

A POWERFUL SIGNAL NEARBY L1 FREQUENCY BAND JAMMING GNSS STATIONS IN OBSERVATOIRE DE PARIS

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Abstract – In the frame of the French metrology organization, the laboratory *Systèmes de Référence Temps-Espace (SYRTE)* in *Observatoire de Paris (OP)* is in charge of fundamental activities in the time and frequency domain. Among other systems, the laboratory is operating stations receiving signals from global navigation satellite systems (GNSS) like the *Global Positioning System (GPS)* or *Galileo*, aiming at accurate time transfer with other remote time laboratories. Since November 2018, the GNSS signal reception in the L1-band has been jammed by a powerful signal transmitted near to OP in a frequency band allocated to space to Earth satellite telecommunication. This signal power was originally more than 35 dB above the GNSS spread-spectrum power level. A formal complaint was raised in early January 2019 to the *Agence Nationale des Fréquences (ANFR)*. The paper describes the jamming signal and its consequences. The effect of this signal on L1-band reception was not the same on all OP stations, depending on the bandwidth of the antenna around the L1 carrier, but also on the receiver's different types. It went from no effect at all for GPS-only stations to large data loss and noise increase for multi-GNSS stations. The power of the jamming signal is changing with time and remains under observation. We discuss what might be done to overcome this issue.

Keywords – Galileo, GNSS, GPS, jamming, L1-band

1. INTRODUCTION

In the frame of the French metrology organization, the laboratory *Systèmes de Référence Temps-Espace (SYRTE)* in *Observatoire de Paris (OP)* is designated by the French National Metrology Institute (NMI) *Laboratoire National de Métrologie et d'Essais (LNE)* for fundamental activities in the time and frequency domain. LNE-SYRTE missions are, among others, the design and operation of primary and secondary frequency standards (PSFS) realizing the SI second [1], and the real-time prediction of Coordinated Universal Time (UTC) in OP, UTC(OP) [2], which is the basis of French legal time. For this aim, LNE-SYRTE is operating with other equipment stations that are able to receive signals from global navigation satellite systems (GNSS) like the *Global Positioning System (GPS)* or *Galileo*, aiming at achieving accurate time transfer between remote clocks with other laboratories.

A large part of the laboratory GNSS activity today is organized to fit into the requirements of the *Bureau International des Poids et Mesures (BIPM)*, in order to provide the French clock contributions for the computation of UTC. LNE-SYRTE is currently continuously operating GPS time transfer stations, which hardware delay calibration is provided by BIPM and stays within a combined uncertainty of

1.7 ns [3]. In addition, LNE-SYRTE is uploading daily to the International GNSS Service (IGS) geodetic RINEX data from two stations: OPMT00FRA [4], which is a GPS-only station, and since Summer 2018 OP7100FRA [5], a multi-GNSS one. The laboratory is also hosting a Ranging and Integrity Monitoring Station (RIMS), as part of the ground segment of the European Geostationary Navigation Overlay Service (EGNOS). This RIMS-PAR allows for a direct connection to UTC(OP) of EGNOS Network Time (ENT), the time scale of the system [6]. Furthermore, LNE-SYRTE is contractually involved in the Time Service Provider (TSP) of the Galileo ground segment. In addition to the provision of calibrated GPS common-view (CV) data related to UTC(OP), the laboratory is also in charge of the relative calibration of the GPS links between the European laboratories contributing to TSP and the Galileo Precise Timing Facilities (PTF). Section 2 describes the GNSS stations implementation and monitoring in the OP.

In November 2018, the GNSS signal reception of OP stations in the L1-band was suddenly jammed by a powerful signal transmitted in a frequency band which is allocated for space to Earth satellite telecommunication, according to the International Telecommunication Union (ITU) regulations, as provided to French users by the *Agence Nationale*

des Fréquences (ANFR) [7]. Section 3 is showing what was observed and the effects of this jamming signal on some of OP stations. Section 4 describes the impact of the jamming signal on laboratory activities. Section 5 details the influence of the different GNSS antenna bandwidths. Section 6 shows how time transfer receivers from one single manufacturer but of different generations are not affected in the same way. The jamming signal is randomly changing with time and section 7 describes the monitoring of this signal. Section 8 discusses the potential way forward to overcome this issue, before concluding the paper.

