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GNSS Interference Along a Highway near an Aircraft Approach Lane: A 5-Month Study †

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Abstract

Intentional and unintentional GNSS interference can greatly affect the performance of precise timing and localization in areas such as automated driving or aviation. Nevertheless, reports show that jamming occurs near many European airports that are located close to a highway or in heavy industry areas due to broadcasting of interfering signals. To assess the impact of such potential risks, we investigated interference occurring on a section of highway located both near to an airport and close to logistics centers as part of the Austrian Security Research Program project CATCH-IN. This section of highway is of particular interest, as the highway runs in parallel to the approach path of aircraft and crosses the approach path 3.7 km before the aircraft touches down (the flight altitude is only 200 m above the ground). For this experiment, we distributed six Septentrio Mosaic x5 GNSS receivers as sensors along the highway and monitored this section for five months. We analyzed the data with AGC monitoring, CN0 monitoring, and baseband sample monitoring to identify interference along the highway that could affect sensors along the descending flight trajectory. During the period of this experiment, we saw events that we believe could cause potential safety risks and problems for aviation safety. In our analysis, we focused on the statistical evaluation of the temporal repetitions, in particular the times of day that see more interference and the frequencies at which more interference occurs. Additionally, we analyzed the performance of different algorithms for dealing with large datasets. The results provide new insight into potential monitoring stations near airports and raise awareness of potential risks and vulnerabilities in aviation safety as well as automated driving along highways.

Keywords: jamming; GNSS position; aviation safety; aircraft approach lane

1. Introduction

Global Navigation Satellite Systems (GNSS) such as Europe's Galileo, U.S. GPS, Russia's GLONASS, and China's BeiDou have become an important role in daily life. GPS also plays an important role in aviation. GNSS receivers provide Position, Navigation, Timing (PNT) information, which supports not only navigation but also critical flight and air traffic management systems. However, GNSS signals are inherently weak and highly susceptible to Radio Frequency Interference (RFI) [1], including jamming and spoofing, whether intentional or unintentional.

In recent years, a sharp increase in GNSS-related incidents has been observed. Reports such as [2,3] show the increase of jamming incidents all over the world, and especially in

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Europe. These incidents increased after the start of the Ukraine war. As depicted in the report on GNSS interference by the Finnish Transport and communications agency, not only jamming incidents but also the number of spoofing incidents have increased in number [4]. Additionally, reports such as [5] show increased spoofing activities in Russia as early as 2017 to 2018.

Concerning aviation, pilots are reporting RFI events more frequently during flight, with some incidents attracting international attention. Between late September and mid-November 2023, over 50 passenger flights experienced spoofing attacks over the Middle East. Similarly, from August 2023 to April 2024 [6], approximately 46,000 aircraft encountered GPS disruptions over the Baltic Sea. According to EUROCONTROL EVAIR [7], in 2022 almost 50% of the recorded flight data in their database reported GPS outages. These events coincide with ongoing geopolitical conflicts in Ukraine and Gaza/Israel, further exacerbating the threat landscape since 2022. The European Union Aviation Safety Agency identifies the most affected geographical areas as areas surrounding conflict, as well as the Middle East, the southern and eastern Mediterranean, the Black Sea, the Baltic Sea, and the Arctic area [8]. These incidents are increasing both in frequency as well as in complexity and impact. The Safety Risk Assessment of the International Air Transport Association (IATA) [1] reported a GPS loss rate from 30.5% for 2022, 30.8% for 2023, and 50.8% for the first half of 2024 of the recorded flights of the Flight Data eXchange program, which is part of the Global Aviation Data Management program.

Such interference happens over both land and sea. According to a study by Gpspatron and Gdynia Maritime University [9] conducted over the period from June–November 2024, threats are also emanating from ships. The study stated that even the weakest interference was strong enough to lead to a positioning error from 3–5 m to over 35 m, whereas strong RFI led to complete loss of position. Moreover, multi-constellation jammer patterns were detected multiple times and were installed on one or more vessels operating in the Baltic Sea.

