Experiences with GNSS interference in flight inspection

Sigurd A. Bjelkarøy, Norwegian Special Mission

BIOGRAPHY

Sigurd A. Bjelkarøy - B.Sc. Avionics, working with flight inspection system design since 1998. Director - Flight Inspection Systems at Norwegian Special Mission.

ABSTRACT

The radio frequency spectrum is getting more and more congested with new types of communication signals. These new communication standards are often installed on airports and can with their relative high signal strength cause interference into the Global Navigation Satellite System (GNSS) band especially for the flight inspection system multi frequency GNSS receivers.

The paper will explain scenarios where new communication signals have caused interference for GNSS receiver. Even though strict standards are followed to ensure that there are no interference between systems the GNSS system is especially sensitive to interference as the received GNSS itself is very weak. There is a clear difference between standard aviation GPS receivers which are be tuned to a single frequency range and the multi frequency GNSS receivers used for flight inspection.
In some cases, the use of multi frequency GNSS systems will improve the position solution in a RF environment with interference but in other cases the wider range of receivable systems makes a multi frequency GNSS more vulnerable for interference.

Now when multi frequency GNSS receivers are becoming more common in aviation, use the experiences made in the flight inspection community should be highlighted so it can be known for a broader audience.
The paper will present the issues seen and how they affected the results. Further on it will describe the typical build-up of GNSS systems and where improvements can be implemented to minimize problems. Description on why multi frequency GNSS systems can both be more affected by interference in some cases and less affected by interference in other cases will be presented.

The regulatory requirements for GNSS systems provided in TSO standards, ICAO Annex 10 and radio frequency regulations will be presented and it will be shown why there still are issues with interference even though these requirements are followed.
Since different receivers will act differently to various types of interference the paper will emphasize the importance to record the behavior of standard aviation GPS receivers with standard TSO'd antennas for validation of instrument flight procedures in addition to recording the multi-frequency GNSS signals from flight inspection receivers.

Finally, the paper will present possible solutions to how GNSS antennas and receivers can improve its robustness to the ever evolving RF spectrum.

INTRODUCTION

. Most standard aviation GPS systems are today relying on single frequency GPS system only. Some aircrafts are also capable of using single frequency GLONASS for positioning.

This is slightly different from the multi constellation multi frequency GNSS systems normally used as position reference for flight inspection. Multi constellation multi frequency GNSS systems are not guarded in the same way as a standard aviation GNSS system since they are operating also outside the normal GNSS band used in aviation.

A multi constellation multi frequency GNSS receiver will have a lot of benefits in term of accuracy and availability, and in some cases, it can prove to be more immune against interference. However, the increased frequency spans a system like this have to cover could also make it more susceptible to interference in other frequency bands.

Different GNSS systems and frequencies are currently being implemented for aviation use. GLONASS, GPS and Galileo are all planned to have dual frequency solutions for aviation use. The GPS frequency L5, GLONASS G3 and Galileo E5 are all in the Aviation Radio Navigation Service (ARNS) frequency band between 1164MHz and 1215Mhz. It is interesting to note that this is the same frequency range that all DME and TACAN ground stations between channel 77X and channel 126X are transmitting on. Sharing these frequencies are only possible due to the natural robustness against pulsed interference by the code division multiple access (CDMA) modulation used by the GNSS systems in this frequency band.

New receivers and antennas will be needed to utilize the new GNSS frequency bands and standards will have to be defined. Positioning reference systems used for flight inspection will also benefit from the implementation of these standards. In the meantime, we can look at what we have experienced from the last two decades using GNSS systems operating also outside the well-guarded original L1 frequency band.

STANDARDS

Aviation equipment are certified against ETSO and TSO standards. These standards are normally documents of few pages which are referring to other standards. Detailed requirements are normally described in RTCA documents or ED documents.

For GNSS equipment alone there are at least 17 different RTCA documents covering various aspects of GNSS systems. For this document the focus has been mainly around the following standards:

- RTCA DO-301 - Minimum Operational Performance Standards for Global Navigation Satellite System (GNSS) Airborne Active Antenna Equipment for the L1 Frequency Band
- RTCA DO-235B - Assessment of Radio Frequency Interference Relevant to the GNSS L1 Frequency Band
- RTCA DO-229E - Minimum Operational Performance Standards for Global Positioning System/Satellite-Based Augmentation System Airborne Equipment.