2. GNSS STATIONS IN OP

Fig. 1 provides an overview of the operational LNE-SYRTE GNSS stations implemented in OP. The external signal source distributed to all stations including the EGNOS RIMS is UTC(OP): a 10 MHz signal, potentially multiplied to generate a 20 MHz signal required by some receivers, and a 1 pulse per second (PPS) signal. All cable delays are measured against a dedicated output port of the PPS main distribution unit. There is a GPS-only ensemble made of receivers called OPMT and OPM2 connected to the same antenna cable and one single GPS-only antenna. One multi-GNSS ensemble is made of two receivers of different types from a single manufacturer, called OPM6 and OP71, both connected to the same antenna cable and to a single multi-GNSS antenna. And there is an additional multi-GNSS station made of another receiver from a third manufacturer, called OPM9, connected to a similar multi-GNSS antenna.

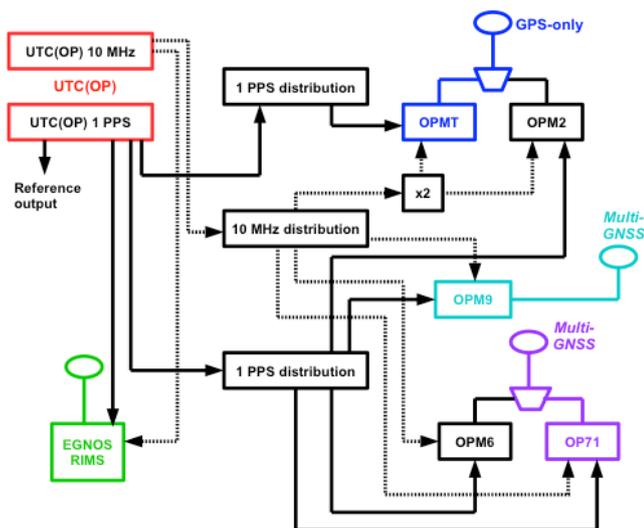


Fig. 1 – GNSS station implementations in OP. OPMT, OPM9 and OP71 stations are calibrated by BIPM. All delays are measured against the reference output of UTC(OP) PPS distribution unit.

Computations of all OP collected GNSS data is carried out daily for monitoring purposes. It provides among other results CV between stations, based on an ionosphere-free P3 linear combination of GPS data [8] in the CGGTTS file format [9] over the last 5 d (days), as is shown in Fig. 2 between OP71 and OPMT. The sampling period is 16 min (minutes). The daily mean offset between these two calibrated stations is typically remaining below 0.3 ns, within a peak-to-peak offset of about 1.5 ns. A small diurnal term is clearly visible.

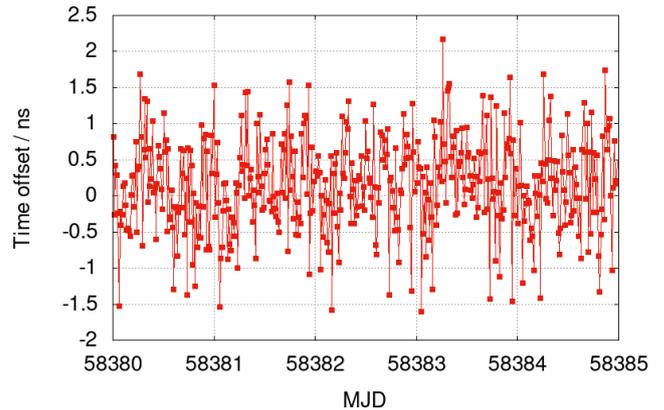


Fig. 2 – Typical offset between OP71 and OPMT based on CV of GPS P3 CGGTTS data, recorded from 29 September to 3 October 2018, modified Julian days (MJD) 58380 to 58384

3. IRRUPTION OF A JAMMING SIGNAL

Fig. 3 shows what was observed between OP71 and OPMT at the end of November 2018. From 26 November (MJD 58448) onwards, it appeared that the differences between both stations were not in line with the claimed uncertainties anymore. There was a severe loss of data in the OP71 CGGTTS files; during some periods, only one single GPS satellite was tracked with a reduced carrier to noise density ratio (C/N_0) compared to normal reception, resulting in peak offsets over 5 ns. Additionally, no Galileo satellite data could be obtained anymore.

