Introduction to Global Navigation Satellite System (GNSS) Service Providers

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GPS
(Global Positioning System)
USA

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History of GPS (1/2)

- Originally designed for military applications at the height of the Cold War in the 1960s, with inspiration coming from the launch of the Soviet spacecraft Sputnik in 1957.
- Transit was the first satellite system launched by the United States and tested by the US Navy in 1960.
  - Just five satellites orbiting the earth allowed ships to fix their position on the seas once every hour.
- GPS developed quickly for military purposes thereafter with a total of 11 “Block” satellites being launched between 1978 and 1985.
- The Reagan Administration in the us had the incentive to open up GPS for civilian applications in 1983.

How to Drop Five Bombs from Different Aircrafts into the Same Hole?
(with an accuracy of 10m)

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History of GPS (2/2)

- Upgrading the GPS was delayed by NASA space shuttle Challenger disaster in 1989 and it was not until 1989 that the first Block II satellites were launched.
- By the summer of 1993, the US launched the 24th GPS satellite into orbit, which complete the modern GPS constellation of satellites.
- In 1995, it was declared fully operational.
- Today's GPS constellation has around 30 active satellites.
- GPS is used for dozens of navigation applications.
  - Route finding for driver, map-making, earthquake research, climate studies, and many other location based services.

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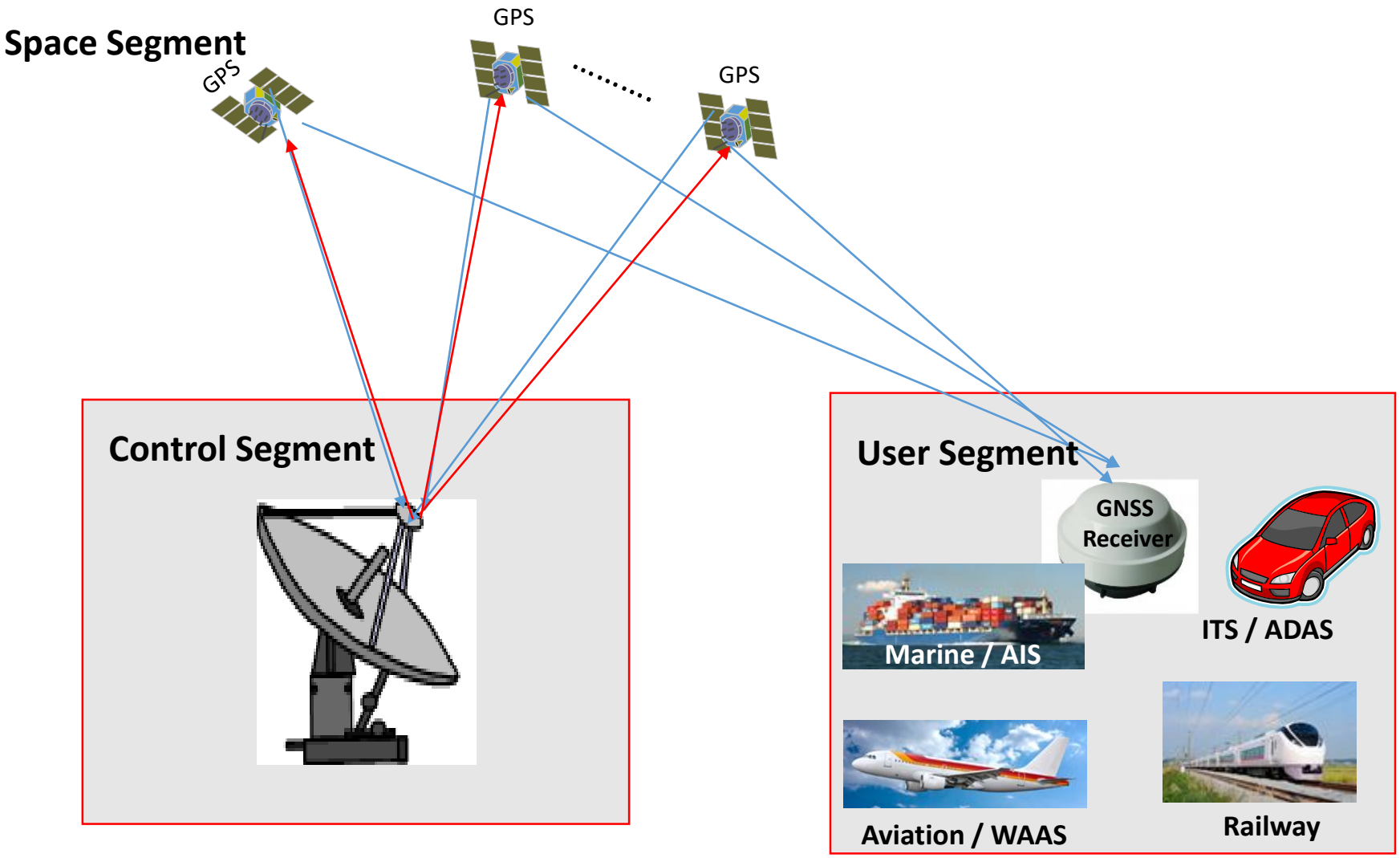
GPS Segments



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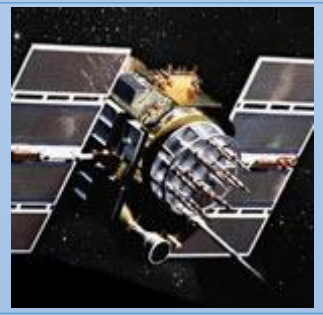
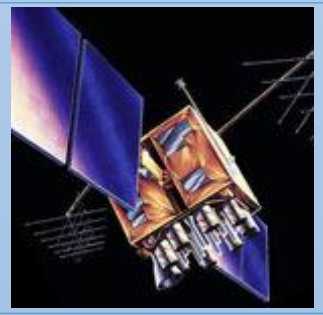
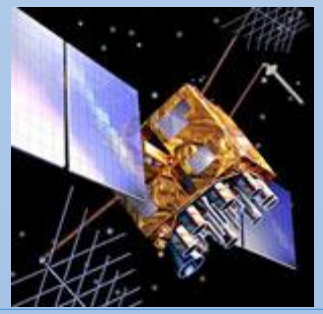
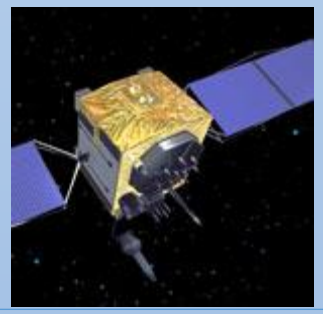
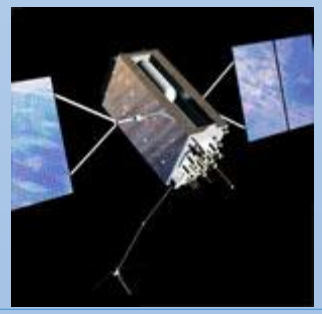
GPS Space Segment: Current & Future Constellation

