Nottingham Presentation

Presentation

By

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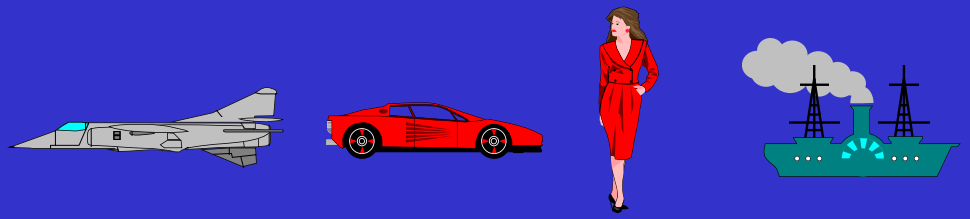
Nottingham presentation: Part C
World developments in GNSS

Status of SATNAV Systems

- Principle of Positioning through one-way range
- GPS
- GLONASS
- Galileo
- GAGAN and IRNSS
- COMPASS
- QZSS
- Augmentations

REQUIREMENTS OF NAVIGATION AND POSITION LOCATION SYSTEMS

- ALL WEATHER
- UNIVERSAL ACCESS
- MULTIMODAL
- CIVIL CONTROLLED
- MAINTAIN SOVEREIGNTY OF NATIONS
- HIGHEST SAFETY REQUIREMENTS
- HIGH REAL TIME POSITION ACCURACY

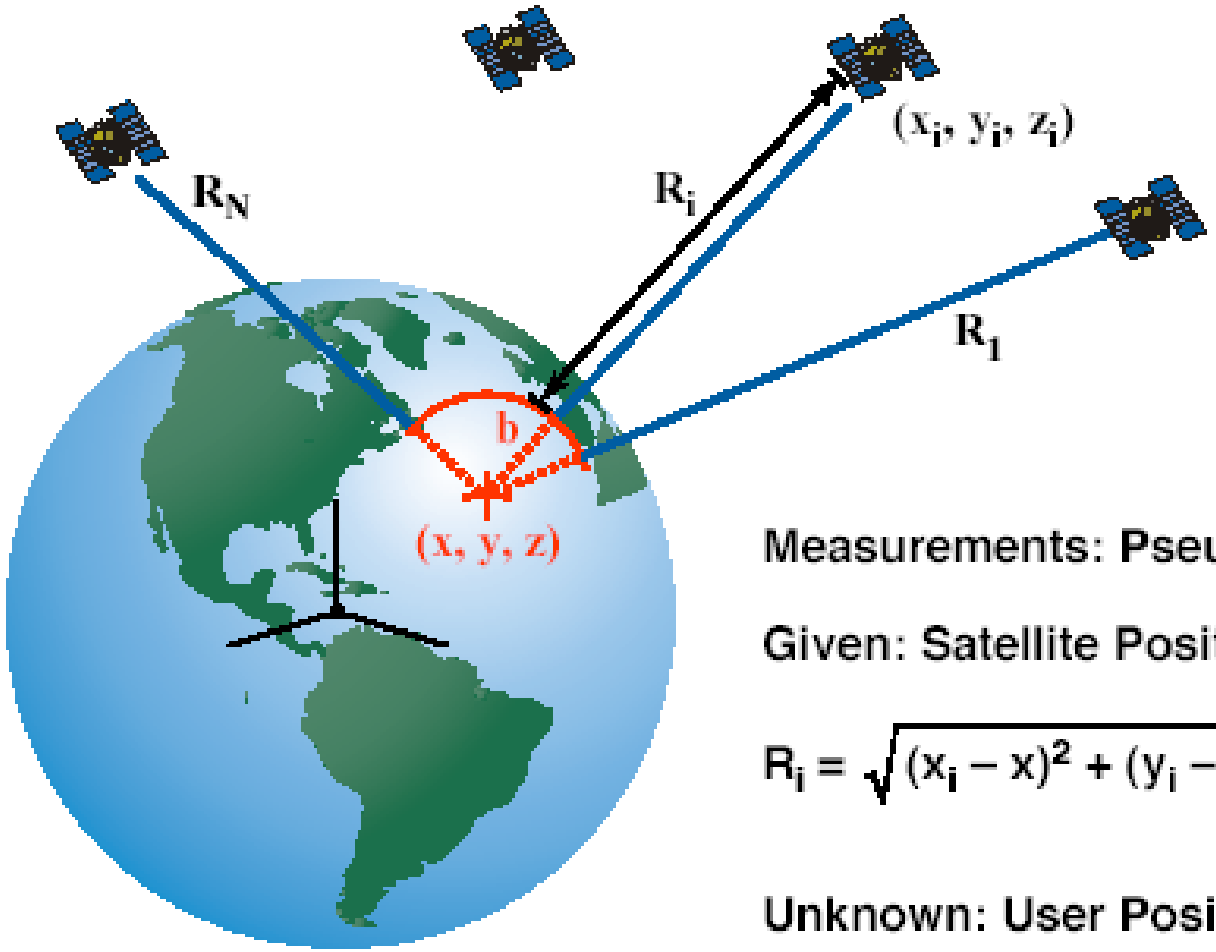


NAVIGATION AND POSITION LOCATION SYSTEMS STANDARDS ARE DRIVEN BY CIVIL AVIATION

Global Positioning System
GPS

Satellite Navigation

Position Estimation by Trilateration



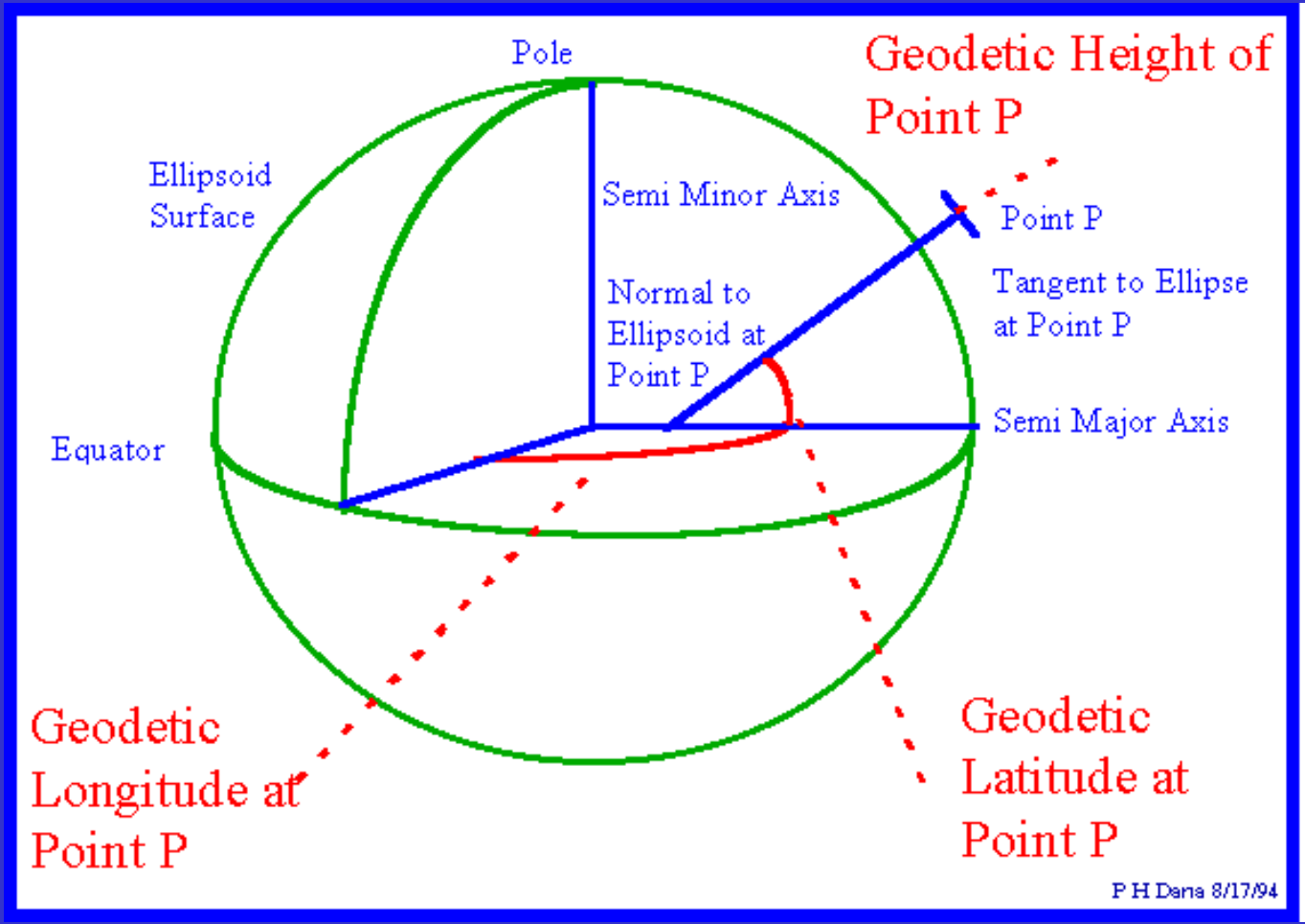
Measurements: Pseudoranges $\{R_i\}$

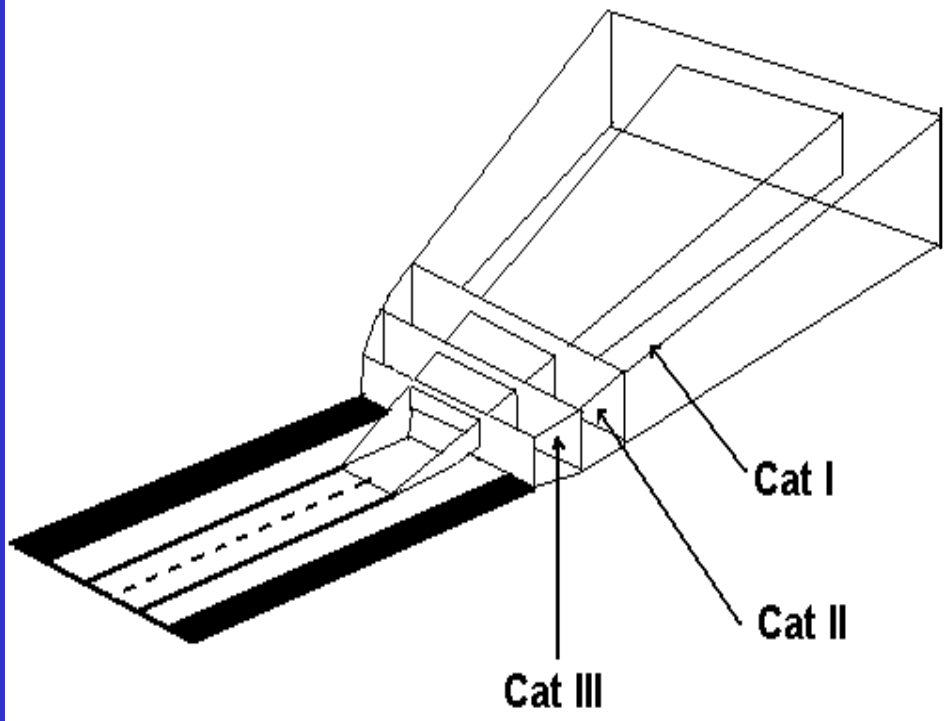
Given: Satellite Positions $\{(x_i, y_i, z_i)\}$

$$R_i = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} - b, \quad i = 1, 2, \ldots, N$$

Unknown: User Position (x, y, z)
Receiver Clock Bias b

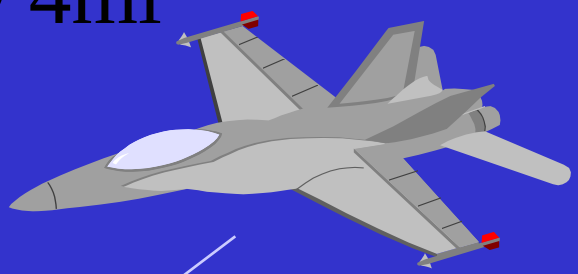
WGS-84 ELLIPSOID

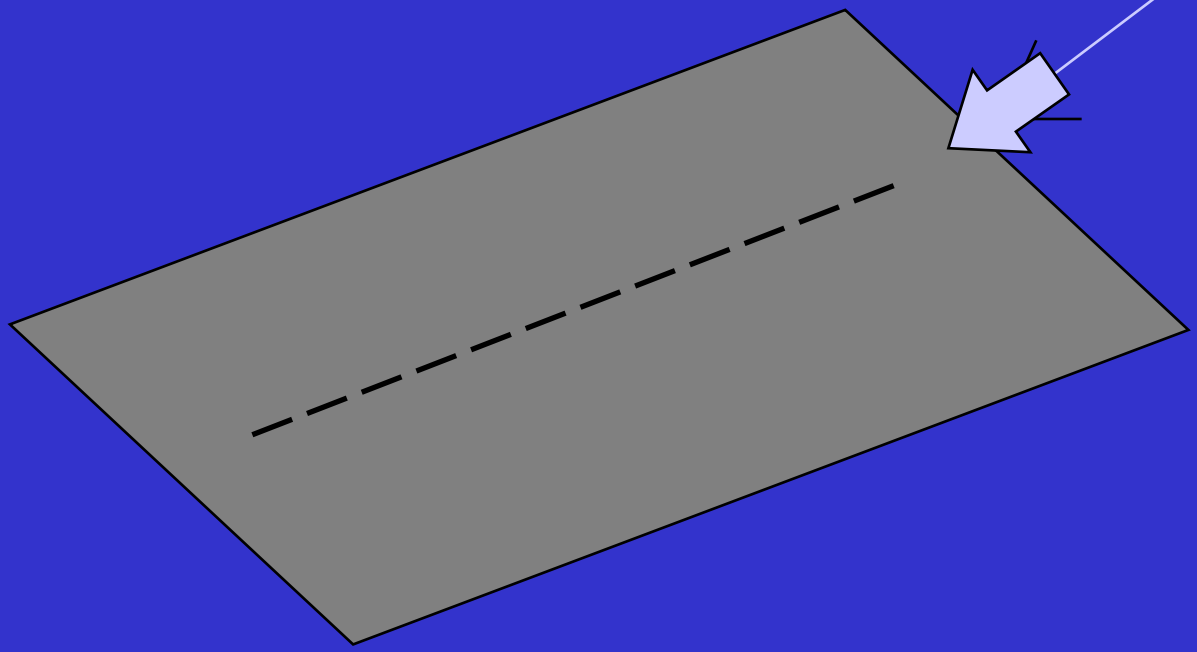




	DH	Lateral	Vertical
Cat-I			
Inner Tunnel	200 ft	+-40 m	+-12.1 m
Outer Tunnel	200 ft	+-120 m	+-36.3 m
Cat-II			
Inner Tunnel	100 ft	+-21.2 m	+-4.5 m
Outer Tunnel	100 ft	+-63.6 m	+-13.6 m
Cat-III			
Inner Tunnel	50 ft	+-15.1 m	+-1.5 m
Outer Tunnel	50 ft	+-45.5 m	+-4.5 m

- Non-Precision Approach - 400 ft @ 4mi
- Precision Approaches
  - -Category I 200 ft @ .5mi
  - -Category II 100 ft @ .25mi
  - -Category III 50 ft @ .125 m





Distance to runway

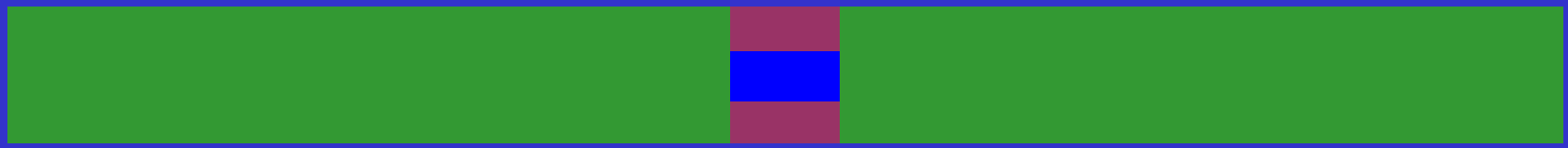
Height above terrain

WIDE AREA DIFFERENTIAL TECHNIQUE

SEPARATION OF ERRORS

ATMOSPHERIC ERROR - 3D
EPHEMERIC ERROR - 3D
CLOCK ERROR - 1D

Performance Comparison



LNAV/VNAV (556 m by 50 m) - Baro VNAV

New APV-I (40 m by 50 m) - SBAS Avionics

APV-II (40 m by 20 m) - SBAS Avionics

COMPARISON

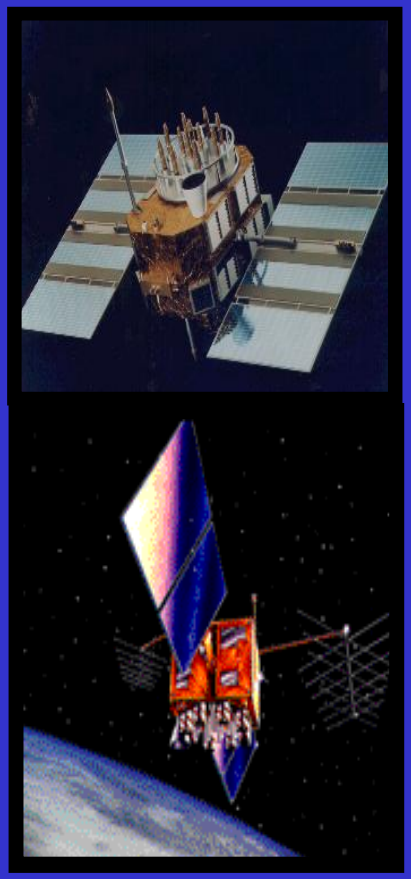
TWO MILITARY-CONTROLLED OPERATIONAL SATELLITE NAVIGATION SYSTEMS

GPS	GLONASS
> 30 SATELLITES	24 SATS BY 1996, 19 NOW
20,000 km. ALT.	19,000 km.
L-BAND (20 MHz @ 1575.42 MHz	L-BAND (23 MHz)
ON-BOARD CLOCK MORE STABLE	LESS STABLE
100 m H POS. ACC 156 m. V POS. ACC	100 m.
340 nsec TT ACC	~1 MICRO SEC
CDMA	FDMA/P-N CODE FOR EACH S/C
7.5 to 10 YEARS S/C LIFE	5 YEARS FOR GLONASS M
> $ 10 BILLION	EST.>$10 BILLION
WGS-84 ECEF	PZ-90 ECEF

