Stars, Moon
    - Complicated, Works only at Clear Night
- Sensors-based Navigation
  - Dead Reckoning
    - Gyroscope, Accelerometer, Compass, Odometer
    - Complicated, Errors accumulate quickly
- Radio-based Navigation
  - LORAN, OMEGA
    - Subject to Radio Interference, Jamming, Limited Coverage
- Satellite-based Navigation or GNSS
  - TRANSIT, GPS, GLONASS, GALILEO, QZSS, BEIDOU (COMPASS), IRNSS
    - Global, Difficult to Interfere or Jam, High Accuracy & Reliability

What is GNSS?

Global Navigation Satellite System (GNSS) is the standard generic term for all navigation satellites systems like GPS, GLONASS, GALILEO, BeiDou, QZSS, NAVIC.

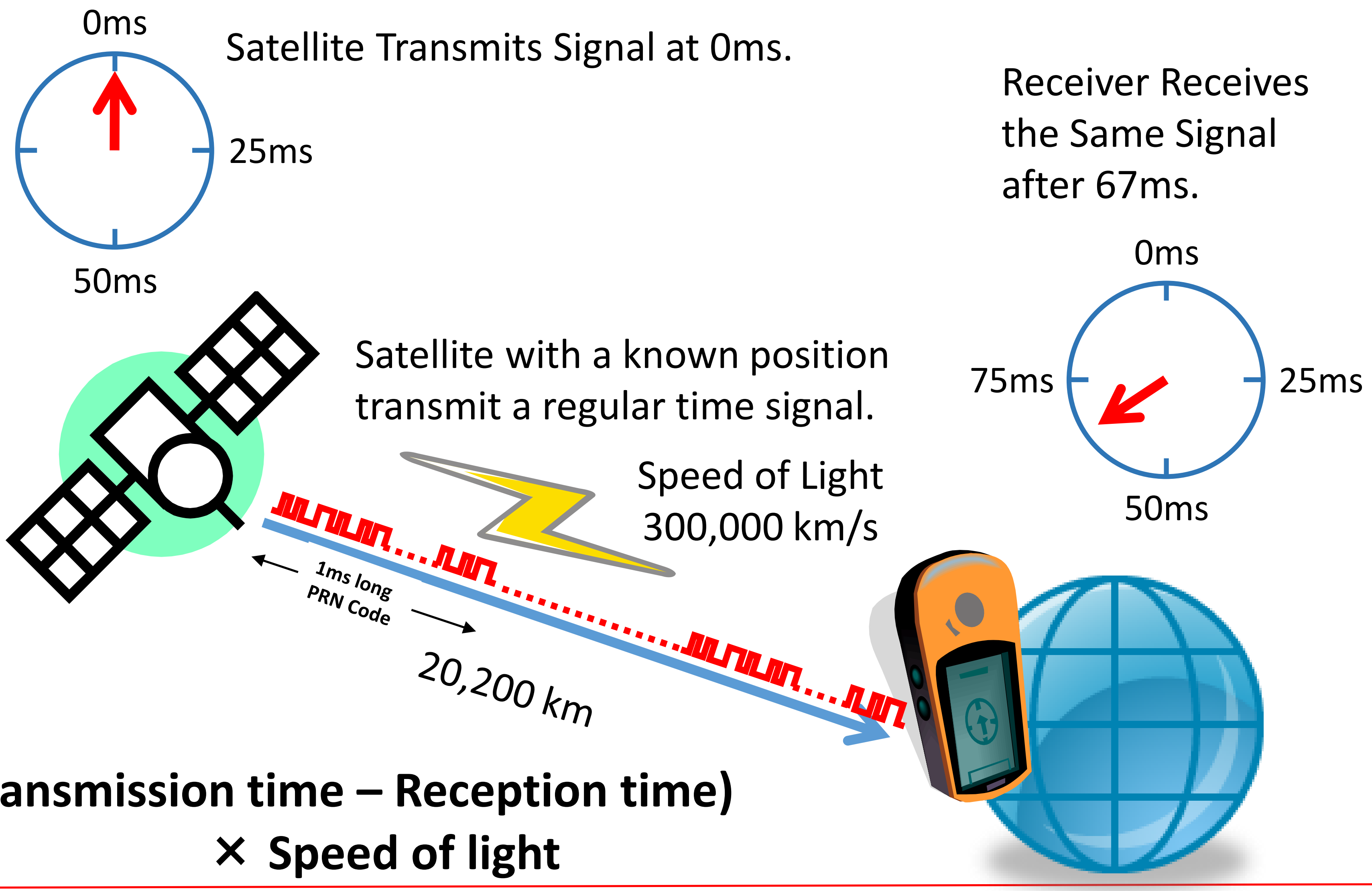
- Global Constellation
  - GPS USA
  - GLONASS, Russia
  - Galileo, Europe
  - BeiDou (COMPASS) / BDS, China
- Regional Constellation
  - QZSS, Japan
  - NAVIC (IRNSS), India

Satellite Based Augmentation System (SBAS)

- Satellite Based Augmentation System (SBAS) are used to augment GNSS Data
  - Provide Higher Accuracy and Integrity
  - Correction data for satellite orbit errors, satellite clock errors, atmospheric correction data and satellite health status are broadcasted from satellites
- SBAS Service Providers
  - WAAS, USA (131,133,135,138)
  - MSAS, Japan (129,137)
  - EGNOS, Europe (120,121,123,124,126,136)
  - BDSBAS, China (130,143,144)
  - GAGAN, India (127,128,132)
  - SDCM, Russia (125,140,141)
  - KASS, Korea (134), Also Navigation System
  - AUS-NZ, Australia (122)
  - NSAS, Nigeria, (147)
  - ASAL, Algeria (148)

PRN code numbers are given in the bracket

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



Satellite Transmits Signal at 0ms.

Receiver Receives
the Same Signal
after 67ms.

Satellite with a known position
transmit a regular time signal.

Speed of Light
300,000 km/s

Distance = (Transmission time – Reception time)
× Speed of light

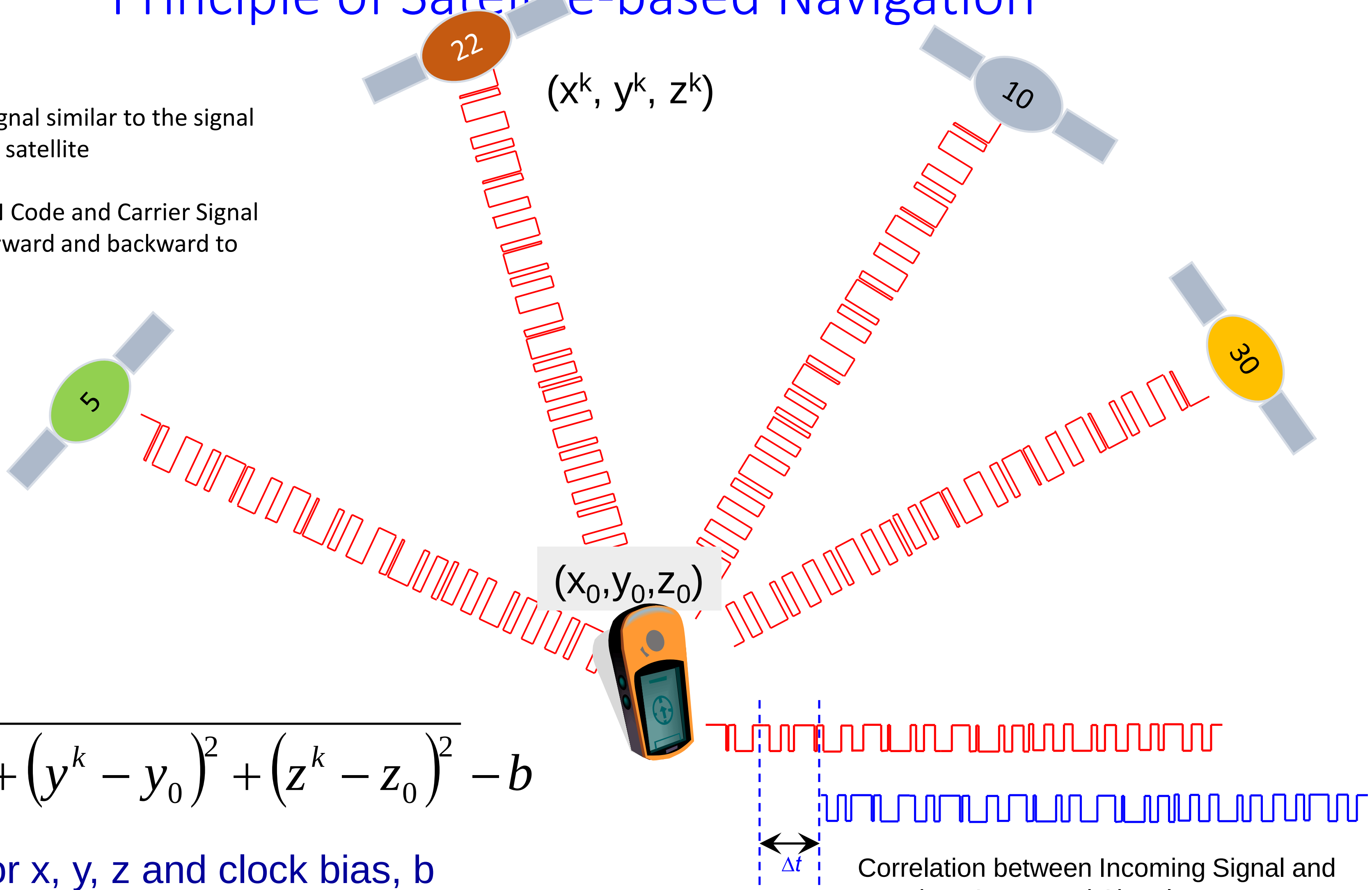
GNSS: How does it work?
Principle of Satellite-based Navigation

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



Correlation between Incoming Signal and Receiver Generated Signal

$$\rho^k = \sqrt{(x^k - x_0)^2 + (y^k - y_0)^2 + (z^k - z_0)^2} - b$$

If k ≥ 4, solve for x, y, z and clock bias, b

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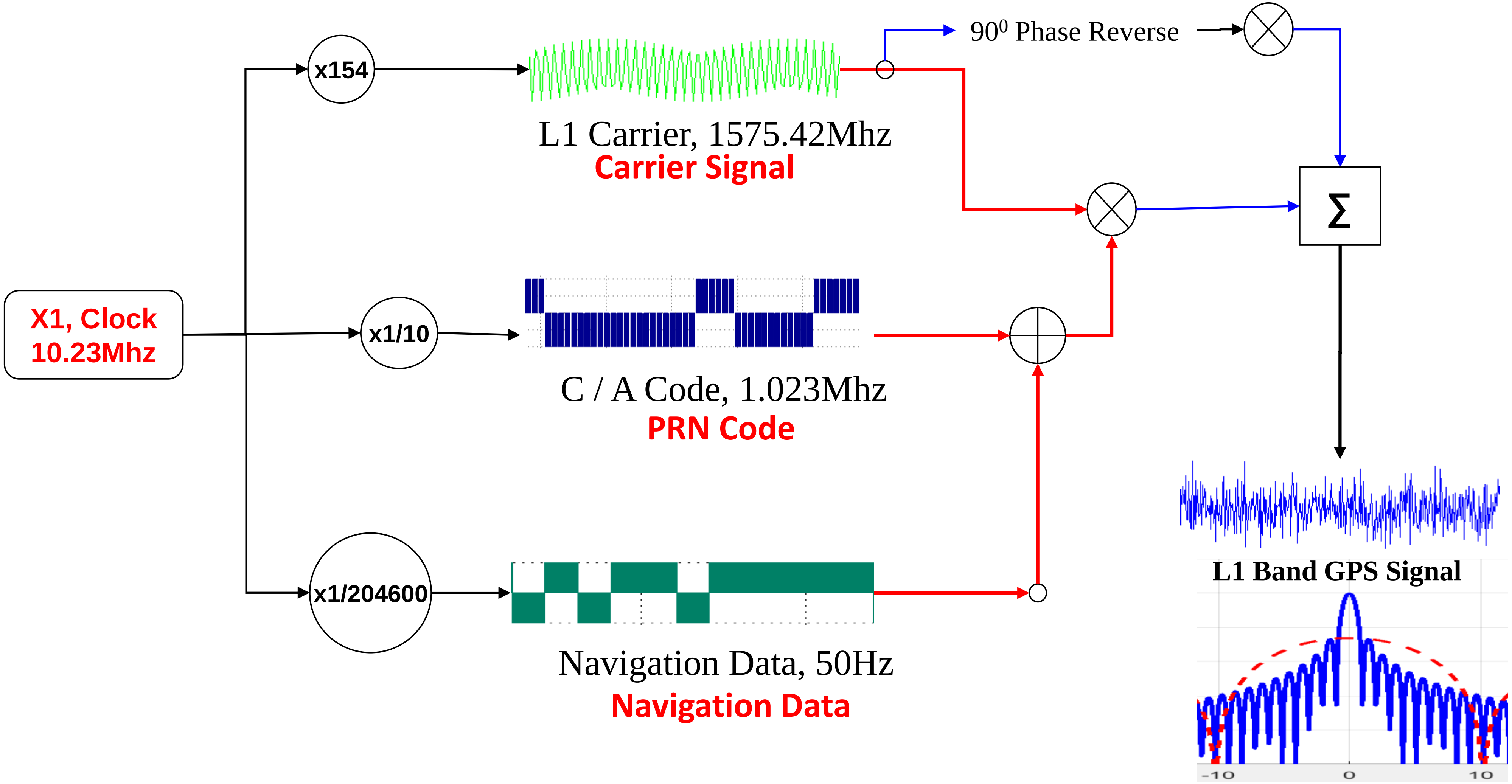
GPS L1C/A Signal Structure

- 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
  - Used to identify satellite ID in CDMA
  - Requires to modulate the data
  - Should have good auto-correlation and cross-correlation properties
- Navigation Data
  - Includes satellite orbit related data (ephemeris data)
  - Includes satellite clock related information (clock errors etc)

GPS L1C/A Signal Structure



X1, Clock 10.23Mhz

x154

L1 Carrier, 1575.42Mhz

Carrier Signal

x1/10

C / A Code, 1.023Mhz

PRN Code

x1/204600

Navigation Data, 50Hz

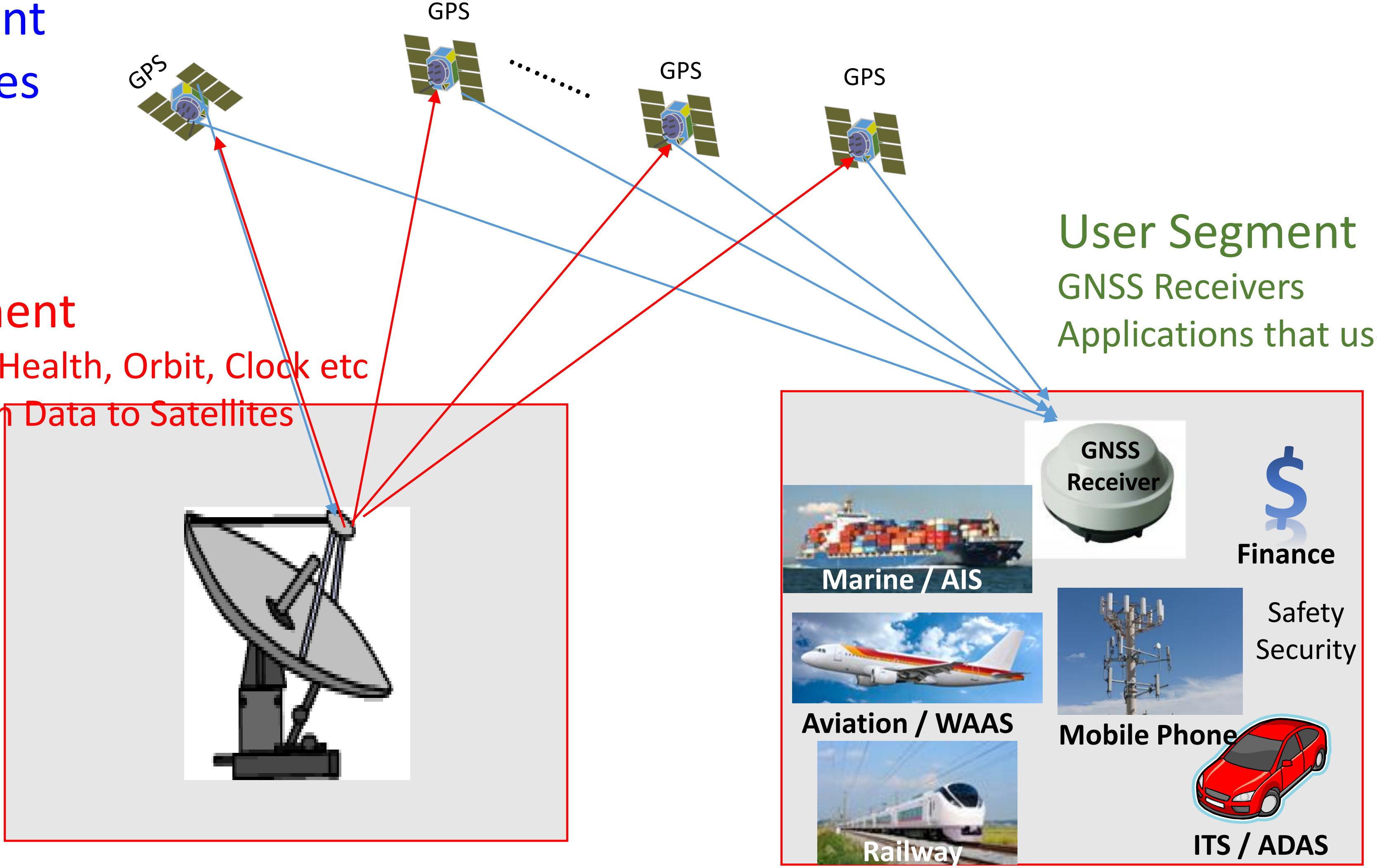
Navigation Data

90^0 Phase Reverse

Σ

L1 Band GPS Signal

GNSS Architecture



Space Segment
GNSS Satellites

Control Segment
Monitor Satellite Health, Orbit, Clock etc
Upload Navigation Data to Satellites

User Segment
GNSS Receivers
Applications that use GNSS

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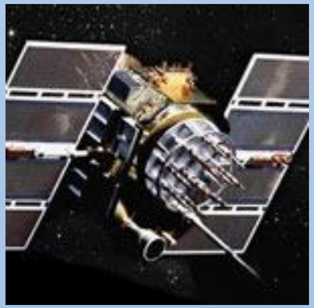
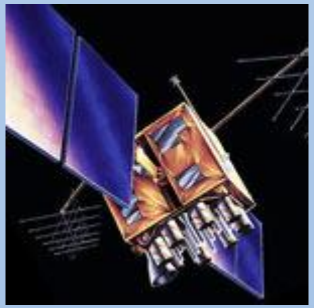
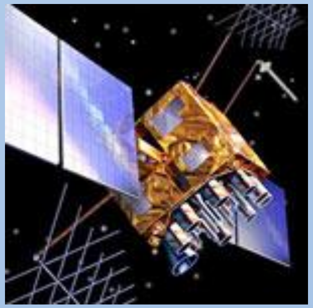
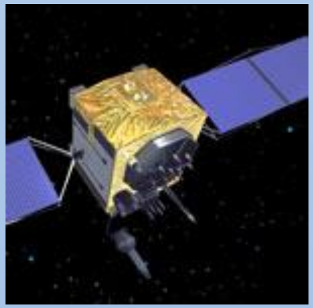
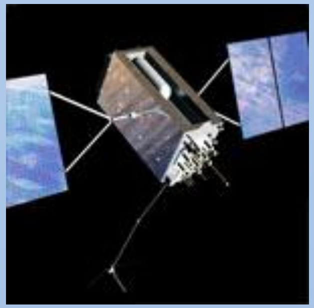
GPS Space Segment: Current & Future Constellation

Legacy Satellites		Modernized Satellites		
				
Block IIA	**Block IIR**	**Block IIR(M)**	**Block IIF**	**GPS III**
0 operational	**9 operational**	**7 operational**	**12 operational**	**2 operational**
• Coarse Acquisition (C/A) code on L1 frequency for civil users • Precise P(Y) code on L1 & L2 frequencies for military users • 7.5-year design lifespan • Launched in 1990-1997 • Last one decommissioned in 2019	• C/A code on L1 • P(Y) code on L1 & L2 • On-board clock monitoring • 7.5-year design lifespan • Launched in 1997-2004	• All legacy signals • 2nd civil signal on L2 (L2C) • New military M code signals for enhanced jam resistance • Flexible power levels for military signals • 7.5-year design lifespan • Launched in 2005-2009	• All Block IIR-M signals • 3rd civil signal on L5 frequency (L5) • Advanced atomic clocks • Improved accuracy, signal strength, and quality • 12-year design lifespan • Launched in 2010-2016	• All Block IIF signals • 4th civil signal on L1 (L1C) • Enhanced signal reliability, accuracy, and integrity • No Selective Availability • 15-year design lifespan • IIIF: laser reflectors; search & rescue payload • First launch in 2018

Source: http://www.gps.gov/systems/gps/space/#IIF
https://www.unoosa.org/oosa/en/ourwork/icg/annual-meetings

Information in this slide may not be the latest information.
Please check the Source HP link and UNOOSA documents

GPS Signals

Band	Frequency, MHz	Signal Type	Code Length msec	Chip Rate, MHz	Modulation Type	Data / Symbol Rate, bps/sps	Notes
L1	1575.42	C/A	1	1.023	BPSK	50	Legacy Signal
		C_{Data}	10	1.023	BOC(1,1)	50 / 100	From 2014
		C_{Pilot}	10	1.023	TMBOC	No Data	BOC(1,1) & BOC(6,1)
		P(Y)	7 days	10.23	BPSK		Restricted
L2	1227.60	CM	20	0.5115	BPSK	25 / 50	Modulated by TDM of (L2CM xor Data) and L2CL
		CL	1500	0.5115		No Data	
		P(Y)	7days	10.23	BPSK		
L5	1176.45	I	1	10.23	BPSK	50 / 100	Provides Higher Accuracy
		Q	1			No Data	

GLONASS (Russia)

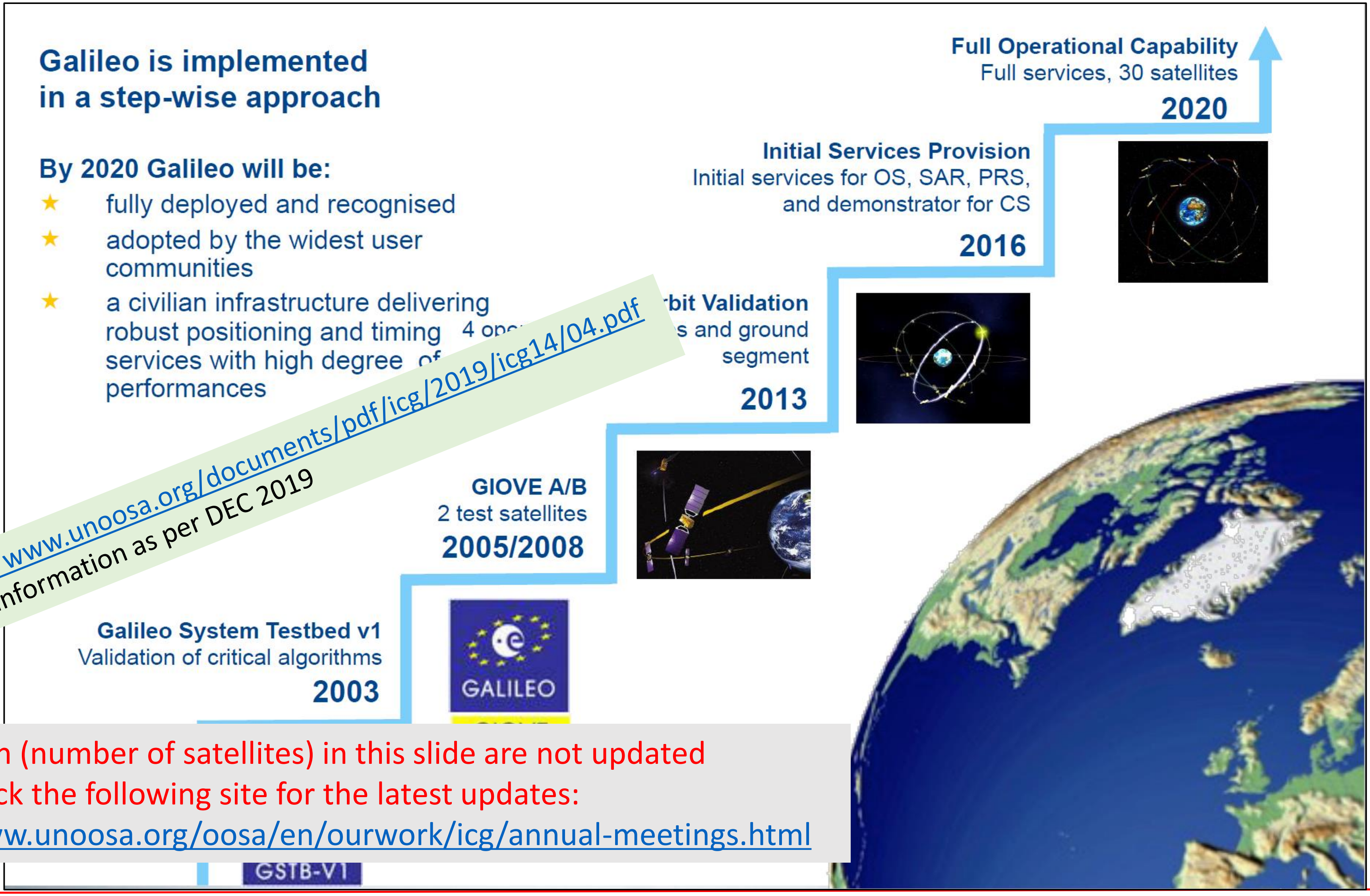
1982 First Launch	2003	2011	Planned Launch
			
GLONASS	**GLONASS-M**	**GLONASS-K1**	**GLONASS-K2**
DECOMMISSIONED **87 Launched** **0 Operational** **81 Retired** **6 Lost**	**Under Normal Operation** **45 Launched** **27 Operational** **12 Retired** **6 Lost**	**Under Production / Operation** **2 Launched** **2 Operational** **First launch**	**2018**
•L1OF, L1SF • L2SF	•L1OF, L1SF •L2OF, L2S •L3OC		L1OF, L1SF •L2OF, L2SF •L1OC, L1SC •L2OC, L2SC •L3OC