Legacy Satellites		Modernized Satellites		
				
Block IIA	**Block IIR**	**Block IIR(M)**	**Block IIF**	**GPS III**
0 operational	**12 operational**	**7 operational**	**12 operational**	**In production**
•L1C/A, L1 P(Y) •L2P(Y) •Launched in 1990-1997 •Last one decommissioned in 2016	•L1C/A, L1P(Y) •L2P(Y) •Launched in 1997-2004	•L1C/A, L1P(Y) •L2P(Y) •L2C, L2M •Launched in 2005-2009	•L1C/A, L1P(Y) •L2P(Y) •L2C, L2M •L5 •Launched in 2010-2016	•L1C/A, L1P(Y) •L2P(Y) •L2C, L2M •L5 •L1C •Available for launch in 2016

http://www.gps.gov/systems/gps/space/#IIF
https://en.wikipedia.org/wiki/Global_Positioning_System

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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	

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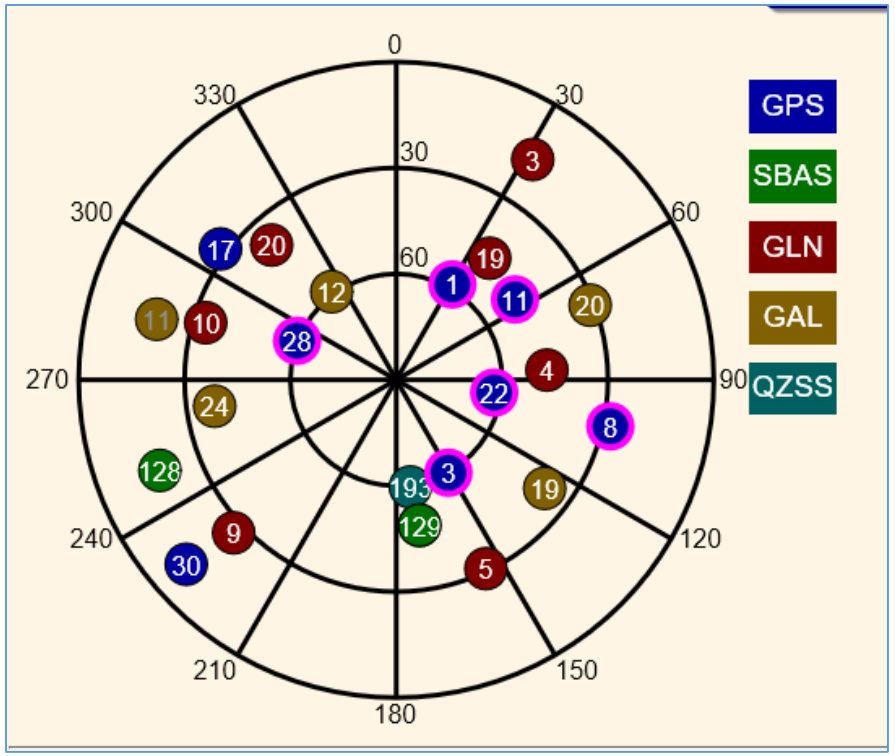
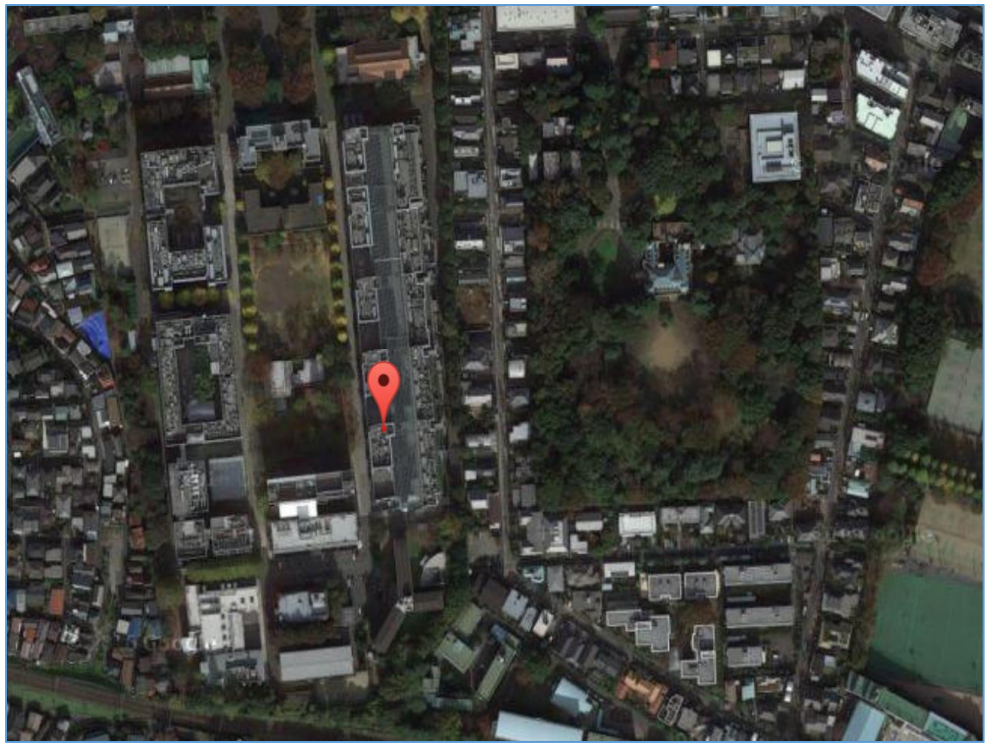
GPS Receiver Outputs (1/3)