Most aviation receivers used today are complying with RTCA DO-229 in some version and the GPS antenna are complying to RTCA DO-301. GNSS systems and antennas capable of multi constellation, multi frequency operation will not be able to fulfill the requirements of the above standards 100% since they will need to operate also outside the guarded frequency band.

Requirements for GNSS systems resistance to interference are also defined in ICAO Annex 10 Vol 1 appendix B chapter 3.7. The levels found in ICAO Annex 10 are the same as listed in the referenced RTCA documents.

GNSS FREQUENCY SPECTRUM

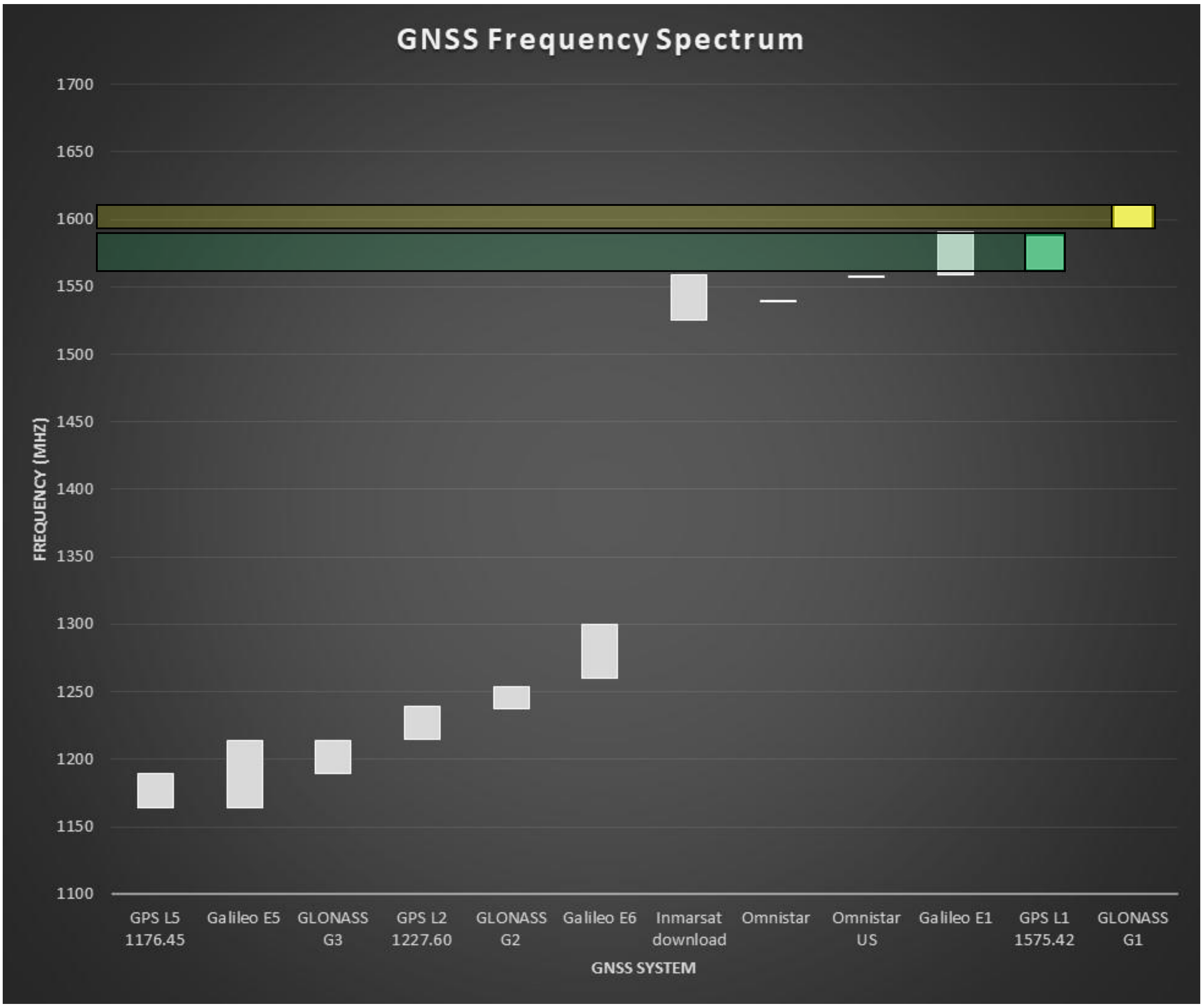
GNSS systems are operating over a wide frequency range as shown in the illustration below. The green sector represents the GPS L1 frequency band and the yellow sector represents the GLONASS G1 frequency band which are the two frequency bands used by aviation receivers today.

