ICG GNSS Interoperability Workshop – A Civil Aviation Perspective

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Overview

- **International Committee on GNSS (ICG) definitions:**
  – *Compatibility* refers to the ability of global and regional navigation satellite systems and augmentations to be used separately or together without causing unacceptable interference and/or other harm to an individual system and/or service
  – *Interoperability* refers to the ability of global and regional navigation satellite systems and augmentations and the services they provide to be used together to provide better capabilities at the user level than would be achieved by relying solely on the open signals of one system
- **This presentation provides a civil aviation perspective on both**

Civil Aviation Use of GNSS

- **Civil aviation is a sizeable, global industry:**
  – Over 300,000 general aviation aircraft
  – Over 30,000 air transport aircraft
  – In 2012, nearly 3B passengers flew the world's airlines
- **Significant fraction of civil aircraft are GNSS-equipped**
  – Primarily GPS or GPS plus Satellite-based Augmentation System (SBAS), but some GLONASS-capable also
  – Well over 100,000 certified receivers sold to date
- **Safety is paramount for certified avionics**
  – Standardization/development/certification is time-consuming and costly
  – Users expect lengthy service life (20+ years) to amortize

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International Civil Aviation Organization (ICAO) Standards

- **GNSS Standards and Recommended Practices (SARPs) first adopted in 2001**
  - First version in Amendment 76 to Annex 10, Vol. 1, to the Convention on International Civil Aviation
  - Many updates, with latest in Amendment 87 (2012)
- **Current SARPs address:**
  - Two core constellations: GPS and GLONASS
  - Augmentation systems: Aircraft-based (ABAS), ground-based (GBAS), satellite-based (SBAS), and ground-based regional (GRAS)
- **ICAO Navigation System Panel (NSP) is updating SARPs to add:**
  - CAT II/III GBAS, L5, GLONASS evolution, Galileo, BeiDou

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Aviation GNSS Receiver Standards

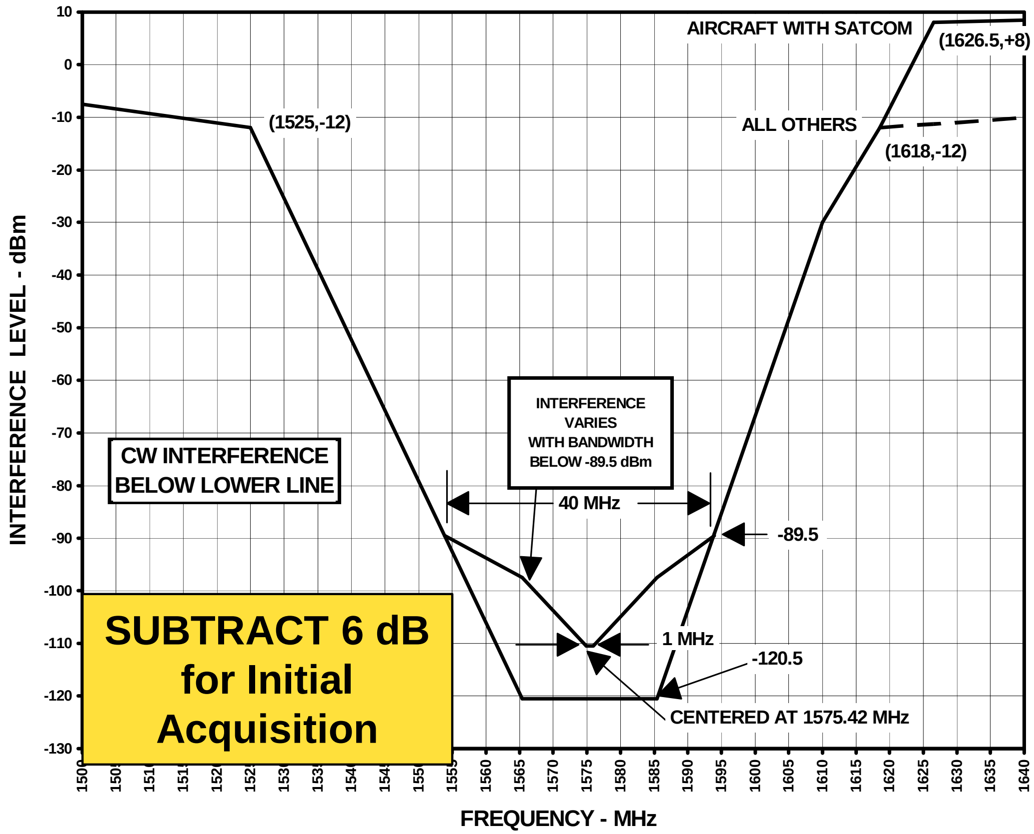
- **RTCA, Inc. and EUROCAE standards are most widely used**
  - Consistent with ICAO SARPs
  - Invoked by many certification authorities
- **Some relevant standards**
  - GPS/ABAS: DO-208, DO-316, ED-72
  - GPS/GBAS: DO-246, DO-253, ED-95, ED-114, ED-144
  - GPS/SBAS: DO-229, ED-97
- **Now in progress**
  - RTCA and EUROCAE are working mainly on dual-frequency standards for GPS, Galileo, and SBAS
  - On-going discussions on possibly adding support for other core constellations (GLONASS and BeiDou)

