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Analysis of the impact of GNSS disruptions on aircraft operations at Romanian airports

Analysis of the impact of GNSS disruptions on aircraft operations at Romanian airports

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Abstract. In the transition towards space-based air navigation, the reliance on Global Navigation Satellite Systems (GNSS) is increasing. However, GNSS disruptions and interference can cause GPS loss in the cockpit. The purpose of this paper is to assess the impact of GNSS vulnerabilities, especially interference, on aircraft operations. The data used for this analysis was collected by GNSS monitoring stations installed at two Romanian airports, specifically selected due to their proximity to possible interference sources. In order to obtain relevant results, the entire assessment is based on the scenario in which all the flights at the airport are using GNSS as their primary means of navigation. Therefore, the flights that could have possibly been affected were identified and the operational impact of interference was assessed. This study emphasises the importance of GNSS monitoring at airports in order to reduce the negative effects of GNSS disruptions on the safe and efficient operations of aircraft.

1. Introduction

In the context of continuous aviation growth in terms of the number of flights, the available airspace needs to be efficiently used. This comes with challenges for the aviation sector in terms of ensuring the safety of aircraft operations. The International Civil Aviation Organization (ICAO) recognizes the need to implement flight procedures that are safer, greener and more cost-effective. The solution to achieve these goals is the Performance Based Navigation (PBN) concept. According to the ICAO PBN Manual [1], the PBN concept describes the airborne performance requirements in terms of integrity, accuracy, availability, continuity and functionality needed for the proposed operation within a particular airspace. This allows the standardization of requirements for aviation applications, supporting the efficient and optimal use of airspace. This solution is also supported by the regulations of the European Commission. [2]

In the framework of transitioning towards PBN, the use of GNSS in civil aviation is increasing. These systems can be used in all phases of flight, and when complemented by an augmentation system, they are considered a safe and cost-effective solution for instrumental flight procedures. However, the GNSS satellites broadcast signals from approximately 20000 km away from Earth, thus the received signals are weak and vulnerable to different types of errors. One vulnerability of these signals is radio frequency interference, which can degrade the positioning accuracy or even cause the loss of GNSS data in the cockpit.

Considering all these aspects, the main purpose of this paper is to provide an assessment of the possible impact of GNSS interference on aircraft operations, using as case studies two Romanian airports. The motivation for performing this analysis is to raise awareness on the importance of continuous monitoring of GNSS signals and radio frequency spectrum at the airports where GNSS-based flight procedures are used. This could contribute to the identification of the local GNSS threats, allowing the authorities to take the appropriate mitigation measures.

2. Global Navigation Satellite Systems in air navigation

This section contains an overview of the GNSS systems and their use in air navigation. Also, the recommendations provided by international aviation organizations are presented, as well as the European initiatives aiming to implement these recommendations. A special interest is dedicated to such an initiative in Romania, from which the data used in the assessment was obtained.

2.1. Global Navigation Satellite Systems

A Global Navigation Satellite System uses a constellation of satellites placed on orbits around the Earth, that broadcast signals to the users, allowing them to determine their 3D position. Knowing the coordinates of the satellites and receiving the signals containing the ranges from the satellites to the user, the user's receiver can compute its position with an accuracy of several meters. More advanced positioning techniques which use improved methods for estimating and eliminating the errors that affect GNSS signals can be used to increase the positioning accuracy.

There are four GNSS constellations which are operational nowadays: GPS, GLONASS, Galileo and BeiDou. There are several frequency bands allocated for these systems. Some of these bands are also allocated to the Aeronautical Radio Navigation Service, being used for safety of life applications. Figure 1 presents the allocation of the frequency bands between the four GNSS constellations. Currently, in civil aviation, only GPS L1 or GLONASS L1 frequency bands can be used.