BeiDou or COMPASS is a GNSS not shown in the illustration since it is utilizing the same frequency ranges as Galileo and currently only has regional coverage.

QZSS system is also not shown since it is sending in the same frequency ranges as GPS and is intended for regional coverage.

Modern multi constellation multi frequency GNSS receivers can be able to utilize all GNSS systems including also COMPASS and QZSS.

Standard SBAS systems operate on GPS L1 frequency while more advanced satellite augmentation systems like Omnistar and Trimble RTX to mention a few provide correction data via geostationary satellites in the same frequency range as Inmarsat and often used to provide high accuracy correction data to flight inspection position reference systems.

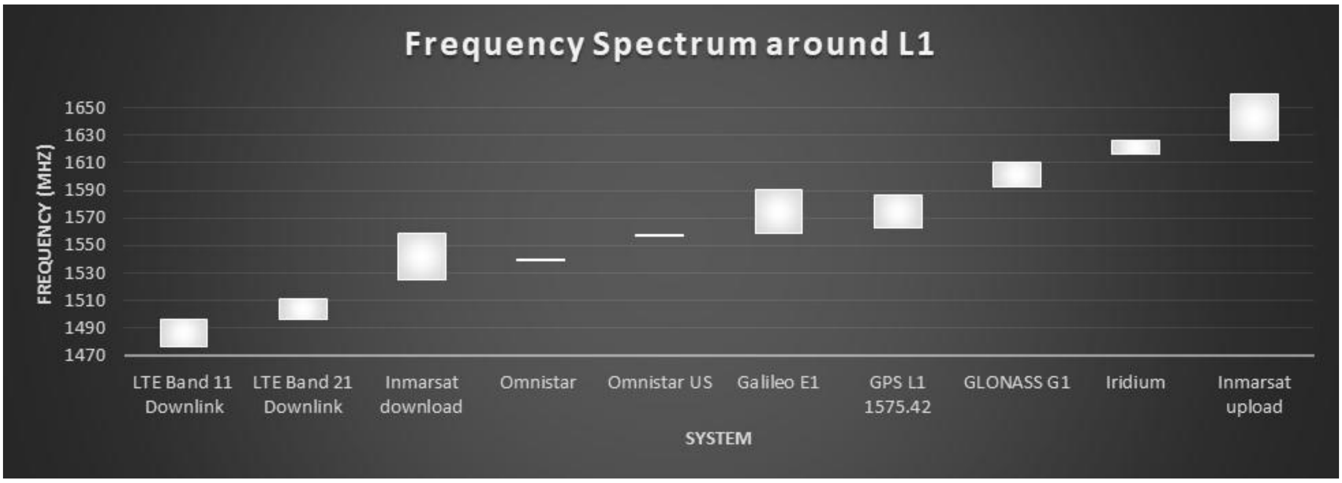


GNSS Frequency Spectrum

In addition to the GNSS there are also many other systems operating around the same frequency range.