Sky Plot: Visibility of Satellites at Receiver Antenna



Computed Position from GPS displayed over Google Map

GPS Receiver Outputs (2/3)

GNSS Signals Received by the Receiver

ALL | GPS | GLONASS | Galileo | QZSS | SBAS | OMNI

SV	Type	Elev. [Deg]	Azim. [Deg]	L1-C/No [dBHz]	L1	L2-C/No [dBHz]	L2	L5-C/No [dBHz]	L5	E6-C/No [dBHz]	E6	IODE	URA [m]	Type
1	GPS	57.51	31.89	42.7	CA	26.4/42.8	E/CM+CL	-	-	-	-	17	2	IIF
3	GPS	61.11	148.93	43.4	CA	27.4/43.9	E/CM+CL	-	-	-	-	17	2	IIF
8	GPS	26.97	103.42	37.3	CA	16.9/36.6	E/CM+CL	-	-	-	-	59	2	IIF
11	GPS	48.36	57.30	41.4	CA	22.3	E	-	-	-	-	83	4	IIR
17	GPS	28.92	307.48	37.9	CA	19.3/37.5	E/CM+CL	-	-	-	-	41	2	IIR-M
22	GPS	61.99	94.37	43.9	CA	26.8	E	-	-	-	-	49	2	IIR
28	GPS	60.44	288.95	43.0	CA	25.3	E	-	-	-	-	53	2.8	IIR
11	Galileo	20.59	285.13	-	-	-	-	-	-	-	-	-	-	-
12	Galileo	59.51	325.63	41.5	CBOC	-	-	-/40.6/40.2	-/B/Alt	-	-	-	-	-
19	Galileo	38.81	125.12	37.7	CBOC	-	-	-/33.8/33.3	-/B/Alt	-	-	-	-	-
20	Galileo	31.05	67.70	33.9	CBOC	-	-	-	-	-	-	-	-	-
24	Galileo	37.41	260.41	40.9	CBOC	-	-	-/40.2/39.9	-/B/Alt	-	-	-	-	-
3	GLONASS	15.60	30.81	33.7/32.3	CA/P	32.3	CA	-	-	-	-	29	2.5	M
4	GLONASS	47.52	83.80	40.5/39.4	CA/P	38.1	CA	-	-	-	-	29	7	M
5	GLONASS	32.37	153.94	32.3/31.0	CA/P	31.0	CA	-	-	-	-	29	2.5	M
9	GLONASS	25.40	225.73	35.6/34.4	CA/P	36.4	CA	-	-	-	-	29	10	M
10	GLONASS	33.33	284.69	39.0/37.6	CA/P	30.9	CA	-	-	-	-	29	4	M
19	GLONASS	46.12	39.85	37.1/35.9	CA/P	36.9	CA	-	-	-	-	29	4	M
20	GLONASS	38.75	318.99	33.0/30.7	CA/P	37.4	CA	-	-	-	-	29	10	M
193	QZSS	59.95	172.80	40.9/42.0/40.7	CA/BOC/SAIF	40.4	CM+CL	-	-	29.2	LEX	212	2	-
128	SBAS	18.24	249.03	32.4	CA	-	-	-	-	-	-	158	4096	-
129	SBAS	48.27	170.87	34.3	CA	-	-	-	-	-	-	124	4096	-
137	SBAS	48.27	170.87	34.1	CA	-	-	-	-	-	-	46	16	-
140	SBAS	-45.00	0.00	35.5	CA	-	-	-	-	-	-	55	N/A	-
141	SBAS	-45.00	0.00	-	-	-	-	-	-	-	-	-	-	-

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GPS Receiver Outputs (3/3)

Position, Velocity, Time (PVT) and Other Observation Related Outputs

Position:

Lat: 35° 39' 40.85496" N
Lon: 139° 40' 41.32632" E
Hgt: 118.521 [m]
Type: Autonomous
Datum: WGS-84

Velocity:

East: 0.01 [m/s]
North: -0.01 [m/s]
Up: -0.02 [m/s]

Position Solution Detail:

Position Dimension: 3D
Augmentation: GPS+GLN+GAL+QZSS
Height Mode: Normal
Correction Controls: Off

Satellites Used:19

GPS(7): 1, 3, 8, 11, 17, 22, 28
GLONASS(8): 3, 4, 5, 9, 10, 11, 19, 20
Galileo(3): 12, 19, 24
QZSS(1): 193

Satellites Tracked:23

GPS (7): 1, 3, 8, 11, 17, 22, 28
GLONASS (8): 3, 4, 5, 9, 10, 11, 19, 20
Galileo (4): 12, 19, 20, 24
SBAS (3): 128, 137, 140
QZSS (1): 193

Receiver Clock:

GPS Week: 1910
GPS Seconds: 447816
Offset: 0.00001 [msec]
Drift: 0.00007 [ppm]

Multi-System Clock Offsets:

Master Clock System: GPS
GLONASS Offset: 97.2 [ns]
Galileo Offset: 0.5 [ns]
GLONASS Drift: -0.044 [ns/s]
Galileo Drift: 0.003 [ns/s]

Dilutions of Precision:

PDOP: 1.5
HDOP: 0.7
VDOP: 1.3
TDOP: 1.1

Error Estimates(1σ):

East: 0.878 [m]
North: 1.123 [m]
Up: 2.691 [m]
Semi Major Axis: 1.155 [m]
Semi Minor Axis: 0.834 [m]
Orientation: 19.9°

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GLONASS
(Global Navigation Satellite System)
Russia

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GLONASS Current & Future Constellation

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 Dec 2014**	**Under Development 3 On Order First Launch Expected 2018**
•L1OF, L1SF • L2SF	•L1OF, L1SF •L2OF, L2SF •L3OC	•L1OF, L1SF •L2OF, L2SF •L3OC	•L1OF, L1SF •L2OF, L2SF •L1OC, L1SC •L2OC, L2SC •L3OC

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

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GLONASS FDMA Signals

- L1 Band 1598.0625 - 1604.40 MHz
  - 1602 MHz + n × 0.5625 MHz
    - where n is a satellite's frequency channel number (n=−7,−6,−5,...,7).
- L2 Band 1242.9375 - 1248.63 MHz
  - 1246 MHz + n×0.4375 MHz