See File
https://www.unoosa.org/documents/pdf/icg/2019/icg14/03.pdf
for the latest information as per DEC 2019

Information (Number of Satellites) in this slide are not updated
Please check the following site for the latest updates:
https://www.unoosa.org/oosa/en/ourwork/icg/annual-meetings.html

GLONASS space segment STATUS & MODERNIZATION, Joint - Stock Company «Academician M.F. Reshetnev» Information Satellite Systems»
ICG-7, November 04-09, 2012 , Beijing, China, https://en.wikipedia.org/wiki/GLONASS-K2

Galileo (Europe)



Galileo is implemented in a step-wise approach

By 2020 Galileo will be:

- ★ fully deployed and recognised
- ★ adopted by the widest user communities
- ★ a civilian infrastructure delivering robust positioning and timing services with high degree of performances

Full Operational Capability
Full services, 30 satellites
2020

Initial Services Provision
Initial services for OS, SAR, PRS, and demonstrator for CS
2016

bit Validation
4 ope s and ground segment
2013

GIOVE A/B
2 test satellites
2005/2008

Galileo System Testbed v1
Validation of critical algorithms
2003

See file https://www.unoosa.org/documents/pdf/icg/2019/icg14/04.pdf for the latest information as per DEC 2019

Information (number of satellites) in this slide are not updated
Please check the following site for the latest updates:
https://www.unoosa.org/oosa/en/ourwork/icg/annual-meetings.html

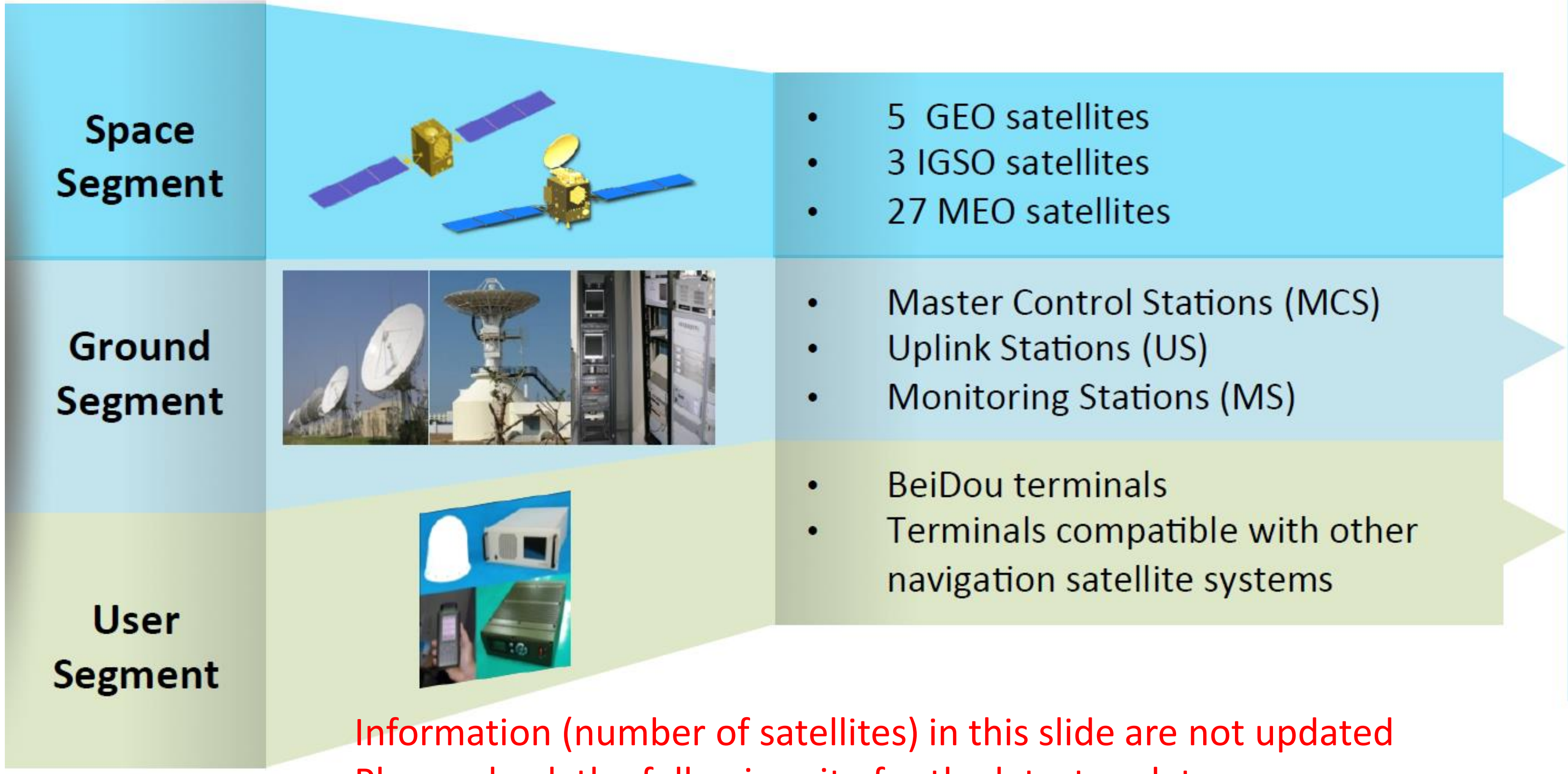
Galileo Signals

Band	Frequency, MHz	Signal Type	Code Length msec	Chip Rate, MHz	Modulation Type	Data / Symbol Rate, bps/sps	Notes
E1	1575.42	A	10	10.23	BOC(15,2.5)	??	Restricted
		B_{Data}	4	1.023	CBOC, Weighted combination of BOC(1,1) & BOC(6,1)	125 / 250	Data
		C_{Pilot}	100	1.023		No Data	Pilot
E6	1278.75	A	10	5.115	BOC(15,5)	??	PRS
		B	1	5.115	BPSK(5)	500 / 1000	Data
		C	100	5.115		No Data	Pilot
E5 1191.795 MHz	1176.45	A-I	20	10.23	AltBOC(15,10)	25 / 50	Data
		A-Q	100	10.23		No Data	Pilot
	1207.14	B-I	4	10.23		125 / 250	Data
		B-Q	100	10.23		No Data	Pilot

Galileo Services

Open Service (OS)	**Freely accessible service for positioning, navigation and timing for mass market**	
Commercial Service (CS)	**Delivers authentication, high accuracy and guaranteed services for commercial applications**	
Public Regulated Service (PRS)	**Encrypted service designed for greater robustness in challenging environments**	
Search And Rescue Service (SAR)	**Locates distress beacons and confirms that message is received**	
Safety of Life Service (SoL)	**The former Safety of Life service is being re-profiled**	

BeiDou Space Segment



Space Segment

- 5 GEO satellites
- 3 IGSO satellites
- 27 MEO satellites

Ground Segment

- Master Control Stations (MCS)
- Uplink Stations (US)
- Monitoring Stations (MS)

User Segment

- BeiDou terminals
- Terminals compatible with other navigation satellite systems

Four types of services:

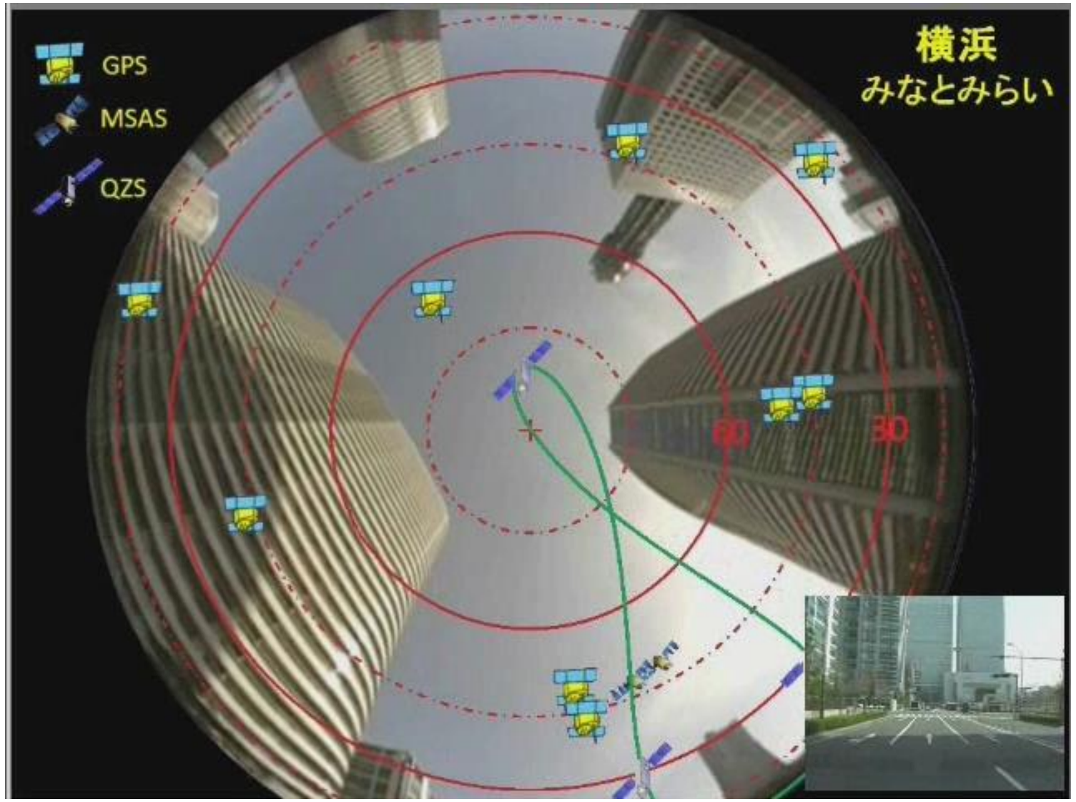
open, authorized, differential augmentation, and short message services.

The nominal positioning accuracy is better than 10 m, timing and velocity accuracy is better than 20 ns and 0.2 m/s respectively.

Information (number of satellites) in this slide are not updated
Please check the following site for the latest updates:
https://www.unoosa.org/documents/pdf/icg/2019/icg14/05.pdf

Source: Update on BeiDou Navigation Satellite System, Chengqi Ran, China Satellite Navigation Office
Tenth Meeting of ICG, NOV 2015

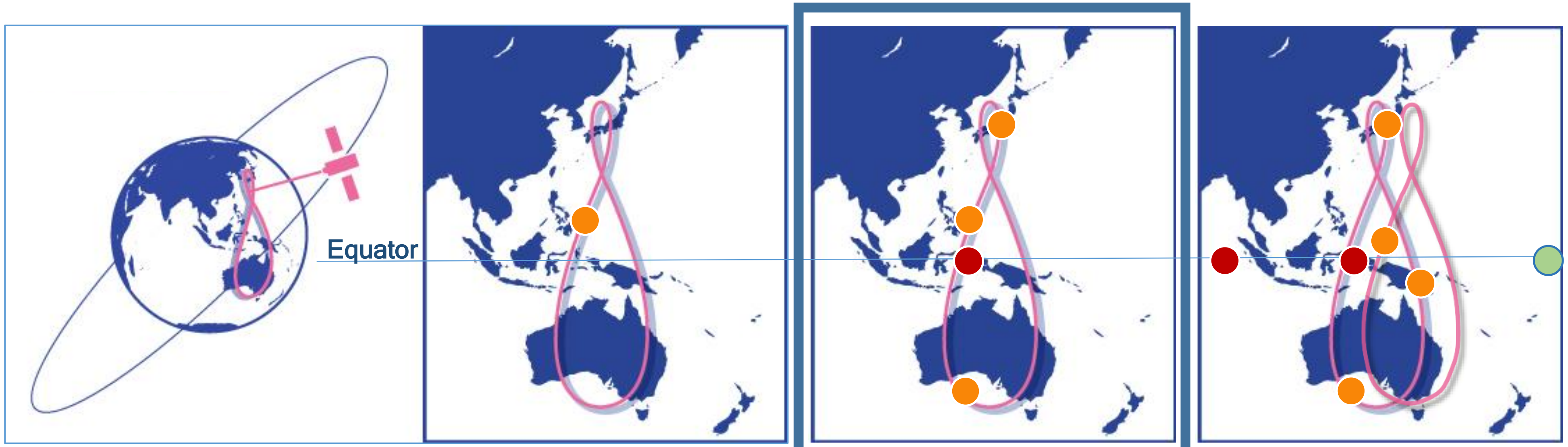
QZSS (Quasi-Zenith Satellite System)
Nickname: MICHIBIKI



[Please check the document for the latest updates:
https://www.unoosa.org/documents/pdf/icg/2019/icg14/06.pdf](https://www.unoosa.org/documents/pdf/icg/2019/icg14/06.pdf)

QZSS orbit is designed in such a way that a satellite is visible for about 8 hours above your head. This makes the satellite visible even in very dense urban area with high-rise buildings. GPS alone is not enough for good position accuracy in such area. QZSS in combination with other visible GNSS satellites provide better position accuracy.

QZSS Constellation Plan

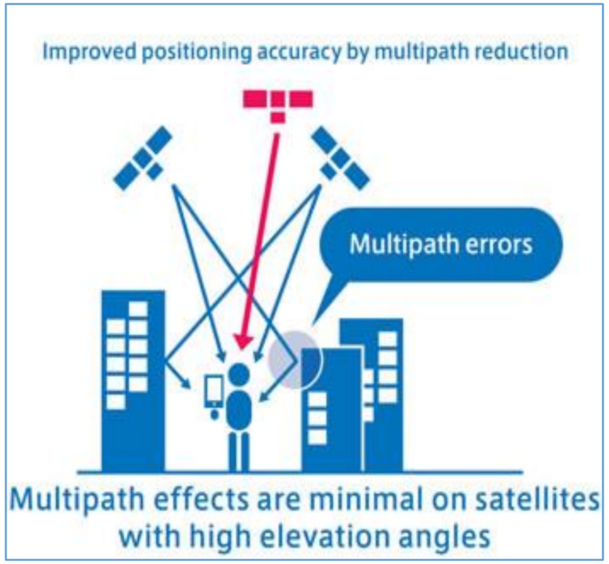


	1 sat constellation	4 sat. constellation	7 sat. constellation
Number of Satellites	QZO ●: 1	QZO ●: 3, GEO ●: 1	QZO●:4, GEO●:2, QGO●:1
Purpose	Research & Development	Operational Complements GPS for positioning	Operational, Autonomous Positioning Capability with QZSS only
Government Authority	JAXA	Cabinet 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

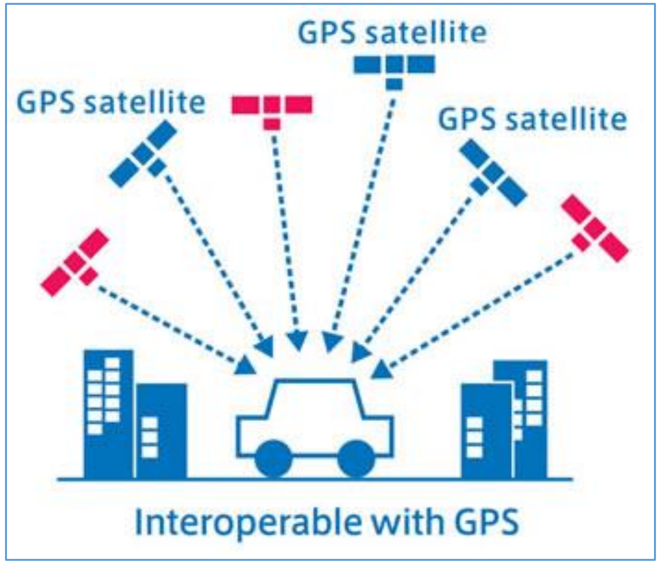
QZO: Quasi-zenith Orbit / GEO: Geosynchronous Orbit / QGO: Quasi-geostationary Orbit

Source: MGA 2019, Mitsubishi

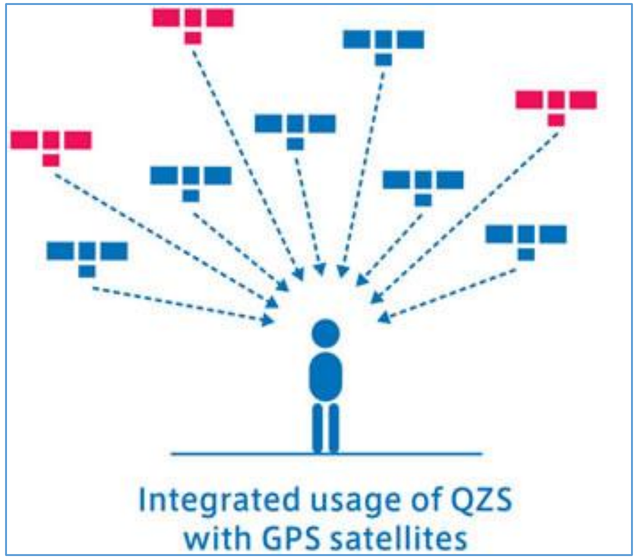
Merits of QZSS



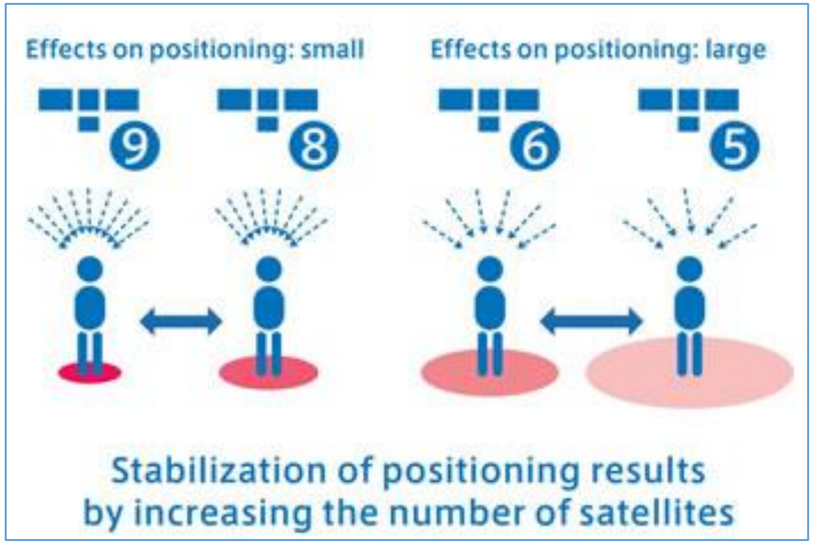
Multipath effects are minimal on satellites with high elevation angles



Interoperable with GPS


Integrated usage of QZS with GPS satellites

- 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



Stabilization of positioning results by increasing the number of satellites

http://qzss.go.jp/en/overview/services/sv04_pnt.html

QZSS PRN Codes

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

https://qzss.go.jp/en/technical/satellites/index.html#QZSS

NavIC Signal Types

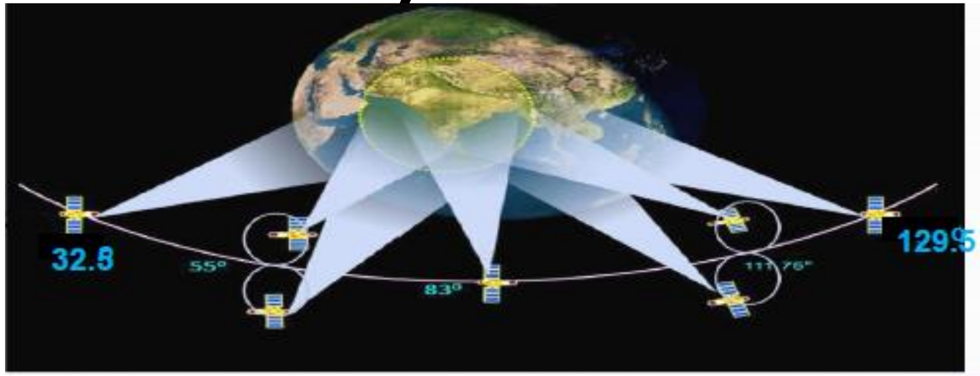
Signal	Carrier Frequency	Bandwidth
L5	1176.45MHz	24MHz
S	2492.028MHz	16.5MHz

Please check the following document for the latest information
https://www.unoosa.org/documents/pdf/icg/2019/icg14/01.pdf

See file 01_NAVIC_ICG_2019.pdf for the latest information as per DEC 2019

NavIC (Navigation with Indian Constellation)

- **Consists of 7 Satellites**
- **4 Geo Synchronous Orbit (GSO) satellites**
  - **at 55ºE and 111.75ºE at an inclination of 27º**
- **3 Geo Stationary Satellites (GEO)**
  - **at 32.5ºE, 83ºE and 129.5º E at an inclination of 5º**
- **Transmits signals in L5 band (1176.45MHz) and S band (2492.028MHz)**



Please check the following site for the latest updates:
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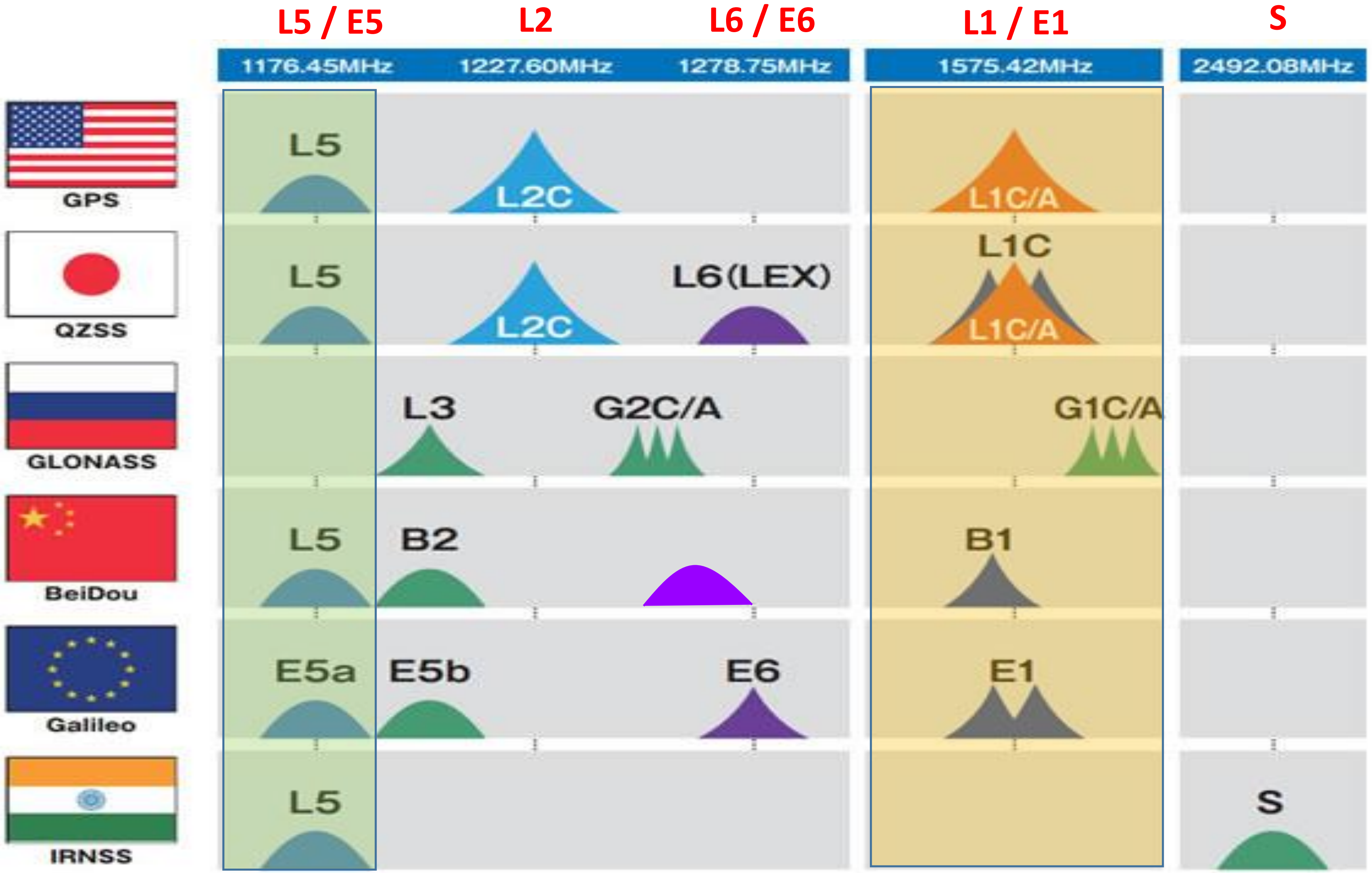
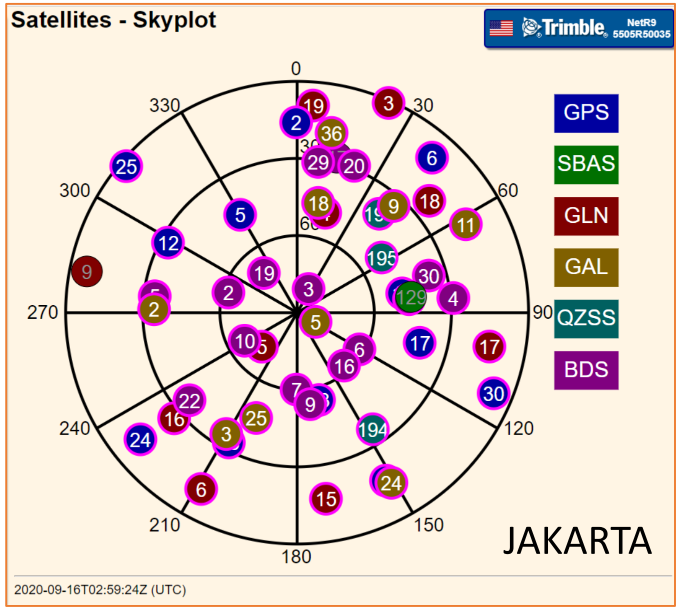
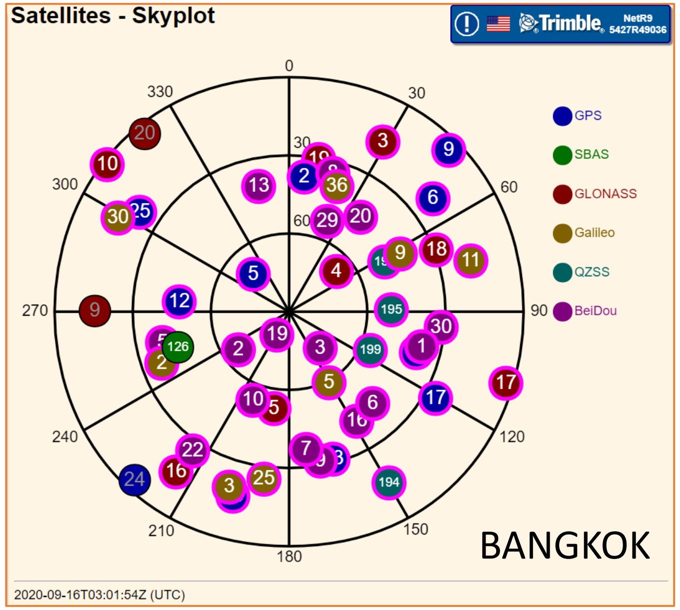
Multi-GNSS Signals