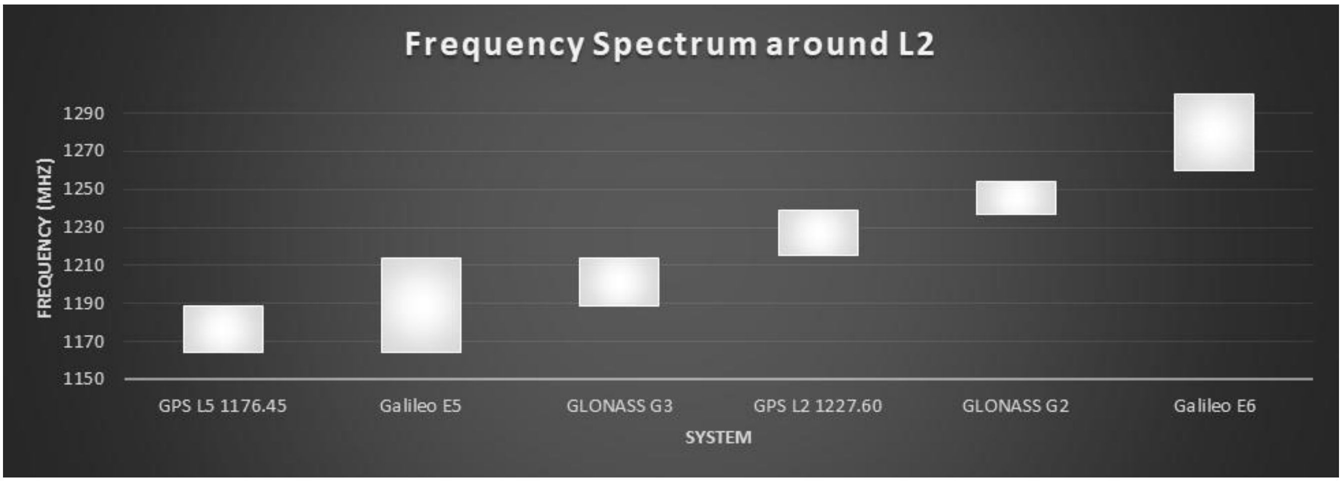
Around the frequency range of GPS L1 / GLONASS G1 there are other systems of interest. Some of the LTE frequency bands used for modern 4G mobile phones in various countries have their base station transmission frequency range around 1500MHz. This is far outside the normal frequency range of multi constellation multi frequency GNSS but still they can cause interference issues in some cases as will be described later in this paper.

Just above the GLONASS G1 frequency range the Iridium and Inmarsat satellite communication systems are placed. Both which are often used on modern aircrafts.



Frequency Spectrum around L1

For GNSS systems around L2 and L5 frequency range we also find all DME and TACAN ground stations which are transmitting between 962MHz up to 1213MHz and Primary Surveillance Radars which can transmit in the frequencies from 1215MHz to 1400MHz. Utilization of GNSS systems in this frequency range without severe interference is possible due to the natural robustness against pulsed interference by the code division multiple access (CDMA) modulation being used.



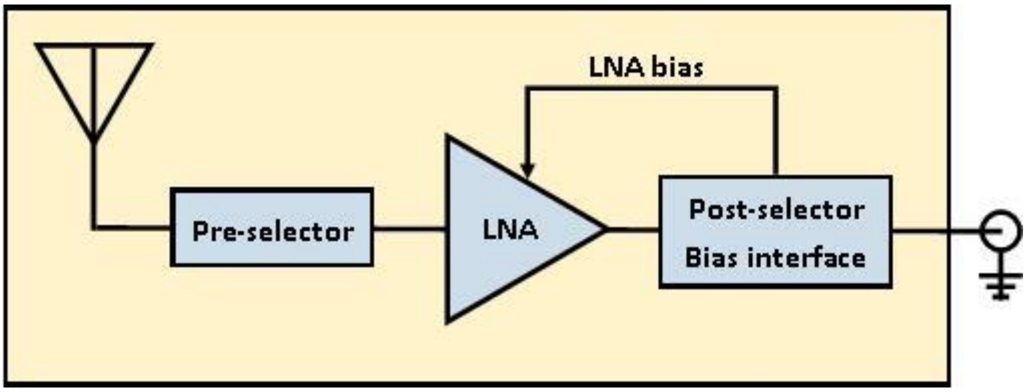
Frequency Spectrum around L2

To understand more why out of GNSS frequency band systems can cause interference to GNSS systems we need to know the basics of a GNSS antenna.

GNSS ANTENNA DESIGN

Most GNSS antennas are active antennas with its own built in amplifier. An active GNSS antenna has in addition to the antenna element, a pre-selector, a low noise amplifier (LNA) and a post-selector / bias interface.

The Pre-selector is there to remove as much as possible of the unwanted signal before it reaches the LNA. The LNA will amplify the received signal and the post-selector / bias interface will feed the DC power to the LNA via the antenna coax plug.