The consequences of GNSS interference are far-reaching, as stated by IATA [1]. Aircraft systems such as Flight Management Systems, Enhanced Ground Proximity Warning Systems, and Terrain Avoidance Warning Systems all rely on accurate GNSS data. Disruption can lead to loss of navigation capabilities, faulty guidance from approach system (e.g., FMS Landing System, GBAS Landing System, Satellite Landing System), abnormal differences in speed readings, false or missing terrain alerts, incorrect ADS-B reporting, degraded collision avoidance, and failures in data communications and runway safety systems. These failures can ultimately result in midair collisions, controlled flight into terrain, or runway excursions.

Approach phases are particularly vulnerable. Studies have shown daily GNSS incidents during this critical stage of flight not only for airports close to war zones but also in Central Europe. International databases confirm these findings and also report heightened stress levels among pilots and air traffic controllers. While early-warning systems such as those used by Austro Control can detect signal degradation, they cannot identify or neutralize interference sources. However, with growing dependence on GNSS, particularly in future strategies aimed at reducing infrastructure and emissions, addressing these vulnerabilities is becoming increasingly urgent.

The topic of project CATCH-IN, which is part of the Austrian Security Research Program, is to study the current RFI situation near Graz Airport and to start a sensor network which can monitor these trends. A first experiment of this project [10] focused on the effect of jamming near an airport on an airplane on the ground. In the experiment, the airplane was jammed while the instrument's output was measured.

This paper evaluates a second experiment conducted as part of project CATCH-IN. The goal of this paper is to evaluate the potential risks associated with GNSS interference and the actual threat situation at an airport in Central Europe. To evaluate the situation, we set up a small sensor network near both an airport and several logistics centers. This particular stretch of highway is of high relevance because it runs parallel to the aircraft approach path and intersects it approximately 3.7 km before touchdown, where aircraft are flying at an altitude of just 200 m above ground level.

For this investigation, six Septentrio Mosaic X5 GNSS receivers were deployed as sensors along the highway and the area was monitored continuously over a five-month period. We employed AGC monitoring, CN0 monitoring, and baseband sample analysis to detect interference that could potentially affect GNSS receivers in aircraft during the approach phase. During the monitoring period, we recorded interference events that may pose safety hazards for aviation. In Section 2 we explain the setup and measurements in more detail.

Our analysis focused on the statistical patterns of these events, particularly their temporal distribution, such as the times of day when interference was most frequent, which days of the week experience more RFI, and the specific frequency bands that were affected. The results of the evaluation can be found in Section 3.

2. The Experiment

The goal of this study was to monitor interference events coming from the highway below the flight path of an airport in Graz, Austria. For this purpose six sensors were set up in a grid to monitor the highway. The specifics of the setup are explained in Section 2.1. The evaluated time duration of this experiment was from 7 October 2024 until 7 January 2025 and from 13 March 2025 until 7 May 2025. These time periods are of special importance since they include the pre-Christmas, Christmas, and Easter logistics time frames. We hypothesize that high traffic is at least partially responsible for the RFI events seen close to the airport. Therefore, we wanted to investigate the interference occurring along the highway with respect to operation hours, workdays, and holidays.

Our primary goal was to monitor the L1/G1/E1/B1I band for interference, while a secondary goal was monitoring other bands. Because airport operations such as radar can also interfere with the other bands, we expected to see heavy interference in these bands. Nevertheless, it was logged to obtain a broader perspective of the interference occurring close to the airport.

For this experiment, we recorded several data types:

- Baseband samples (BB) for three center frequencies: 1584 MHz, 1249 MHz, 1188 MHz.
- Automatic Gain Control values (AGC) for each frequency band.
- Carrier-to-Noise ratio (CN0) values for each satellite signal.

The data were gathered and evaluated in postprocessing. Four algorithms were used to evaluate the data for interference. First, we monitored the AGC values for each frequency band for significant drops. Second, we monitored the CN0 values grouped in constellations for each band for systematic change. Third, we monitored the Power Spectral Density (PSD) of the BB samples for a significant spike in power above the noise level, i.e., 9 dbW/Hz. Lastly, we cross-correlated the BB samples for each frequency between all sensors and monitored the result for significant peaks. More details on these monitoring algorithms and explanations can be found in Section 2.2.

