The Evolution of the Global Navigation Satellite System (GNSS) Spectrum Use

Spectrum Management 2012

National Spectrum Management Association

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(with thanks to Chris Hegarty, MITRE)

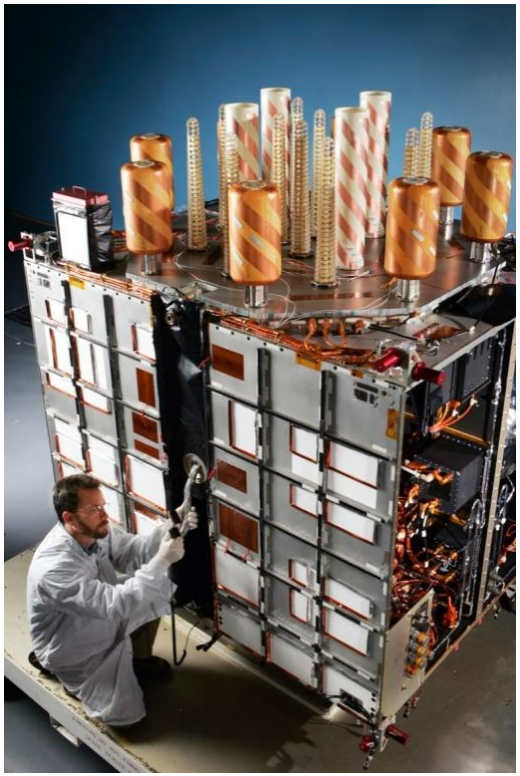
Space Policy Institute

George Washington University

May 15-16, 2012

Global Positioning System (GPS)

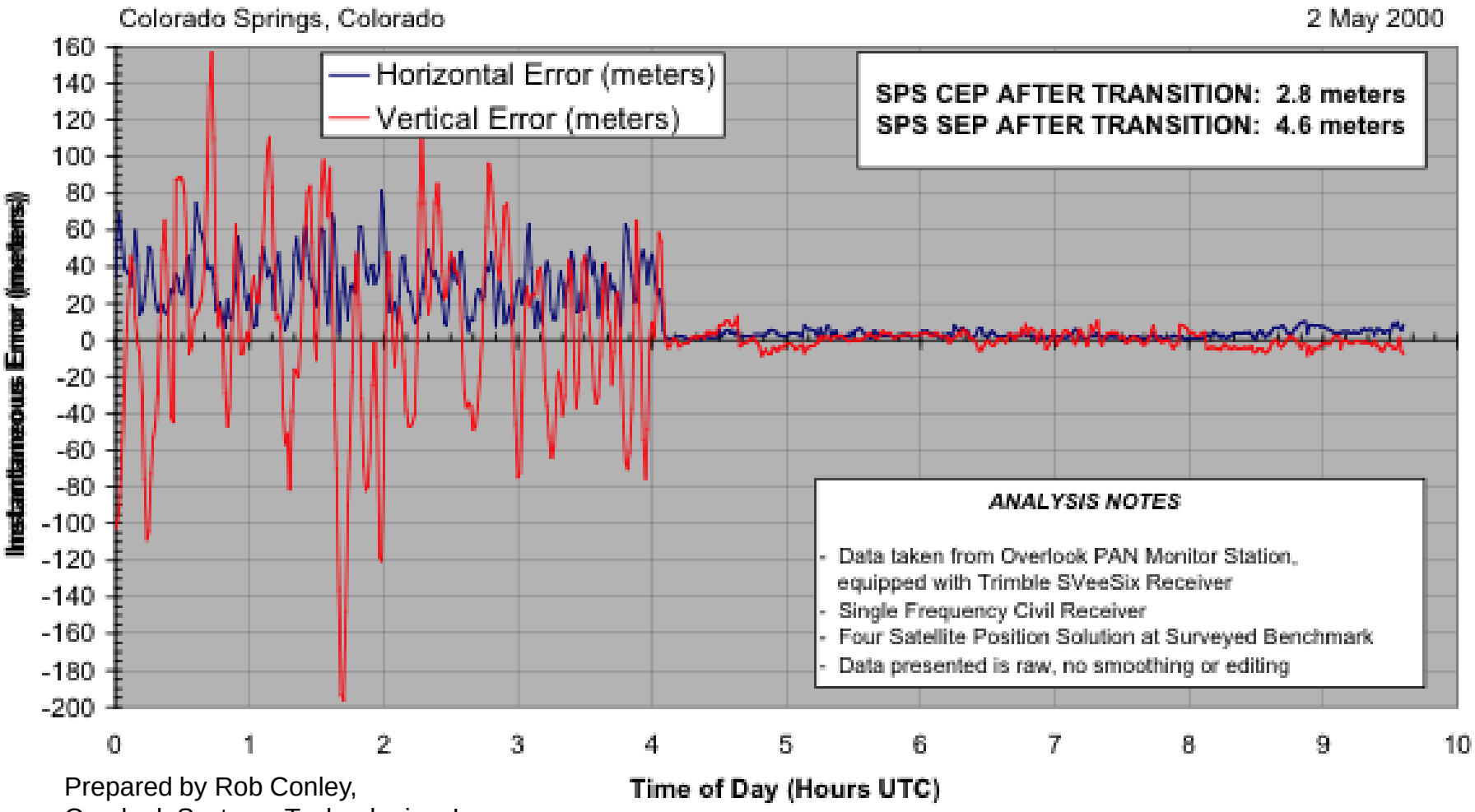
- **U.S. satellite navigation system**
  - **Program began in early 1970's**
  - **First launch in 1978**
  - **Declared fully operational in 1995**
- **Nominal 24-satellite constellation**
  - **~20,200 km altitude (12-hour orbit)**
  - **55 degree inclination**
  - **6 orbital planes**
  - **Now 31 operational satellites**



GPS Block IIR-M Satellite

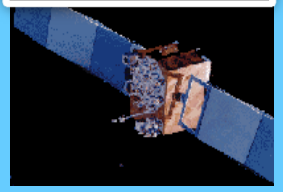
Source: Lockheed-Martin.

