IAG/FIG Commission 5/ICG Technical Seminar

Reference Frame in Practice

Rome, Italy 4–5 May 2012

Multi GNSS
Current Status and Future

Session 2.3 Multi GNSS Environment

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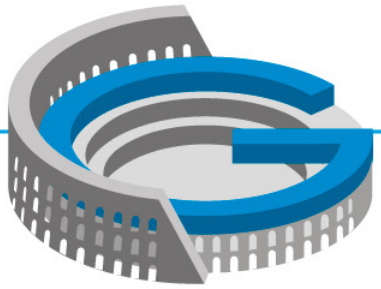

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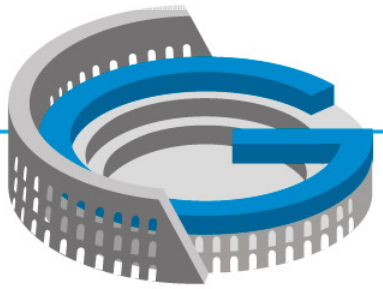
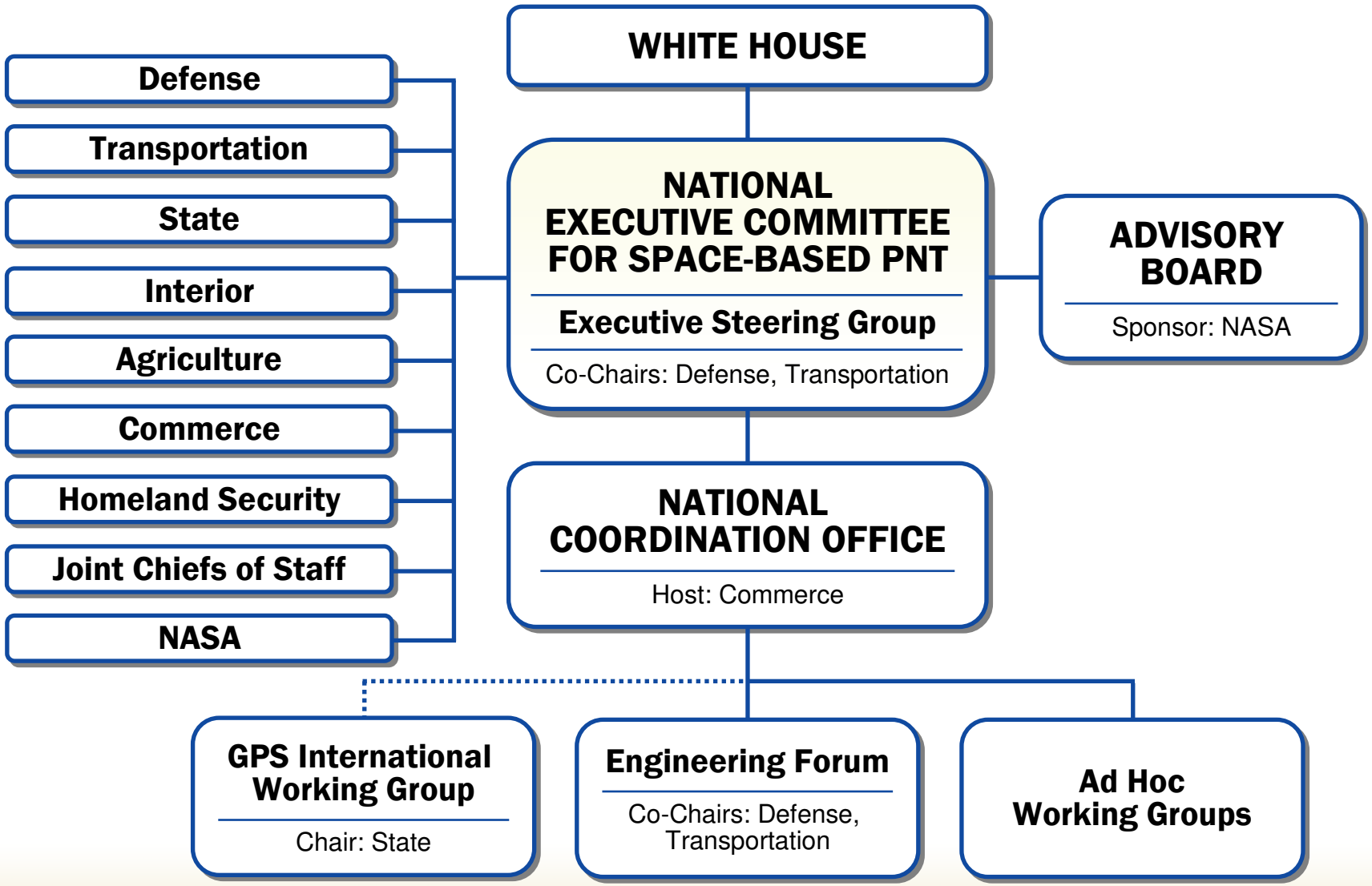
- **GNSS**
- **GPS Performance and Modernization**
- **Multi-GNSS and Reference Frame Issues**
- **GNSS Signal Interfernce and Detection**
  - **LightSquared Matter - Status**



U.S. Space-Based PNT Organization Structure



GNSS SIGNALS

A Twice-Monthly Newsletter from the Publishers of Inside GNSS Magazine

GPS | GALILEO | GLONASS | COMPASS

April 30, 2012

Abandon the Common GPS Galileo Civil Signal? It Could Happen.
[SIGNALS exclusive] The U.S. government is so unhappy about a British patent claim on the new civil GPS signal that, if things cannot be worked out, officials might consider abandoning the interoperable signal structure. The British military establishment is seeking royalties from GPS receiver manufacturers, asserting it holds a patent on the technology at the heart of the new GPS and Galileo civil signals. (**more**)

Cybersecurity Bills Could Reshape GPS Anti-Interference Efforts
[GNSS SIGNALS Exclusive] Legislation moving through Congress could reshape efforts to counter GPS interference as the government steps up its efforts to fight cybercrime and protect critical systems like the power grid and communications networks. (**more**)