2.1. Experimental Setup

The setup of the six sensors is depicted in Figure 1. The six sensors were Septentrio Mosaic X5 GNSS receivers, which were each placed into a waterproof box. Because our

primary goal was to monitor the L1/G1/E1/B1I band using low-cost components, we used a u-blox ANN-MB1 AllBand active GNSS antenna. In this setup, four sensors were placed directly at the highway while two sensors were placed within a small distance to the highway. The sensors were placed in such a way that they measured any RFI interference that might affect aircraft during approach.

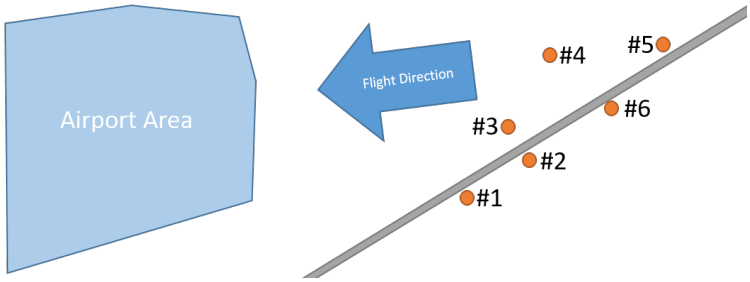


Figure 1. The setup of the experiment along a highway segment. In gray, the highway; in light blue, the airport area; the general flight path is pictured by a blue arrow. The positions of the six sensors are marked by the orange numbered dots. The distance between #1 and #5 is 1300 m.

2.2. Experiment Data Evaluation

For the data evaluation, we used four algorithms for interference detection: AGC monitoring for each sensor, CN0 monitoring for each sensor, PSD monitoring for BB samples for each sensor, and cross correlation of the BB samples from two different sensors.

To monitor the AGC values, we monitored the relative change with respect to the mean of the last five values. This approach does not require different absolute thresholds, and can monitor every band in the same way.

For monitoring the CN0 values, we considered an approach using the relative behavior. However, because the CN0 value can be affected by factors such as weather (e.g., the case of snow on an antenna in [11]) as well as the elevation angle of the satellite, we only considered systematic changes in the CN0 value. More precisely, we monitored for systematic changes in the CN0 value in a whole constellation for a certain band. This tactic proved more reliable than simply monitoring each satellite on its own.

The third method was monitoring the Power Spectral Density (PSD) of the BB samples. The PSD of a signal is the distribution of the signal power over the allocated frequencies. PSD monitoring belongs to the category of spectral monitoring (see [12], (Chapter 5.4). Because the frequency spectrum used by GNSS is strictly regulated for the L1/G1/E1/B1I band, changes in the PSD of the signal indicate the presence of interference. Therefore, it is possible to monitor the PSD for unusual high power above the maximum expected power, which is derived using the number of GNSS signals that are transmitted together with their known power plus thermal noise. this method can be used in the same way for other bands; however, interference in these bands could be due to radar, distance-measuring equipment, and other equipment at the airport.

The forth method was monitoring of the cross-correlation, which is based on the idea that if an interferer is in line-of-sight of two sensors, then both of the BB samples should be affected in a similar way. This means that a peak occurs in the cross-correlation output of both signals if the sensors are both synchronized in time.

In the end, we obtained detections from each method separately. To determine whether there was indeed RFI, we checked whether at least two types of detection monitoring detected the same event at the same timestamp. We also filtered these events for PSD power and checked whether the peak PSD power was 9.0 dBW/Hz above the noise power at least one time. This ensures counting of only significant RFI events that were either very strong or very close to the receivers.

3. Results and Discussion

3.1. Evaluation of One Week—30 October 2024 to 6 November 2024

For a more thorough investigation of the temporal distribution of RFI events over the time of day and days of the week, we look at one week, 30 October–6 November 2024, and count the events over the hours of each day. The week of 30 October–6 November 2024 included a holiday. We wanted to see whether this holiday impacted the amount of interference as well as whether the hour of the day influenced on the interference.