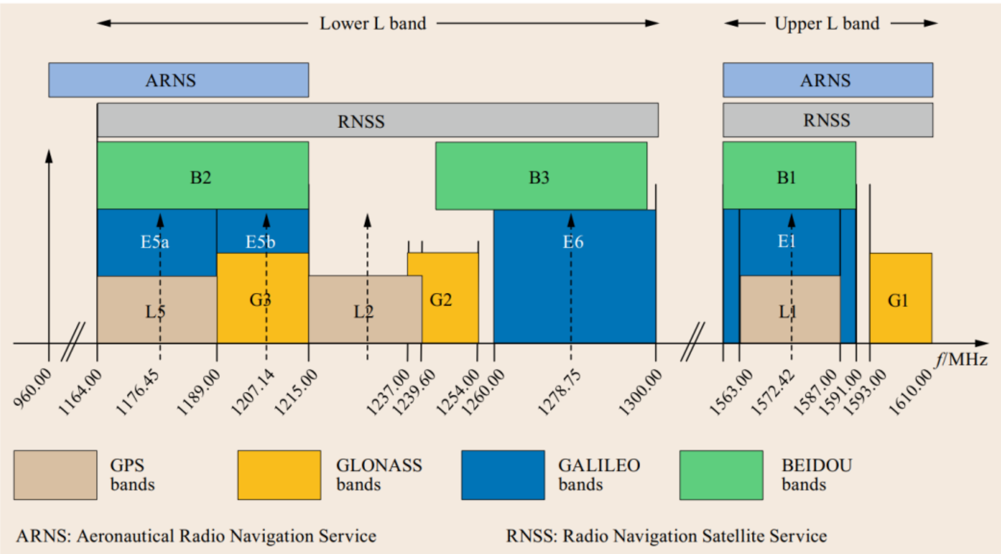

Figure 1. Allocation of GNSS frequency bands [3]

In aviation, GNSS is an attractive navigation solution due to its high performance that meets the requirements of the aviation users. Even though the positioning accuracy provided by GNSS is an important performance characteristic, the confidence in the provided data has equal importance. The concept of integrity defines the level of confidence in the positioning system, and it is provided by an augmentation system, which can be aircraft-based, ground-based or satellite-based. The use of GNSS in air navigation allowed the introduction of more performant flight procedures. For example, during approaches, the Controlled Flight into Terrain (CFIT) is a real danger. Using these more performant procedures, the pilot is provided with improved situational awareness and the risk of CFIT is reduced. Another advantage is the lower approach minima provided for runways which are not equipped with a system for precision approach and landing.

Besides being used in navigation, GNSS positions are also used in aircraft surveillance or air traffic control purposes. Using this data, the controller has a surveillance picture of the aircraft in the airspace, independent of the information provided by the radar. The benefit of using GNSS in this application is the improved positioning accuracy, the integrity monitoring capability and the low cost of the system compared to a network of traditional surveillance radars.

One of the most unpredictable threats to GNSS signals is radio frequency interference. As near the surface of the Earth the signals are weak, they can be disrupted by unintentional and intentional interference. Sources of intentional interference can be radars, harmonics of television stations, mobile communications, etc. Intentional interference can be caused by low-cost GNSS jammers used to trick GNSS tracking, which can accidentally disrupt more receivers in the area than the targeted one. On the other hand, spoofing is a type of interference that imitates the structure and content of the GNSS signal, while transmitting false information to the receiver. Thus, the receiver can provide an accurate solution, but in a wrong location or even in a location chosen by the spoofer. In order to protect the aviation users from the interference threats, ICAO issued an interference mitigation plan for threat monitoring, risk assessment and deployment of appropriate actions. [3]

2.2. International recommendations and initiatives for GNSS monitoring

There are several recommendations and regulations issued at international level, aiming to provide harmonized guidelines for the use of GNSS in aircraft operations. In this context, ICAO recognizes the need for monitoring the GNSS performance by all States approving GNSS-based flight procedures at their airports. The ICAO Annex 10, Volume I [4] and the ICAO Doc 9849 Global Navigation Satellites Systems (GNSS) Manual [5] contain the proposed activities for efficiently monitoring the GNSS performance, for GPS and GLONASS single frequency positioning services. Thus, the GNSS monitoring concept is divided into four activities: the periodic analysis of GNSS performance parameters, the operational status monitoring, the recording of relevant GNSS data and the interference monitoring.

Considering these guidelines and the impact that GNSS performance degradations may have on aircraft operations, several projects were initiated with the purpose of addressing these issues and finding mitigation solutions. At European level, such initiatives include a network of 11 GNSS monitoring stations distributed across Spain [6] and the BlueGNSS system of monitoring stations in Greece, Italy and Cyprus [7].