Satellites - Skyplot
Trimble NetR9 5505R50035
GPS
SBAS
GLN
GAL
QZSS
BDS
JAKARTA
2020-09-16T02:59:24Z (UTC)


Satellites - Skyplot
Trimble NetR9 5427R49036
GPS
SBAS
GLONASS
Galileo
QZSS
BeiDou
BANGKOK
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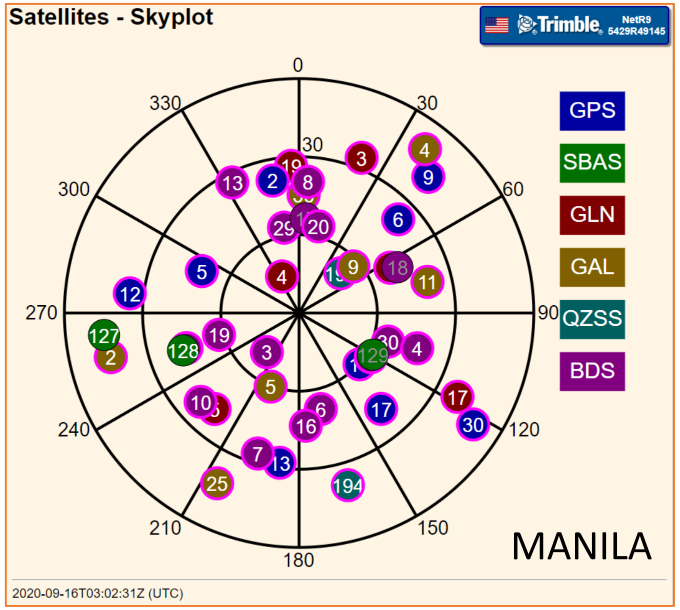
Satellites - Skyplot
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GPS
SBAS
GLN
GAL
QZSS
BDS
MANILA
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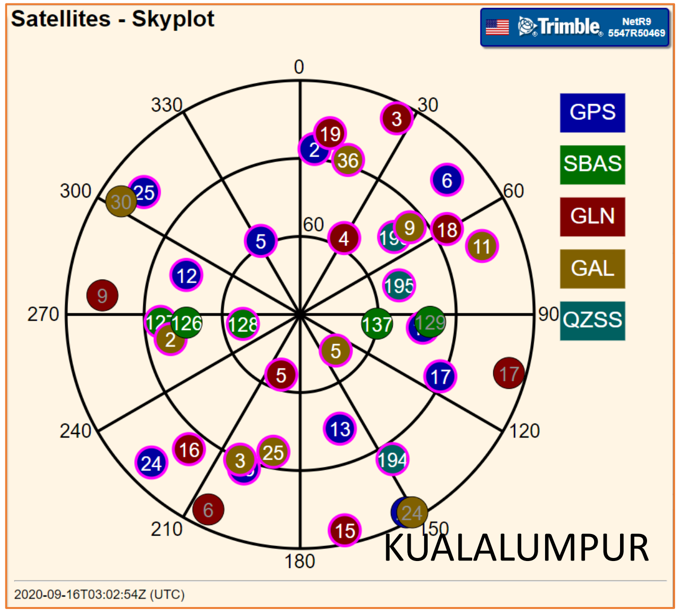
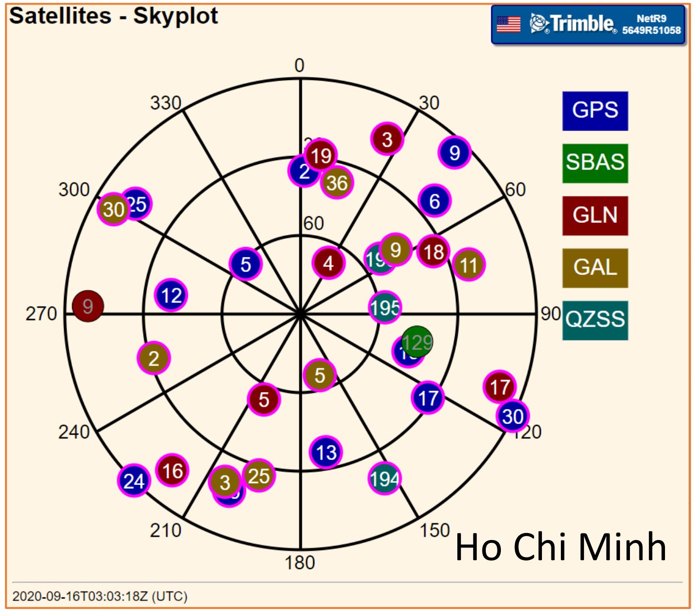
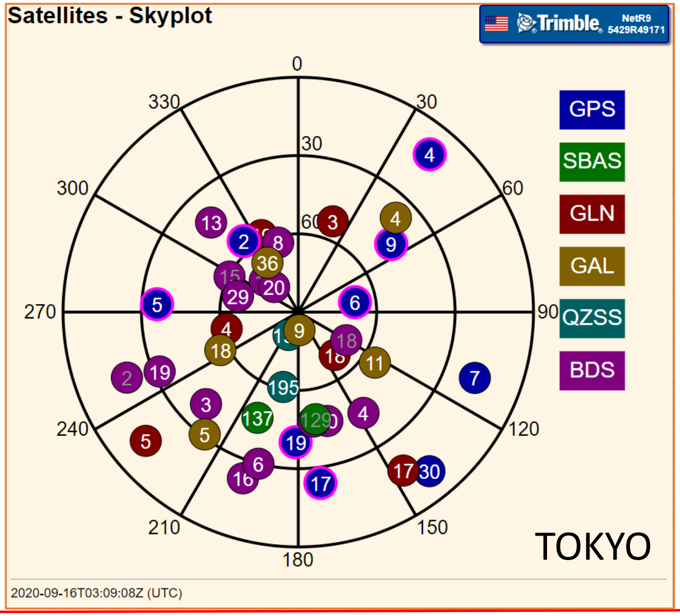
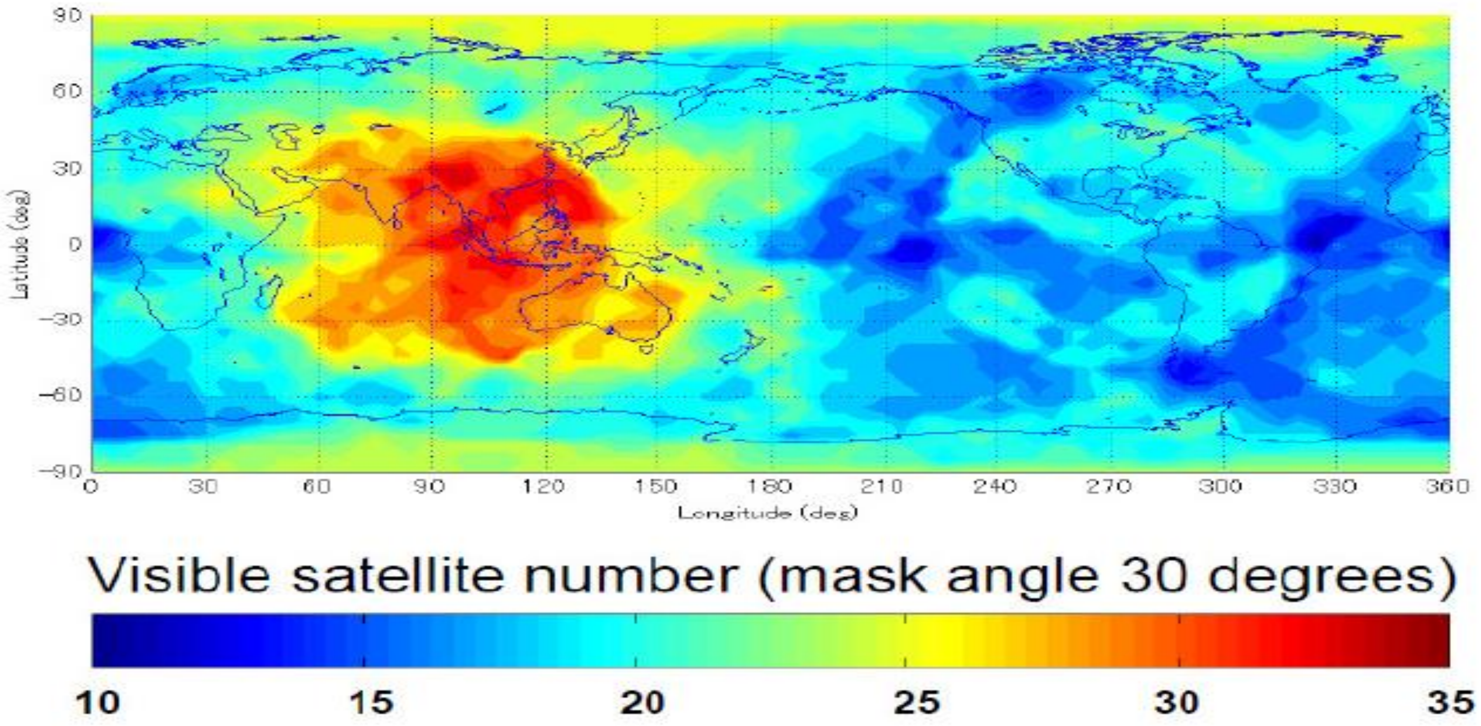

Satellites - Skyplot
Trimble NetR9 5547R50469
GPS
SBAS
GLN
GAL
QZSS
KUALALUMPUR
2020-09-16T03:02:54Z (UTC)


Satellites - Skyplot
Trimble NetR9 5649R51058
GPS
SBAS
GLN
GAL
QZSS
Ho Chi Minh
2020-09-16T03:03:18Z (UTC)


Satellites - Skyplot
Trimble NetR9 5429R49171
GPS
SBAS
GLN
GAL
QZSS
BDS
TOKYO
2020-09-16T03:09:08Z (UTC)

Multi GNSS Signals: Benefits to Users

- GPS+GLONASS+Galileo+BeiDou+QZSS+NAVIC
- Asia-Oceanic region will see the maximum number of satellites



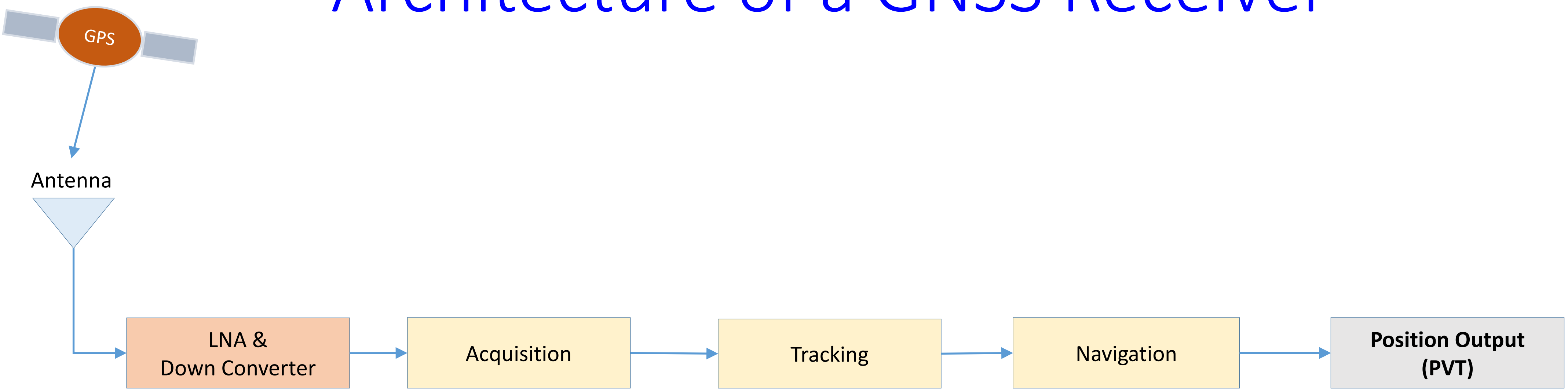
Visible satellite number (mask angle 30 degrees)

Multi GNSS Signals: Benefits to Users

- Increase in usable SVs, signals and frequencies
  - Increase in availability and coverage
  - More robust and reliable services
  - Higher accuracy in bad conditions
  - Less expensive high-end services
  - Better atmospheric correction
- Emerging new and expanding existing applications are to be expected
  - Atmosphere related applications
  - Short Message Broadcasting
  - SAR (Search And Rescue Applications)
  - Signal Authentication and Secured Positioning Services
  - Bi-static Remote Sensing (GNSS Reflectometry)
    - Compute Soil Moisture, Wind Velocity, Sea Wave Height etc…

Part - B

Architecture of a GNSS Receiver



Antenna

LNA &
Down Converter

Acquisition

Tracking

Navigation

**Position Output
(PVT)**

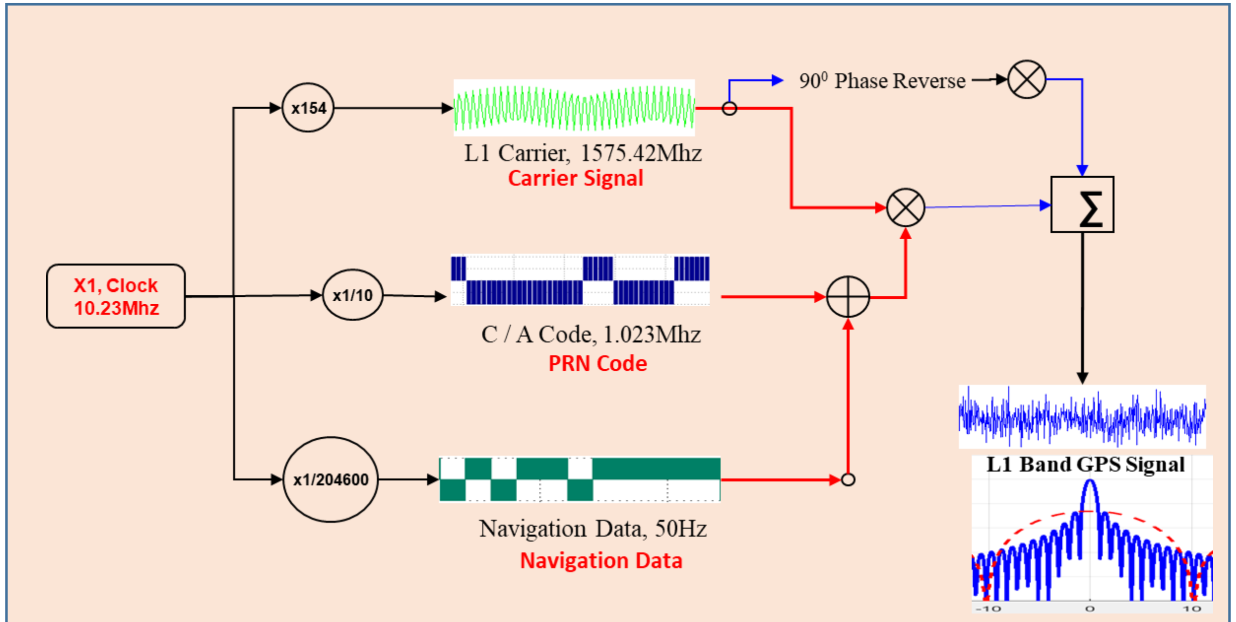
To find out visible satellites,
approximate Doppler
and Code-phase

To continuously demodulate the signal
to extract the navigation data bits
Done by using DLL, FLL and PLL.

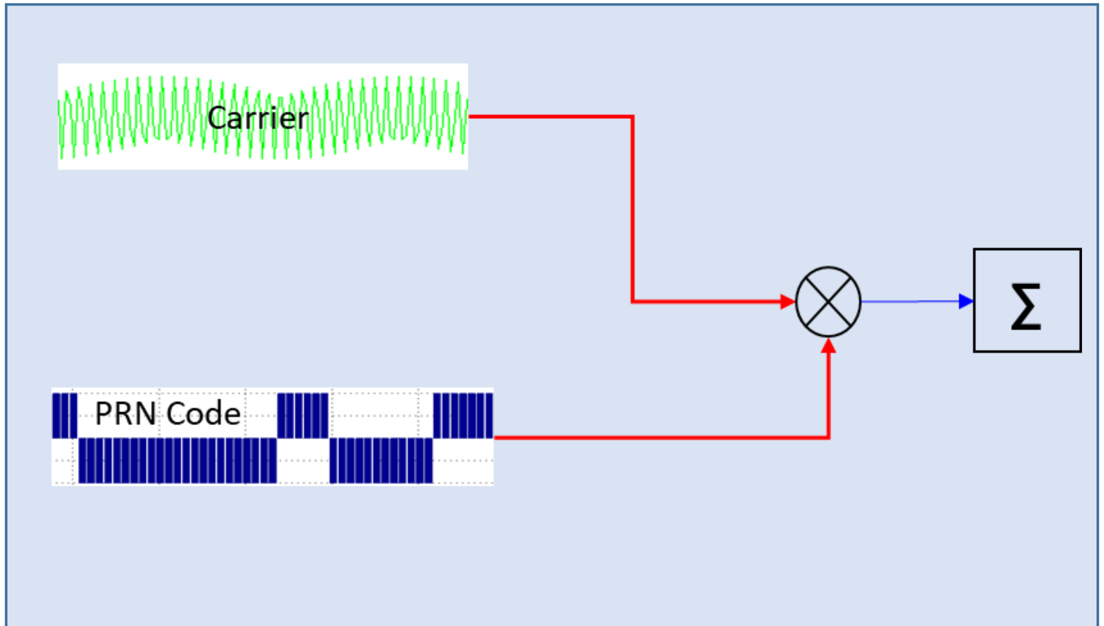
Generate Pseudorange, Doppler etc
Extract Ephemeris or
Satellite Orbit related Data
Extract Clock related data

PVT Output
Position, Velocity and Time
Satellite Related Data
Signal Related Data

GPS Signal Processing in a Receiver: Signal Demodulation



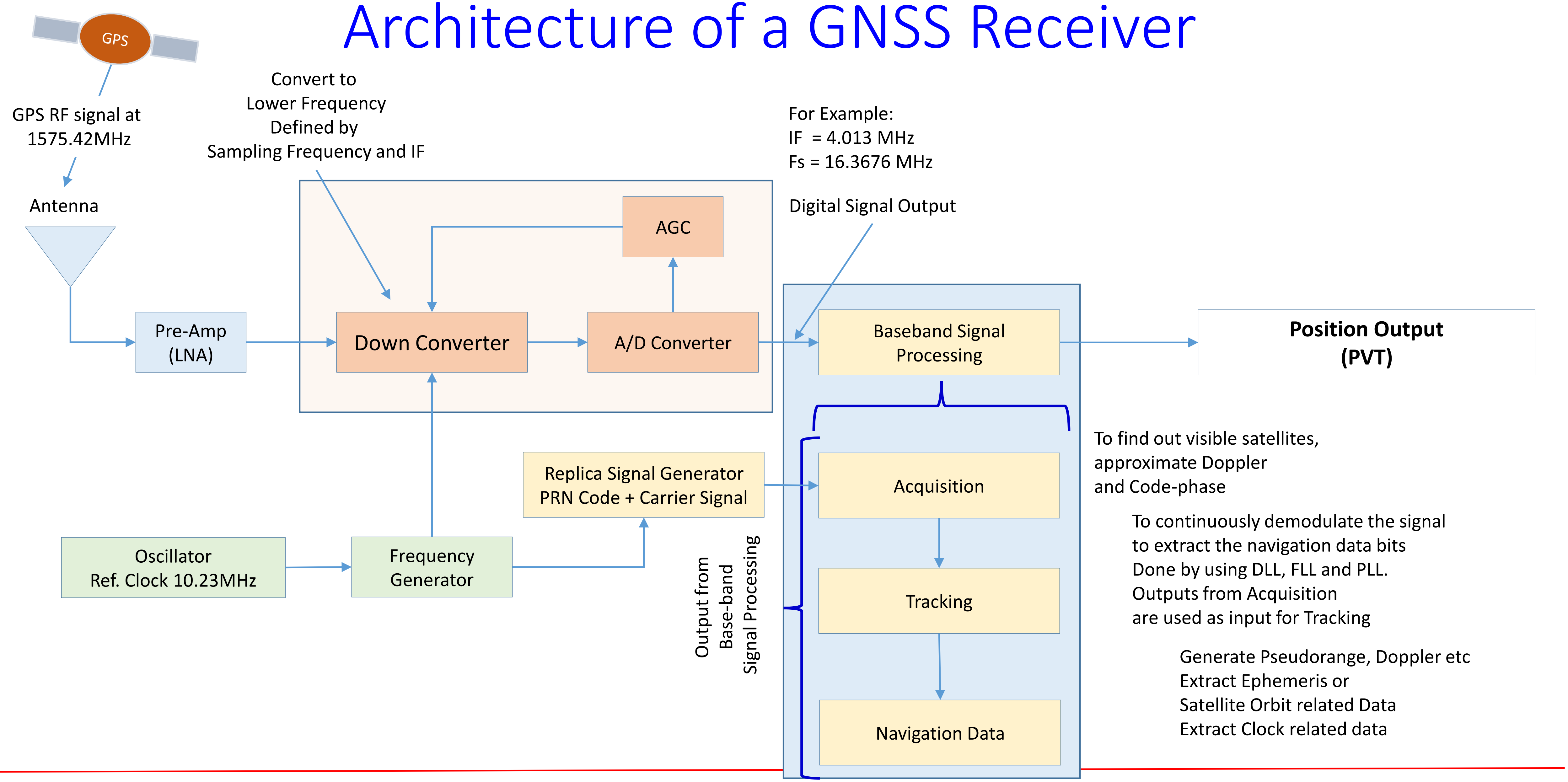
Incoming signal from satellite to a receiver



Replica signal generated in a receiver

- GPS receiver demodulates the incoming signal to extract navigation data and other signal related values that are necessary to compute position of the receiver
- This is done by generating a replica signal (carrier and PRN code) that is similar to GPS incoming signal in the receiver
- All these process are done in steps called (1) Acquisition (2) Tracking (3) Navigation

Architecture of a GNSS Receiver



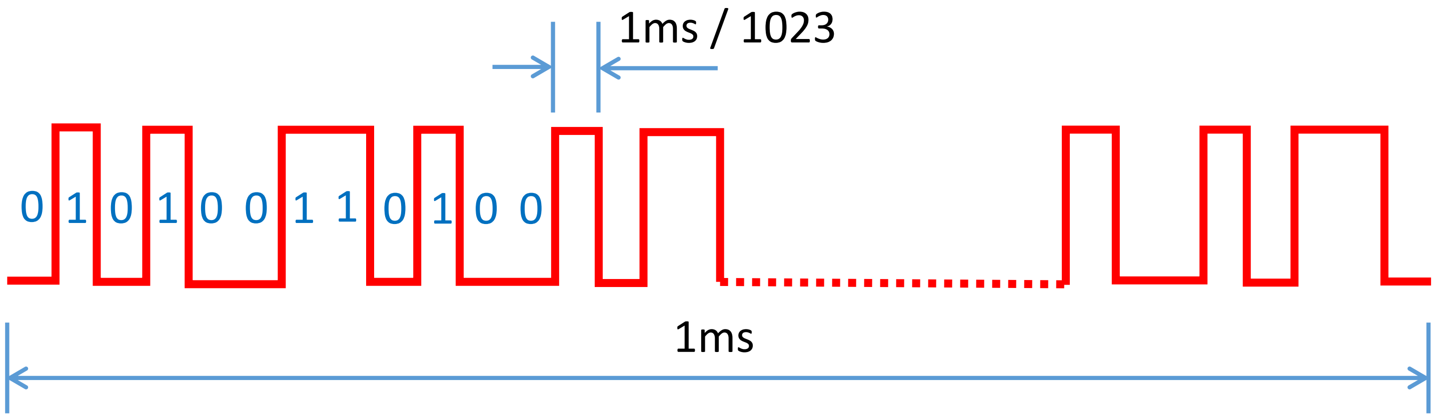
To find out visible satellites, approximate Doppler and Code-phase

To continuously demodulate the signal to extract the navigation data bits Done by using DLL, FLL and PLL. Outputs from Acquisition are used as input for Tracking

Generate Pseudorange, Doppler etc
Extract Ephemeris or Satellite Orbit related Data
Extract Clock related data

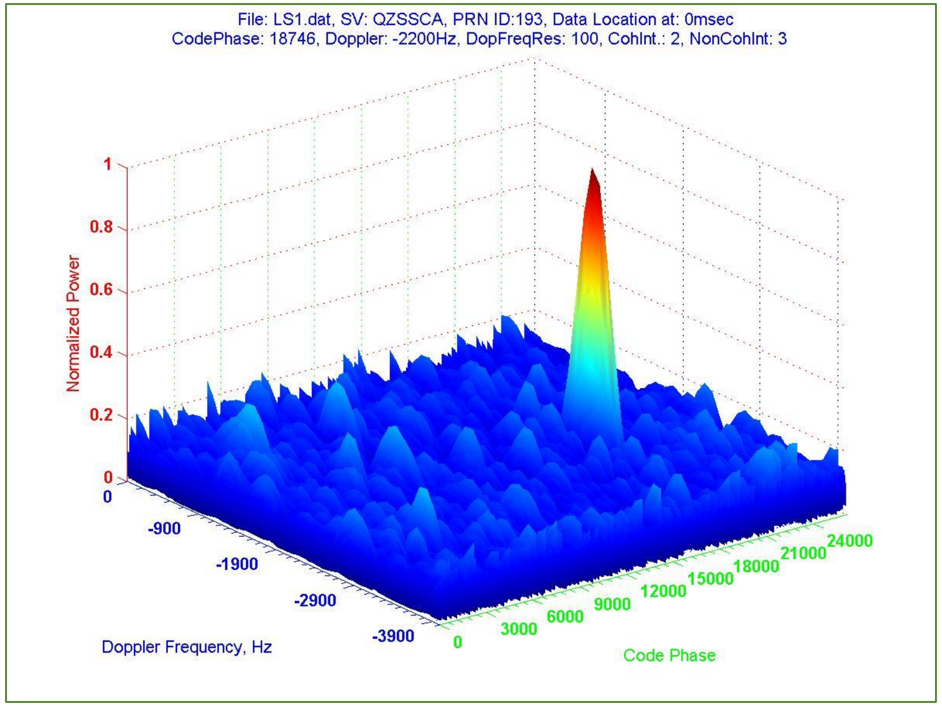
PRN (Pseudo Random Noise) Code

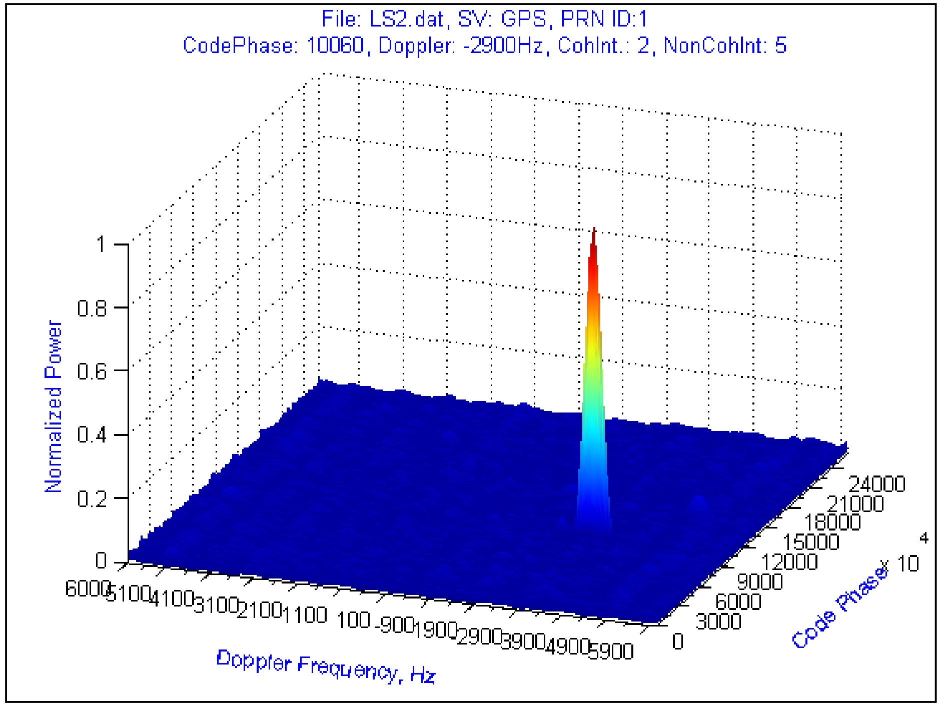
- PRN Code is a sequence of randomly distributed zeros and ones that is one millisecond long.
  - This random distribution follows a specific code generation pattern called Gold Code.
  - There are 1023 bits of combination of zeros and ones in one millisecond.
- Each GPS satellite transmits a unique PRN Code.
  - GPS receiver identifies satellites by its unique PRN code or ID.
- It is continually repeated every millisecond and serves for signal transit time measurement.
  - The receiver can measure where the PRN code terminated or repeated. The start and end points are known.