GPS Constellation Status

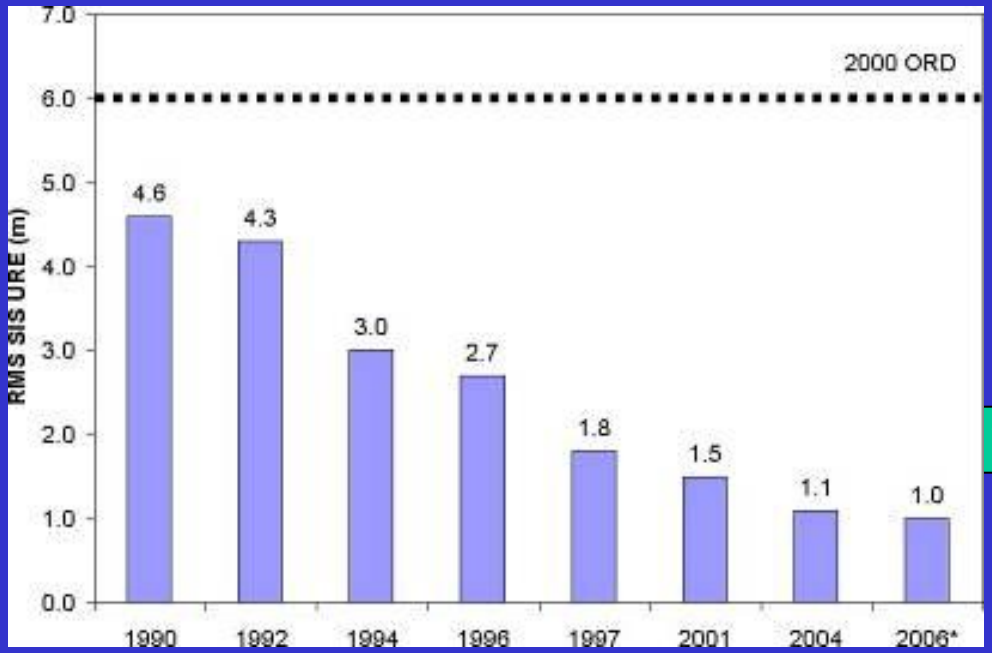
30 Healthy Satellites
Baseline Constellation: 24

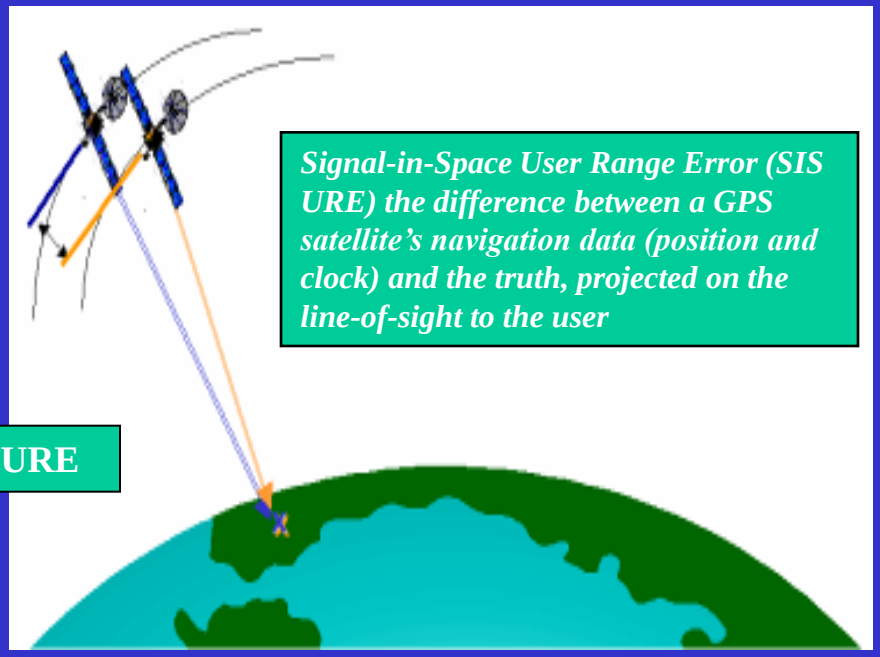
- 13 Block IIA satellites operational
- 12 Block IIR satellites operational
- 5 Block IIR-M satellites operational
  - 4th IIR-(17)M successfully launched on 17 Oct 07
    - Set healthy on 31 Oct 07
  - 5th IIR-(17)M successfully launched on 21 Dec 07
    - Set healthy on 3 Jan 08
- 3 additional satellites to launch through FY 2008
  - IIR-(19)M in Mar 08
  - IIR-(20)M in Jun 08
  - IIR-(21)M in Sep 08



Current GPS Accuracy

- Signal-In-Space (SIS) User Range Error (URE)
  - One-year RMS as of Jun 07: 0.95 meters
- Zero Age-Of-Data (AOD) URE
  - One-year RMS as of Jun 07: 0.26 meters



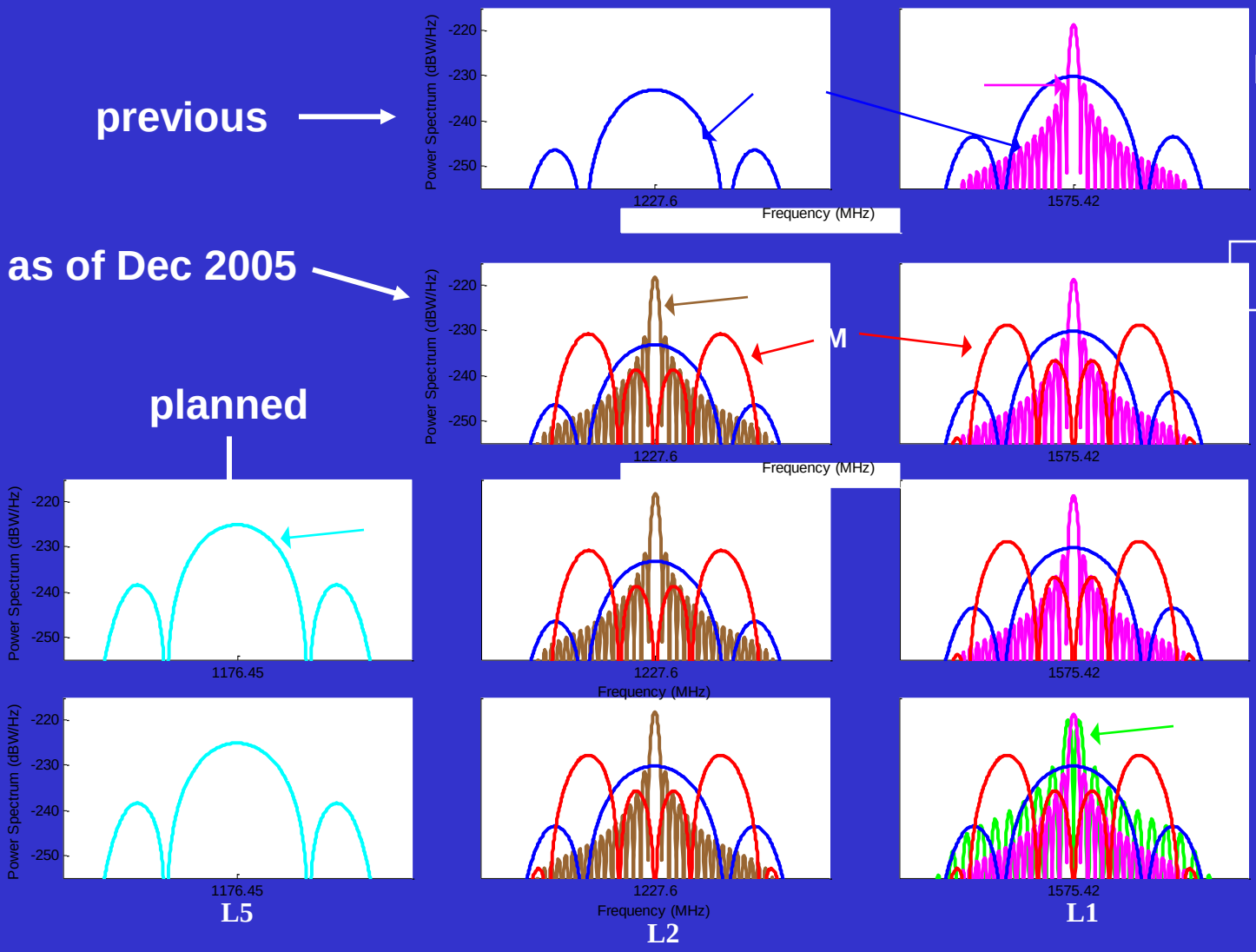


GPS Modernization – Spectrum

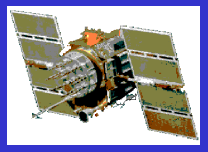
previous

as of Dec 2005

planned



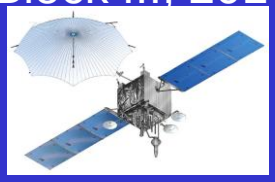
Block IIA/IIR, 1990



Block IIR-M, 2005

Block IIF, 2009

Block III, 2014

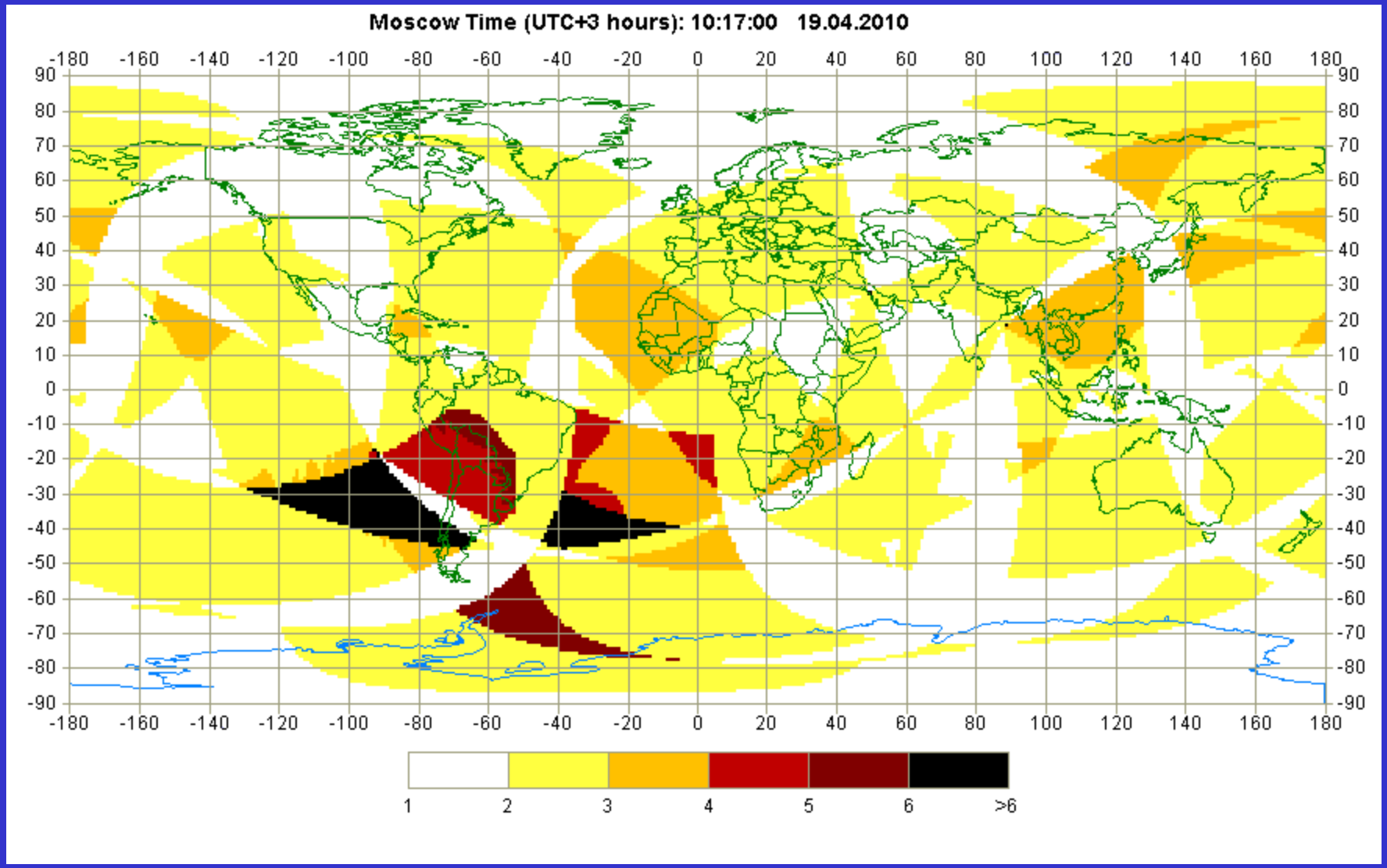


(artist's concept)

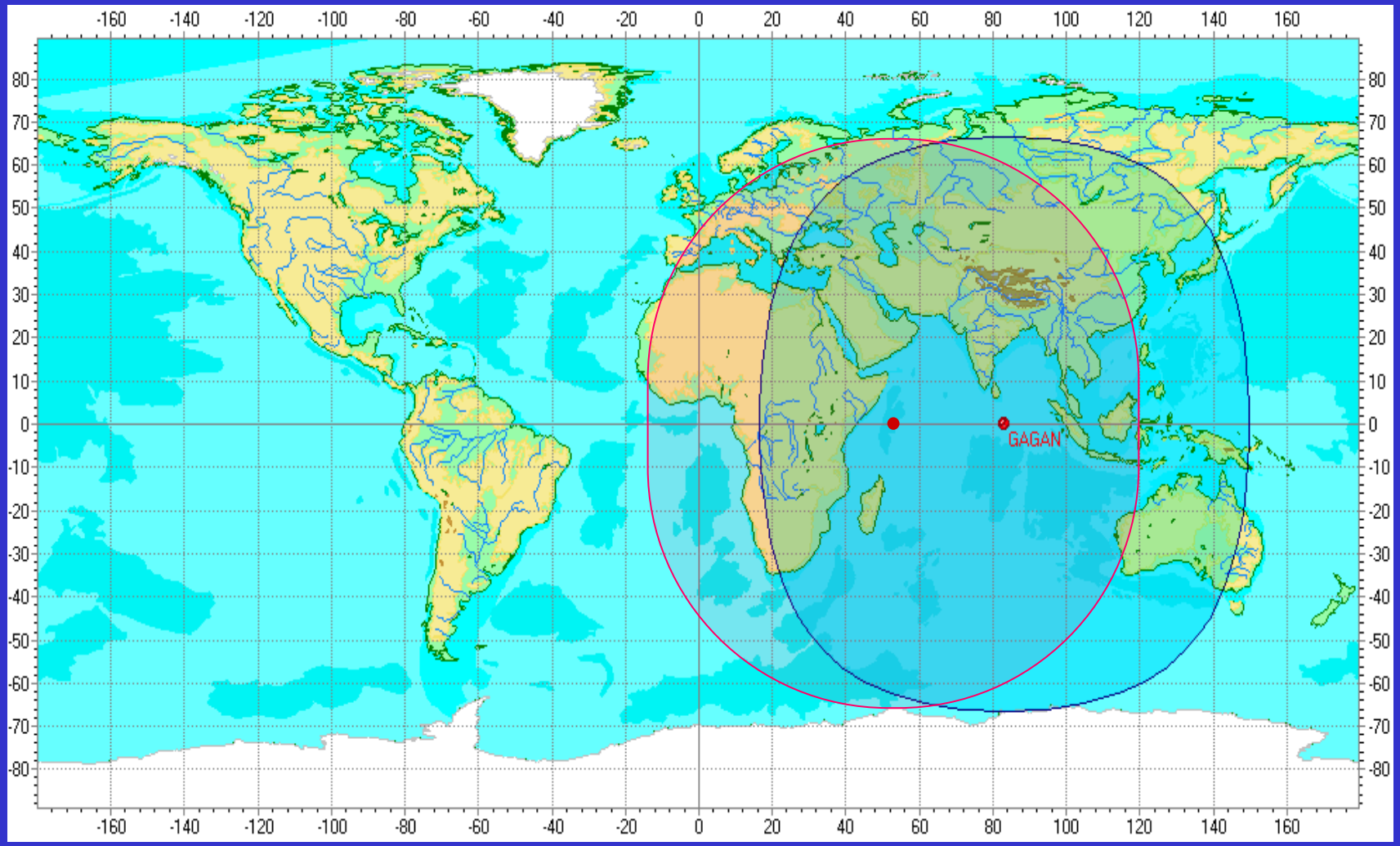
GLONASS constellation status, 19.04.2010г.

Total satellites in constellation	23 SC
Operational	21 SC
In commissioning phase	-
In maintenance	-
Spares	2 SC
In decommissioning phase	-

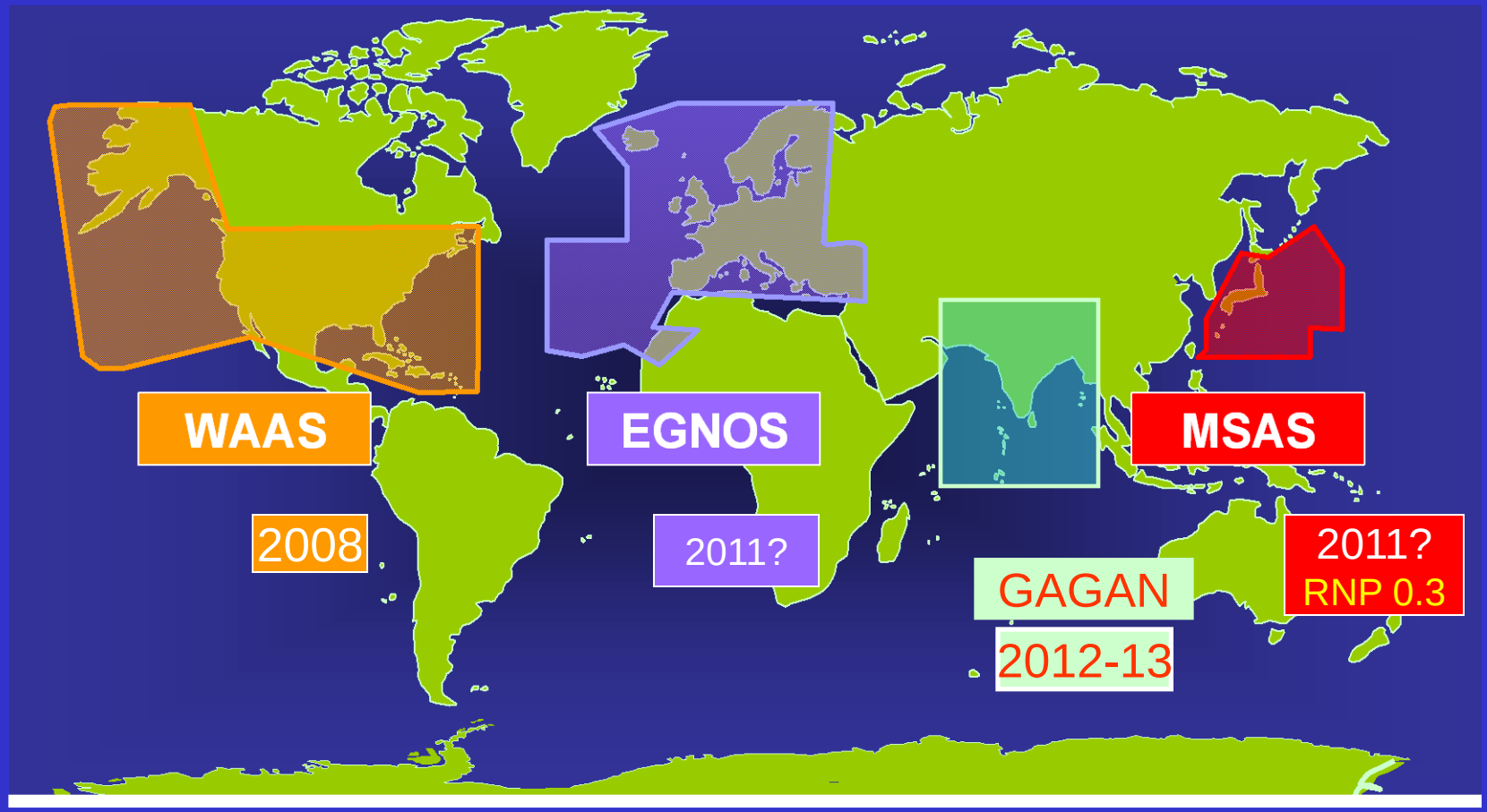
Current values of position geometry factor PDOP on the Eath surface (the mask angle: 5°)