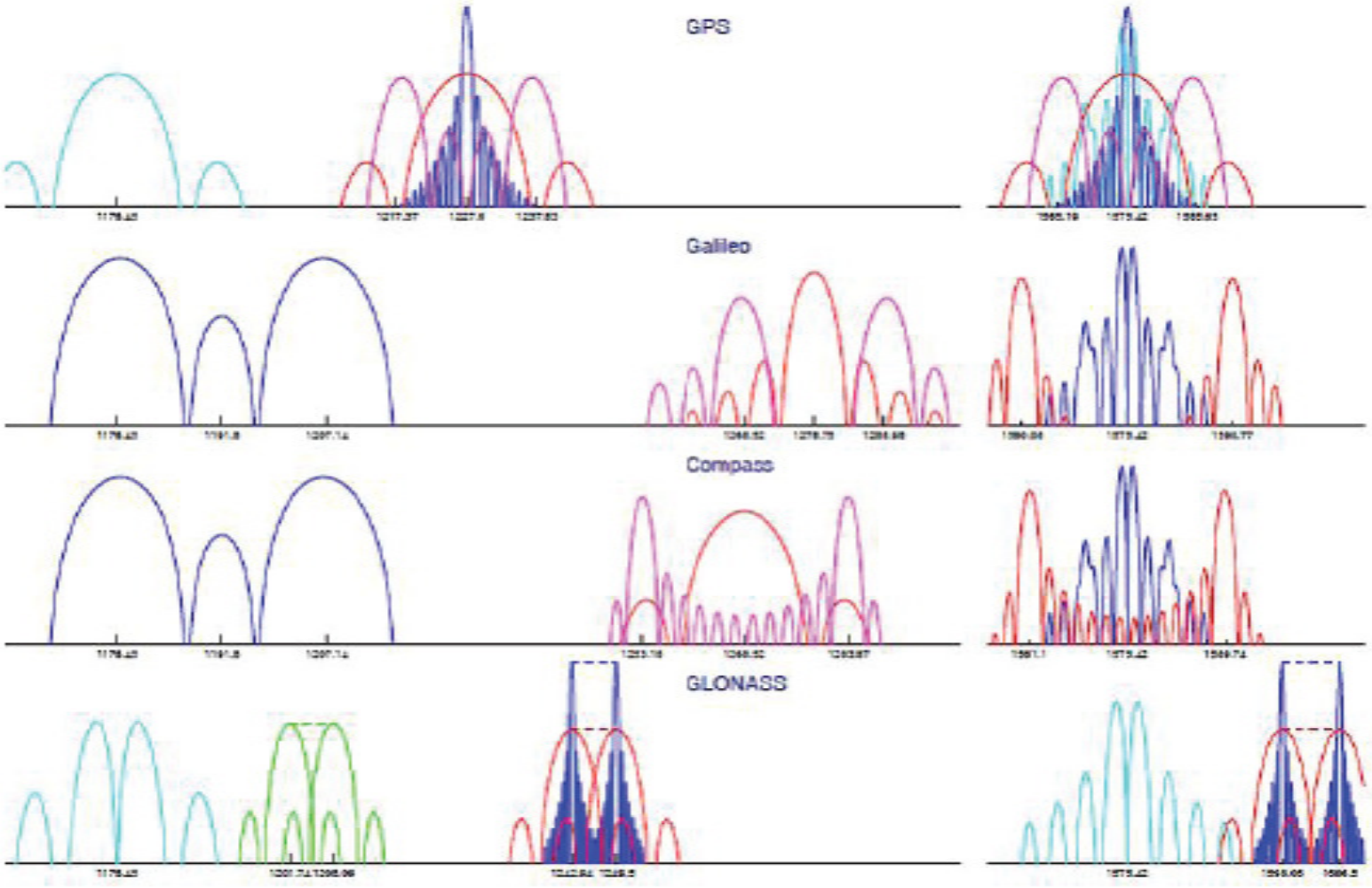
China Succeeds with Dual BeiDou-2 Compass Satellite Launch
China successfully launched two Compass satellites into space at 4:50 a.m. Beijing Time on Monday, April 30 (20:50 UTC, April 29). Designated Compass M3 and M4, these are the 12th and 13th of its second-generation Beidou-2 spacecraft to reach orbit and the second and third middle-Earth-orbiting (MEO) spacecraft launched by China's GNSS program. (**more**)

NASA Backs Test of Real-time GPS Earthquake and Tsunami Alerts
Evolution of real-time GNSS reference networks and data processing has evolved to the point that NASA-backed researchers believe they can soon implement large-scale demonstration tests to provide earthquake and tsunami alerts to the general public and emergency responders. (**more**)

Falcone Appears Ready to Step Away from LightSquared
Harbinger Capital Management LLC fund manager Philip Falcone has reportedly agreed to eventually withdraw from his leadership position with LightSquared Inc., the would-be wireless broadband that ran into problems because its proposed terrestrial transmitters would have caused interference to GPS receivers. (**more**)

Signals of GNSS Open Services

Global Navigation Satellite Systems	Frequency	Center Frequency (MHz)	Modulation Mode	Interoperable or Not
GPS	L1 C/A	1575.42	BPSK(1)	
	L1C	1575.42	MBOC(6,1,1/11)	Yes
	L2C	1227.6	BPSK(1)	
	L5C	1176.45	QPSK	Yes
GLONASS	L1OF/L1OCM	1598.06~1604.40	BPSK	
	L2OF/L1OCM	1242.94~1248.63	BPSK	
	L3 OC	1202.025/1207.14	BPSK	
BeiDou	B1-C	1575.42	MBOC(6,1,1/11)	Yes
	B2a	1191.795	AltBOC(15,10)	Yes
	B2b			
GALILEO	E5a	1191.795	AltBOC(15,10)	Yes
	E5b			
	E1	1575.42	MBOC(6,1,1/11)	Yes

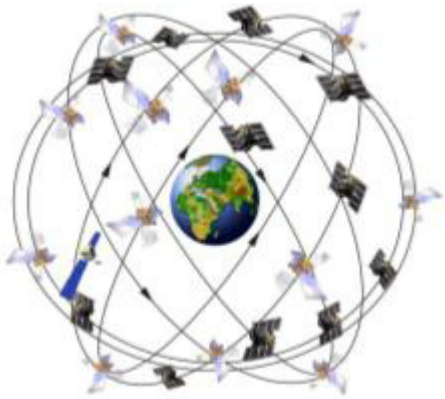


Signal spectra for GPS, Galileo, Compass, and GLONASS. From the left, new GPS satellites radiate at L5 (1176.45 MHz), L2 (1227.60 MHz), and L1 (1575.42 MHz)

GPS Enterprise View

Civil Cooperation

•1+ Billion civil & commercial users
•Search and Rescue
•Civil Signals
- **L2C (2nd Civil Signal)**
- L5 (Safety of Life)
- L1C (International)

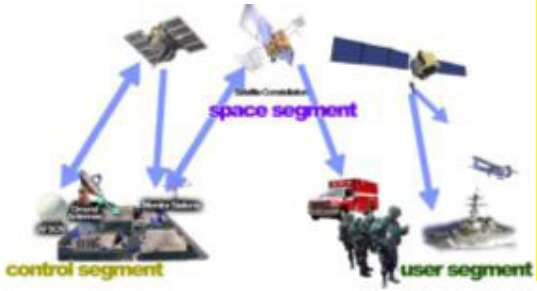


International Cooperation

•Deconflict PRN usage for 8 global PNT systems
- 63 for US and 147 for other GNSS
• 25+ Years of Cooperation with 50+ Nations
•GNSS
- **China – COMPASS (BeiDou)**
- **Europe – Galileo/EGNOS**
- **India – IRNSS/GAGAN**
- **Japan – QZSS/MSAS**
- **Russia – GLONASS/SDCM**

Spectrum

•World Radio Conference
•International Telecommunication Union
•Bilateral Agreements



34 Satellites/ 31 Set Healthy
Baseline Constellation: 24 Satellites

Satellite	Quantity	Avg Life	Oldest
GPS IIA	10	18.0	21.3
GPS IIR	12	10.2	14.6
GPS IIR-M	7	4.6	6.4
GPS IIF	2	1.2	1.8
Constellation	31	10.9	21.3

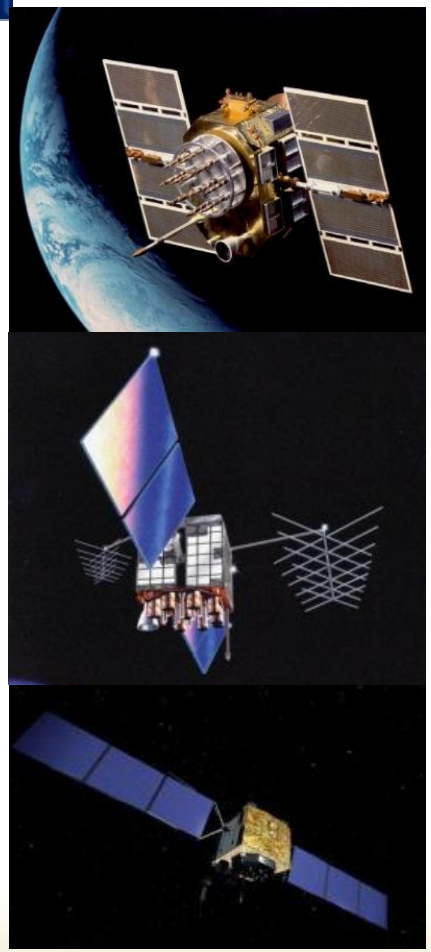
Dual Use Management

• Department of Defense Services (Army, Navy, AF, USMC)
  • Agencies (NGA, DISA, etc.)
  • US Naval Observatory
• Department of Transportation
• PNT EXCOMS, NPEF, etc
• GPS Partnership Council