SA Transition -- 2 May 2000



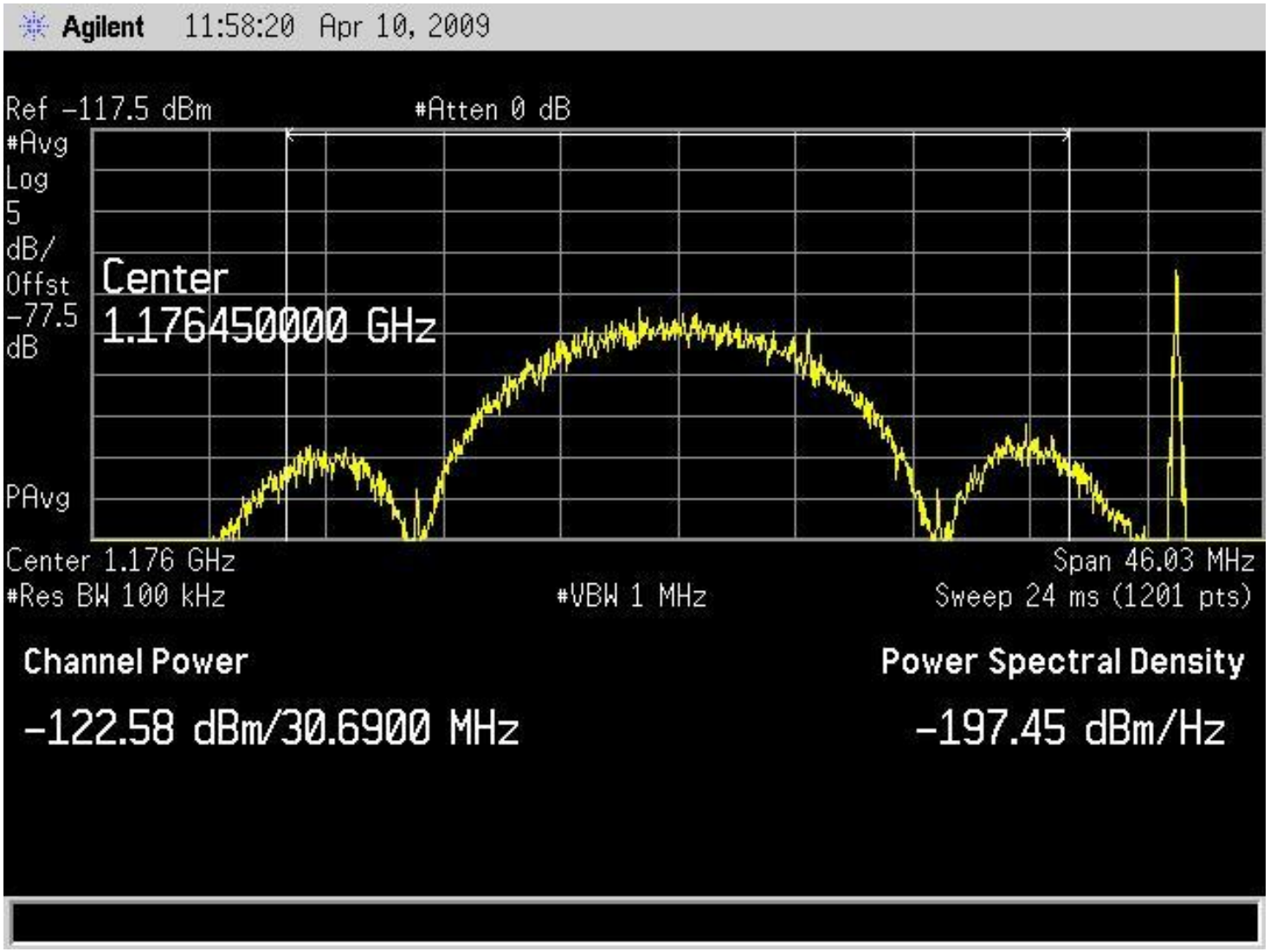
Prepared by Rob Conley,
Overlook Systems Technologies, Inc.

GPS Modernization Program

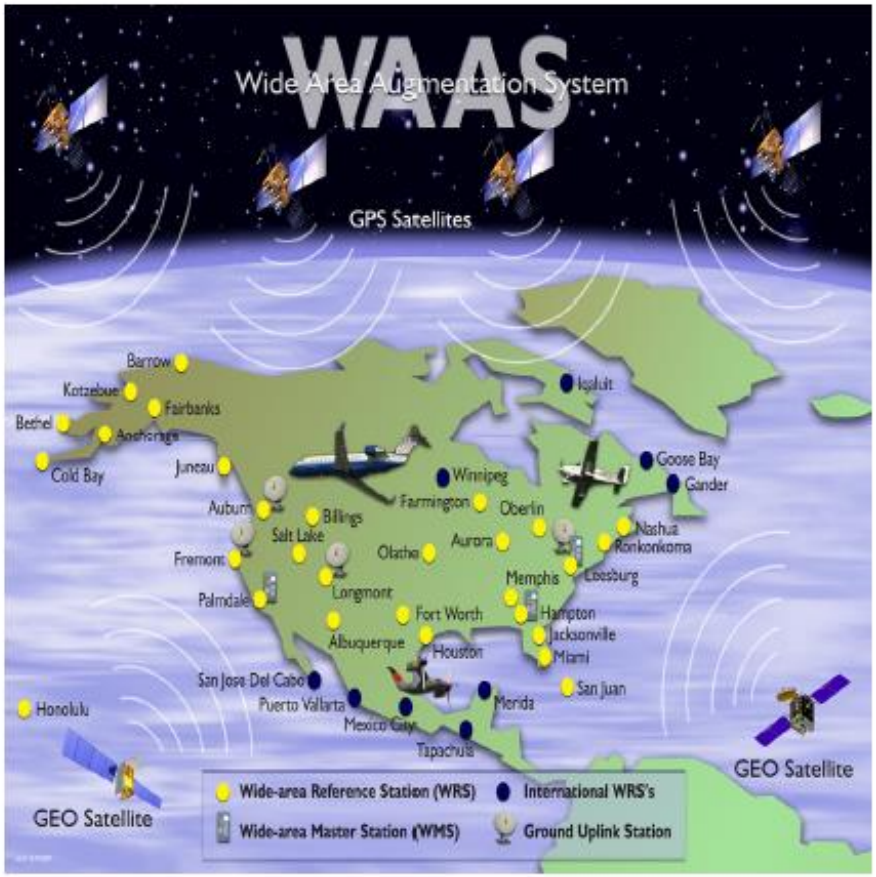
1978 - 1985	1989 – 1997	1997- 2004	2005 - 2009	2010 - Present	2014 – 2024
					
