GNSS RFI impact assessment on PBN Instrument Flight Procedures

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ABSTRACT

RFI impact on GNSS signal is now well known and is a major concern for most states who implemented PBN Flight Procedures.

France has put a lot of efforts in achieving ICAO 37th assembly resolution to publish RNP approaches on all IFR runway ends by the end of 2016. Systematic interference assessment has been performed on each of the 260 approaches promulgated in France so far. Spectrum analysis assessment skills and techniques have been improved along the years as well as impact analysis on GNSS signal. It allowed to detect several GNSS RFI and to turn off the suspected source or seize it when it was possible.

Based on this strong experience, the French ANSP (DSNA) has implemented a method to evaluate the impact of an RFI on PBN Flight Procedures that allows an appropriate response of all actors and entities. Instead of considering only the field strength of the interfering signal, GNSS receiver behavior is also taken into account in order to assess the threat.

The proposed paper will – after a brief update on the PBN deployment in France – present this impact assessment method, the various actors involved and the lessons learned from several actual RFI cases.

INTRODUCTION

RNP landing procedures are now very common and are being used more and more thanks to the gradual upgrade of onboard equipment. Thus, in France 270 RNP APCHs are promulgated (206 in mainland France and 64 overseas) and many Cat I ILS on small airports have been decommissioned in favor of a set of LNAV, LNAV/VNAV and LPV procedures in most cases as prescribed by the European PBN Implementation Rule.

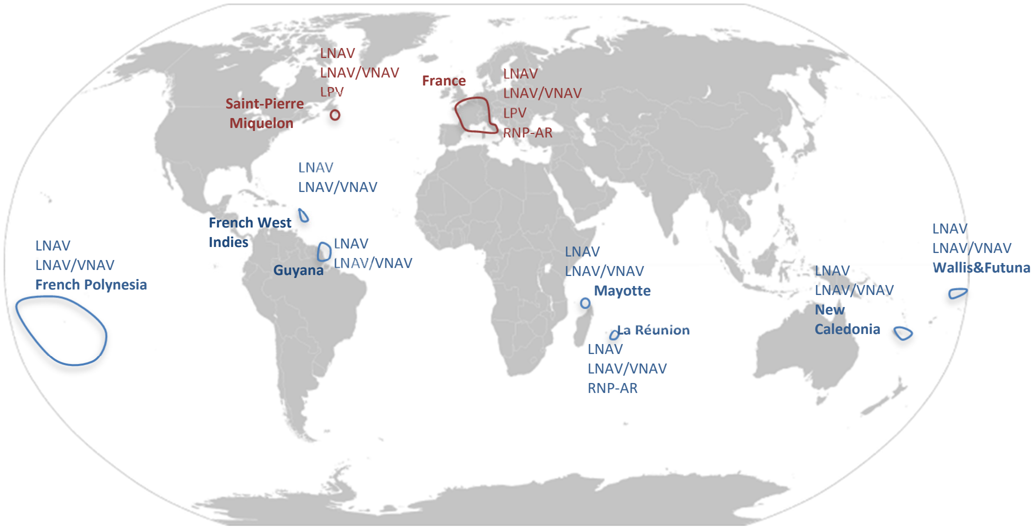

Fig 1 : PBN implementation in France

Any radio link whatsoever is likely to be disturbed by an interfering signal. For aeronautical systems, interference has always been a phenomenon to be considered and many efforts have been made to reduce their impact, either by improving the radio link characteristics or by fighting against the sources of interference themselves. GNSS is no exception. Interference and jamming of the GNSS frequencies and their impact on the use of these systems for air navigation is a widely debated subject. Many presentations and publications have been made on this subject. The fact remains that these problems are more than ever critical and increasingly perceived as a real threat against the use of GNSS systems for civil aviation.

Two specific aspects make GNSS quite exposed to these problems.

- Since the genesis of these systems in the 80s, it has been assessed that the link budget is one critical point.
  On GPS L1 frequency (1575.42MHz), the emitted power at satellite shows an EIRP of +57dBm. The orbital altitude of GPS constellation at 20200km implies a free space loss of 182dB. Losses due to the atmosphere add 2dB. The power received on the ground is typically -127.4dBm. Even a weak interfering signal can be received at levels well above the legitimate signal in a large geographic area. The J/S (Jammer / Signal) ratio is commonly used to characterize this received power.
- The second point to consider is the very use of GNSS systems in today's world. While conventional navaids are used only by the aviation community, it is far from being the same for GNSS as it is used for various purposes throughout modern society. This simple observation implies that there are many reasons - good or bad - for trying to disturb its operation by using a jammer. There is thus a very wide range of jammers intended for personal use (commonly called PPD for Personal Privacy Devices). Users of these systems rarely intend to disrupt the aeronautical use of GNSS.