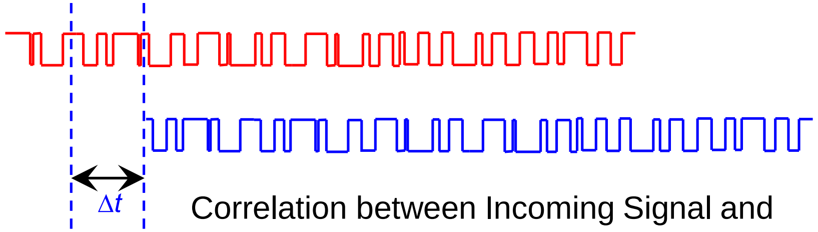


Acquisition of GPS L1C/A Signal

Correlate incoming signal with replica signal generated by the receiver







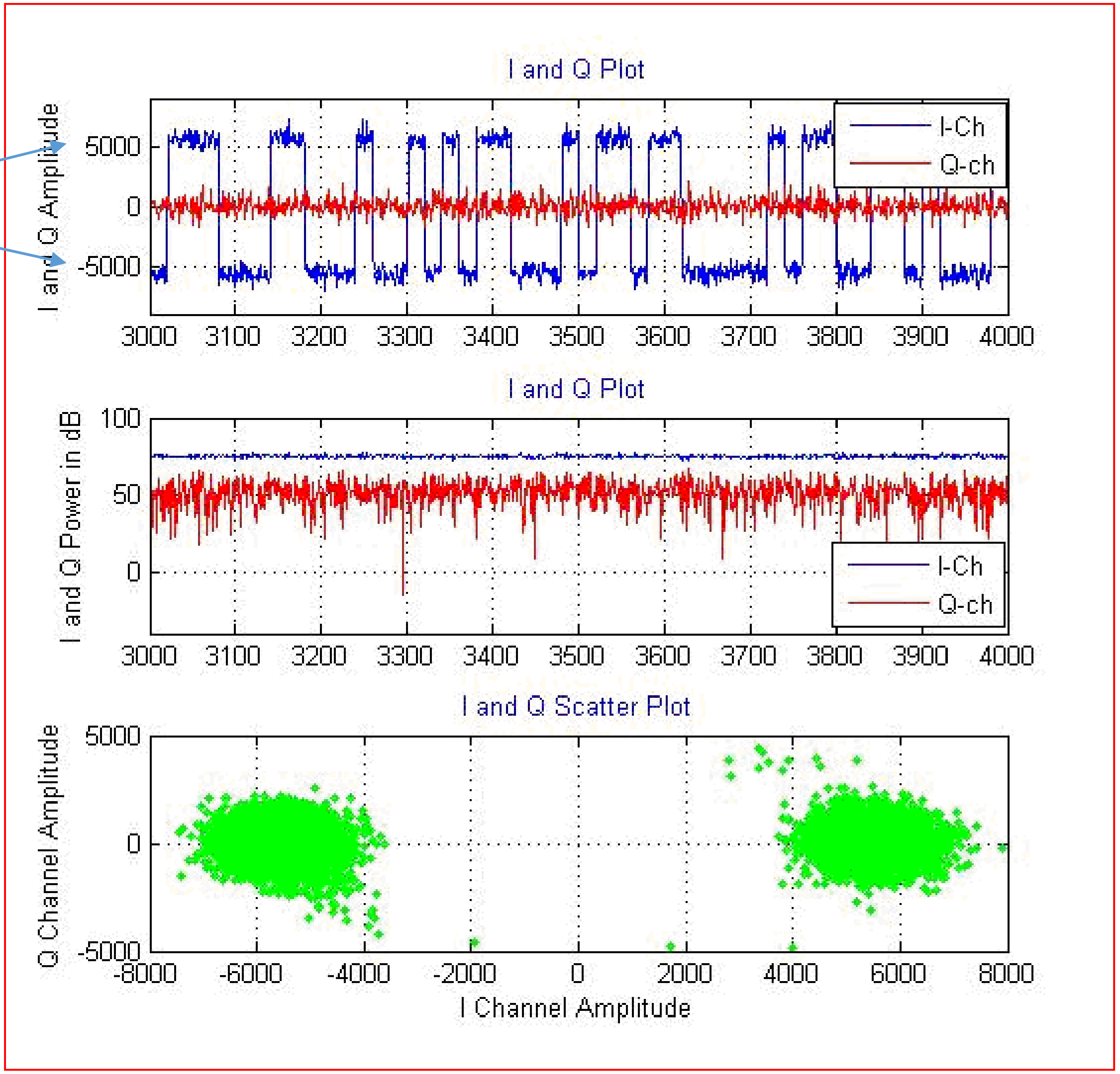
Correlation between Incoming Signal and
Receiver Generated Signal

GPS Signal Tracking

- Tracking Loops (PLL & DLL) are used to continuously lock the incoming signal and demodulate it by using the carrier frequency and code phase values detected in Acquisition.
- PLL
  - Phase Lock Loop
  - To Track the Carrier Frequency
- DLL
  - Delay Lock Loop
  - To Track the Code Phase (PRN Code Delays)

GPS Signal Tracking Output

Navigation Data Bits 1’s and 0’s

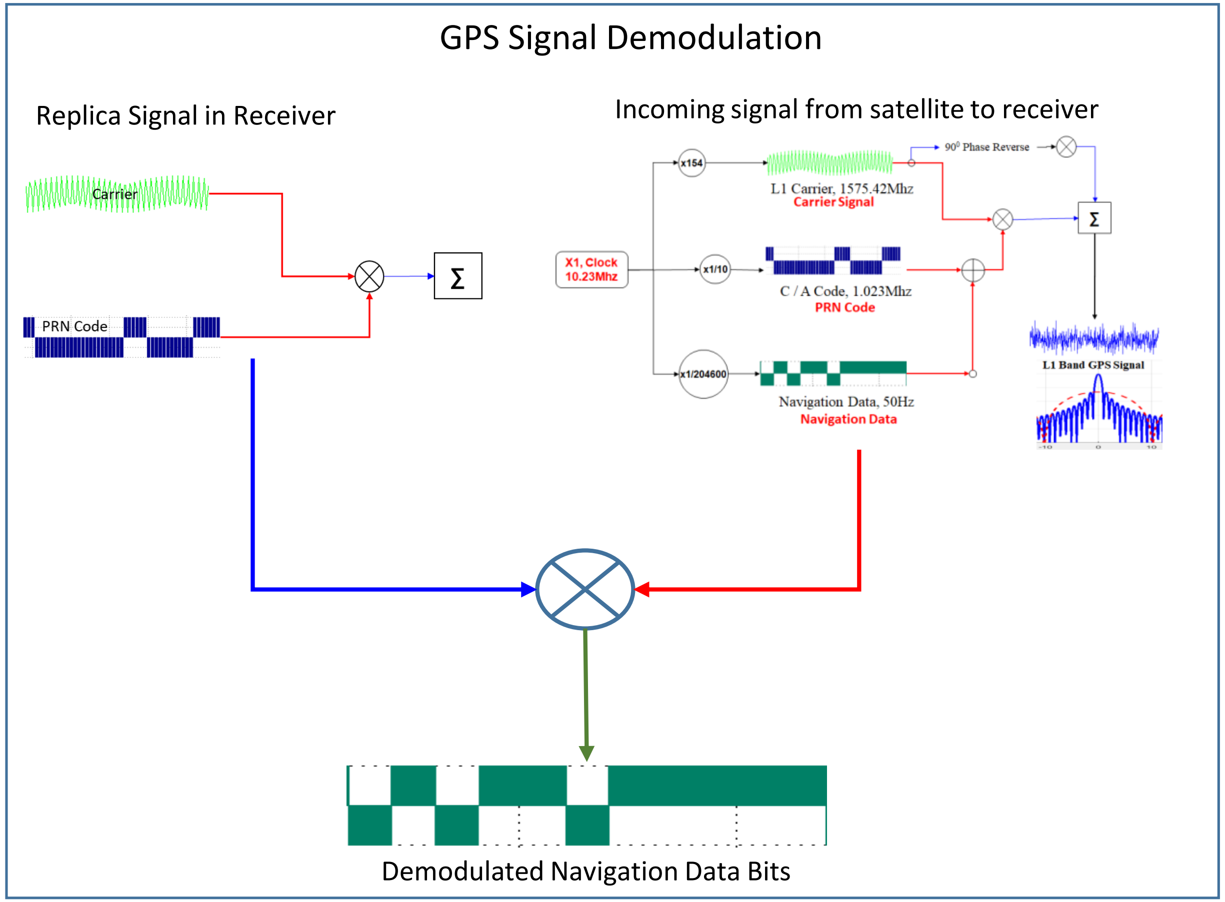


Now, we have all necessary outputs

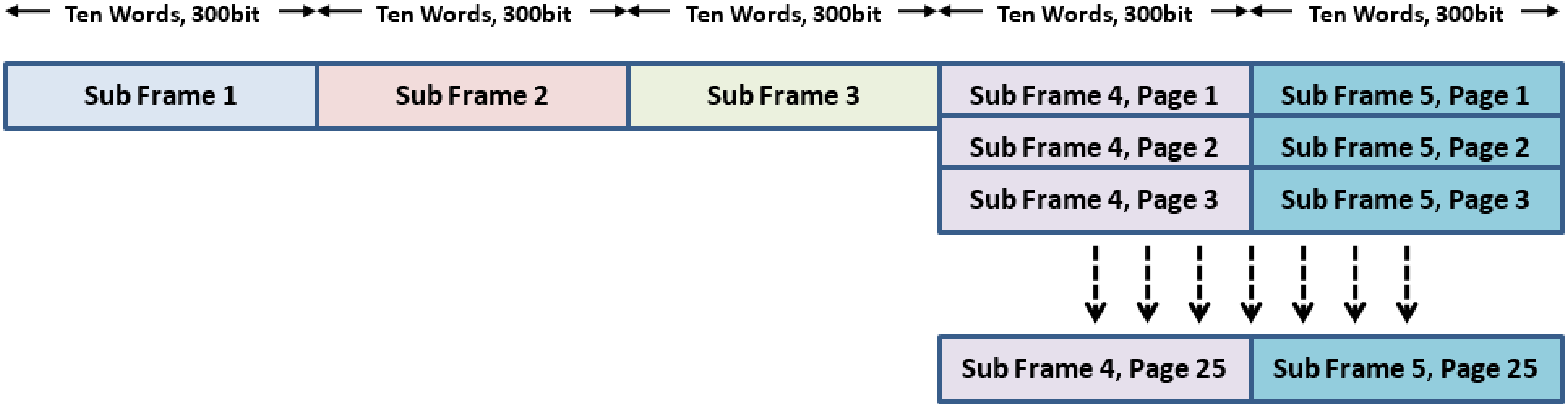
1. Information necessary to compute Pseudorange and code phase from DLL Outputs
2. Information necessary to computer Doppler and carrier phase from PLL outputs
3. Navigation data bits from tracking output
    1. It provides clock related information, satellite orbit information (Ephemeris and Almanac), health status and many other parameters.
4. Other signal properties like SNR

Navigation Data

- Navigation Data or Message is a continuous stream of digital data transmitted at 50 bits per second.
- Each satellite broadcasts the following information to users.
    - Its own highly accurate orbit and clock correction (**ephemeris**)
    - Approximate orbital correction for all other satellites (**almanac**)
    - System health and other signal and satellite related inforamtion



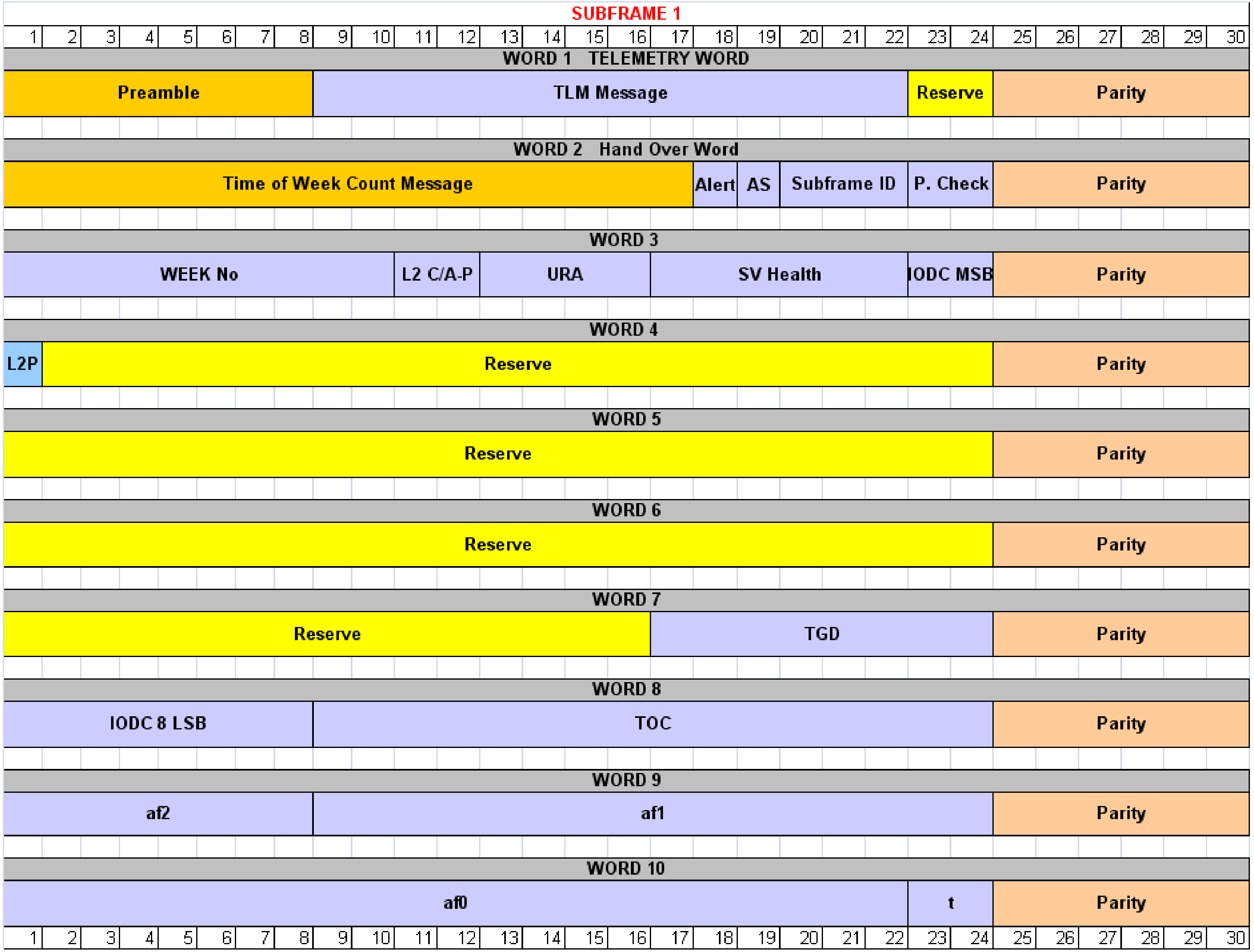
GPS L1C/A Signal NAV MSG



Ten Words, 300bit | Ten Words, 300bit | Ten Words, 300bit | Ten Words, 300bit | Ten Words, 300bit

Sub Frame 1	Sub Frame 2	Sub Frame 3	Sub Frame 4, Page 1	Sub Frame 5, Page 1
			Sub Frame 4, Page 2	Sub Frame 5, Page 2
			Sub Frame 4, Page 3	Sub Frame 5, Page 3
			Sub Frame 4, Page 25	Sub Frame 5, Page 25

GPS L1C/A, Navigation Message, Sub-frame 1



SUBFRAME 1

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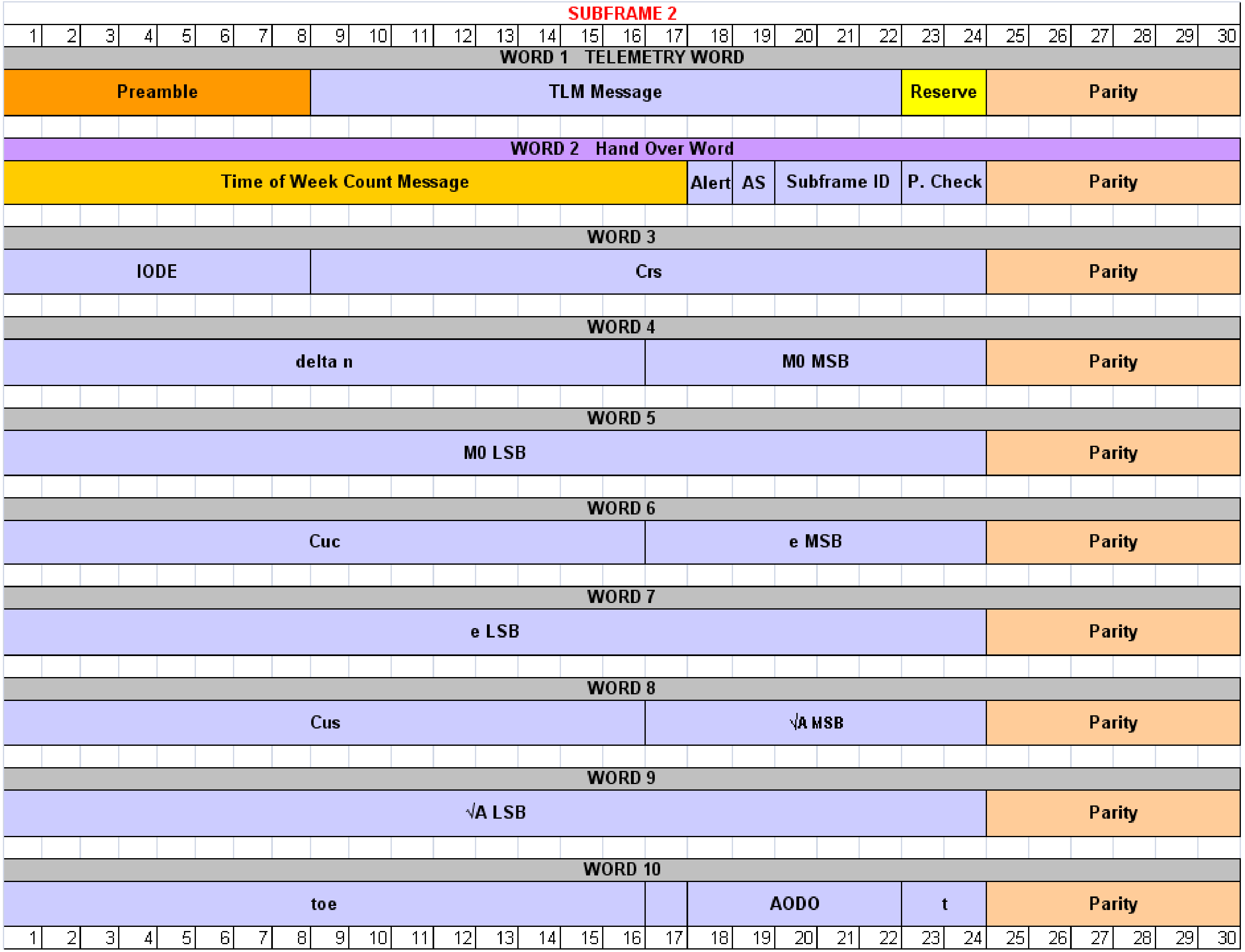
WORD 1 TELEMETRY WORD																													
Preamble								TLM Message														Reserve		Parity					
WORD 2 Hand Over Word																													
Time of Week Count Message																	Alert	AS	Subframe ID			P. Check		Parity					
WORD 3																													
WEEK No										L2 C/A-P		URA				SV Health						IODC MSB		Parity					
WORD 4																													
L2P	Reserve																							Parity					
WORD 5																													
Reserve																								Parity					
WORD 6																													
Reserve																								Parity					
WORD 7																													
Reserve																TGD								Parity					
WORD 8																													
IODC 8 LSB								TOC																Parity					
WORD 9																													
af2								af1																Parity					
WORD 10																													
af0																						t		Parity					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

GPS L1C/A Signal NAV MSG, Sub-frame 2



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<tr><td colspan="30">WORD 1 TELEMETRY WORD</td></tr>
<tr><td colspan="8">Preamble</td><td colspan="14">TLM Message</td><td colspan="2">Reserve</td><td colspan="6">Parity</td></tr>
<tr><td colspan="30">WORD 2 Hand Over Word</td></tr>
<tr><td colspan="17">Time of Week Count Message</td><td>Alert</td><td>AS</td><td colspan="3">Subframe ID</td><td colspan="2">P. Check</td><td colspan="6">Parity</td></tr>
<tr><td colspan="30">WORD 3</td></tr>
<tr><td colspan="8">IODE</td><td colspan="16">Crs</td><td colspan="6">Parity</td></tr>
<tr><td colspan="30">WORD 4</td></tr>
<tr><td colspan="16">delta n</td><td colspan="8">M0 MSB</td><td colspan="6">Parity</td></tr>
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<tr><td colspan="16">Cuc</td><td colspan="8">e MSB</td><td colspan="6">Parity</td></tr>
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<tr><td colspan="24">e LSB</td><td colspan="6">Parity</td></tr>
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<tr><td colspan="16">Cus</td><td colspan="8">√A MSB</td><td colspan="6">Parity</td></tr>
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<tr><td colspan="30">WORD 10</td></tr>
<tr><td colspan="16">toe</td><td></td><td colspan="5">AODO</td><td colspan="2">t</td><td colspan="6">Parity</td></tr>
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GPS L1C/A Signal NAV MSG, Sub-frame 3