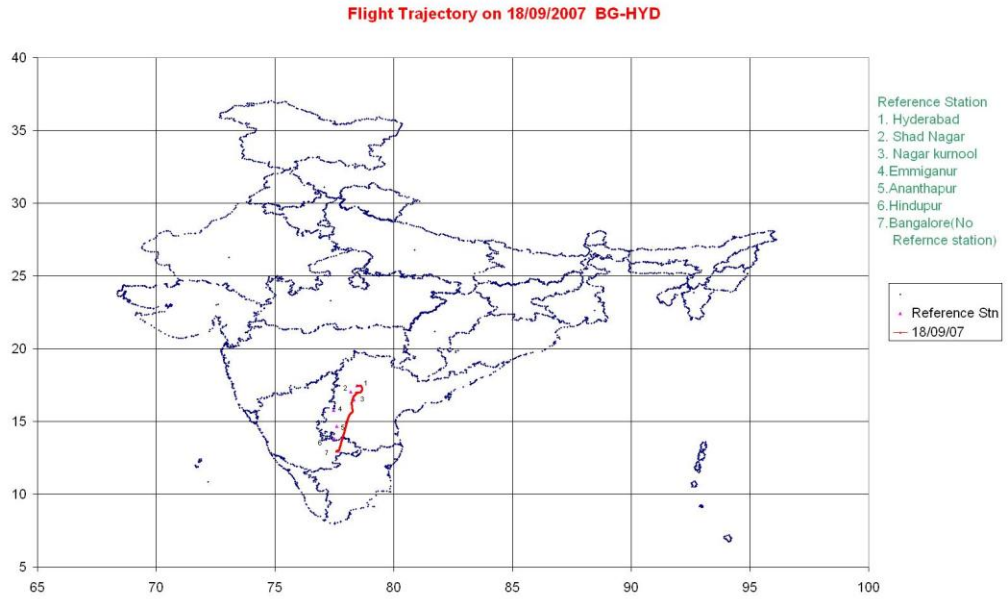
COVERAGE FROM 82 & 55 Deg.E

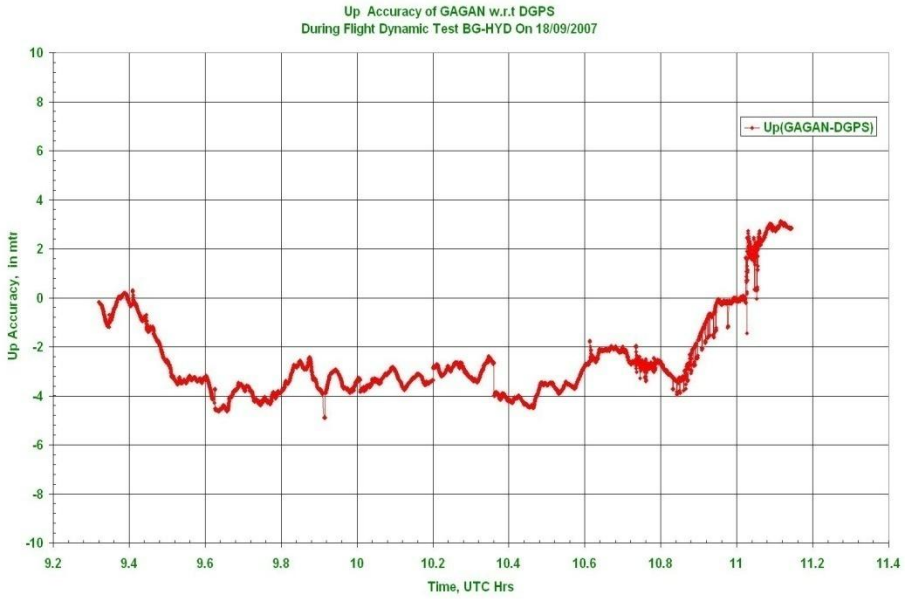


GPS Augmentation systems in the World (For APV - 1.5 capability)

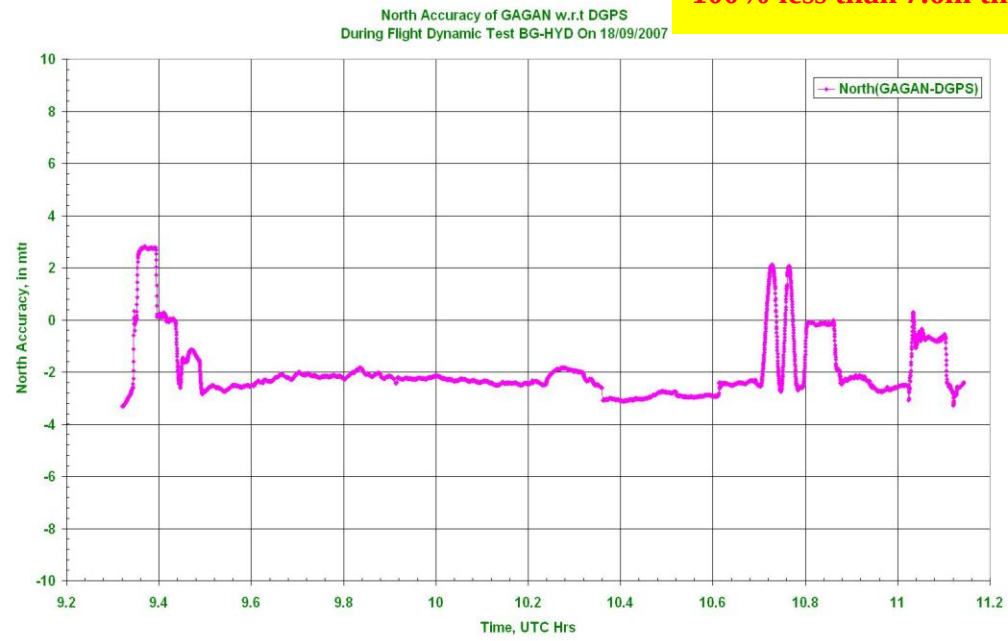


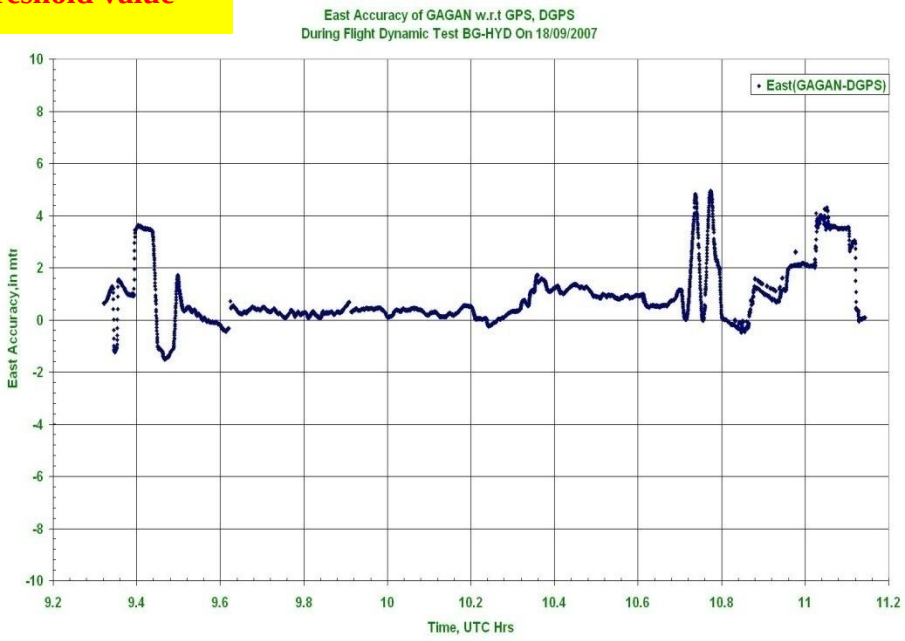
Position Accuracy of GAGAN, BG- HYD Sortie on 18/09/2007



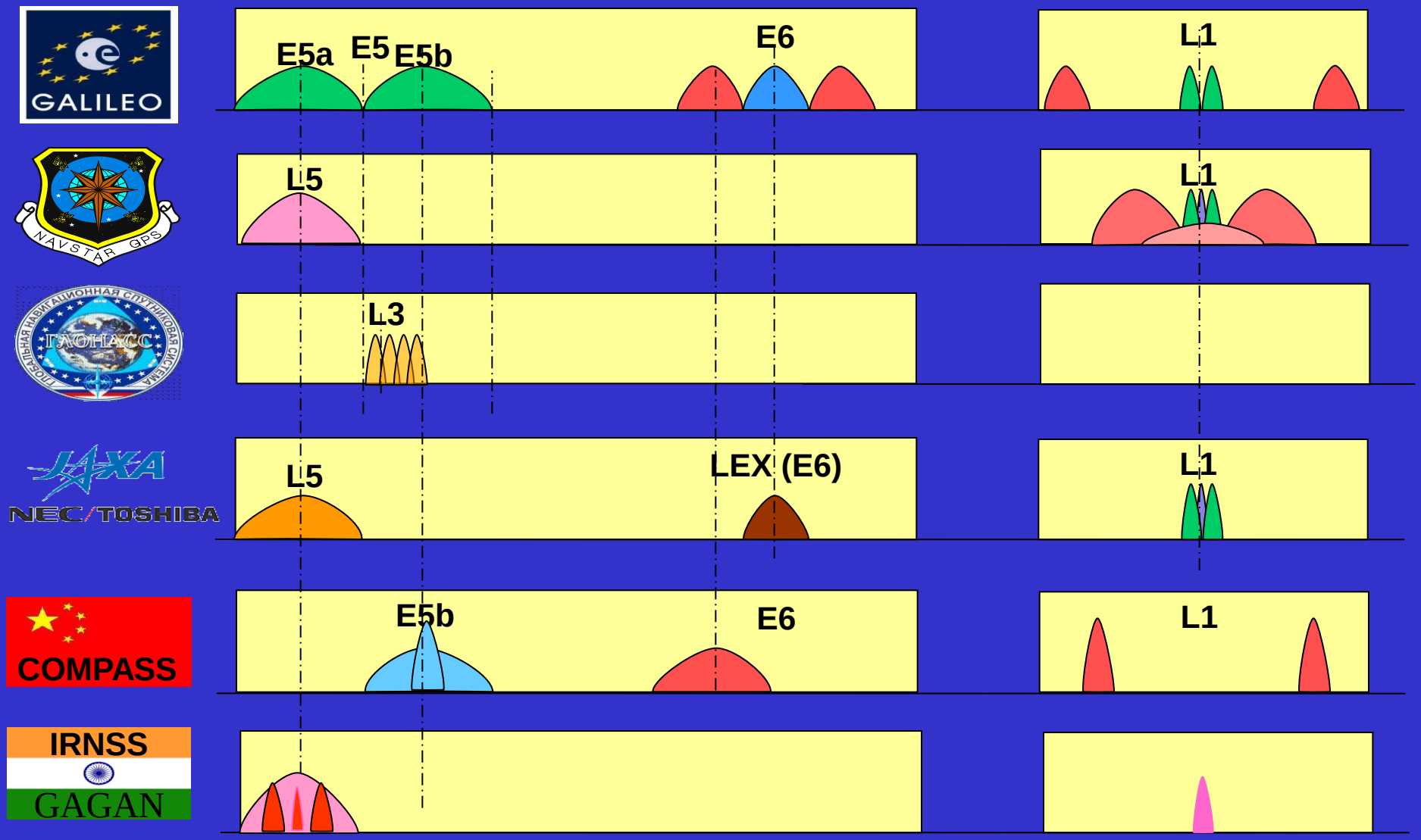


100% less than 7.6m threshold value

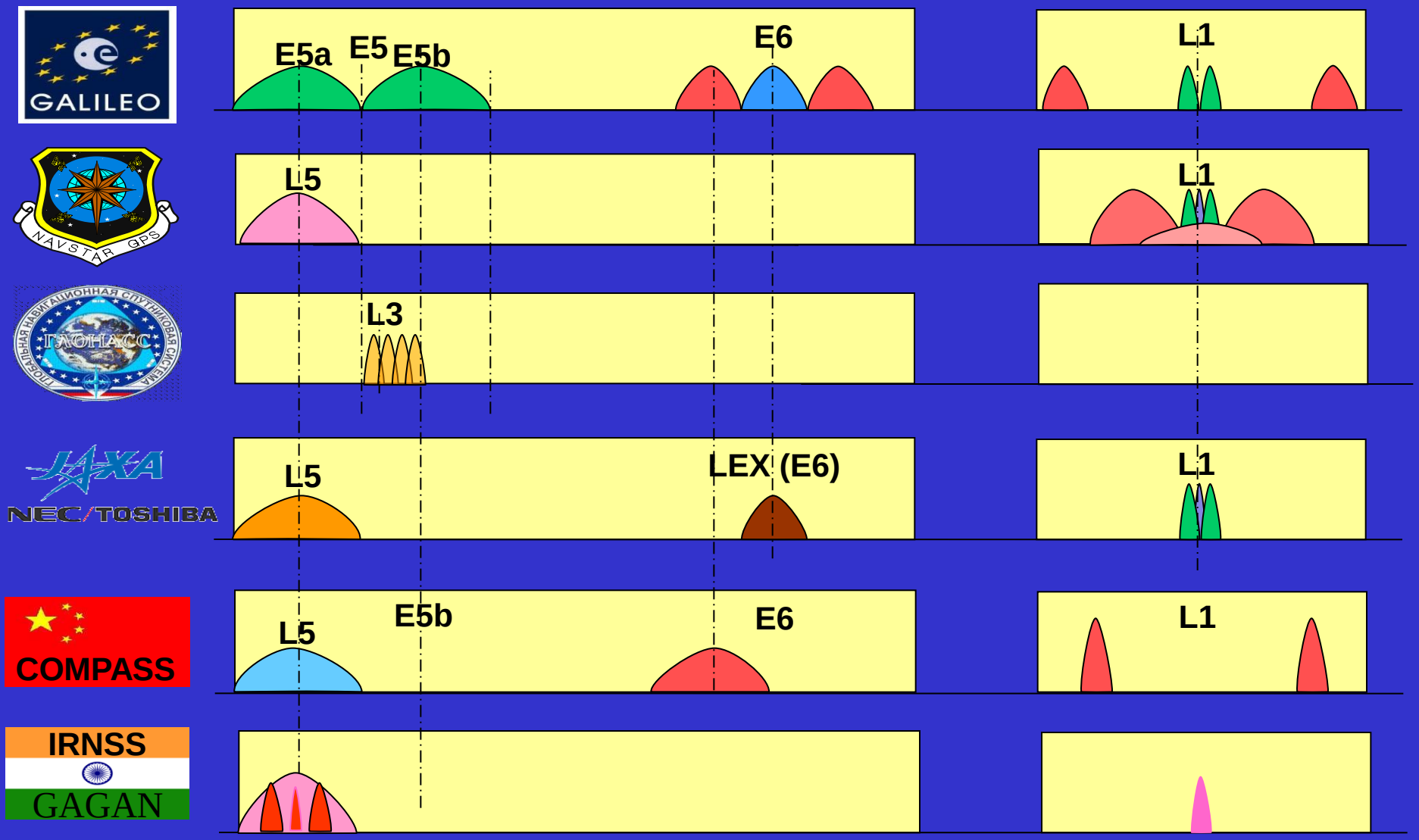




Compatibility & interoperability with other GNSS



Compatibility & interoperability with other GNSS

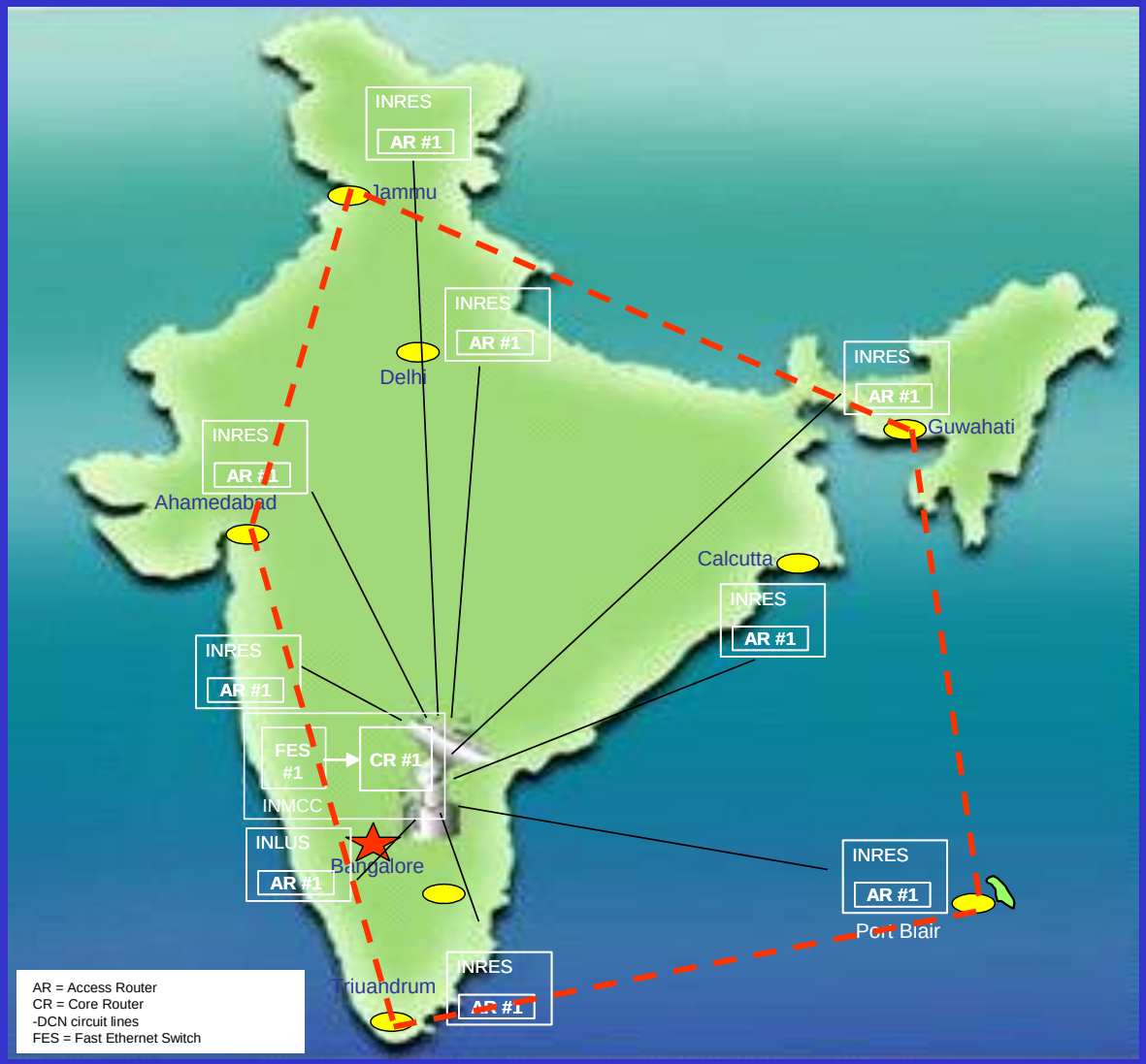


GAGAN SPACE SEGMENT AVAILABILITY

- GAGAN FOP approved by the Indian Govt.
- The Department of Space has planned GAGAN L1 & L5 frequency payloads on GSAT-4, GSAT-8 & GSAT-9 satellites.The present schedules for these satellites are

1. GSAT-4 Launch by early 2010 on-board GSLV
2. GSAT-8 Launch by last quarter of 2010
3. GSAT-9 to be launched by second half of 2011. (GSAT-9 is planned to be an in-orbit spare.)
4. GSAT-10 planned to launched in 2011.