Block I	**Block II/IIA**	**Block IIR**	**Block IIR-M**	**Block IIF**	**Block III**
11 (10) Satellites	**28 Satellites**	**13 (12) Satellites**	**8 Satellites**	**12 Satellites**	**32 Satellites**
Demonstration system	**Basic GPS Provides Initial Navigation Capabilities**	**IIA/IIR Capabilities "Plus"**	**IIR -M Capabilities "Plus"**	**IIF Capabilities "Plus"**	
• L1 (CA) Navigation signal • L1 & L2 (P Code) Navigation signal • 5 Year Design Life	• Standard Service • Single Frequency (L1) • C/A code navigation • Precise Service • Two frequencies (L1 & L2) • P (Y) -Code navigation • 7.5 Year Design Life	• 2nd Civil Signal L2 (L2C) • Earth Coverage M-Code on L1/L2 • L5 Demo • Anti-Jam Flex Power • 7.5 Year Design Life	• 3rd Civil Signal L5 • Reprogrammable Nav Processer • Increased Accuracy requirement • 12 Year Design Life	IIIA • Increased accuracy • Increased Earth Coverage power • 15 Year Design Life • 4th Civil Signal (L1C) IIIB • near-real-time commanding IIIC • Navigation Integrity • Spot Beam for AJ	

Increasing Space System Capabilities – Increasing Military/Civil User Benefits

L5 Signal Turned on 10 Apr 2009



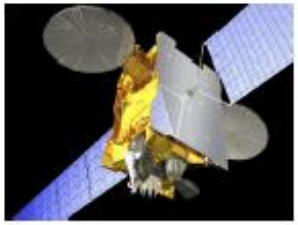
Wide Area Augmentation System (WAAS)