Radio Frequency Compatibility (RFC)

- **Current ICAO, RTCA, and EUROCAE standards currently support:**
  - Airborne processing of GPS/SBAS L1 C/A-code signals
  - GBAS and SBAS ground systems processing of GPS/SBAS L1 C/A-code and SBAS ground system semicodeless GPS L1/L2 P(Y)-code tracking
- **Standards include maximum tolerable interference requirements and test procedures**
  - Earlier standards did not anticipate presence of new GNSS signals; new standards do only to limited extent

Protection of existing user equipment against radio frequency interference for many years is a priority for aviation GNSS users.

RTCA Aviation Receiver Interference Standards



Maximum Tolerable External Interference (also in ICAO SARPs)

Receiver Function	Effective Noise Density
Initial acquisition	-172.2 dBm/Hz
Tracking and reacquisition	-171.9 dBm/Hz

"GNSS Noise" (Added in 2006 and only assumes GPS, Galileo, SBAS, QZSS)

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RFC Perspectives

- **Existing aviation standards did not anticipate the possibility of 150+ GNSS satellites, e.g.,**
  - 30+ GPS, 30+ Galileo, 30+ GLONASS, 35+ BeiDou
  - 24+ regional (e.g., SBAS, QZSS, IRNSS)
- **C/A-code link margin has been eroded by external interference sources; currently very small**
- **To ensure continued utility of worldwide avionics investment, important to ensure "unanticipated" intra- and inter-system interference is negligible**
  - Also that new external interference sources do not exceed maximum tolerable interference levels (in-, adjacent-, or out-of-band)
- **Also important to accurately reflect future GNSS environment in new avionics standards**

Interoperability

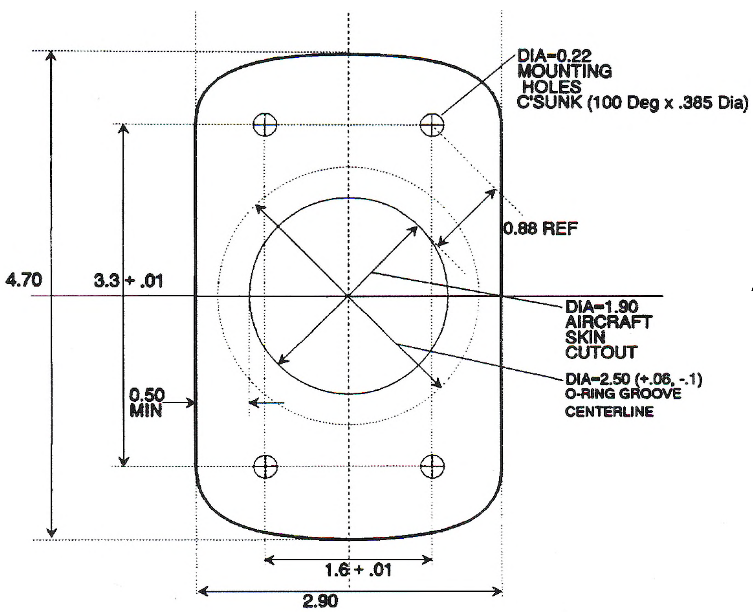
- **Aviation users can benefit from additional signals**
  - However, users are extremely cost-sensitive
  - Incremental benefit/cost ratio must be sufficient to warrant retrofit or initial investment
  - Quite likely that many users will opt to retain L1 GPS/SBAS-only equipment for decades
- **Desirable for new signals to be interoperable:**
  - Common carrier frequencies (e.g., L1 and L5/E5a)
  - Common/interoperable modulations
  - Common pseudorandom noise (PRN) code families
  - Common data elements