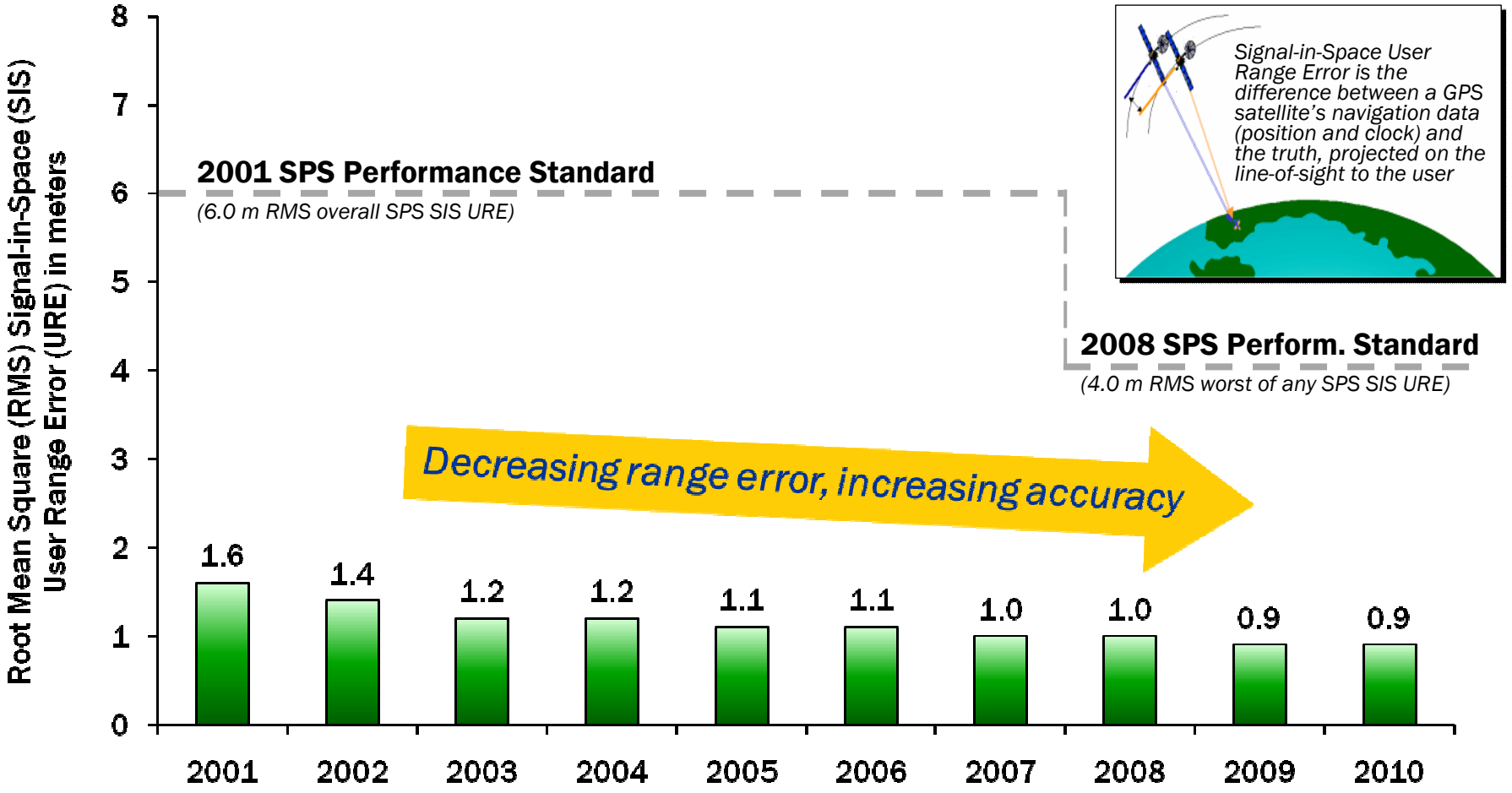
GPS Constellation Status

31 Healthy Satellites
Baseline Constellation: 24 + 3

- 10 Block IIA Satellites
- 12 Block IIR Satellites
- 7 Block IIR-M Satellites
- 2 Block IIF Satellites
  - *IIF-2 healthy as of October 16, 2011*
  - *Next IIF launch scheduled mid-2012*
- Global GPS civil service performance commitment met continuously since December 1993



Standard Positioning Service (SPS) Signal-in-Space Performance



System accuracy exceeds published standard

Civil Capability Improvements

Second civil signal "L2C"

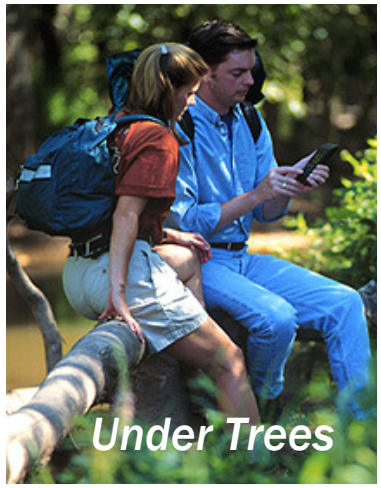
- Designed to meet commercial needs
- Higher accuracy through ionospheric correction
- Available since 2005 without data message
  - Currently, 7 IIR-Ms transmitting L2C
- Full capability: 24 satellites ~2016

Third civil signal "L5"

- Designed to meet demanding requirements for transportation safety
- Uses highly protected Aeronautical Radio Navigation Service (ARNS) band
- Operational on 2 GPS IIF satellites
- Full capability: 24 satellites ~2018

After 2020, with L2C and L5 online, the USG will no longer support semi-codeless access to military GPS signals

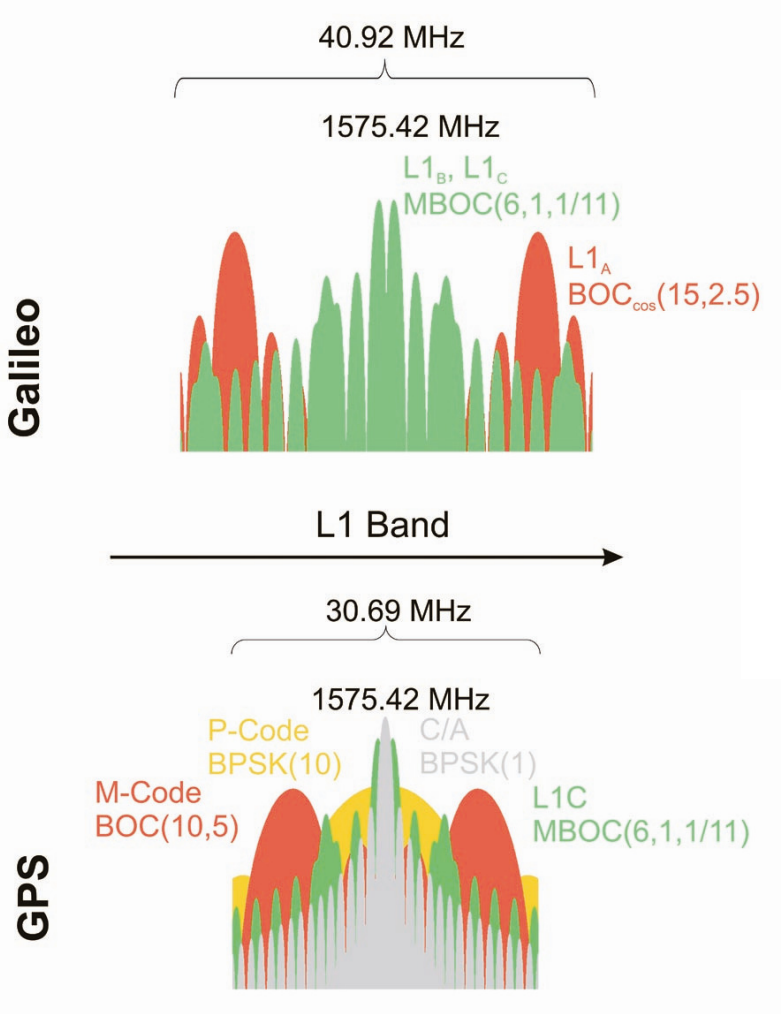
Civil Capability Improvements



Fourth civil signal "L1C"