38 Reference Stations

3 Master Stations

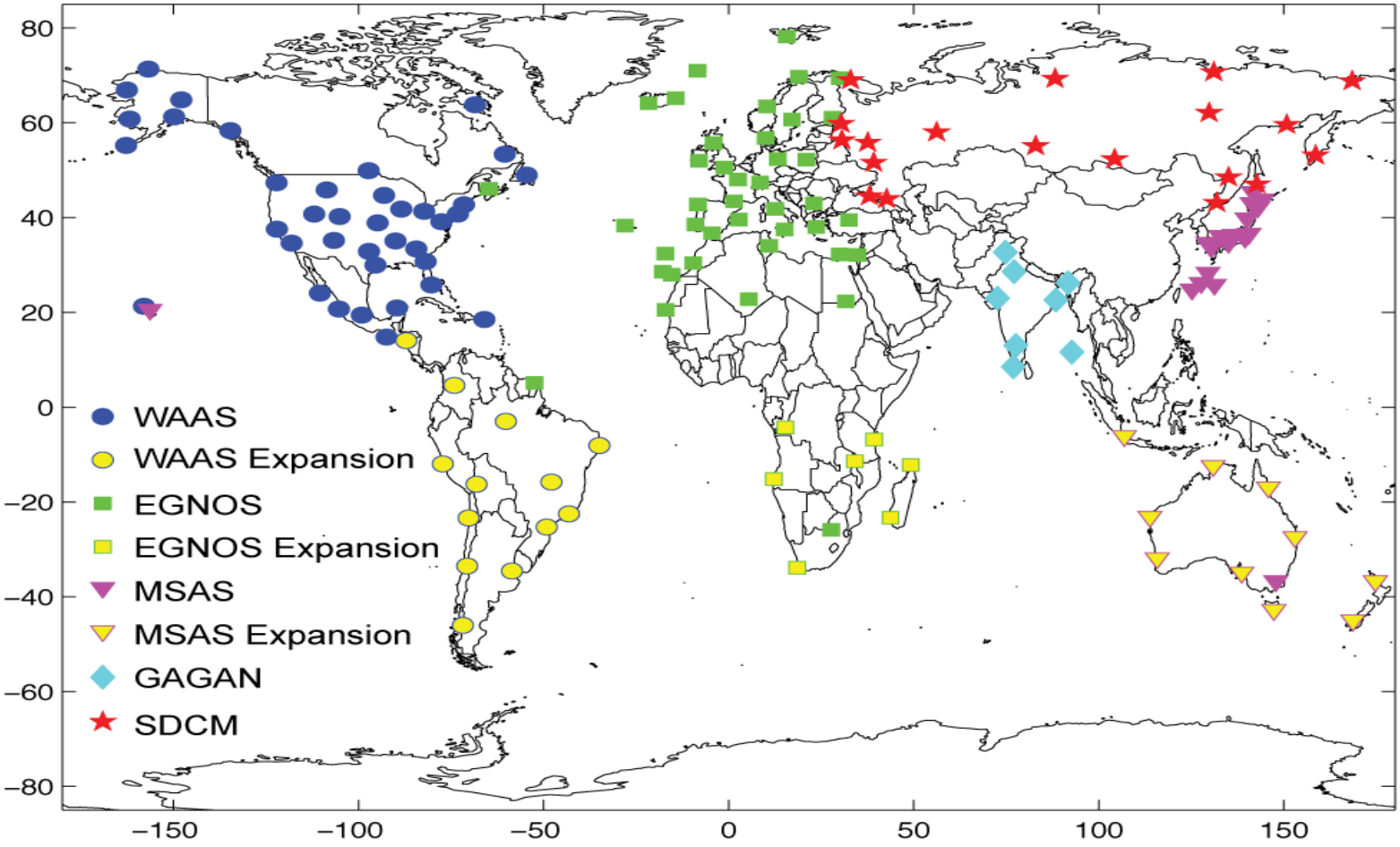
4 Ground Earth Stations



2 Geostationary Satellite Links

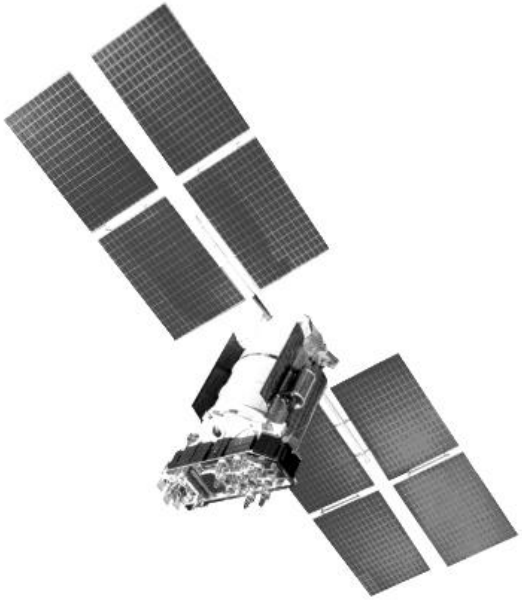
2 Operational Control Centers

Future Possible Expanded SBAS Networks



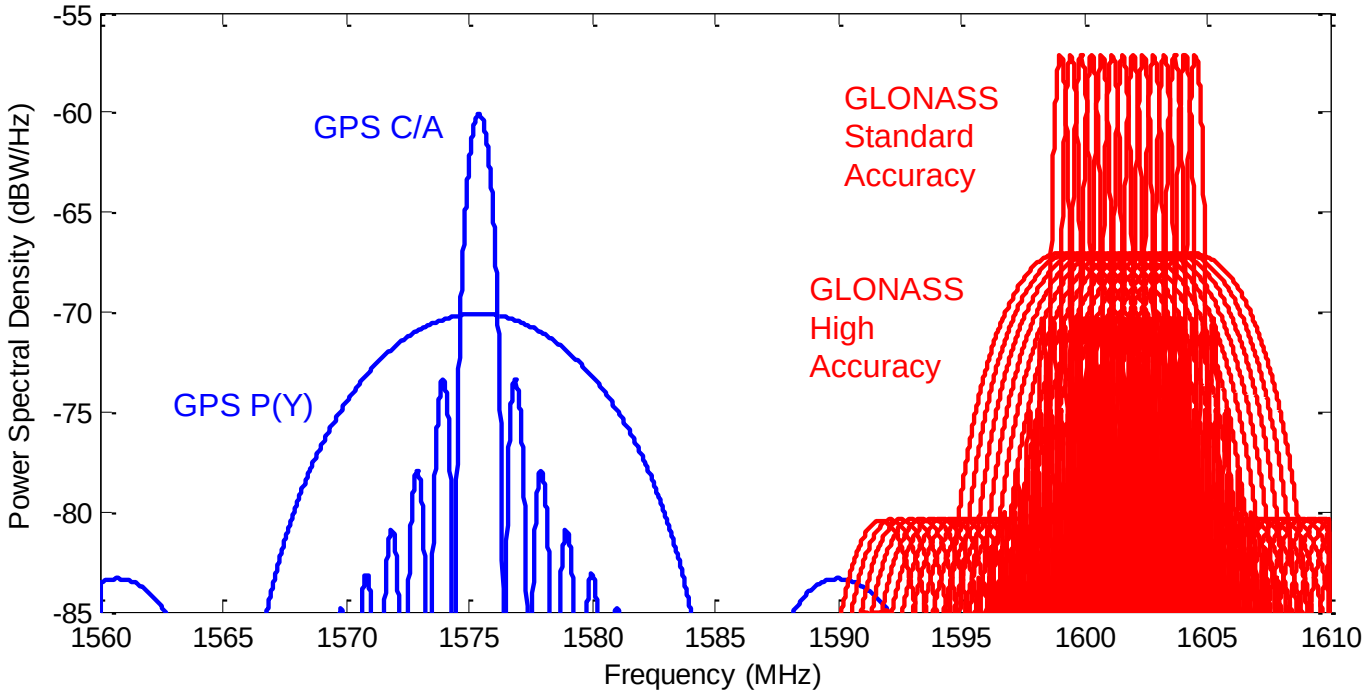
GLObal'naya NAvigatsionnaya Sputnikovaya Sistema (GLONASS)

- **Russian satellite navigation system**
  - **First launch in 1982**
- **Nominal 24-satellite constellation**
  - **19,100 km altitude, 3 planes**
  - **Fully populated in 1995…**
  - **…but then deteriorated to as low as 7**
- **Now fully replenished – 24 operational satellites as of December 2011**
- **Frequency Division Multiple Access (FDMA)**
  - **Originally one open signal FDMA band, then two**
  - **Modernization plans are adding code division multiple access (CDMA) signals**



Source: Russian Federation.