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Galileo, Europe

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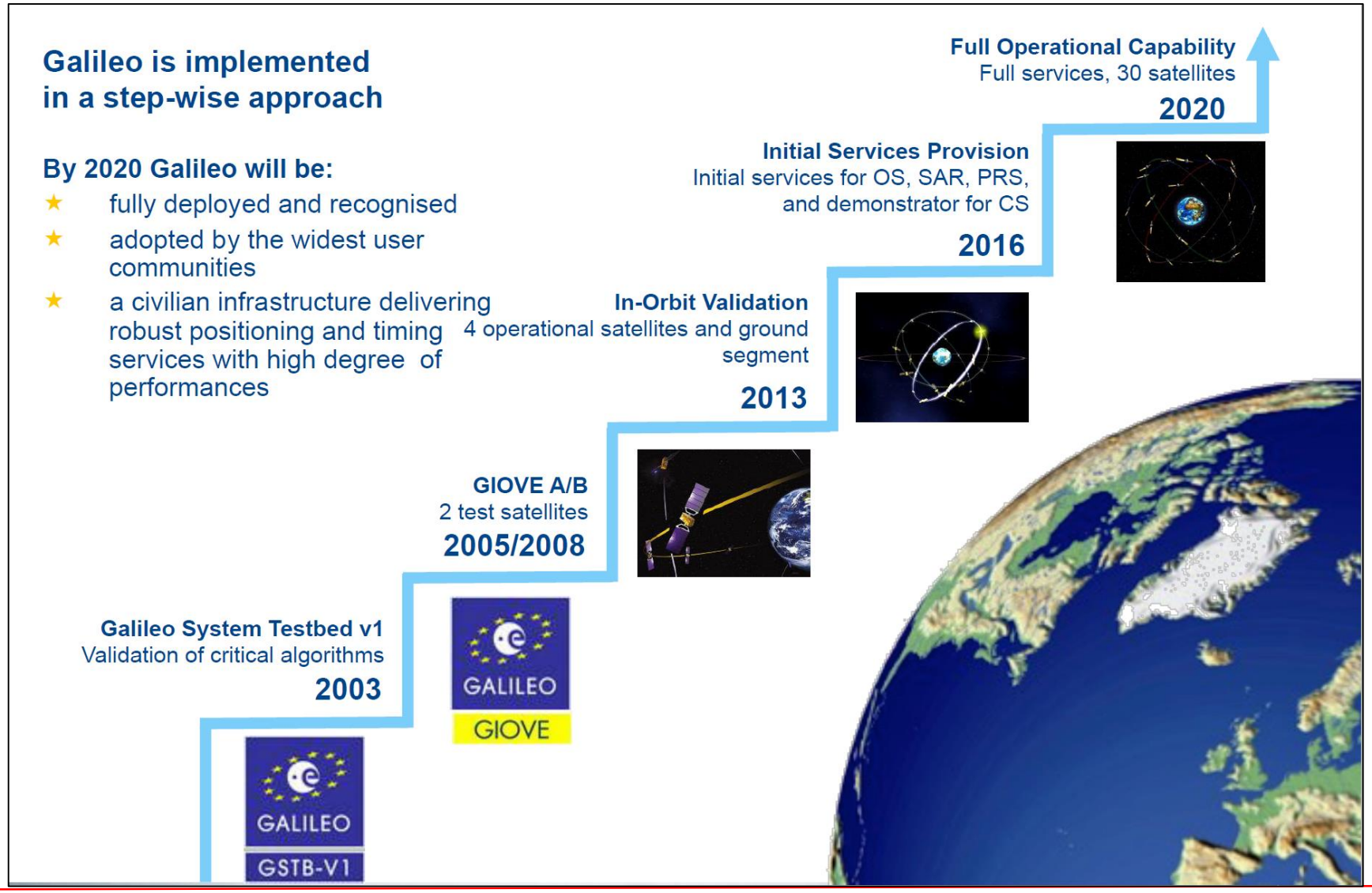
Galileo Space Segment



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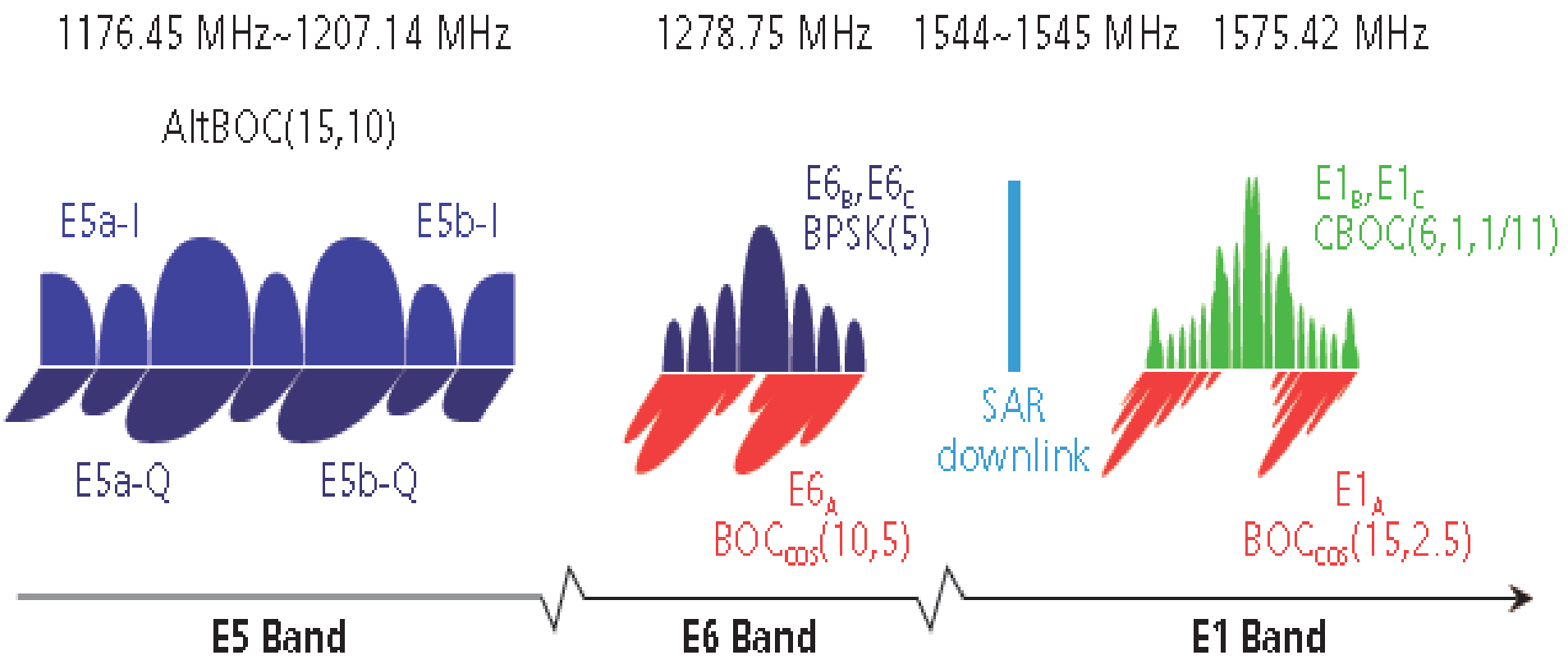
Galileo Signals