- Designed with international partners for interoperability
- Modernized civil signal at L1 frequency
  - More robust navigation across a broad range of user applications
  - Improved performance in challenged tracking environments
  - Original signal retained for backward compatibility
- Specification developed in cooperation with industry
- Launches with GPS III in 2014
- On 24 satellites by ~2021

Patent Issue on L1C



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GPS IIR/IIR-M Status

- All GPS IIR and IIR-M satellites are on orbit
  - Current backbone of the GPS constellation
- Excellent on-orbit performance
  - SIS URE of .50 meters
    (1 yr performance Jul 11)
- Excellent life expectancy
  - Solar array capacity far exceeds specification
  - No clock failures to date

GPS IIF Status

- On-orbit performance for IIF-1
  - SIS URE of .30 meters (1 yr performance Jul 11)
- Launched GPS IIF-2 on 15 Jul 11
  - SVN 63, PRN 1
  - Set healthy 14 October 2011
  - Second operational L5
  - Increases the enhanced GPS clock performance coverage
- 10 more IIFs in the pipeline
  - SVs 3-8 are in Assembly, Integration & Test
- IIF-3 launch scheduled Sept. 2012

GPS III Status

- Newest block of GPS satellites
  - First GPS satellite to broadcast L1C signal
  - Multiple civil and military signals; L1 C/A, L1 P(Y), L1M, L1C, L2C, L2 P(Y), L2M, L5
  - Three Rubidium clocks
- Completed Critical Design Review
- Prototype and engineering unit build/test underway
  - Completed 57 of 59 Manufacturing Readiness Reviews
  - Completed 43 of 59 Test Readiness Reviews
- GPS Nonflight Satellite Testbed (GNST) integration underway
- Initiated Capability Insertion Program for SV-9+

GPS Modernization Program

Increasing System Capabilities ◆ Increasing User Benefit

Block IIA/IIR

Basic GPS

- Standard Service
  - Single frequency (L1)
  - Coarse acquisition (C/A) code navigation
- Precise Service
  - Y-Code (L1Y & L2Y)
  - Y-Code navigation

Block IIR-M, IIF

IIR-M – Basic GPS capability plus

- 2nd civil signal (L2C)
- M-Code (L1M & L2M)

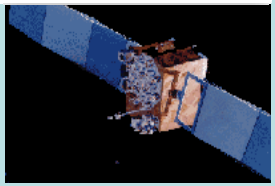
IIF – IIR-M capability plus

- 3rd civil signal (L5)
- 2 Rb + 1 Cs Clocks
- 12 year design life

Block III

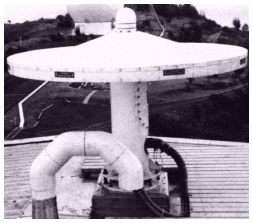
- Backward compatibility
- 4th civil signal (L1C)
- Improved User Range Error
- Increased availability
- Increased integrity
- 15 year design life

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

Control Segment Status



Monitor Station

Master Control Stations at Schriever AFB, Colorado

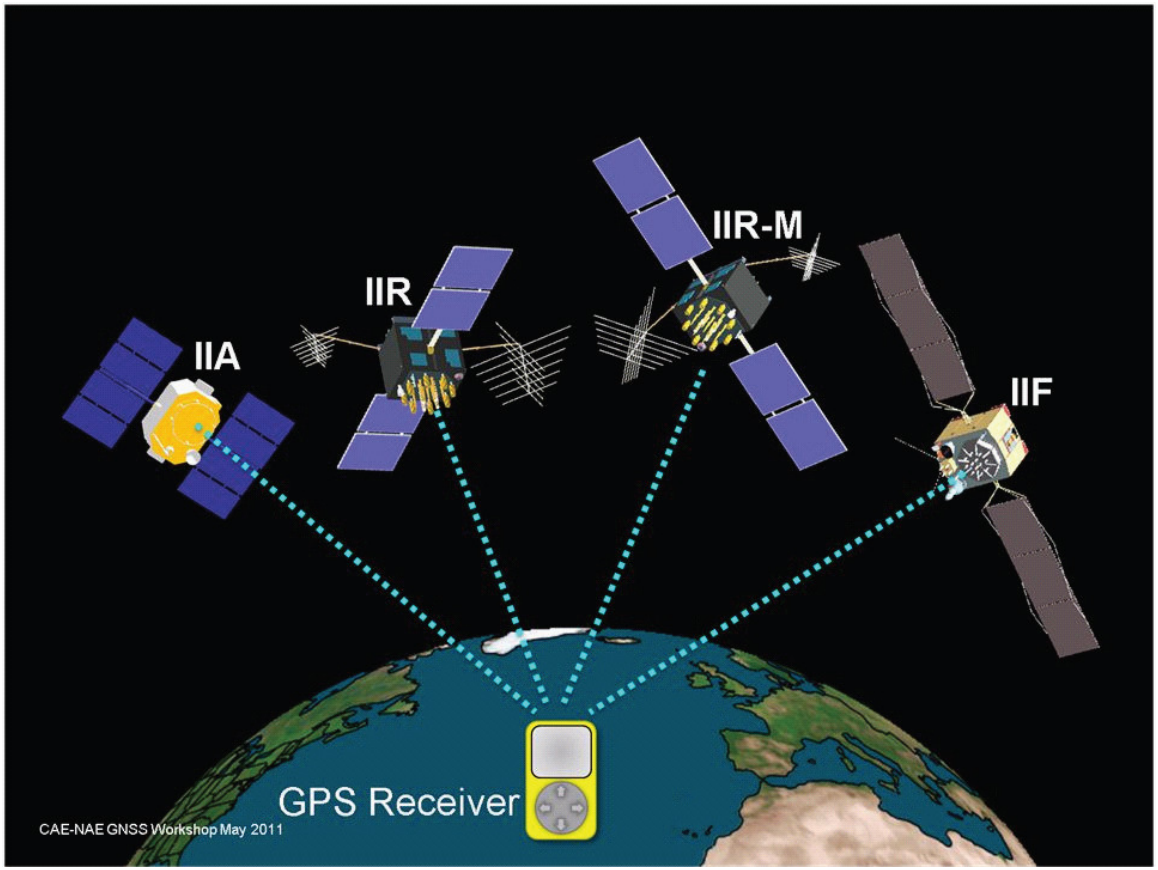
Ground Antenna

- Operational Control Segment (OCS)
  - Now flying Block IIA/IIR/IIR-M/IIF constellation
  - Added the capability for anomaly resolution and disposal ops for IIF
- Next Generation Operational Control System (OCX)
  - Preliminary Design Review concluded August 2011
  - OCX Block I deployment planned for August 2015
  - New Launch and Checkout System will control first GPS III satellites prior to OCX Block I

GPS Status Summary

- GPS has continuously met its commitments to all users
- Modernization of all GPS Segments is on track
- Striving to continually improve navigation and timing services while maintaining backward compatibility with legacy equipment
- GPS is committed to open and transparent cooperation with the international GNSS community