RNP Flight inspection

In France, the national regulation for Instrument Flight Procedures implementation requires that a flight inspection of any RNP procedure approach and any PBN departure SID is performed prior to their promulgation, mainly to ensure that no interference on GNSS signals impacts the achieved performance and for LPV to validate the final approach FAS datablock. This regulation also requires quality assurance validation of these procedures with respect to the published data, which task is delegated to flight inspection unit at DSNA, as an independent verification actor.

Flyability assessment and other flight validation aspects are only required when procedure design shows out limits design criteria or lack of quality in the input data. In this context, the tasks of the flight inspector are various. A first step is to carry out a ground validation of all the data provided by the procedure designer. draft chart, data, coding proposal, LPV FAS Data Block, magnetic variation and thresholds coordinates are verified and checked during a process that may require several exchanges with the designer. It is only when this first stage is completed that the flight inspection can take place.

It covers:

- RFI monitoring and impact assessment.
- validation of the FASDB,
- real-time recording and analysis of aircraft attitude parameters, GNSS information, trajectory, crosstracks, etc...,

This first task requires the flight inspection aircraft to be fitted with a complete L-band spectrum monitoring system, in particular a high-performance spectrum analyzer and an amplified antenna. Dedicated software specially designed for use on board the aircraft allows spectrum monitoring at the same time as recording GNSS parameters.

RFI MONITORING

The DSNA flight inspection service has a major role for several decades in the fight against RFI and jamming. Initially, this activity mainly concerned the aeronautical VHF band which is strongly impacted by numerous spurious and signals of all kinds. The experience accumulated during numerous interventions in this band has made it possible to develop the most suitable combination of hardware, software, and methods for successfully identifying and locating sources of interference.

The transposition of the spectrum monitoring part of this activity in the GNSS domain was therefore quite simple at least from the hardware and software point of view. The same receivers (R&S EB500 or EM100) and software are used.

Fig 2 : Rohde & Schwarz EB500

Methods had to be adapted to the specificities of this band. In particular, it was necessary to consider the extremely low levels encountered and the new types of interfering signals such as the PPD chirps.

There is still work to be done on the localization of the interference source. The legacy direction finding systems that are available for airborne use are not well suited to the typology of the signals we encounter in this band. The DSNA flight inspection entity is currently developing in partnership with a company specialized in this field a high resolution direction finding system.

GNSS RFI TRIALS

GPS L1 frequency in France is a frequency assigned to 3 different governmental users: Civil Aviation, Space (CNES) and Defense (Army).

The French Ministry of Defense regularly carries out GNSS jamming live trials to test different military systems. In preparation for these test campaigns, the other assigning authorities in this band (Space and Civil Aviation) as well as the spectrum regulator entity (ANFr *Agence Nationale des Fréquences*) are informed and consulted. In order to protect aeronautical users, the French main ANSP, DSNA, must provide aeronautical information specifying the volume impacted by the interference.

The first approach consists in calculating – given the EIRP of the jammer under test and the free space loss – a radius around the emission site out which the criteria of the ICAO interference threshold level mask is respected.

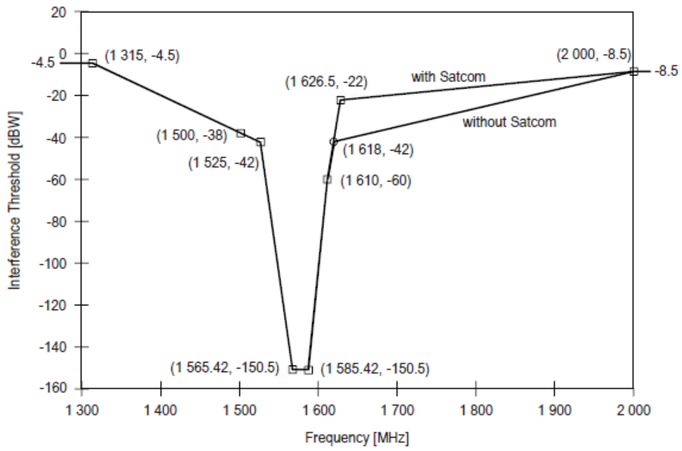

Figure B-15. CW interference thresholds for GPS and SBAS receivers used for precision approach