GPS and GLONASS in RNSS Band

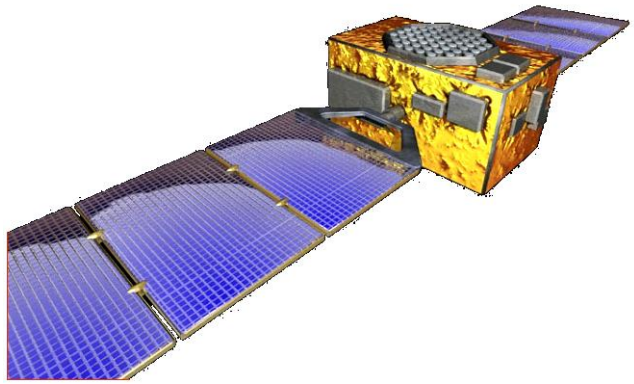


Note that highest carrier for GLONASS was moved down to 1605 MHz to accommodate Big LEO MSS CDMA systems (e.g., protection between 1605-1610 less than in GPS band…linear interpolation from -70 dBW/MHz at 1605 to -10 dBW/MHz at 1610 MHz) and protect RAS at 1610.6-1613.8 MHz in mid-to-late 1990s. This effectively "relinquished" 5 MHz of RNSS spectrum.

Courtesy of Dr. John Betz, MITRE

GALILEO

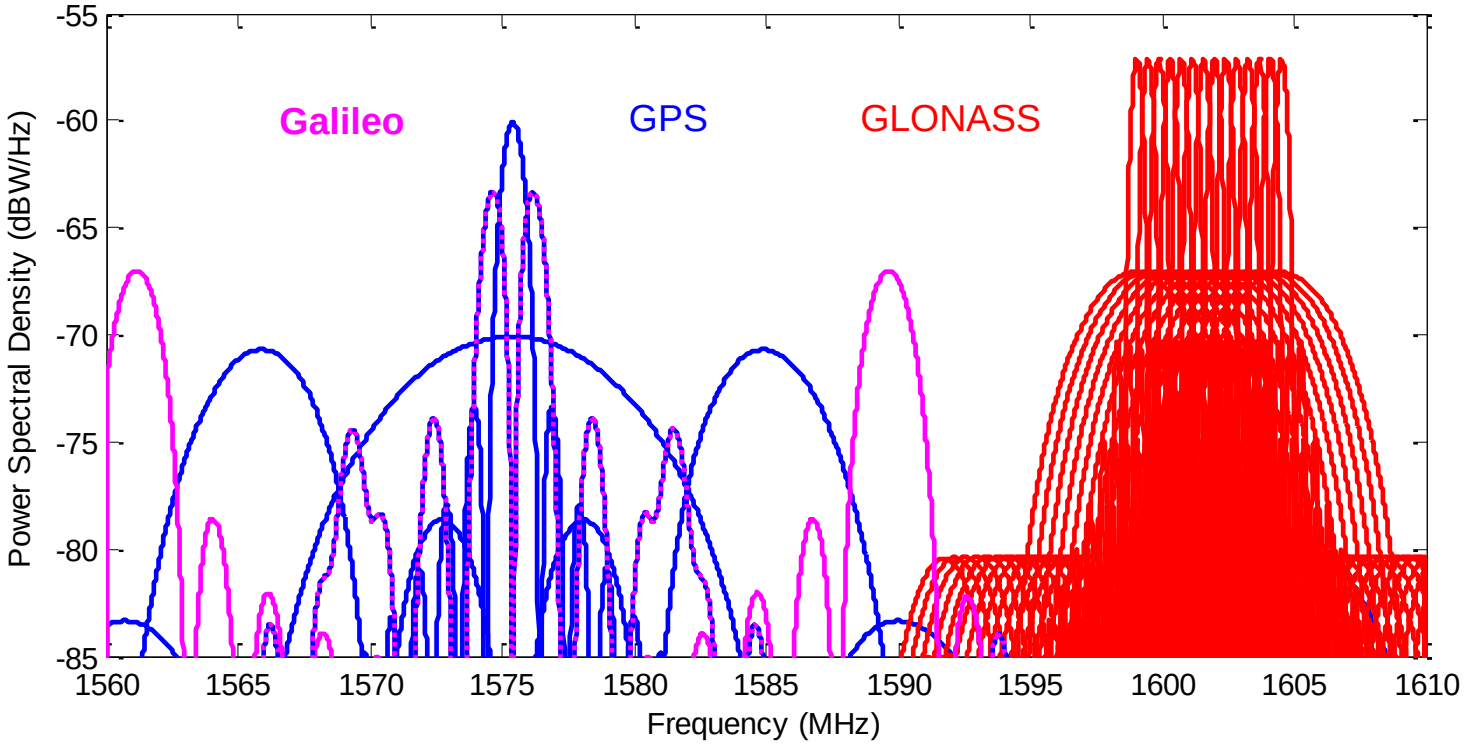
- **European contribution to the GNSS**
  - **Jointly financed by European Commission (EC) and European Space Agency (ESA)**
  - **Program gained significant boost in March 2002 with release of ~$1.1B euro**
- **27+ satellite constellation**
  - **3-planes**
  - **56 deg inclination**
  - **~23,200 km altitude**



Source: European Space Agency.