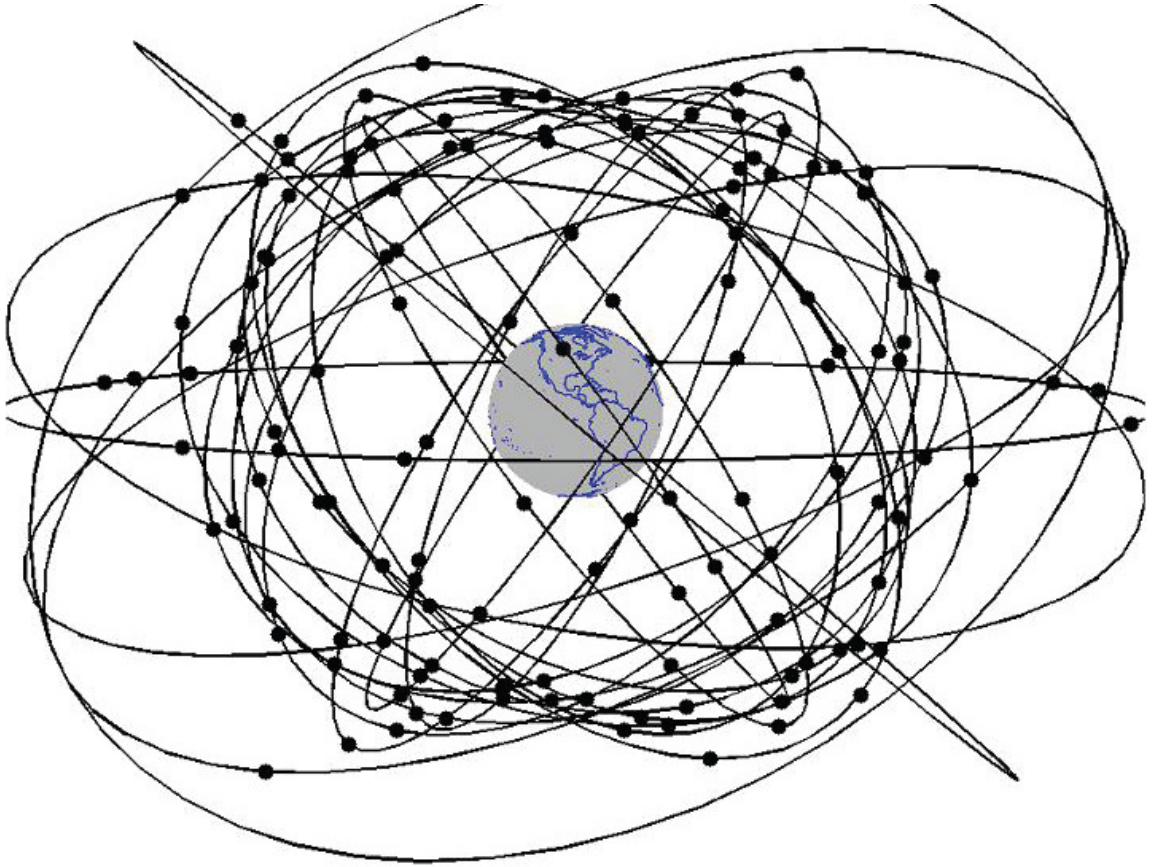
Reference frame issues



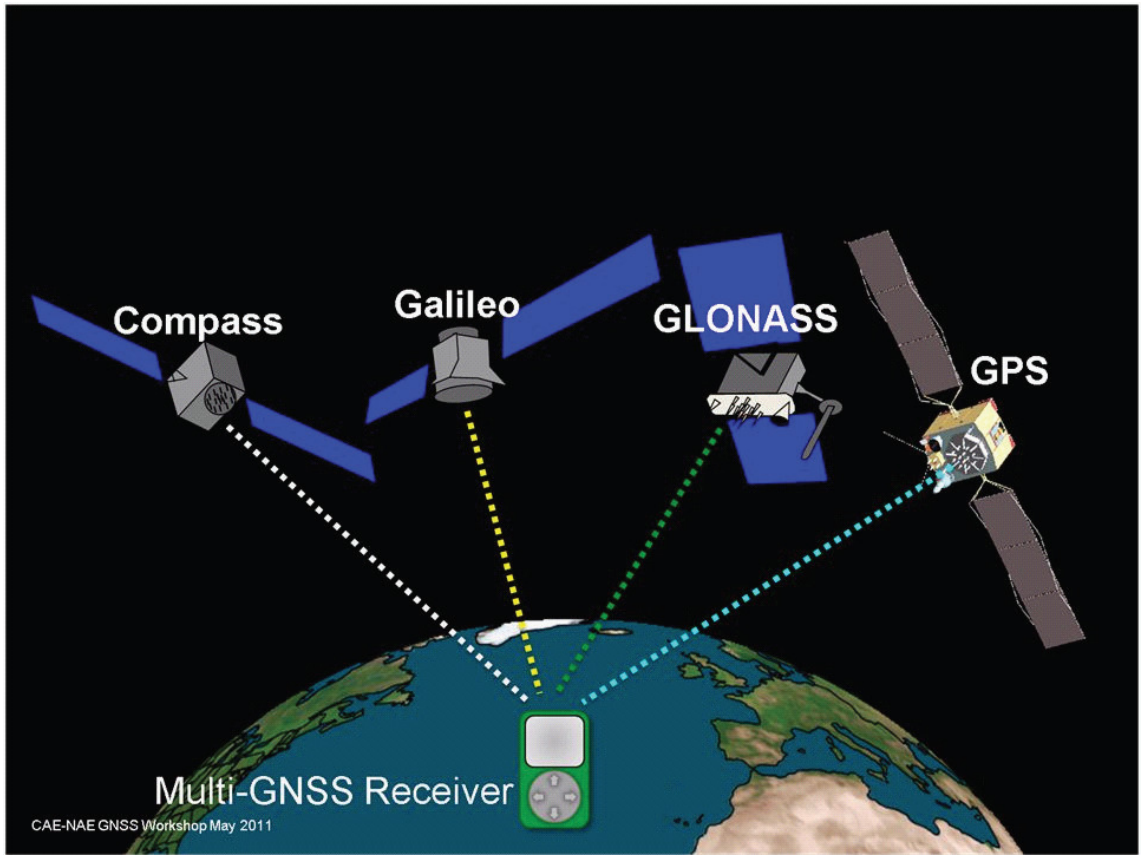
Receivers track four different GPS satellite types

Multi-GNSS

In the future, GNSS may grow to include more than 100 satellites, mostly in medium Earth orbit, with some in geostationary and inclined elliptical orbits