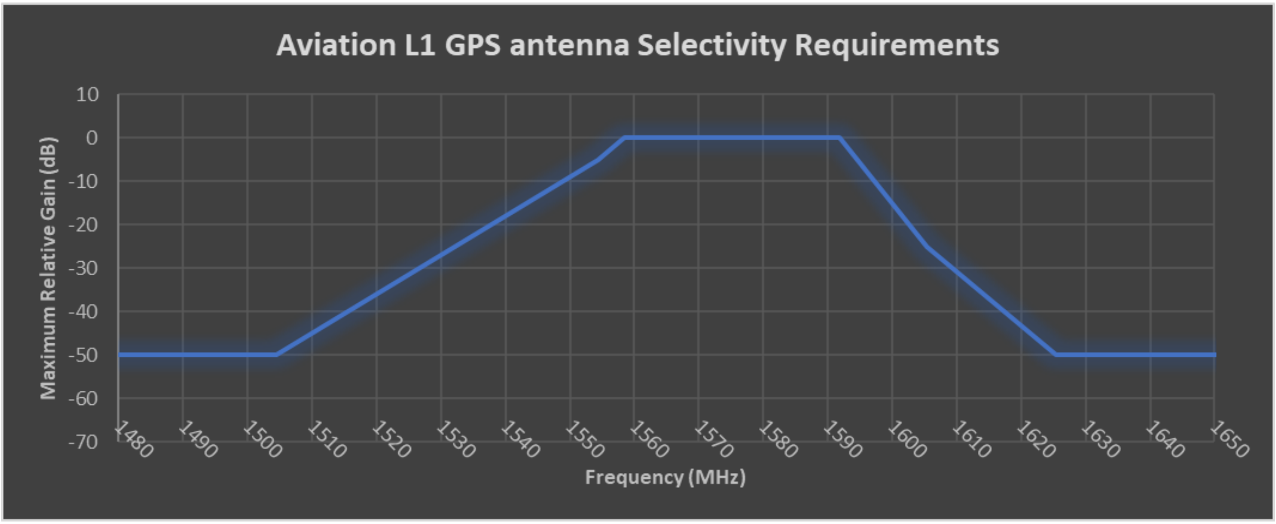


Block Diagram for active GNSS antenna

The minimum gain for a standard active GPS antenna should be not less than 26.5dB according to RTCA-DO 301. This means that the intention is to at least amplify the received power of the GPS signal 450 times.

Multi GNSS GPS antennas used for the flight inspection system reference positioning system often have gain in the range of 35dB to 43dB. These antennas are better suited to receive weak GNSS signals but they are at the same time also amplifying interfering sources more. 43dB gain is amplification of 20 000 times the power of the input signal This is considerably higher than the minimum required gain.

The pre-selector shall be able to remove unwanted signals and a standard L1 aviation GPS antenna shall be able to suppress the out of band signals according to the following graph:



Selectivity requirement for L1 GPS antenna

The purpose of this is to reduce the level of any out of band signals reaching the LNA so the LNA can work freely on amplifying the wanted signals. The problem with this antenna is that it would not be able to receive other GNSS frequency bands well.

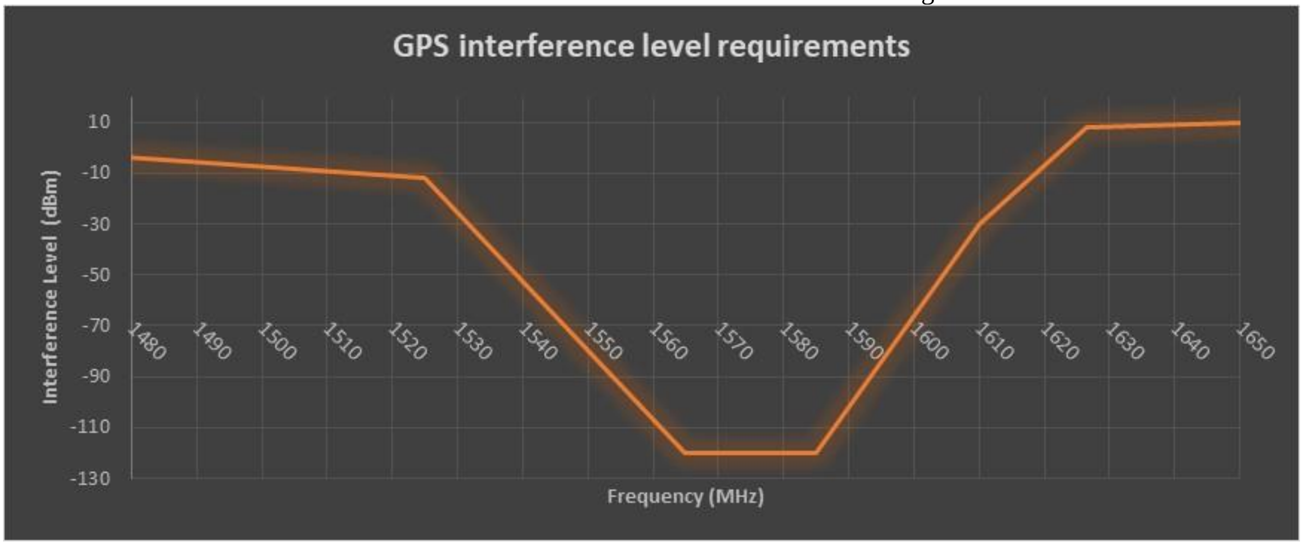
A multi constellation multi frequency GNSS antenna must be able to receive the wanted signals in all the GNSS frequency bands so the selectivity must be expanded still while attenuating unwanted signals as much as possible.