Simultaneously, no abnormal behavior was noticed on the OPMT/OPM2 ensemble, but perturbations were detected on OPM6 and OPM9 data, even if not as large as for OP71. The EGNOS operators were alerted, but no significant effect was detected in the EGNOS data recorded in OP. Numerous tests with spare receivers and antennas available in OP lead to the conclusion that the issue was coming from outside the laboratory. A spectrum analyzer connected to the OPM9 multi-GNSS antenna using a power splitter highlighted the issue source. Fig. 4 shows the spectrum observed around the L1 carrier frequency at 1575.42 MHz. Just below the

GNSS L1-band, down from 1559 MHz, a powerful signal more than 35 dB above the GNSS spread-spectrum power level is clearly visible. A space to ground telecommunication signal would add just a few dB on the noise level. We also checked with other laboratories in the Paris suburbs that the signal was not visible there. Hence the transmitter could only be ground based in the vicinity of OP. We observed that the jamming signal was not continuously transmitting.

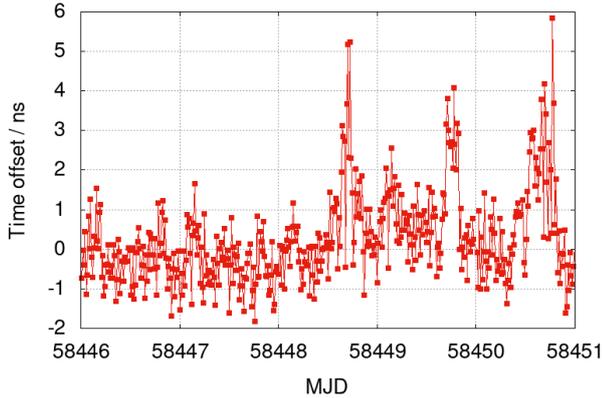


Fig. 3 – Offset between OP71 and OPMT based on CV of GPS P3 CGGTTS data, recorded from 24 to 28 November 2018 (MJD 58446 to 58450)

clock and common-antenna set-up, and despite being from the same manufacturer even if of different types, both units are not reacting to the jamming signal in the same way. We also noticed some large time offsets of a few ns between OPM9 and OPMT. But there was some coupling with temperature effects typically affecting OPM9, which are not the subject of this paper. Hence OPM9 is disregarded here. Significantly, no abnormal offset between OPMT and OPM2 was detected over that period of time.

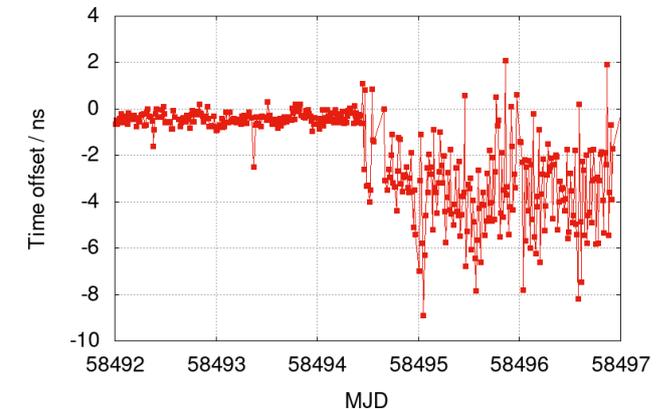
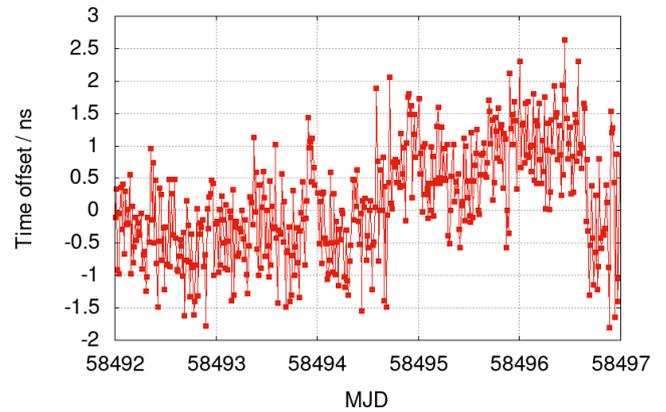
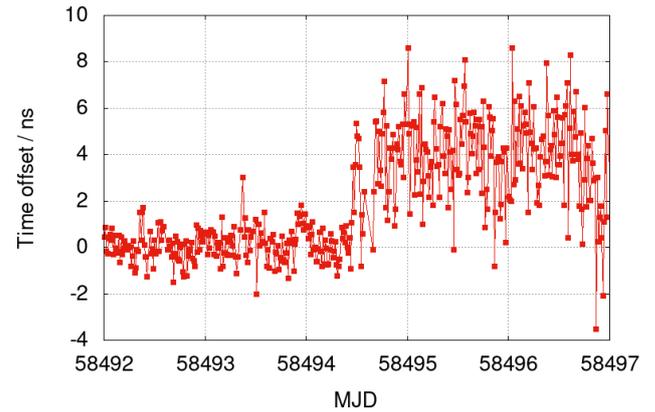


