Field test of susceptibility of aviation GPS receivers to radio frequency interference

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Abstract—Susceptibility to Radio Frequency Interference (RFI) of aviation receivers in the GPS L1 band has been investigated in trials flights. With 200mW, the equivalent isotopically radiated power was comparable to common GPS jamming signals. For the first time in Switzerland, civil and military aircraft had the opportunity to investigate the performance of their GPS receivers in realistic jamming scenarios. The analysis of recorded GPS data allows investigating performance parameters.

From the transmitting power of a GPS jammer the calculation of the field strength at the GPS receiver is straightforward. Since the GPS antennas are normally located on top of the aircraft and the jamming signal is presumed to be transmitted from the ground, the received power of the RFI can only be estimated. Experiments in the laboratory might not reflect the situation in real environments correctly. In addition, investigations of dynamic effects are costly and are most often not performed. Thus, field trials are required to investigate the effect of jamming signals under real conditions.

This paper describes the experimental set-up. Four different types of interference signals were radiated at a biconical broadband antenna during predefined times. The bandwidth of the interference signals was limited to 2 MHz around the center frequency of the GPS L1 band. Civil and military organization participated with different aircraft, fixed wing and rotorcraft. Operators with multi-band GPS receivers were instructed to use the L1 band only. Several flights were conducted with active interference signals.

As a result, it turned out that most of the GPS receivers were not resistant to three types of the transmitted interference signals, even with a relatively low power of 200mW of the jammer. Those three signals were pseudo random noise sequence, continuous wave and frequency hopping signals. The remaining signal, a pulse with high repetition frequency, seemed not to interfere the GPS signals. Analysis of the recorded data showed that the detection of the interference event is reliable.

Keywords—radio frequency interference, jamming, aviation GPS receivers, field test.

I. INTRODUCTION

In aviation, GPS is the primary means of en-route navigation and becomes more and more important for approach and departure procedures. Aircraft increasingly rely on GPS close to the ground, where intentional or unintentional jamming signals are more likely compared to en-route. Because of the low power of the received signal, GPS is susceptible to Radio Frequency Interference (RFI), even for low power jammers. While theoretical calculations and laboratory experiments are essential for the understanding of jamming effects, they cannot reflect the real environment in all the details. In case of RFI in the GPS L1 band, an aircraft would have to revert to legacy navigation procedures. If the impact of the RFI is local and short in time, no critical situation arises. In case of a large-area and continuing non-availability of GPS, workload of the air traffic controllers and thus the overall safety risk would be increased. Once appropriate mitigation measures are taken, pilots are still forced to choose inefficient routes. This would increase cost to the airlines.

This paper investigates the susceptibility of aviation GPS receivers to RFI by evaluating data of an arranged in-field test in the presence of predefined interference signals. It must be noted that law generally prohibits the emission of signals in the GPS L1 band. To limit the potential unwanted influence on other GPS users, like e.g. rescue organizations or public and private GPS dependent infrastructure, an agreement with the Swiss regulators, namely the Swiss Federal Office of Communications (OFCOM) and the Federal Office of Civil Aviation (FOCA) was required. The proper planning and official communication was essential for the safe execution of the jamming trials.

II. MOTIVATION

There are several parameters involved in the calculation of the impact of the RFI. Presuming the Equivalent Isotropically Radiated Power (EIRP) $P_t$ of the interference is known, the power density $P_d$ in function of the distance $d$ is given by (1):

$$P_d = P_t / (4\pi d^2)$$

(1)

The received power $P_r$ is a function of $P_d$, gain $G_r$ of the receiver antenna and the aperture $A_e$, where:

$$A_e = \lambda^2 / (4\pi)$$

(3)

The aperture is a function of the known wavelength $\lambda$. GPS antennas normally include a low noise amplifier with a gain of about 30dB. Since the receiver antenna is in many cases mounted on top of the aircraft, while the interference signal is...
transmitted from the ground, the fuselage of the aircraft adds some unknown negative gain to the total receiver gain \( G_r \).

Equation (4) recap the received power by the GPS receiver:

\[
P_r = P_x \lambda^2 G_r / (16 \pi^2 d^2)
\]

The total receiver gain \( G_r \) cannot be easily defined by experiments in the laboratory or by simulation. From (4) follows, if the estimation of \( G_r \) was 20 dB off, the distance \( d \) would vary by a factor of 10. Without knowledge of the total receiver gain \( G_r \), the calculation of the interference power at the GPS receiver, and thus the interference-to-signal ratio \( (J/S) \) or the carrier-to-noise ratio \( (C/N_0) \) is not feasible. Thus it was decided to determine this variable by a field test.