The result of this is that even out of frequency band signals may not be attenuated enough causing either the LNA to provide a strong interfering signal to the GNSS receiver or that the LNA itself get saturated by the interfering signal so it is not able to provide the GNSS receiver with the wanted portion of the signal with sufficient low noise.

GNSS RECEIVER INTERFERENCE IMMUNITY

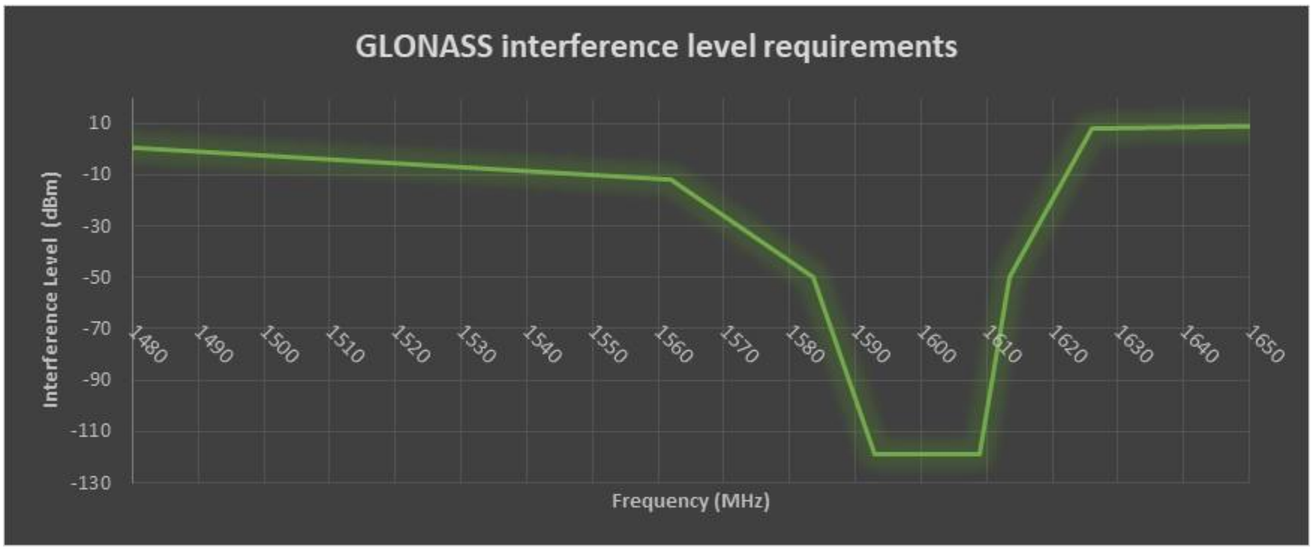
ICAO and RTCA have requirements for how much interference a GNSS sensor shall handle while still operating normally. The requirements are defining different levels for different types of interference.

For CW interference in the GPS L1 band the receiver shall be able to handle the following levels:



CW interference levels for GPS (L1)

For GLONASS a similar curve exists:



SW interference levels for GLONASS (G1)

In the same was as for the GNSS antenna a Multi constellation multi frequency GNSS receiver will need to be capable of receiving the very week GNSS signals in frequency ranges outside the defined ranges for GPS L1 and GLONASS G1 which will make it more challenging for the GNSS receiver to handle interference.

Cable losses are normally wanted to be kept to a minimum. ARINC 743A suggest that an appropriate assumption for GPS antenna cable insertion loss is 13dB. This is considering large air transport category aircrafts. For our smaller flight inspection aircrafts where we normally also select the best feasible coax cables to avoid as much signal loss as possible we have typical cable loss values of 2dB to 6dB depending on the installation and size of aircraft. Also on this point the typical flight inspection system position reference GNSS receiver will see a signal which is 8dB stronger than what normally is considered for a standard installation.