Fig 3 : ICAO Annex X Mask (CW)

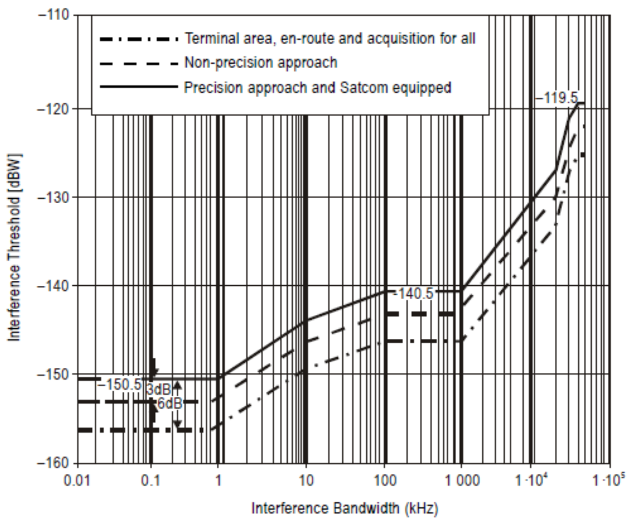

Figure B-17. Interference thresholds versus bandwidth for GPS and SBAS receivers

Fig 4 : ICAO Annex X Mask (Wide band signals)

For example, for a +10dBm (0.1W) EIRP CW signal this calculation leads to protecting an area of 27Nm radius.

In the absence of further testing, these values are applied. The volume to be protected is quite large and coordination with all the bodies potentially impacted (airports, enroute ATC area, etc.) becomes problematic.

After the first live trials, looking at civil aviation users reports, it became obvious that the estimated impacted area was way too large. Consequently, it was decided by DSNA to involve the flight inspection measurement capabilities to take part in several of these jamming campaigns in order to evaluate in real conditions the GNSS receivers' behavior when confronted to the intentional jamming signals and ultimately establish a more relevant impact radius.

The various test flights consisted in

- recording the evolution of spectrum and field strength level during a level flight toward the RFI source,
- evaluating the FIS GNSS receivers.

One criterion used to characterize the receiver status was the C/N0 ratio of each satellite received and tracked during the measurement.

Tests on constellation simulator have shown the behavior of these C/N0 ratios in the presence of an interfering signal.

Different types of modulation have been tested, in particular a chirp signal similar to those encountered on most PPDs.

- C : Carrier = -127.4dBm
- N0 = log(kT) = -204dBW/Hz (with T=290°K)

This ratio is also impacted by the gain and the noise factors of the antenna and various components of the receiver (Front end, filtering and quantification stages). The typical final value is 41.5 dB.Hz.

This value also fluctuates by ±6dB depending on the elevation of the satellite.

The evolution of this C / N0 ratio in the presence of interference is given by:

$$\left[\frac{C}{N_0}\right]_{eq}^{dB} = -10\log\left(10^{-\frac{\left[C/N_0\right]^{dB}}{10}} + \frac{10^{\frac{\left[J/S\right]^{dB}}{10}}}{Q.Rc}\right)$$

Where:

- J/S : Jammer to signal power ratio
- Q : Quality factor
- Rc : Symbol Rate

Below (Fig 5) is a real example of the C/N0 behavior of an onboard receiver when passing close to a PPD located on the ground :