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<tr><td colspan="30">WORD 1 TELEMETRY WORD</td></tr>
<tr><td colspan="8">Preamble</td><td colspan="14">TLM Message</td><td colspan="2">Reserve</td><td colspan="6">Parity</td></tr>
<tr><td colspan="30">WORD 2 Hand Over Word</td></tr>
<tr><td colspan="17">Time of Week Count Message</td><td>Alert</td><td>AS</td><td colspan="3">Subframe ID</td><td colspan="2">P. Check</td><td colspan="6">Parity</td></tr>
<tr><td colspan="30">WORD 3</td></tr>
<tr><td colspan="16">Cic</td><td colspan="8">Ω0 MSB</td><td colspan="6">Parity</td></tr>
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<tr><td colspan="30">WORD 5</td></tr>
<tr><td colspan="16">Cis</td><td colspan="8">i0 MSB</td><td colspan="6">Parity</td></tr>
<tr><td colspan="30">WORD 6</td></tr>
<tr><td colspan="24">i0 LSB</td><td colspan="6">Parity</td></tr>
<tr><td colspan="30">WORD 7</td></tr>
<tr><td colspan="16">Crc</td><td colspan="8">ω MSB</td><td colspan="6">Parity</td></tr>
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<tr><td colspan="24">ω LSB</td><td colspan="6">Parity</td></tr>
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<tr><td colspan="24">Ω</td><td colspan="6">Parity</td></tr>
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<tr><td colspan="8">IODE</td><td colspan="14">IDOT</td><td colspan="2">t</td><td colspan="6">Parity</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td></tr>
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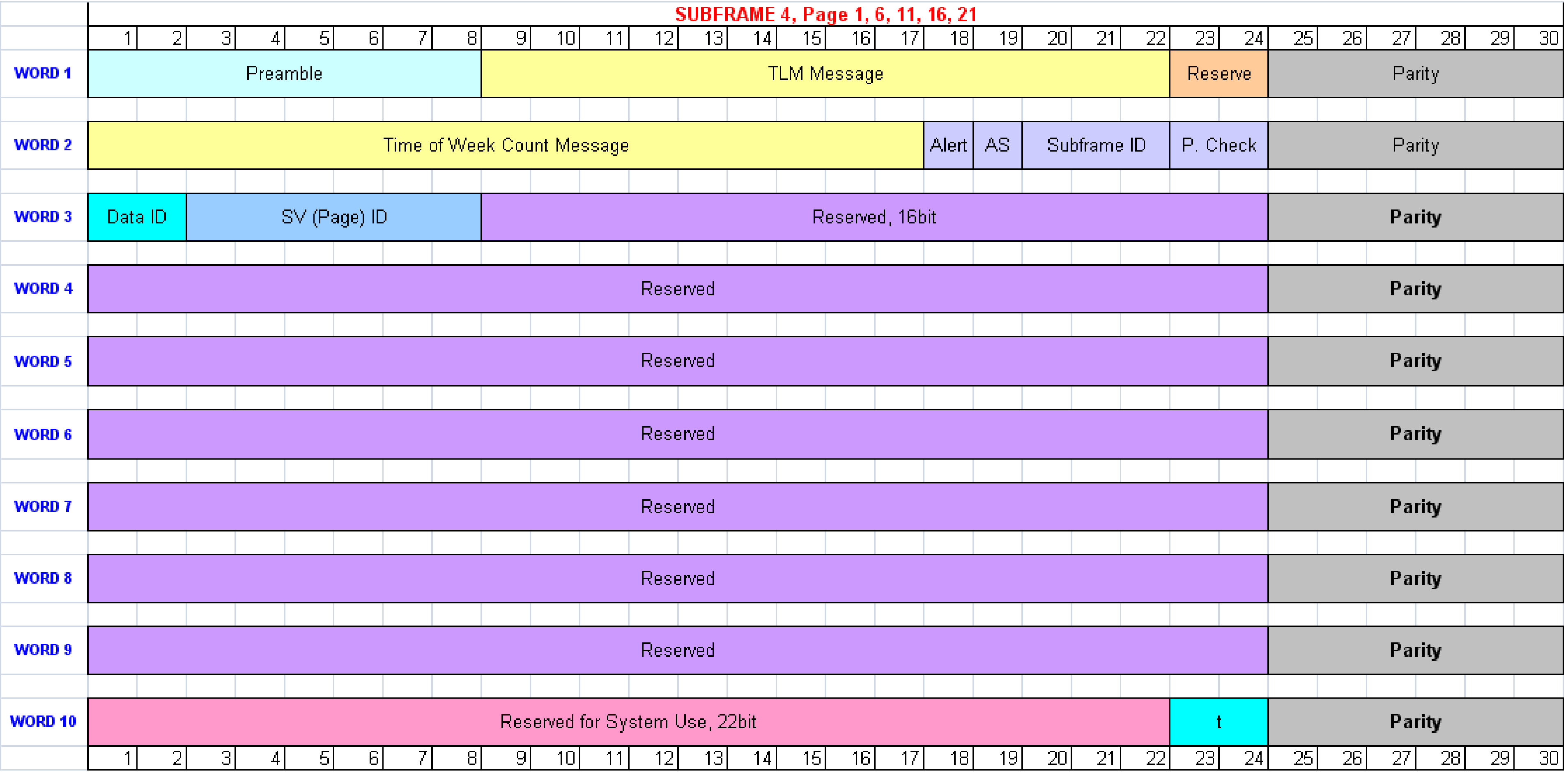
GPS L1C/A Signal NAV MSG, Sub-frame 4 Page 1,6,11,16,21



SUBFRAME 4, Page 1, 6, 11, 16, 21

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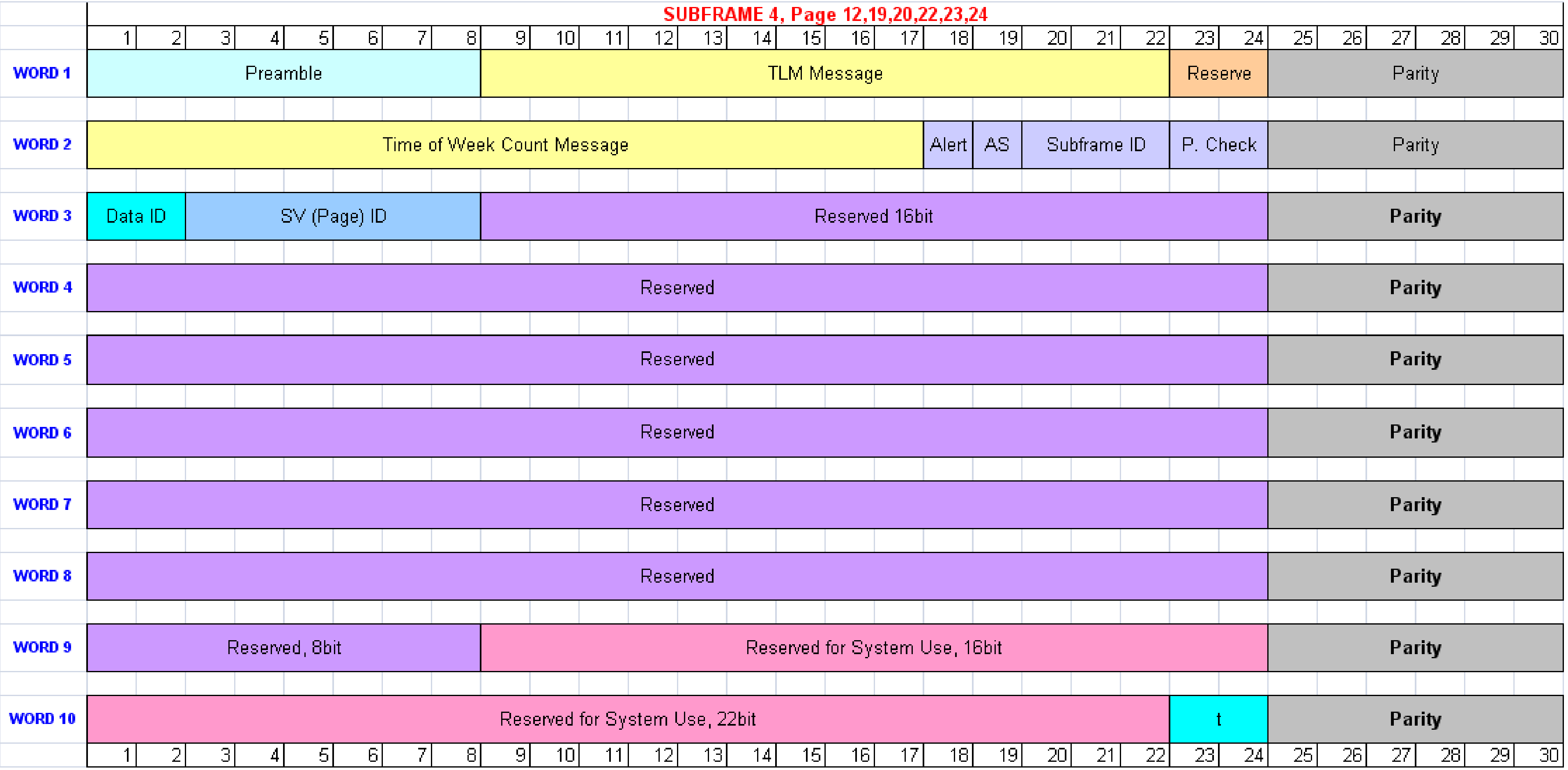
WORD 1	Preamble								TLM Message														Reserve		Parity					
WORD 2	Time of Week Count Message																	Alert	AS	Subframe ID			P. Check		Parity					
WORD 3	Data ID		SV (Page) ID						Reserved, 16bit																**Parity**					
WORD 4	Reserved																								**Parity**					
WORD 5	Reserved																								**Parity**					
WORD 6	Reserved																								**Parity**					
WORD 7	Reserved																								**Parity**					
WORD 8	Reserved																								**Parity**					
WORD 9	Reserved																								**Parity**					
WORD 10	Reserved for System Use, 22bit																						t		**Parity**					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

GPS L1C/A Signal NAV MSG, Sub-frame 4 Page 12,19,20,22,23,24



SUBFRAME 4, Page 12,19,20,22,23,24

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WORD 1	Preamble								TLM Message														Reserve		Parity					
WORD 2	Time of Week Count Message																	Alert	AS	Subframe ID			P. Check		Parity					
WORD 3	Data ID		SV (Page) ID						Reserved 16bit																**Parity**					
WORD 4	Reserved																								**Parity**					
WORD 5	Reserved																								**Parity**					
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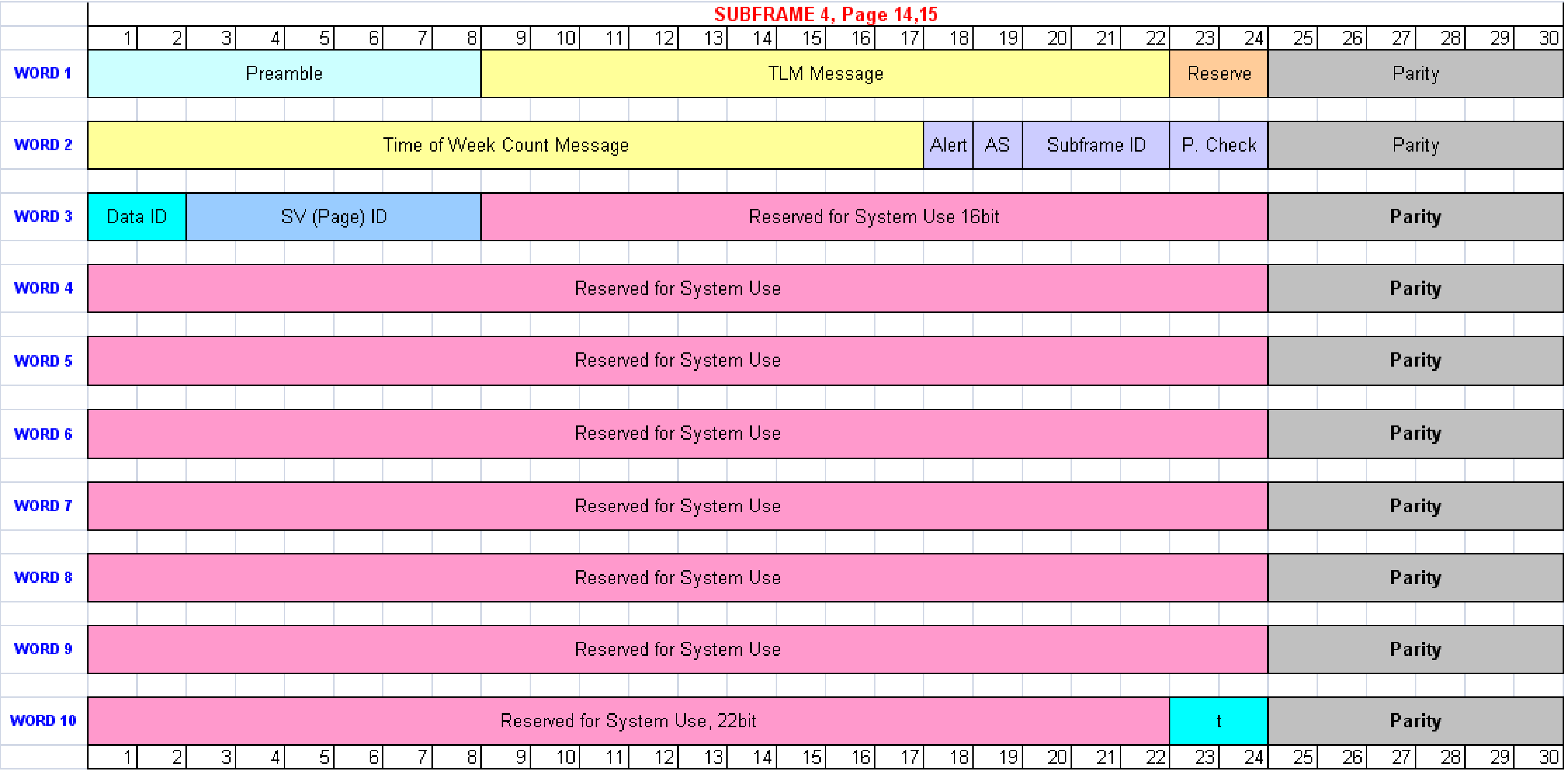
WORD 7	Reserved																								**Parity**					
WORD 8	Reserved																								**Parity**					
WORD 9	Reserved, 8bit								Reserved for System Use, 16bit																**Parity**					
WORD 10	Reserved for System Use, 22bit																						t		**Parity**					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

GPS L1C/A Signal NAV MSG, Sub-frame 4, Page 14, 15



	SUBFRAME 4, Page 14,15																													
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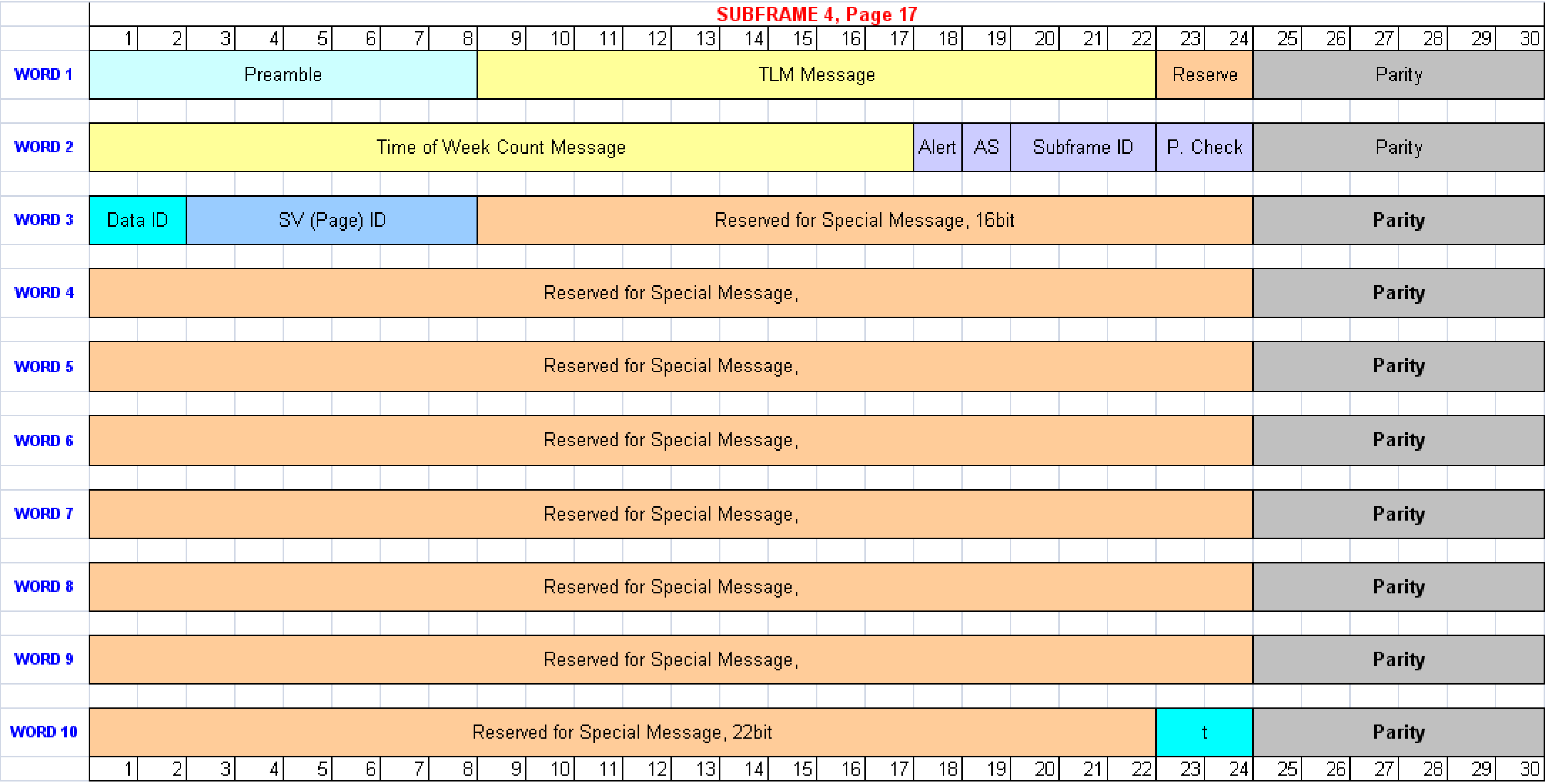
WORD 1	Preamble								TLM Message														Reserve		Parity					
WORD 2	Time of Week Count Message																	Alert	AS	Subframe ID			P. Check		Parity					
WORD 3	Data ID		SV (Page) ID						Reserved for System Use 16bit																**Parity**					
WORD 4	Reserved for System Use																								**Parity**					
WORD 5	Reserved for System Use																								**Parity**					
WORD 6	Reserved for System Use																								**Parity**					
WORD 7	Reserved for System Use																								**Parity**					
WORD 8	Reserved for System Use																								**Parity**					
WORD 9	Reserved for System Use																								**Parity**					
WORD 10	Reserved for System Use, 22bit																						t		**Parity**					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

GPS L1C/A Signal NAV MSG, Sub-frame 4, Page 17



SUBFRAME 4, Page 17

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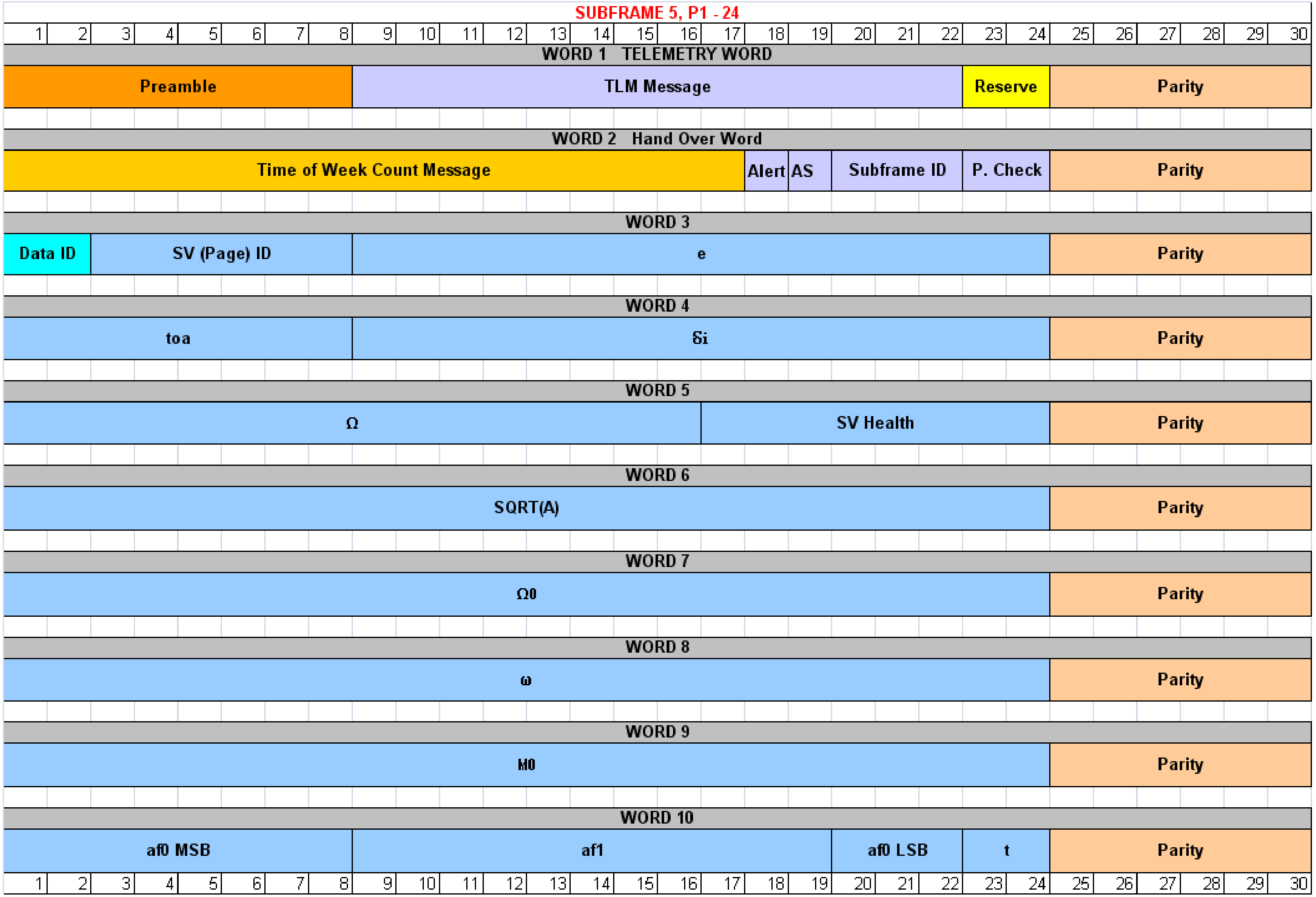
WORD 1	Preamble								TLM Message														Reserve		Parity					
WORD 2	Time of Week Count Message																	Alert	AS	Subframe ID			P. Check		Parity					
WORD 3	Data ID		SV (Page) ID						Reserved for Special Message, 16bit																**Parity**					
WORD 4	Reserved for Special Message,																								**Parity**					
WORD 5	Reserved for Special Message,																								**Parity**					
WORD 6	Reserved for Special Message,																								**Parity**					
WORD 7	Reserved for Special Message,																								**Parity**					
WORD 8	Reserved for Special Message,																								**Parity**					
WORD 9	Reserved for Special Message,																								**Parity**					
WORD 10	Reserved for Special Message, 22bit																						t		**Parity**					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

GPS L1C/A Signal NAV MSG, Sub-frame 5



SUBFRAME 5, P1 - 24

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<tr><td colspan="30">WORD 1 TELEMETRY WORD</td></tr>
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<tr><td colspan="30">WORD 2 Hand Over Word</td></tr>
<tr><td colspan="17">Time of Week Count Message</td><td>Alert</td><td>AS</td><td colspan="3">Subframe ID</td><td colspan="2">P. Check</td><td colspan="6">Parity</td></tr>
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<tr><td colspan="30">WORD 4</td></tr>
<tr><td colspan="8">toa</td><td colspan="16">δi</td><td colspan="6">Parity</td></tr>
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<tr><td colspan="30">WORD 9</td></tr>
<tr><td colspan="24">M0</td><td colspan="6">Parity</td></tr>
<tr><td colspan="30">WORD 10</td></tr>
<tr><td colspan="8">af0 MSB</td><td colspan="11">af1</td><td colspan="3">af0 LSB</td><td colspan="2">t</td><td colspan="6">Parity</td></tr>
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</table>

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

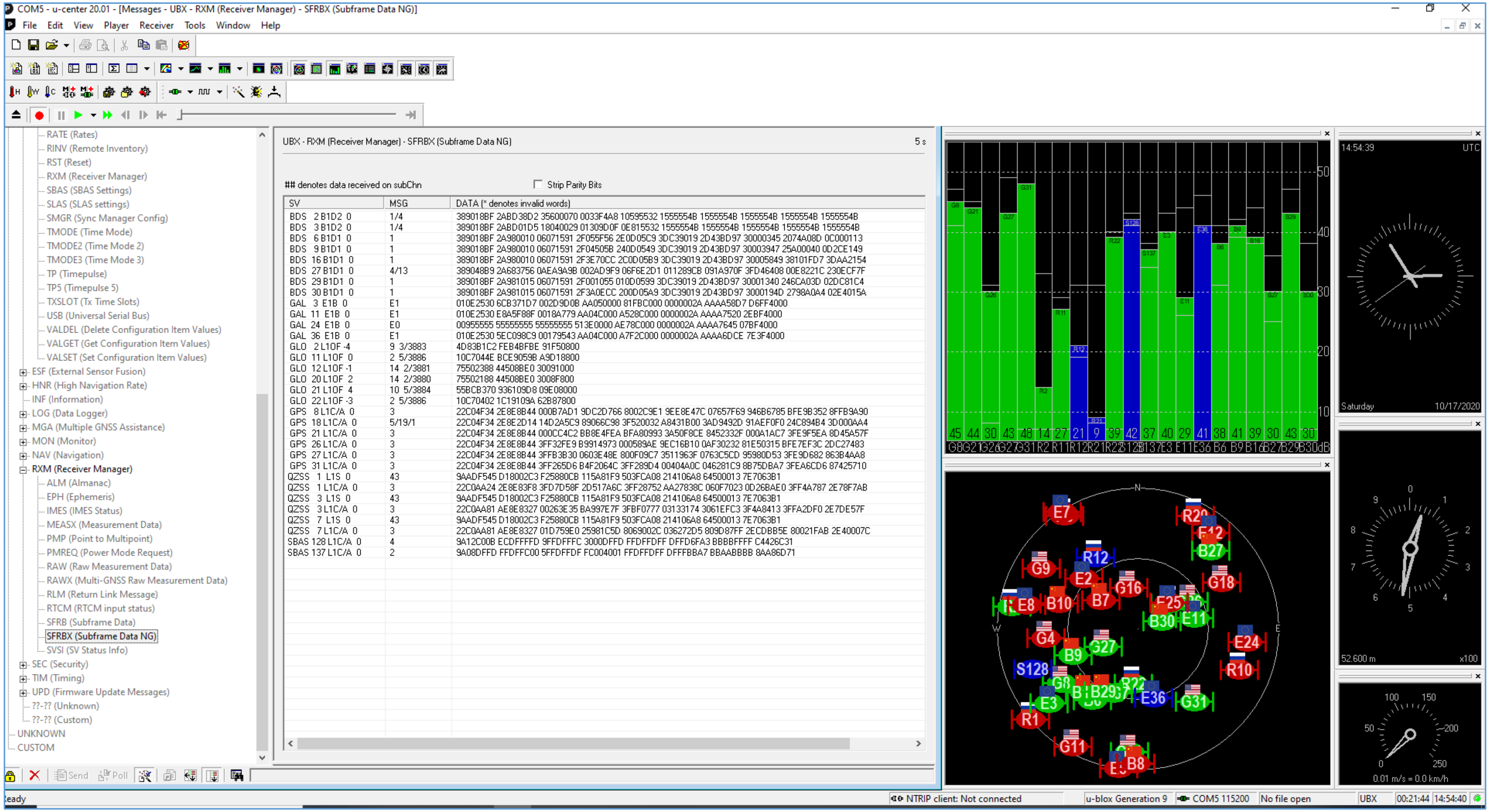
Part - C

SBAS Message Format

Preamble **8 bits**	**Message Type** **6 bits**	**Data** **212 bits**	**CRC** **24 bits**