2.3. ECHO project

In Romania, a pilot system of GNSS monitoring and interference detection stations installed at seven airports is developed within the ECHO project. This is an ongoing activity, started in March 2021, by a consortium containing Romanian InSpace Engineering, the Romanian Space Agency and ROMATSA, the Romanian ANSP, who will be the end user of the system. The project is financed within the NAVISP Element 3 programme of the European Space Agency. [8]

At each airport, a pair of one GNSS Signal-in-Space (SIS) monitoring station and one interference detection station are installed. The GNSS SIS monitoring station collects measurements from all GNSS constellations and frequencies while the interference detection station uses multiple antennas to estimate the direction of the interference source. The information is provided to the user on two paths: a real-time path, providing information about the GNSS status and interference detection. In case an event occurs (i.e., a degradation of the GNSS performance or the detection of interference), an alarm is sent to the user. The other information path contains the periodic reports, which include detailed information about GNSS performance parameters calculated over a 14-days period.

3. Methodology

This section presents in detail the analysis of the impact of GNSS interference on aircraft operations at two Romanian airports. The methodology includes the identification of the detected interference events and their correlation with carrier-to-noise density and number of used satellites. Finally, the possible impact of the identified events on the aircraft operations at the selected airports is evaluated.

3.1. Analysis of interference events

In order to identify the presence of interference, the data collected by two GNSS monitoring stations was used. The stations use Septentrio GNSS receivers which log Septentrio Binary Files (SBF), every hour, at a 1 Hz rate. These files are organized in blocks of data. For this analysis, the RFStatus block was used, which contains information about the frequency bands where interference has been detected and if any mitigation measures were applied by the receiver. The parameters of interest are the receiver time stamp, the centre frequency of the band, expressed in Hz, and the bandwidth, expressed in kHz.

Two airports from the ECHO network were selected as case studies for this assessment. The first one is the International Airport "Henri Coanda" Bucharest, being the largest airport in Romania, with 10506 flights in August 2022. [9] It has two parallel runways and it is located between two major roads, the National Road 1, with a traffic of over 50000 cars/day, and the highway A3. The other one is the International Airport "Mihail Kogalniceanu" Constanta. It has only one runway and only eight flights per week. However, it is located near a military base and in the Black Sea region. Both airports are placed in the South-Eastern part of the country.

In the case of Bucharest airport, a period of 30 days was used for analysis, in August and September 2022. After extracting the RFStatus blocks, it was observed that the data set contained approximately 2 hours and 30 minutes of detected interference, with a maximum period of 1985 seconds (approximately 33 minutes and 5 seconds) in which interferences were detected in a single day. At Constanta airport, a period of 26 days was analysed, also containing data from August and September 2022. As compared to Bucharest airport, there were fewer seconds with detected interference, with a total duration of 25 minutes and a maximum value of 188 seconds in a single day.

The bar charts in Figure 2 and Figure 3 present the number of seconds affected by interference in each day of the analysed periods at Bucharest and Constanta airports.

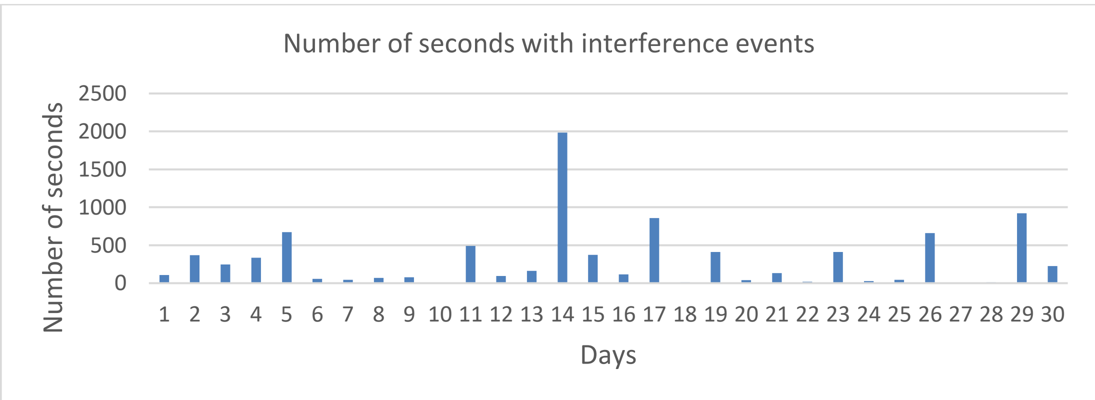

Figure 2. Number of seconds with detected interference per day at Bucharest airport