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 Signals



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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**	

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BeiDou, China

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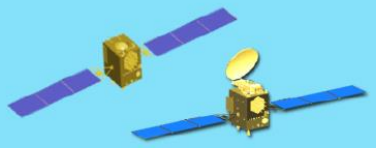
BeiDou Space Segment

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.

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

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COMPASS / BEIDOU Signals: Already Transmitted

Band	Frequency MHz	Signal Type	Chip Rate (MHz)	Modulation Type	Data / Symbol rate	Notes
B1	1561.098	B1(I)	2.046	QPSK	50 / 100	Open
		B1(Q)			None	Authorized
	1589.742	B1-2(I)	2.046	QPSK	50 / 100	Open
		B1-2(Q)			25 / 50	Authorized
B2	1207.14	B2(I)	2.046	QPSK	None	Open
		B2(Q)	10.23		50 / 100	Authorized
B3	1268.52	B3	10.23	QPSK	500	Authorized

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QZSS
(Quasi-Zenith Satellite System)
Japan

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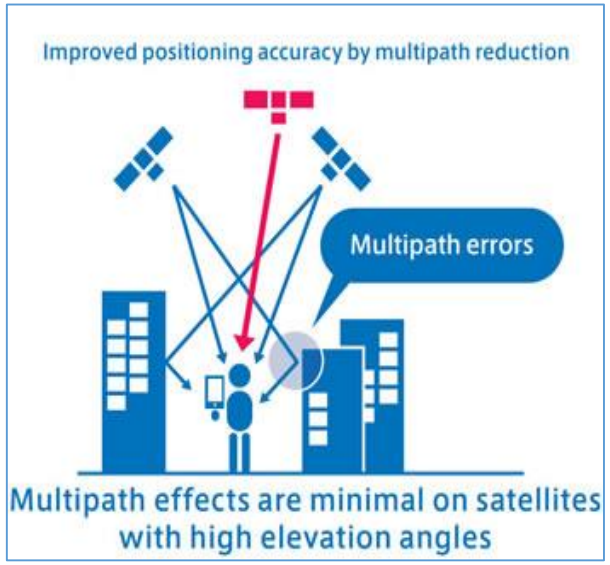
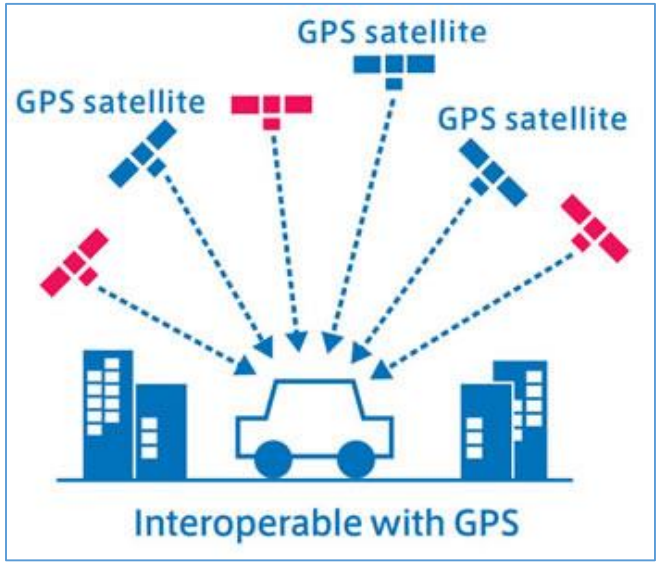
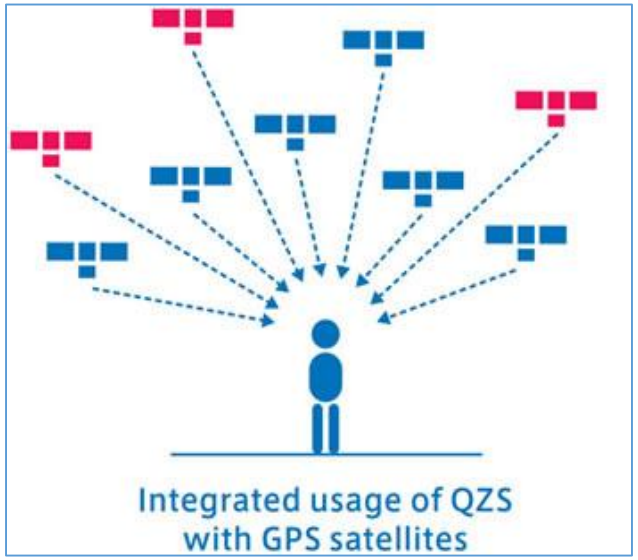
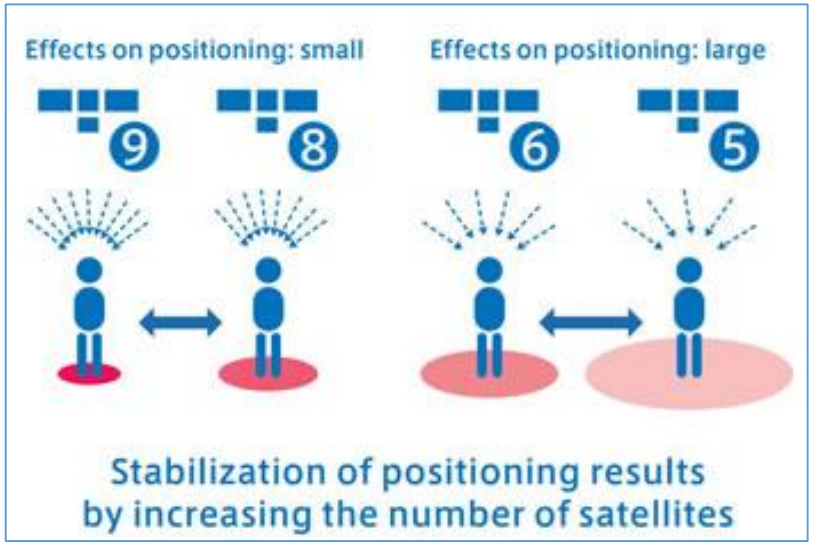
Merits of QZSS