Data Rate	: 250bps
Symbol Rate	: 500sps (1/2 rate FEC)

U-blox Screen Shot

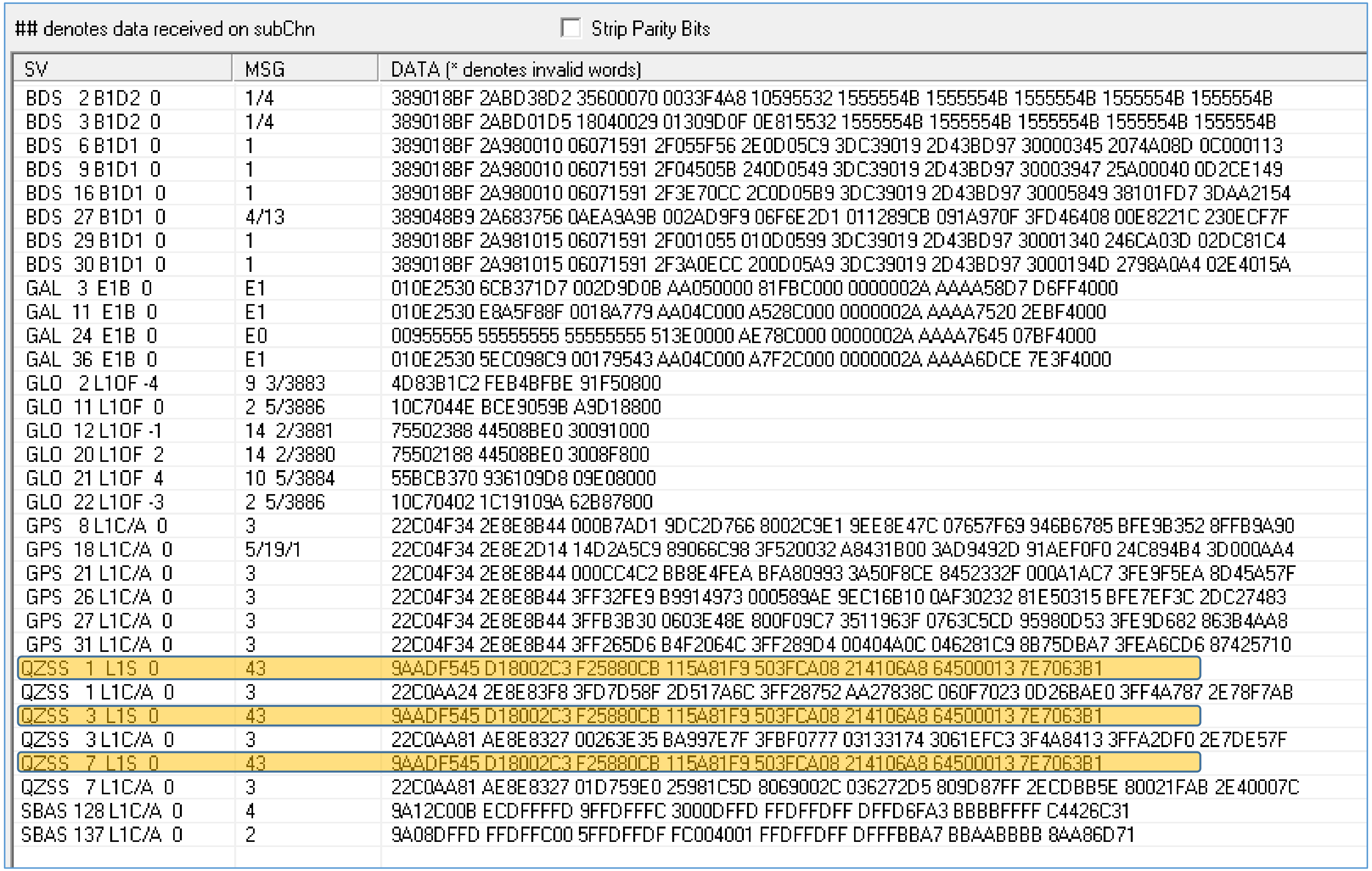


UBX - RXM (Receiver Manager) - SFRBX (Subframe Data NG)

denotes data received on subChn ☐ Strip Parity Bits

```
SV                 MSG          DATA (* denotes invalid words)
BDS   2 B1D2  0    1/4          389018BF 2ABD38D2 35600070 0033F4A8 10595532 1555554B 1555554B 1555554B 1555554B 1555554B
BDS   3 B1D2  0    1/4          389018BF 2ABD01D5 18040029 01309D0F 0E815532 1555554B 1555554B 1555554B 1555554B 1555554B
BDS   6 B1D1  0    1            389018BF 2A980010 06071591 2F055F56 2E0D05C9 3DC39019 2D43BD97 30000345 2074A08D 0C000113
BDS   9 B1D1  0    1            389018BF 2A980010 06071591 2F04505B 240D0549 3DC39019 2D43BD97 30003947 25A00040 0D2CE149
BDS  16 B1D1  0    1            389018BF 2A980010 06071591 2F3E70CC 2C0D05B9 3DC39019 2D43BD97 30005849 38101FD7 3DAA2154
BDS  27 B1D1  0    4/13         389048B9 2A683756 0AEA9A9B 002AD9F9 06F6E2D1 011289CB 091A970F 3FD46408 00E8221C 230ECF7F
BDS  29 B1D1  0    1            389018BF 2A981015 06071591 2F001055 010D0599 3DC39019 2D43BD97 30001340 246CA03D 02DC81C4
BDS  30 B1D1  0    1            389018BF 2A981015 06071591 2F3A0ECC 200D05A9 3DC39019 2D43BD97 3000194D 2798A0A4 02E4015A
GAL   3  E1B  0    E1           010E2530 6CB371D7 002D9D0B AA050000 81FBC000 0000002A AAAA58D7 D6FF4000
GAL  11  E1B  0    E1           010E2530 E8A5F88F 0018A779 AA04C000 A528C000 0000002A AAAA7520 2EBF4000
GAL  24  E1B  0    E0           00955555 55555555 55555555 513E0000 AE78C000 0000002A AAAA7645 07BF4000
GAL  36  E1B  0    E1           010E2530 5EC098C9 00179543 AA04C000 A7F2C000 0000002A AAAA6DCE 7E3F4000
GLO   2 L1OF -4    9  3/3883    4D83B1C2 FEB4BFBE 91F50800
GLO  11 L1OF  0    2  5/3886    10C7044E BCE9059B A9D18800
GLO  12 L1OF -1    14  2/3881   75502388 44508BE0 30091000
GLO  20 L1OF  2    14  2/3880   75502188 44508BE0 3008F800
GLO  21 L1OF  4    10  5/3884   55BCB370 936109D8 09E08000
GLO  22 L1OF -3    2  5/3886    10C70402 1C19109A 62B87800
GPS   8 L1C/A  0   3            22C04F34 2E8E8B44 000B7AD1 9DC2D766 8002C9E1 9EE8E47C 07657F69 946B6785 BFE9B352 8FFB9A90
GPS  18 L1C/A  0   5/19/1       22C04F34 2E8E2D14 14D2A5C9 89066C98 3F520032 A8431B00 3AD9492D 91AEF0F0 24C894B4 3D000AA4
GPS  21 L1C/A  0   3            22C04F34 2E8E8B44 000CC4C2 BB8E4FEA BFA80993 3A50F8CE 8452332F 000A1AC7 3FE9F5EA 8D45A57F
GPS  26 L1C/A  0   3            22C04F34 2E8E8B44 3FF32FE9 B9914973 000589AE 9EC16B10 0AF30232 81E50315 BFE7EF3C 2DC27483
GPS  27 L1C/A  0   3            22C04F34 2E8E8B44 3FFB3B30 0603E48E 800F09C7 3511963F 0763C5CD 95980D53 3FE9D682 863B4AA8
GPS  31 L1C/A  0   3            22C04F34 2E8E8B44 3FF265D6 B4F2064C 3FF289D4 00404A0C 046281C9 8B75DBA7 3FEA6CD6 87425710
QZSS   1  L1S  0   43           9AADF545 D18002C3 F25880CB 115A81F9 503FCA08 214106A8 64500013 7E7063B1
QZSS   1 L1C/A  0  3            22C0AA24 2E8E83F8 3FD7D58F 2D517A6C 3FF28752 AA27838C 060F7023 0D26BAE0 3FF4A787 2E78F7AB
QZSS   3  L1S  0   43           9AADF545 D18002C3 F25880CB 115A81F9 503FCA08 214106A8 64500013 7E7063B1
QZSS   3 L1C/A  0  3            22C0AA81 AE8E8327 00263E35 BA997E7F 3FBF0777 03133174 3061EFC3 3F4A8413 3FFA2DF0 2E7DE57F
QZSS   7  L1S  0   43           9AADF545 D18002C3 F25880CB 115A81F9 503FCA08 214106A8 64500013 7E7063B1
QZSS   7 L1C/A  0  3            22C0AA81 AE8E8327 01D759E0 25981C5D 8069002C 036272D5 809D87FF 2ECDBB5E 80021FAB 2E40007C
SBAS 128 L1C/A  0  4            9A12C00B ECDFFFFD 9FFDFFFC 3000DFFD FFDFFDFF DFFD6FA3 BBBBFFFF C4426C31
SBAS 137 L1C/A  0  2            9A08DFFD FFDFFC00 5FFDFFDF FC004001 FFDFFDFF DFFFBBA7 BBAABBBB 8AA86D71
```

GNSS Navigation Data Bits



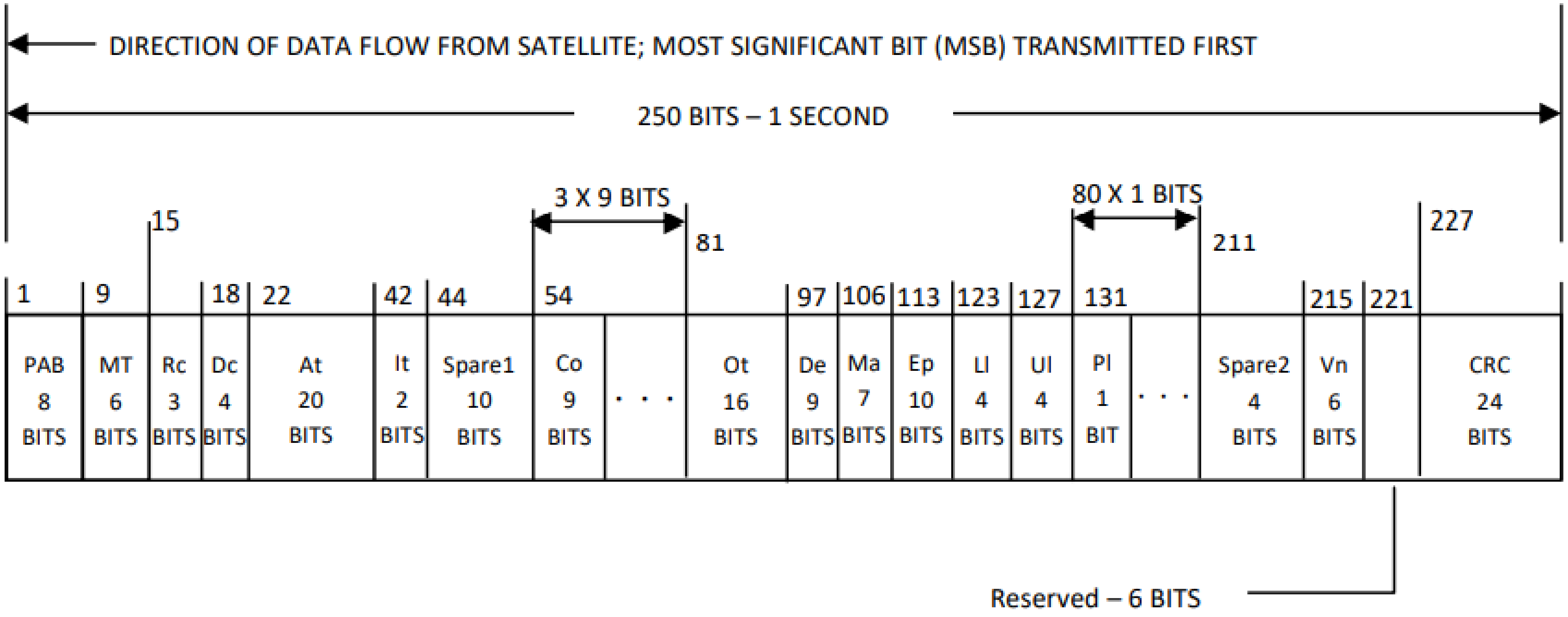
denotes data received on subChn ☐ Strip Parity Bits

SV	MSG	DATA (* denotes invalid words)
BDS 2 B1D2 0	1/4	389018BF 2ABD38D2 35600070 0033F4A8 10595532 1555554B 1555554B 1555554B 1555554B 1555554B
BDS 3 B1D2 0	1/4	389018BF 2ABD01D5 18040029 01309D0F 0E815532 1555554B 1555554B 1555554B 1555554B 1555554B
BDS 6 B1D1 0	1	389018BF 2A980010 06071591 2F055F56 2E0D05C9 3DC39019 2D43BD97 30000345 2074A08D 0C000113
BDS 9 B1D1 0	1	389018BF 2A980010 06071591 2F04505B 240D0549 3DC39019 2D43BD97 30003947 25A00040 0D2CE149
BDS 16 B1D1 0	1	389018BF 2A980010 06071591 2F3E70CC 2C0D05B9 3DC39019 2D43BD97 30005849 38101FD7 3DAA2154
BDS 27 B1D1 0	4/13	389048B9 2A683756 0AEA9A9B 002AD9F9 06F6E2D1 011289CB 091A970F 3FD46408 00E8221C 230ECF7F
BDS 29 B1D1 0	1	389018BF 2A981015 06071591 2F001055 010D0599 3DC39019 2D43BD97 30001340 246CA03D 02DC81C4
BDS 30 B1D1 0	1	389018BF 2A981015 06071591 2F3A0ECC 200D05A9 3DC39019 2D43BD97 3000194D 2798A0A4 02E4015A
GAL 3 E1B 0	E1	010E2530 6CB371D7 002D9D0B AA050000 81FBC000 0000002A AAAA58D7 D6FF4000
GAL 11 E1B 0	E1	010E2530 E8A5F88F 0018A779 AA04C000 A528C000 0000002A AAAA7520 2EBF4000
GAL 24 E1B 0	E0	00955555 55555555 55555555 513E0000 AE78C000 0000002A AAAA7645 07BF4000
GAL 36 E1B 0	E1	010E2530 5EC098C9 00179543 AA04C000 A7F2C000 0000002A AAAA6DCE 7E3F4000
GLO 2 L1OF -4	9 3/3883	4D83B1C2 FEB4BFBE 91F50800
GLO 11 L1OF 0	2 5/3886	10C7044E BCE9059B A9D18800
GLO 12 L1OF -1	14 2/3881	75502388 44508BE0 30091000
GLO 20 L1OF 2	14 2/3880	75502188 44508BE0 3008F800
GLO 21 L1OF 4	10 5/3884	55BCB370 936109D8 09E08000
GLO 22 L1OF -3	2 5/3886	10C70402 1C19109A 62B87800
GPS 8 L1C/A 0	3	22C04F34 2E8E8B44 000B7AD1 9DC2D766 8002C9E1 9EE8E47C 07657F69 946B6785 BFE9B352 8FFB9A90
GPS 18 L1C/A 0	5/19/1	22C04F34 2E8E2D14 14D2A5C9 89066C98 3F520032 A8431B00 3AD9492D 91AEF0F0 24C894B4 3D000AA4
GPS 21 L1C/A 0	3	22C04F34 2E8E8B44 000CC4C2 BB8E4FEA BFA80993 3A50F8CE 8452332F 000A1AC7 3FE9F5EA 8D45A57F
GPS 26 L1C/A 0	3	22C04F34 2E8E8B44 3FF32FE9 B9914973 000589AE 9EC16B10 0AF30232 81E50315 BFE7EF3C 2DC27483
GPS 27 L1C/A 0	3	22C04F34 2E8E8B44 3FFB3B30 0603E48E 800F09C7 3511963F 0763C5CD 95980D53 3FE9D682 863B4AA8
GPS 31 L1C/A 0	3	22C04F34 2E8E8B44 3FF265D6 B4F2064C 3FF289D4 00404A0C 046281C9 8B75DBA7 3FEA6CD6 87425710
QZSS 1 L1S 0	43	9AADF545 D18002C3 F25880CB 115A81F9 503FCA08 214106A8 64500013 7E7063B1
QZSS 1 L1C/A 0	3	22C0AA24 2E8E83F8 3FD7D58F 2D517A6C 3FF28752 AA27838C 060F7023 0D26BAE0 3FF4A787 2E78F7AB
QZSS 3 L1S 0	43	9AADF545 D18002C3 F25880CB 115A81F9 503FCA08 214106A8 64500013 7E7063B1
QZSS 3 L1C/A 0	3	22C0AA81 AE8E8327 00263E35 BA997E7F 3FBF0777 03133174 3061EFC3 3F4A8413 3FFA2DF0 2E7DE57F
QZSS 7 L1S 0	43	9AADF545 D18002C3 F25880CB 115A81F9 503FCA08 214106A8 64500013 7E7063B1
QZSS 7 L1C/A 0	3	22C0AA81 AE8E8327 01D759E0 25981C5D 8069002C 036272D5 809D87FF 2ECDBB5E 80021FAB 2E40007C
SBAS 128 L1C/A 0	4	9A12C00B ECDFFFFD 9FFDFFFC 3000DFFD FFDFFDFF DFFD6FA3 BBBBFFFF C4426C31
SBAS 137 L1C/A 0	2	9A08DFFD FFDFFC00 5FFDFFDF FC004001 FFDFFDFF DFFFBBA7 BBAABBBB 8AA86D71

QZSS Navigation Message Data Bits

```
SV          MSG         DATA (* denotes invalid words)
QZSS  1     L1S     0   43          9AADF545 D18002C3 F25880CB 115A81F9 503FCA08 214106A8 64500013 7E7063B1
QZSS  1     L1C/A  0    3           22C0AA24 2E8E83F8 3FD7D58F 2D517A6C 3FF28752 AA27838C 060F7023 0D26BAE0 3FF4A787 2E78F7AB
QZSS  3     L1S    0    43          9AADF545 D18002C3 F25880CB 115A81F9 503FCA08 214106A8 64500013 7E7063B1
QZSS  3     L1C/A  0    3           22C0AA81 AE8E8327 00263E35 BA997E7F 3FBF0777 03133174 3061EFC3 3F4A8413 3FFA2DF0 2E7DE57F
QZSS  7     L1S    0    43          9AADF545 D18002C3 F25880CB 115A81F9 503FCA08 214106A8 64500013 7E7063B1
QZSS  7     L1C/A  0    3           22C0AA81 AE8E8327 01D759E0 25981C5D 8069002C 036272D5 809D87FF 2ECDBB5E 80021FAB 2E40007C
```

Earthquake Early Warning Message Format



https://qzss.go.jp/en/technical/ps-is-qzss/ps-is-qzss.html

https://qzss.go.jp/en/technical/ps-is-qzss/is_qzss_dcr_008_agree.html

Earthquake Early Warning Message Format

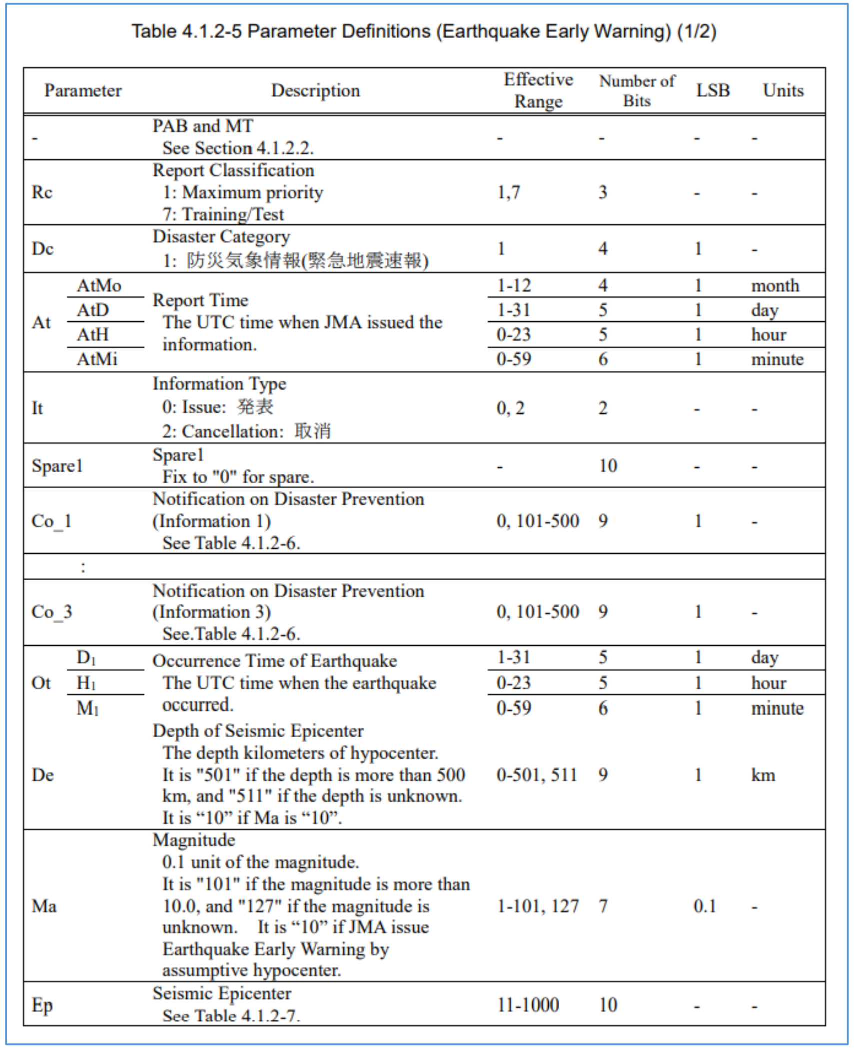


Table 4.1.2-5 Parameter Definitions (Earthquake Early Warning) (1/2)

Parameter	Description	Effective Range	Number of Bits	LSB	Units
-	PAB and MT See Section 4.1.2.2.	-	-	-	-
Rc	Report Classification 1: Maximum priority 7: Training/Test	1,7	3	-	-
Dc	Disaster Category 1: 防災気象情報(緊急地震速報)	1	4	1	-
At AtMo	Report Time The UTC time when JMA issued the information.	1-12	4	1	month
AtD		1-31	5	1	day
AtH		0-23	5	1	hour
AtMi		0-59	6	1	minute
It	Information Type 0: Issue: 発表 2: Cancellation: 取消	0, 2	2	-	-
Spare1	Spare1 Fix to "0" for spare.	-	10	-	-
Co_1	Notification on Disaster Prevention (Information 1) See Table 4.1.2-6.	0, 101-500	9	1	-
:					
Co_3	Notification on Disaster Prevention (Information 3) See.Table 4.1.2-6.	0, 101-500	9	1	-
Ot D_1	Occurrence Time of Earthquake The UTC time when the earthquake occurred.	1-31	5	1	day
H_1		0-23	5	1	hour
M_1		0-59	6	1	minute
De	Depth of Seismic Epicenter The depth kilometers of hypocenter. It is "501" if the depth is more than 500 km, and "511" if the depth is unknown. It is “10” if Ma is “10”.	0-501, 511	9	1	km
Ma	Magnitude 0.1 unit of the magnitude. It is "101" if the magnitude is more than 10.0, and "127" if the magnitude is unknown. It is “10” if JMA issue Earthquake Early Warning by assumptive hypocenter.	1-101, 127	7	0.1	-
Ep	Seismic Epicenter See Table 4.1.2-7.	11-1000	10	-	-

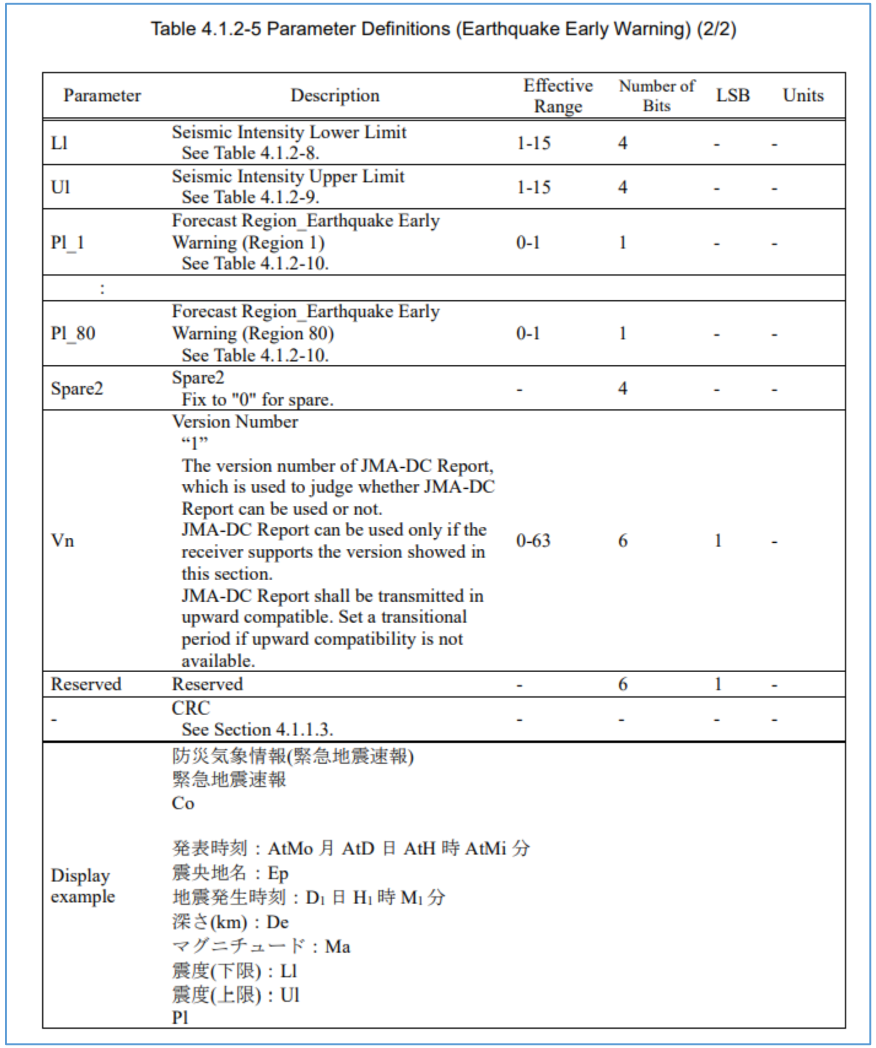


Table 4.1.2-5 Parameter Definitions (Earthquake Early Warning) (2/2)