TDS CONFIGURATION FOR FSAT



Ground Segment

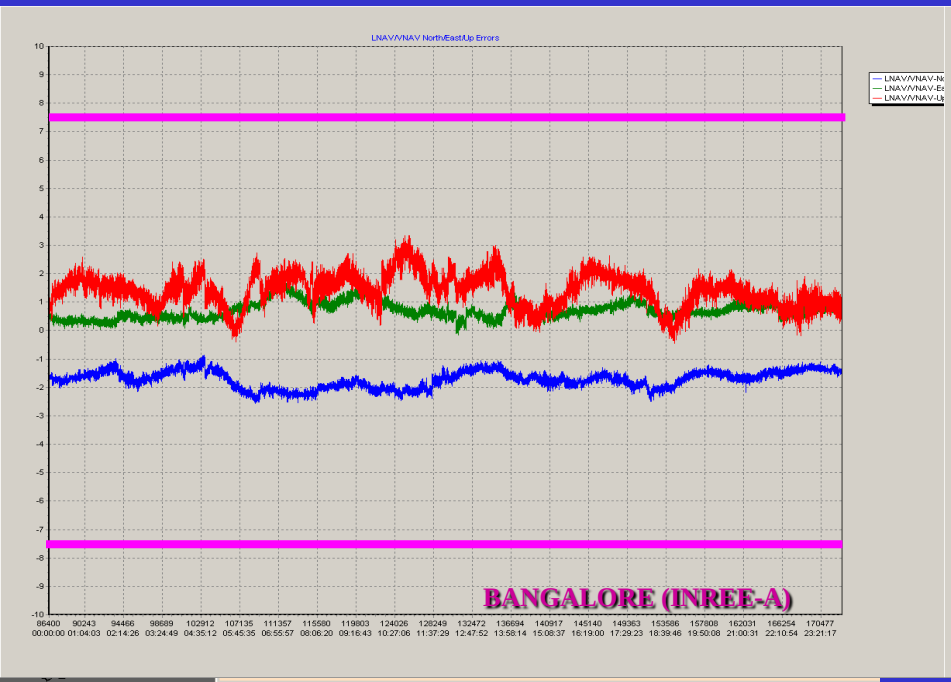
- 8 INRES: 2 INREEs
- 1 INMCC
- 1 INLUS
- 1 ring of OFC (7 INRES)
- 1 VSAT link (GPB)

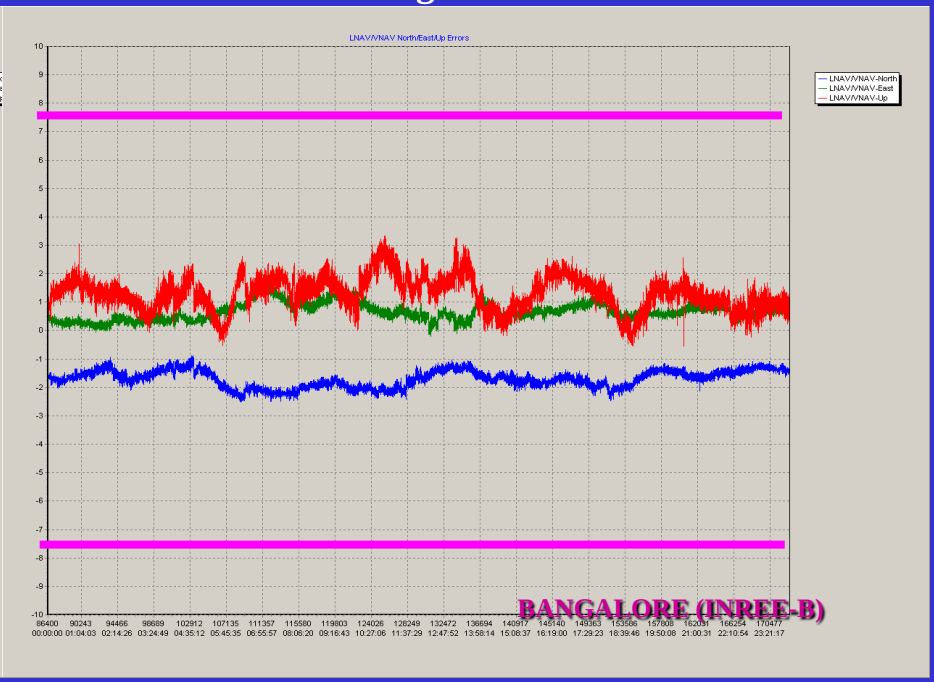
Space Segment

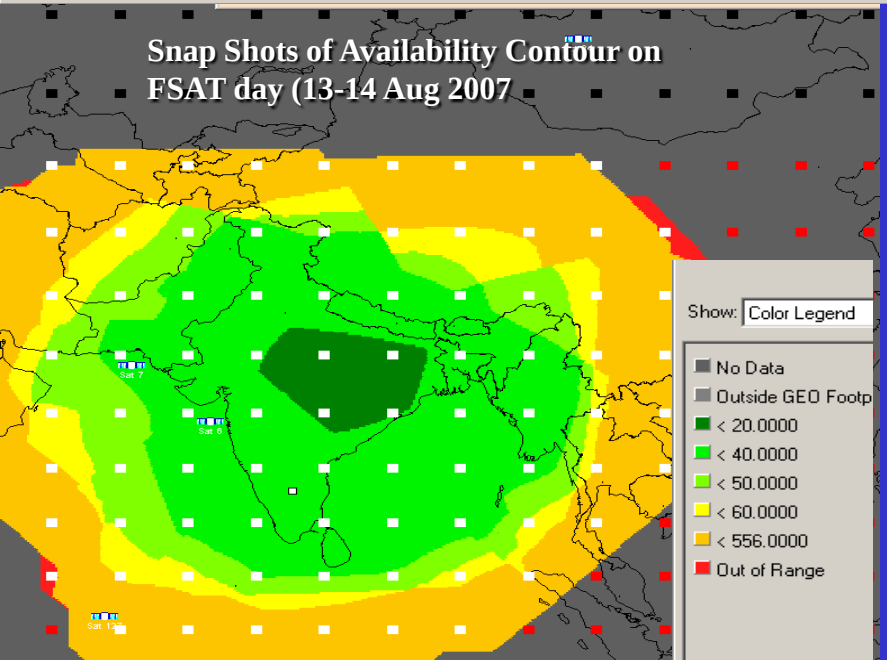
- INMARSAT-4F1

FSAT RESULTS

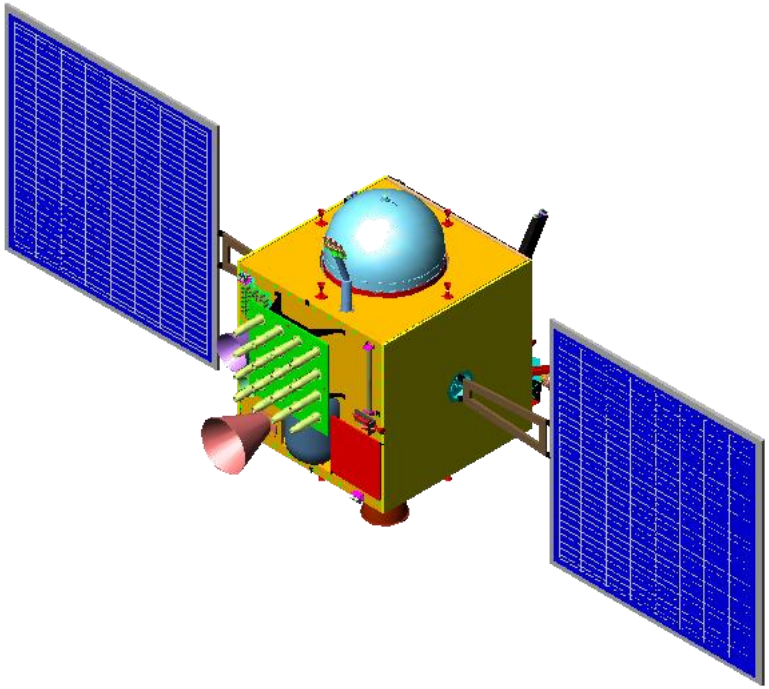
ACCURACY TIMELINE FOR BANGALORE INRES During FSAT



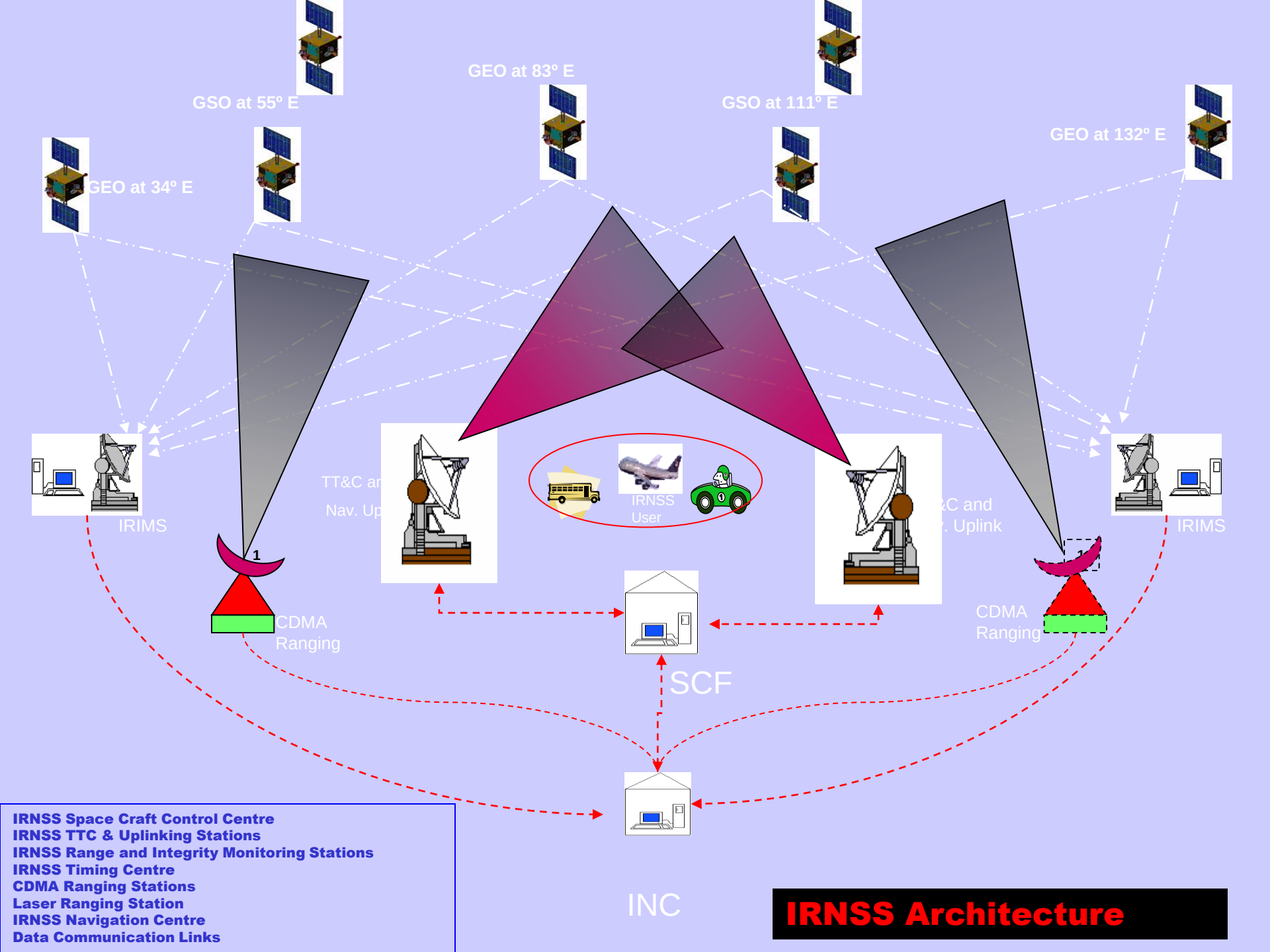




SBAS Rx Performance During FSAT



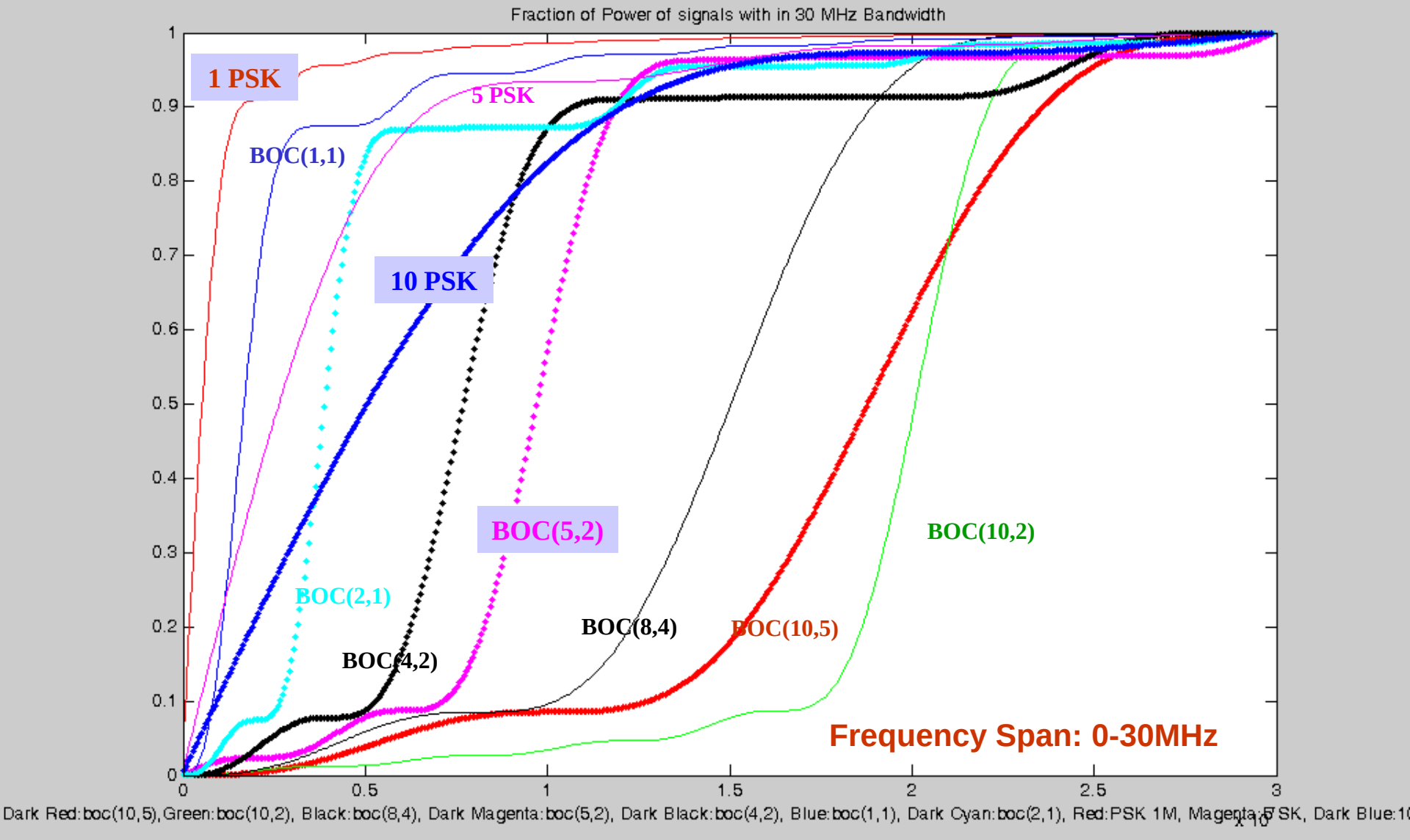
IRNSS - An Overview

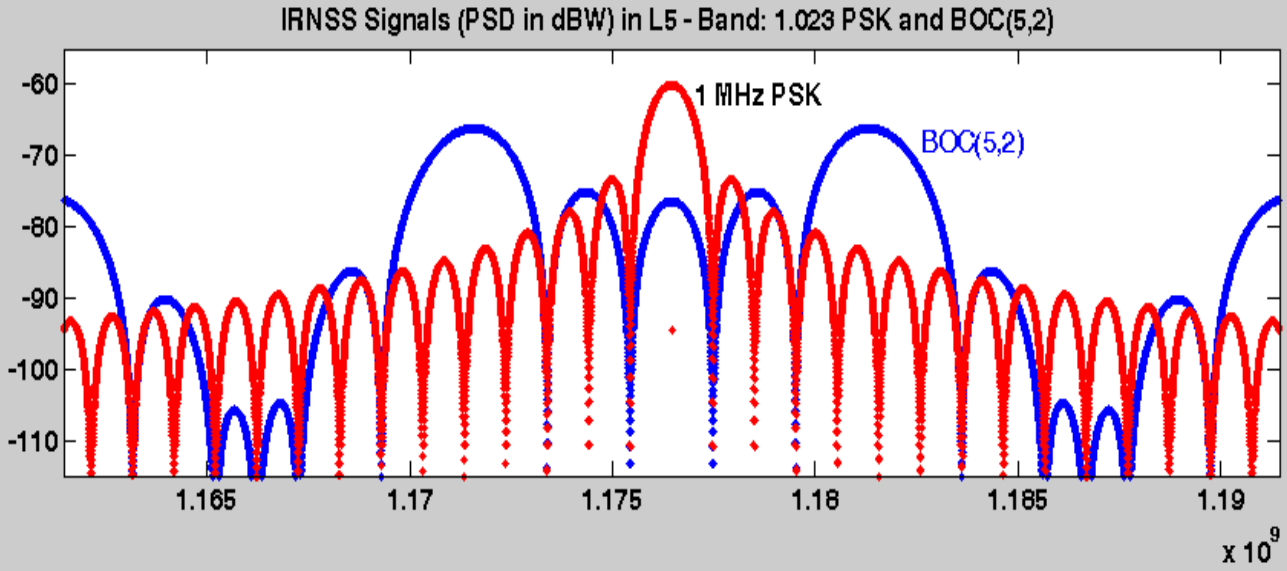

GEO at 83° E
GSO at 55° E
GSO at 111° E
GEO at 34° E
GEO at 132° E
IRIMS
IRIMS
TT&C ar
Nav. Up
IRNSS
User
&C and
. Uplink
CDMA
Ranging
CDMA
Ranging
SCF
INC
IRNSS Space Craft Control Centre
IRNSS TTC & Uplinking Stations
IRNSS Range and Integrity Monitoring Stations
IRNSS Timing Centre
CDMA Ranging Stations
Laser Ranging Station
IRNSS Navigation Centre
Data Communication Links
IRNSS Architecture