### III. Laboratory Experiments

By laboratory experiments the critical thresholds of \( J/S \) or \( C/N_0 \), where the tracking of the C/A code is lost, has been determined for different types of interference signals for the aviation receiver CMA-5024. The four investigated test signals are the following:

1. Pseudo Random Noise sequence (PRN)
2. Continuous Wave (CW)
3. Pulse with high Pulse Repetition Frequency (PRF)
4. Frequency Hopping signal (FH)

The first test signal, the PRN, is the most interfering one with the GPS signal. If the PRN power is about 0-10 dB above the received GPS power, even a robust aviation receiver like the CMA-5024 stops tracking. Less robust receivers already have issues with less power.

A spread spectrum signal, as used with GPS, is robust against a CW interference. However, experiments show that a strong CW would hinder GPS reception. It is presumed, that this is due to the nonlinear nature to the automatic gain control. With a received CW power of about 60 dB above the received GPS power, the receiver stops tracking.

The third signal is a short pulse with high PRF of 20 kHz. In theory, such a signal will not interfere with the GPS signal essentially, since the spectral lines are spread 20 times wider than the ones of the GPS signal. Experiments in the laboratory support this view.

Finally, a FH signal with delta frequency of 1 kHz and dwell time of 3 ms would have similar impact as a CW interference. A GPS receiver’s issue with tracking because of RFI is indicated by the reduction of \( C/N_0 \). Because of applied filters, the impact on the estimated position error is not immediate, but delayed. If finally the receiver stops tracking, GNSS navigation is not possible anymore. If GNSS navigation solution fails, the flight management system (FMS) retrieves its position from inertial reference or conventional navigation system if available.

### IV. Test Setup

The interference signals were radiated at a biconical broadband antenna with known EIRP \( P_x \) of 200 mW during predefined times. The location of the transmitter in a valley prevents the GPS interference to impact a large area on the ground. The power was chosen high enough to effect GPS outages on different aircraft types and as low as possible to reduce the impact on other GPS users in a distance \( d \) of about 2-5 NM.

The calculation of the distance \( d \) with potential impact on different receivers was based on estimations of the receiver gain \( G_r \), as described above. The bandwidth of the interference signals was limited to 2 MHz around the center frequency of the GPS L1 band. This limitation seems appropriate for the intended field test and reduces the impact on other GNSS systems. The transmitted signals, as recorded by a spectrum analyzer 400 m apart from the jammer, are depicted in Fig. 1 and Fig. 2.

![Fig. 1. PRN (left) and CW (right), center 1.57542 GHz.](image1.jpg)

![Fig. 2. Pulse with high PRF of 20480 Hz (left) and FH signal, delta_f = 1 kHz, dwell time = 3ms.](image2.jpg)

Civil and military organizations participated with 2 jet fighters, 4 helicopters, 2 business jets and 1 flight calibration aircraft. The aircraft passed close to the jammer with an overflight height of 600 ft to 1200 ft above ground.

Three helicopters and one of the business aviation aircraft are equipped with specific recorder units that collect data from the aviation GPS receiver, the FMS and the Attitude and Heading Reference System (AHRS) of the aircraft [4]. In addition, independent multi-band GNSS receivers record reference tracks in the GPS and GLONASS band.

The following parameters were recorded among others: in the range domain the \( C/N_0 \) and in the position domain the numbers of satellites used (SAT used), the Horizontal Integrity Level (HIL) and position information. The multiband GNSS receiver recorded the carrier phase solution. The latter allows the calculation of the position difference to the on board GPS as outlined in [3]. It must be noted that the position differences also include the offset between the locations of the ordinary GPS antenna and the reference antenna.
V. RESULTS

Most of the GPS L1 receivers were susceptible to three of the four transmitted jamming signals, namely the PRN sequence, the CW and the FH. According to pilots reporting, receiver outages occurred in about 1-2 NM distance to the jammer. The pulse with high PRF seemed not to have an impact on GPS reception.

Data of the four aircraft equipped with additional data recorder units are analyzed. Some results for the Eurocopter EC635 are discussed in the following. GPS data for this aircraft originate from a CMA-5024 aviation GPS receiver.

Fig. 3 illustrates position solutions and average decrease of $C/N_0$ for one selected overflight over the jammer (indicated by a red triangle). The $C/N_0$ decreases slowly before it stops. However, the behavior flying to and from the jammer is not symmetrical. This is probably due to the antenna mounting on the tail of the helicopter and fuselage shielding.