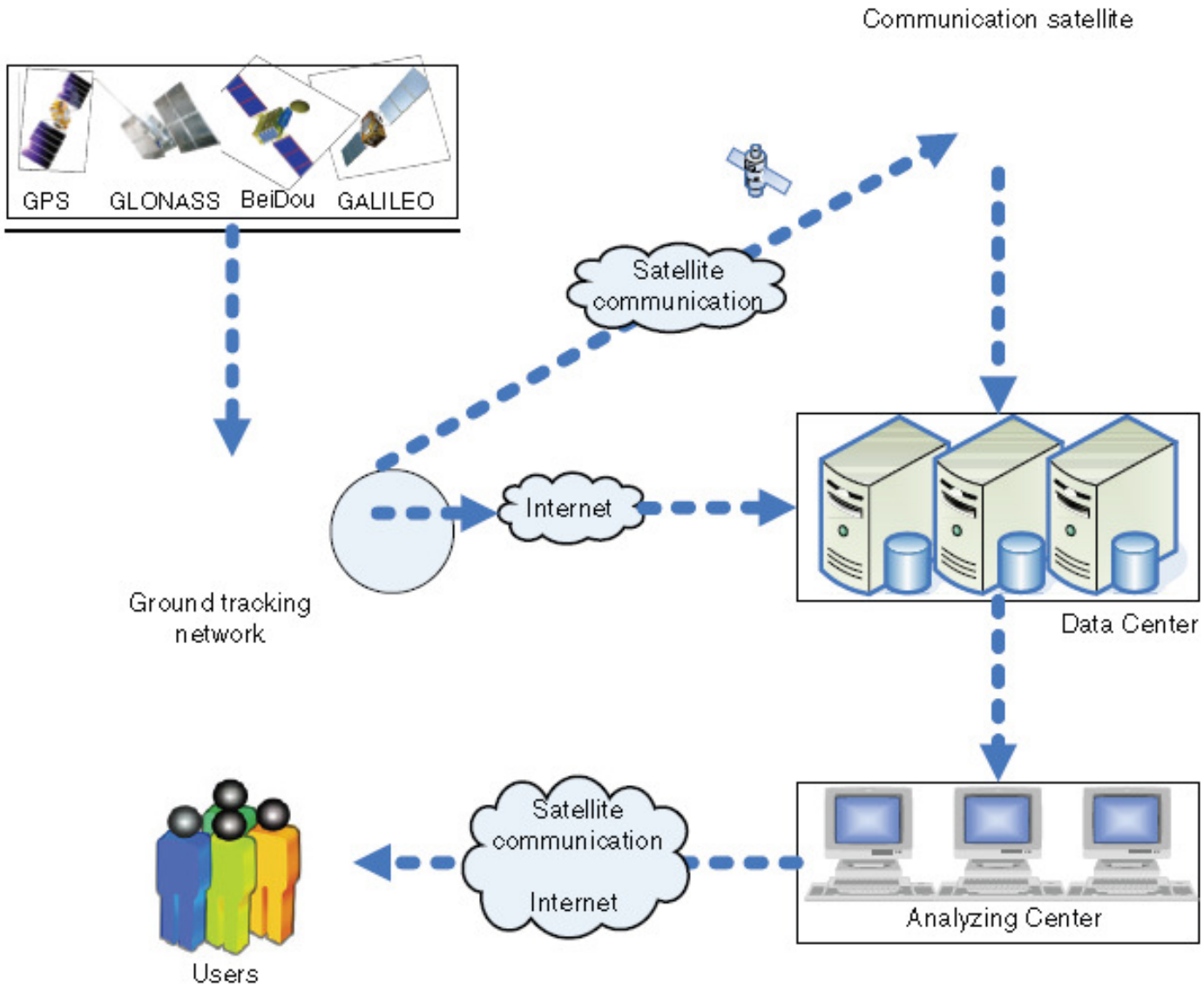


Reference frame issues



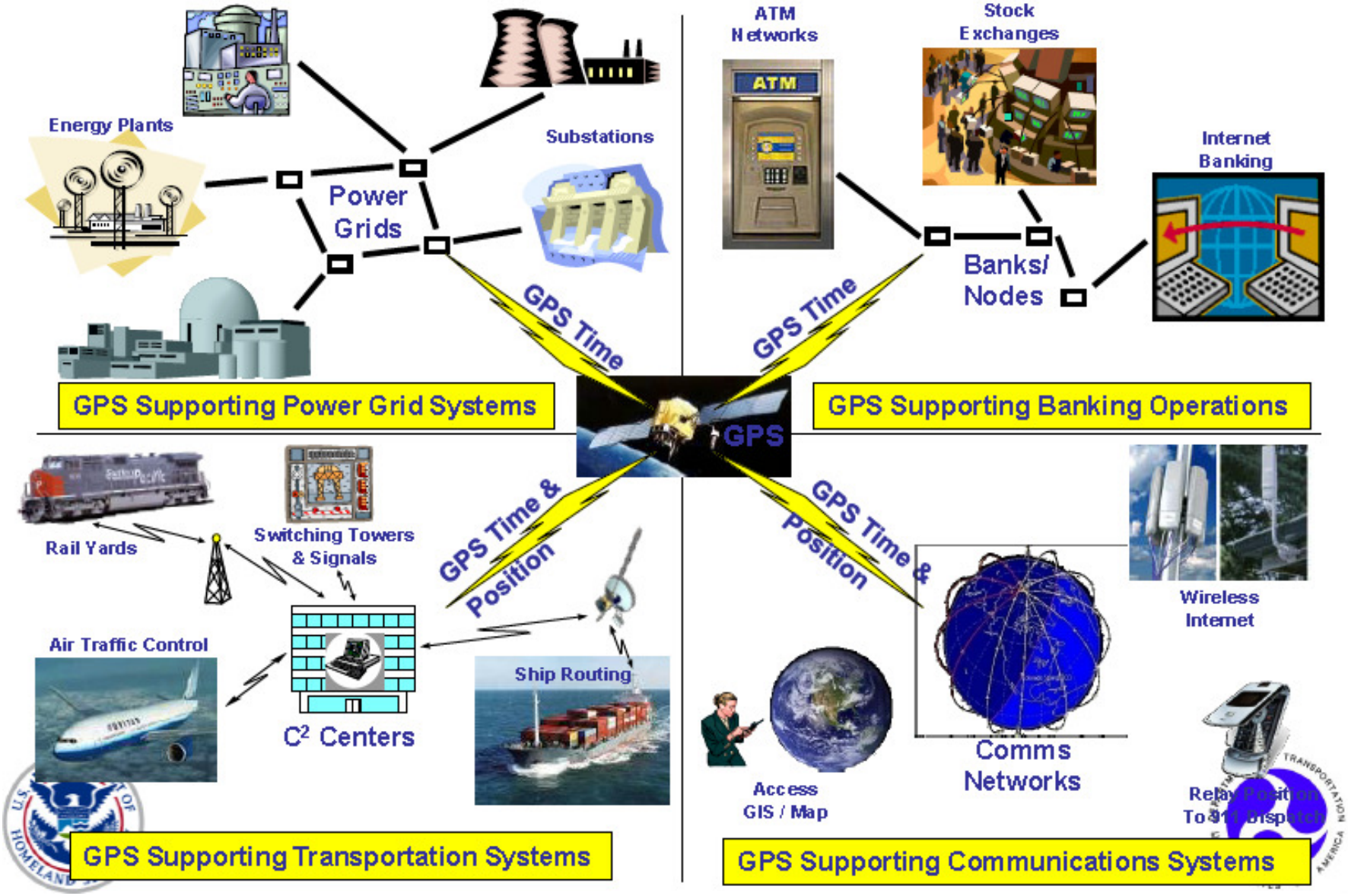
Transparent multi-GNSS interoperability is achievable through system and receiver design.