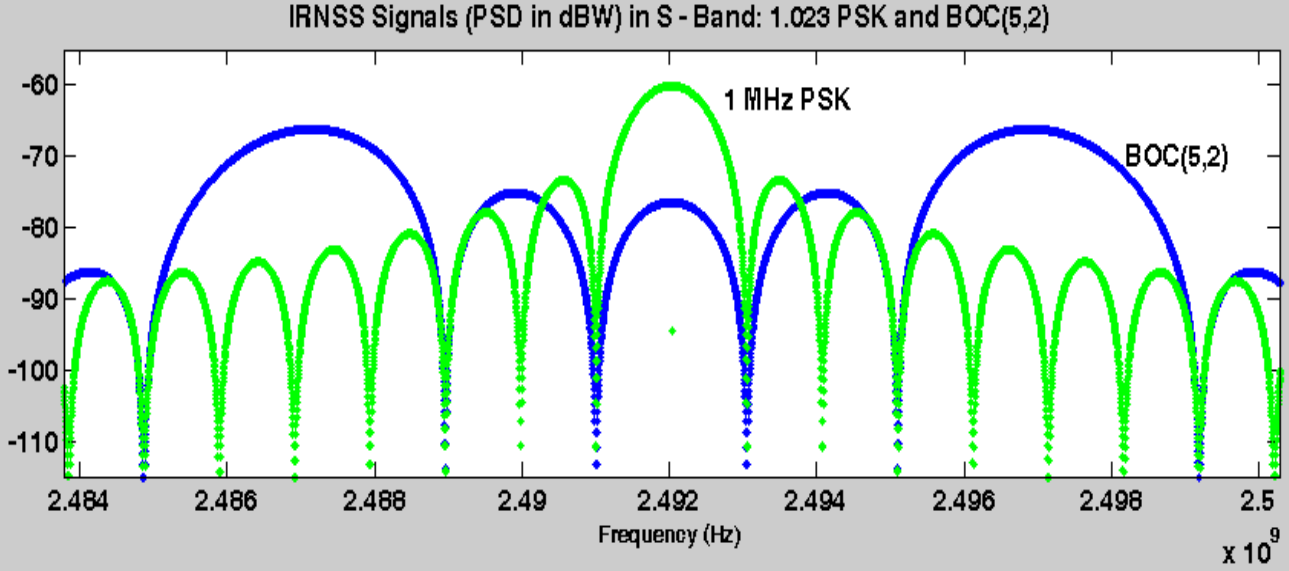
IRNSS SERVICES & CENTRE FREQUENCIES

Service Type	Signals	Frequency Band
Standard Positioning Service	1 MHz BPSK	L5 (1176.45 MHz) S (2492.08 MHz)
Restricted Services	BOC(5,2)	L5 (1176.45 MHz) S (2492.08 MHz)

Navigation Signals –Fraction of power within Bandwidth

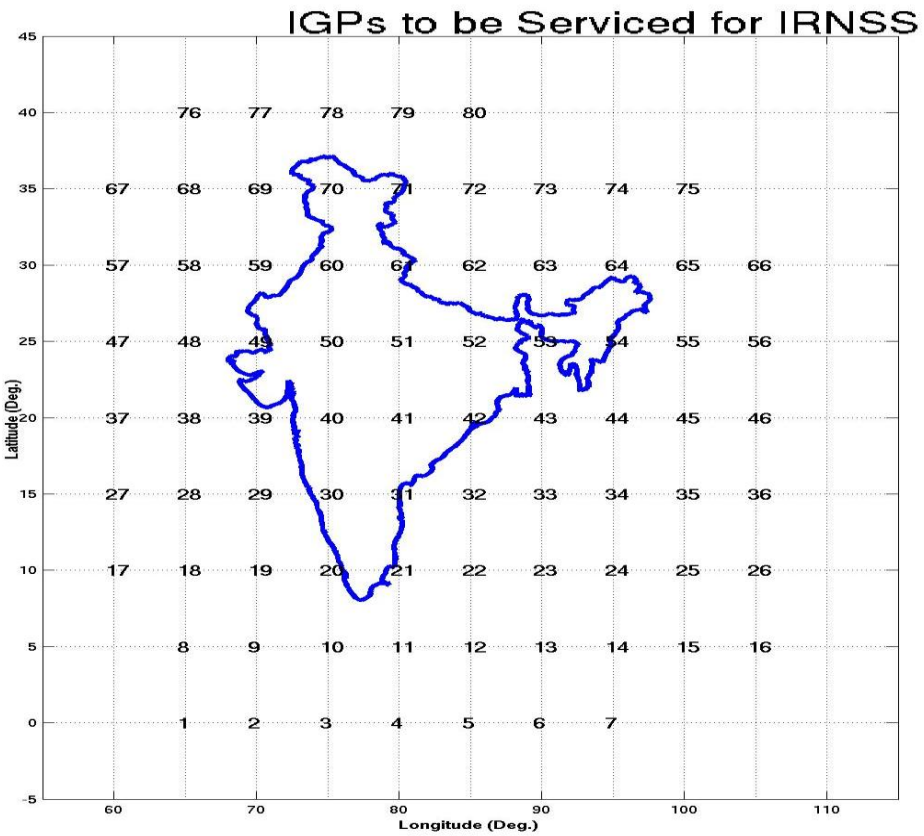



IRNSS Signals (PSD in dBW) in L5 - Band: 1.023 PSK and BOC(5,2)
1 MHz PSK
BOC(5,2)
-60
-70
-80
-90
-100
-110
1.165
1.17
1.175
1.18
1.185
1.19
x 10^9

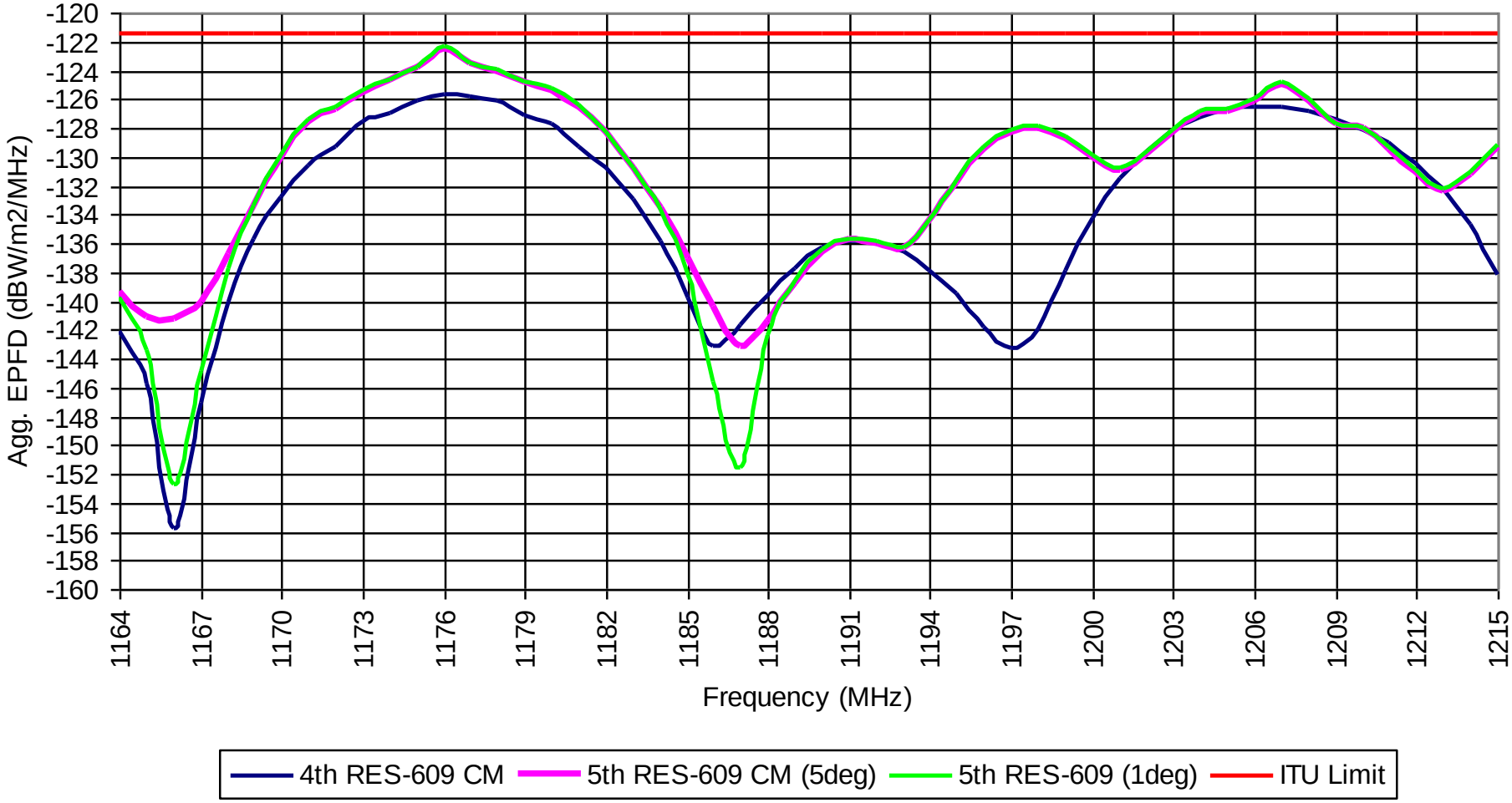

IRNSS Signals (PSD in dBW) in S - Band: 1.023 PSK and BOC(5,2)
1 MHz PSK
BOC(5,2)
-60
-70
-80
-90
-100
-110
2.484
2.486
2.488
2.49
2.492
2.494
2.496
2.498
2.5
Frequency (Hz)
x 10^9

Data structure

- ***Data structure for SPS and RS is the same and will include a grid model.*** The clock, ephemeris, almanac data for 7 IRNSS satellites is planned to be (?) transmitted with the same accuracy as in legacy GPS, GLONASS & Galileo.
- Since the number of satellites in IRNSS are 7 as against 30 for GPS, the field available for extra satellites is used up for inserting a 80 grid points ionospheric model for the benefit of single frequency user.
- Being discussed at present,Data structure similar to augmentation, L2C/L5 systems and L1C is being further studied (33 bit ephemerides, message type structure, reduced almanac, new coding etc).


IGPs to be Serviced for IRNSS
Latitude (Deg.)
Longitude (Deg.)
45
40
35
30
25
20
15
10
5
0
-5
60
70
80
90
100
110
76 77 78 79 80
67 68 69 70 71 72 73 74 75
57 58 59 60 61 62 63 64 65 66
47 48 49 50 51 52 53 54 55 56
37 38 39 40 41 42 43 44 45 46
27 28 29 30 31 32 33 34 35 36
17 18 19 20 21 22 23 24 25 26
8 9 10 11 12 13 14 15 16
1 2 3 4 5 6 7

Aggregate EPFD values computed during 4th & 5th RES-609 Consultaion Meetings



4th RES-609: -125.68dBW/m^2/MHz, 5th RES-609(5deg): -122.46 dBW/m^2/MHz, 5th RES-609(1deg): -122.34 dBW/m^2/MHz

COMPASS – Technical description

- COMPASS consists of a constellation of 30 Non-geostationary satellites and 5 geostationary satellites at 58.75 deg.E, 80 deg.E, 110.5 deg.E, 140 deg.E and 160 deg.E.
- COMPASS operations are centred around 1575.42 MHz, 1191.795 MHz and 1268.52 MHz.
- The geostationary satellites also use downlink in S-band (2483.5 – 2500 MHz).
- The MEO constellation of COMPASS consists of 27 satellites in 3 orbital planes, inclined approx.55 deg.E to the equator and orbital altitude of 21500 kms.

COMPASS – Technical description (Contd.,)

- COMPASS signals in the L1 band uses BOC (14,2) modulation (B signal). It is modulated with 50 bits/seconds/100 symbols/second navigation data. There is a pilot which is dataless and is called $B1_P$. The B1-C signal consists of two components in phase quadrature. $B1\text{-}C_D$ is modulated with 100 symbols/sec navigation data and $B1C_P$ is dataless. $B1\text{-}C_P$ represented by

$$MBOC(f) = \frac{29}{33} BOC_{1,1}(f) + \frac{4}{33} BOC_{6,1}(f)$$

The total psd of the B1-C components is given below:

$$S(f) = \frac{1}{4} BOC_{1,1}(f) + \frac{3}{4} MBOC(f) = \frac{10}{11} BOC_{1,1}(f) + \frac{1}{11} BOC_{6,1}(f)$$

COMPASS signals in the frequency band 1 164-1 300 MHz

- COMPASS operates four signals in the 1 164-1 300 MHz RNSS band. The signals include B2, B3 and B3-A.
- The COMPASS B2 signal is centred on a frequency of 1 191.795 MHz and is generated with an AltBOC modulation of side-band sub-carrier rate of 15.345 MHz. The power spectral density of the AltBOC signal is given below:

$$G(f) = \frac{1}{2\pi^2 f^2 T_c} \frac{\cos^2(\pi f T_c)}{\cos^2(\pi f T_c / n)} \left[\cos^2\left(\pi f \frac{T_{sc}}{2}\right) - \cos\left(\pi f \frac{T_{sc}}{2}\right) - 2\cos\left(\pi f \frac{T_{sc}}{2}\right)\cos\left(\pi f \frac{T_{sc}}{4}\right) + 2 \right]$$

- With $T_{sc} = \frac{1}{f_{sc}} \cdot f_{sc}$ is the subcarrier frequency, f_c the chip rate, T_c chip period and T_{sc} the period of the subcarrier.

COMPASS signals in the frequency band 1 164-1 300 MHz (Contd)

- The B2 signal consists of two components in phase quadrature. One component, $B2_D$, is modulated with a 50 bit/s/100 Symbol/s binary navigation data stream and the other, $B2_P$, is dataless.
- The B3 signal is centred on 1 268.52 MHz. The carrier is QPSK modulated with a pseudo-random noise (PRN) code having a chip rate of 10.23 Mchip/s (in I channel or Q channel), which is Modulo-2 added to a 500 bit/s binary navigation data stream prior to modulation.
- The B3-A signal is also centred on 1 268.52 MHz, and uses a BOC(15,2.5) modulation. The B3-A signal consists of two components in phase quadrature. One component, $B3\text{-}A_D$, is modulated with a 50 bit/s/100 Symbol/s binary navigation data stream and the other, $B3\text{-}A_P$, is dataless.

Signal power and spectra

- The minimum received power level on the surface of the Earth, for any elevation angle equal or more than 5°, based on an ideally matched and isotropic 0 dBi receiver antenna are as follows:

B1 signal: −153.4 dBW for MEO network, −155.2 dBW for GSO/IGSO network.

B1-C signal: −156.4 dBW for MEO network,−158.2 dBW for GSO/IGSO network.

B2 signal: −153 dBW for MEO network,−154.8 dBW for GSO/IGSO network.

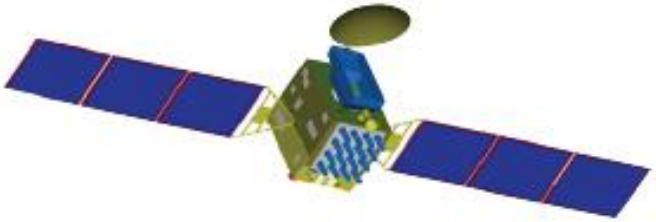
B3/B3-A signal: −156.5 dBW for MEO network,−158.3 dBW for GSO/IGSO network.

System Structure-1

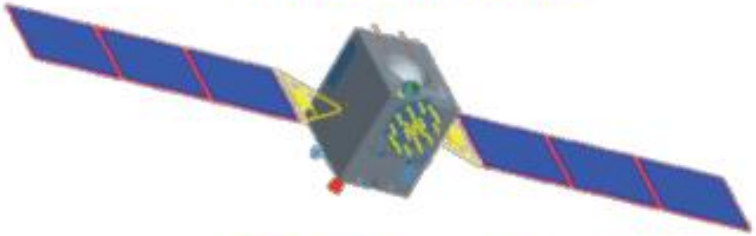
- ***Space Segment***

5 GEO satellites and 30 Non-GEO satellites

Constellation



GEO Satellite



MEO Satellite

Signal Frequencies

- Frequencies

  B1: 1559.052~1591.788MHz

  B2: 1166.22~1217.37MHz

  B3: 1250.618~1286.423MHz

Signal Characteristics (2)

- *To be transmitted: B1, B2 and B3*

Component	Carrier Rrequency (MHz)	Chip Rate (cps)	Data/Symbol Rate (bps/sps)	Modulation Type	Service Type
$B1\text{-}C_D$	1575.42	1.023	50/100	MBOC(6,1,1/11)	Open
$B1\text{-}C_P$			No		
B1		2.046	50/100	BOC（14，2）	Authorized
			No		
$B2a_D$	1191.795	10.23	25/50	AltBOC(15,10)	Open
$B2a_P$			No		
$B2b_D$			50/100		
$B2b_P$			No		
B3	1268.52	10.23	500bps	QPSK(10)	Authorized
$B3\text{-}A_D$		2.5575	50/100	BOC(15,2.5)	Authorized
$B3\text{-}A_P$			No		