When we consider the number of events that occur in this week, we have to note that 1 November 2024 was the holiday and 3 November 2024 was a Sunday. We see 13 interference events on these two days, compared to 19 on 2 November (Saturday) and 4 November (Monday), which in turn show a slight decrease compared to 30 October (Wednesday) and 31 October (Thursday) with 22–23 events. Afterwards, we see an increase for 5 November and 6 November with 30–33 events. Therefore, there was a significant decline in RFI events on the holiday and Sunday during this week.

When it comes to the number of events, we can consider Figure 2 in more detail. During this week, we see events occurring throughout the day with a slight decrease around midnight; except for the holiday (1 November) and Sunday (3 November), the events are more or less evenly spread through the day, with a decrease in activity between 23:00 and 2:00 (see Figure 2).

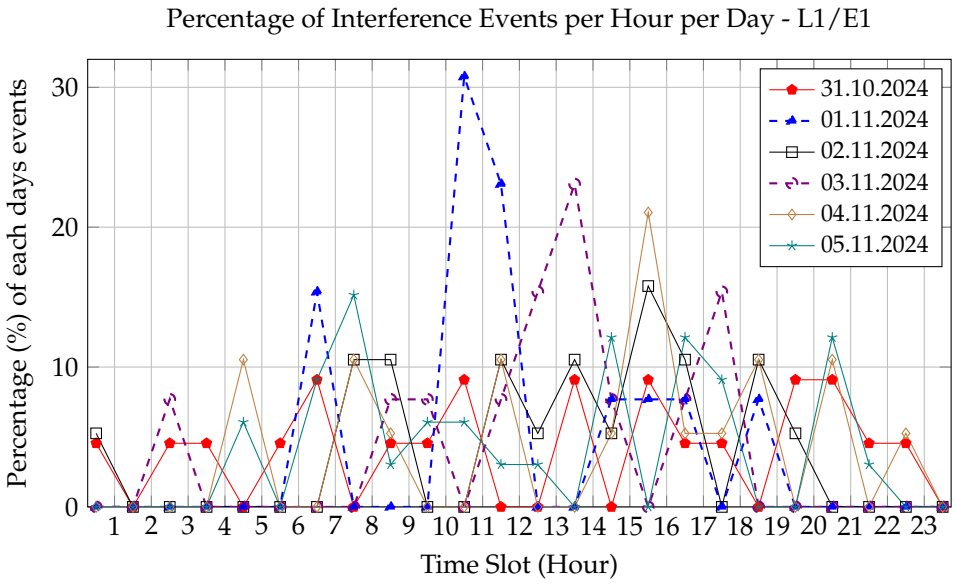


Figure 2. This figure shows for each day the percentage of events occurring during each hour with respect to the total number of events during this day, starting at 0:00 until 23:59 and placing the percentage that occurred within this hour in the timeslot of half past the hour.

3.2. Evaluation of the Whole Experiment

In the last section, we did not see a significant trend in the week of 30 October 2024–6 November 2024. Therefore, we also investigated the whole period of the experiment for a difference in the time of day and the differences in weekdays next. Since our hypothesis was that traffic and especially logistics do indeed impact the number of RFI events, we wanted to see whether there was any difference between the work days and Sundays.

To investigate which time of day is most effected by RFIs, we grouped the events into four groups based on the time of day: Q1 from 00:00 until 06:00, Q2 from 06:00 until 12:00, Q3 from 12:00 until 18:00, and Q4 from 18:00 until 00:00. The results of the mean number of events occurring in each month during each quarter of the day can be found in

Table 1 in columns Q1/2/3/4 $\overline{\#}$. Here, we see a significant change in the mean number of events throughout the quarters of the day. There are more events during the day in Q2 and Q3 than during the night-time Q1 and Q2. In particular, Q3 sees more events throughout the months than any other. The mean time duration of the events in seconds can also be seen in Table 1. Here, we see a decline in the mean duration during Q1. This might be because the traffic is less dense, meaning that the interferer can drive more quickly along the highway. The slight decrease in time duration in January is because some of the sensors had a malfunction and only three sensors were operational; therefore, they were seeing only part of the monitoring grid.