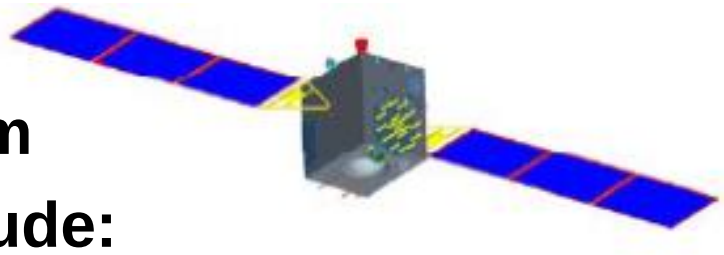
- **Two test satellites launched in 2005, 2008**
- **In-orbit validation (IOV) satellites: two launched Oct 2011, next two Summer 2012**

GPS Modernization and Galileo



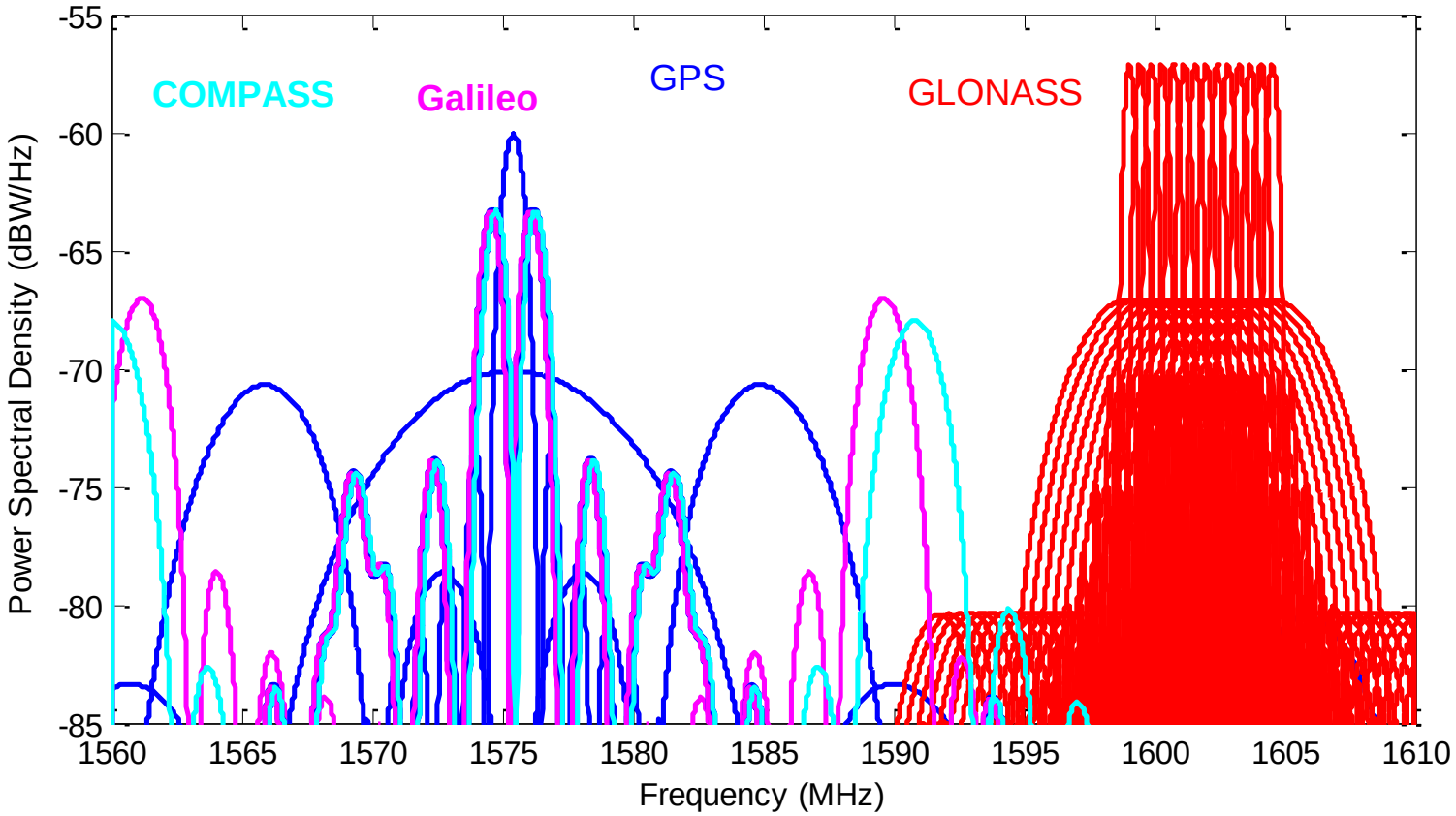
Courtesy of Dr. John Betz, MITRE

COMPASS



- Chinese satellite navigation system
- Final constellation planned to include:
  - 27 satellites in medium Earth orbit (MEO)
    - 55 degree inclination, ~21,500 km altitude
  - 5 satellites in geostationary orbit (GEO)
  - 3 - 5 satellites in inclined geosynchronous orbit (IGSO)
- Launches:
  - Four experimental GEOs: 2000 (2), 2003, 2007
  - MEO: April 2007, GEOs: 2009, 2010 (3)
  - IGSOs: 2010 (2), 2011 (3)