Signal Characteristics

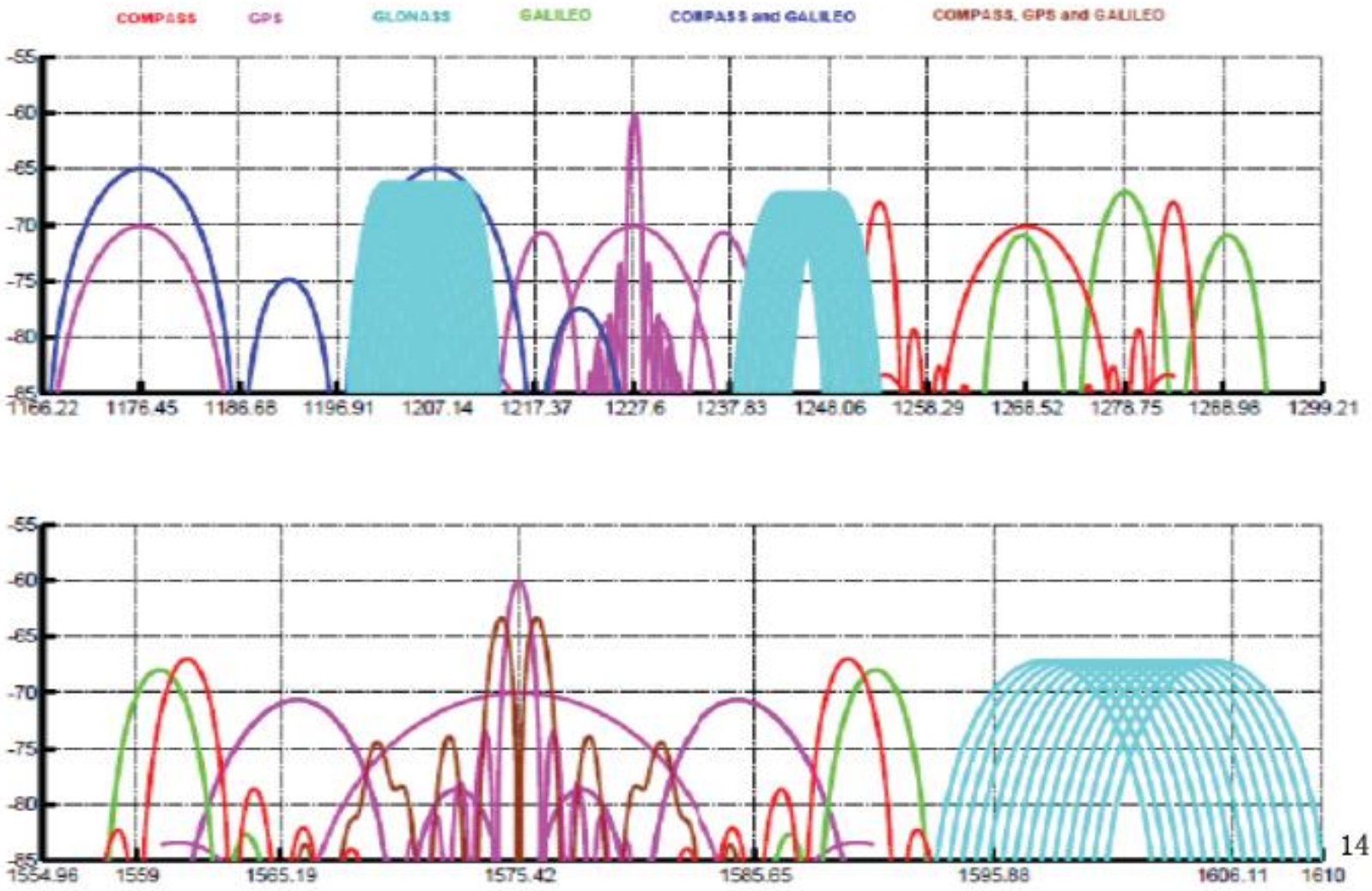
- ***Already transmitted: B1, B1-2, B2, and B3***

Component	Carrier Frequency (MHz)	Chip Rate (cps)	Bandwidth (MHz)	Modulation Type	Service Type
B1(I)	1561.098	2.046	4.092	QPSK	Open
B1(Q)		2.046			Authorized
B1-2(I)	1589.742	2.046	4.092	QPSK	Open
B1-2(Q)		2.046			Authorized
B2(I)	1207.14	2.046	24	QPSK	Open
B2(Q)		10.23			Authorized
B3	1268.52	10.23	24	QPSK	Authorized

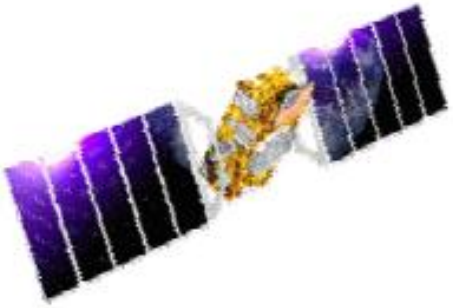
To be transmitted: B1, B2 and B3

Component	Carrier Rrequency (MHz)	Chip Rate (cps)	Data/Symbol Rate (bps/sps)	Modulation Type	Service Type
B1-C_D	1575.42	1.023	50/100	MBOC(6,1,1/11)	Open
B1-C_P			No		
B1		2.046	50/100	BOC（14，2）	Authorized
			No		
$B2a_D$	1191.795	10.23	25/50	AltBOC(15,10)	Open
$B2a_P$			No		
$B2b_D$			50/100		
$B2b_P$			No		
B3	1268.52	10.23	500bps	QPSK(10)	Authorized
B3-A_D		2.5575	50/100	BOC(15,2.5)	Authorized
B3-A_P			No		

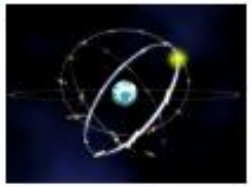
Spectrum of Compass and Other GNSS Systems



Galileo Programme



Full Operational Capability
27 (+3) Galileo Satellites



In-Orbit Validation
4 satellites plus
ground segment

Galileo System Testbed v2
Initial Test Satellites

GALILEO
GIOVE

Galileo System Testbed v1
Validate critical algorithms

GALILEO
GSTB-V1

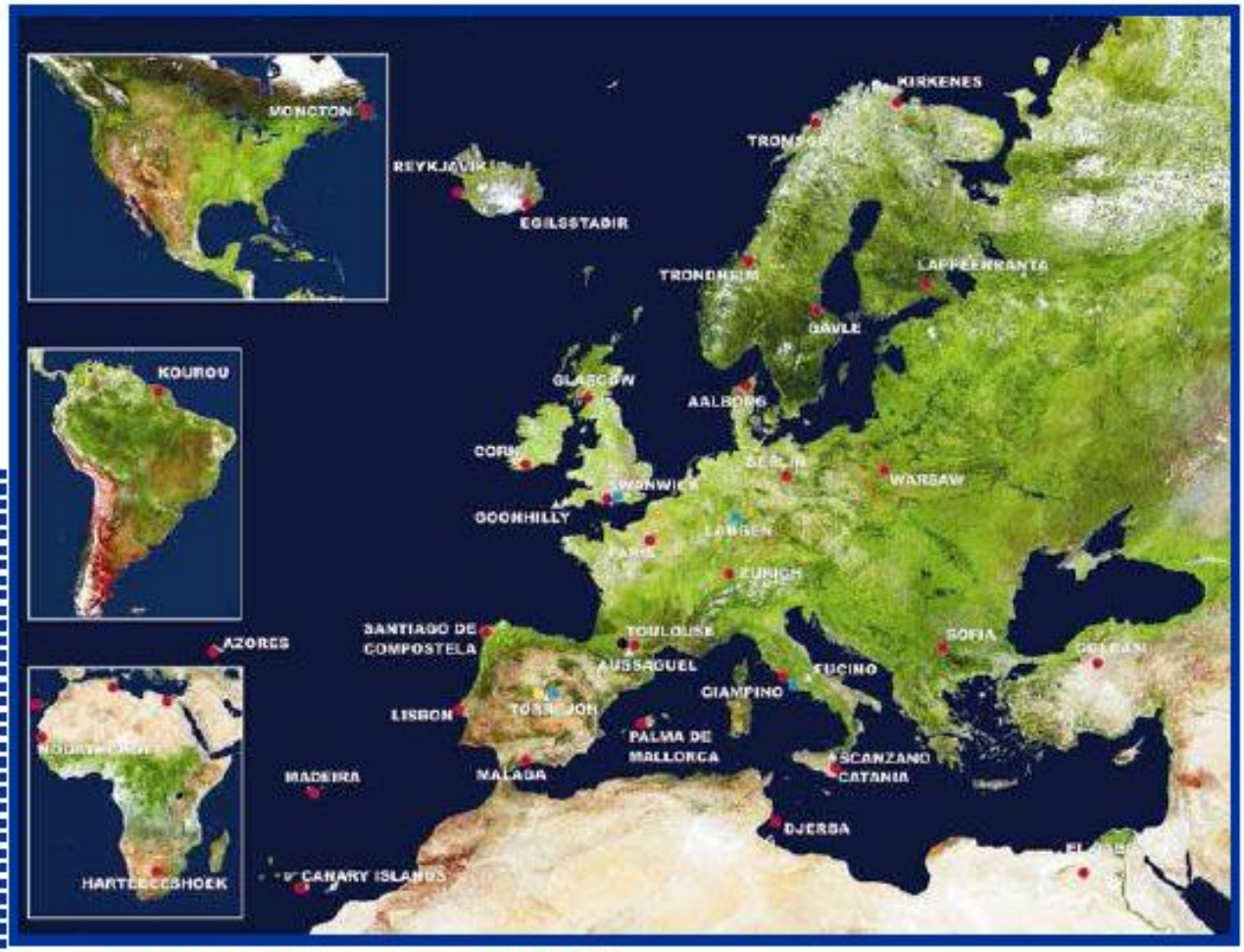
EGNOS System Architecture

Users

6 NLES Navigation Land Earth Stations

• 2 Support Facilities

▫ 4 MCC Mission Control Centers



EWAN

• 34 RIMS Ranging & Integrity Monitoring Stations

EGNOS Performance

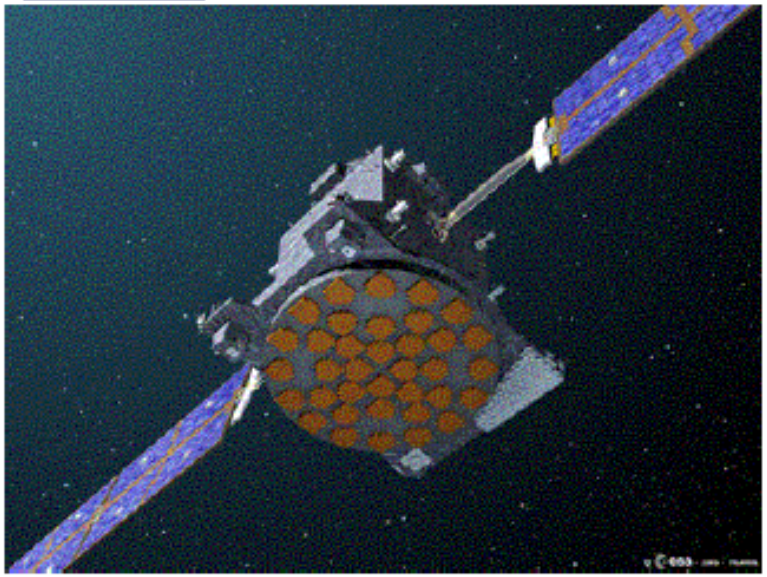
Standards v Actual Performance (5-11 August, 2007)

	APV-1 requirement	Measured at Toulouse (France)	Measured at Warsaw (Poland)	Measured at Brussels (Belgium)
Horizontal Accuracy	16 m	0.91 m (95% HNSE)	2.23 m (95% HNSE)	0.91 m (95% HNSE)
Vertical Accuracy	20 m	1.34 m (95% VNSE)	2.58 m (95% VNSE)	1.34 m (95% VNSE)
Availability	99%	99.9049%* (worst day: 99.33%)	97.6457%* (worst day: 95.08%)	99.9049%* (worst day: 98.219%)
Continuity	$1\text{-}8.10^{-6}$ / 15s	Not measured	Not measured	Not measured

* Availability computed from data collected when EGNOS SiS is available.

Source: ESA EGNOS Real-Time Performance: http://www.egnos-pro.esa.int

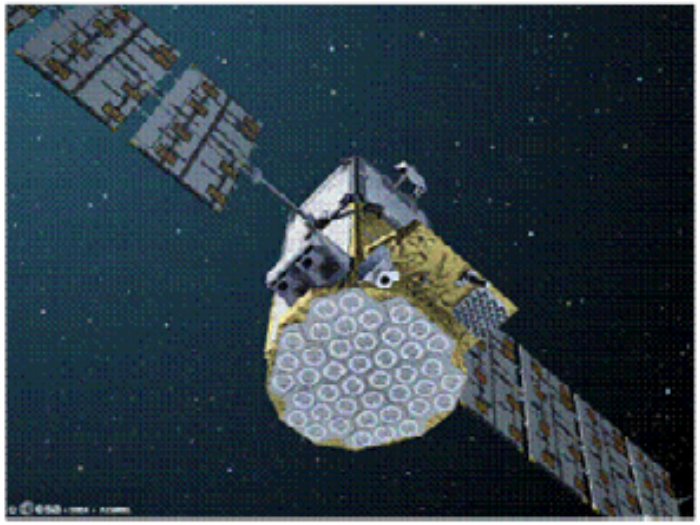
GIOVE-A/GIOVE-A2



- GIOVE-A is Europe's first MEO satellite
- Launched on 28 December 2005
- The GIOVE-A satellite:
  - Transmits the Galileo signals
  - Tests critical technologies
    - rubidium atomic clock
    - signal generator
  - Measures environment for FOC

- GIOVE-A2 risk mitigation activities started in March 2007
  - Secure in-orbit presence
  - Continue experiments
  - Monitoring of the MEO environment
  - Support EU/US L1 Open Service common baseline

GIOVE-B



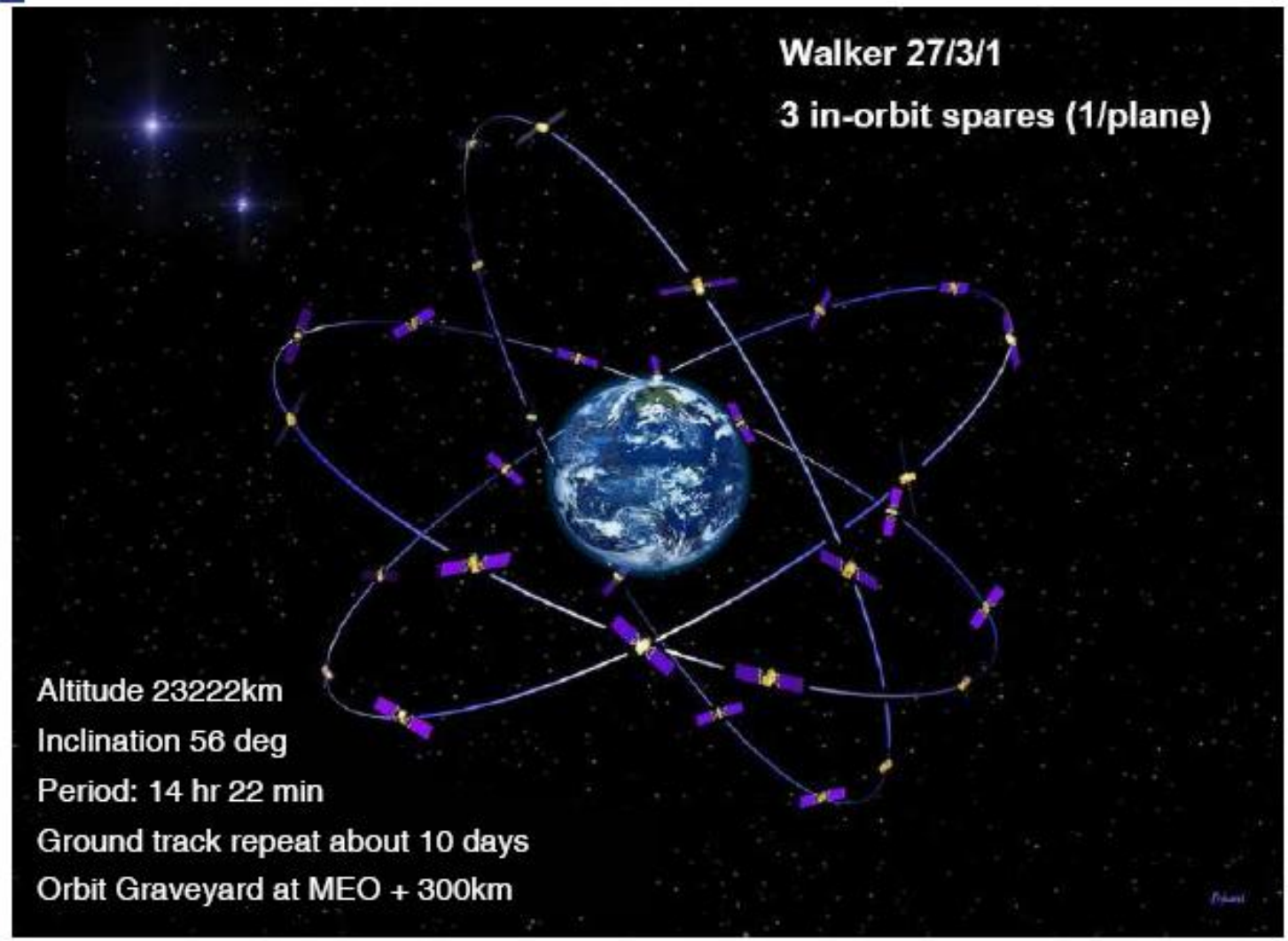
Constructed by Galileo Industries
Lift-off mass: 485 kg
Power demand: 940 W
Stowed Dimensions: 1 m x 1 m x 2.4 m

- The GIOVE-B satellite will:
  - Transmit the Galileo signals
  - Test critical technologies: passive hydrogen maser clock, rubidium atomic, signal generator
  - Measure environment for future constellation
- GIOVE-B is expected to be launched in December 2007

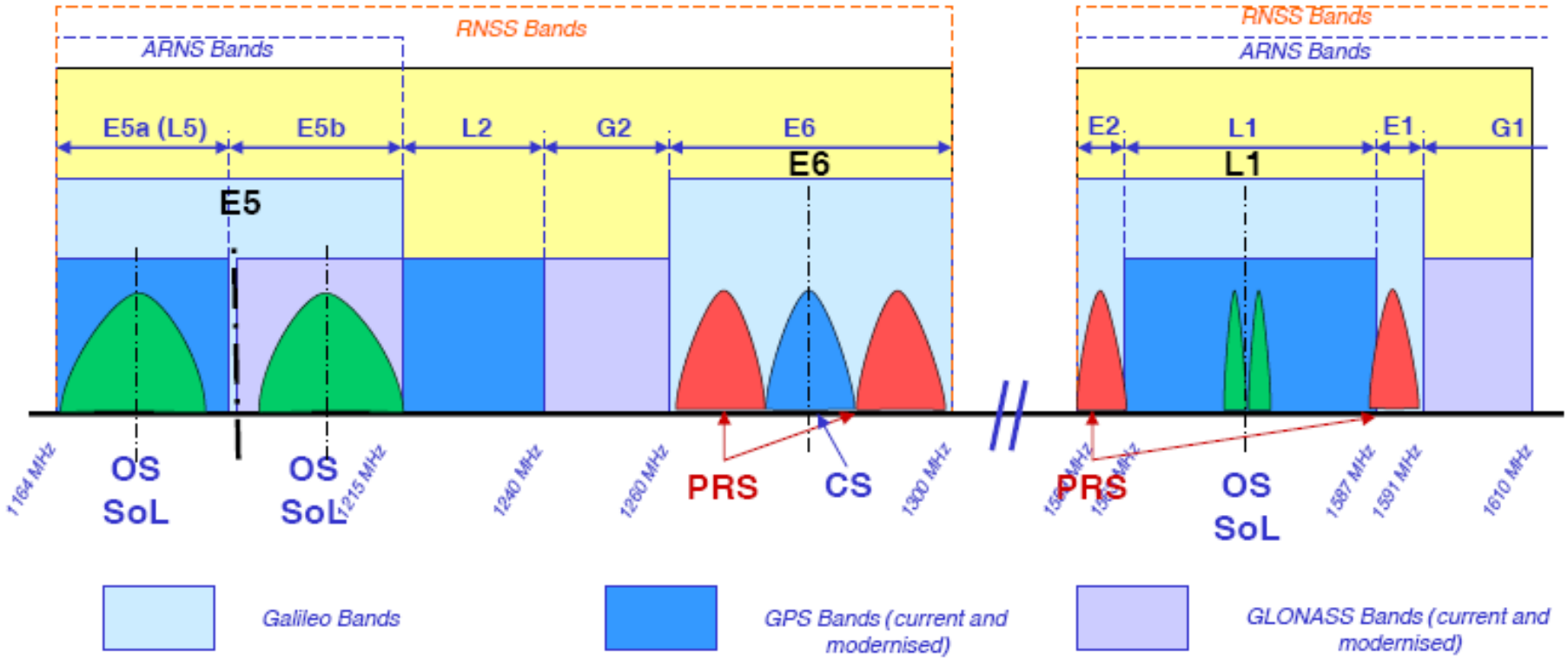
Galileo Performances
Dual Frequency

Galileo Service	Horizontal Accuracy (95%)	Vertical Accuracy (95%)	Availability	Integrity
Open Service	4 m	8 m	> 99.8%	NO
Safety of Life	4 m	8 m	> 99.8%	YES
Commercial Service	Detailed performance requirements under elaboration			
Public Regulated Service	4 m	8 m	> 99.8%	YES