Fig. 5 – Based on CV of GPS P3 CGGTTS data, offsets between OP71 and OPMT (top), OPM6 and OPMT (middle), and OPM6 and OP71 (bottom), recorded from 10 to 14 January 2019. When the jamming signal is on after the middle of the period, amplitudes of a few ns are largely above the usual uncertainties for such local time offsets, even if the different operational stations are not affected in the same way.

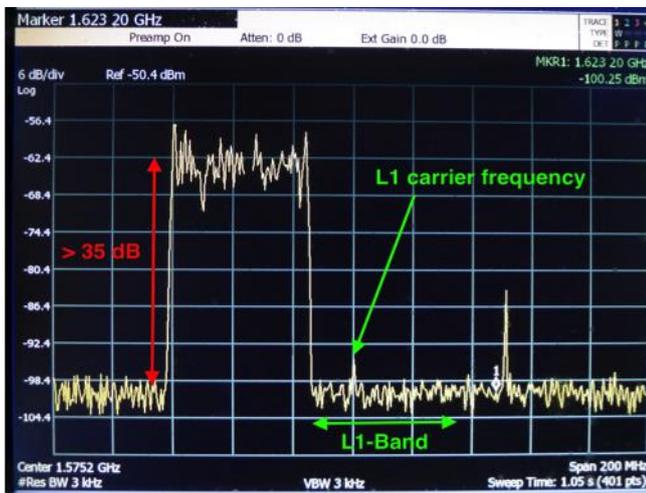


Fig. 4 – Frequency spectrum observed on 16 January 2019. The center frequency is 1575.2 MHz. The span is 200 MHz. The Y-axis scale is 6 dBm/div. The GNSS allocated L1-band from 1559 MHz to 1610 MHz is highlighted in green.

Fig. 5 shows the simultaneous effects of the jamming signal on different GNSS stations in OP over the period from 10 to 14 January 2019. Even if the amplitude is not at the same level, the offsets of OPM6 and OP71 against OPMT are significant when the jamming signal is on. We obtained similar plots against OPM2 (not shown in the figure). In addition, the offset between OPM6 and OP71 is also plotted in Fig. 5. Despite being implemented in a common-

4. IMPACT OF THE JAMMING SIGNAL ON LABORATORY ACTIVITIES

When considering that all activities depending on multi-GNSS signal reception were impacted by the jamming signal, the list of perturbations is quite large. The LNE-SYRTE had started operational multi-GNSS data provision in August 2018, after implementation and agreement of the IGS station OP7100FRA, and after the computation of the hardware delays for Galileo signals against GPS delays [10]. The laboratory had also started to deliver multi-GNSS data to other users, in particular in the frame of industrial contracts. All this was down depending on the power of the jamming signal received in OP, and we had to interrupt the upload of multi-GNSS data to the IGS. The OP71 station was also supposed to become the reference station for all hardware calibrations campaigns, either as achieved by BIPM, the next campaign being planned for early 2019, or as achieved by LNE-SYRTE for other laboratories, as was planned for the first half of 2019. We were lucky enough to have a few days without jamming in January 2019 to start both activities. But a multi-laboratory campaign requires a closure period when the traveling equipment is back home, and this would require additional days without jamming during summer later. Finally, the laboratory efforts to analyse the issue, and to update the laboratory structure to maintain the GNSS metrology missions as much as possible was done to the detriment of other planned activities.