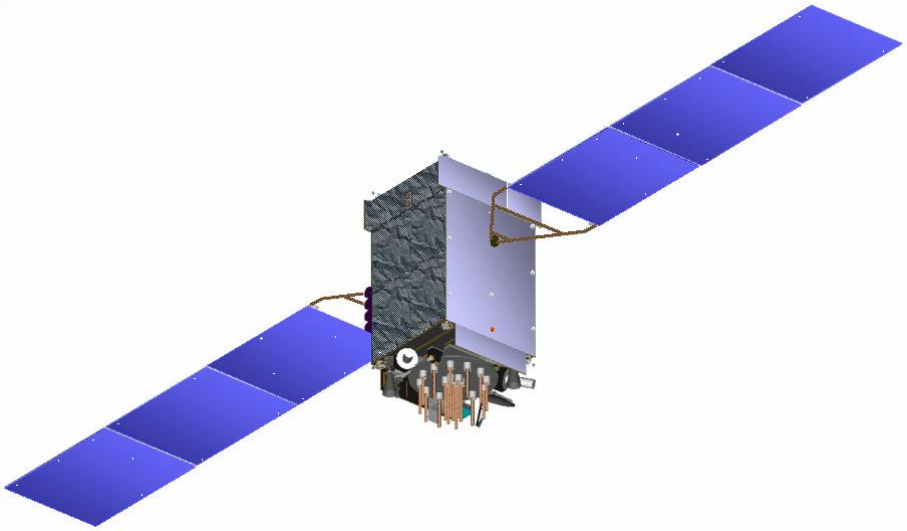
COMPASS will share same RNSS band

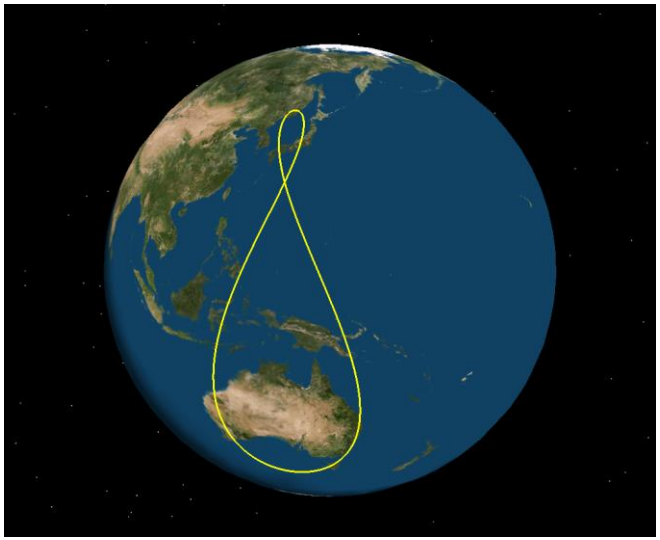


Courtesy of Dr. John Betz, MITRE

Quasi Zenith Satellite System (QZSS)

- **Japanese system**
- **Plan calls for three (to seven) satellites**
  - **Highly elliptical ~36,000 km altitude orbits**
- **First satellite launched September 2010**

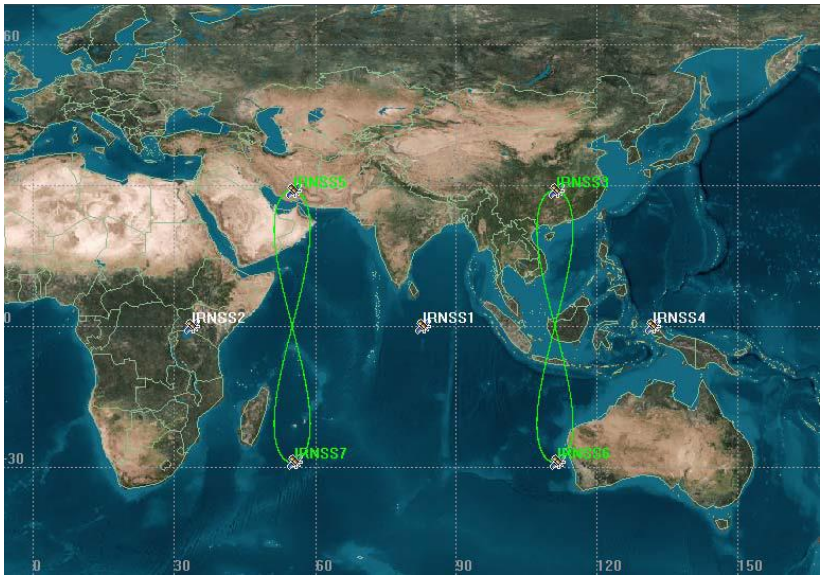




Source: Japan Aerospace Exploration Agency.

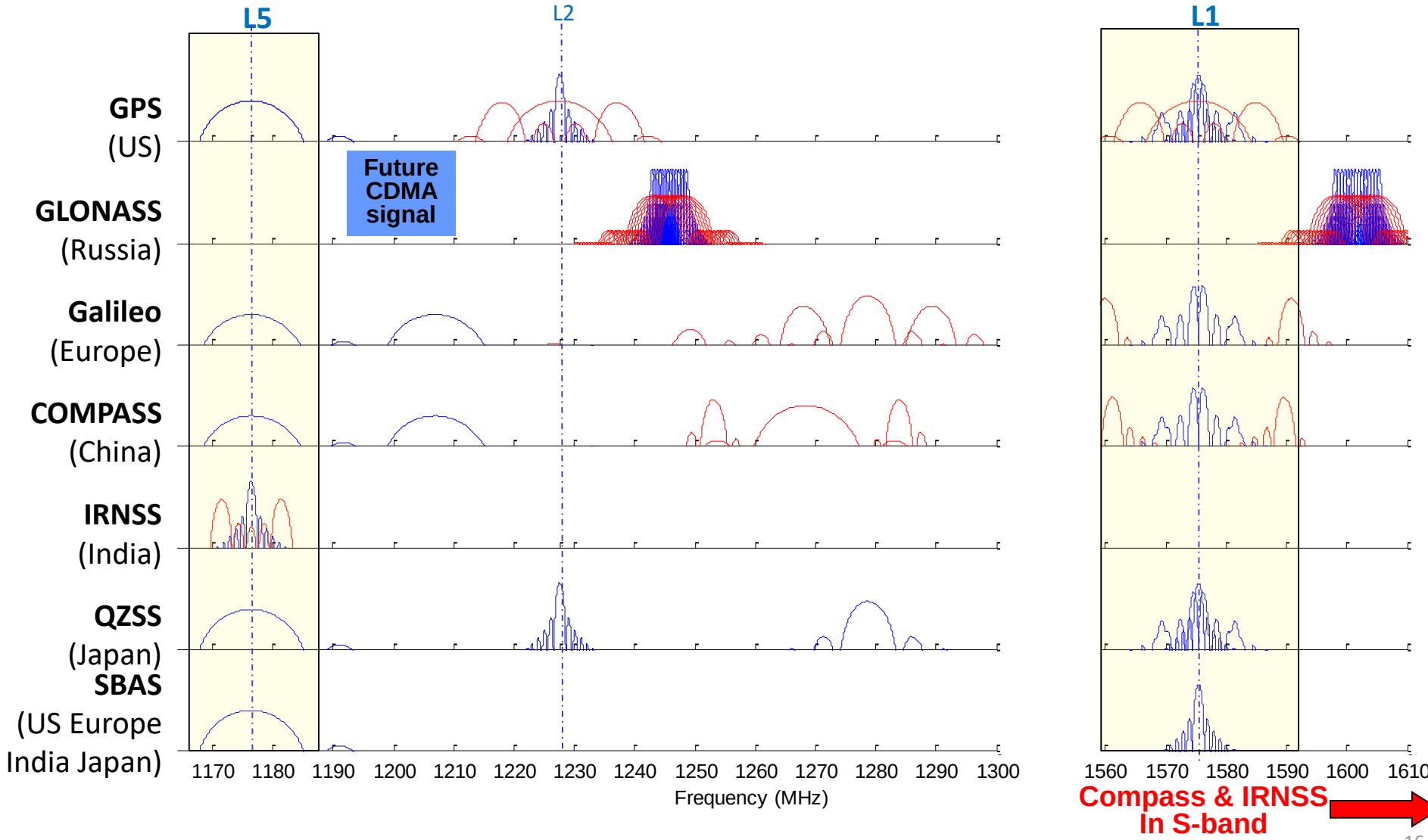
Indian Regional Navigation Satellite System (IRNSS)