In order to analyze the mean $C/N_0$ loss further, the values are plotted in Fig. 4 with respect to the Modified Julian Date (MJD). The top line is the number of space vehicles (SV) used. This number drops to zero, when the helicopter overflights the jammer. The red line is the averaged and normalized $C/N_0$ of the individual $C/N_0$ of all satellites in view. The latter are plotted on the bottom with different colors and a separate scale.

The mean $C/N_0$ drops 20 dB below the normal level at the position of the jammer. The detection of the interference with a threshold of -10 dB would occur about 1 minute before the GPS outage. It must be noted that the speed of the helicopter was slow for this test. Such a jamming detection has been suggested in [1]. At the end of the track, the helicopter performs a left turn. There the $C/N_0$ decreases again, because its GPS antenna is exposed to the jammer.

Fig. 5 depicts the FMS, aviation GPS positions and to the independent multiband GNSS receiver (JAVAD). The position of the jammer is given with a red dot. Where the value of HIL is below 40 m it is presumed reliable and black dots are plotted. Where blue dots are plotted, HIL is not reliable. A small deviation from the true position can be observed for the FMS and the GPS solution about 0.5 NM after the jammer. However, the helicopter pilot is alerted that the GPS solution is not reliable.
Fig. 6 shows the number of satellites used (SAT used), the Horizontal Integrity Level (HIL) in meters, the position differences of GPS and FMS to the reference position. With the number of used satellites decreasing from 10 to zero, the HIL increases and the GPS position differences start drifting shortly after. This effect has been investigated in detail in [2]. Where no values for HIL are available, a zero is plotted. As soon as the helicopter leaves the jamming area, the satellites in view are tracked again and the HIL and the GPS position differences revert to normal. The degradation of the horizontal integrity indicates the position error correctly.

Fig. 6. Jammer signal PRN: resulting number of satellites, HIL and position difference of EC635 near jammer (▲). Since the reference antenna was temporarily installed in the cockpit, the distance to ordinary antenna installed on the tail includes the length of the helicopter of about 10 m.

From the described overflight result two distances, where the jammer affects GPS reception. At one distance, the number of used satellites drops below four and at the other, it raises above four again. For the first test signal, namely the PRN, those distances are 0.6 to 0.7 NM.

Similarly, the overflight with the test signal CW has been analyzed. The results are given in Fig. 7 and Fig. 8.

Fig. 7. Jammer signal CW: resulting FMS and GPS positions of EC635. Arrow indicates flight direction.

For the test signal CW, the impact is similar to PRN, but more pronounced. The deviation from the true positions raises to several hundred meters. Again, HIL is indicating correctly an issue with position estimation.

The resulting distances to the jammer, where the number of used satellites drops below four satellites used, is 1 to 1.6 NM for the second test signal CW.

The third test signal is the pulse with high PRF. As presumed from theoretical calculations, this test signal does not affect the GPS reception. The GSP and FMS positions remain exactly on the reference track (Fig. 9).

Fig. 9. Jammer signal pulse with high PRF: resulting FMS and GPS positions of EC635. Arrow indicates flight direction.

The number of used satellites does not change and thus the HIL remains low (Fig. 10). This result corresponds well with findings from laboratory experiments. Besides power, the density of the spectral lines turns out to be an important parameter.
The results of the fourth test signal, the FH, are comparable to the ones of the CW.

The in the field test evaluated distance $d$, where the jammer affects GPS reception, varies from 0.6 to 1.6 NM. Before the test, this distance was estimated from 2 to 5 NM, thus the real distance was about 3 times shorter than primary expected. From (4) we derive that the total receiver gain $G_r$ needs to be adjusted by a factor of 10 dB to reflect real conditions. This holds true for the aviation receiver CMA-5024 and antenna mounting on EC635 discussed in this paper.

VI. CONCLUSIONS

It can be concluded that the low power (200 mW) of the test signal was enough to cause unreliable position information on the FMS for three of the four test signals, namely PRN, CW and FH. The effect of outages differs for the four test signals and the involved aircraft types. The pulse with high PRF did not have an impact on GPS reception.

On the one hand, this is positive for further analysis of the test, since the transmitted power was chosen appropriate to influence the onboard GPS receivers. On the other hand, that means, that a low power jammer device, probably powered by a battery only, would already have a significant impact on a low flying aircraft. However, the test setup was chosen appropriately, so that nearby GPS users where not affected by the test signals.

The detection of RFI as described in [1] would support the perception of pilots. The distance, where the jammer affected the GPS reception was evaluated and the total receiver gain $G_r$ was adjusted by a factor of 10 dB for the aviation receiver CMA-5024. In the future, this value will facilitate the prediction of the affected area by jammers with similar signals but different power.

As a next step, further analyses is performed for other aircraft types and different GPS receivers.

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REFERENCES