We are having only scarce information from the manufacturers about the built-in filters in the signal conditioning stage of the different GNSS receivers in operation in OP, and more especially about the bandwidth of such filters [11]. It was therefore not easy to determine if the jamming effects were due to a saturation of front-end low noise amplifier, which is our assumption, or if the issue was related to the down conversion of the expected GNSS signals, or something else [12,13]. Note also that such a study is normally not part of LNE-SYRTE missions.

5. GNSS ANTENNA BANDWIDTH

A characterization of different types of GNSS antennas was conducted in LNE-SYRTE, using a microwave vector network analyzer equipped with appropriate connectors and calibration kits. Figures 6 and 7 give the scattering parameters, S_{11} and S_{12} respectively, over the entire frequency band

1-2 GHz. The reflection and transmission losses are thus precisely determined with respect to the frequency and for different types of antennas, either GPS-only in red, or multi-GNSS in black and in blue. What is apparent here is that the GPS-only antenna is exhibiting a limited bandwidth around the GPS carriers L1 (1575.42 MHz) and L2 (1227.60 MHz) compared to the other antennas. The jamming signal appearing below 1559 MHz is then rejected enough to avoid any significant effect on the GPS-only receivers. But the jamming signal is collected along with the GNSS signal by the multi-GNSS antennas, and we assume it is powerful enough to saturate the low-noise amplifier, preventing a proper reception of GNSS data by the station main units. We assume that the EGNOS RIMS antenna bandwidth profile is also sharp enough to reject the jamming signal. Note that the sharp limits of the multi-GNSS antenna bandwidths around the L1 carrier frequency also explain the sharp cut-off of the jamming signal at about 1510 MHz, as seen in Fig. 4.

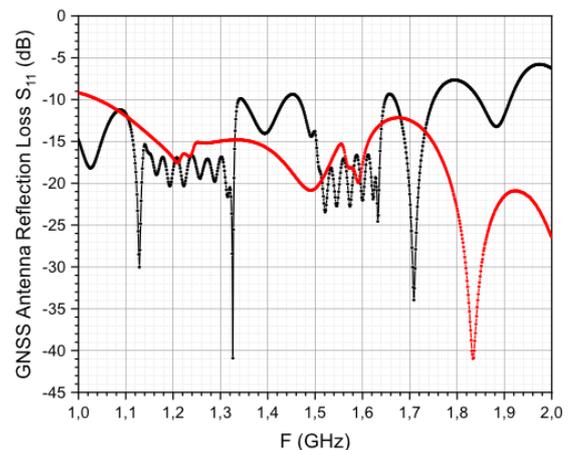


Fig. 6 – Antenna mismatch loss around L1 (1575.42 MHz) and L2 (1227.60 MHz) carrier frequencies: GPS-only in red, multi-GNSS in black

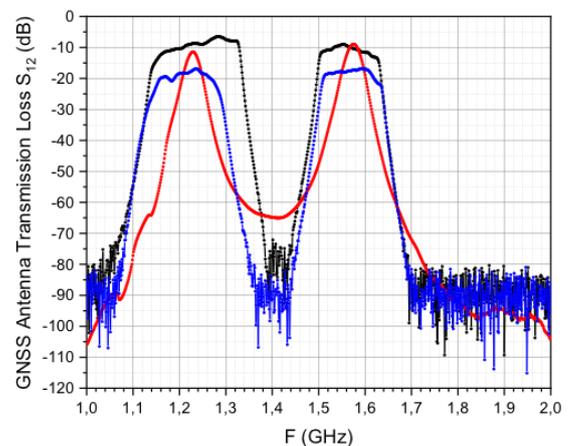


Fig. 7 – Antenna rejection loss around L1 (1575.42 MHz) and L2 (1227.60 MHz) carrier frequencies: GPS-only in red, multi-GNSS of two different types in black and in blue

6. DIFFERENT EFFECTS ON TIME TRANSFER RECEIVERS

It appeared that three different generations of time transfer receivers from one single manufacturer were not reacting similarly to the GPS L1-band jamming. Fig. 8 shows the plots of C/N_0 data, satellite by satellite, for receivers of generation 3 (G3), 4 (G4) and 5 (G5) of this manufacturer as obtained in RINEX files. G3 and G4 are part of the operational OP implementation, where G5 was used for experiment purposes only. When the jamming signal was on around midday, G4 shows a small improvement compared to G3, reaching an average C/N_0 of about 47 dBHz for about 43 dBHz only for G3. On the other hand, G5 seems to better handle the jamming even at the cost of increased data dispersion; the satellite track related parabolic shape of the C/N_0 can no longer be seen during the jamming period. We assume that the filtering and the code correlation process were improved from one generation to the other, together with the automatic gain control. But G5 is not yet included in the operation ensemble at LNE-SYRTE.