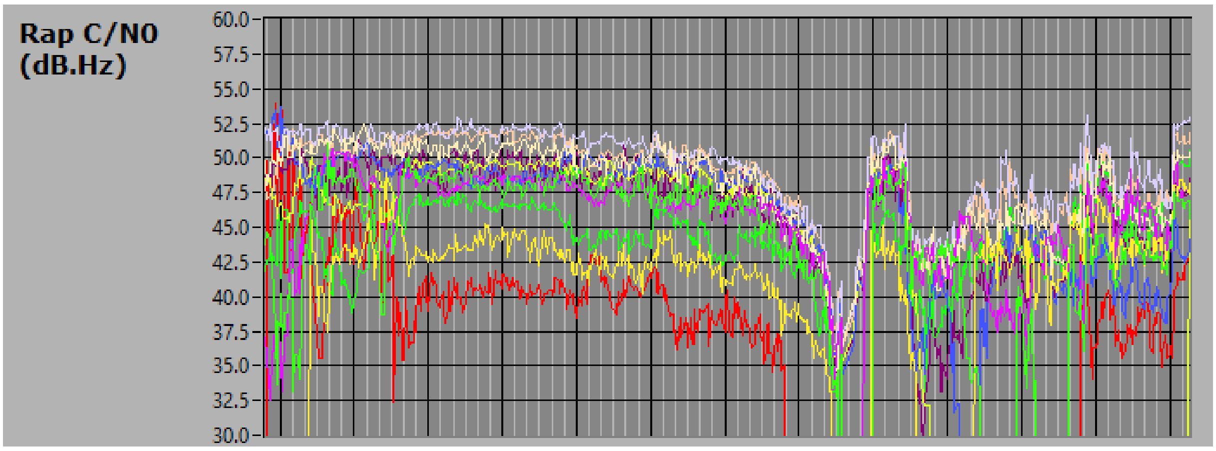

Fig 5 : RFI level and C/N0 evolution during RFI flyby

Considering this parameter allowed reassessing the effective interference impact zone. Thus on the following example of a +11 dBm EIRP CW signal the calculation with the ICAO mask gave 33Nm radius. This value was reduced to 5 Nm considering the beginning of C/N0 degradation on the Ashtech GG24 receiver. This GNSS receiver model was later considered by DSNA as a reference receiver.

On the graphs below (Fig 6), the upper curves show the Field strength level received. The lower curves give the C/N0 ratios of three amongst 11 satellites received during this measurement.