- **Indian regional system**
- **Final constellation planned to include:**
  - **3 satellites in geostationary orbit (GEO)**
  - **4 satellites in inclined GSO**
- **First launch planned ~2012**



Source: Indian Space Research Organization.

GNSS Signal Plans



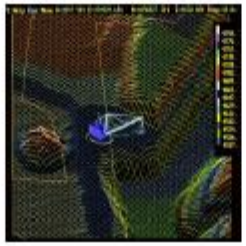
GPS Permeates the US Infrastructure

- Military
- Civil
  - Transportation
    - Aviation
    - Automobile
    - Maritime
    - Rail Control
  - Public Services
  - Precise Machine Control
  - Timing & Frequency
  - Surveying
  - Surveillance
  - Recreational

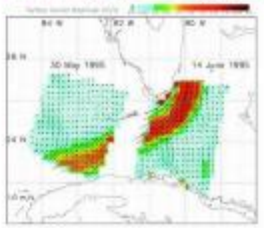








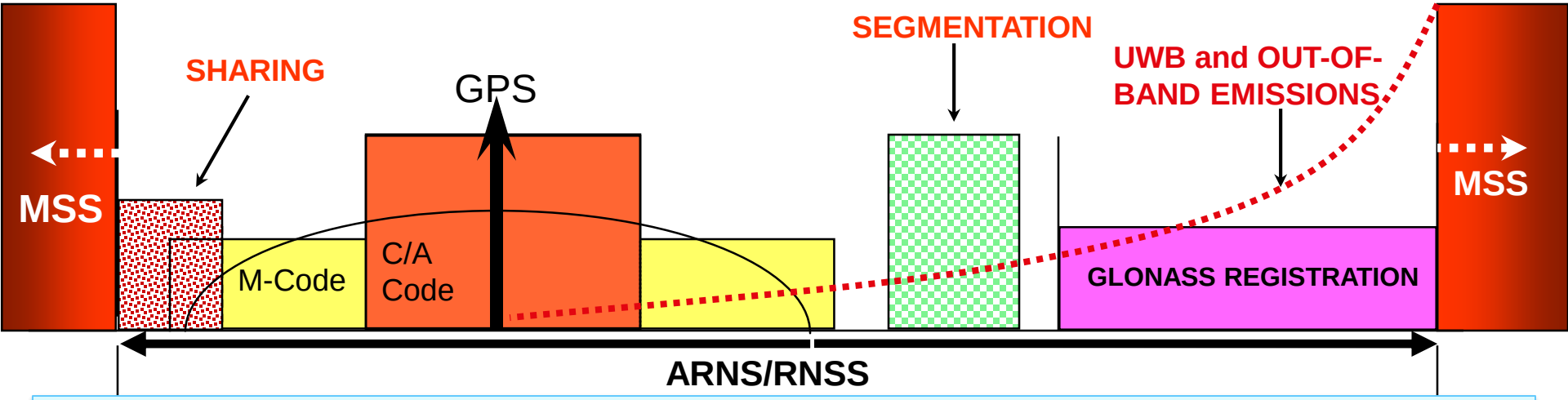


There are fundamental differences between Radio Communications and Radio Navigation

- **Digital Radio Communications:**
  - **Incoming *message is not known* – finding it is the whole point**
  - **Must determine whether each signal "bit" is a one or a zero**
  - **Use sophisticated methods to correct errors**
- **Digital Radio Navigation**
  - **Incoming signal sequence (ones and zeros) is totally known by user**
  - **The goal of the user is to *precisely time* the *transition* from one to zero (and zero to one)**

GPS can be Harmed Several Ways



The ARNS/RNSS spectrum is a unique resource

- **Sharing with higher power services jams weaker signals**
- **Out-of-band and ultra wide-band emissions raise the noise floor**
- **Segmentation prevents future evolution**

Spread spectrum GPS signals are unlike communication signals

- **10^{-16} W received power, one-way**
- **Any filter can be overwhelmed if exposed to enough power**

Approved ITU Recommendations on Protection Criteria Exist