Importance

- **Common/consistent geodetic and time systems are also important**

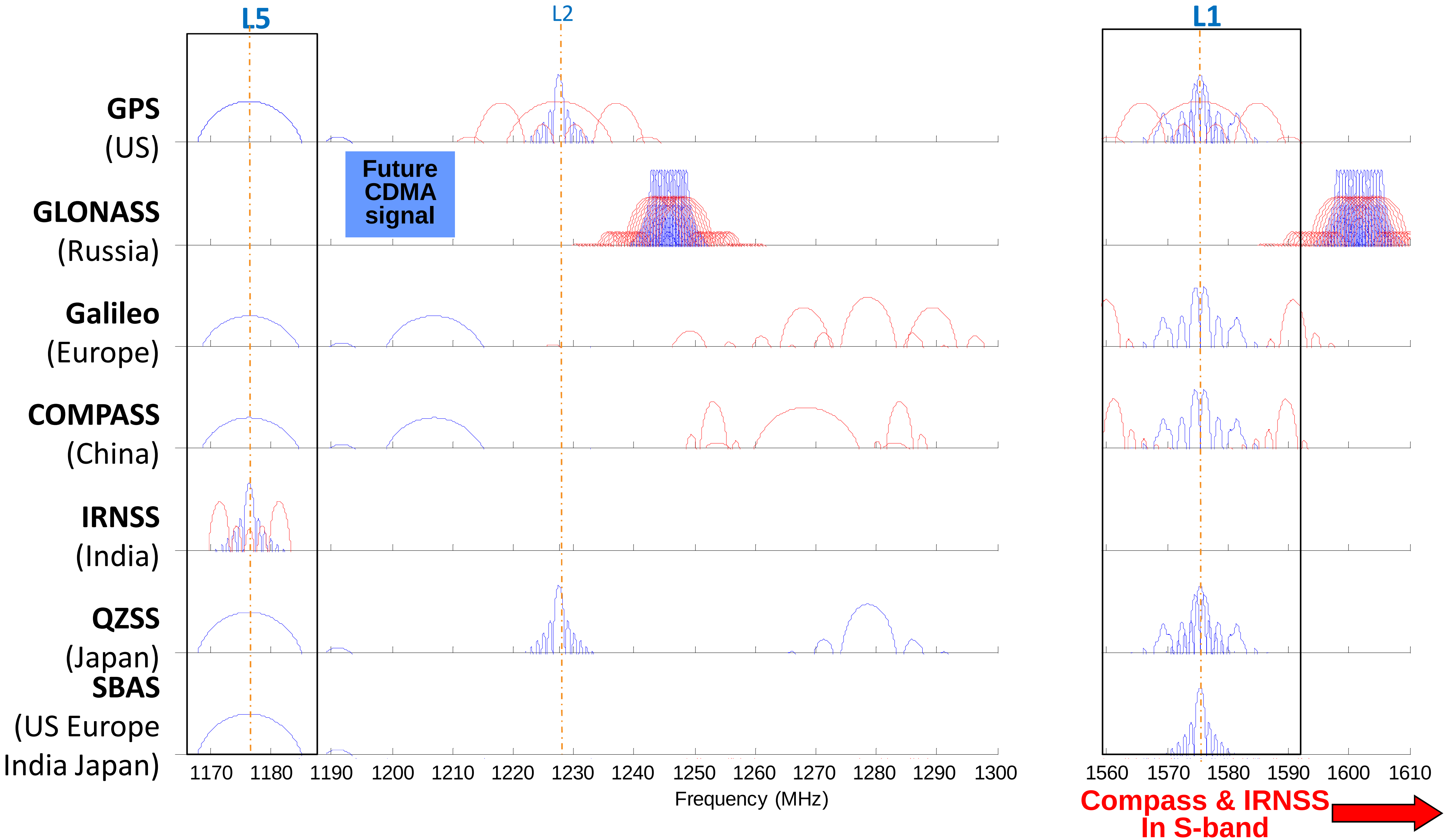
User Antennas

- **Most airborne equipment uses patch antennas**
  - Conformal, compact, and provide good performance
- **Patch antennas are resonant**
  - Element stacking used for dual-frequency
  - Design challenge to retain performance/size as more frequencies added
- **RTCA and EUROCAE focusing on 1575/1176 MHz**



ARINC 743 Form Factor
(11.9 × 7.4 × 1.9 cm^3)

GNSS Signal Plans



1575/1176 MHz are current focus for aviation receiver standards

Coordinate and Time Systems

- **Coordinate system**
  - GNSS SARPs requires that “The position information provided by the GNSS to the user shall be expressed in terms of the World Geodetic System — 1984 (WGS-84) geodetic reference datum”
  - SARPs note that conversion parameters should be supplied if other coordinate system is employed
  - WGS-84 described in other SARPs (Annex 4, 11, 14, 15)
- **Time - GNSS SARPs requires use of Universal Time Coordinated (UTC)**
- **The above are not difficult for GNSS**
  - Most coordinate systems, including WGS-84, are adjusted periodically to align with ITRF
  - GNSS time systems are generally steered to UTC

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Other Important Considerations

- **Because of the enormous costs and long equipment lifetimes, civil aviation is “risk-adverse”**
- **Even if GNSS components are included in ICAO SARPs, there is no guarantee they will be used**
- **The following factors encourage use:**
  - Commitment to constellation sustainment and provision of services without direct user charges
  - Availability of signal-in-space specifications
  - Performance history
    - Rarity of anomalies
    - Transparency in resolution
  - Mature maintenance processes and Notices to Airmen (NOTAMs)
    - History of properly setting satellites unhealthy as needed
    - Reliable NOTAMs

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Summary

- **Civil aviation is, and is expected to remain, an important GNSS market segment**
- **Civil aviation receivers are expensive to standardize/develop/certify/install and users expect to retain them for decades**
- **RFC is of tremendous importance to protect significant investments and preserve safety**
- **Civil aviation users look forward to additional interoperable GNSS components/signals**
  - Common signal characteristics (especially carrier frequencies) and consistent coordinate/time systems will encourage use

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