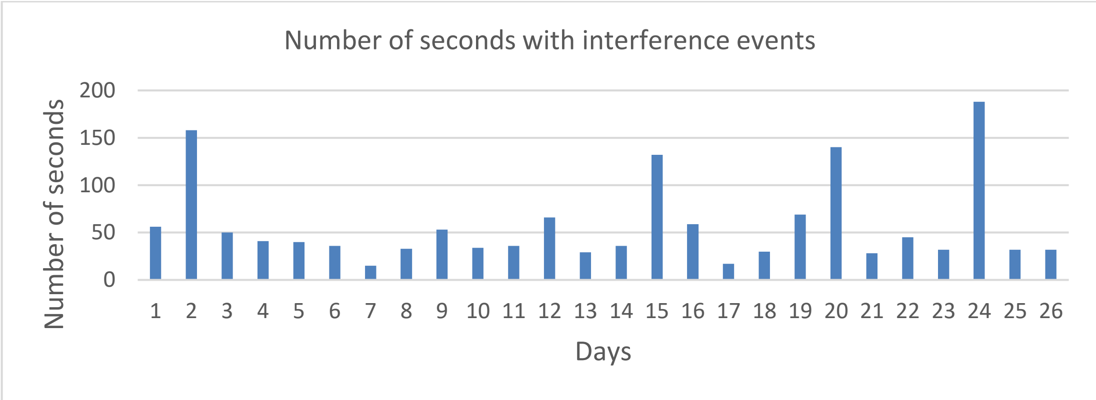

Figure 3. Number of seconds with detected interference per day at Constanta airport

The detected interference events were compared to the signal spectrum for each constellation and frequency recommended by ICAO to be used in civil aviation. Table 1 contains the central frequency and the upper and lower limits of the spectrum, as defined in the first volume of Annex 10. [4]

Table 1. Signal spectrum of GNSS constellations as defined by ICAO.

Constellation	Frequency band	Central frequency (MHz)	Lower limit (MHz)	Upper limit (MHz)
GPS	L1	1575.42	1563.42	1587.42
GLONASS	L1	1600.00	1594.25	1605.75

Most of the detected interference is within the L1 spectrum of GPS and GLONASS. There are also a few days with interference detected at 1250 MHz However, there was no interference on the L5 band (1176.45 MHz). As one of the next steps for improving the resilience of GNSS in aviation is to use two frequencies, using GPS L1 and L5 frequencies shall provide better protection against interference.

3.2. Impact on GNSS performance

The next step was to analyse some GNSS performance parameters in order to identify possible connections with the presence of interference. It was observed that the presence of interference cannot be directly linked to the behaviour of other GNSS parameters. However, it was observed in many cases that, when interference is detected, the number of satellites used in the positioning solution has a sudden drop. Sometimes, these drops are quite significant, reducing the number of satellites with more than 10.

Another parameter whose behaviour could indicate the presence of interference is the carrier-to-noise density (C/N_0), which represents the ratio between the carrier power and the noise power per unit bandwidth. Through the value of C/N_0, the receiver indicates the signal power of the tracked satellite and the noise density, as it is perceived at the front-end of the receiver. As mentioned in [3], a drop in the C/N_0 that is not the result of signal shadowing is an indicator of the presence of interference. The relation between interference and C/N_0 mean values is also confirmed in [10].

Figure 4 illustrates the relation of the detected interference with the number of satellites used for positioning and with the average C/N_0 for GPS and GLONASS L1, respectively.