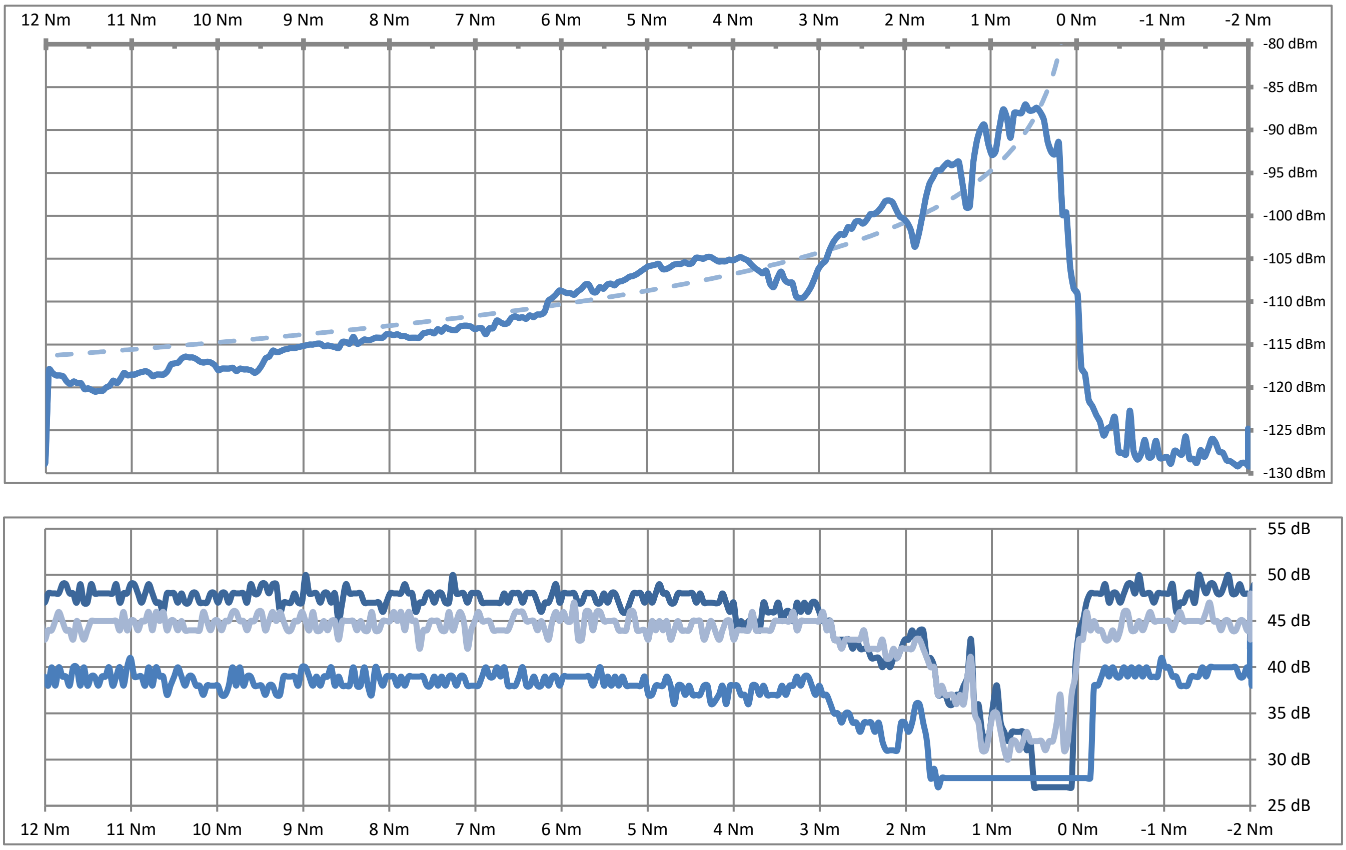

Fig 6 : C/N0 evolution in the presence of RFI

APPLICATION TO THE PBN FLIGHT INSPECTION.

Consideration of these tests with the military, as well as the study of several in-flight detections of interference by PPDs and the analysis of airline reports and ATC events led DSNA to consider the C/N0 degradation criterion as an indicator of the effective impact of interference observed during a flight inspection.

In order to characterize this impact more precisely, two values have been taken into account:

- The RTCA and EUROCAE certification standards for GNSS receivers indicate that a C/N0 below 30dB.Hz no longer allows tracking of a satellite.
- A degradation of 1dB of C/N0 is the in-band intercompatibility criterion and has proven to be detectable on all satellites when flying towards the RFI.

And of course, the loss of tracking also remains a strong indicator of the impact of interference.

From these considerations the following classification has been established:

White	No RFI visible	No degradation (except A/C attitude related)
Green	RFI visible on the spectrum (i.e. J/S >0dB)	No degradation on C/N0
Yellow	RFI visible on the spectrum	C/N0 drop >1dB
Orange	RFI visible on the spectrum	C/N0 drops below 30dB.Hz
Red	RFI visible on the spectrum	Loss of position

During a PBN procedure flight inspection, in the event of RFI detection in the spectrum analysis, the flight inspector will therefore use this classification to establish the severity of the phenomenon. This information then appears in the provisional and final reports.

The flight inspector must also pay particular attention to the context in which this correlation between measured level and C/N0 is made. The attitude of the aircraft, by changing the exposure of the receiving antenna, directly affects the C/N0. Assessing the C/N0 ratio can be performed only during a straight trajectory outside any significant banking maneuver.

This classification determines the measures that are subsequently taken to mitigate the interference detected. These measures concern both the fight against interference process put in place within the DSNA and also the validation and publication process of the tested procedure.

Green case: Weak interference was noted but had no impact on the receiver. The case is reported and traced in the flight inspection report but no further action is taken.

Yellow case: The RFI detected causes degradation of the C/N0 ratios. No immediate action is taken, but the case is being analyzed by experts from the central CNS entity of DSNA (DTI). Depending on the type of interference and the context (urban area, case already reported, obvious link with user complaints, etc.) a complaint to the spectrum regulation entity may be filed.

Orange case: C/N0 are strongly impacted by RFI. A complaint to the spectrum regulation entity is filed immediately. The process of procedure approval for promulgation is continued. Depending on the results of the investigations, risk reduction means can be implemented; monitoring of event notifications, reporting obligation, fixed spectrum monitoring system on the ground for long term observation, etc…

Red case: The same search and monitoring process as for the orange case is applied but the publication process is postponed. Coordination with the regulator is necessary before any further promulgation of the procedure with risk reduction means such as an increase in minima until the source of interference has been neutralized.

This methodology has been applied by flight control since July 2016 with convincing results.

Thus, during the commissioning of RNP procedures, it was reported in the flight inspection reports:

- 25 Green Cases
- 9 Yellow Cases
- 4 Orange Cases
- 2 Red cases

About 80% of these cases were caused by a signal similar to a PPD one.

Two “red” cases which led to a delay in the publication of the procedure:

- The first disappeared spontaneously after which made it possible to withdraw the protective measures taken for publication (NOTAM, Minima enhanced) (See presentation IFIS 2014)
- The second red case observed at the end of 2019 concerns Paris CDG and Paris Le Bourget

PARIS CDG ET PARIS LE BOURGET SEPT/OCT 2019

Paris Le Bourget Airport's LFPB runway 27 is the preferred runway for westbound landings its approach being parallel to Paris Charles de Gaulle 27/28 finals. Simultaneous approaches can be carried out even if the crosstrack distance between CdG and Le Bourget final axis is less than 1.5Nm.