- 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



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

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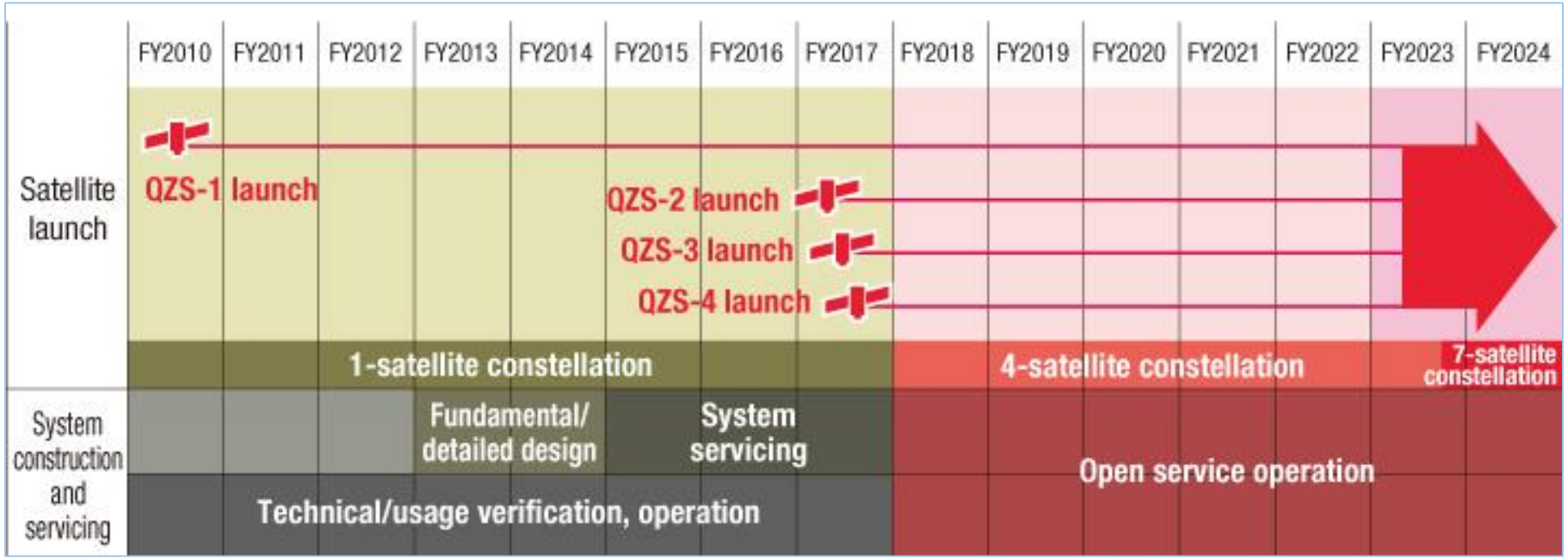
QZSS Development Plan



1st Satellite launched on 11th September 2010 : QZ Orbit
2nd Satellite launched on 1st June 2017 : QZ Orbit
3rd Satellite launched on 19th August 2017 : Geostationary Orbit

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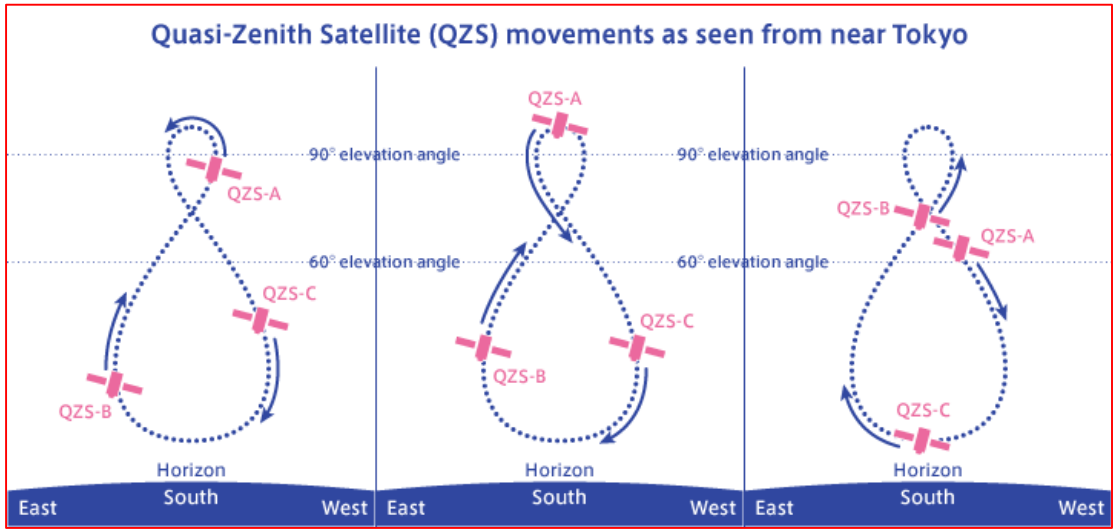
QZSS Constellation Status

- Current Status
  - One Satellite launched on 11th SEP 2010
- Total constellation of Seven Satellites
  - Three more satellites were launched by the end of 2017