Parameter	Description	Effective Range	Number of Bits	LSB	Units
Ll	Seismic Intensity Lower Limit See Table 4.1.2-8.	1-15	4	-	-
Ul	Seismic Intensity Upper Limit See Table 4.1.2-9.	1-15	4	-	-
Pl_1	Forecast Region_Earthquake Early Warning (Region 1) See Table 4.1.2-10.	0-1	1	-	-
:					
Pl_80	Forecast Region_Earthquake Early Warning (Region 80) See Table 4.1.2-10.	0-1	1	-	-
Spare2	Spare2 Fix to "0" for spare.	-	4	-	-
Vn	Version Number “1” The version number of JMA-DC Report, which is used to judge whether JMA-DC Report can be used or not. JMA-DC Report can be used only if the receiver supports the version showed in this section. JMA-DC Report shall be transmitted in upward compatible. Set a transitional period if upward compatibility is not available.	0-63	6	1	-
Reserved	Reserved	-	6	1	-
-	CRC See Section 4.1.1.3.	-	-	-	-
Display example	防災気象情報(緊急地震速報) 緊急地震速報 Co 発表時刻：AtMo 月 AtD 日 AtH 時 AtMi 分 震央地名：Ep 地震発生時刻：D_1 日 H_1 時 M_1 分 深さ(km)：De マグニチュード：Ma 震度(下限)：Ll 震度(上限)：Ul Pl				

DC Report message output from a receiver

- DC Report message output format
  - All output data shall be interpreted as ASCII characters
  - The beginning of the sentence is message header "$QZQSM“
  - Satellite ID is 6 LSB of the 8 bit which represented PRN of the L1S
    - PRN 183 → 0xB7 → 10110111_b → 110111_b (Take 6LSBs) → 55_{10}
    - PRN 183 corresponds to 55
  - 250bit DC Report Message are added two binary data "00" at end of a message to make 252 bit data
  - A carriage return code (CR) and a linefeed code (LF) are added at the end of a sentence

DC Report message output from a receiver

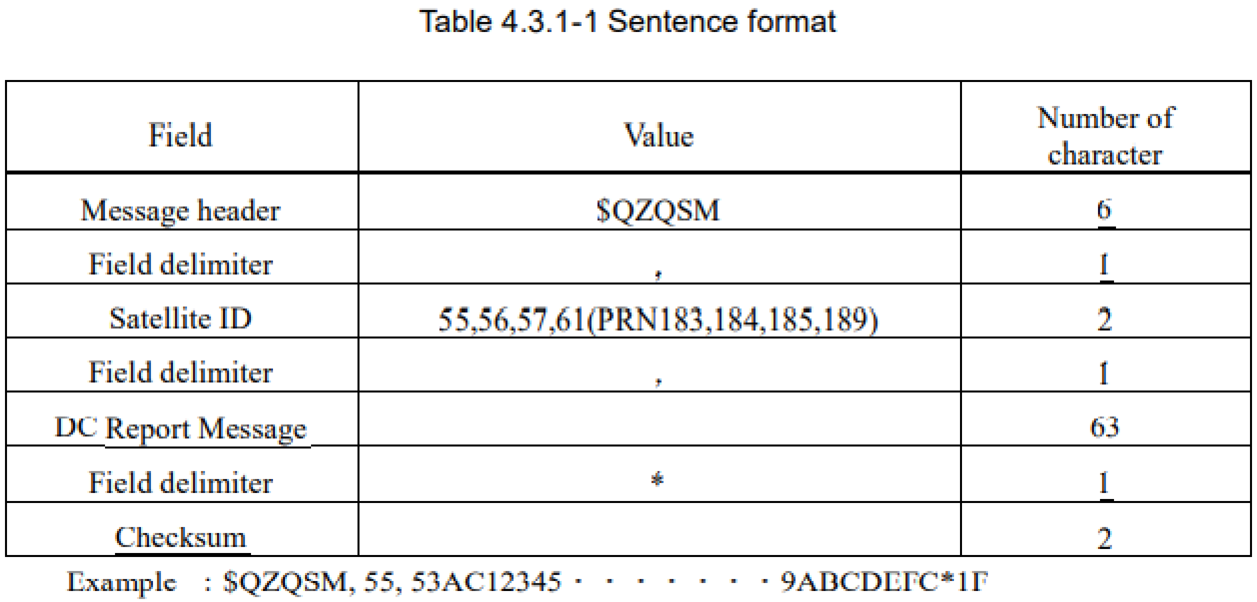


Table 4.3.1-1 Sentence format

Field	Value	Number of character
Message header	$QZQSM	6
Field delimiter	,	1
Satellite ID	55,56,57,61(PRN183,184,185,189)	2
Field delimiter	,	1
DC Report Message		63
Field delimiter	*	1
Checksum		2

Example : $QZQSM, 55, 53AC12345・・・・・・・9ABCDEFC*1F

Part - D

Data Formats: NMEA, RINEX, RTCM

References: https://www.nmea.org/
http://freenmea.net/docs

National Marine Electronics Association (NMEA) Format

- NMEA is format to output measurement data from a sensor in a pre-defined format in ASCII
- In the case of GPS, It outputs GPS position, velocity, time and satellite related data
- NMEA sentences (output) begins with a “Talker ID” and “Message Description”
  - Example: $GPGGA,123519,4807.038,N,01131.000,E,1,08,0.9,545.4,M,46.9,M,,*47
  - “$GP” is Talker ID
  - “GGA” is Message Description to indicate for Position Data

NMEA Data Format

GGA - Fix data which provide 3D location and accuracy data.

$GPGGA,123519,4807.038,N,01131.000,E,1,08,0.9,545.4,M,46.9,M,,*47

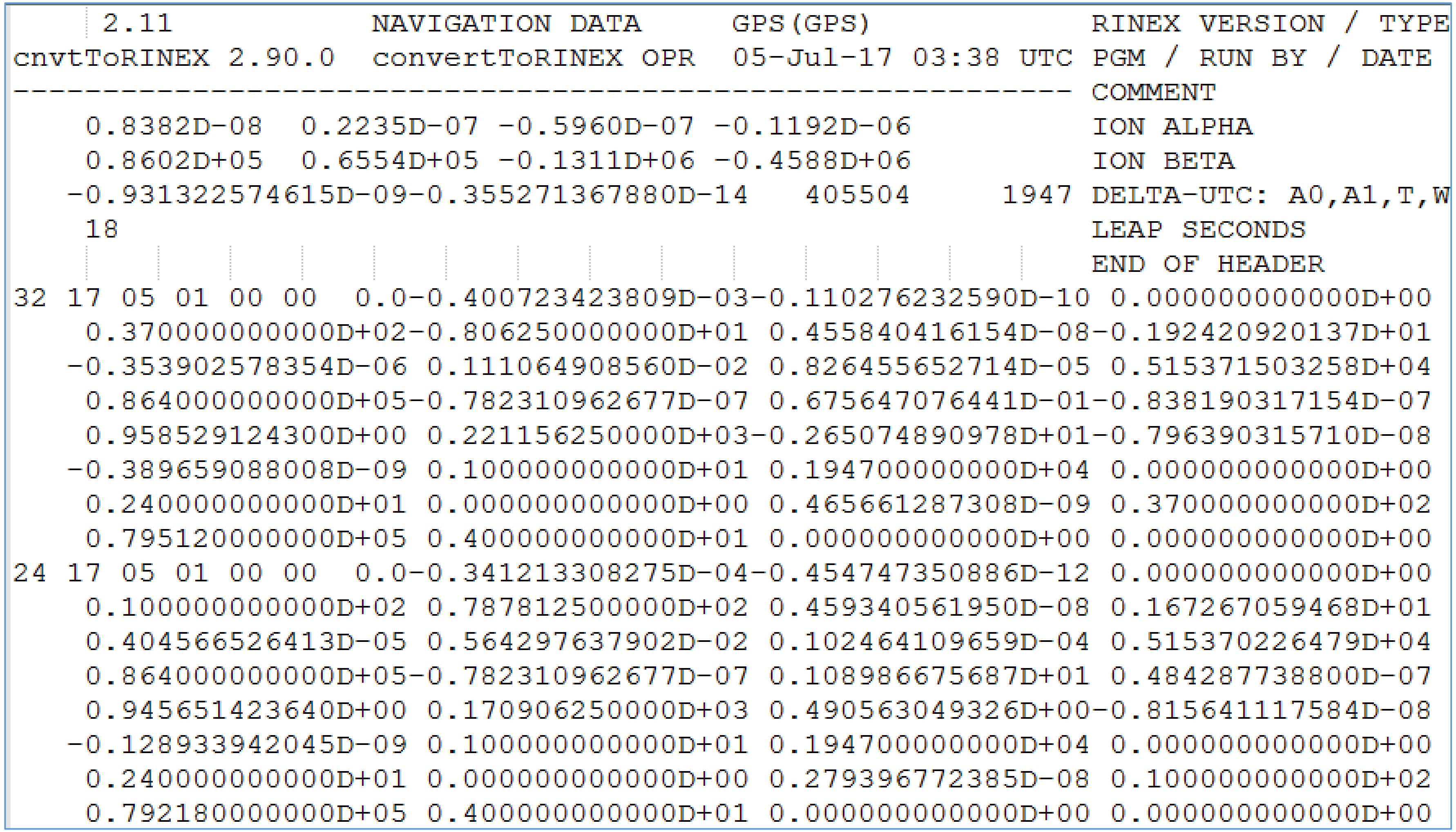
Where: GGA Global Positioning System Fix Data

123519	Fix taken at 12:35:19 UTC
4807.038, N	Latitude 48 deg 07.038' N
01131.000, E	Longitude 11 deg 31.000' E
1 Fix quality:	
	0 = invalid ,
	1 = GPS fix (SPS),
	2 = DGPS fix,
	3 = PPS fix,
	4 = Real Time Kinematic
	5 = Float RTK
	6 = estimated (dead reckoning) (2.3 feature)
	7 = Manual input mode
	8 = Simulation mode
08	Number of satellites being tracked
0.9	Horizontal dilution of position
545.4,M	Altitude, Meters, above mean sea level
46.9,M	Height of geoid (mean sea level) above WGS84 ellipsoid
(empty field)	time in seconds since last DGPS update (empty field) DGPS station ID number
*47	the checksum data, always begins with *

RINEX Data Format

- RINEX: Receiver Independent Exchange Format is a data exchange format for raw satellite data among different types of receivers.
  - Different types of receivers may output position and raw data in proprietary formats
  - For post-processing of data using DGPS or RTK it is necessary to use data from different types of receivers. A common data format is necessary for this purpose.
  - Example: How to post process data from Trimble, Novatel and Septenrtio receivers to compute a position?
- RINEX only provides Raw Data. It does not provide position output.
  - User has to post-process RINEX data to compute position
  - Raw data consists of Pseudorage, Carrierphase, Doppler, SNR
- RINEX basically consists of two data types
  - “*.*N” file for Satellite and Ephemeris Related data.
    - Also called Navigation Data
  - “*.*O” file for Signal Observation Data like Pseudorange, Carrier Phase, Doppler, SNR
    - Also called Observation Data
- The latest RINEX version is 3.04, 23 NOV 2018
  - Note: Not all the software and receivers are yet compatible with the latest version
  - Make sure which version of RINEX works the best with your software

RINEX "N" File for GPS



```
     2.11           NAVIGATION DATA     GPS(GPS)            RINEX VERSION / TYPE
cnvtToRINEX 2.90.0  convertToRINEX OPR  05-Jul-17 03:38 UTC PGM / RUN BY / DATE
----------------------------------------------------------- COMMENT
    0.8382D-08  0.2235D-07 -0.5960D-07 -0.1192D-06          ION ALPHA
    0.8602D+05  0.6554D+05 -0.1311D+06 -0.4588D+06          ION BETA
   -0.931322574615D-09-0.355271367880D-14   405504     1947 DELTA-UTC: A0,A1,T,W
    18                                                      LEAP SECONDS
                                                            END OF HEADER
32 17 05 01 00 00  0.0-0.400723423809D-03-0.110276232590D-10 0.000000000000D+00
    0.370000000000D+02-0.806250000000D+01 0.455840416154D-08-0.192420920137D+01
   -0.353902578354D-06 0.111064908560D-02 0.826455652714D-05 0.515371503258D+04
    0.864000000000D+05-0.782310962677D-07 0.675647076441D-01-0.838190317154D-07
    0.958529124300D+00 0.221156250000D+03-0.265074890978D+01-0.796390315710D-08
   -0.389659088008D-09 0.100000000000D+01 0.194700000000D+04 0.000000000000D+00
    0.240000000000D+01 0.000000000000D+00 0.465661287308D-09 0.370000000000D+02
    0.795120000000D+05 0.400000000000D+01 0.000000000000D+00 0.000000000000D+00
24 17 05 01 00 00  0.0-0.341213308275D-04-0.454747350886D-12 0.000000000000D+00
    0.100000000000D+02 0.787812500000D+02 0.459340561950D-08 0.167267059468D+01
    0.404566526413D-05 0.564297637902D-02 0.102464109659D-04 0.515370226479D+04
    0.864000000000D+05-0.782310962677D-07 0.108986675687D+01 0.484287738800D-07
    0.945651423640D+00 0.170906250000D+03 0.490563049326D+00-0.815641117584D-08
   -0.128933942045D-09 0.100000000000D+01 0.194700000000D+04 0.000000000000D+00
    0.240000000000D+01 0.000000000000D+00 0.279396772385D-08 0.100000000000D+02
    0.792180000000D+05 0.400000000000D+01 0.000000000000D+00 0.000000000000D+00
```

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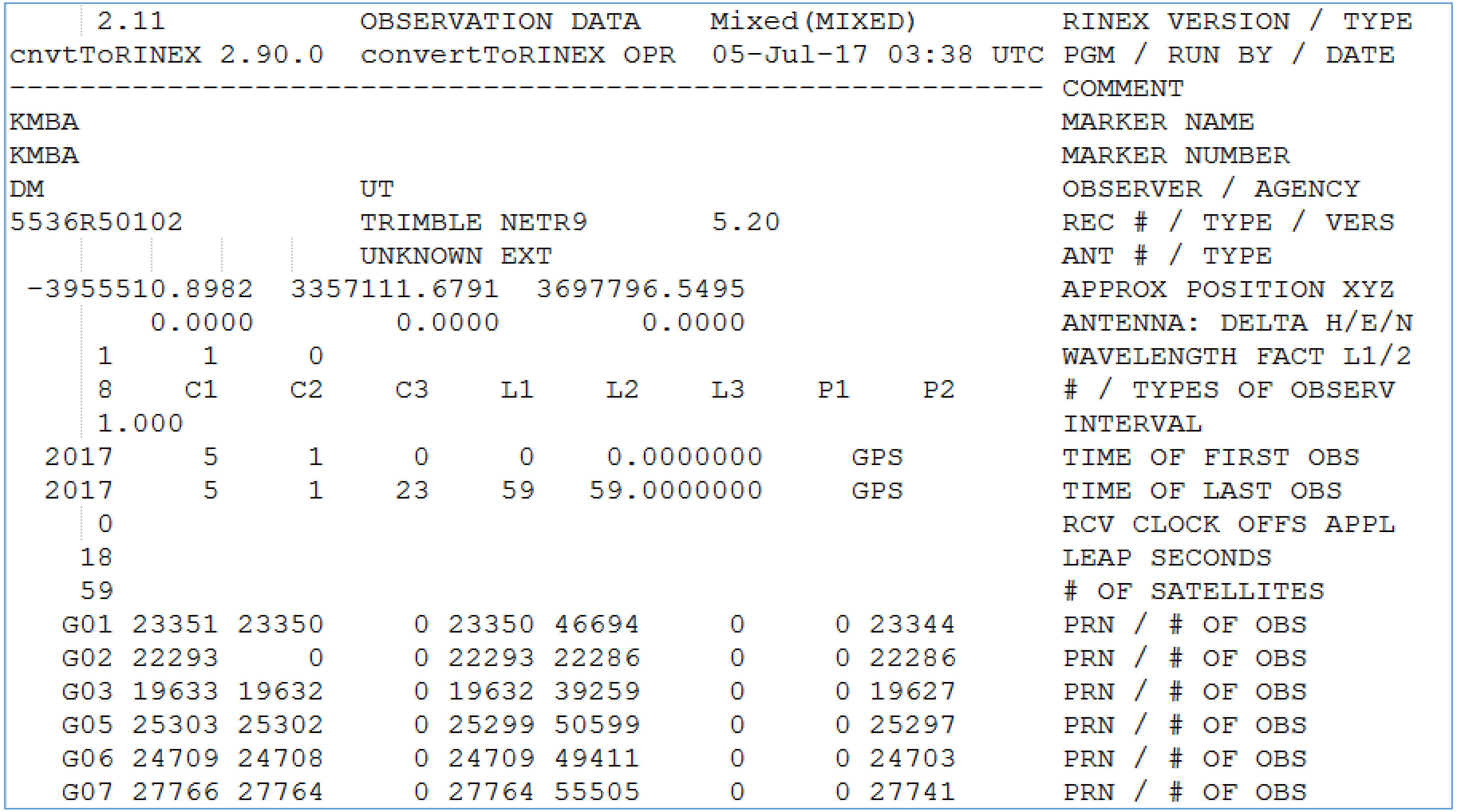
RINEX “O” File GPS, GLONASS, GALILEO, QZSS, SBAS



```
     2.11           OBSERVATION DATA    Mixed(MIXED)        RINEX VERSION / TYPE
cnvtToRINEX 2.90.0  convertToRINEX OPR  05-Jul-17 03:38 UTC PGM / RUN BY / DATE
------------------------------------------------------------COMMENT
KMBA                                                        MARKER NAME
KMBA                                                        MARKER NUMBER
DM                  UT                                      OBSERVER / AGENCY
5536R50102          TRIMBLE NETR9       5.20                REC # / TYPE / VERS
                    UNKNOWN EXT                             ANT # / TYPE
 -3955510.8982  3357111.6791  3697796.5495                  APPROX POSITION XYZ
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
     1     1     0                                          WAVELENGTH FACT L1/2
     8    C1    C2    C3    L1    L2    L3    P1    P2      # / TYPES OF OBSERV
     1.000                                                  INTERVAL
  2017     5     1     0     0    0.0000000     GPS         TIME OF FIRST OBS
  2017     5     1    23    59   59.0000000     GPS         TIME OF LAST OBS
     0                                                      RCV CLOCK OFFS APPL
    18                                                      LEAP SECONDS
    59                                                      # OF SATELLITES
   G01 23351 23350     0 23350 46694     0     0 23344      PRN / # OF OBS
   G02 22293     0     0 22293 22286     0     0 22286      PRN / # OF OBS
   G03 19633 19632     0 19632 39259     0     0 19627      PRN / # OF OBS
   G05 25303 25302     0 25299 50599     0     0 25297      PRN / # OF OBS
   G06 24709 24708     0 24709 49411     0     0 24703      PRN / # OF OBS
   G07 27766 27764     0 27764 55505     0     0 27741      PRN / # OF OBS
```

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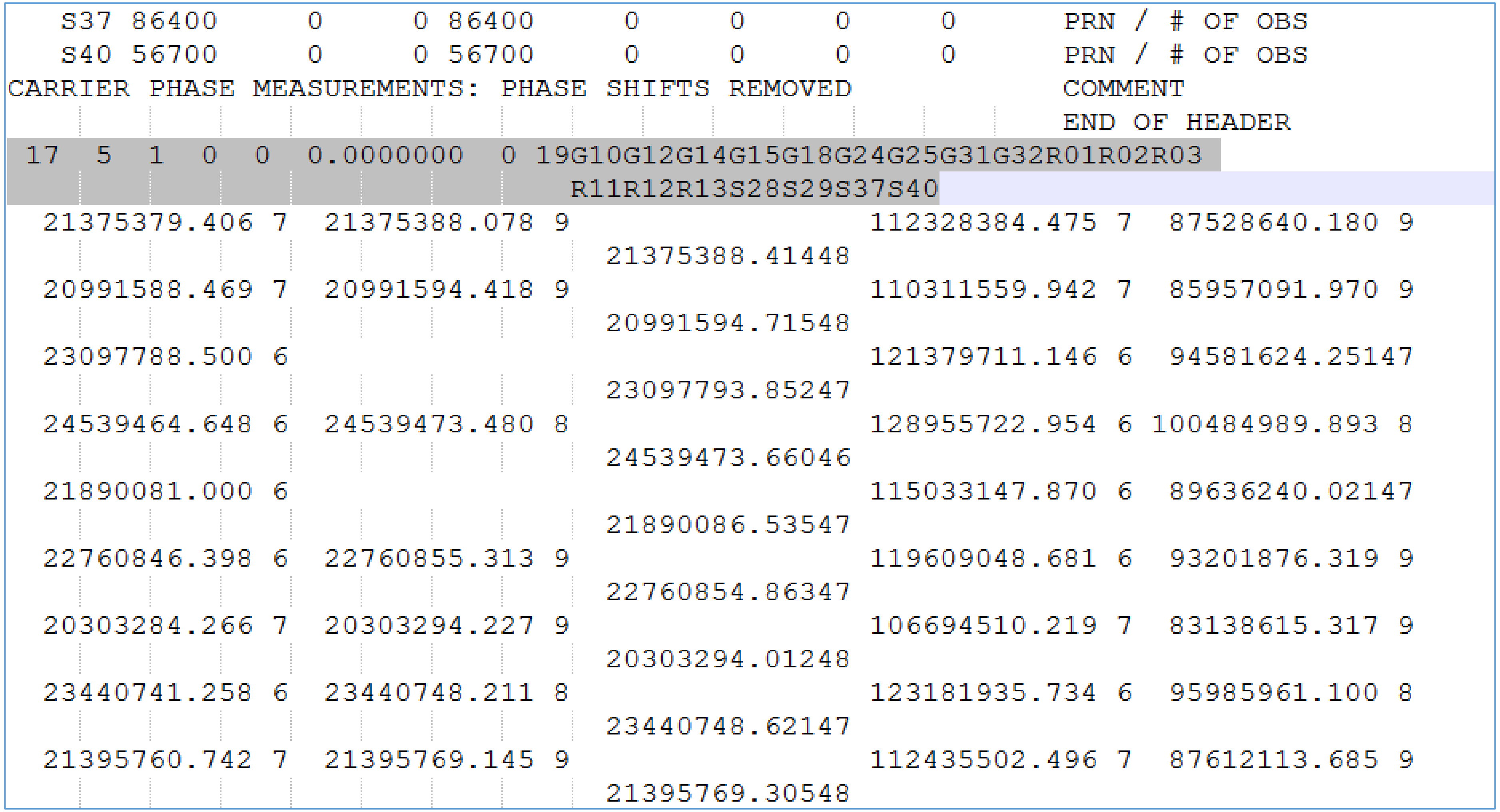
RINEX “O” File, Continued from previous slide