This runway is equipped with an ILS Cat I (set in Cat III due to parallel approaches) and an RNP approach with LNAV, LNAV / VNAV and LPV 200 minima. ILS approaches are the standard procedures for both airports.

At the end of 2019 LFPB ILS 27 was stopped to allow its replacement. The only approaches available during this period were the RNP 27 and the VOR/DME 27 (parallel approaches are not available in this case downgrading both airports capacity).

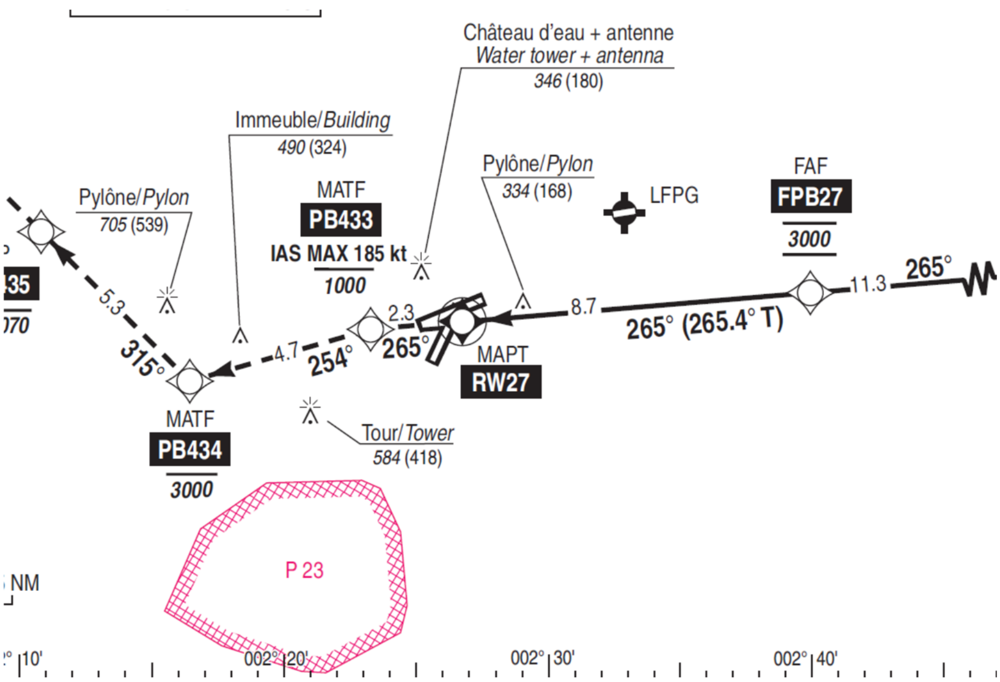

Fig 7 : LFPB RNP27 procedure

From September 29th, Le Bourget ATC received reports from pilots declaring GNSS loss between 7Nm and 4Nm on the RNP27 final. A complaint to the spectrum management entity was unsuccessful, as the ground crews failed to identify possible RFI.

That same week, one of our FI Be200s carried out the commissioning flight inspection of the RNP 08R/26L procedures at Paris Charles de Gaulle LFPG. The flight inspector in charge observed a very strong chirp-type signal, the level was sufficient to cause complete loss of GNSS tracking on short final 26L. This RFI was therefore classified as "red". On the 08R final the same signal was observed but at lower level classifying it "yellow".