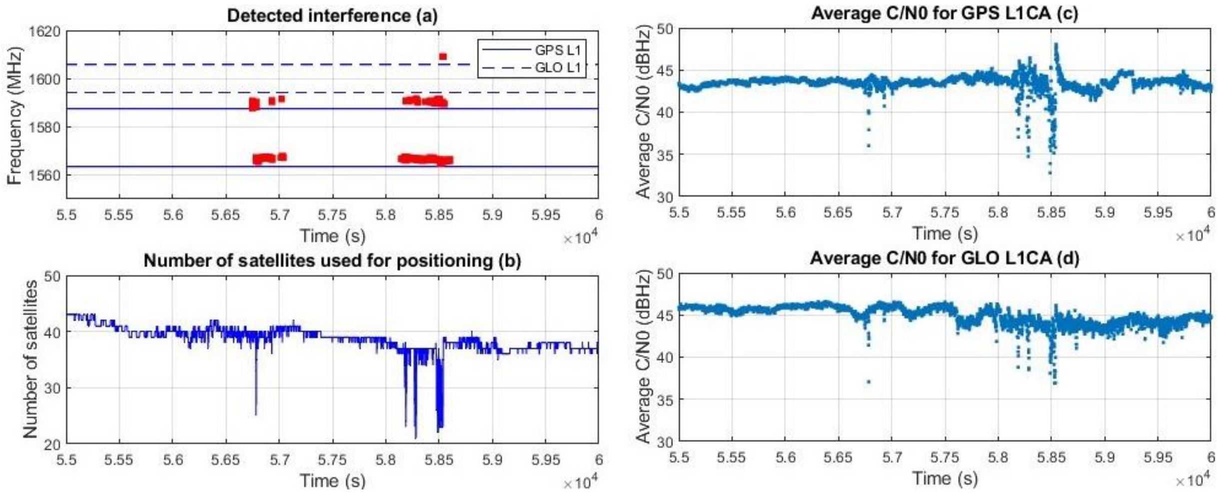

Figure 4. Impact of detected interference (a) on the number of used satellites (b) and on the C/N_0 average for GPS (c) and for GLONASS (d)

The data presented in Figure 4 was collected at Bucharest Airport. The detected interference events are plotted in the signal spectrum of the L1 frequency bands corresponding to the GPS and GLONASS systems, as described in Table 1. In subplot a, the solid lines represent the lower and upper bounds of the GPS L1 signal spectrum, while the dashed lines correspond to the bounds of the GLONASS L1 signal spectrum. The dots represent the detected interference, considering their full bandwidth. In subplot b, the number of satellites represents all satellites from all constellations used by the receiver in computing its position. Subplots c and d contain the average C/N_0 values for GPS L1 and GLONASS L1, respectively. The average is computed using all values of C/N_0 for all tracked satellites at that timestamp.

It can be observed that there are two main periods of time when interferences are detected, at different frequencies. Table 2 lists these frequency ranges and the duration of the detected interference. According to ICAO [4], an alarm should be raised if the detected interference lasts more than two minutes. In this case, there is one interference event with a duration of 4 minutes and 45 seconds, in the GPS L1 frequency spectrum.

Table 2. Periods and duration of interference events.

Lower limit (MHz)	Upper limit (MHz)	Duration (s)
1565.35	1567.86	108
1587.74	1591.58	9
1564.68	1567.5	285
1589.36	1591.57	59

The presence of interference has a significant impact on the number of satellites used for positioning. Drops in the number of satellites can be clearly observed during both periods with identified interference. For the first group of interference events, the number of satellites drops from 39 to 25 and it increases to 38 after six seconds. As the second group of interference events has a longer duration, the number of used satellites encounters multiple decreases, from 37 satellites to 21 – 26 satellites, lasting for approximately six minutes.

In terms of the impact of interference on C/N_0, it can be noticed from Figure 4 that the C/N_0 average drops when interference is detected, for both GPS and GLONASS. The drops are most significant in the period with the longer interference event. There, the C/N_0 average drops from 44 dB-

Hz to a minimum value of 32 dB-Hz. Since the nominal C/N_0 value for GPS L1 is around 45.5 dB-Hz, such large decreases can be good indicators that there is a degradation of the signal.

3.3. Possible impact on aircraft operations

In order to evaluate the possible impact of the detected interference events on aircraft operations at the two airports chosen as case studies, data about past flights was needed. The provider of the data was Flightradar24, which is a global flight tracking service. During the analysed period, there were 19 flights at Bucharest airport that could be correlated with the periods with detected interference, ten arrivals and nine departures. At Constanta airport, due to the significantly lower number of flights per day and the cancellations of several flights, there were only two flights that arrived at the airport in a period with detected interference. As most of the flights were performed with B737 aircraft, this type of airplane shall be considered in the further analysis of interference impact on aircraft operations. Regarding the types of flights performed with B737 aircraft, there were four national flights and eight international flights at Bucharest airport.