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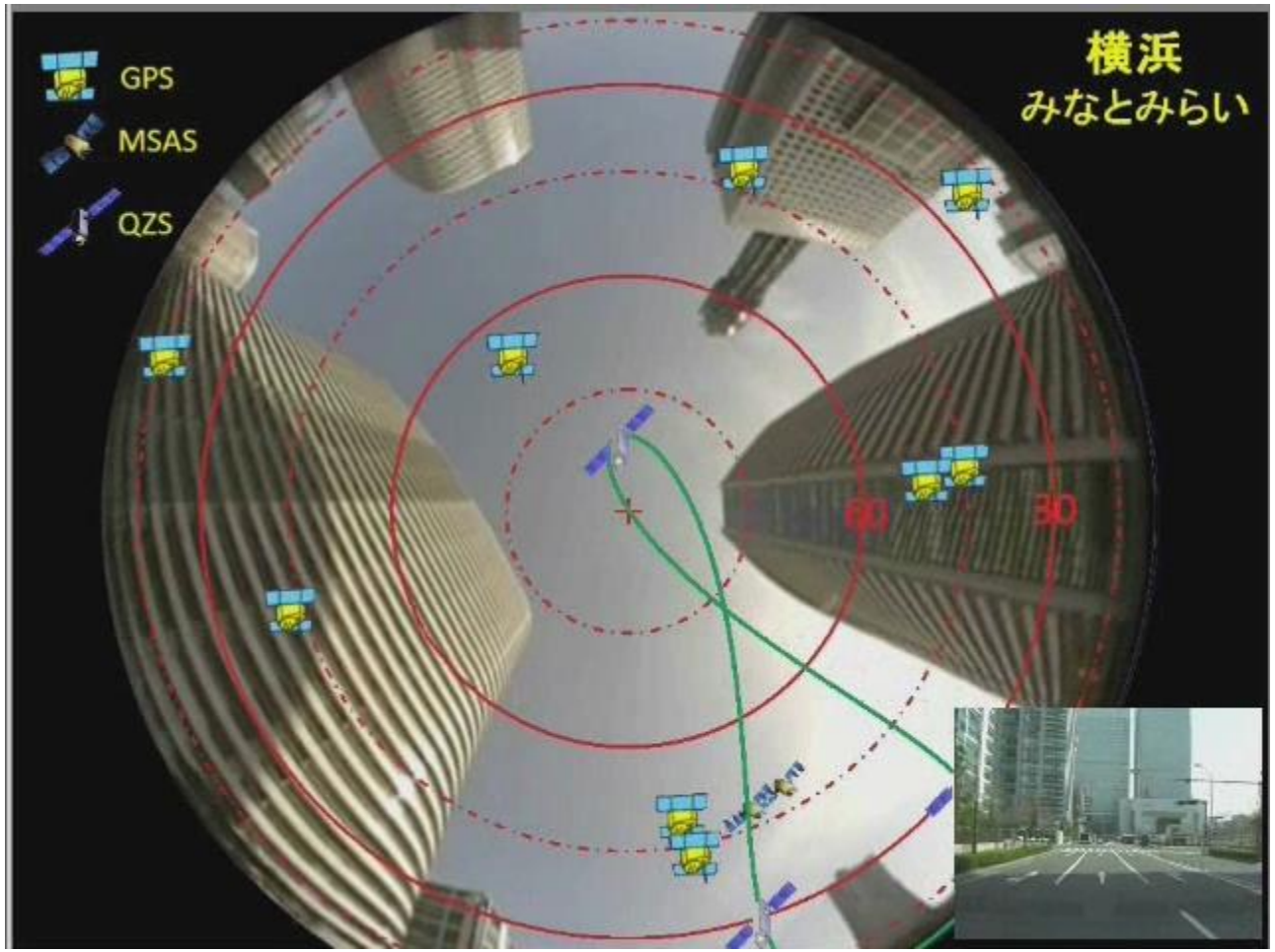
QZSS Satellite Visibility



Source: SPAC Animation Video

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QZSS Satellites & Signal Types

Signal Name	QZS-1	QZS-2 to QZS-4		Transmission service	Center Frequency MHz
	Block IQ	Block IIQ	Block IIG		
	(QZO)	(QZO)	(GEO)		
	1	2	1		
L1C/A	◎	◎	◎	Satellite positioning service	1575.42
L1C	◎	◎	◎	Satellite positioning service	
L1SAIF	◎			Sub-meter Level Augmentation Service (SLAS) / Disaster and Crisis Management	
L1S		◎	◎		
L1Sb	-	-	◎	SBAS Transmission Service from around 2020	
L2C	◎	◎	◎	Satellite positioning service	1227.60
L5	◎	◎	◎	Satellite positioning service	1176.45
L5S	-	◎	◎	Positioning Technology Verification Service	
LEX	◎			MADOCA	1278.75
L6		◎	◎	Centimeter Level Augmentation Service (CLAS)	
S-band	-	-	◎	QZSS Safety Service / SAR	2GHz

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QZSS New Applications

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QZSS New Applications

- Short Message Broadcast during Emergencies and Disasters
  - L1SAIF / L1S Signals
- Sub-meter Level Augmentation Service (SLAS)
  - L1SAIF / L1S / L1Sb Signals
- Centimeter Level Augmentation Service (CLAS)
  - L6 Signal
    - PPP-RTK
  - LEX Signal : MADOCA Service
    - PPP

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Short Message Broadcast during Disaster