7. MONITORING OF JAMMING SIGNAL

Fig. 9 shows the typical spectrum observed from the end of January 2019 onwards. The jamming signal was transmitted with less power, allowing the detection of the main lobe of the GNSS signal on the plot centered on the L1 carrier. The received power of the jamming signal is here between -98 dBm to -80 dBm for a GNSS spread-spectrum noise level of about -102 dBm.

Fig. 10 shows the C/N_0 mean value of OP71 L1-band reception from 1 January to 28 February 2019, as provided by the manufacturer software. One can see the effects of the jamming signal change over the period, between no signal at all to a typical C/N_0 mean value close to 45 dBHz. But this is usually a post-correlation estimate value. If a loss-of-lock would occur, the receiver does not provide this estimation anymore, inducing missing data. This kind of plot was therefore appearing too limited to monitor the jamming signal power changes with time.

As a consequence, an additional monitoring of the frequency band occupied by the jamming signal was put into operation starting 21 February 2019. Fig. 11 shows a plot of the received power mean value measured by a spectrum analyzer between 1515 MHz and 1561 MHz. The sampling period was 20 min at the start, then 10 min during the last part

of the plot. One can see that the power of the jamming signal changes with time, and is even shut down sometimes during some periods. But the received power level is randomly changing, as can be seen at the end of the period, where a peak power about 35 dB over the typical bottom power level is visible again.