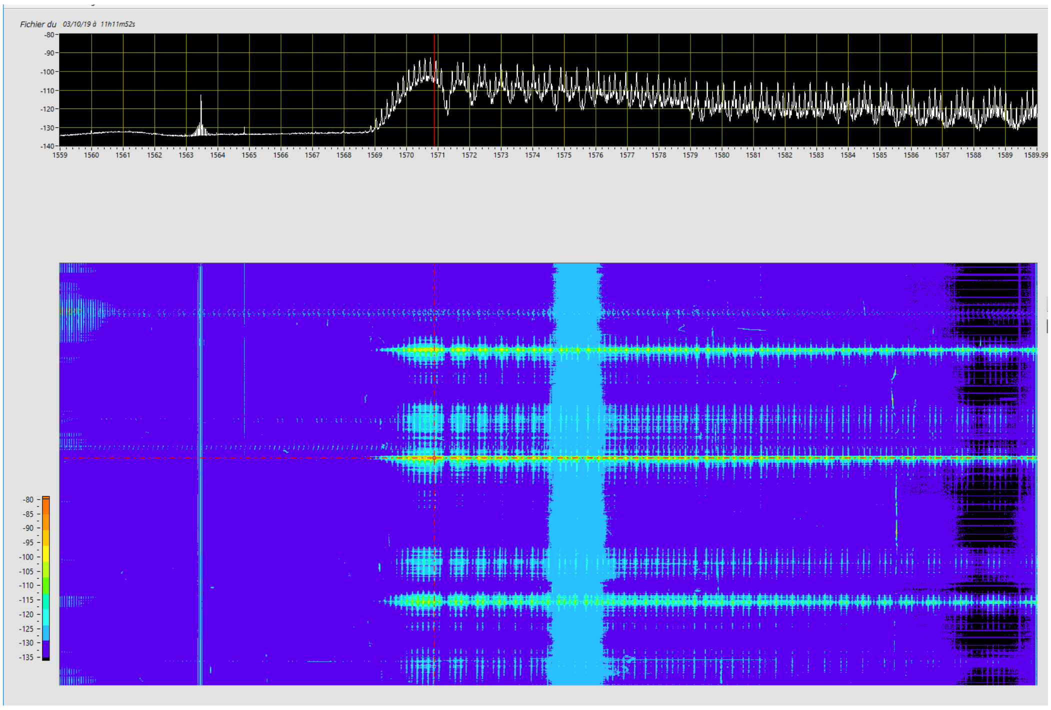

Fig 8:: Chirp observed during LFPG RNP26L Flight inspection

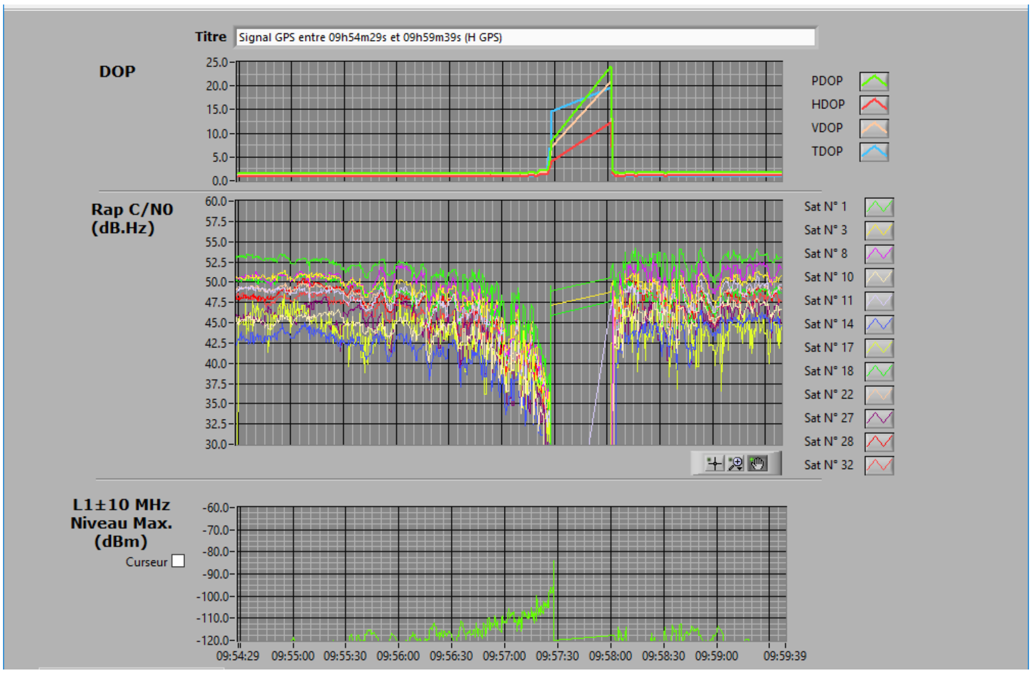

Fig 9 : C/N0 degradation during LFPG RNP26L Final approach

The flight inspector then required a specific search flight allowing him to geolocate the source of the emission with sufficient precision so that an urgent ground intervention could be undertaken again.