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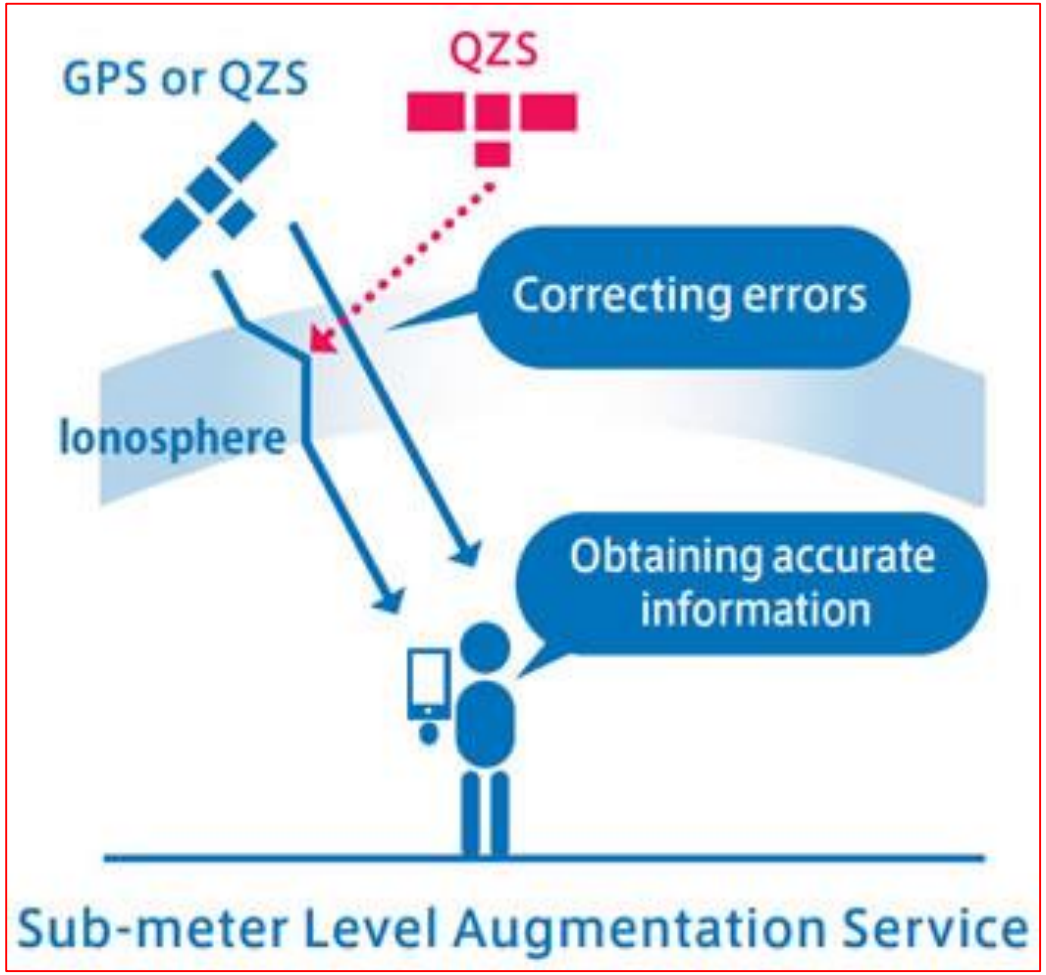
Sub-meter Level Augmentation Service (SLAS)



SLAS : Sub-meter Level Augmentation Service

Signal Used: L1SAIF / L1S

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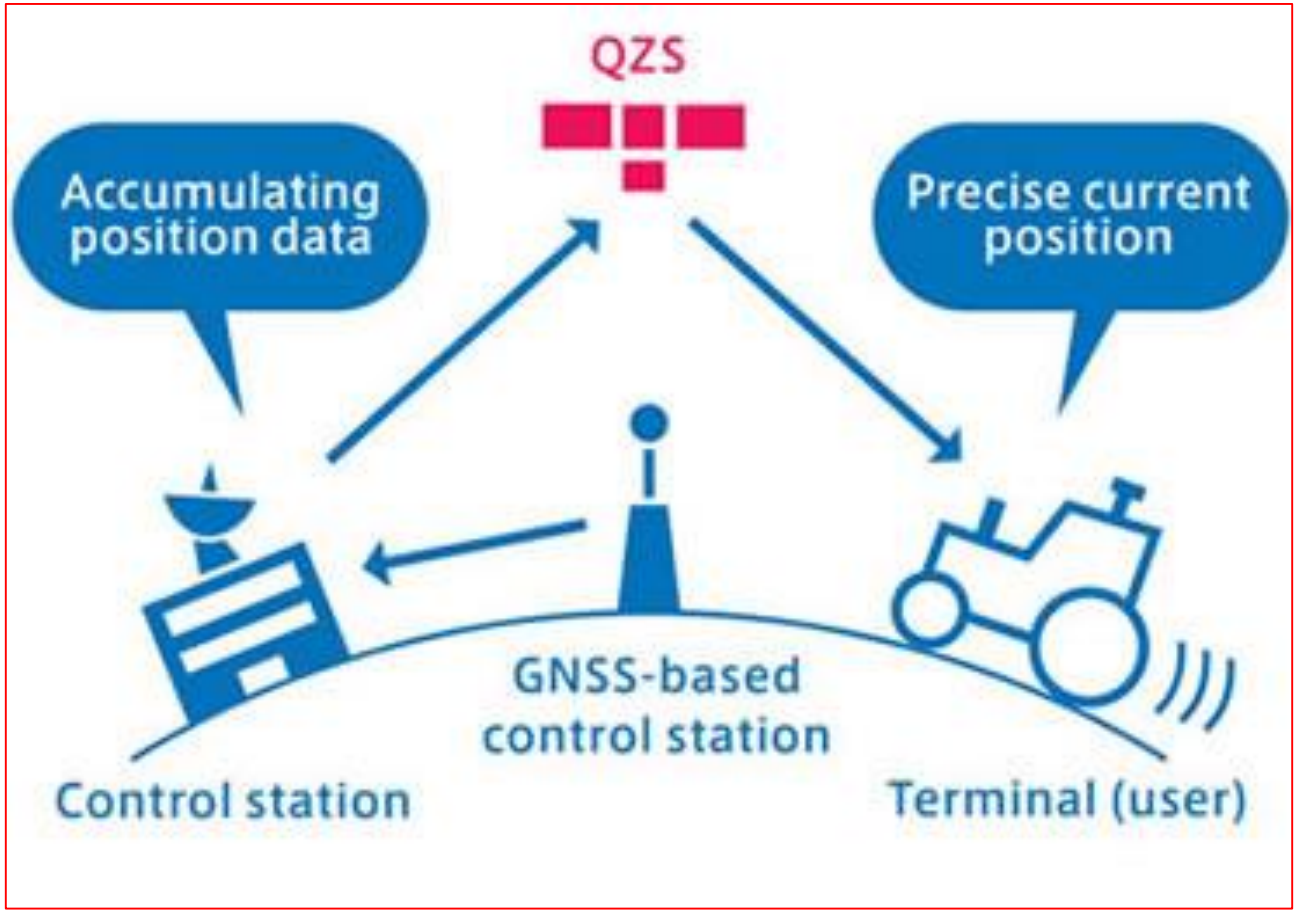
Centimeter Level Augmentation Service (CLAS)



CLAS : Centimeter Level Augmentation Service
Signal Used: LEX: MADOCA & L6

NAVIC, India
(Indian Regional Navigation Satellite System)

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

IRNSS Signal Types

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

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