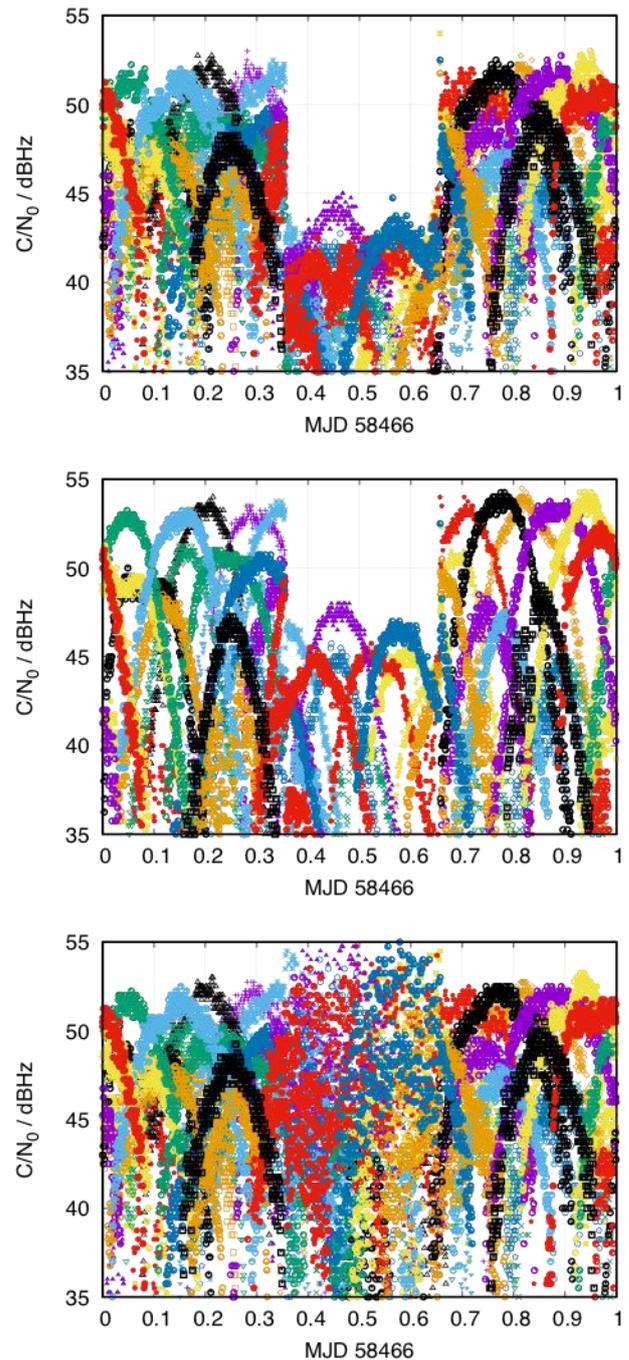


Fig. 8 – All visible satellite C/N_0 obtained in RINEX files on 14 December 2018 from GPS L1 band, for three generations of receivers from one single manufacturer: G3 (top), G4 (middle) and G5 (bottom)



Fig. 9 – Typical spectrum observed from end of January 2019 onwards. The center frequency is L1, the span is 200 MHz. Marker 1 highlights the threshold where the power received from the jamming signal is already surpassing the GNSS main lobe power inside the L1-band.

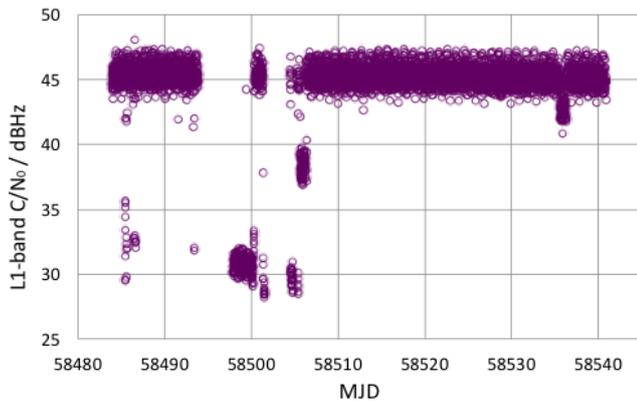


Fig. 10 – C/N_0 of OP71 in the L1-band from 1 January to 28 February 2019. Each point is a mean value of the S1 parameter in RINEX data averaged between simultaneously tracked satellites sampled over 0.1 d.

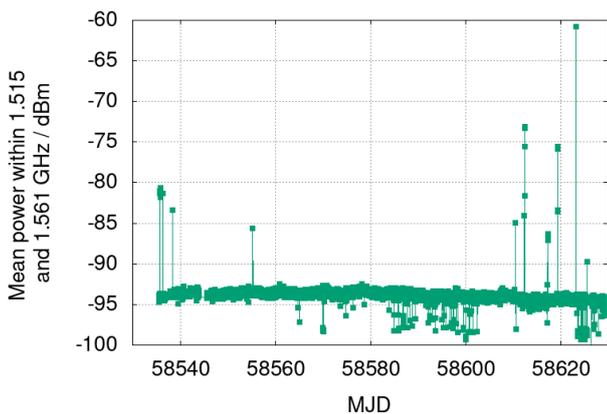


Fig. 11 – Mean power values of the detected signal in the frequency band 1515 MHz to 1561 MHz from 21 February to 20 May 2019. Sampling period is from 20 min to 10 min.

8. THE WAY FORWARD

A formal complaint was raised in early January 2019 to ANFR, the National Frequency Agency which manages the radio frequencies in France. Two technicians came to OP within three days and confirmed all the elements provided by LNE-SYRTE. The jamming signal is under formal observation and this is an ongoing process.

LNE-SYRTE is involved in different GPS station-relative calibration campaigns for the first half of 2019. But the idea is to extensively test afterwards with all available spare receivers and antennas in order to relate more precisely the power of the jamming signal to the GNSS signal reception of OP stations. A multi-GNSS station based on a receiver from a fourth additional manufacturer is also currently being put into operation, in order to improve our knowledge about such different units. However, due to the unsteady nature of the jamming signal, it is not easy to plan comprehensive tests with all available equipment allowing the computing of a consistent correlation function between the jamming signal power and the GNSS collected data.