INTERFERENCE FROM AIRCRAFT SYSTEMS

Typical on-board systems that can cause interference issues to GNSS systems are aircraft SATCOM systems. Aircraft Iridium and Inmarsat systems are transmitting quite high-power signals in the frequency just above GLONASS G1 frequency range and this can cause interference issues especially on smaller aircraft where the antenna separation is small.

VHF COMM transceivers and UHF COMM transceivers can cause interference to GNSS systems. This is also related to antenna separation and their relative low free space loss due to their low frequency range combined with high output power. The Carrier frequency itself is not an issue for VHF and UHF COMM systems but the 4^{th} to 6^{th} harmonics of the UHF carrier and the 10^{th} to 12^{th} harmonics of the VHF carrier could if not sufficiently suppressed by the receiver design cause interference directly into the GNSS bands.

INTERFERENCE FROM OTHER SYSTEMS

GNSS jammers and GNSS spoofing systems are designed specifically to cause problems for GNSS receivers. Also, transmitters outputting unwanted noise outside their intended frequency range can cause GNSS interference. These are all unwanted signal sources not considered in this paper.

The sources of interest are those sending within its designated frequency range and fulfilling its specification while still causing possible interference to GNSS systems specifically multi constellation multi frequency systems. Some LTE base stations may cause interference issues and probably other systems can do the same.

EXAMPLES

Example 1. Iridium SATCOM system cause interference to GNSS system.
During use of Iridium SATCOM phone the tracked GNSS satellites where temporary reduced also causing reduction in signal to noise ratio for the received GNSS signals.

Example 2. LTE base station causing loss of correction data sent via geostationary satellites in the L-band frequency.

When operating near the airport (on approach) where LTE base station was installed, the LTE base station signal transmitting in the frequency range between 1496MHz and 1511MHz was received by the multi constellation multi frequency GNSS system with such a signal level that is cause temporary loss of reception of correction data from the geostationary L-band satellite operating on 1539MHz. This issue was described in detail during IFIS 2016 in the presentation held by JCAB flight inspector Oguro Kazuya-san.

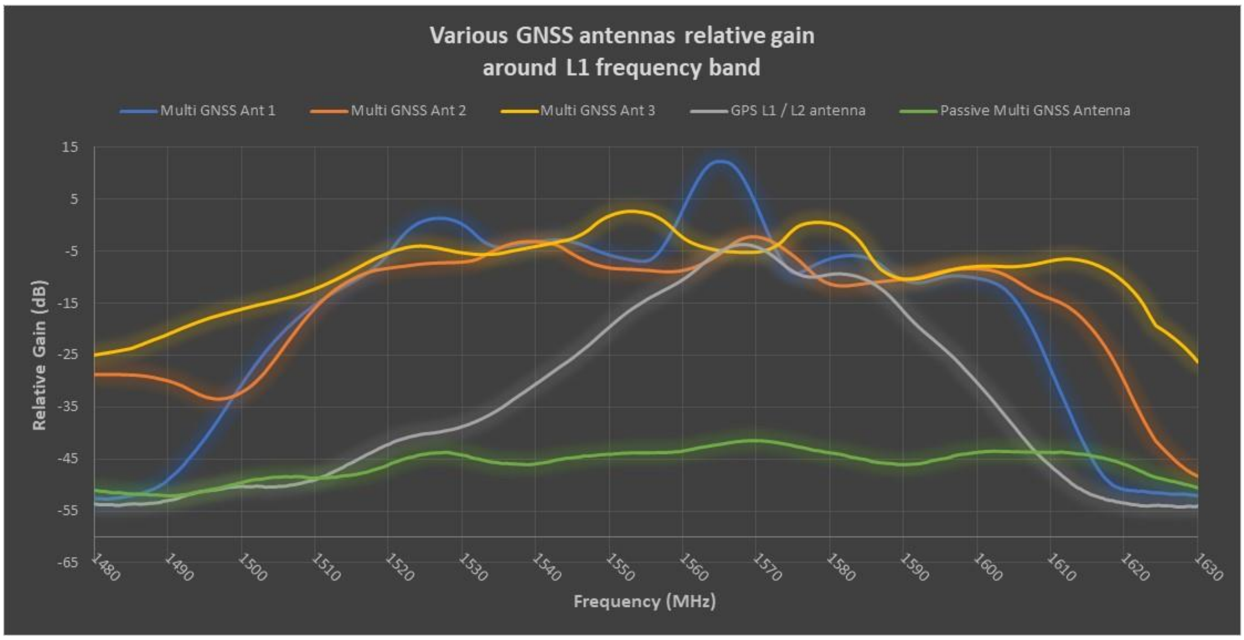
SOLUTIONS

Interference from aircraft systems can often be avoided by installing the antennas wisely with optimum separation between all systems. For smaller flight inspection aircrafts where sufficient antenna separation is not possible GNSS antennas with built in filters can help attenuating the unwanted signals.