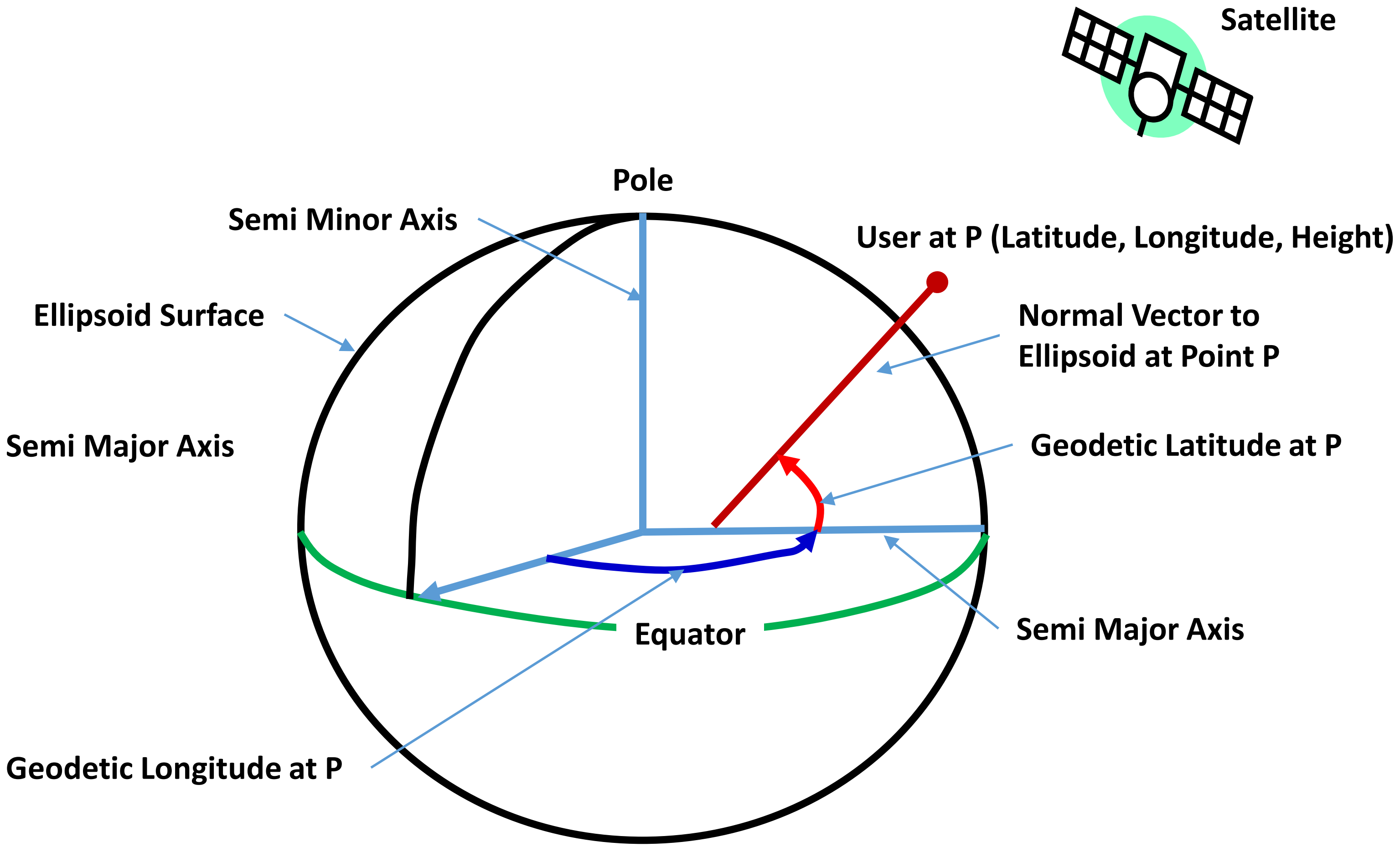
```
   S37 86400     0     0 86400     0     0     0     0      PRN / # OF OBS
   S40 56700     0     0 56700     0     0     0     0      PRN / # OF OBS
CARRIER PHASE MEASUREMENTS: PHASE SHIFTS REMOVED            COMMENT
                                                            END OF HEADER
 17  5  1  0  0  0.0000000  0 19G10G12G14G15G18G24G25G31G32R01R02R03
                                R11R12R13S28S29S37S40
  21375379.406 7  21375388.078 9                 112328384.475 7  87528640.180 9
                                  21375388.41448
  20991588.469 7  20991594.418 9                 110311559.942 7  85957091.970 9
                                  20991594.71548
  23097788.500 6                                 121379711.146 6  94581624.25147
                                  23097793.85247
  24539464.648 6  24539473.480 8                 128955722.954 6 100484989.893 8
                                  24539473.66046
  21890081.000 6                                 115033147.870 6  89636240.02147
                                  21890086.53547
  22760846.398 6  22760855.313 9                 119609048.681 6  93201876.319 9
                                  22760854.86347
  20303284.266 7  20303294.227 9                 106694510.219 7  83138615.317 9
                                  20303294.01248
  23440741.258 6  23440748.211 8                 123181935.734 6  95985961.100 8
                                  23440748.62147
  21395760.742 7  21395769.145 9                 112435502.496 7  87612113.685 9
                                  21395769.30548
```

RTCM

- RTCM : Radio Technical Commission for Maritime Services
  - An internationally accepted data transmission standard for base-station data transmission to a rover defined. The standards are defined and maintained by RTCM SC-104
- RTCM SC-104 (Special Committee 104)
  - Defines data formats for Differential GPS and
  - RTK (Real-Time Kinematic Operations)
- The Current Version is RTCM-3 (10403.3)
- Refer https://www.rtcm.org/ for detail information and document
  - Documents are not free
  - A normal user does not need RTCM document.
  - GNSS receivers with base-station capabilities will setup necessary messages for RTK
  - If you are developing a system or application you may need it

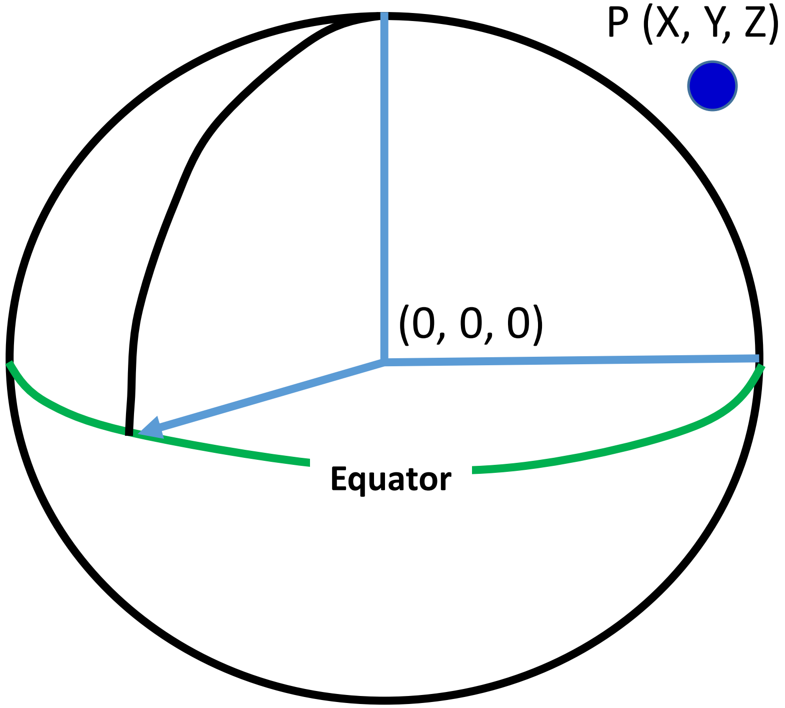
Coordinate Systems

Geodetic Coordinate System



ECEF (Earth Centered, Earth Fixed)

ECEF Coordinate System is expressed by assuming the center of the earth coordinate as (0, 0, 0)



Coordinate Conversion from ECEF to Geodetic and vice versa

Geodetic Latitude, Longitude & Height to ECEF (X, Y, Z)

$$X = (N+h)\cos\varphi\cos\lambda$$

$$Y = (N+h)\cos\varphi\sin\lambda$$

$$\mathrm{Z} = [N(1-e^2)+h]\sin\varphi$$

$$\varphi = Latitude$$
$$\lambda = Longitude$$
h = Height above Ellipsoid

ECEF (X, Y, Z) to Geodetic Latitude, Longitude & Height

$$\varphi\text{=atan}\left(\frac{Z+e^2b\,sin^3\theta}{p-e^2acos^3\theta}\right)$$

$$\lambda\text{=atan2}(y,x)$$

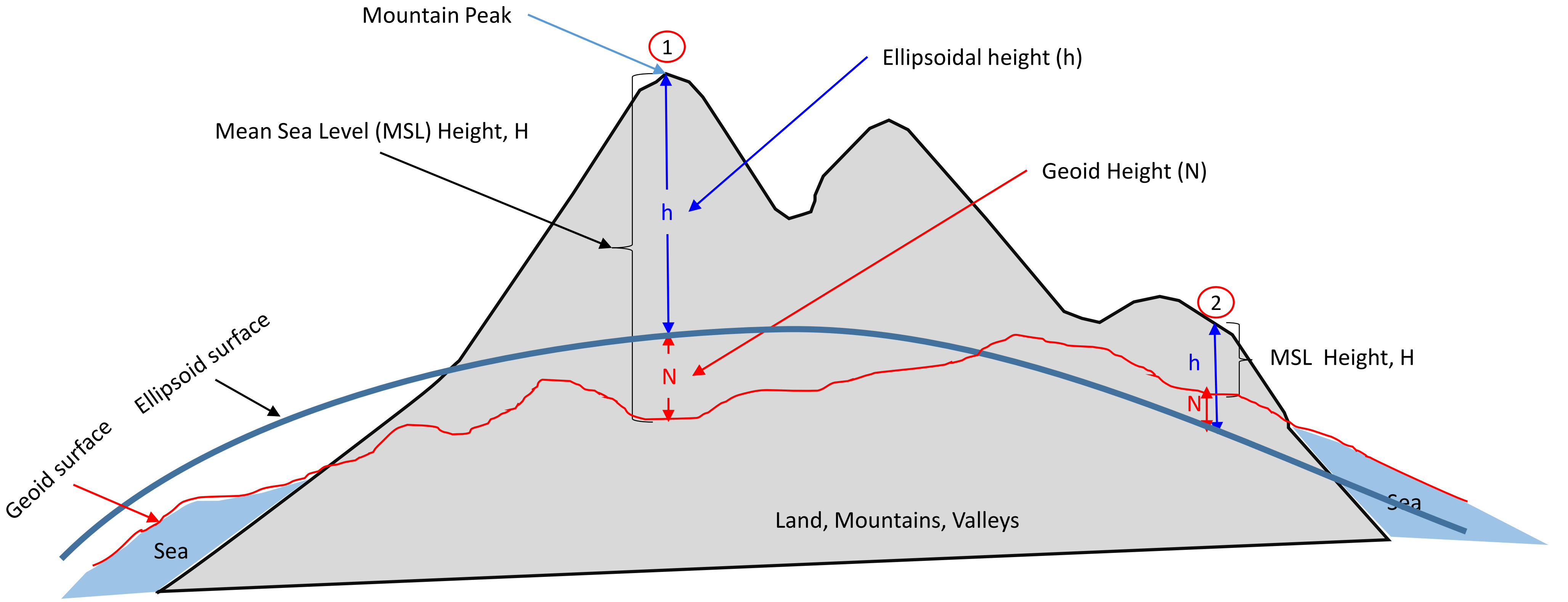
$$h = \frac{P}{\cos\varphi} - \mathrm{N}(\varphi)$$

$$P = \sqrt{x^2+y^2}$$

$$\theta = atan\left(\frac{Za}{Pb}\right)$$

$$N(\varphi) = \frac{a}{\sqrt{1-e^2sin^2\varphi}}$$

Ellipsoid, Geoid and Mean Sea Level (MSL)



MSL Height (H) = Ellipsoidal height (h) – Geoid height (N)
Geoid Height is negative if its below Ellipsoidal height

Example at point (1) : h = 1200m, N = -30m
H = h – N = 1200 – (-30) = 1200 + 30 = 1230m

Example at point (2) : h = 300m, N = +15m
H = h – N = 300 – 15 = 285m

Height Data Output in u-blox Receiver, NMEA Sentence, $GNGGA Sentence

MSL (Altitude)

Geoid Height (Separation between Geoid and Ellipsoid)

```
$GNVTG,,T,,M,0.010,N,0.018,K,D*30
$GNGGA,012039.00,3554.18235,N,13956.35867,E,2,12,0.48,54.4,M,39.6,M,0.0,0000*5D
$GNGSA,A,3,03,04,06,09,17,19,22,28,194,195,02,,0.92,0.48,0.78,1*06
$GNGSA,A,3,11,12,04,24,19,31,33,,,,,,0.92,0.48,0.78,3*00
$GNGSA,A,3,30,01,03,14,08,28,33,04,02,07,10,13,0.92,0.48,0.78,4*08
$GPGSV,5,1,17,01,18,076,,02,04,279,36,03,43,045,43,04,34,109,41,1*6C
$GPGSV,5,2,17,06,38,295,43,09,26,152,40,11,02,107,29,17,74,330,47,1*67
$GPGSV,5,3,17,19,53,320,45,22,22,048,39,28,36,213,43,41,18,249,39,1*6D
$GPGSV,5,4,17,50,46,201,40,193,52,172,43,194,16,193,40,195,85,163,46,1*5E
$GPGSV,5,5,17,199,46,201,37,1*66
$GAGSV,2,1,07,04,25,175,40,11,28,299,37,12,65,007,43,19,50,105,40,7*72
$GAGSV,2,2,07,24,27,245,41,31,09,198,36,33,33,082,42,7*43
$GBGSV,4,1,15,01,48,172,43,02,19,248,36,03,39,225,43,04,44,148,42,1*7C
$GBGSV,4,2,15,06,00,185,29,07,39,214,41,08,53,305,43,10,44,248,42,1*7C
$GBGSV,4,3,15,13,33,283,42,14,23,043,38,27,55,323,48,28,61,092,48,1*71
$GBGSV,4,4,15,30,05,306,36,32,17,206,42,33,48,055,46,1*4F
$GNGLL,3554.18235,N,13956.35867,E,012039.00,A,D*76
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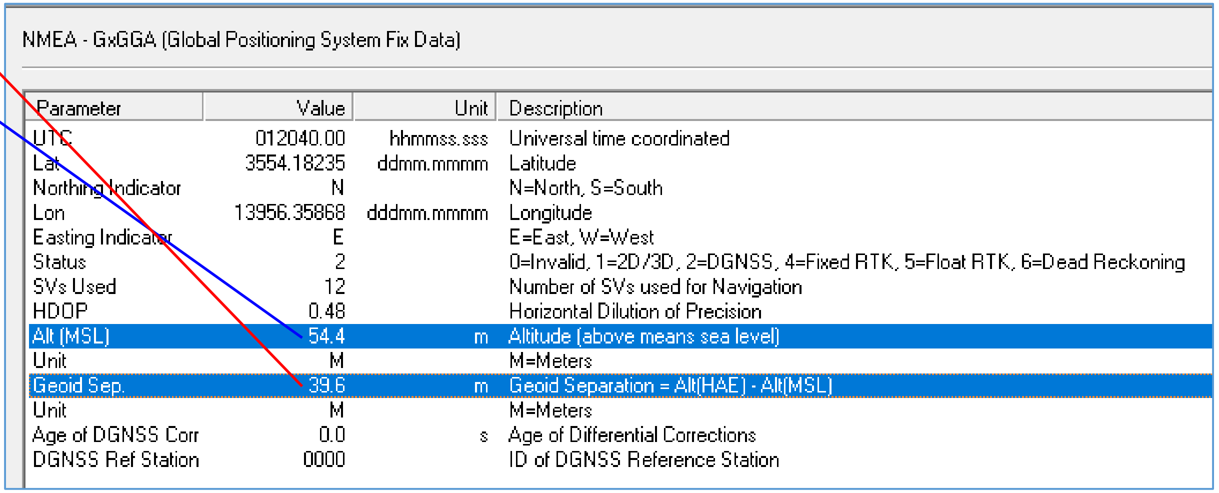


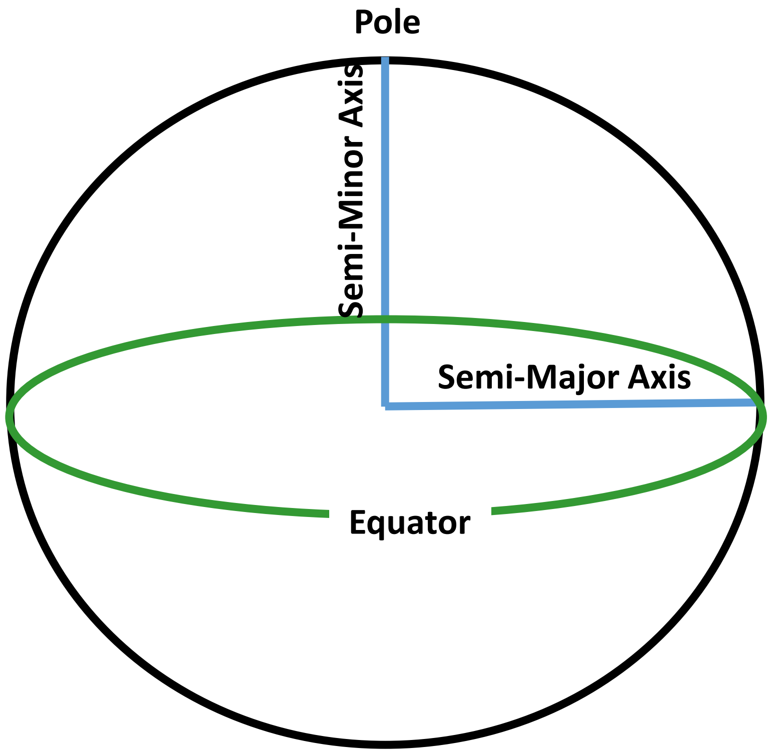
NMEA - GxGGA (Global Positioning System Fix Data)

Parameter	Value	Unit	Description
UTC	012040.00	hhmmss.sss	Universal time coordinated
Lat	3554.18235	ddmm.mmmm	Latitude
Northing Indicator	N		N=North, S=South
Lon	13956.35868	dddmm.mmmm	Longitude
Easting Indicator	E		E=East, W=West
Status	2		0=Invalid, 1=2D/3D, 2=DGNSS, 4=Fixed RTK, 5=Float RTK, 6=Dead Reckoning
SVs Used	12		Number of SVs used for Navigation
HDOP	0.48		Horizontal Dilution of Precision
Alt (MSL)	54.4	m	Altitude (above means sea level)
Unit	M		M=Meters
Geoid Sep.	39.6	m	Geoid Separation = Alt(HAE) - Alt(MSL)
Unit	M		M=Meters
Age of DGNSS Corr	0.0	s	Age of Differential Corrections
DGNSS Ref Station	0000		ID of DGNSS Reference Station

The NMEA sentences in this figure are from u-blox receiver.
NMEA format uses "Mean Sea Level" for height data (shown in blue texts).
Also it provides Geoid Height (Geoid Separation) value.
GPS by default is Ellipsoidal height and this height is converted to Mean Sea Level height using the geoid Height (shown in red texts) .
This means, u-blox receiver uses a built-in database of Geoid Height.

U-blox also outputs Ellipsoidal height in proprietary message $PUBX,00 (marked as altRef)
$PUBX,00,time,lat,NS,long,EW,**altRef**,navStat,hAcc,vAcc,SOG,COG,vVel,diffAge,HDOP,VDOP,TDOP,numSvs,reserved,DR,*cs<CR><LF>
altRef ➔ Altitude above user datum ellipsoid

Geodetic Datum: Geometric Earth Model



GPS uses WGS-84 Datum

But, topographic maps and many other maps use different datum. Before using GPS data on these maps, its necessary to convert GPS coordinates from WGS-84 to local coordinate system and datum. Many GPS software have this tool. Also, GPS receivers have built-in datum selection capabilities.

Check your receiver settings before using.

WGS-84 Geodetic Datum Ellipsoidal Parameters

Semi-Minor Axis, b = 6356752.3142m

Semi-Major Axis, a = 6378137.0m

Flattening, f = (a-b)/a

= 1/298.257223563

First Eccentricity Square = e^2 = 2f-f^2

= 0.00669437999013

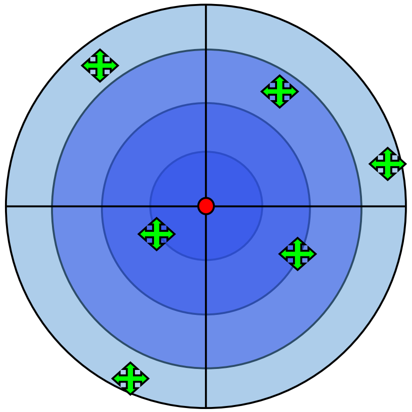
Points to Be Careful in GPS Survey

- Datum
  - Which Datum is used for GPS Survey?
  - By default, GPS uses WGS-84
  - But, your Map may be using different datum like Everest
    - Make Sure that Your Map and Your Coordinates from the GPS are in the same Datum, if not, datum conversion is necessary
    - You can get necessary transformation parameters from your country's survey department
- Height
  - Which Height is used?
  - By default GPS uses Ellipsoidal Height
  - But, your Map may be using Mean Sea Level (MSL or Topographic) Height
    - You need to convert from Ellipsoidal Height into MSL Height
    - Use Ellipsoidal and Geoid height Difference Data for your survey region
      - You can get it from your country's survey office

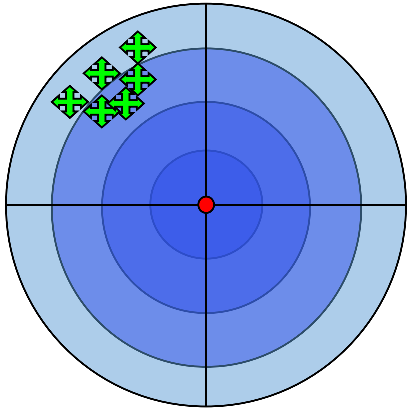
GNSS Errors

Background Information: Accuracy vs. Precision

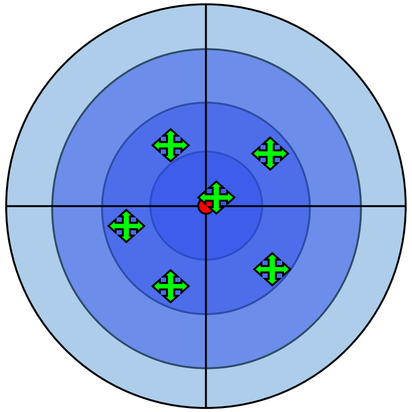
- Accuracy
  - Capable of providing a correct measurement
  - Measurement is compared with true value
  - Affected by systematic error
- Precision
  - Capable of providing repeatable and reliable measurement
  - Statistical analysis of measurement provides the precision
  - Measure of random error
  - Systematic error has no effect



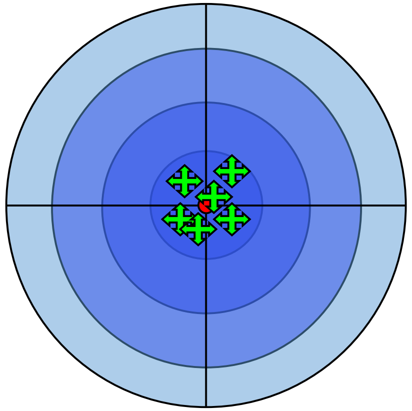
Neither Precise nor Accurate



Precise but Not Accurate



Accurate but Not Precise



Precise and Accurate

GNSS Measurement Errors

Measure	Abbreviation	Definition
Root Mean Square	RMS	The square root of the average of the squared errors
Twice Distance RMS	2D RMS	Twice the RMS of the horizontal errors
Circular Error Probable	CEP	A circle's radius, centered at the true antenna position, containing 50% of the points in the horizontal scatter plot
Horizontal 95% Accuracy	R95	A circle's radius, centered at the true antenna position, containing 95% of the points in the horizontal scatter plot
Spherical Error Probable	SEP	A sphere’s radius centered at the true antenna position, containing 50% of the points in the three dimensional scatter plot

Source: GPS Accuracy: Lies, Damn Lies, and Statistics, GPS World, JAN 1998
https://www.gpsworld.com/gps-accuracy-lies-damn-lies-and-statistics/

Commonly Used GNSS Performance Measurements

- TTFF
  - True Time to First Fix
  - Parameter: Cold Start, Warm Start, Hot Start
- Standard Accuracy
  - Accuracy attainable without any correction techniques
- DGPS Accuracy
  - Accuracy attainable by differential correction data
  - Code-phase correction
- RTK Accuracy
  - Accuracy attainable by differential correction data
  - Use both Code-Phase and Carrier Phase correction

TTFF and Typical Example Values

- TTFF
  - Cold Start : < 36 seconds
    - Time required to output first position data since the receiver power is on
    - No reference data like time or almanac are available
  - Warm Start : < 6 seconds
    - Time required to output first position data since the receiver power is on with the latest satellite almanac data in the receiver's memory
    - Time and almanac related reference data are already known
  - Hot Start : < 1 second
    - Receiver has already output position data
    - Time to reacquire an already tracked satellite due to temporary blockage by buildings or trees

Performance Measurement of RTK Accuracy

- A fix error and a variable error with respect to base-length is given
  - Such as : x cm + y ppm
  - Example: 2cm + 1ppm
    - There is a fix error of 2cm plus 1ppm error due to base-length between the Base and Rover
    - 1ppm → 1 parts per million
    - → 1cm of error in 1 million centimeter distance between the Base and the Rover
    - → 1cm of error in 1000000 centimeter distance between the Base and the Rover
    - → 1cm of error in 10000 meter distance between the Base and the Rover
    - → 1cm of error in 10 kilometer distance between the Base and the Rover
    - → **1cm of error for every 10Km of distance between the Base and the Rover**
    - → 4cm of error for 40Km of distance between the Base and the Rover
    - **Thus the total error is : 2cm + 4cm due to 40Km of base length**
  - The longer the base-length, the larger the error
    - Do not assume that this error is linear
    - And it may not be valid for longer base-lines
    - Normally the recommended base-length for RTK for a Geodetic Receiver is 40Km

Part - E

GNSS Applications

GNSS Applications - 1

- Surveying, Mapping and Geodesy
- Transportation
  - Car Navigation, ITS, ADAS, V2X
  - Railway Network
  - Marine : AIS, VMS
  - Aviation : SBAS / GBAS
  - UAV / DRONE
    - 3-D Mapping without GCP
- Vehicle Accidents / Emergency Services
  - eCall/ ERA-GLONASS / E-911
- Taxation / Insurance
  - Taxation based on location or distance traveled

GNSS Applications - 2

- Legal and Law Enforcement
  - Fishing Zone Management, Illegal Fishing Control
  - Crime Prevention
- Agriculture
  - Precise farming, Auto or Semi-Auto Driving of Tractors
  - Product Supply-Chain Management
- Location Based Applications
  - Services, Entertainment, Advertisement, Gaming, Marketing
- Warning during Disasters
  - EWS of QZSS, SAR of GALILEO
- Geo-Fencing / Geo-Securities
- Robotics
  - Navigation, Actions based on Location
- Scientific Applications
  - Space Weather : Scintillation, Radio Occultation, Plasma Bubble

GNSS Applications - 3

- Telecommunication
  - Synchronize cell towers, microsecond order for CDMA
  - Network Time Protocol , millisecond order
- Power Grid
  - Phase Synchronization between grids is required for higher efficiency and avoid power failures
- Time Stamping of
  - Financial and Banking Transactions
  - Legal, Clerical, Shipping Documents
- Scientific Timing Applications
  - Time stamping of events
    - e. g. Global VLBI Observation, earthquake occurrences, arrival of neutrino in particle physics

Abbreviations

- ASAL – Algerian Space Agency
- AUS-NZ – Geoscience Australia/New Zealand System
- BDSBAS – BeiDou Satellite-Based Augmentation System
- EGNOS – European Geostationary Navigation Overlay Service
- GAGAN – GPS-Aided Geo-Augmented Navigation
- GBAS – Ground-Based Augmentation System
- KASS – Korean Augmentation Satellite System
- MSAS – MTSAT Space-Based Augmentation System
- NSAS – Nigerian Satellite Augmentation System
- PRN – Pseudorandom Noise
- QZSS – Quazi-Zenith Satellite System
- SDCM – System of Differential Correction and Monitoring
- WAAS – Wide Area Augmentation System

Contact and Additional Information

- Homepage
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    https://gnss.peatix.com/
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