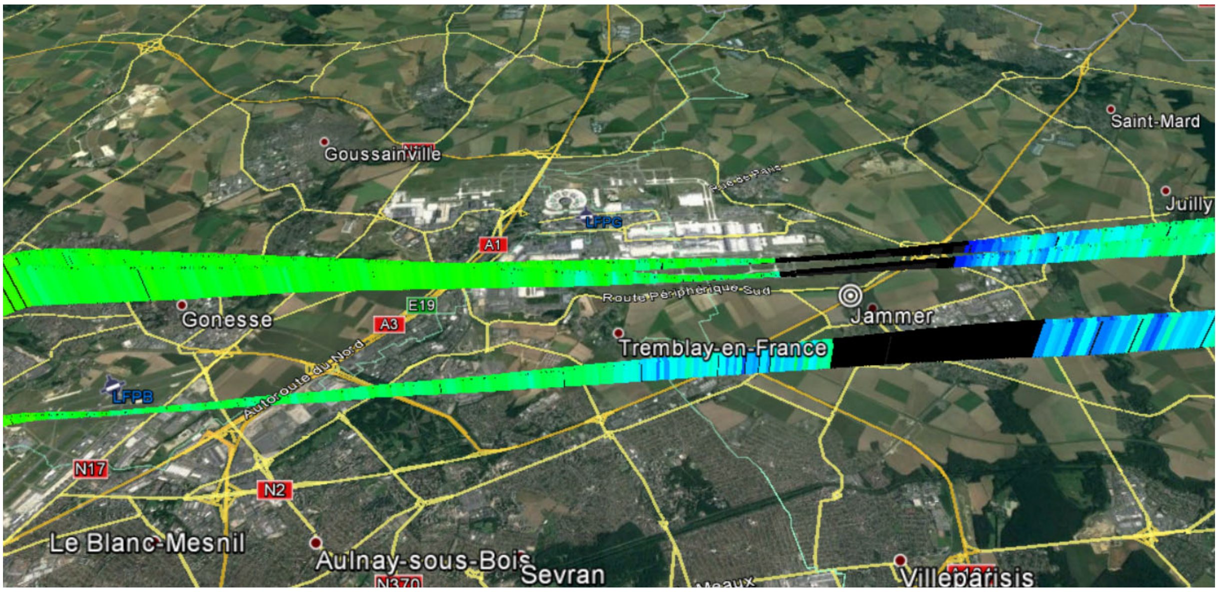

Fig 10 : Finals approaches on CDG and Le Bourget (Color function of the C/N0 parameter)

In the afternoon, the technical staff of the spectrum management entity, accompanied by the police, located the interference in an apartment building located between the finals of CDG and Le Bourget. The user switched off his jammer transmission just before the agents were able to intervene, preventing its identification and cease. The interference has not occurred since.

This case illustrates both RFI detected by flight inspection during a RNP procedure commissioning and RFI affecting users of an already published procedure.

PBN REPORTS ANALYSIS

In addition to these operational methods for flight inspection, a team of CNS experts from DTI meets monthly to analyze PBN and GNSS event reports from ATC and crews.

The purpose of this so called "GNSS squad" is to identify and classify the most likely causes of the reported issues and suggests actions if necessary.

Since its creation in 2015, **130** reports have been submitted and processed:

Interference	GNSS Outage or degradation caused by RFI	**45 (11 suspected)**
Constellation	Satellite coverage or any other constellation related degradation	**12**
ATC	ATC induced issue (short interception, altitude constraint,…)	**1**
Procedure	Problem caused by procedure design (Complexity, unpracticable design,…)	**5**
Avionics	Avionics related error (Database, Path/Terminator interpretation,…)	**13**
Crew	Crew induced issue (unstabilized approach, wrong minimas selection,Avionics usage and procedure flying…)	**46**
Other	Any other problem (weather conditions,…)	**6**

CONCLUSIONS

This method of determining the impact of an RFI proves to be easily applicable and - confronted with the analysis of reports indicating probable interference - fairly representative of the real impact that an RFI has on onboard equipment.

It makes it possible to address priority cases without committing the necessarily limited human and material resources in a permanent hunt for PPDs which are by definition mobile and elusive.

The fight against the spread of that kind of device is still a major issue. It remains a priority and is the subject of high-level coordination work between the various stakeholders (frequency agency, regulators and assigning authorities) in order to strengthen regulatory and legal means.

From a technical point of view, the applied thresholds - in particular the 30dB.Hz limit described above - remain subject to discussion. The same goes for the reference receiver used on board which could in the near future be changed to a more recent model.