Possible Framework of International Multi-GNSS Service

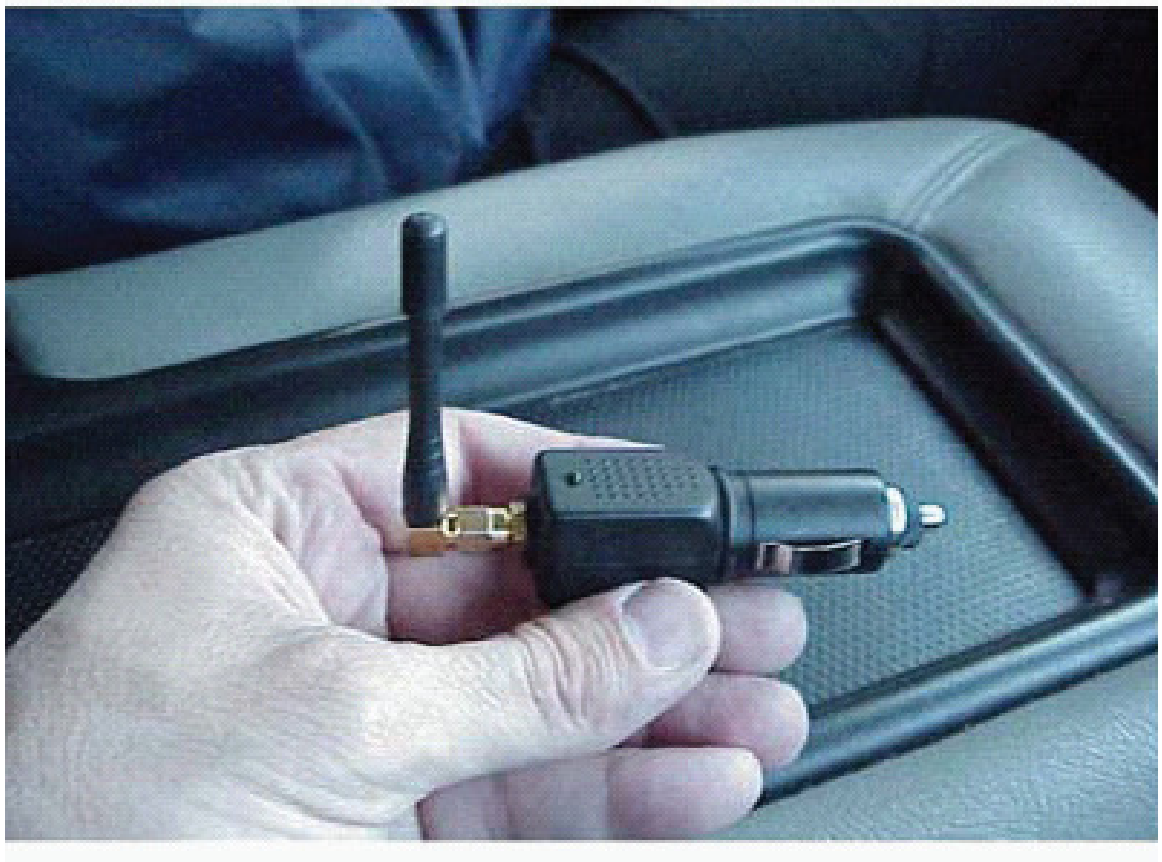


GNSS Signal Interference and Detection

Extent of GPS Dependencies



Personal protection devices (PPDs)



Example of a personal privacy device (PPD)

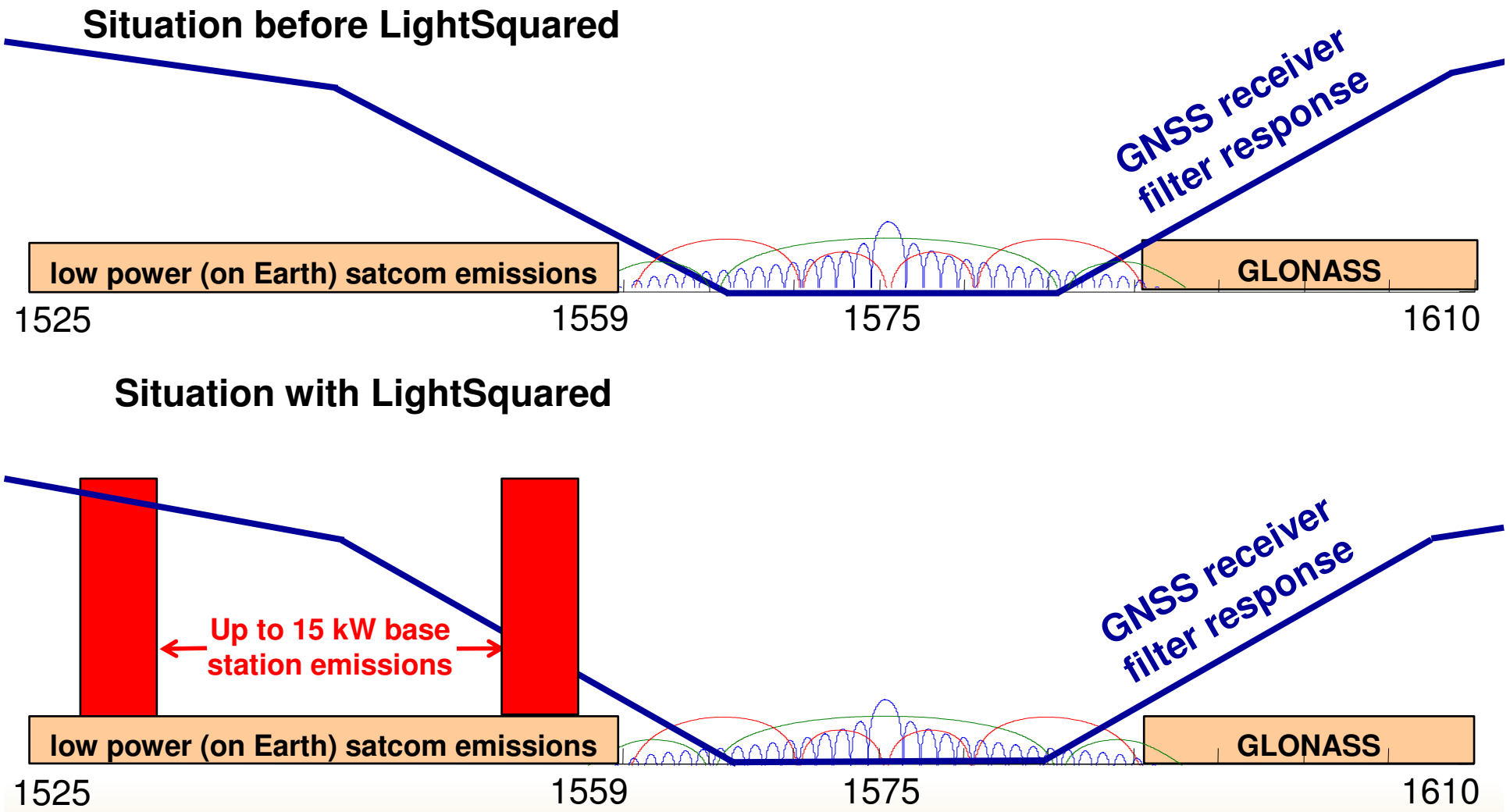
Harmonics May Interfere with GPS L1 Band

ORDER	BAND (MHz)	USAGE
L1	1571.42 - 1579.42	C/A-GPS
2th	785.71 - 788.71	UHF TV
3th	523.807 - 526.473	UHF TV
4th	392.855 - 394.855	Mobile/Station
5th	314.284 - 315.884	Mobile/Station
6th	261.903 - 263.237	Mobile/Station
7th	224.488 - 225.631	Broadcasting
8th	196.427 - 197.428	VHF TV
9th	174.602 - 175.491	VHF TV
10h	157.142 - 157.942	VHF Maritime
11th	142.856 - 143.584	VHF Military
12th	130.952 - 131.618	VHFCOM
13th	120.878 - 121.494	VHFCOM
14th	112.244 - 112.816	VOR/ILS
15th	104.761 - 105.295	FM
16th	98.214- 98.714	FM