Another prospective study is to design and to develop a low-noise active microwave diplexer in the 1 - 2 GHz frequency band to be inserted between the antenna and the detection unit of a multi-GNSS receiver (Fig. 12). The principle is to implement two different band-pass filters; one around the L1 carrier, including the E1 band of the Galileo signal, and the other one around the GPS L2 and L5 carriers, and including the E5a and E5b bands of the Galileo signal. However, such a development will have to take into consideration three important aspects. First, Galileo full signals, either Open Service (OS) or Public Regulated Service (PRS), are slightly beyond the ITU allocated GNSS L1-band [14,15], hence partly inside the jamming signal frequency band. Second, the sensitivity to temperature fluctuations of such band-pass filters should be monitored closely. And third, the hardware delays of the low-noise active diplexer have to be calibrated at sub-ns level for all GNSS signals for accurate time transfer.

Finally, LNE-SYRTE has started some very preliminary tests by using a directional antenna for the monitoring of the jamming signal. This might allow for better focus on the jamming signal fluctuations with time.

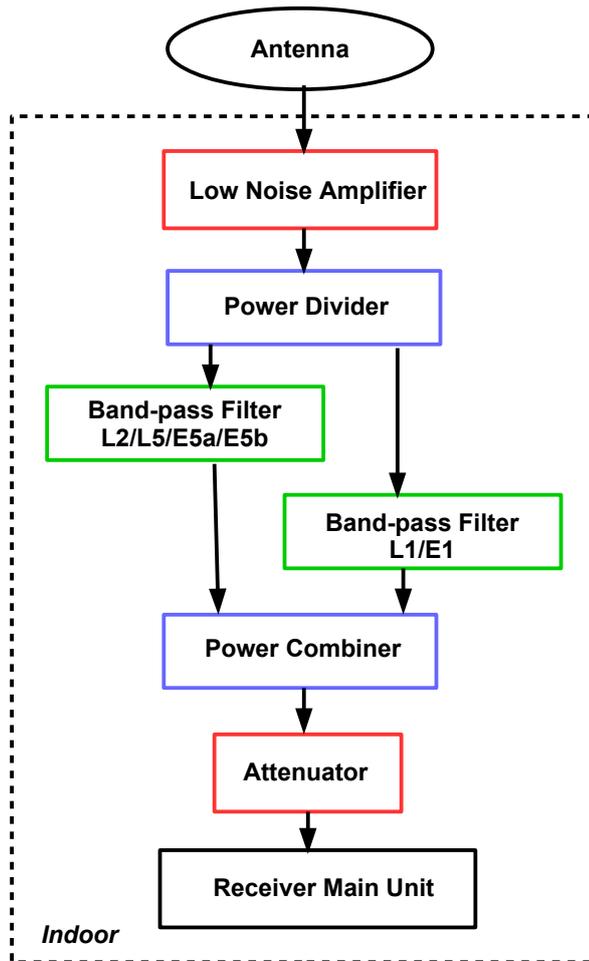


Fig. 12 – Block diagram of the low-noise active microwave diplexer aiming at filtering out the jamming signal

9. CONCLUSION

For fulfilling its time and frequency metrology missions, LNE-SYRTE is operating an ensemble of calibrated GNSS stations in OP aiming at accurate time transfer between remote atomic standards. But since November 2018, a powerful signal occupying a frequency band just below the L1 frequency band allocated to GNSS signals has appeared. Its signal power level is indicating a ground source near to OP. This is apparently not in line with ITU frequency tables, where this frequency band is allocated to space to Earth satellite telecommunications. The signal is jamming OP stations' reception when using large bandwidth multi-GNSS antennas and receivers. A formal complaint was raised to ANFR in early 2019.

The impact of this jamming signal was observed in different ways. First, a sudden loss of some GNSS data, together with an increase of noise, was detected, leading to unexpected large offsets between calibrated OP stations. Second, the C/N_0 in

the L1-band was severely affected, depending on the receiver's type and on the bandwidth of the antenna used. GPS-only stations were not affected, because the related antenna bandwidth is sharp enough around L1 carrier frequency to reject the jamming signal.

Changes in the jamming signal power were observed over time, according to some provisional monitoring. The potential implementation of a low-noise active microwave diplexer is under study. In addition, future plans are to implement a more consistent dedicated observation of the jamming signal, and more generally of the frequency spectrum around all the GNSS frequency bands. To develop our knowledge in this field appears mandatory today for all future GNSS activities according to the laboratory time metrology missions.

ACKNOWLEDGEMENT

We acknowledge the Agence Nationale des Fréquences (ANFR) for the help in trying to solve the issue.

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