Galileo Orbits

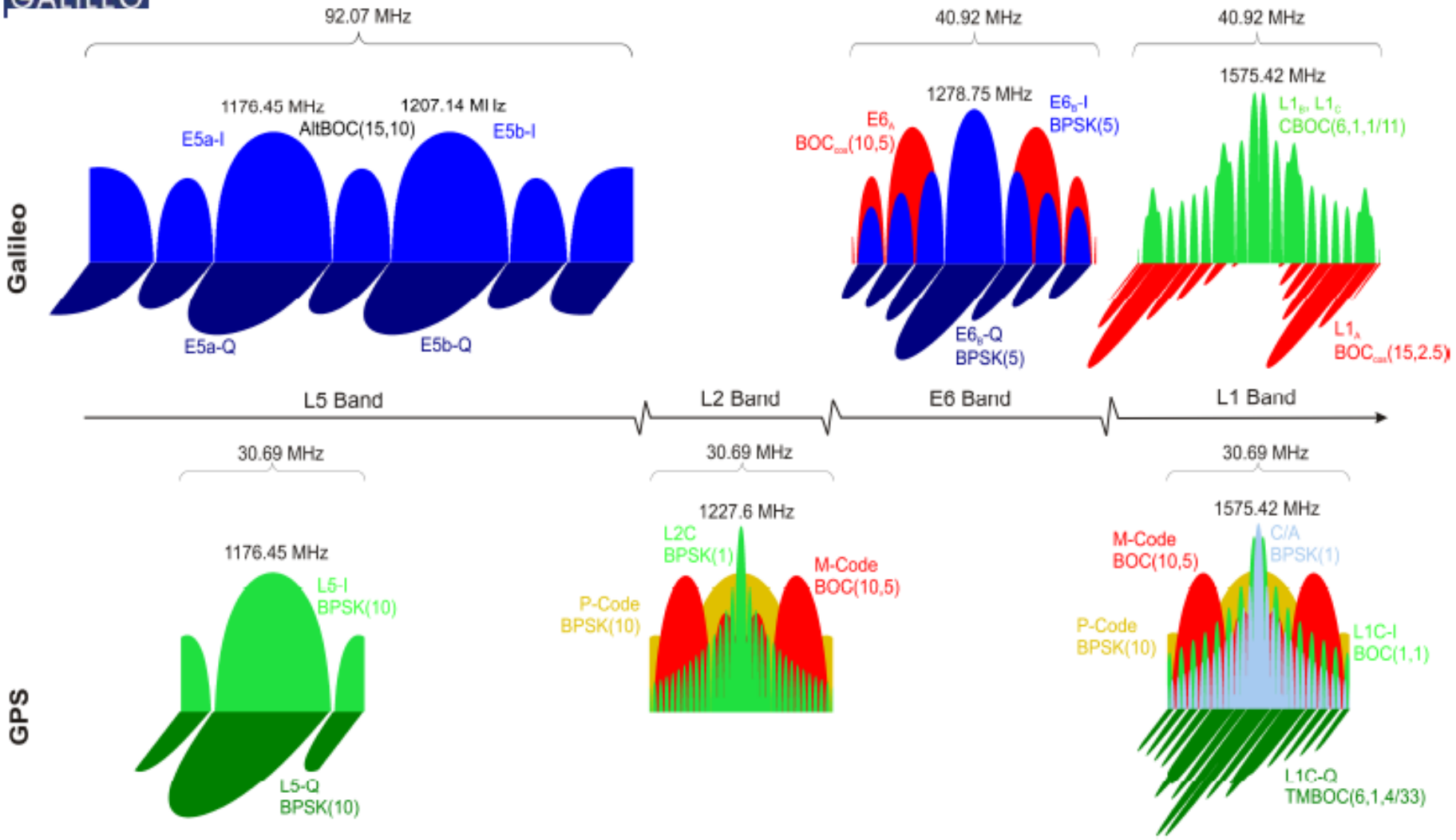


Galileo Signal and Frequency Plan

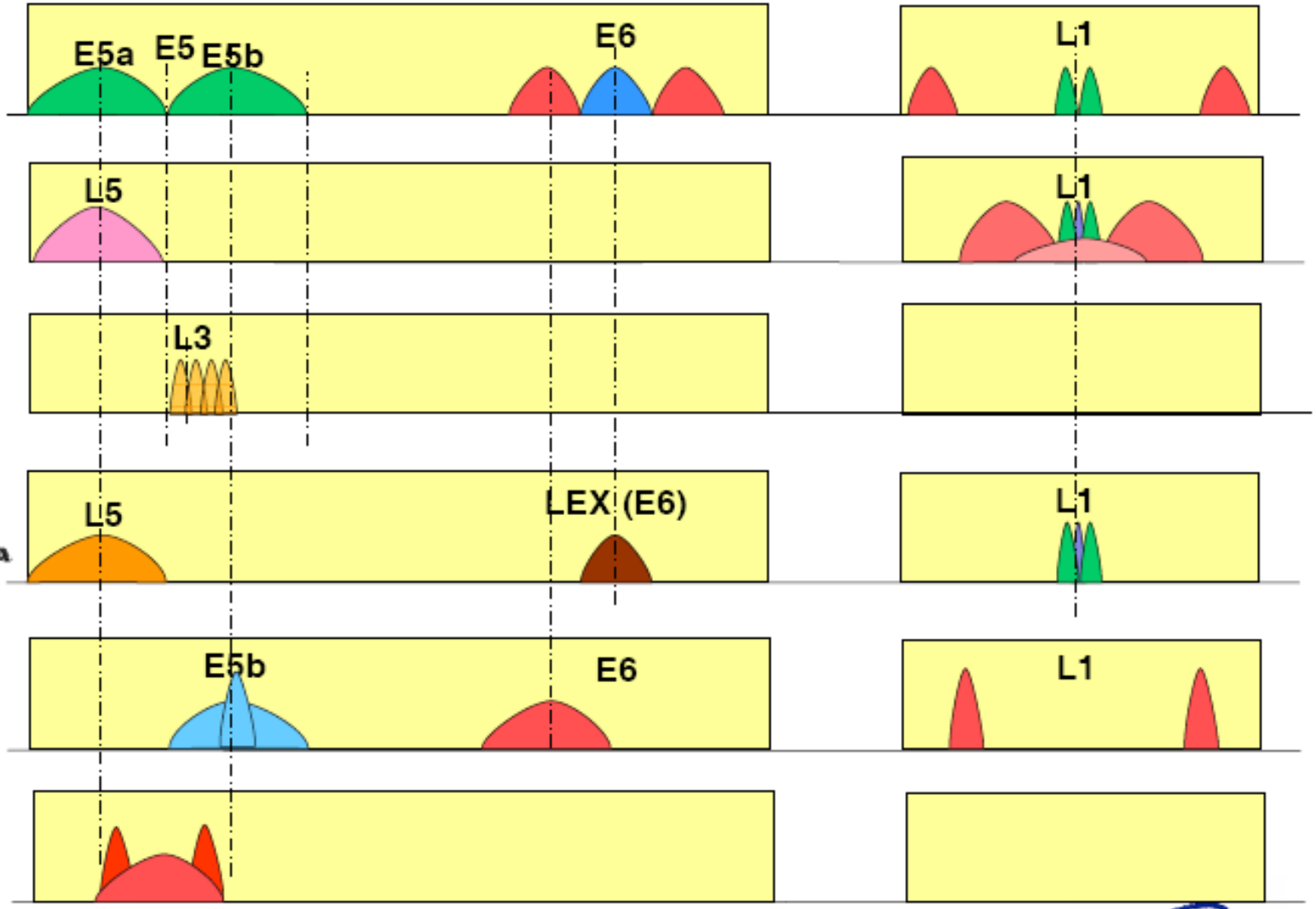


Not to scale

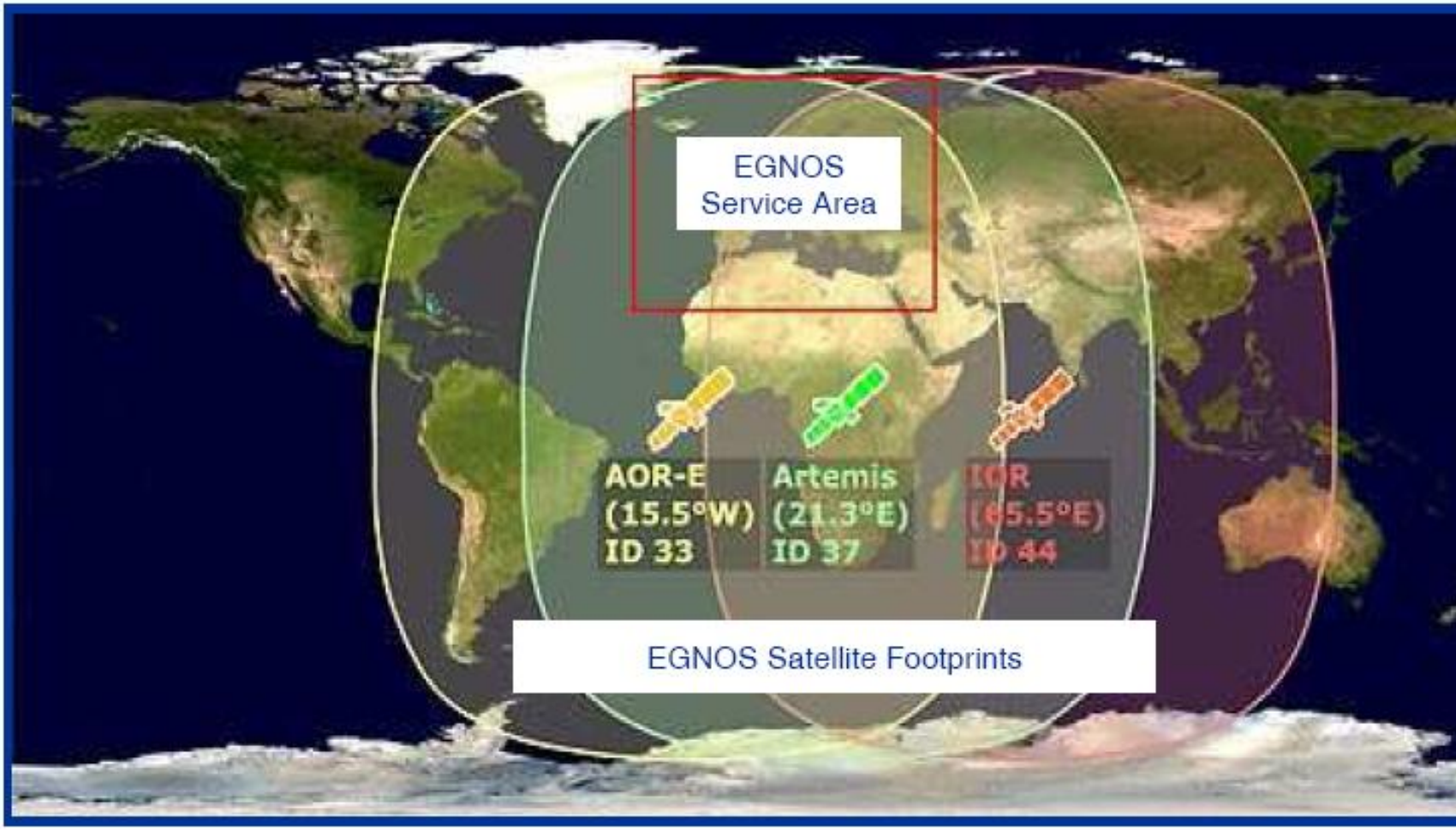
Galileo and GPS signal structure



Compatibility & interoperability with other GNSS

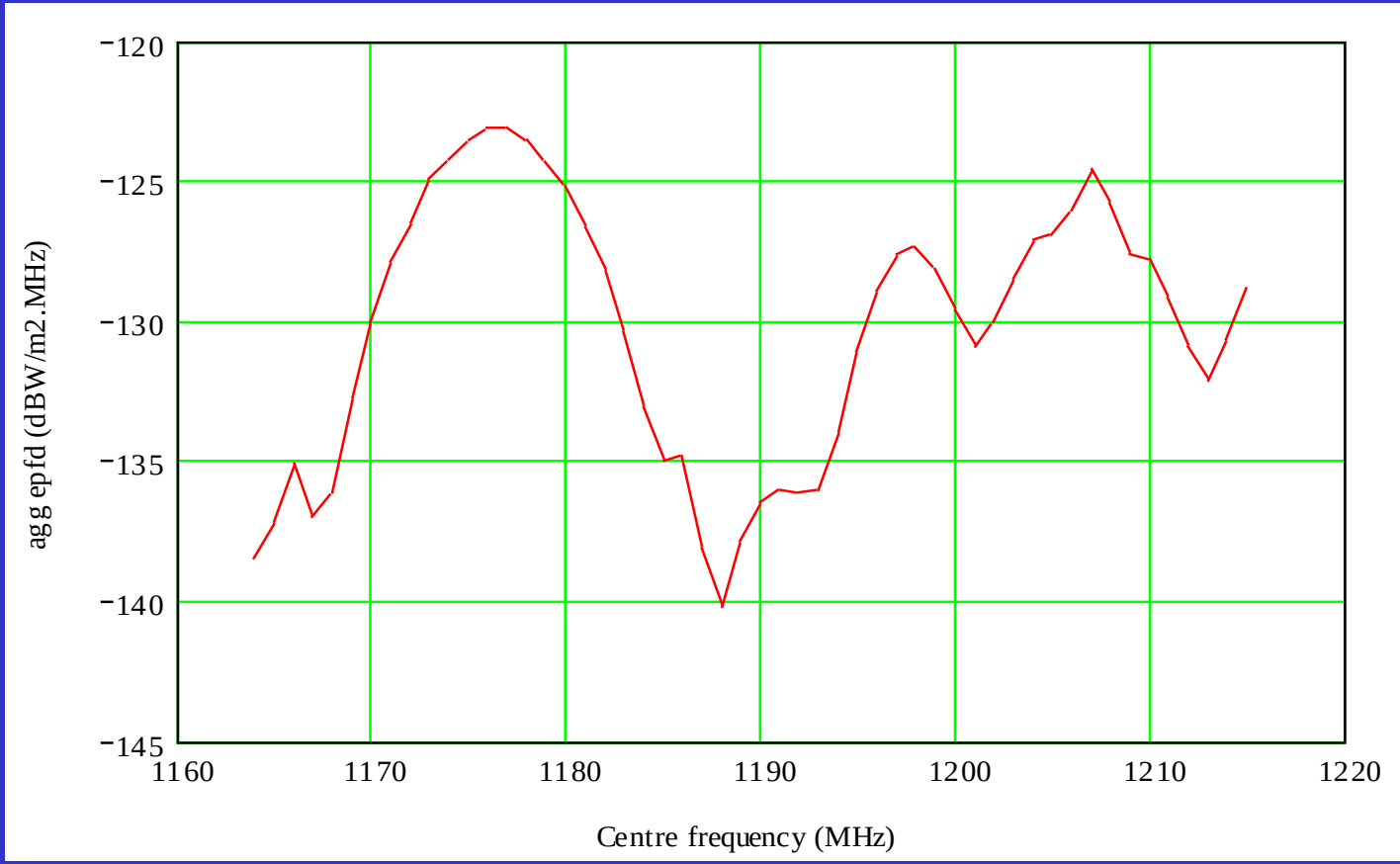


EGNOS Overview

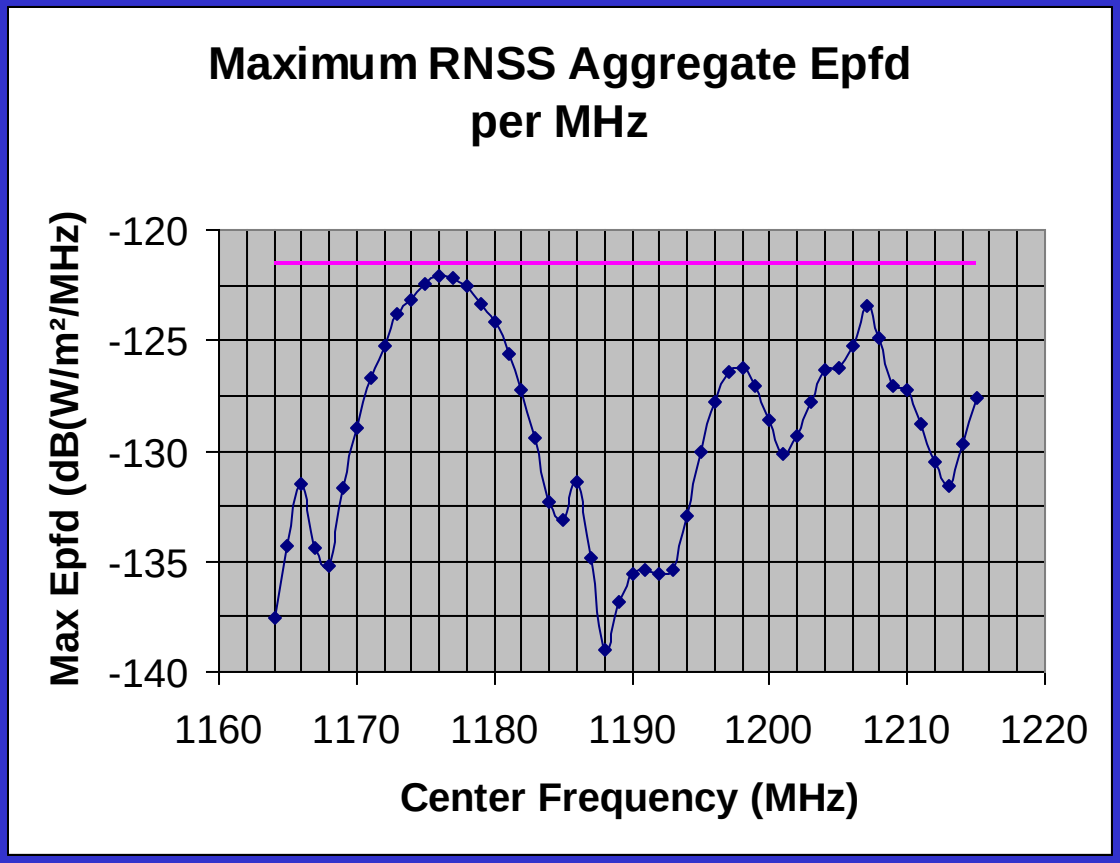


UK Data

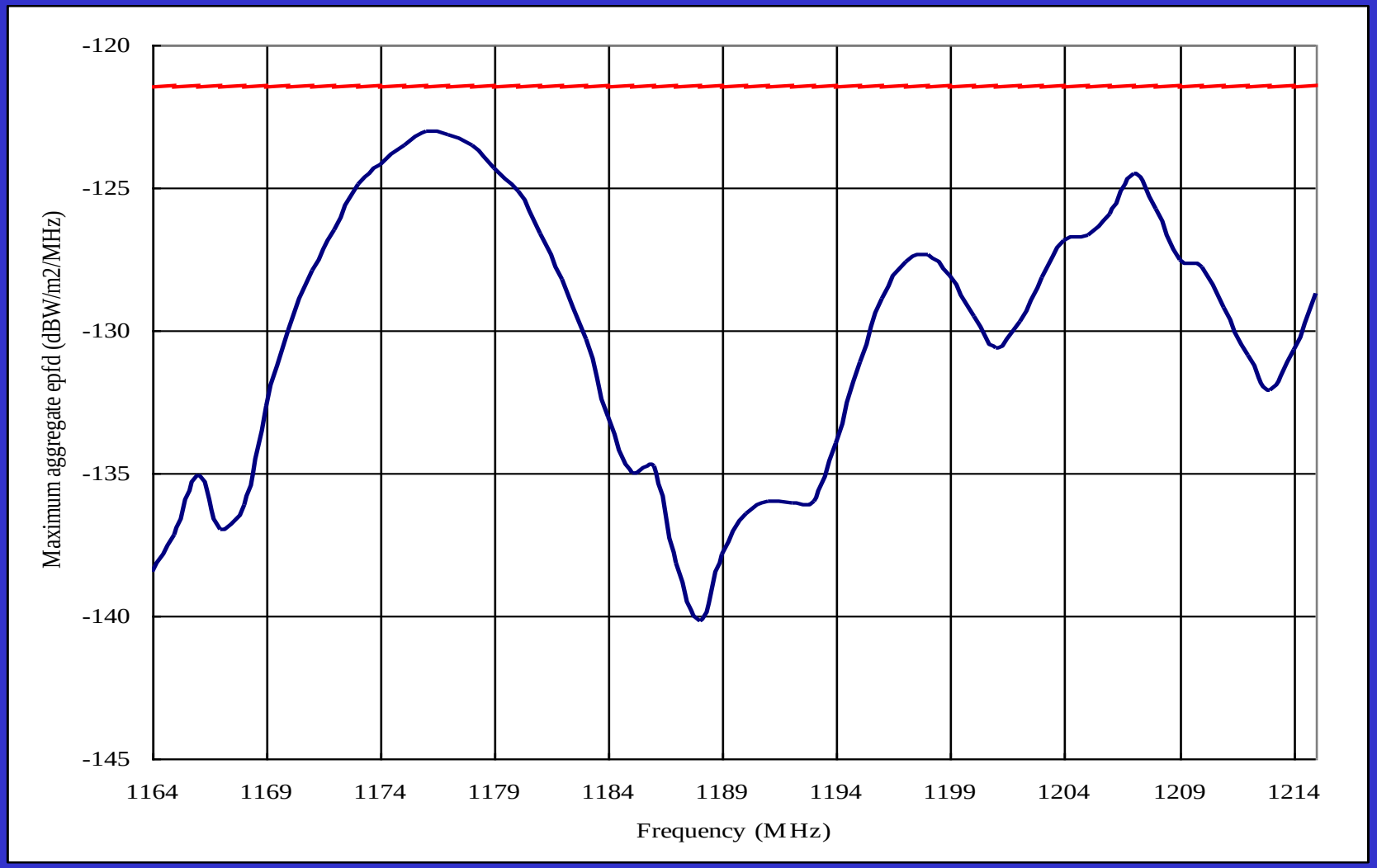
The results of the aggregate epfd calculation for the above systems are shown in the figure and table below.



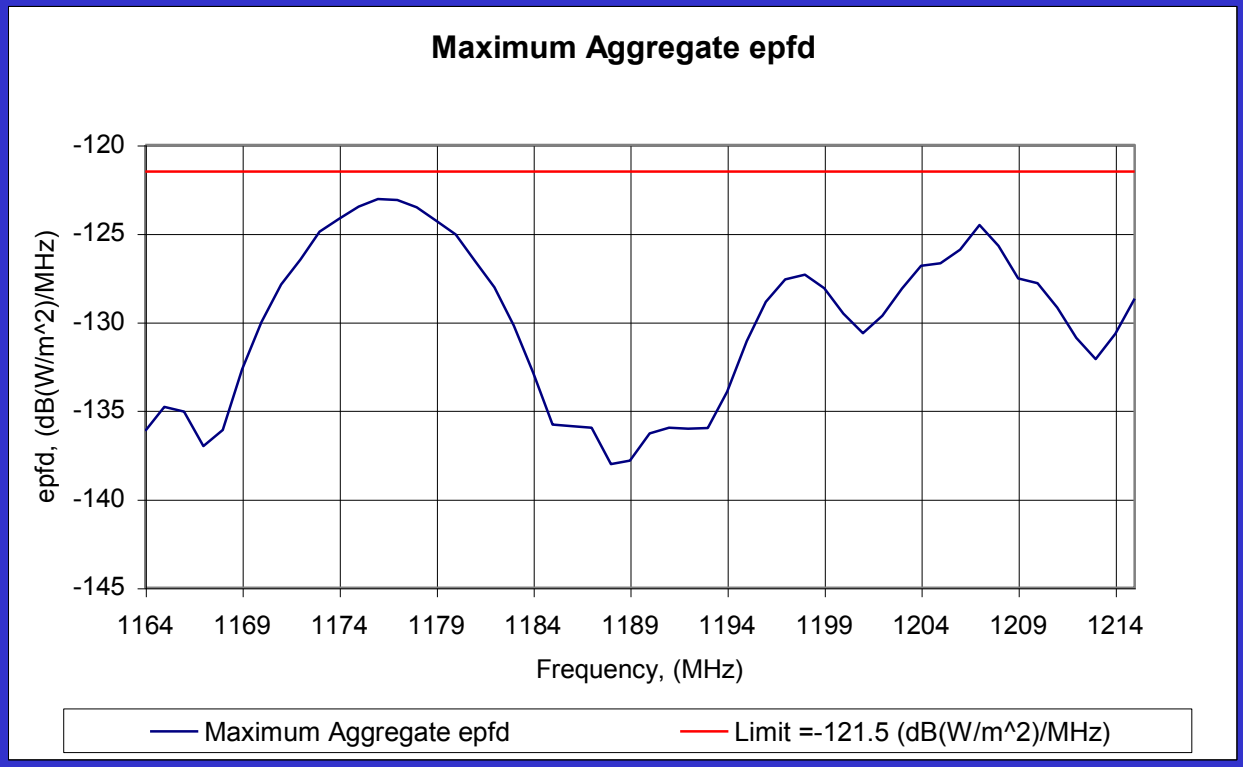
US Data


Maximum RNSS Aggregate Epfd per MHz
Max Epfd (dB(W/m²/MHz)
-120
-125
-130
-135
-140
1160
1170
1180
1190
1200
1210
1220
Center Frequency (MHz)

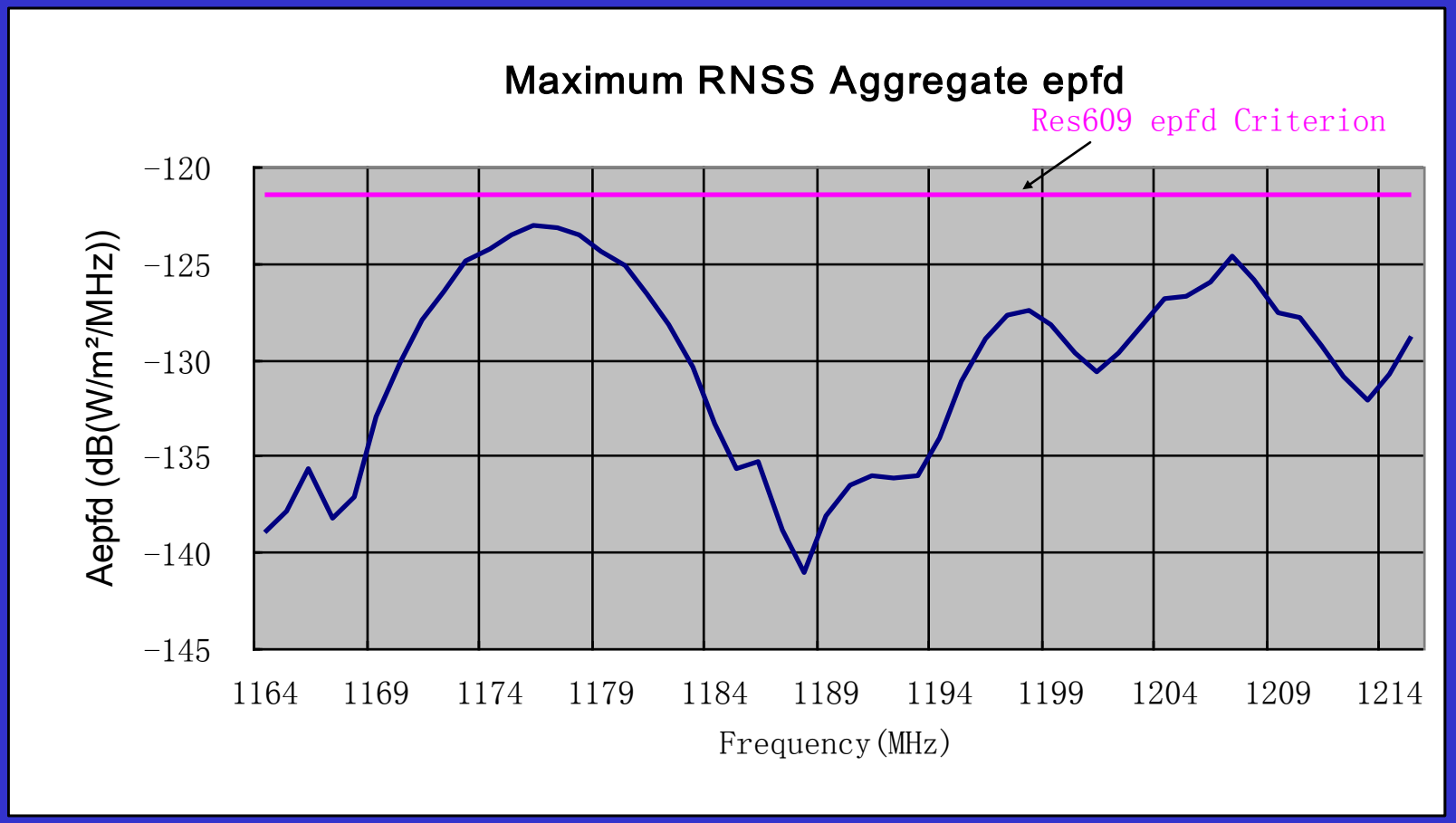
Japan Data


-120
-125
-130
-135
-140
-145
Maximum aggregate epfd (dBW/m2/MHz)
1164
1169
1174
1179
1184
1189
1194
1199
1204
1209
1214
Frequency (MHz)

Russian data



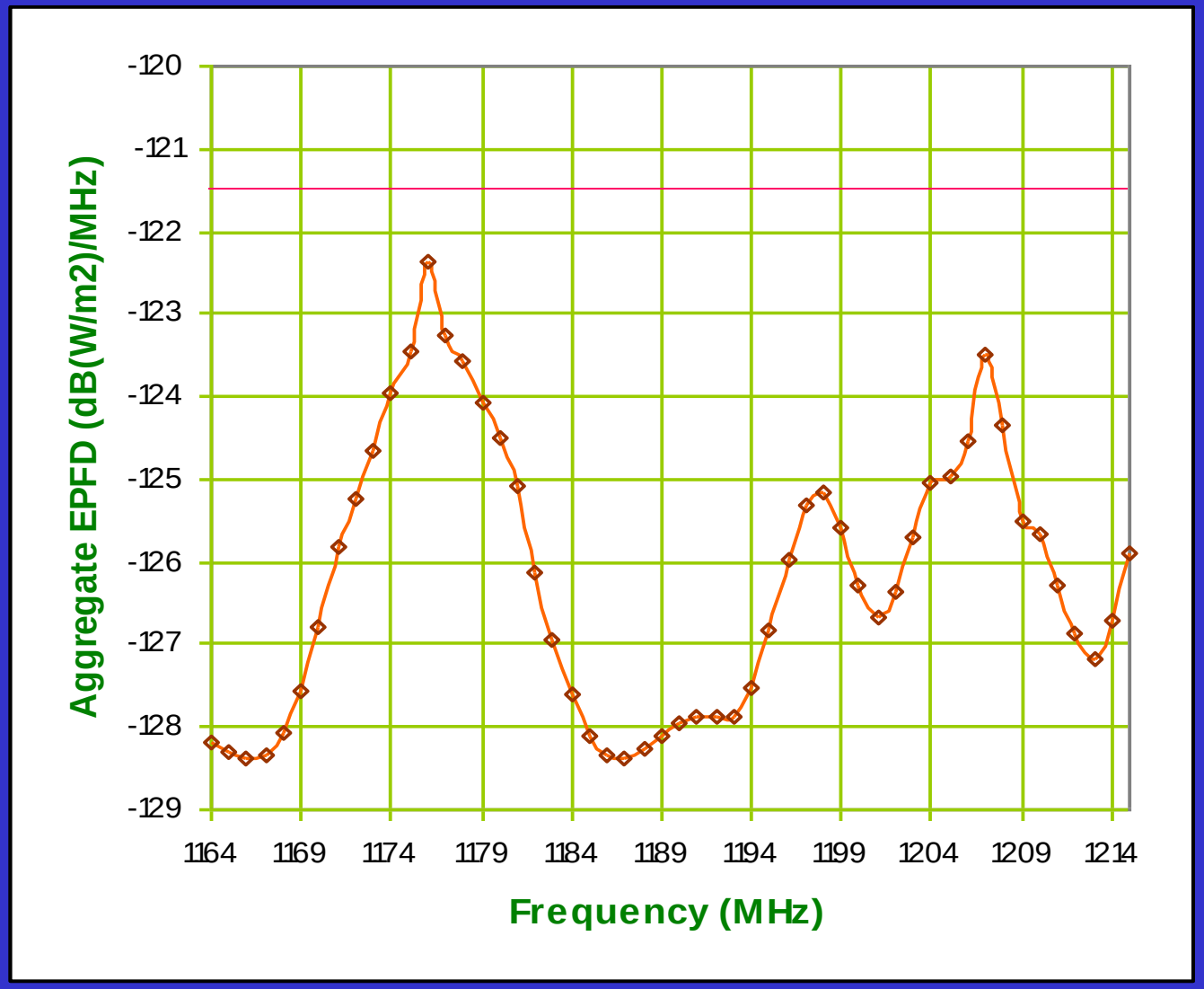
China data


Maximum RNSS Aggregate epfd
Res609 epfd Criterion
Aepfd (dB(W/m²/MHz))
-120
-125
-130
-135
-140
-145
1164
1169
1174
1179
1184
1189
1194
1199
1204
1209
1214
Frequency (MHz)

MAXIMUM AGGREGATE EPFD

[INDIA WITH BEAM CENTRE (83,5) & BOC(5,2) + 1 MHz BPSK]

1164	-128.17	1190	-127.95
1165	-128.3	1191	-127.86
1166	-128.39	1192	-127.89
1167	-128.33	1193	-127.86
1168	-128.07	1194	-127.53
1169	-127.57	1195	-126.82
1170	-126.78	1196	-125.98
1171	-125.82	1197	-125.31
1172	-125.23	1198	-125.17
1173	-124.66	1199	-125.6
1174	-123.97	1200	-126.29