Lastly, we want to investigate the impact of workdays on the RFI count. For this, we can consider Tables 2–4.

Table 1. Mean number of events $\overline{\#}$ and mean duration in seconds $\overline{\Delta t}$ by each quarter of the day (GPS/GLO/GalL1/B1) for the period from 8 October 2024 to 7 January 2025 and from 13 March to 31 April 2025.

Month	Q1 $\overline{\#}$	Q2 $\overline{\#}$	Q3 $\overline{\#}$	Q4 $\overline{\#}$	Q1 $\overline{\Delta t}$	Q2 $\overline{\Delta t}$	Q3 $\overline{\Delta t}$	Q4 $\overline{\Delta t}$
10	8.33	9.08	8.29	4.17	37.23	63.24	44.88	60.61
11	2.87	6.47	9.03	3.97	24.78	31.11	73.44	34.28
12	1.84	4.90	5.74	2.90	19.87	33.54	33.58	29.39
1	1.43	2.57	4.14	1.57	7.41	21.99	23.41	17.04
3	3.42	4.79	5.11	1.79	28.26	38.84	39.75	30.73
4	5.4	5.47	7.53	2.17	38.27	46.63	40.73	31.12

Table 2. Number of events (GPS/GLO/GalL1/B1) sorted by weekday for the period from 8 October 2024 to 7 January 2025 and from 13 March to 7 May 2025.

Month	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.	Total
10	76	77	55	252	154	66	37	717
11	102	113	101	77	119	92	66	670
12	37	68	84	74	74	78	62	477
1	1	8	12	11	13	14	9	68
3	60	30	29	32	56	50	30	287
4	59	105	104	109	127	62	51	617
5	17	14	15	21	13	5	11	81

We begin with analyzing the impact on the GPS/GLO/GalL1/B1 band. Table 2 and Figure 3 show a slight decrease in activity in the GPS/GLO/GalL1/B1 band on Sundays. During the months of October, November, December, March and April, Sundays experience the lowest number of RFI events compared to the other days. In December and April, we also see a decrease on Mondays. Surprisingly, the total number of interference events went down in December. This is possibly due to the holidays around the end of the year and the resulting decrease in traffic. On the sixth of January, which was a Monday and a holiday, we only see one event, which occurred during Q4, i.e., between 18:00 and 00:00 in Table 1. Surprisingly, the first of January, which was also a holiday, saw twelve events. These events were focused mainly in Q1, with seven out of twelve. Figure 3 shows that a lot of interference takes place on Friday. Friday seems to consistently have a high percentage of the total number of events during each month. On the other hand, the total percentage of interference that occurs during a weekend is only high in December, January, and March. These three months all had either a long period of holidays or only one to two weeks of data.

With this reasoning, we deduce the following for months with more than two weeks of data, namely, October, November, December, and April. First, the day of the week has an effect on the number of events; second, Fridays saw more interference than Saturdays and

Sundays, except for during December, in which Saturdays had a similar count to Fridays. Figure 3 shows that Sundays experienced less events than the average week days during each month, with the exception of December.

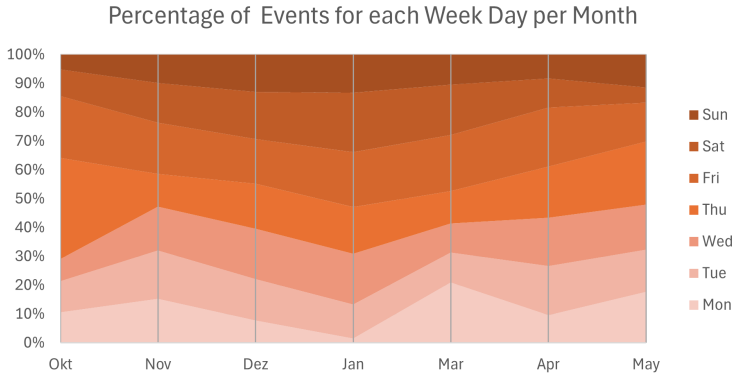


Figure 3. A graphical representation of the number of events sorted by weekday corresponding to Table 2 (GPS/GLO/GalL1/B1) for the periods from 8 October 2024 to 7 January 2025 and from 13 March to 7 May 2025.