The graphs below show the frequency response of 5 different GNSS antennas in the frequency range between 1480MHz and 1630MHz. The test is not performed with a calibrated test antenna but all antennas where tested in the exact same setup only to show the difference how gain of both wanted and unwanted signals are performed differently from antenna type to antenna type. As a reference one of the antennas was a passive multi GNSS antenna (green curve).

The GPS L1 / L2 antenna in the test (grey curve) is clearly designed to receive GPS L1 frequency only while attenuating most other signals. This antenna has the characteristics similar to what is defined in RTCA DO-301 and it would not be able to receive well neither GLONASS G1 nor L-band correction data in the Inmarsat frequency rang.

The blue, yellow and orange curves are all multi GNSS antennas with different frequency responses outside the wanted frequency bands. The blue curve has quite a steep attenuation of both signals above 1610MHz and also below 1510MHz and will therefore not forward as much unwanted RF energy to the GNSS receivers as the other two antennas.



Various multi GNSS antennas frequency response around L1 frequency band

The optimum way is to remove unwanted signals from reaching the GNSS antenna LNA to avoid possible saturation of the LNA. This can be done with good pre-selector design.

Secondly in line notch filters can be installed between the GNSS antenna and the GNSS receiver to further attenuate unwanted interference signals.

If these solution does not remove the interference a possibility is to install a passive multi frequency GNSS antenna and connecting it to specially designed notch filter / LNA unit that can be made with sharper filtering than what the available space inside an active GNSS aircraft antenna can allow.

ACKNOWLEDGMENTS

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REFERENCES

ICAO Annex 10 Aeronautical Telecommunications Volume 1 – Radio Navigation Aids

RTCA DO-301 - Minimum Operational Performance Standards for Global Navigation Satellite System (GNSS) Airborne Active Antenna Equipment for the L1 Frequency Band

RTCA DO-235B - Assessment of Radio Frequency Interference Relevant to the GNSS L1 Frequency Band

RTCA DO-229E - Minimum Operational Performance Standards for Global Positioning System/Satellite-Based Augmentation System Airborne Equipment

IFIS 2016 Presentation: Critical Impact given by the interference from LTE to the implementation of flight inspection in Japan by Oguro Kazuya-san

Other GNSS related RTCA standards:

DO-368 - Minimum Operational Performance Standards for GPS/GLONASS (FDMA + antenna) L1-only Airborne Equipment

DO-327 - Assessment of the LightSquared Ancillary Terrestrial Component Radio Frequency Interference Impact on GNSS L1 Band Airborne Receiver Operations

DO-316 - Minimum Operational Performance Standards for Global Positioning System/Aircraft Base Augmentation System

DO-310 - Minimum Operational Performance Standards for GPS Ground-based Regional Augmentation System Airborne Equipment

DO-292 - Assessment of Radio Frequency Interference Relevant to the GNSS L5/E5A Frequency Band

DO-261 - NAVSTAR GPS L5 Signal Specification

DO-247 - The Role of the Global Navigation Satellite System (GNSS) in Supporting Airport Surface Operations

DO-246E - GNSS-Based Precision Approach Local Area Augmentation System (LAAS) Signal-in-Space Interface Control Document (ICD)

DO-245A - Minimum Aviation System Performance Standards for Local Area Augmentation System (LAAS)

DO-235B - Assessment of Radio Frequency Interference Relevant to the GNSS L1 Frequency Band

DO-228 - Minimum Operational Performance Standards for Global Navigation Satellite Systems (GNSS) Airborne Antenna Equipment

DO-217 Change 2 - Minimum Aviation System Performance Standards DGNSS Instrument Approach System: Special Category 1 (SCAT-1)

DO-208 Change 1 - Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS)

DO-202 - Report of Special Committee 159 on Minimum Aviation System Performance Standards (MASPS) for Global Positioning System (GPS)