1175	-123.45	1201	-126.68
1176	-122.35	1202	-126.35
1177	-123.26	1203	-125.71
1178	-123.57	1204	-125.06
1179	-124.06	1205	-124.98
1180	-124.51	1206	-124.52
1181	-125.1	1207	-123.49
1182	-126.14	1208	-124.34
1183	-126.94	1209	-125.5
1184	-127.6	1210	-125.66
1185	-128.09	1211	-126.27
1186	-128.34	1212	-126.87
1187	-128.38	1213	-127.17
1188	-128.27	1214	-126.7
1189	-128.11	1215	-125.91



LIST OF RNSS SYSTEMS USED FOR AGGREGATE EPFD CALCULATIONS

RNSS NETWORK	ADMN.	SYSTEM	IFIC
COMPASS -58.75E	CHINA	GSO	2420-2489
COMPASS -80E	CHINA	GSO	2420-2489
COMPASS –110.5E	CHINA	GSO	2420-2489
COMPASS – 140E	CHINA	GSO	2420-2489
COMPASS – 160E	CHINA	GSO	2512-2552
COMPASS – MHMG	CHINA	N-GSO	2513-2563
GLONASS-M	RUSSIA	N-GSO	2469
INMAR GSO-2N (64E)	G	GSO	2476-2507
INMAR GSO-2L(53W)	G	GSO	2453-1497
INMAR 4 – 25E	G	GSO	2504-2537
INMAR 4 – 143.5E	G	GSO	2504-2537
INMAR 4 – 98W	G	GSO	2527-2553

LIST OF RNSS SYSTEMS USED FOR AGGREGATE EPFD CALCULATIONS (Contd.,)

RNSS NETWORK	ADMN.	SYSTEM	IFIC
NAVSTAR GPS	USA	N-GSO	2479-2538
MSAT NAV 2	FRANCE	N-GSO	2415-2490
NSAT HEO 2	JAPAN	N-GSO	2490-2603
MTSAT-C-140E	JAPAN	GSO	2578-2595
MTSAT-C-140E	JAPAN	GSO	2578-2595
INSAT NAV A 34E	INDIA	GSO	2603
INSAT NAV A 83E	INDIA	GSO	2603
INSAT NAV A GS	INDIA	N-GSO	2603
INSAT NAV A 132E	INDIA	GSO	2603
INSAT NAV 55E	INDIA	GSO	2592
INSAT NAV 82	INDIA	GSO	2510-2552
RPS 1	USA	GSO	2482-2488

LIST OF RNSS SYSTEMS USED FOR AGGREGATE EPFD CALCULATIONS (Contd)

RNSS NETWORK	ADMN.	SYSTEM	IFIC
RPS 2	USA	GSO	2482 - 2488
NIGCOMSAT 1G	NIGERIA	GSO	2546 - 2606

Thank-you