If GPS becomes unavailable on board an aircraft flying in the airport area, there are several contingency solutions, such as the use of an alternative flight procedure, radar vectoring provided by the air traffic controller or a missed approach. All these alternative solutions may cause delays to the flight schedule. Except the unpleasantness caused by the extra time of flight and the arrival at the gate later than scheduled, these delays can cause additional costs produced by extra fuel consumption and increased workload for the crew and ATC.

In terms of fuel, the average price of aviation fuel in August 2022 was approximately 903.70 euro per 1000 litres. There are many variables to be taken into consideration when computing the fuel consumption of an aircraft, such as the aircraft weight, flaps settings, environmental conditions, etc. A Boeing 737-800 aircraft burns on average 2530 kg of fuel per hour, most of it being consumed at take-off and during cruise. For a standard approach, it can be estimated that this type of aircraft burns around 112 kg of fuel. There are several methods to reduce the fuel consumption by adjusting the flaps settings or flying low-drag approaches. However, if the pilot needs to perform a missed approach, the additional fuel burn can counterbalance all the fuel savings of the entire flight. A usual missed approach starts with stopping the descent at the Missed Approach Point, then the pilot increases the engine power, retracts the flaps and climbs to a safe altitude, from where other manoeuvres can be performed. According to [11], the estimated fuel burn required for a missed approach can be two to 28 times more than the fuel burn required for the descent and approach phases. Moreover, there is also the fuel required for flying additional manoeuvres for landing the aircraft. Therefore, a B737-800 aircraft can consume up to 127 kg of additional fuel when performing a missed approach. Considering the price of 1.13 euros per 1 kg of fuel, the cost of fuel burnt during a missed approach can be estimated at 143.5 euros. Adding also the additional fuel burn for a new approach procedure, the total cost can be 270 euros.

Furthermore, additional time spent in the air means that the flight crew needs to be paid more. In addition, there is an increased workload both for the pilots and for the air traffic controller managing that aircraft. If the loss of GPS signal is a problem that impacts more aircraft in the sector, the air traffic controller has to provide additional instructions to all the affected aircraft. This can also lead to changes in the schedule of departures and arrivals.

4. Conclusions

Considering the increased reliance on GNSS in air navigation, the impact of GNSS disruptions is a serious issue. Apart from the predicted outages for which contingency measures can be taken in advance, there are other unpredictable disruptions, such as interference, that can degrade the navigation performance of the on-board GPS receiver. In the transition towards making GNSS the primary means of navigation, an alternative navigation solution has to be available to maintain the required level of safety in case of GNSS outages.

In the cockpit, the pilot may receive an alert indicating that GPS is lost or the required navigation performance cannot be achieved. In this case, the air traffic controller must be informed, and the pilot shall switch to an alternative navigation method. As there is no other source of information about a spontaneous GPS outage and no automatic transmission of the alert from the aircraft, the controller does not know that there is a problem with the aircraft unless the pilot transmits the alert. The air traffic controller needs to assess the situation and identify if there are other affected aircraft in the area in order to take the appropriate measures.

Therefore, as the only source of information available to the controller for the occurrence of a GPS disruption is the pilot communicating such an alert, a GNSS monitoring system becomes a valuable tool for detecting such unpredictable disruptions and providing information about the operational status of the system to the controllers. The advantages of such a system have been already proven by previous projects, such as BLUEGNSS, in which the interference events detected by the monitoring station installed at Nicosia Airport were confirmed by pilots reporting GPS loss in the airport area [7]. Therefore, the alerts provided by a monitoring system, combined with reports from pilots, could contribute to the identification of interferences and their sources, allowing then the authorities to take the appropriate mitigation measures.

Solutions for increasing GNSS resilience are already considered by the international aviation community. One of these solutions is the use of dual frequency multi constellation GNSS, by introducing the L5 frequency and other constellations such as Galileo and BeiDou. This shall provide more robustness to the navigation solution, due to the increased number of available satellites and the additional frequency which can provide correct positions in case the other one is affected by interference. In addition, satellite-based augmentation systems shall also be updated to provide corrections for both L1 and L5 frequencies and for multiple constellations.

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