For RFI interference in the GPSL2/GLOL2 and L5/E5a/B2a bands, we do not see a systematic change over the days in Tables 3 and 4. The main contribution to these interference numbers is the local Distance Measurement Unit (DME), which is located close to the vicinity of the test campaign. Next to these numbers, on the average of once to twice a month, we saw interference in all bands, but the main interference cases on the highway not coming from the DME are notably in the L1 band.

Table 3. Number of events (GPSL2/GLOL2) sorted by weekday for the period from 8 October 2024 to 7 January 2025.

Month	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Total
10	2323	2646	2279	2527	1927	2640	2529	16,871
11	4208	4813	4336	3614	5494	5608	4271	32,344
12	4248	5073	4029	4105	3985	4887	6610	32,937
1	1217	1158	1136	1176	1197	1181	1231	8296

Table 4. Number of events (L5/E5a/B2a) sorted by weekday for the period from 8 October 2024 to 7 January 2025.

Month	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Total
10	2813	3346	2949	3643	2963	3568	2933	22,215
11	4495	5378	5586	3993	6937	6145	4798	37,332
12	4890	5653	4220	4260	4256	5642	7365	36,286
1	1408	1311	1356	1379	1369	1355	1401	9579

4. Conclusions

The goal of this study was to monitor interference events in GNSS bands that originated from the highway below the flight path of an airport in Graz, Austria. We wanted to analyze the occurrence of these events with respect to operation hours, workdays, and holidays. For this purpose, a network of six sensors was set up to monitor a highway section directly below the flight path toward the approach lane. For this study, data were continuously gathered within the time frame from 7 October 2024 until 7 January 2025 and from 13 March 2025 until 7 May 2025. These time periods are of special importance because they include the pre-Christmas, Christmas, and Easter logistics periods. We hypothesized

that traffic is at least partially responsible for the RFI events seen close to the airport, with a focus on evaluating RFI in the GPS/GLO/GalL1/B1 band.

For the GPS/GLO/GalL1/B1 band, we saw a difference between workdays and work-free days such as holidays and Sundays, as presented in Section 3.2. In general, Sundays and most holidays experienced a decline in the RFI activity along the highway section. During the months of October, November, December, March, and April, we found that Sunday experienced the lowest number of RFI events compared to the other weekdays in the respective months. In December and April, we also saw a decrease on Mondays. Surprisingly, the total number of interference events went down in December, possibly due to the holidays around the end of the year and the resulting decrease in traffic.

Additionally, the data suggest that the number of events on the highway did indeed increase during normal operational hours. Throughout the months of November, December, January, March, and April, the most interference occurred in the third quarter of the day (Q3) between 12:00 and 18:00 as compared to the other quarters of the day. During November, December and January, the first quarter of the day (00:00–06:00) experienced the fewest RFI events, with about one-third of the number in Q3. During October, March, and April the time frame from 18:00-00:00 saw the fewest events, with one-third to one-half the number of events in Q3. Therefore, this study shows that there are significantly fewer events during the night-time, i.e., from 18:00 until 06:00.

When considering the GPSL2/GLOL2 and L5/E5a/B2a bands, we did not see any correlation between the number of events and the day of the week. We did not see any changes during the day or any effect of workdays on the RFI count in these two bands.

The results of this experiment show significant RFI activity around the highway. Therefore, we find it reasonable to assume that workdays and the hour of the day have an effect on the number of RFI events along the monitored highway section. The findings of this experiment can support the design and implementation of interference monitoring systems at airports, helping to safeguard the integrity of airport communications.

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Abbreviations

The following abbreviations are used in this manuscript:

GNSS	Global Navigation Satellite System
IATA	International Air Transport Association
BB	Baseband
RFI	Radio Frequency Interference
AGC	Automatic Gain Control
CN0	Carrier-to-Noise Ratio
PSD	Power Spectral Density

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