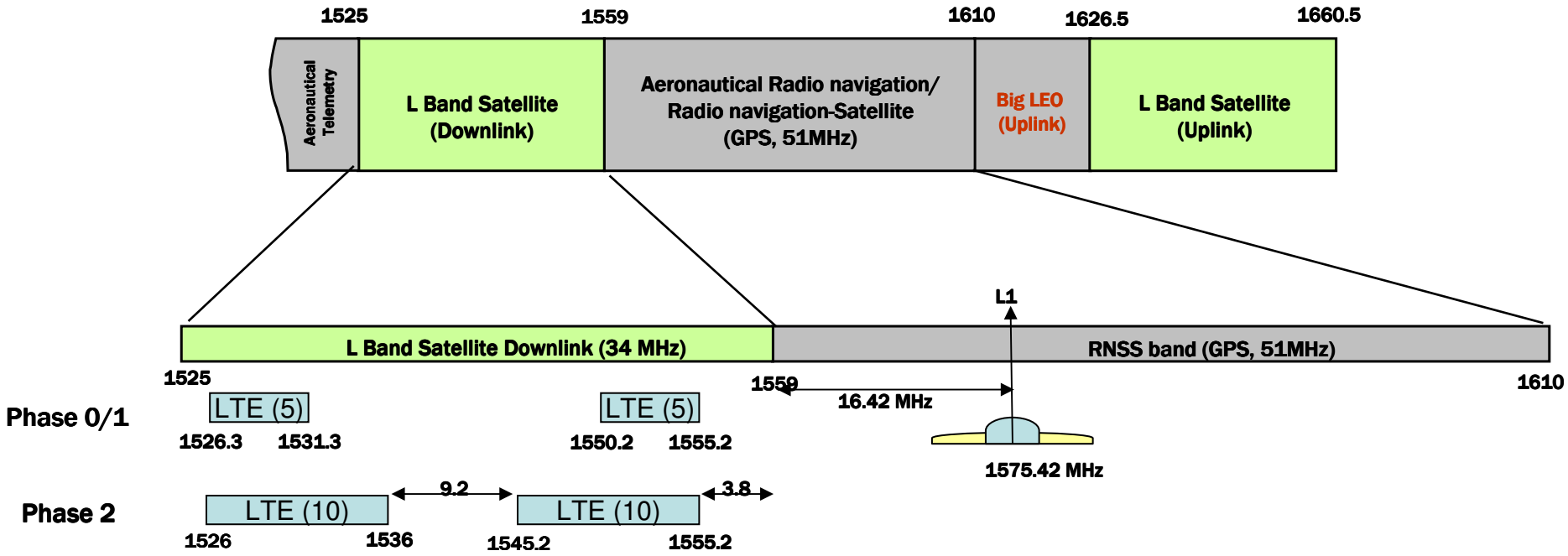
LightSquared Matter

- Created 2010 (previously known as “SkyTerra”)
  - Mobile satellite service (MSS) licensee in the 1525-1559 MHz/1626.5-1660.5 MHz band
  - Authorized in 2003 to operate ancillary terrestrial component (ATC) as satellite “fill-in”
    - Required dual-mode MSS/ATC devices to meet gating criteria
  - LightSquared’s goal is to build out a nationwide 4G broadband network (to cover 92% of USA by 2015)
- Nov 18, 2010 – Request submitted to FCC for modification of its ATC authority
- Jan 26, 2011 – FCC Order & Authorization
  - Granted conditional waiver (ATC-only handsets)
  - Requires resolving GPS concerns before commencing commercial operations

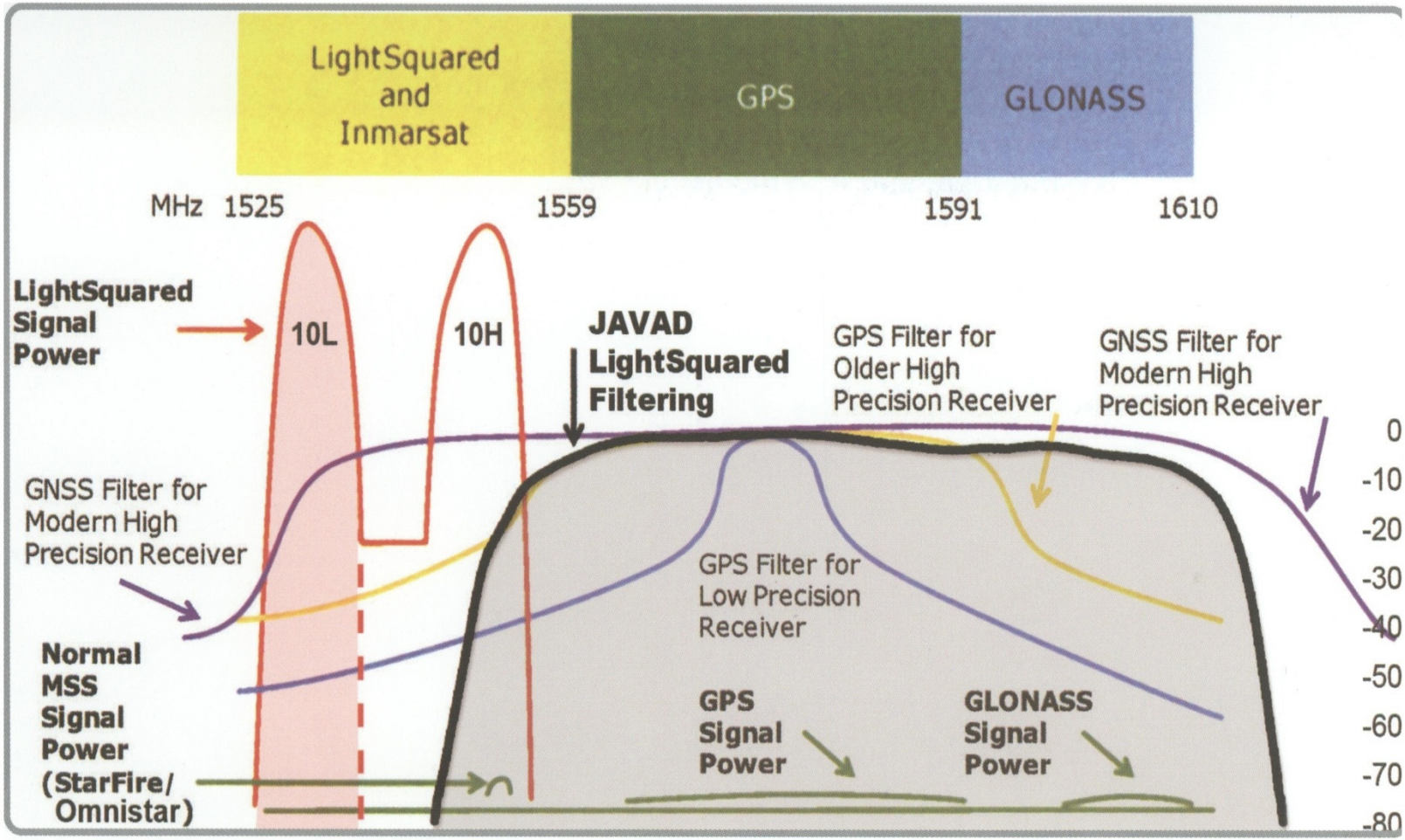
Illustration of Concerns with LightSquared



Original LightSquared Spectrum Plan



Javad Filter Response to Mitigate the Lower 10 MHz LightSquared Signal



LightSquared (LSQ)

- Testing of LSQ signal directly adjacent to GPS from LSQ towers to identify impact on the GPS signal
  - Testing conclusively showed that the LSQ's signal interfered directly with GPS receiver operation

- **On February 14, 2012 the FCC rescinded the "Conditional Waiver Order" to continue to protect GPS receiver operation**

- Federal Communications Commission (FCC) Office of Engineering and Technology is reviewing spectrum efficiency and receivers
  - **This is to enhance the use of spectrum for mobile broadband without affecting the GPS spectrum**

- U.S. Department of Transportation and Commerce Department's National Telecommunications and Information Administration (NTIA)
  - NTIA is the other U.S. organization that manages government spectrum
  - **U.S. interagency working to draft new GPS spectrum-interference standards to further strengthen existing policy protection of GPS**

Summary on LightSquared

- LightSquared signals caused harmful interference to majority of GPS receivers tested
  - With exception of cellular phones, Lower 10 MHz does not solve the problem, particularly with high-precision receivers
- Even an acceptable filter solution would need a long term transition/implementation plan to protect legacy GPS service and users (similar to semi-codeless GPS or analog to digital TV)

IAG/FIG Commission 5/ICG Technical Seminar

Reference Frame in Practice

Rome, Italy 4–5 May 2012

THANK YOU

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